Fisheries Assessment Plenary

May 2022

Stock Assessments and Stock Status

Volume 1: Introductory sections and Alfonsino to Hoki

Fisheries New Zealand
Tini a Tangaroa

Te Kāwanatanga o Aotearoa
New Zealand Government

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PREFACE

Fisheries Assessment Plenary reports have represented a significant annual output of Fisheries New Zealand and its predecessors for the last 38 years. The Plenary is now more than 2300 pages long and is split into four volumes, three of which are produced in May and one in November of each year. The Plenary reports provide summaries of the available fisheries and scientific information and are in turn supported by 70–100 more detailed reports published on-line each year, with a cumulative total of almost 2000 such supporting, detailed documents.

The May 2022 Plenary summarises fisheries, biological, environmental, stock assessment and stock status information for 83 of New Zealand's commercial fish species or species groups in a series of Science Working Group (SWG) or Plenary reports. In the early years of New Zealand's efforts to conduct fish stock assessments, all such assessments went through a Plenary process (meaning that as many as possible of all experts and involved parties had the opportunity to participate in the review). However, as more data has been collected; more analyses have been conducted; more sophisticated models have been developed; peer review processes have become increasingly more rigorous and incorporated into research and science standards and terms of reference; more experts have been trained; and more constructive collaborations with industry, recreational and environmental interests have developed, it has become expedient to finalise increasingly more stock assessments in SWG processes alone.

The main reasons that a new stock assessment is subjected to the additional Plenary review nowadays is if it:

- Results in a substantially different assessment of stock status compared to the previous assessment, particularly if the new assessment is likely to result in fisheries management actions to alter catch limits or other regulatory measures, in order to address either sustainability concerns or utilisation opportunities;

- Is novel, complex, or contentious; for example, it is the first time a successful assessment has been conducted for a given stock, or the relevant SWG was divided on its validity, or if the methodology is of sufficient complexity as to warrant a further layer of review;

- To suggest future research considerations that could contribute to the objective of continually improving future assessments for that stock.

Each species or species group is split into 1–10 stocks for management purposes. However, the boundaries of biological stocks often differ from the management boundaries. In general, biological stocks tend to occur at smaller scales than management boundaries, although in a few instances the reverse is true. Most stock assessments are conducted at biologically meaningful scales.

In addition to this May Plenary report, a November Plenary report is produced for species that operate on different management cycles and includes 18 SWG and Plenary summaries for highly migratory species, rock lobster, scallops and dredge oysters.

Over time, continual improvements have been made in data acquisition, stock assessment techniques, the development of reference points to guide fisheries management decisions, the provision of increasingly comprehensive and meaningful information from a range of sources, and peer review processes. SWG and Plenary meetings have continued the effort to populate the Status of the Stocks summary tables, which are used to provide comprehensive summary information about current stock status and the prognosis for these stocks, to evaluate fisheries performance relative to the 2008 Harvest Strategy Standard for New Zealand Fisheries and other management measures, and to rank the quality of stock assessment inputs and outputs based on the 2011 Research and Science Information Standard for New Zealand Fisheries. Even when complete information is not available, it is sometimes possible to at least make scientifically sound statements about recent trends in stock size and fishing intensity levels.

Over the past few years, sections on environmental and ecosystem considerations have also been developed for some species by the SWGs that oversee aquatic environment and biodiversity issues associated with New Zealand fisheries and the ocean environment in which they reside. Chapter sections on how ocean warming, ocean acidification and other ecosystem trends affect, for example, productivity and fish distributions will be incorporated as new information becomes available. Fisheries New Zealand recognises the need to increase our knowledge of the impacts of important environmental factors.

The Plenary reports take into account the most recent data and analyses available to SWGs and Fisheries Assessment Plenary meetings, and also incorporate relevant analyses undertaken in previous years. Due to time and resource constraints, recent data for some stocks may not yet have been fully analysed by the SWGs or the Plenary.

We would like to recognise and thank the large number of research providers, scientists and other representatives from research organisations, academia, the seafood industry, recreational fisheries, environmental NGOs, customary non-commercial interests and Fisheries New Zealand; along with all other technical and non-technical participants in present and past SWG and Plenary meetings for their substantial contributions to this report. Our sincere thanks to each and all who have contributed.

We would also like to pay particular tribute to Fisheries New Zealand's past and present Science Officers who put tireless effort into checking and collating each Plenary report. The acting Science Officer for this report was Campbell Murray, with additional support from William Gibson. Our technical science editor, Suze Baird, is thanked for conscientiously checking and editing this report.

We are pleased to endorse this document as representing the best available scientific information relevant to fisheries and stock status, as at 31 May 2022.

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Introduction

This report summarises the conclusions and recommendations from the meetings of the Fisheries Assessment Working Groups and the Fisheries Assessment Plenary held since last year's Plenary report was published. The meetings were convened to assess the fisheries managed within the Quota Management System, as well as other important fisheries in the New Zealand EEZ, and to discuss various matters that pertain to fisheries assessments.

In addition, summaries of environmental effects of fishing from research presented to the Aquatic Environment Working Group (AEWG) and the Biodiversity Advisory Group (BRAG) that have relevance to fisheries management have been incorporated for selected species. Paragraph 11 of the Terms of Reference for Fisheries Assessment Working Groups (FAWGs) includes "…information and advice on other management considerations (e.g., …by-catch issues, effects of fishing on habitat…)", and states that "Sections of the Working Group reports related to bycatch and other environmental effects of fishing will be reviewed by the Aquatic Environment Working Group although the relevant FAWG is encouraged to identify to the AEWG Chair any major discrepancies between these sections and their understanding of the operation of relevant fisheries". In addition, the Terms of Reference for the AEWG (Paragraph 9) specifies the need "to review and revise existing environmental and ecosystem consideration sections of Fisheries Assessment Plenary report text based on new data or analyses, or other relevant information".

The report addresses, for each species, relevant aspects of the Fisheries Act 1996 and related considerations, as defined in the Terms of Reference for Fisheries Assessment Working Groups for 2021. In all cases, consideration has been based on and limited by the best available information. The purpose has been to provide objective, independent assessments of the current status of the fish stocks.

There are two types of catch limits used in this document – total allowable catch (TAC) and total allowable commercial catch (TACC). The current definition is that a TAC is a limit on the total removals from the stock, including those taken by the commercial, recreational and customary non-commercial sectors, illegal removals and all other mortality to a stock caused by fishing. A TACC is a limit on the catch taken by the commercial sector only. The definition of TAC was changed in the 1990 Fisheries Amendment Act when the term TACC was introduced. Before 1990, the term TAC applied only to commercial fishing. In the Landings and TAC tables in this report, the TAC figures equate to the TACC unless otherwise specified.

Only actual TACCs are provided. The actual TACCs are the values as of the last day of the fishing year; e.g., 30 September.

In considering customary non-commercial, and recreational interests, the focus has been on current interests and activities rather than historical activities. In most cases, there is little information available on the nature and extent of non-commercial interests, although estimates of recreational harvest are available in some instances. Information on illegal catches and other sources of mortality is provided where available.

Yield Benchmarks

The biological reference points, Maximum Constant Yield (*MCY*) and Current Annual Yield (*CAY*) first used in the 1988 assessment continue to be used in a small number of stock assessments. This approach is described in the section of this report titled "Guide to Biological Reference Points for Fisheries Assessment Meetings".

Sources of Data

A major source of information for these assessments is the fisheries statistics system. It is important to maintain and develop this system to provide adequate and timely data for stock assessments.

Other Information

For some assessments, draft Fisheries Assessment Reports that more fully describe the data and the analyses have been prepared in time for the Working Group or Plenary process. Once finalised, these documents are placed on the Fisheries New Zealand website in a searchable database.

Environmental Effects of Fishing

The scientific information to assess the environmental effects of fishing and enable this outcome comes primarily from research commissioned by Fisheries New Zealand and, for protected species only, the Department of Conservation (DOC). The work is reviewed by the Aquatic Environment Working Group (AEWG) (or a similar DOC technical working group) or by the Biodiversity Research Advisory Group (BRAG). Fisheries New Zealand has developed an “Aquatic Environment and Biodiversity Annual Review”, which summarises the current state of knowledge on the environmental interactions between fisheries and the aquatic environment. The Aquatic Environment and Biodiversity Annual Review assesses the various known and potential effects of fishing on an issue-by-issue basis (e.g., the total impact of all bottom trawl and dredge fisheries on benthic habitat), whereas relatively brief fisheries-specific summaries have been progressively included in this report since 2005, starting with hoki. These fisheries-specific sections are reviewed by AEWG rather than by the FAWGs responsible for the stock assessment sections in each Working Group report.

Status of Stocks Summary Tables

Since 2009, the key information relevant to providing more comprehensive and meaningful information for fisheries managers, stakeholders and other interested parties has been summarised at the end of each chapter in a table format using the Guidelines for Status of the Stocks Summary Tables on pages 46–52. Beginning in 2012, Status of Stocks tables have incorporated a new science information quality ranking system, as specified in the Research and Science Information Standard for New Zealand Fisheries (2011). Beginning in 2013, Status of Stocks tables have incorporated explicit statements regarding the status of fisheries relative to overfishing thresholds.

Glossary of Common Technical Terms

Abundance Index: A quantitative measure of fish density or abundance, usually as a relative time series. An abundance index can be specific to an area or to a segment of the **stock** (e.g., mature fish), or it can refer to abundance stock-wide; the index can reflect abundance in numbers or in weight (**biomass**).

ACE: Annual catch entitlement is the right to catch a certain amount of a fish stock during a fishing year.

AEWG: The Aquatic Environment (Science) Working Group.

Age frequency: The proportions of fish of different ages in the **stock,** or in the **catch** taken by either commercial fisheries or research fishing. This is often estimated based on a sample. Sometimes called an age composition.

Age-length key: The proportion of fish of each age in each length-group in a sample of fish.

Age-structured stock assessment: An assessment that uses a model to estimate how the numbers at age in the stock vary over time in order to determine the past and present **status** of a fish **stock**.

a_{50}: Either the age at which 50% of fish are mature (= A_M) or 50% are recruited to fisheries (=A_R).

AIC: The Akaike Information Criterion is a measure of the relative quality of a statistical model for a given set of data. As such, AIC provides a means for model selection; the preferred model is the one with the minimum AIC value.

A_M: *Age at maturity* is the age at which fish, of a given sex, are considered to be reproductively mature. See **a_{50}**.

AMP: *Adaptive Management Programme*. This involves increased **TACCs** (for a limited period, usually 5 years) in exchange for which the industry is required to provide data that will improve understanding of **stock status**. The industry is also required to collect additional information (biological data and detailed catch and effort) and perform the analyses (e.g. **CPUE** standardisation or age structure) necessary for monitoring the **stock.**

ANTWG: Antarctic (Science) Working Group.

A_R : *Age of recruitment* is the age when fish are considered to be **recruited** to fisheries. In **stock assessments**, this is usually the youngest age group considered in the analyses. See **a_{50}**.

a_{to95} : The number of ages between the age at which 50% of a stock is mature (or recruited) and the age at which 95% of the stock is mature (or recruited).

B_0: *Virgin biomass, unfished biomass*. This is the theoretical **carrying capacity** of the **recruited** or **vulnerable** or **spawning biomass** of a fish **stock**. In some cases, it refers to the average **biomass** of the **stock** in the years before fishing started. More generally, it is the average over recent years of the biomass that theoretically would have occurred if the stock had never been fished. B_0 is often estimated from stock modelling and various percentages of it (e.g., 40% B_0) are used as **biological reference points (BRPs)** to assess the relative status of a **stock**.

B_{AV} : The average historical **recruited biomass**.

Bayesian stock assessment: an approach to stock assessment that provides estimates of uncertainty (**posterior distributions**) of the quantities of interest in the assessment. The method allows the initial uncertainty (that before the data are considered) to be described in the form of **priors**. If the data are informative, they will determine the posterior distributions; if they are uninformative, the posteriors will resemble the **priors**. The initial model runs are called **MPD** (mode of the posterior distribution) runs, and provide point estimates only, with no uncertainty. Final runs (Markov Chain Monte Carlo runs or **MCMCs)**, which are often very time consuming, provide both point estimates and estimates of uncertainty.

B_{BEG}: The estimated **stock biomass** at the beginning of the fishing year.

$B_{CURRENT}$: Current **biomass** in the year of the assessment (usually a **mid-year biomass**).

Benthic: The ecological region at the lowest level of a body of water, including the sediment surface and some sub-surface layers

Biological Reference Point (BRP): A benchmark against which the **biomass** or abundance of the **stock,** or the **fishing mortality rate** (or **exploitation rate**), or **catch** itself can be measured in order to determine **stock status**. These reference points can be **targets**, **thresholds** or **limits** depending on their intended use.

Biomass: Biomass refers to the size of the **stock** in units of weight. Often, biomass refers to only one part of the **stock** (e.g., **spawning biomass, vulnerable biomass** or **recruited biomass**, the latter two of which are essentially equivalent).

B_{MSY}: The average **stock biomass** that results from taking an average catch of ***MSY*** under various types of harvest strategies. Often expressed in terms of spawning **biomass**, but may also be expressed as **recruited** or **vulnerable biomass.**

Bootstrap: A statistical methodology used to quantify the uncertainty associated with estimates obtained from a **model**. The bootstrap is often based on **Monte Carlo** re-sampling of residuals from the initial **model** fit.

BRAG: Biodiversity Research Advisory Group.

B_{REF}: A reference average biomass usually treated as a management target.

Bycatch: Refers to fish species, or size classes of those species, caught in association with key target species.

B_{YEAR}: Estimated or predicted **biomass** in the named year (usually a **mid-year biomass**).

Carrying capacity: The average **stock** size expected in the absence of **fishing**. Even without fishing the **stock** size varies through time in response to stochastic environmental conditions. See B_0.

Catch (C): The total weight (or sometimes number) of fish caught by fishing operations.

CAY*: Current annual yield** is the one year **catch** calculated by applying a reference **fishing mortality**, F_{REF}, to an estimate of the fishable **biomass** at the beginning of the fishing year. Also see ***MAY.

CELR: Catch Effort Landing Return.

CLR: Catch Landing Return.

Cohort: Those individuals of a **stock** born in the same spawning season. For annual spawners, a year's **recruitment** of new individuals to a **stock** is a single cohort or **year-class**.

Collapsed: Stocks that are below the **hard limit** are deemed to be **collapsed**.

Convergence: In reference to **MCMC** results from a **Bayesian stock assessment**, convergence means that the average and the variability of the parameter estimates are not changing as the **MCMC** chain gets longer.

CPUE: Catch per unit effort is the quantity of fish caught with one standard unit of fishing effort; e.g., the number of fish taken per 1000 hooks per day or the weight of fish taken per hour of trawling. CPUE is often assumed to be a relative **abundance index**.

Customary catch: Catch taken by tangata whenua to meet their customary needs.

CV: Coefficient of variation. A statistic commonly used to represent variability or uncertainty. For example, if a biomass estimate has a CV of 0.2 (or 20%), this means that the error in this estimate (the difference between the estimate and the true biomass) will typically be about 20% of the estimate.

Density-dependence: Fish populations are thought to self-regulate: as population biomass increases, growth may slow down, mortality may increase, recruitment may decrease or maturity may occur later. Growth is density-dependent if it slows down as biomass increases.

Depleted: Stocks that are below the **soft limit** are deemed to be **depleted**. Stocks can become **depleted** through **overfishing**, or environmental factors, or a combination of the two.

Discards: the portion of the catch thrown away at sea.

DWWG: The Deepwater (Science) Working Group.

ECER: Eel Catch-Effort Return.

ECLR: Eel Catch Landing Return.

Ecosystem: A biological community of interacting organisms and their physical environment.

EEZ: An **Exclusive Economic Zone** is a maritime zone beyond the **Territorial Sea** over which the coastal state has sovereign rights over the exploration and use of marine resources. Usually, a state's EEZ extends to a distance of 200 nautical miles (370 km) out from its coast, except where resulting points would be closer to another country.

Equilibrium: A theoretical model state that arises when the **fishing mortality**, **exploitation pattern** and other fisheries or **stock** characteristics (growth, natural mortality, **recruitment**) do not change from year to year.

ERS: Electronic Reporting System

Exploitable biomass: Refers to that portion of a **stock's biomass** that is available to fisheries. Also called **recruited biomass** or **vulnerable biomass**.

Exploitation pattern: The relative proportion of each age or size class of a **stock** that is vulnerable to fishing. See **selectivity ogive.**

Exploitation rate: The proportion of the **recruited** or **vulnerable biomass** that is caught during a certain period, usually a fishing year.

F: The **fishing intensity** or **fishing mortality rate** is that part of the total mortality rate applying to a fish **stock** that is caused by fishing. Usually expressed as an instantaneous rate.

$F_{0.1}$: The **fishing mortality rate** at which the increase in **equilibrium yield per recruit** in weight per unit of effort is 10% of the **yield per recruit** produced by the first unit of effort on the unexploited **stock** (i.e., the slope of the **yield per recruit** curve for the $F_{0.1}$ rate is only 1/10th of the slope of the **yield per recruit** curve at its origin).

$F_{40\%B0}$: The **fishing mortality rate** associated with a biomass of 40% **B_0** at **equilibrium** or on average.

$F_{40\%SPR}$: The **fishing mortality rate** associated with a spawning biomass per recruit (**SPR**) (or equivalently a spawning potential ratio) of 40% B_0 at equilibrium or on average.

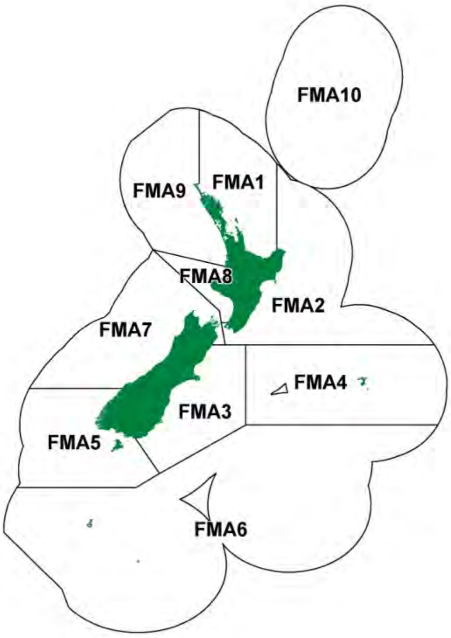
FAWGs: Fisheries Assessment (Science) Working Groups.

Fishing intensity: A general term that encompasses the related concepts of **fishing mortality** and **exploitation rate**.

Fishing mortality: That part of the total mortality rate applying to a fish **stock** that is caused by fishing. Usually expressed as an instantaneous rate.

Fishing year: For most fish stocks, the fishing year runs from 1 October in one year to 30 September in the next. The second year is often used as shorthand for the split years. For example, 2015 is shorthand for 2014–15.

FMA: Fishery Management Area. The New Zealand **EEZ** is divided into 10 fisheries management units:



F_{MAX}: The **fishing mortality rate** that maximises **equilibrium yield per recruit**. **F_{MAX}** is the **fishing mortality** level that defines **growth overfishing**. In general, F_{MAX} is different from **F_{MSY}** (the **fishing mortality** that maximises **sustainable yield**) and is always greater than or equal to **F_{MSY}**, depending on the **stock-recruitment relationship**.

F_{MEY}: The fishing mortality corresponding to the maximum (**sustainable**) economic yield.

F_{MSY}: The **fishing mortality rate** that, if applied constantly, would result in an average catch corresponding to the **Maximum Sustainable Yield** (***MSY***) and an average biomass corresponding to **B_{MSY}**. Usually expressed as an instantaneous rate.

F_{REF}: The **fishing mortality** that is associated with an average biomass of **B_{REF}**.

FRML: Fisheries Related Mortality Limit.

Growth overfishing: Growth overfishing occurs when the **fishing mortality rate** is above **F_{MAX}**. This means that on average fish are caught before they have a chance to reach their maximum growth potential.

Hard Limit: A biomass limit below which fisheries should be considered for closure.

Harvest Strategy: For the purpose of the Harvest Strategy Standard, a harvest strategy simply specifies **target** and **limit reference points** and management actions associated with achieving the **targets** and avoiding the **limits**.

HMS: Highly Migratory Species.

HMSWG: Highly Migratory Species (Science) Working Group.

Hyperdepletion: The situation where an abundance index, such as **CPUE**, decreases faster than the true abundance.

Hyperstability: The situation where an abundance index, such as **CPUE**, decreases more slowly than the true abundance.

Incidental capture: Refers to non-fish and protected species which were not targeted, but were caught.

Index: Same as an **abundance index**.

LCER: Longline Catch-Effort Return.

Length frequency: The distribution of numbers at length from a sample of the **catch** taken by either commercial fisheries or research fishing. This is sometimes called a length composition.

Length-Structured Stock Assessment: An assessment that uses a model to estimate how the numbers at length in the stock vary over time in order to determine the past and present **status** of a fish **stock**.

Limit: A **biomass** or fishing mortality **reference point** that should be avoided with high probability. The Harvest Strategy Standard defines both **soft limit**s and **hard limit**s.

***M*:** The (instantaneous) **natural mortality rate** is that part of the total mortality rate applying to a fish **stock** that is caused by predation and other natural events.

MAFWG: Marine Amateur Fisheries (Science) Working Group.

MALFIRM: Maximum Allowable Limit of Fishing Related Mortality.

Maturity: Refers to the ability of fish to reproduce.

Maturity ogive: A curve describing the proportion of fish of different ages or sizes that are mature.

MAY*: Maximum average yield** is the average **maximum sustainable yield** that can be produced over the long term under a constant fishing mortality strategy, with little risk of **stock** collapse. A constant fishing mortality strategy means catching a constant percentage of the biomass present at the beginning of each fishing year. *MAY* is the long-term average annual catch whereas the catch each year is the *CAY*. Also see ***CAY.

MCMC: Markov Chain Monte Carlo. See **Bayesian stock assessment**.

***MCY*: Maximum constant yield** is the maximum sustainable yield that can be produced over the long term by taking the same catch year after year, with little risk of stock collapse.

MIDWG: Middle-depths (Science) Working Group.

Mid-year biomass: The biomass after half the year's catch has been taken.

MLS: Minimum Legal Size. Fish above the MLS can be retained whereas those below it must be returned to the sea.

Model: A set of equations that represents the population dynamics of a fish stock.

Monte Carlo Simulation: An approach whereby the inputs that are used for a calculation are re-sampled many times assuming that the inputs follow known statistical distributions. The Monte Carlo method is used in many applications such as **Bayesian stock assessments**, parametric bootstraps and stochastic **projections**.

MPD: Mode of the (joint) posterior distribution. See **Bayesian stock assessment**.

***MSY*: Maximum sustainable yield** is the largest long-term average catch or yield that can be taken from a **stock** under prevailing ecological and environmental conditions, and the current selectivity patterns exhibited by fisheries.

MSY*-compatible reference points:** *MSY*-compatible references points include $\boldsymbol{B_{MSY}}$, $\boldsymbol{F_{MSY}}$ and ***MSY itself, as well as analytical and conceptual **proxies** for each of these three quantities.

Natural mortality (rate): That part of the total mortality rate applying to a fish **stock** that is caused by predation and other natural events. Usually expressed as an instantaneous rate.

NCELR: Set Net Catch-Effort Landing Return.

NINSWG: Northern Inshore (Science) Working Group.

Objective function: An equation to be optimised (minimised or maximised) given certain constraints using non-linear programming techniques.

Otolith: One of the small bones or particles of calcareous substance in the internal ear of teleosts (bony fishes) that are used to determine their age.

Overexploitation: A situation where observed **exploitation** (or **fishing mortality**) rates are higher than **target levels**.

Overfishing: A situation where observed **fishing mortality** (or **exploitation**) rates are higher than **target** or **threshold** levels.

Partition: The way in which a fish stock or population is characterised, or split, in a stock assessment model; for example, by sex, age and maturity.

PCELR: Paua Catch-Effort Landing Return.

Population: A group of fish of one species that shares common ecological and genetic features. The **stocks** defined for the purposes of **stock assessment** and management do not necessarily coincide with self-contained populations.

Population dynamics: In general, refers to the biological and fishing processes that result in changes in fish **stock** abundance over time.

Posterior: A mathematical description of the uncertainty in some quantity (e.g., **biomass**) estimated in a **Bayesian stock assessment**. This is generally depicted as a frequency distribution (often plotted along with the **prior** distribution to show how much the two diverge).

Potential Biological Removal (PBR): An estimate of the number of seabirds that may be killed without causing the population to decline below half the carrying capacity.

Pre-recruit: An individual that has not yet entered the fished component of the **stock** (because it is either too young or too small to be vulnerable to fisheries).

Prior: Available information (often in the form of expert opinion) regarding the potential range of values of a parameter in a **Bayesian stock assessment**. Uninformative priors are used where there is no such information.

Production Model: A **stock model** that describes how the **stock biomass** changes from year to year (or, how **biomass** changes in **equilibrium** as a function of **fishing mortality**), but which does not keep track of the age or length frequency of the stock. The simplest production functions aggregate all of the biological characteristics of growth, **natural mortality** and reproduction into a simple, deterministic **model** using three or four parameters. Production models are primarily used in simple data situations, where total catch and effort data are available but age-structured information is either unavailable or deemed to be less reliable (although some versions of production models allow the use of age-structured data).

Productivity: Productivity is a function of the biology of a species and the environment in which it lives. It depends on growth rates, **natural mortality**, **age at maturity**, maximum average age and other relevant life history characteristics. Species with high **productivity** are able to sustain higher rates of **fishing mortality** than species with lower **productivity**. Generally, species with high productivity are more resilient and take less time to rebuild from a **depleted** state.

Projection: Predictions about trends in stock size and fisheries dynamics in the future. Projections are made to address “what-if” questions of relevance to management. Short-term (1–5 years) projections are typically used in support of decision-making. Longer term projections become much more uncertain in terms of absolute quantities, because the results are strongly dependent on **recruitment,** which is very difficult to predict. For this reason, long-term projections are more useful for evaluating overall management strategies than for making short-term decisions.

Proxy: A surrogate for $\boldsymbol{B_{MSY}}$, $\boldsymbol{F_{MSY}}$ or ***MSY*** that has been demonstrated to approximate one of these three metrics through theoretical or empirical studies.

***q*: Catchability** is the proportion of fish that are caught by a defined unit of fishing effort. The constant relating an **abundance index** to the true biomass (the **abundance index** is approximately equal to the true biomass multiplied by the catchability).

Quota Management Areas (QMA): QMAs are geographic areas within which fish stocks are managed in the **TS** and **EEZ**.

Quota Management System (QMS): The **QMS** is the name given to the system by which the total commercial catch from all the main fish **stocks** found within New Zealand's 200 nautical mile **EEZ** is regulated.

Recruit: An individual that has entered the fished component of the **stock**. Fish that are not recruited are either not catchable by the gear used (e.g., because they are too small) or live in areas that are not fished.

Recruited biomass: Refers to that portion of a **stock's biomass** that is available to fisheries; also called **exploitable biomass** or **vulnerable biomass**.

Recruitment: The addition of new individuals to the fished component of a **stock**. This is determined by the size and age at which fish are first caught.

Reference Point: A benchmark against which the biomass or abundance of the **stock** or the **fishing mortality rate** (or **exploitation rate**) can be measured in order to determine its **status**. These reference points can be targets, thresholds or limits depending on their intended use.

RLWG: Rock Lobster (Science) Working Group.

SAMWG: Statistics, Assessments and Methods (Science) Working Group.

S_{AV}: The average historical **spawning biomass**.

Selectivity ogive: Curve describing the relative vulnerability of fish of different ages or sizes to the fishing gear used.

SFWG: The Shellfish (Science) Working Group.

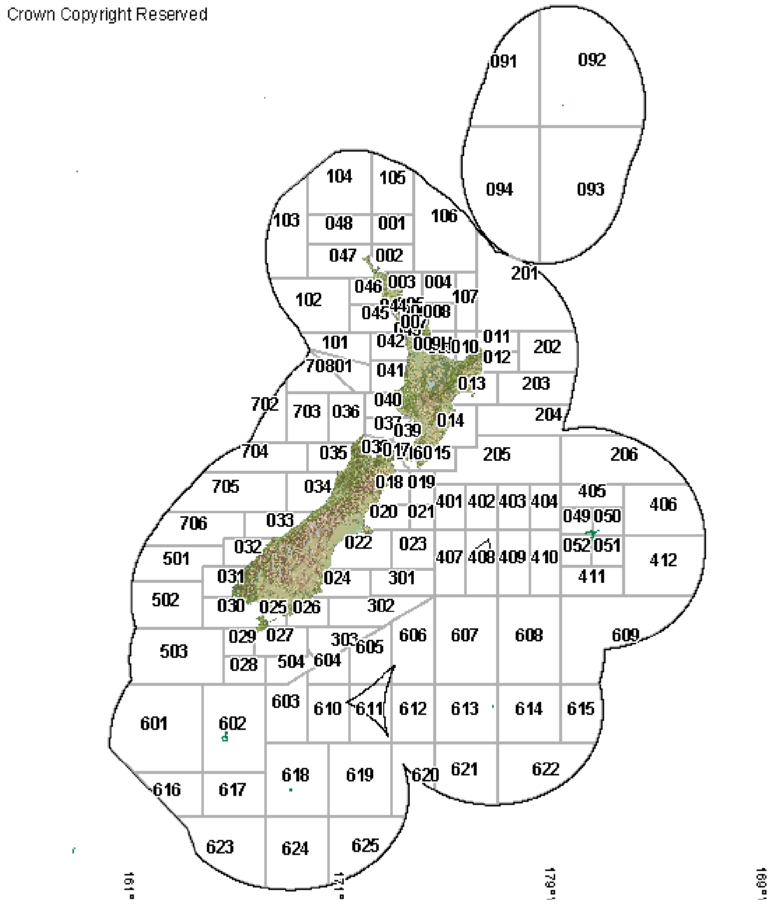
SINSWG: Southern Inshore (Science) Working Group.

Soft Limit: A **biomass** limit below which the requirement for a formal, time-constrained **rebuilding plan** is triggered.

Spawning biomass: The total weight of sexually mature fish in the **stock**. This quantity depends on the abundance of **year classes**, the **exploitation** pattern, the rate of growth, both fishing and **natural mortality rates**, the onset of sexual maturity, and environmental conditions. Same as **mature biomass**.

Spawning (biomass) Per Recruit or Spawning Potential Ratio (SPR): The expected lifetime contribution to the **spawning biomass** for the average recruit to a fishery. For a given exploitation pattern, rate of growth, maturity schedule and **natural mortality**, an **equilibrium** value of SPR can be calculated for any level of fishing mortality. SPR decreases monotonically with increasing fishing mortality.

Statistical area: See the map below for the official **Territorial Sea** and Exclusive Economic Zone (**EEZ**) statistical areas.



Steepness: A parameter of **stock-recruitment relationships** that determines how rapidly, or steeply, it rises from the origin, and therefore how resilient a stock is to rebounding from a depleted state. It equates to the proportion of virgin recruitment that corresponds to 20% B_0. A steepness value greater than about 0.9 is considered to be high, whereas one less than about 0.6 is considered to be low. The minimum value is 0.2.

Stock: The term has different meanings. Under the Fisheries Act, it is defined with reference to units for the purpose of fisheries management (Fishstock). On the other hand, a biological stock is a population of a given species that forms a reproductive unit and spawns little if at all with other units. However, there are many uncertainties in defining spatial and temporal geographical boundaries for such biological units that are compatible with established data collection systems. For this reason, the term "stock" is often synonymous with an assessment /management unit, even if there is migration or mixing of some components of the assessment/management unit between areas.

Stock assessment: The analysis of available data to determine stock status, usually through application of statistical and mathematical tools to relevant data in order to obtain a quantitative understanding of the **status** of the **stock** relative to defined management benchmarks or **reference points** (e.g., B_{MSY} and/or F_{MSY}).

Stock-recruitment relationship: An equation describing how the expected number of recruits to a stock varies as the **spawning biomass** changes. The most frequently used stock-recruitment relationship is the asymptotic Beverton-Holt equation, in which the expected number of recruits changes very slowly at high levels of spawning biomass.

Stock status: Refers to a determination made, on the basis of **stock assessment** results, about the current condition of the **stock**. Stock status is often expressed relative to management benchmarks and **biological reference points** such as B_{MSY} or B_0 or F_{MSY} or $F_{\%SPR}$. For example, the current biomass may be said to be above or below $\boldsymbol{B_{MSY}}$ or to be at some percentage of $\boldsymbol{B_0}$. Similarly, fishing mortality may be above or below $\boldsymbol{F_{MSY}}$ or $\boldsymbol{F_{\%SPR}}$.

Stock structure: (1) Refers to the geographical boundaries of the **stocks** assumed for assessment and management purposes (e.g., albacore tuna may be assumed to comprise two separate **stocks** in the North Pacific and South Pacific), (2) Refers to boundaries that define self-contained **stocks** in a genetic sense, (3) refers to known, inferred or assumed patterns of residence and migration for stocks that mix with one another.

Surplus production: The amount of **biomass** produced by the **stock** (through growth and **recruitment**) over and above that which is required to maintain the [total stock] **biomass** at its current level. If the catch in each year is equal to the surplus production, then the biomass will not change.

Sustainability: Pertains to the ability of a fish **stock** to persist in the long term. Because fish **populations** exhibit natural variability, it is not possible to keep all fisheries and **stock** attributes at a constant level simultaneously, thus sustainable fishing does not imply that the fisheries and the **stock** will persist in a constant **equilibrium** state. Because of natural variability, even if $\boldsymbol{F_{MSY}}$ could be achieved exactly each year, **catches** and **stock biomass** will oscillate around their average ***MSY*** and $\boldsymbol{B_{MSY}}$ levels, respectively. In a more general sense, sustainability refers to providing for the needs of the present generation while not compromising the ability of future generations to meet theirs.

TAC: Total Allowable Catch is the sum of the Total Allowable Commercial Catch (**TACC**) and the allowances for customary Māori interests, recreational fisheries interests and other sources of fishing-related mortality that can be taken in a given period, usually a year.

TACC: Total Allowable Commercial Catch is the total regulated commercial catch from a **stock** in a given time period, usually a fishing year.

Target: Generally, a **biomass**, **fishing mortality** or **exploitation rate** level that management actions are designed to achieve with at least a 50% probability.

Threshold: Generally, a **biological reference point** that raises a “red flag” indicating that **biomass** has fallen below the **target**, or **fishing mortality** or **exploitation rate** has increased above its **target**, to the extent that additional management action may be required in order to prevent the stock from declining further and possibly breaching the **soft limit**.

TCEPR: Trawl Catch Effort Processing Return.

TCER: Trawl Catch Effort Return.

TLCER: Tuna Longline Catch Effort Return.

TS: Territorial Sea. A belt of coastal waters extending at most 12 nautical miles (22.2 km; 13.8 mi) from the baseline (usually the mean low-water mark) of a coastal state.

$\boldsymbol{U_{MSY}}$**:** The **exploitation rate** associated with the maximum sustainable yield.

$\boldsymbol{U_{40\%B0}}$**:** The **exploitation rate** associated with a biomass of 40% $\boldsymbol{B_0}$ at equilibrium or on average.

von Bertalanffy equation: An equation describing how fish increase in length as they grow older. The mean length (L) at age a is

$$L = L_\infty(1 - e^{-k(a-t_0)})$$

where L_∞ is the average length of the oldest fish, k is the average growth rate (Brody coefficient) and t_0 is a constant.

Vulnerable biomass: Refers to that portion of a **stock's biomass** that is available to fisheries. Also called **exploitable biomass** or **recruited biomass**.

Year class (cohort): Fish in a **stock** that were born in the same year. Occasionally, a **stock** produces a very small or very large year class which can be pivotal in determining **stock** abundance in later years.

Yield: Catch expressed in terms of weight.

Yield per Recruit (YPR): The expected lifetime **yield** for the average recruit. For a given **exploitation pattern**, rate of growth, and **natural mortality**, an **equilibrium** value of YPR can be calculated for each level of **fishing mortality**. YPR analyses may play an important role in advice for management, particularly as they relate to minimum size controls.

***Z*:** Total mortality rate. The sum of **natural** and **fishing mortality rates**.

Terms of Reference for Stock Assessment Working Groups in 2022

Overall purpose
The purpose of the Stock Assessment Working Groups is to assess the status of fish stocks managed within the Quota Management System, as well as other important species of interest to New Zealand. Based on scientific information the Stock Assessment Working Groups assess the current status of fish stocks or species relative to MSY-compatible reference points and other relevant indicators of stock status, conduct projections of stock size and status under alternative management scenarios, and review results from relevant research projects. They do not make management recommendations or decisions (this responsibility lies with Fisheries New Zealand fisheries managers and the Minister responsible for fisheries).

Preparatory tasks

1. Prior to the beginning of the main sessions of stock assessment meetings (January to May and July to November), Fisheries New Zealand fisheries scientists will produce a list of stocks and issues for which new stock assessments or evaluations are likely to become available prior to the next scheduled sustainability rounds. This list will include stocks for which the fishing industry and others intend to directly purchase scientific analyses. It is therefore incumbent on those purchasing research to inform the relevant Stock Assessment Working Group chair of their intentions at least three months prior to the start of the sustainability round. Stock Assessment Working Group Chairs will determine the final timetables and agendas for each Working Group.

2. At least six months prior to the main sessions of Stock Assessment Working Group meetings, Fisheries New Zealand fisheries managers will alert Fisheries New Zealand science managers and relevant Working Group chairs to unscheduled special cases for which assessments or evaluations are urgently needed.

Technical objectives

3. To review new research information on stock structure, productivity, abundance and related topics for each fish stock/issue under the purview of individual Stock Assessment Working Groups.

4. Where possible, to derive appropriate MSY-compatible reference points[1] for use as reference points for determining stock status, based on the Harvest Strategy Standard for New Zealand Fisheries[2] (the Harvest Strategy Standard).

5. To conduct stock assessments or evaluations for selected fish stocks in order to determine the status of the stocks relative to MSY-compatible reference points[1] and associated limits, based on the "Guide to Biological Reference Points for Fisheries Assessment Meetings"[3], the Harvest Strategy Standard, and relevant management reference points and performance measures set by fisheries managers.

6. For stocks where the status is unknown, Stock Assessment Working Groups should use existing data and analyses to draw logical conclusions about likely future trends in biomass levels and/or

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[1] MSY-compatible reference points include those related to stock biomass (i.e., B_{MSY}), fishing mortality (i.e., F_{MSY}) and catch (i.e., MSY itself), as well as analytical and conceptual proxies for each of the three of these quantities.

[2] Link to the Harvest Strategy Standard: https://fs.fish.govt.nz/Page.aspx?pk=113&dk=16543

[3] Included in Fisheries Assessment Plenary Reports

fishing mortality (or exploitation) rates if current catches and/or TACs/TACCs are maintained, or if fishers or fisheries managers are considering modifying them in other ways.

7. Where appropriate and practical, to conduct projections of likely future stock status using alternative fishing mortality (or exploitation) rates, or catches, or other relevant management actions, based on the Harvest Strategy Standard and input from the Stock Assessment Working Group and fisheries managers.

8. For stocks that are deemed to be depleted or collapsed, to develop alternative rebuilding scenarios based on the Harvest Strategy Standard and input from the Stock Assessment Working Group and fisheries managers.

9. For fish stocks for which new stock assessments or analyses are not conducted in the current year, to review the existing Fisheries Assessment Plenary report text on the "Status of the Stocks" in order to determine whether the latest reported stock status summary is still relevant; else to revise the evaluations of stock status based on new data or analyses, or other relevant information.

Working Group reports

10. To include in the Working Group report information on commercial, Māori customary, non-commercial and recreational interests in the stock; as well as all other mortality to that stock caused by fishing, which might need to be allowed for in setting a TAC or TACC. Estimates of recreational harvest will normally be provided by the Marine Amateur Fisheries Working Group (MAFWG).

11. To provide information and advice on other management considerations (e.g. area boundaries, by-catch issues, effects of fishing on habitat, other sources of mortality, and input controls such as mesh sizes and minimum legal sizes) required for specifying sustainability measures. Sections of the Working Group reports related to bycatch and other environmental effects of fishing will be reviewed by the Aquatic Environment Working Group (AEWG) although the relevant Stock Assessment Working Group is encouraged to identify to the AEWG Chair any major discrepancies between these sections and their understanding of the operation of relevant fisheries.

12. To summarise the stock assessment methods and results, along with estimates of MSY-compatible references points and other metrics that may be used as benchmarks for assessing stock status.

13. To complete, or review and update if necessary, the "Status of the Stocks" tables in the May and November Fisheries Assessment Plenary reports for all stocks under the purview of individual Stock Assessment Working Groups (including those for which a full assessment has not been conducted in the current year) based on new data or analyses, or other relevant information.

14. It is desirable that full agreement amongst technical experts is achieved on the text of the Stock Assessment Working Group reports, particularly the "Status of the Stocks" sections, noting that the AEWG will review sections on bycatch and other environmental effects of fishing, and the MAFWG will provide text on recreational harvests. If full agreement amongst technical experts cannot be reached, the Chair will determine how this will be depicted in the Stock Assessment Working Group report, will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes.

Working Group input to the Plenary

15. To advise the Fisheries Assessment Plenary chair(s) about stocks requiring review by the Fisheries Assessment Plenary and those stocks that are not believed to warrant review by the

Plenary. The general criteria for determining which stocks should be discussed by the Plenary are that:

(i) the assessment is controversial and Working Group members have had difficulty reaching consensus on one or more base cases, or

(ii) the assessment is the first for a particular stock or the methodology has been substantially altered since the last assessment, or

(iii) new data or analyses have become available that alter the previous assessment, particularly assessments of recent or current stock status, or projections of likely future stock status. Such information could include:

- new or revised estimates of MSY-compatible reference points, recent or current biomass, productivity or yield projections;
- the development of a major trend in the catch or catch per unit effort; or
- any new studies or data that extend understanding of stock structure, fishing patterns, or non-commercial activities, and result in a substantial effect on assessments of stock status.

Membership and Protocols for all Science Working Groups

16. Stock Assessment Working Group members are bound by the Membership and Protocols required for all Science Working Groups (see separate document).

Terms of Reference for the Aquatic Environment Working Group (AEWG) in 2022

Overall purpose

For all New Zealand fisheries in the New Zealand TS and EEZ as well as other important fisheries in which New Zealand engages to assess, based on scientific information, the effects of (and risks posed by) fishing on the aquatic environment, including:

- bycatch and unobserved mortality of protected species (e.g., seabirds and marine mammals), fish, and other marine life, and consequent impacts on populations;
- effects on benthic ecosystems, species, and habitat;
- effects on biodiversity, including genetic diversity; and
- changes to ecosystem structure and function from fishing, including trophic effects.

Where appropriate and feasible, such assessments should explore the implications of the effect, including with respect to government standards, other agreed reference points, or other relevant indicators of population or environmental status. Where possible, projections of future status under alternative management scenarios should be made.

AEWG does not make management recommendations or decisions (this responsibility lies with Fisheries New Zealand fisheries managers and the Minister responsible for Fisheries).

Fisheries New Zealand also convenes a Biodiversity Research Advisory Group (BRAG) which has a similar review function to the AEWG. Projects reviewed by BRAG and AEWG have some commonalities in that they relate to aspects of the marine environment. However, the key focus of projects considered by BRAG is on the functionality of the marine ecosystem and its productivity, whereas projects considered by AEWG more commonly focus on the direct effects of fishing.

Preparatory tasks

1. Prior to the beginning of AEWG meetings each year, Fisheries New Zealand fisheries scientists will produce a list of issues for which new assessments or evaluations are likely to become available that year.

2. The Ministry's research planning processes should identify most information needs well in advance but, if urgent issues arise, Fisheries New Zealand staff will alert the relevant AEWG Chair prior to the required meeting of items that could be added to the agenda. AEWG Chairs will determine the final timetables and agendas for meetings.

Technical objectives

3. To review any new research information on fisheries, including risks of impacts, and the relative or absolute sensitivity or susceptibility of potentially affected species, populations, habitats, and systems.

4. To estimate appropriate reference points for determining population, system, or environmental status, noting any draft or published Standards.

5. To conduct environmental assessments or evaluations for selected species, populations, habitats, or systems in order to determine their status relative to appropriate reference points and Standards, where such exist.

6. In addition to determining the status of the species, populations, habitats, and systems relative to reference points, and particularly where the status is unknown, AEWG should explore the potential for using existing data and analyses to draw conclusions about likely future trends in

fishing effects or status if current fishing methods, effort, catches, and catch limits are maintained, or if fishers or fisheries managers are considering modifying them in other ways.

7. Where appropriate and practical, to conduct or request projections of likely future status using alternative management actions, based on input from AEWG, fisheries plan advisers, and fisheries and standards managers, noting any draft or published Standards.

8. For species or populations deemed to be depleted or endangered, to develop ideas for alternative rebuilding scenarios to levels that are likely to ensure long-term viability based on input from AEWG, fisheries managers, noting any draft or published Standards.

9. To review and revise existing environmental and ecosystem consideration sections of Fisheries Assessment Plenary report text based on new data or analyses, or other relevant information.

Working Group input to the Aquatic Environment and Biodiversity Annual Review

10. To include in contributions to the Aquatic Environment and Biodiversity Annual Review (AEBAR) summaries of information on selected issues that may relate to species, populations, habitats, or systems that may be affected by fishing. These contributions are analogous to Working Group reports from the Fisheries Assessment Working Groups.

11. To provide information and scientific advice on management considerations (e.g., area boundaries, bycatch issues, effects of fishing on habitat, other sources of mortality, and input controls such as mesh sizes and minimum legal sizes) that may be relevant for setting sustainability measures.

12. To summarise the assessment methods and results, along with estimates of relevant standards, references points, or other metrics that may be used as benchmarks or to identify risks to the aquatic environment.

13. It is desirable that full agreement among technical experts is achieved on the text of contributions to the AEBAR. If full agreement among technical experts cannot be reached, the Chair will determine how this will be depicted in the AEBAR, will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes.

14. To advise the Fisheries New Zealand Principal Science Advisors and Aquatic Environment team manager about issues of particular importance that may require independent review or updating in the AEBAR. The general criterion for determining which issues should be discussed by a wider group or text changed in the AEBAR is that new data or analyses have become available that alter the previous assessment of an issue, particularly assessments of population status or projection results. Such information could include:

    - New or revised estimates of environmental reference points, recent or current population status, trend, or projections;
    - The development of a major trend in bycatch rates or amount;
    - Any new studies or data that extend understanding of population, system, or environmental susceptibility to an effect or its recoverability, fishing patterns, or mitigation measures that have a substantial implications for a population, system, or environment or identify risks associated with fishing activity; and
    - Consistent performance outside accepted reference points or Standards.

Membership and Protocols for all Science Working Groups

15. The AEWG is bound by the same membership and protocols as are other Science Working Groups (see separate document).

Terms of Reference for the Biodiversity Research and Advisory Group (BRAG) in 2022

Overall purpose

Since 2000, the objectives of the Biodiversity Research Programme have been drawn directly from Fisheries New Zealand commitments to Theme 3 of the New Zealand Biodiversity Strategy (NZBS) 2000. Within this framework, the workstreams of the Biodiversity Research Programme have been adapted over time as new issues emerge, to build on synergies with other research programmes and work where biodiversity is under greatest threat from fishing or other anthropogenic activities, within the constraints of the overall purpose of the programme, which are:

> "To improve our understanding of New Zealand marine ecosystems in terms of species diversity, marine habitat diversity, and the processes that lead to healthy ecosystem functioning, and the role that biodiversity has for such key processes" and the NZBS definition of biodiversity (the variability among living organisms from all sources including inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species, and of ecosystem), the science currently commissioned broadly aims to:

- Describe and characterise the distribution and abundance of fauna and flora, as expressed through measures of biodiversity, and improving understanding about the drivers of the spatial and temporal patterns observed;

- Determine the functional role of different organisms or groups of organisms in marine ecosystems, and assess the role of marine biodiversity in mitigating the impacts of anthropogenic disturbance on healthy ecosystem functioning; and

- Identify which components of biodiversity must be protected to ensure the sustainability of a healthy marine ecosystem as well as to meet societal values on biodiversity.

Fisheries New Zealand also convenes an Aquatic Environment Working Group (AEWG) which has a similar review function to BRAG. Projects reviewed by BRAG and AEWG have some commonalities in that they relate to aspects of the marine environment. However, the key focus of projects considered by BRAG is on marine issues related to the functionality of the marine ecosystem and its productivity, whereas projects considered by AEWG are more commonly focused on the direct effects of fishing.

BRAG may identify natural resource management issues that extend beyond fisheries management and make recommendations on priority areas of research that will inform Fisheries New Zealand or other government departments of emerging science results that require the attention of managers, policymakers, and decision-makers in the marine sector. BRAG does not make management recommendations or decisions (this responsibility lies with Fisheries New Zealand fisheries managers and the Minister responsible for Fisheries).

Preparatory tasks

1. Prior to the beginning of BRAG meetings each year, Fisheries New Zealand fisheries scientists will produce a list of issues for which new research projects are likely to be required in the forthcoming financial year. The BRAG Chair will determine the final timetables and agendas.

2. The Ministry's research planning processes should identify most information needs well in advance but, if urgent issues arise, Fisheries New Zealand fisheries managers will alert the Aquatic Environment and Biodiversity Science Manager and the Principal Advisor Fisheries Science at least three months prior to the required meetings where possible.

BRAG technical objectives

3. It is the responsibility of the BRAG to review, discuss, and convey views on the results of marine biodiversity research projects contracted by Fisheries New Zealand. The review process

is an evaluation of how existing research results can be built upon to address emerging research issues and needs. It is essentially an evaluation of "what we already know" and how this can be used to obtain "what we need to know”. This information should be used by BRAG to identify gaps in our knowledge and for developing research plans to address these gaps.

4. It is the responsibility of BRAG participants to discuss, evaluate, make recommendations, and convey views on particular research area as required. Individual related projects on a species or fishery or research topic need to be aligned to relevant strategic and policy directions.

5. The recommendations on project proposals for the next financial year will be submitted via the Chair of BRAG to the Principal Science Advisor Fisheries.

6. The Biodiversity Research Programme includes research in New Zealand’s TS, EEZ, Extended Continental Shelf, the South Pacific Region, and the Ross Sea region. There are six scientific work streams as follows:

   - To provide ecological information for a whole-of-systems approach to domestic fisheries management;
   - To develop tools and methods to assess and track the footprint of fisheries related activities on biodiversity and ecosystem functioning;
   - To identify and monitor threats and opportunities for adaptation or mitigation associated with environmental change;
   - To develop the blue-green economy within environmental constraints;
   - To evaluate and safeguard natural capital for future generations; and
   - To progress ecosystem-based fisheries management under international obligations.

BRAG input to the Fisheries Assessment Plenary and the Aquatic Environment and Biodiversity Annual Review

7. To contribute to and summarise progress on biodiversity research in the Aquatic Environment and Biodiversity Annual Review. This contribution is analogous to Working Group Reports from the Fisheries Assessment Working Groups.

8. To summarise the assessment methods and results, along with estimates of relevant standards, references points, or other metrics that may be relevant to biodiversity objectives, the Biodiversity Strategy, and international obligations.

9. It is desirable that full agreement among technical experts is achieved on the text of these contributions. If full agreement among technical experts cannot be reached, the Chair will determine how this will be depicted in the Aquatic Environment and Biodiversity Annual Review, will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes.

10. To advise the Principal Science Advisor Fisheries about issues of particular importance that may require review by a Plenary meeting or summarising in the Aquatic Environment and Biodiversity Annual Review. The general criterion for determining which issues should be discussed by a wider group include:

    - Emerging issues, recent or current biodiversity status assessments, trends, or projections;
    - The development of a major trend in the marine environment that will impact on marine productivity or ecosystem resilience to stressors; and
    - Any new studies or data that impact on international obligations.

Membership and Protocols for all Science Working Groups

11. The BRAG is bound by the same membership and protocols as other Science Working Groups (see separate document).

Terms of Reference for the Marine Amateur Fisheries Working Group (MAFWG) in 2022

Overall purpose

The purpose of the MAFWG is to assess the harvest of marine amateur fishers from fish stocks managed within or outside the Quota Management System and to review other scientific or research information relevant to the management of marine amateur fisheries. MAFWG does not make management recommendations or decisions; this responsibility lies with Fisheries New Zealand fisheries managers and the Minister responsible for fisheries.

Preparatory tasks

1. It is anticipated that marine amateur fisheries research will focus primarily on the estimation of amateur harvests of fish stocks based on corroborated off-site national surveys conducted about every 5 years. At least six months before any such survey is conducted, Fisheries New Zealand fisheries managers will alert Fisheries New Zealand science managers and the Fisheries New Zealand Principal Science Advisors to their priority stocks for harvest estimation to facilitate good survey design. In years when national surveys are not being conducted, Fisheries New Zealand fisheries managers and fisheries scientists will work closely together to prioritise the meeting of other key information needs in relation to marine amateur fisheries.

Technical objectives

2. To review new research information on the harvest and harvesting patterns of marine amateur fishers using off-site and/or on-site methods, focussing primarily on priority non-commercial and shared stocks or fisheries identified by fisheries managers.

3. To develop methods for making reliable estimates of total catch by fish stock (finfish and shellfish); catch per unit of effort (CPUE); fish lengths and weights within the harvest; daily bag sizes in relation to limits; the spatial and temporal variability of fishing, CPUE, or harvest; and other information likely to inform fisheries management decisions, the development of environmental standards, or the formulation of relevant policy.

Working Group reports

4. In collaboration with relevant Stock Assessment Working Group Chairs, to provide timely and current information on marine amateur harvest for Working Group reports for non-commercial and shared stocks. MAFWG will also periodically review information on marine amateur harvest in Working Group reports to ensure accuracy and currency.

5. As necessary, provide information and advice on other management considerations for marine amateur fisheries (e.g. effects of fishing on habitat, other sources of mortality, and potential input controls such as bag limits, mesh sizes, and minimum legal sizes) required for specifying sustainability measures.

6. It is desirable that full agreement amongst technical experts is achieved on the information provided for Working Group reports on the harvest and other aspects of marine amateur fisheries. If full agreement amongst technical experts cannot be reached, the Chair will determine how this will be depicted in the Working Group report, will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes.

Membership and Protocols for all Science Working Groups

7. MAFWG members are bound by the Membership and Protocols required for all Science Working Group members (see separate document).

Terms of Reference for the Antarctic Working Group (ANTWG) in 2022

Overall purpose

The purpose of the ANTWG is to review science and research information intended for submission to or use by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR is an inter-governmental organisation that is committed to conserving the marine life of the Southern Ocean while allowing rational use of marine resources, including commercial fishing. The CCAMLR Convention requires that management considers the effects of fishing on dependent and associated species as well as on the target species. The area of jurisdiction of the CCAMLR Convention is approximately south of the circumpolar Antarctic Polar Front in the Southern Ocean. Science and research requested or used by CCAMLR may include, inter alia, fishery characterisations, abundance indices, catch-at-age or catch-at-length data, and stock assessment modelling to assess the status of fish stocks managed by CCAMLR; bycatch and unobserved mortality of protected species, fish, and other marine life; effects on biodiversity and benthic biodiversity, species, and habitat; and changes to ecosystem structure and function as a result of fishing, including trophic effects. The ANTWG also undertakes scientific review of documents and papers that may be submitted to the scientific working groups of CCAMLR to aid and inform its management. The ANTWG does not make management recommendations or decisions; these responsibilities lie with CCAMLR's Scientific Committee and the Commission.

Preparatory tasks

1. Prior to the first meeting of the ANTWG each year, the ANTWG Chair will produce a list of stocks/issues for which new stock assessments, evaluations, impact assessments, risk assessments, or other scientific analyses have been requested by the CCAMLR Scientific Committee or the Commission (including its contributing bodies), fishing industry, or other stakeholders. The ANTWG Chair will determine the final timetables and agendas of the working group each year, taking account of the available time and resources.

Technical objectives

2. To review new research information on stock structure, productivity, abundance and related topics for each fish stock or environmental issue under the purview of the ANTWG.

3. Where possible, to derive yields or reference points requested by CCAMLR's Scientific Committee or Commission related to fish stocks or environmental issues relevant to CCAMLR fisheries.

4. To conduct stock assessments or evaluations for selected stocks in order to determine the precautionary yields and status of the stocks relative to the requested reference points or, if no such reference points are specified by CCAMLR, MSY-compatible reference points and associated limits, based on the "Guide to Biological Reference Points for Fisheries Assessment Meetings" and New Zealand's Harvest Strategy Standard.

5. For stocks where the status is unknown, the ANTWG should, where possible, use any existing data and analyses to draw conclusions about likely future trends in biomass levels and/or fishing mortality (or exploitation) rates if current catches and/or TACs are maintained, or if fishers or CCAMLR are considering modifying them in other ways.

6. Where requested by the CCAMLR Scientific Committee or Commission, to conduct projections of likely future stock status using alternative fishing mortality (or exploitation) rates or catches and other relevant management actions, based on input from the ANTWG and any guidance from the CCAMLR Scientific Committee or Commission.

7. Where requested by the CCAMLR Scientific Committee or Commission, in relation to specified stocks, to develop and report on alternative rebuilding scenarios.

8. To conduct environmental impact assessments and qualitative or quantitative risk assessments in relation to bycatch species, other species of concern, benthic systems, or vulnerable marine ecosystems to support the work of the CCAMLR Scientific Committee and Commission.

Working Group reports

9. To review, and update if necessary, the "Status of the Stocks" tables in the Fisheries Assessment Plenary report based on new data or analyses, or other relevant information.

10. To complete (and/or update) the Status of Stocks tables using the template provided in the Introductory chapter of the most recent May Plenary report.

11. To review, and update if necessary, the "Antarctic Science" chapter of the Aquatic Environment and Biodiversity Review (AEBAR) based on new data or analyses, or other relevant information.

12. It is desirable that full agreement amongst technical experts is achieved on the text of the ANTWG reports. If full agreement amongst technical experts cannot be reached, the Chair will determine how this will be depicted in the ANTWG report, will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes.

Papers and reports to CCAMLR

13. Papers and reports summarising work reviewed by the ANTWG are generally submitted to CCAMLR's Scientific Committee, and their content varies widely. It is desirable that full agreement amongst technical experts is achieved on the content of such papers or reports, noting that deadlines for submission to CCAMLR may require the Chair to finalise text after a meeting of the ANTWG has considered and resolved scientific issues. If full agreement amongst technical experts cannot be reached, the Chair will determine how this will be depicted in the paper or report to be submitted to CCAMLR. In such cases, the Chair will also document the extent to which agreement or consensus was achieved and record and attribute any residual disagreement in the meeting notes.

Membership and Protocols for all Science Working Groups

14. ANTWG members are bound by the Membership and Protocols required for all Science Working Group members (see separate document).

Terms of Reference for the South Pacific Assessment Working Group (SPACWG) in 2022

Overall purpose

The purpose of the SPACWG is to review science and research information intended for submission to or use by the South Pacific Regional Fisheries Management Organisation (SPRFMO). SPRFMO is an inter-governmental organisation that is committed to the long-term conservation and sustainable use of the fishery resources of the South Pacific Ocean and, in so doing, safeguarding the marine ecosystems in which the resources occur. The SPRFMO Convention applies to the high seas of the South Pacific. Science and research information requested or used by SPRFMO may include, *inter alia*, fishery characterisations, abundance indices, catch-at-age or catch-at-length data, and stock assessment modelling to assess the status of fish stocks managed by SPRFMO. Also included will be characterisations, impact assessments, or risk assessments for the environmental effects of fisheries in the SPRFMO Area, particularly regarding vulnerable marine ecosystems (VMEs), and modelling work to assess the trade-offs inherent in, or likely outcomes of, potential management choices. SPACWG does not make management recommendations or decisions; these responsibilities lie with SPRFMO's Scientific Committee, Compliance and Technical Committee, and the Commission.

Preparatory tasks

1. Prior to the first meeting of SPACWG each year, the SPACWG Chair will produce a list of stocks/issues for which new stock assessments, evaluations, impact assessments, or risk assessments have been requested by the SPRFMO Commission (including its contributing bodies) or by fishing industry or other stakeholders. The SPACWG Chair will determine the final timetables and agendas of the working group each year, taking account of the available time and resources.

Technical objectives

2. To review new research information on stock structure, productivity, abundance and related topics for each fish stock or environmental issue under the purview of SPACWG.

3. Where possible, to derive reference points requested by SPRFMO's Scientific Committee or Commission related to fish stocks or environmental issues relevant to SPRFMO fisheries.

4. To conduct stock assessments or evaluations for selected stocks in order to determine the status of the stocks relative to the requested reference points or, if no such reference points are specified by SPRFMO, MSY-compatible reference points and associated limits, based on the "Guide to Biological Reference Points for Fisheries Assessment Meetings" and New Zealand's Harvest Strategy Standard.

5. For stocks where the status is unknown, SPACWG should, where possible, use any existing data and analyses to draw conclusions about likely future trends in biomass levels and/or fishing mortality (or exploitation) rates if current catches and/or TACs are maintained, or if fishers or SPRFMO are considering modifying them in other ways.

6. Where requested by the SPRFMO Commission or Scientific Committee, to conduct projections of likely future stock status using alternative fishing mortality (or exploitation) rates or catches and other relevant management actions, based on input from the SPACWG and any guidance from the SPRFMO Scientific Committee or Commission.

7. Where requested by the SPRFMO Scientific Committee or Commission, in relation to specified stocks, to develop and report on alternative rebuilding scenarios.

8. To conduct environmental impact assessments and qualitative or quantitative risk assessments in relation to bycatch species, other species of concern, benthic systems, or vulnerable marine ecosystems to support the work of the SPRFMO Scientific Committee and Commission.

Papers and reports to SPRFMO

9. Papers and reports summarising work reviewed by SPACWG are generally submitted to SPRFMO's Scientific Committee, and their content varies widely. It is desirable that full agreement amongst technical experts is achieved on the content of such papers or reports, noting that deadlines for submission to SPRFMO may require the Chair to finalise text after a meeting of SPACWG has considered and resolved scientific issues. If full agreement amongst technical experts cannot be reached, the Chair will determine how this will be depicted in the paper or report to be submitted to SPRFMO. In such cases, the Chair will also document the extent to which agreement or consensus was achieved and record and attribute any residual disagreement in the meeting notes.

Membership and Protocols for all Science Working Groups

10. SPACWG members are bound by the Membership and Protocols required for all Science Working Group members (see separate document).

Terms of Reference for the Statistics, Assessments and Methods Working Group (SAMWG) in 2022

Overall purpose

The purpose of the SAMWG is to review and evaluate statistical methods, stock assessment methods, risk assessment methods, and any other quantitative or qualitative methods used in stock assessments, or research into the environmental effects of fishing, or assessments of marine biodiversity. The SAMWG will:

a) Develop a work programme each year to review and progress statistics, assessments and methods used by, or suitable for, Fisheries New Zealand purposes; and

b) Review quantitative and qualitative methods, particularly those that are novel, complex or contentious, referred by the Chairs of other Science Working Groups (SWGs).

The extent to which the SAMWG can fulfil these two purposes will be contingent on the availability of qualified quantitative staff and research providers to undertake and present the necessary analyses. On the basis of its reviews, the SAMWG will make recommendations, formulate guidelines, or suggest future research and provide these to other relevant SWGs or other entities. The SAMWG does not make management recommendations or decisions (this responsibility lies with Fisheries New Zealand fisheries managers and the Minister responsible for fisheries).

Preparatory tasks

1. Prior to the beginning of the financial year, Fisheries New Zealand fisheries scientists will produce a list of projects likely to be progressed in the coming year. This will be conducted in conjunction with the Chairs of other SWGs, and will be reviewed periodically with the Chairs throughout the year.

2. The list should also include relevant projects, including those already contracted or undertaken, and those anticipated by stakeholders directly purchasing scientific analyses. It is therefore incumbent on those purchasing research to inform the SAMWG Chair(s) of their intentions, preferably at least three months prior to the start of the financial year.

3. Some research purchased by Fisheries New Zealand fisheries managers may also benefit from review by the SAMWG. Fisheries New Zealand managers should be involved in producing the initial list of projects, and should alert Fisheries New Zealand science managers and the Fisheries New Zealand Principal Science Advisors to unscheduled special cases for which review or evaluation are urgently needed.

4. The SAMWG may have different Fisheries New Zealand Chairs for specific topic areas.

5. SAMWG Chair(s) will determine the final timetables and agendas for each Working Group.

Technical objectives

In conjunction with the Chairs of relevant SWGs and fisheries managers, the SAMWG will:

6. Review and evaluate new research information on statistical methods, stock assessment methods, risk assessment methods, and any other quantitative or qualitative methods used in stock assessments, or research into the environmental effects of fishing, or assessments of marine biodiversity, as specified in an annual research programme, or in ad hoc opportunities or requests throughout the year for such reviews, or as referred by the Chairs of other SWGs or fisheries managers.

7. Review and evaluate new methodologies for determining reference points for stock assessments and risk assessments.

8. Review and evaluate new methodologies for assessing the status of low information stocks or non-target species, or assessing risks to low information stocks or non-target species.

9. Review and evaluate new approaches to developing Management Procedures, Management Strategy Evaluations and Harvest Control Rules.

10. Review and evaluate new methods for assessing or mitigating the environmental effects of fishing.

11. Review and evaluate novel tools for accessing, querying, analysing and storing data to solve specific fisheries problems.

Reports produced

12. The SAMWG will make recommendations, formulate guidelines, or suggest future research and provide these to research providers, or to other relevant SWGs, or to other entities. These may be recorded in the records of SAMWG meetings, or written up more formally in Fisheries Research Reports (FARs) or Aquatic Environment and Biodiversity Reports (AEBRs).

13. In general, such recommendations, guidelines and future research considerations will be made in the form of a report outlining the rationale by which the SAMWG reached its conclusions. Where relevant, the research evaluated by the SAMWG may be published either as a FAR or an AEBR. Alternatively, the report of the SAMWG could be appended to a relevant FAR or AEBR, or provided to relevant entities as a separate, unpublished (but publicly available) short document.

14. It is desirable that full agreement amongst technical experts is achieved on the text of the documents to which the SAMWG contributes. If full agreement amongst technical experts cannot be reached, the Chair will determine how this will be depicted in the SAMWG minutes or other documents, will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes.

Working Group input to the Plenary and AEBAR

15. The SAMWG will contribute appropriate text to the Plenary and AEBAR, as needed, in coordination with the Chairs of other SWGs.

Membership and Protocols for all Science Working Groups

16. SAMWG members are bound by the Membership and Protocols required for all Science Working Group members (see separate document).

Membership and Protocols for all Science Working Groups in 2022

This document summarises the protocols for membership and participation in all Science Working Groups including Stock Assessment Working Groups, the Aquaculture Working Group (AQWG), the Aquatic Environment Working Group (AEWG), the Biodiversity Research Advisory Group (BRAG), the Statistics, Assessments and Methods Working Group (SAMWG), the South Pacific Working Group (SPACWG), the Antarctic Working Group (ANTWG), and the Marine Amateur Fisheries Working Group (MAFWG).

Working Group chairs

1. Fisheries New Zealand will select and appoint the Chairs for Science Working Groups. The Chair will be a Fisheries New Zealand fisheries or marine scientist who is an active participant in the Working Group, providing technical input, rather than simply being a facilitator. Working Group Chairs will be responsible for:

* ensuring that Working Group participants are aware of the Terms of Reference for the Working Group, and that the Terms of Reference are adhered to by all participants;

  * setting the rules of engagement, facilitating constructive questioning, and focussing on relevant issues;

  * ensuring that all peer review processes are conducted in accordance with the Research and Science Information Standard for New Zealand Fisheries[4] (the Research Standard), and that research and science information is reviewed by the relevant Working Group against the *PRIOR* principles for science information quality (page 6 in the Research Standard) and the criteria for peer review (pages 12–16 in the Research Standard);

  * requesting and documenting the names and affiliations of participants at each Working Group meeting and ensuring that these are noted in the Working Group meeting notes. Chairs are responsible for managing conflicts of interest (refer to page 15 of the Research Standard), and ensuring that fisheries management or aquaculture implications do not jeopardise the objectivity of the review or result in biased interpretation of results;

  * ensuring that the quality of information that is intended or likely to inform fisheries management or aquaculture decisions, the development of environmental standards, or the formulation of relevant fisheries policy is ranked in accordance with the information ranking guidelines in the Research Standard (page 21–23), and that resulting information quality ranks are appropriately documented in the Fisheries Assessment Plenary and the Aquatic Environment and Biodiversity Annual Review (AEBAR);

  * striving for consensus while ensuring the transparency and integrity of research analyses, results, conclusions and final reports; and

  * reporting on Working Group recommendations, conclusions and action items; and ensuring follow-up and communication with Fisheries New Zealand Principal Science Advisors, relevant Fisheries New Zealand fisheries management or aquaculture staff, and other key stakeholders.

Working Group members

2. Membership of Science Working groups will be open to any participant with the agreement of the Working Group Chair, provided that they expect to meet a participation threshold that may vary depending on the Working Group in question. All members are expected to actively

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[4] Link to the Research Standard: https://www.mpi.govt.nz/dmsdocument/3692-Research-and-Science-Information-Standard-for-New-Zealand-Fisheries

participate in at least two and preferably considerably more Working Group meetings during a given year.

3. Working Groups will consist of the following participants:
   * Fisheries New Zealand science chair – required;
   * research providers – required (may be the primary researcher, or a designated substitute capable of presenting and discussing the agenda item);
   * other scientists not conducting the presented research to act in a peer review capacity;
   * representatives of relevant Fisheries New Zealand fisheries management or aquaculture teams; and
   * any interested party who meets the participation threshold and agrees to the standards of participation below.

4. Working Group participants must commit to:
   * participating appropriately in discussions;
   * resolving issues;
   * following up on agreements and tasks;
   * maintaining confidentiality of Working Group discussions and deliberations (unless otherwise agreed in advance, and subject to the constraints of the Official Information Act);
   * adopting a constructive approach;
   * avoiding repetition of earlier deliberations, particularly where agreement has already been reached;
   * facilitating an atmosphere of honesty, openness and trust;
   * respecting the role of the Chair; and
   * listening to the views of others, and treating them with respect.

5. Participants in Working Group meetings will be expected to declare their sector affiliations and contractual relationships to the research under review, and to declare any substantial conflicts of interest related to any particular issue or scientific conclusion.

6. Working Group participants must adhere to the requirements of independence, impartiality and objectivity listed under the Peer Review Criteria in the Research Standard (pages 12–16). It is understood that Working Group participants will often be representing particular sectors and interest groups and may be expressing the views of those groups. However, when participating in the review of science information, representatives are expected to step aside from their sector affiliations, and to ensure that individual and sector views do not result in bias in the science information and conclusions.

7. Participants in each Working Group will have access to the corresponding sections of the Science Working Group website including the Working Group papers and other information provided in those sections. Access to Science Working Group websites will generally be restricted to those who have a reasonable expectation of attending at least two meetings of a given Science Working Group each year.

8. Working Group members who do not adhere to the standards of participation (paragraph 4), or who use Working Group papers and related information inappropriately (see paragraph 10), may be requested by the Chair to leave a particular meeting or to refrain from attending one or more future meetings. In more serious instances, members may be removed from the Working

Group membership and denied access to the Working Group website for a specified period of time, or permanently.

Working Group papers and related information

9. Working Group papers will be posted on the Fisheries New Zealand website prior to meetings if they are available. As a general guide, PowerPoint presentations and draft or discussion papers should be available at least two working days before a meeting, and near-final papers should be available at least five working days before a meeting if the Working Group is expected to agree to the paper. However, it is also likely that some papers will be made available for the first time during the meeting due to time constraints. If a paper is not available for sufficient time before the meeting, the Chair may provide for additional time following the meeting for additional comments from Working Group members.

10. Working Group papers are “works in progress” intended to facilitate the discussion of analyses by the Working Groups. They often contain preliminary results that are receiving peer review for the first time and, as such, may contain errors or preliminary analyses that will be superseded by more rigorous work. **For these reasons, no-one may release the papers or any information contained in these papers to external parties. In general, Working Group papers should not be cited.** Exceptions may be made in rare instances by obtaining permission in writing from an FNZ Principal Science Advisor or an FNZ Science Manager, and the authors of the paper. It is also anticipated that Working Group participants who are representing others at a particular Working Group meeting or series of such meetings may wish to communicate preliminary results to the people they are representing. Participants, along with recipients of the information, are required to exercise discretion in doing this, and to guard against preliminary results being made public.

11. From time to time, Fisheries New Zealand commissions external reviews of analyses, models or issues. Terms of Reference for these reviews and the names of external reviewers may be provided to the Working Group for information or feedback. It is extremely important to the proper conduct of these reviews that all contact with the reviewers is through the Chair of the Working Group or Chair of the review. Under no circumstances should Working Group members approach reviewers directly until after the final report of the review has been published.

Working Group meetings

12. Meetings will take place as required, generally January–May and July–November for Stock Assessment Working Groups and throughout the year for other Working Groups (AEWG, AQWG, BRAG, HMSWG, SPACWG, ANTWG and MAFWG).

13. A quorum will be reached when the Chair, the designated presenter, and at least three other technical experts are present. In the absence of a quorum, the Chair may decide to proceed as a sub-group, with outcomes being discussed with the wider Working Group via email or taken forward to the next meeting at which a quorum is formed.

14. The Chair is responsible for deciding, with input from the entire Working Group, but focussing primarily on the technical discussion and the views of technical expert members:

    * the quality and acceptability of the information and analyses under review;

    * the way forward to address any deficiencies;

    * the need for any additional analyses;

    * contents of research reports, Working Group reports and AEBAR chapters;

    * choice of best models and sensitivity analyses to be presented; and

- the status of the stocks, or the status/performance in relation to any relevant environmental standards or targets.

15. The Chair is responsible for facilitating a consultative and collaborative discussion.

16. Working Group meetings will be run formally, with agendas pre-circulated, and formal records kept of recommendations, conclusions and action items.

17. A record of recommendations, conclusions and action items will be posted on the Fisheries New Zealand website after each meeting has taken place.

18. Data upon which analyses presented to the Working Groups are based must be provided to Fisheries New Zealand in the appropriate format and level of detail in a timely manner (i.e. the data must be available and fully-accessible to Fisheries New Zealand; however, data confidentiality concerns mean that some data may not necessarily be made available to Working Group members).

19. Working Group processes will be evaluated periodically, with a view to identifying opportunities for improvement. Terms of Reference and the Membership and Protocols may be updated as part of this review.

20. Fisheries New Zealand scientists and science officers will provide administrative support to the Working Groups.

Information Quality Ranking

21. Science Working Groups are required to rank the quality of research and science information that is intended or likely to inform fisheries management or aquaculture decisions, in accordance with the science information quality ranking guidelines in the Research Standard (pages 21–23). Information quality rankings should be documented in Working Group reports and, where appropriate, in Status of Stock summary tables. Note that:

    - Working Groups are not required to rank all research projects and analyses, but key pieces of information that are expected or likely to inform fisheries management or aquaculture decisions, the development of environmental decisions, or the formulation of relevant policy should receive a quality ranking;
    - explanations substantiating the quality rankings will be included in Working Group reports. In particular, the quality shortcomings and concerns for moderate/mixed and low-quality information should be documented; and
    - the Chair, working with participants, will determine which pieces of information require a quality ranking. Not all information resulting from a particular research project would be expected to achieve the same quality rank, and different quality ranks may be assigned to different components, conclusions or pieces of information resulting from a particular piece of research.

Record-keeping

22. The overall responsibility for record-keeping rests with the Chair of the Working Group, and includes:

    - keeping notes on recommendations, conclusions and follow-up actions for all Working Group meetings, and to ensure that these are available to all members of the Working Group in a timely manner. If full agreement on the recommendations or conclusions cannot readily be reached amongst technical experts, then the Chair will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes; and

* compiling a list of generic assessment issues and specific research needs for each stock, species or environmental issue under the purview of the Working Group, for use in subsequent research planning processes.

Fisheries Assessment Working Groups: Membership 2022

Antarctic Working Group

Convenors: Nathan Walker

Members: Matthew Baird, Stephanie Brown, Jennifer Devine, Alistair Dunn, Jack Fenaughty, Greig Funnell, Simon Hoyle, Leyla Knittweis-Mifsud, Dan MacGibbon, Monique Messina, Bradley Moore, Philipp Neubauer, Richard O'Driscoll, Steve Parker, Matt Pinkerton, Brodie Plum, Darryn Shaw, Andy Smith, Perry Smith, Josh van Lier, Tim Vaughan-Sanders, D'Arcy Webber, Barry Weeber.

Species: Antarctic toothfish

Aquatic Environment Working Group – Protected Species

Convenors: William Gibson and Ben Sharp

Members: Ed Abraham, Carolyn Aguilar, Owen Anderson, Sonja Austin, Hilary Ayrton, Karen Baird, Barry Baker, Scott Baker, Joshua Baller, Josh Barclay, Steve Beatson, Erik Behrens, Elizabeth Bell, Mike Bell, Katrin Berkenbusch, Tiffany Bock, Laura Boren, Christine Bowden, David Bowden, Erin Breen, Paul Breen, Anthony Brett, Tom Brough, Curly Brown, Ian Brown, Sarah Bury, Glen Carbines, Susan Chalmers, Mark Chambers, Simon Childerhouse, Malcolm Clark, Tom Clark, Katie Clemens-Seely, Deanna Clement, George Clement, Damian Cloeter, Rochelle Constantine, Justin Cooke, Vonda Cummings, Roberta D'Archino, Steve Dawson, Igor Debski, Jessica Desmond, Jennifer Devine, Christopher Dick, Peter Dillingham, Clinton Duffy, Alistair Dunn, Matt Dunn, Charles Edwards, Mark Edwards, Pablo Esobar-Flores, Jack Fenaughty, Brit Finucci, David Foster, Allen Frazer, Debbie Freeman, Richa Garg, Sharleen Gargiulo, Shane Geange, Mark Geytenbeek, Dave Goad, Bruce Hartill, Barb Hayden, Jeremy Helson, Hannah Hendriks, Kristina Hillock, Freyda Hjorvarsdottir, Lyndsey Holland, Steven Holmes, Simon Hoyle, Lucy Jacob, Emma Jones, Daniel Kerrigan, Brianna King, Kirstie Knowles, Jo Lambie, Todd Landers, Kath Large, Laws Lawson, Mary Livingston, Carolyn Lundquist, Dave Lundquist, Greg Lydon, Gemma McGrath, Andy McKenzie, Darryl MacKenzie, Lucy Manning, Thomas Mattern, Sue Maturin, Stefan Meyer, Karen Middlemiss, David Middleton, Jodi Milne, Janice Molloy, Kiri Morgan, Mark Morrison, Riki Mules, Philipp Neubauer, Richard O'Driscoll, Enrique Pardo, Graham Parker, Steve Parker, Darren Parsons, Michael Patrick, Heiko Philippi, Johanna Pierre, Matt Pinkerton, Tiffany Plencner, Will Rayment, Trish Rea, Nathan Reid, Yvan Richard, Jesse Rihia, Peter Ritchie, Jim Roberts, Ashley Rowden, Richard Saunders, Carol Scott, Katherine Short, Liz Slooten, Andy Smith, Paul Starr, Kevin Sullivan, Darryl Sykes, John Taunton-Clark, Graeme Taylor, David Thompson, Finlay Thompson, Hamish Tijsen, Rob Tilney, Geoff Tingley, Rob Tinkler, Di Tracey, Ian Tuck, Dominic Vallieres, Anton van Helden, Josh van Lier, Adam Watson, Shannon Weaver, D'Arcy Webber, Trudi Webster, Barry Weeber, Richard Wells, Tamar Wells, James Williams, Oliver Wilson, Andrew Wright, Jingjing Zhang.

Aquatic Environment Working Group – Benthic Habitats

Convenors: Karen Tunley

Members: Carolyn Aguilar, Harry Allard, Vikki Ambrose, Owen Anderson, Sonja Austin, Mike Beentjes, Andrew Biggerstaff, Tiffany Bock, David Bowden, Tom Brough, Curly Brown, Glen Carbines, Anthony Charsley, Michelle Cherrington, Malcolm Clark, Tom Clark, George Clement, Roberta D'Archino, Jean Davis, Jennifer Devine, Christopher Dick, Kim Drummond, Clinton Duffy, Charles Edwards, Rosa Edwards, Jack

Fenaughty, David Foster, Shane Geange, Bianca Hampton, Barb Hayden, Freya Hjorvarsdottir, Lyndsey Holland, Aaron Irving, Emma Jones, Daniel Kerrigan, Brianna King, Jo Lambie, Laws Lawson, Daniel Leduc, Eva Leunissen, Megan Linwood, Drew Lohrer, Carolyn Lundquist, Greg Lydon, Kevin Mackay, Alicia McKinnon, Olivia Maes, Karen Middlemiss, David Middleton, Marco Milardi, Jodi Milne, Bradley Moore, Sophie Mormede, Mark Morrison, Charlotte Mortimer, Riki Mules, Campbell Murray, Wendy Nelson, Philipp Neubauer, Richard O'Driscoll, Enrique Pardo, Darren Parsons, Matt Pinkerton, Marine Pomarède, Nathan Reid, Mathilde Richer de Forges, Jesse Rihia, James Robertson, Ashley Rowden, Kareen Schnabel, Clara Schlieman, Alexandra Schwaab, Carol Scott, Katherine Short, Paul Sieberhagen, Andy Smith, Benjamin Steele-Mortimer, Scott Stephens, Fabrice Stephenson, Phillip Sutton, Jordi Tablada, Amelia Tan, John Taunton-Clark, Karli Thomas, Rob Tilney, Geoff Tingley, Robert Tinkler, Di Tracey, Laura Tremblay-Boyer, Ian Tuck, Josh van Lier, Oli Wade, Cath Wallace, Barry Weeber, Richard Wells, James Williams, John Willmer, Oliver Wilson, Robert Win, Brent Wood, Andrew Wright.

Aquatic Environment Working Group – Non-Target Fish and Invertebrate Catch

Convenors: Marco Milardi and Josh van Lier

Members: Owen Anderson, Hilary Ayrton, Tiffany Bock, Ian Brow, Glen Carbines, Mark Chambers, Simon Childerhouse, Tom Clark, Damien Cloeter, Rochelle Constantine, Jean Davis, Jennifer Devine, Clinton Duffy, Charles Edwards, Rosa Edwards, Malene Felsing, Jack Fenaughty, Brit Finucci, David Foster, Dave Goad, Kat Goddard, Phil Heath, Lyndsey Holland, Aaron Irving, Emma Jones, Brianna King, Todd Landers, Kath Large, Mary Livingston, David Lundquist, Greg Lydon, Stefan Meyer, Karen Middlemiss, David Middleton, Sophie Mormede, Mark Morrison, Campbell Murray, Richard O'Driscoll, Enrique Pardo, Darren Parsons, Trent Rasmussen, Nathan Reid, Jesse Rihia, Carol Scott, Fabrice Stephenson, Karli Thomas, Rob Tilney, Rob Tinkler, Ian Tuck, Karen Tunley, Te Aomihia Walker, Cath Wallace, Barry Weeber, Richard Wells, Tamar Wells, John Willmer.

Biodiversity Research and Advisory Group (BRAG)

Convenor: Mary Livingston

Members: Teresa A'mar, Tara Anderson, Owen Anderson, Erik Behrens, Katrin Berkenbusch, Tiffany Bock, David Bowden, Paul Breen, Sarah Bury, Glen Carbines, Malcolm Clark, Tom Clark, George Clement, Damien Cloester, Vonda Cummings, Roberta D'Archino, Moira Decima, Matt Dunn, Pablo Escobar-Flores, Jack Fenaughty, Debbie Freeman, Jonathan Gardner, Sharleen Gargiulo, Shane Geange, William Gibson, Britt Graham, Barb Hayden, Lyndsey Holland, Steven Holmes, Aaron Irving, Emma Jones, Daniel Kerrigan, Brianna King, Kirstie Knowles, Todd Landers, Cliff Law, Daniel Leduc, Carolyn Lundquist, Dave Lundquist, Greg Lydon, Alison MacDiarmid, Jeremy McKenzie, David Middleton, Marco Milardi, Te Taiawatea Moko-Mead, Wendy Nelson, Philipp Neubauer, Richard O'Driscoll, Enrique Pardo, Darren Parsons, Michael Patrick, Rachael Peart, Matt Pinkerton, Nathan Reid, Jesse Rihia, Peter Ritchie, Jim Roberts, Karen Robinson, Ashley Rowden, Carol Scott, Andy Smith, Aroha Spinks, Kevin Sullivan, Phil Sutton, Rob Tilney, Geoff Tingley, Di Tracey, Karen Tunley, Josh van Lier, Trudi Webster, Richard Wells, Tamar Wells, Oliver Wilson.

Deepwater Working Group

Convenors: Gretchen Skea and Pamela Mace

Members: Sira Ballara, Andrew Biggerstaff, Tiffany Bock, George Clement, Jennifer Devine, Ian Doonan, Alistair Dunn, Matt Dunn, Pablo Escobar-Flores, Jack Fenaughty, David Foster, Bruce Hartill, Charles Heaphy, Steven Holmes, Simon Hoyle, Aaron Irving, Leyla Knittweis, Yoann Ladroit, Adam Langley, Kath Large, Greg Lydon, Gavin Macaulay, Dan MacGibbon, Vidette McGregor, Jeremy McKenzie, David Middleton, Sophie Mormede, Philipp Neubauer, Richard O'Driscoll, Jim Roberts, Richard Saunders, Paul Starr, Benjamin Steele-Mortimer, Darren Stevens, Rob Tilney, Geoff Tingley, Rob Tinkler, Ian Tuck, Nathan Walker, D'Arcy Webber, Barry Weeber, Richard Wells.

Species:

Alfonsino
Arrow squid
Barracouta (BAR 4,5 & 7)
Black cardinalfish
Black oreo
Blue mackerel (EMA 3&7)
Frostfish (FRO 3 – 9)
Gemfish (SKI 3&7)
Dark ghost shark (GSH 4 – 6)
Pale ghost shark
Hake
Hoki
Jack mackerel (JMA 3&7)
Ling
Lookdown dory
Orange roughy
Redbait
Ribaldo (RIB 3 – 8)
Rubyfish
Scampi
Sea perch (SPE 3 – 7)
Silver warehou
Smooth oreo
Southern blue whiting
Spiny dogfish (SPD 4&5)
White warehou

Eel Working Group

Convenor: Marc Griffiths

Members: Kahu Aki, Dale Arbury, Mike Beentjes, Jacques Boubee, Anthony Charsley, Bill Chisholm, Shannan Crow, Allen Frazer, Tom Hollings, Mike Holmes, Simon Howard, Simon Hoyle, Mark James, John Jameson, Nicole Kleven, Pamela Mace, Taniera Manaia, Michael Martin, Marco Milardi, Duncan Petrie, Taroi Rawiri, Alan Riwaka, Te Aomihia Walker, Dave West, Erica Williams, Leah Wyatt.

Species: Freshwater eels

Marine Amateur Fisheries Working Group

Convenors: Ian Tuck

Members: Sonja Austin, Hilary Ayrton, Cliff Baird, Marty Bowers, Paul Breen, Glen Carbines, Tom Clark, Martin Cryer, Niki Davey, Mark Edwards, Mark Geytenbeek, William Gibson, Alistair Gray, Bianca Hampton, Bruce Hartill, Andreas Heinemann, Andy Heinemann, Sonja Hempel, John Holdsworth, Jake Hore, Jade Maggs, Graeme McGregor, Andy McKay, Alicia McKinnon, David Middleton, Carol Scott, Paul Starr, Daryl Sykes, John Taunton-Clark, Scott Tindale, D'Arcy Webber, Oliver Wilson.

Northern and Southern Inshore Working Groups

Convenor: Marc Griffiths

Members: Teresa A'mar, John Annala, Cliff Baird, Mike Beentjes, Heather Benko, Anthony Brett, Alex Burton, Glen Carbines, Bill Chisholm, Denham Cook, Jennifer Devine, Ian Doonan, Alistair Dunn, Matt Dunn, Rosa Edwards, Pablo Escobar-Flores, Allen Frazer, Mark Geytenbeek, Aari Hale, Bruce Hartill, Melanie Hayden, Sonja Hempel, Tyla Hill-

Moana, John Holdsworth, Steven Holmes, Emma Jones, Briana King, Adam Langley, Kath Large, Laws Lawson, Pamela Mace, Dan MacGibbon, Andy McKenzie, Jeremy McKenzie, Alicia McKinnon, Craig Marsh, Keith Mawson, David Middleton, Jodi Milne, Bradley Moore, Charlotte Mortimer, Philipp Neubauer, Richard O'Driscoll, Darren Parsons, Trent Rasmussen, Nathan Reid, Matt Rolfe, Richard Saunders, Ali Schwaab, Carol Scott, Adam Slater, Paul Starr, Finlay Thompson, McKenzie Tornquist, Rodney Tribe, John Taunton-Clark, Ian Tuck, Ali Undorf-Lay, Nathan Walker, Cameron Walsh, Adam Watson, John Willmer, Oliver Wilson, Robert Win.

Species:

Anchovy
Barracouta (BAR 1)
Bluenose
Blue cod
Blue mackerel (EMA 1&2)
Blue moki
Blue warehou
Butterfish
Elephant fish
Flatfish
Gemfish (SKI 1&2)
Garfish
Grey mullet
Groper
Jack mackerel (JMA 1)
John dory
Kahawai
Kingfish
Leatherjacket
Ling (LIN 1&2)
Parore
Pilchard
Porae
Red cod
Red gurnard
Red snapper
Rig
Ribaldo (RIB 1, 2 & 9)
Rough skate
School shark
Sea perch (SPE1,2,8,9)
Smooth skate
Snapper
Spiny dogfish (SPD1,3,7,8)
Sprats
Stargazer
Tarakihi
Trevally
Trumpeter
Yellow-eyed mullet

Shellfish Working Group

Convenors: Marine Pomarède, Ian Tuck

Members: Karl Aislabie, Michael Arbuckle, Mike Astwood, Sam Astwood, Cliff Baird, Mike Beentjes, Roger Belton, Katrin Berkenbusch, Tony Brett, Maaka Cherrington, Bill Chisholm, Jeremy Cooper, Paul Creswell, Samik Datta, Jean Davis, Jennifer Devine, Ian Doonan, Alistair Dunn, Allen Frazer, Mark Geytenbeek, Zachary Goeden, Shelton Harley, Trude Hellesland, Tyla Hill-Moana, Jules Hills, John Holdsworth, Tom Hollings, Monique Holmes, Steven Holmes, Te Maire Hoskins, Kyuhan Kim, Mike Kwant, Brad Leggott, Hilton Leith, Tasmin McCormack, Tom McCowan, Andy McKay, Rebecca McLeod, Campbell McManaway, Craig Marsh, Craig Marshall, Keith Michael, David Middleton, Irene Middleton, Marco Milardi, Bryony Miller, Mark Morrison, Philipp Neubauer, Grant Northcott, Tanayaz Patil, Duncan Petrie, Trent Rasmussen, Trish Rea, Jesse Rihia, Matthew Rolfe, Alexandra Schwaab, David Skeggs, Adam Slater, Storm Stanley, Paul Starr, John Taunton-Clark, Gail Thompson, McKenzie Tornquist, Laura Tremblay-Boyer, Adam Watson, D'Arcy Webber, Lindsey White, James Williams, John Willmer, Oliver Wilson, Robert Win, Graeme Wright.

Species:

Cockles (COC 1A & 7A)
Deepwater crab
Dredge oysters (OYU 5, OYS 7 & 7C)
Deepwater (king) clam (Geoduc)
Deepwater tuatua
Fine (Silky) dosinia
Frilled venus shell
Giant spider crab
Green-lipped mussel
Horse mussel Kina
King crab
Knobbled whelk
Large trough shell
Paddle crab
Pāua (PAU 2-7)
Pipi (PPI 1A)
Prawn killer
Queen scallop
Red crab
Ringed dosinia
Scallop (SCA 1, CS & 7)
Sea cucumber
Surf clam
Toheroa
Triangle shell
Trough shell
Tuatua

South Pacific Working Group

Convenor: Fabrice Stephenson

Members: Owen Anderson, Matt Benion, Andrew Biggerstaff, Tiffany Bock, Tom Brough, Malcolm Clark, Duncan Currie, Igor Debski, Alistair Dunn, Matt Dunn, Jack Fenaughty, Shane Geange, Jan Gert Hiddink, Niels Hintzen, Lyndsey Holland, Ellie Hooper, Jim Ianelli, Dean Jurasovich, Amanda Leathers, Carolyn Lundquist, Richard O'Driscoll, Brodie Plum, Mathilde Richer de Forges, Keri Robertson, Ash Rowden, Richard Saunders, Geremy Schofield, Andy Smith, Colin Smith, John Syslo, Jordi Tablada, Karli Thomas, Hamish Tijsen, Trent Timmiss, Geoff Tingley, Ian Tuck, Karen Tunley, Cath Wallace, Barry Weeber.

Statistics, Assessments and Methods Working Group

Convenor: Pamela Mace

Members: Teresa A'mar, John Annala, Cliff Baird, Jennifer Devine, Ian Doonan, Alistair Dunn, Matt Dunn, Charlie Edwards, Mark Edwards, Rosa Edwards, Jack Fenaughty, Dave Foster, Allen Frazer, William Gibson, Marc Griffiths, Charles Heaphy, Sonja Hempel, Tyla Hill-Moana, Freya Hjorvarsdottir, John Holdsworth, Steven Holmes, Simon Hoyle, Emma Jones, Sophie Kincaid, Leyla Knitttweis, Brianna King, Adam Langley, Kath Large, Laws Lawson, Vidette McGregor, Andy McKenzie, Jeremy McKenzie, Craig Marsh, David Middleton, Marco Milardi, Jodi Milne, Charli Mortimer, Philipp Neubauer, Richard O'Driscoll, Marine Pomarède, Trent Rasmussen, Nathan Reid, Jim Roberts, James Robertson, Alice Sagar, Clara Schlieman, Ali Schwaab, Carol Scott, Gretchen Skea, Paul Starr, Kevin Stokes, John Taunton-Clark, Geoff Tingley, Rob Tinkler, McKenzie Tornquist, Ian Tuck, Nathan Walker, D'Arcy Webber, James Williams, John Wilmer, Oliver Wilson, Robert Win, Shijie Zhou.

Guide to Biological Reference Points for Fisheries Assessment Meetings

The Guide to Biological Reference Points was originally developed by a Stock Assessment Methods Working Group in 1988, with the aim of defining commonly used terms, explaining underlying assumptions, and describing the biological reference points used in fisheries assessment meetings and associated reports. However, this document has not been substantially revised since 1992 and the methods described herein, while still used in several assessments, have been replaced with other approaches in a number of cases. Some of the latter approaches are described in the Harvest Strategy Standard for New Zealand Fisheries and the associated Operational Guidelines, and are being further developed in various Fisheries Assessment Working Groups and the current Stock Assessment Methods Working Group.

Here, methods of estimation appropriate to various circumstances are given for two levels of yield: Maximum Constant Yield (***MCY***) and Current Annual Yield (***CAY***), both of which represent different forms of maximum sustainable yield (***MSY***). The relevance of these to the setting of Total Allowable Catches (TACs) is discussed.

Definitions of *MCY* and *CAY*

The Fisheries Act 1996 defines Total Allowable Catch in terms of maximum sustainable yield (***MSY***). The definitions of the biological reference points, ***MCY*** and ***CAY***, derive from two ways of viewing ***MSY***: a static interpretation and a dynamic interpretation. The former, associated with ***MCY***, is based on the idea of taking the same catch from fisheries year after year. The latter interpretation, from which ***CAY*** is derived, recognises that fish populations fluctuate in size from year to year (for environmental and biological, as well as fisheries, reasons) so that to get the best yield from fisheries it is necessary to alter the catch every year. This leads to the idea of maximum average yield (***MAY***) which is how fisheries scientists generally interpret ***MSY*** (Ricker 1975).

The definitions are:

> ***MCY*** – Maximum Constant Yield
> The maximum constant catch that is estimated to be sustainable, with an acceptable level of risk, at all probable future levels of biomass.

and

> ***CAY*** – Current Annual Yield
> The one-year catch calculated by applying a reference fishing mortality, F_{REF}, to an estimate of the fishable biomass present during the next fishing year. F_{REF} is the level of (instantaneous) fishing mortality that, if applied every year, would, within an acceptable level of risk, maximise the average catch from fisheries.

Note that ***MCY*** is dependent to a certain extent on the current state of the fish stock. If a stock is fished at the ***MCY*** level from a virgin state then over the years its biomass will fluctuate over a range of levels depending on environmental conditions, abundance of predators and prey, etc. For stock sizes within this range the ***MCY*** remains unchanged (though our estimates of it may well be refined). If the current state of the stock is below this range the ***MCY*** will be lower.

The strategy of applying a constant fishing mortality, F_{REF}, from which the ***CAY*** is derived each year is an approximation to a strategy which maximises the average yield over time. For the purposes of this document the ***MAY*** is the long-term average annual catch when the catch each year is the ***CAY***. With perfect knowledge it would be possible to do better by varying the fishing mortality from year to year. Without perfect knowledge, adjusting catch levels by a ***CAY*** strategy as stock size varies is probably the best practical method of maximising average yield. Appropriate values for F_{REF} are discussed below.

What is meant by an "acceptable level of risk" for ***MCY***s and ***CAY***s is intentionally left undefined here. For most stocks our level of knowledge is inadequate to allow a meaningful quantitative assessment of risk. However, we have two qualitative sources of information on risk levels: the experience of fisheries scientists and managers throughout the world, and the results of simulation exercises such as those of Mace (1988a). Information from these sources is incorporated, as much as is possible, in the methods given below for calculating ***MCY*** and ***CAY***.

It is now well known that ***MCY*** is generally less than ***MAY*** (see, e.g., Doubleday 1976, Sissenwine 1978, Mace 1988a). This is because ***CAY*** will be larger than ***MCY*** in the majority of years. However, when fishable biomass becomes low (through overfishing, poor environmental conditions, or a combination of both), ***CAY*** will be less than ***MCY***. This is true even if the estimates of ***CAY*** and ***MCY*** are exact. The following diagram shows the relationships between ***CAY***, ***MCY*** and ***MAY***.

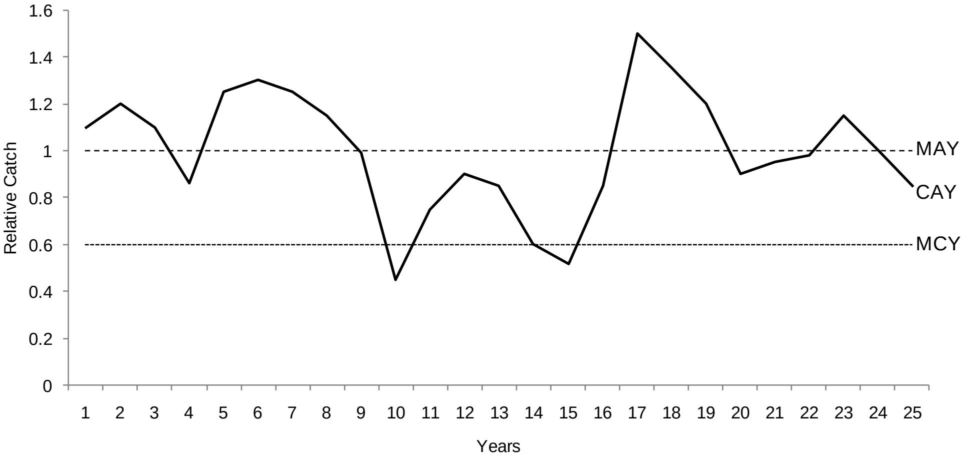

Figure 1: Relationship between *CAY*, *MCY* and *MAY*.

In this example ***CAY*** represents a constant fraction of the fishable biomass, and so (if it is estimated and applied exactly) it will track the fish population exactly. ***MAY*** is the average over time of ***CAY***. The reason ***MCY*** is less than ***MAY*** is that ***MCY*** must be low enough so that the fraction of the population removed does not constitute an unacceptable risk to the future viability of the population. With an ***MCY*** strategy, the fraction of a population that is removed by fishing increases with decreasing stock size. With a ***CAY*** strategy, the fraction removed remains constant. A constant catch strategy at a level equal to the ***MAY***, would involve a high risk at low stock sizes.

Relationship Between *MCY*, *CAY*, TAC and Total Allowable Commercial Catch (TACC)

The TAC covers all mortality to a fish stock caused by human activity, whereas the TACC includes only commercial catch. ***MCY*** and ***CAY*** are reference points used to evaluate whether the current stock size can support the current TAC and/or TACC. It should not be assumed that the TAC and/or TACC will be equal to either one of these yields. There are both legal and practical reasons for this.

Legally, we are bound by the Fisheries Act 1996. In setting or varying any TACC for any quota management stock, ‘the Minister shall have regard to the total allowable catch for that stock and shall allow for –

(a) The following non-commercial fishing interests in that stock, namely –
    (i) Māori customary non-commercial fishing interests; and
    (ii) Recreational interests; and
(b) All other mortality to that stock caused by fishing.

From a practical point of view it must be acknowledged that the concepts of ***MCY*** and ***CAY*** are directly applicable only in idealised management regimes. The ***MCY*** could be used in a regime where a catch level was to be set for once and for all; our system allows changes to be made if, the level is found to be too low or too high.

With a ***CAY*** strategy the yield would probably change every year. Even if there were no legal impediments to following a ***CAY*** strategy, the fishing industry's desire for stability may be a sufficient reason to make TACC changes only when the need is pressing.

Natural and Fishing Mortality

Before describing how to calculate ***MCY*** and ***CAY*** we must discuss natural and fishing mortality, which are used in these calculations. Both types of mortality are expressed as instantaneous rates (thus, over n years a total mortality Z will reduce a population of size B to size Be^{-nZ}, ignoring recruitment and growth). Units for mortalities are 1/year.

Natural mortality

Methods of estimating natural mortality, M, are reviewed by Vetter (1988). When a lack of data rules out more sophisticated methods, M may be estimated by the formula,

$$M = \frac{\log_e(p)}{A}$$

where p is the proportion of the population that reaches age A (or older) in an unexploited stock. p is often set to 0.01, when A is the "maximum age" observed. Other values for p may be chosen dependent on the fishing history of the stock. For example, in an exploited stock the maximum observed age may correspond to a value of $p = 0.05$, or higher. For a discussion of the method see Hoenig (1983).

Reference Fishing Mortalities

Reference fishing mortalities in widespread use include $F_{0.1}$, F_{MSY}, F_{MAX}, F_{MEY}, and M.

The most common reference fishing mortality used in the calculation of ***CAY*** (and, in some cases, ***MCY***) is $F_{0.1}$ (pronounced `F zero point one'). This is used as a basis for fisheries management decisions throughout the world and is widely believed to produce a high level of yield on a sustainable basis (Mace 1988b). It is estimated from a yield per recruit analysis as the level of fishing mortality at which the slope of the yield-per-recruit curve is 0.1 times the slope at $F = 0$. If an estimate of $F_{0.1}$ is not available an estimate of M may be substituted.

F_{MAX}, the fishing mortality that produces the maximum yield per recruit. It may be too high as a target fishing mortality because it does not account for recruitment effects (e.g. recruitment declining as stock size is reduced). However, it may be a valid reference point for those fisheries that have histories of sustainable fishing at this level.

F_{MSY}, the fishing mortality corresponding to the deterministic ***MSY***, is another appropriate reference point. F_{MSY} may be estimated from a surplus production model, or a combination of yield per recruit and stock recruitment models.

When economic data are available it may be possible to calculate F_{MEY} the fishing mortality corresponding to the maximum (sustainable) economic yield.

Every reference fishing mortality corresponds to an equilibrium or long-run average stock biomass. This is the biomass which the stock will tend towards or randomly fluctuate around, when the reference fishing mortality is applied constantly. The fluctuations will be caused primarily by variable recruitment. It is necessary to examine the equilibrium stock biomass corresponding to any candidate reference fishing mortality.

A reference fishing mortality which corresponds to a low stock biomass may be undesirable if the low biomass would lead to an unacceptable risk of stock collapse. For fisheries where this applies a lower reference fishing mortality may be appropriate.

Natural Variability Factor

Fish populations are naturally variable in size because of environmental variability and associated fluctuations in the abundance of predators and food. Computer simulations (e.g., Mace 1988a) have shown that, all other things being equal, the ***MCY*** for a stock is inversely related to the degree of natural variability in its abundance. That is, the higher the natural variability, the lower the ***MCY***.

The natural variability factor, ***c***, provides a way of incorporating the natural variability of a stock's biomass into the calculation of ***MCY***. It is used as a multiplying factor in method 5 below. The greater the variability in the stock, the lower is the value of ***c***. Values for ***c*** should be taken from the table below and are based on the estimated mean natural mortality rate of the stock. It is assumed that because a stock with a higher natural mortality will have fewer age-classes it will also suffer greater fluctuations in biomass. The only stocks for which the table should be deviated from are those where there is evidence that recruitment variability is unusually high or unusually low.

Natural mortality rate *M*	Natural variability factor *c*
< 0.05	1.0
0.05-0.15	0.9
0.16-0.25	0.8
0.26-0.35	0.7
> 0.35	0.6

Methods of Estimating *MCY*

It should be possible to estimate ***MCY*** for most fish stocks (with varying degrees of confidence). For some stocks, only conservative estimates for ***MCY*** will be obtainable (e.g., some applications of Method 4) and this should be stated. For other stocks it may be impossible to estimate ***MCY***. These stocks include situations in which: the fisheries are very new; catch or effort data are unreliable; strong upwards or downwards trends in catch are not able to be explained by available data (e.g., by trawl survey data or by catch per unit effort data).

When catch data are used in estimating ***MCY*** all catches (commercial, illegal, and non-commercial) should be included if possible. If this is not possible and the excluded catch is thought to be a significant quantity, then this should be stated.

The following examples define ***MCY*** in an operational context with respect to the type, quality and quantity of data available. Knowledge about the accuracy or applicability of the data (e.g., reporting anomalies, atypical catches in anticipation of the introduction of the Quota Management System) should play a part in determining which data sets are to be included in the analysis.

As a general rule it is preferable to apply subjective judgements to input data rather than to the calculated ***MCY***s. For example, rather than saying "with the official catch statistics the ***MCY*** is ***X*** tonnes, but we think this is too high because the catch statistics are wrong" it would be better to say "we believe (for reasons given) that the official statistics are wrong and the true catches were probably such and such, and the ***MCY*** based on these catches is ***Y*** tonnes".

Background information on the rationale behind the following calculation methods can be found in Mace (1988a) and other scientific papers listed at the end of this document.

New fisheries

$$MCY = 0.25F_{0.1}B_0$$

where B_0 is an estimate of virgin recruited biomass. If there are insufficient data to conduct a yield per recruit analysis $F_{0.1}$ should be replaced with an estimate of natural mortality (M). Tables 1–3 in Mace (1988b) show that $F_{0.1}$ is usually similar to (or sometimes slightly greater than) M.

It may appear that the estimate of ***MCY*** for new fisheries is overly conservative, particularly when compared to the common approximation to MSY of $\mathbf{0.5}MB_0$ (Gulland 1971). However various authors (including Beddington & Cooke 1983; Getz et al 1987; Mace 1988a) have shown that $\mathbf{0.5}MB_0$ often overestimates ***MSY***, particularly for a constant catch strategy or when recruitment declines with stock size. Moreover it has often been observed that the development of new fisheries (or the rapid expansion of existing fisheries) occurs when stock size is unusually large, and that catches plummet as the accumulated biomass is fished down.

It is preferable to estimate ***MCY*** from a stochastic population model (Method 5), if this is possible. The simulations of Mace (1988a) and Francis (1992) indicate that the appropriate factor to multiply $F_{0.1}B_0$ may be somewhat higher or somewhat lower than **0.25**. This depends primarily on the steepness of the assumed stock recruitment relationship (*see* Mace & Doonan 1988 for a definition of steepness).

New fisheries become developed fisheries once F has approximated or exceeded M for several successive years, depending on the lifespan of the species.

2. Developed fisheries with historical estimates of biomass

$$MCY = 0.5F_{0.1}B_{AV}$$

where B_{AV} is the average historical recruited biomass, and fisheries are believed to have been fully exploited (i.e., fishing mortality has been near the level that would produce ***MAY***). This formulation assumes that $F_{0.1}$ approximates the average productivity of a stock.

As in the previous method an estimate of M can be substituted for $F_{0.1}$ if estimates of $F_{0.1}$ are not available.

3. Developed fisheries with adequate data to fit a population model

$$MCY = {}^{2}\!/_{3}\,MSY$$

where ***MSY*** is the deterministic maximum equilibrium yield.

This reference point is slightly more conservative than that adopted by several other stock assessment agencies (e.g., ICES, CAFSAC) that use as a reference point the equilibrium yield corresponding to 2/3 of the fishing effort (fishing mortality) associated with the deterministic equilibrium ***MSY***.

If it is possible to estimate ***MSY*** then it is generally possible to estimate ***MCY*** from a stochastic population model (Method 5), which is the preferable method. The simulations of Mace (1988a) and Francis (1992) indicate that the appropriate factor to multiply ***MSY*** varies between about **0.6** and **0.9**. This depends on various parameters of which the steepness of the assumed stock recruitment relationship is the most important.

If the current biomass is less than the level required to sustain a yield of 2/3 ***MSY*** then

$$MCY = {}^{2}\!/_{3}\,CSP$$

where ***CSP*** is the deterministic current surplus production.

4. Catch data and information about fishing effort (and/or fishing mortality), either qualitative or quantitative, without a surplus production model

$$MCY = cY_{AV}$$

where $\boldsymbol{c}$ is the natural variability factor (defined above) and $\boldsymbol{Y_{AV}}$ is the average catch over an appropriate period.

If the catch data are from a period when the stock was fully exploited (i.e. fishing mortality near the level that would produce ***MAY***), then the method should provide a good estimate of ***MCY***. In this case, $\boldsymbol{Y_{AV}}$ = ***MAY***. If the population was under-exploited the method gives a conservative estimate of ***MCY***.

Familiarity with stock demographics and the history of the fisheries is necessary for the determination of an appropriate period on which to base estimates of $\boldsymbol{Y_{AV}}$. The period chosen to perform the averaging will depend on the behaviour of the fishing mortality or fishing effort time series, the prevailing management regime, the behaviour of the catch time series, and the lifespan of the species.

The period should be selected so that it contains no systematic changes in fishing mortality (or fishing effort, if this can be assumed to be proportional to fishing mortality). Note that for species such as orange roughy, where relatively static aggregations are fished, fishing mortality cannot be assumed to be proportional to effort. If catches during the period are constrained by a TACC then it is particularly important that the assumption of no systematic change in fishing mortality be adhered to. The existence of a TACC does not necessarily mean that the catch is constrained by it.

The period chosen should also contain no systematic changes in catch. If the period shows a systematic upward (or downward) trend in catches, then the ***MCY*** will be under-estimated (over-estimated). It is desirable that the period be equal to at least half the exploited life span of the fish.

5. Sufficient information for a stochastic population model

This is the preferred method for estimating ***MCY*, **but it is the method requiring the most information. It is the only method that allows some specification of the risk associated with an ***MCY***.

The simulations in Mace (1988a) and Breen (1989) provide examples of the type of calculations necessary for this method. A trial and error procedure can be used to find the maximum constant catch that can be taken for a given level of risk. The level of risk may be expressed as the probability of stock collapse within a specified time period. At the moment Fisheries New Zealand has no standards as to how stock collapse should be defined for this purpose, what time period to use, and what probability of collapse is acceptable. These will be developed as experience is gained with this method.

Methods of Estimating *CAY*

It is possible to estimate ***CAY*** only when there is adequate stock biomass data. In some instances, relative stock biomass indices (e.g., catch per unit effort data) and relative fishing mortality data (e.g., effort data) may be sufficient. ***CAY*** calculated by method 1 includes non-commercial catch.

If method 2 is used and it is not possible to include a significant non-commercial catch, then this should be stated.

1. Where there is an estimate of current recruited stock biomass, ***CAY*** may be calculated from the appropriate catch equation. Which form of the catch equation should be used will depend on the way fishing mortality occurs during the year. For many fisheries it will be a reasonable approximation to assume that fishing is spread evenly throughout the year so that the Baranov catch equation is appropriate and ***CAY*** is given by

$$CAY = \frac{F_{ref}}{F_{ref} + M}(1 - e^{-(F_{ref}+M)})B_{beg}$$

where $\boldsymbol{B_{beg}}$ is the projected stock biomass at the beginning of the fishing year for which the $\boldsymbol{CAY}$ is to be calculated and $\boldsymbol{F_{ref}}$ is the reference fishing mortality described above.

If most of the fishing mortality occurs over a short period each year it may be better to use one of the following equations:

$$CAY = (1 - e^{-F_{ref}})B_{beg}$$

$$CAY = (1 - e^{-F_{ref}})e^{-\frac{M}{2}}B_{beg}$$

$$CAY = (1 - e^{-F_{ref}})e^{-M}B_{beg}$$

where the first equation is used when fishing occurs at the beginning of the fishing year, the second equation when fishing is in the middle of the year, and the third when fishing is at the end of the year.

It is important that the catch equation used to calculate $\boldsymbol{CAY}$ and the associated assumptions are the same as those used in any model employed to estimate stock biomass or to carry out yield per recruit analyses. Serious bias may result if this criterion is not adhered to. The assumptions and catch equations given here are by no means the only possibilities.

The risk associated with the use of a particular $\boldsymbol{F_{REF}}$ may be estimated using simulations.

2. Where information is limited but the current (possibly unknown) fishing mortality is thought to be near the optimum, there are various "status quo" methods which may be applied. Details are available in Shepherd (1984, 1991) and Pope (1983).

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Guidelines for Status of the Stocks Summary Tables

The format for Status of the Stocks summaries was developed by the Stock Assessment Methods Working Group over the period February-April 2009. The purpose of this project was to provide more comprehensive and meaningful information for fisheries managers, stakeholders, and other interested parties. Previously, Status of the Stocks summary sections had not reflected the full range of information of relevance to fisheries management contained in the earlier sections of Plenary reports and were of variable utility for evaluating stock status and informing fisheries management decisions.

Status of the Stocks summary tables should be constructed for all stocks except those designated as "nominal"; e.g. those with administrative TACs or TACCs (generally less than 10–20 t) or those for which a commercial or non-commercial development potential has not currently been demonstrated. As of November 2021, there were a total of 290 stocks in this classification. The list of nominal stocks can be found at: https://www.mpi.govt.nz/dmsdocument/44899-NZ-nominal-fish-stocks-2020-report.

In 2012 a number of changes were made to the format for the Status of the Stocks summary tables, primarily for the purpose of implementing the science information quality rankings required by the Research and Science Information Standard for New Zealand Fisheries that was approved in April 2011 (New Zealand Ministry of Fisheries 2011a). At the time, these changes were only applied for Status of Stocks tables updated in 2012. Subsequently, an attempt has been made to revise all tables.

In 2013, the format was further modified to require Science Working Groups to make a determination about whether overfishing is occurring, and to further standardise and clarify the requirements for other parts of the table.

It is anticipated that the format of the Status of the Stocks tables will continue to be reviewed, standardised and modified in the future so that it remains relevant to fisheries management and other needs. New formats will be implemented each time stocks are reviewed and as time allows.

The table below provides a template for the Status of the Stocks summaries. The text following the template gives guidance on the contents of most of the fields in the table. Superscript numbers refer to the corresponding numbered paragraph in the following text. Light blue text provides an example of how the table might be completed.

STATUS OF THE STOCKS TEMPLATE[1]

Stock Structure Assumptions[2]
<insert relevant text>

- **Fishstock name**[3]

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	Base case model
Reference Points[4]	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%B0}$
Status in relation to Target[5,6]	B_{2019} was estimated to be 50% B_0; Very Likely (> 90%) to be at or above the target[6]
Status in relation to Limits[5,6]	B_{2019} is Very Unlikely (< 10%) to be below both the soft and hard limits[6]

Status in relation to Overfishing[6,7]	The fishing intensity in 2014 was Very Unlikely (< 10%) to be above the overfishing threshold [or, Overfishing is Very Unlikely (<10%) to be occurring][6]

Historical Stock Status Trajectory and Current Status[8]
<insert relevant graphs>

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy[9]	Biomass reached its lowest point in 2001 and has since consistently increased.
Recent Trend in Fishing Intensity or Proxy[6,9]	<insert relevant graphs, if available> Fishing intensity reached a peak of F=0.54 in 1999, subsequently declining to less than F=0.2 since 2006.
Other Abundance Indices[10]	-
Trends in Other Relevant Indicators or Variables[11]	Recent recruitment (2005–2017) is estimated to be near the long-term average.

Projections and Prognosis[12]	
Stock Projections or Prognosis	Biomass is expected to stay steady over the next 5 years assuming current (2016–17) catch levels.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits[6,13]	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence[6,13]	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type[14]	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2019	Next assessment: 2020
Overall assessment quality rank[15]	1 – High Quality	
Main data inputs (rank)[15]	- Research time series of abundance indices (trawl and acoustic surveys)	1 – High Quality
	- Proportions at age data from the commercial fisheries and trawl surveys	1 – High Quality
	- Estimates of biological parameters	1 – High Quality
Data not used (rank)[16]	Commercial CPUE	3 – Low Quality: does not track stock biomass
Changes to Model Structure and Assumptions[17]	None since the 2012 assessment	

Major sources of Uncertainty[18]	- The base case model deals with the lack of older fish in commercial catches and surveys by estimating natural mortality at age which results in older fish suffering high natural mortality. However, there is no evidence to validate this outside the model estimates. - Aside from natural mortality, other major sources of uncertainty include stock structure and migration patterns, stock-recruit steepness and natal fidelity assumptions. Uncertainty about the size of recent year classes affects the reliability of stock projections.

Qualifying Comments[19]
The impact of the current young age structure of the population on spawning success is unknown.

Environmental and Ecosystem Considerations[20]	
Observer coverage	Highly variable year to year (from 1.6 to 11.1%), but higher from 2008 onwards.
Non-target fish and invertebrate catch	Blue shark, lancetfish and porbeagle shark are the most commonly non-target fish species caught by the longline fleet (by number), but are rarely retained. Other species, like Rays bream and moonfish are caught more rarely, but are more frequently retained.
Incidental catch of seabirds	Observed capture rates of seabirds was highly variable prior to 2008 due to low levels of observer coverage. This fishery contributes primarily to the risk to Black petrel, Northern Buller's albatross and Gibson's albatross, among other species.
Incidental catch of cetaceans	Between 2002 and 2018, observers recorded one unidentified cetacean, two common dolphin, and one long finned pilot whale captured in this fishery. All of these cetaceans were released alive.
Incidental catch of pinnipeds	Between 2002 and 2018, there were two observed captures of New Zealand fur seals in this fishery. Both were released alive.
Incidental catch of other protected species	Between 2002 and 2018 incidental captures of 17 sea turtles were observed, these were leatherback turtles (10), unidentified turtles (5), green (1) and loggerhead (1) turtles.
Benthic interactions	There are no known benthic interactions for this fishery.

Guidance on preparing the Status of the Stocks summary tables

1. Everything included in the Status of the Stocks summary table should be derived from earlier sections in the Working Group or Plenary report. No new information should be presented in the summary that was not encompassed in the main text of the Working Group or Plenary report.

Stock Structure Assumptions

2. The current assumptions regarding the stock structure and distribution of the stocks being reported on should be briefly summarised. Where the assessed stock distribution differs from the relevant QMA fishstock(s), an explanation must be provided of how the stock relates to the QMA fishstock(s) it includes.

Stock Status

3. One Status of the Stocks summary table should be completed for each assessed stock or stock complex.

4. Management targets for each stock will be established by fisheries managers. Where management targets have not been established, it is suggested that an interim target of 40% B_0, or a related B_{MSY}-compatible target (or $F_{40\%}$, or a related target) should be assumed. In most cases, the soft and hard limits should be set at the default levels specified in the Harvest Strategy Standard (20% B_0 for the soft limit and 10% B_0 for the hard limit). Similarly, the overfishing threshold should be set at F_{MSY}, or a related F_{MSY}-compatible threshold. Overfishing thresholds can be expressed in terms of fishing mortality, exploitation rates, or other valid measures of fishing intensity. When agreed reference points have not been established, stock status may be reported against interim reference points.

5. Reporting stock status against reference points requires Working Group agreement on the model run to use as a base case for the assessment. The preference, wherever possible, is to report on the best estimates from a single base case, or to make a single statement that covers the results from a range of cases. In general, ranges or confidence intervals should not be included in the table. Only where more than one equally plausible model run exists, and agreement cannot be reached on a single base case, should multiple runs be reported. This should still be done simply and concisely (e.g. median results only).

6. Where probabilities are used in qualifying a statement regarding the status of the stock in relation to target, limit, or threshold reference levels, the following probability categories and associated verbal descriptions are to be used (IPCC 2007):

Probability	**Description**
> 99 %	Virtually Certain
> 90 %	Very Likely
> 60 %	Likely
40–60 %	About as Likely as Not
< 40 %	Unlikely
< 10 %	Very Unlikely
< 1 %	Exceptionally Unlikely

Probability categories and associated descriptions should relate to the probability of being “at or above” biomass targets (or “at or below” fishing intensity targets if these are used), below biomass limits, and above overfishing thresholds. Note, however, that the descriptions and associated probabilities adopted need not correspond exactly to model outputs; rather they should be superimposed with the Working Group’s belief about the extent to which the model fully specifies the probabilities. This is particularly relevant for the “Virtually Certain” and “Exceptionally Unlikely” categories, which should be used sparingly.

7. The status in relation to overfishing can be expressed in terms of an explicit overfishing threshold, or it can simply be a statement about the Working Group’s belief, based on the evidence at hand, about the likelihood that overfishing is occurring (based on, for example, a stock abundance index exhibiting a pronounced recent increase or decline). The probability rankings in the IPCC (2007) table above should be used. Overfishing thresholds can be considered in terms of fishing mortality rates, exploitation rates, or other valid measures of fishing intensity.

Historical Stock Status Trajectory and Current Status

8. This heading should be changed to reflect the graphs that are available to illustrate trends in biomass or fishing intensity (or proxies) and the current stock or fishery status. Trends can be reported individually for biomass and fishing intensity or they can be combined into a single phase plot or “snail trail”.

Recent Fishery and Stock Trends

9. Recent stock or fishery trends should be reported in terms of stock size and fishing intensity (or proxies for these), respectively. For full quantitative (Level 1) assessments, median results should be used when reporting biomass. Observed trends should be reported using descriptors such as increasing, decreasing, stable, or fluctuating without trend. Where it is considered relevant and important to fisheries management, mention could be made of whether the indicator is moving towards or away from a target, limit, threshold, or long term average.

10. Other Abundance Indices: This section is primarily intended for reporting of trends where a Level 2 (partial quantitative) evaluation has been conducted, and appropriate abundance indices (such as standardised CPUE or survey biomass) are available.

11. Other Relevant Indicators or Variables: This section is primarily intended for reporting of trends where only a Level 3 (qualitative) evaluation has been conducted. Potentially useful indicators might include trends in mean size, size or age composition, or recruitment indices. Catch trends vs TACC may be relevant here, provided these are qualified when other factors are known to have influenced the trends.

Projections and Prognosis

12. These sections should be used to report available information on likely future trends in biomass or fishing intensity or related variables under current (or a range of) catch levels over a period of approximately 3–5 years following the last year in the assessment. If a longer period is used, this must be stated.

13. When reporting probabilities of current catches or TACC levels causing declines below limits, the probability rankings in the IPCC (2007) table above should be used. Results should be reported separately (i.e., split into two rows) if the catch and TACC differ appreciably, resulting in differing conclusions for each level of removals, with the level of each specified. The timeframe for the projections should be approximately 3–5 years following the last year in the assessment unless a longer period of time is required by fisheries managers.

Assessment Methodology and Evaluation

14. Assessment type: the envisaged Assessment Levels are:

    1 – Full Quantitative Stock assessment: There is a reliable index of abundance and an assessment indicating status in relation to targets and limits.
    2 – Partial Quantitative Stock Assessment: An evaluation of agreed abundance indices (e.g., standardised CPUE) or other appropriate fisheries indicators (e.g. estimates of F (Z) based on catch-at-age) is available. Indices of abundance or fishing intensity have not been used in a full quantitative stock assessment to estimate stock or fisheries status in relation to reference points.
    3 – Qualitative Evaluation: A fisheries characterisation with evaluation of fisheries trends (e.g., catch, effort, unstandardised CPUE, or length-frequency information) has been conducted but there is no agreed index of abundance.
    4 – Low Information Evaluation: There are only data on catch and TACC, with no other fisheries indicators.

    Management Procedure (MP) updates should be presented separately from the most recent full assessment results.

    Table content will vary for these different assessment levels.

Ranking of Science Information Quality

15. The Research and Science Information Standard for New Zealand Fisheries (2011a) specifies (pages 21–23) that the processes that rank the quality of research and science information used in support of fisheries management decisions will be implemented. The quality ranking system is:

    1 – High Quality: information that has been subjected to rigorous science quality assurance and peer review processes as required by this Standard, and substantially meets the key principles for science information quality; i.e., is fit for purpose. Such information can confidently be accorded a high weight in fisheries management decisions. An explanation is not required in the table for high quality information.

    2 – Medium or Mixed Quality: information that has been subjected to some level of peer review against the requirements of the Standard and has been found to have some shortcomings with regard to the key principles for science information quality, but is still useful for informing management decisions. Such information should be accompanied by a description of its shortcomings.

    3 – Low Quality: information that has been subjected to peer review against the requirements of the Standard but has substantially failed to meet the key principles for science information quality. Such information should be accompanied by a description of its shortcomings and should not be used to inform management decisions.

    One of the key purposes of the science information quality ranking system is to inform fisheries managers and stakeholders of those datasets, analyses, or models that are of such poor quality – or otherwise not fit for purpose – that they should not be used to make fisheries management decisions (i.e. those ranked as “3”). Most other datasets, analyses or models that have been subjected to peer review or staged technical guidance in the Fisheries New Zealand’s Science Working Group processes and have been accepted by these processes should be given the highest score (ranked as “1”). Uncertainty, which is inherent in all fisheries science inputs and outputs, should not by itself be used as a reason to score down a research output, unless it has not been properly considered or analysed, or if the uncertainty is so large as to render the results and conclusions meaningless (in which case, the Working Group should consider rejecting the output altogether). A ranking of 2 (medium or mixed quality) should only be used where there has been limited or inadequate peer review or the Working Group has mixed views on the validity of the outputs, but believes they are nevertheless of some use to fisheries management.

16. In most cases, the “Data not used” row can be filled in with “N/A”; it is primarily useful for specifying particular datasets that the Working Group considered but did not use in an assessment because they were of low quality and should not be used to inform fisheries management decisions.

Changes to Model Assumptions and Structure

17. The primary purpose of this section is to briefly identify only the most significant model changes that directly resulted in significant changes to results on the status of the stock concerned, and to briefly indicate the main effect of these changes. Details on model changes should be left in the main text of the report.

Major sources of Uncertainty

18. The purpose of this section is to identify the most significant sources of uncertainty, or assumptions behind the contrasting sensitivity model runs presented.

Qualifying Comments

19. The purpose of the "Qualifying Comments" section is to provide for any necessary explanations to avoid misinterpretation of information presented in the sections above. This section may also be used for brief further explanation considered important to understanding the status of the stock.

Environmental and Ecosystem Considerations

20. The "Environmental and Ecosystem Considerations" section should be used to summarise the observer coverage and list QMS bycatch species, non-QMS bycatch species and protected / endangered species and bycatch interactions. It should be restricted to information relevant to the stock in question.

FOR FURTHER INFORMATION

IPCC (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, Pachauri, R K; Reisinger, A (eds.)]. IPCC, Geneva, Switzerland, 104 p.

New Zealand Ministry of Fisheries (2008) Harvest Strategy Standard for New Zealand fisheries. 25 p. Available at http://fs.fish.govt.nz/Page.aspx?pk=61&tk=208&se=&sd=Asc&filSC=&filAny=False&filSrc=False&filLoaded=False&filDCG=9&filDC=0&filST=&filYr=0&filAutoRun=1.

New Zealand Ministry of Fisheries (2011a) Research and Science Information Standard for New Zealand Fisheries. 31 p. Available at http://www.fish.govt.nz/en-nz/Publications/Research+and+Science+Information+Standard.htm.

New Zealand Ministry of Fisheries (2011b) Operational Guidelines for New Zealand's Harvest Strategy Standard Revision 1. 78 p. Available at http://fs.fish.govt.nz/Doc/22847/Operational_Guidelines_for_HSS_rev_1_Jun_2011.pdf.ashx.

Fisheries New Zealand

Tini a Tangaroa

New Zealand Government

FNZ management teams and primary species managed

FISHERIES MANAGEMENT - INSHORE

Common name	Code	Stock
Anchovy	ANC	All
Barracouta	BAR	BAR1
Bladder kelp	KBB	All
Blue cod	BCO	All
Blue moki	MOK	All
Blue warehou	WAR	All
Bluenose	BNS	All
Butterfish	BUT	All
Cockle	COC	All
Deepwater (king) clam	PZL	All
Dredge oyster	OYS, OYU	All
Elephantfish	ELE	All
English mackerel	EMA	EMA1, 2
Flatfish	FLA	All
Freshwater eels (NI and SI)	ANG, LFE, SFE	All
Frostfish	FRO	FRO1, 2
Garfish	GAR	All
Gemfish	SKI	SKI1, 2
Ghost shark, dark	GSH	GSH1-3, 7-9
Greenlipped mussel	GLM	All
Grey mullet	GMU	All
Gurnard	GUR	All
Hapuka / bass	HPB	All
Horse mussel	HOR	All
Jack mackerel	JMA	JMA1
John dory	JDO	All
Kahawai	KAH	All
Kina	SUR	All
Kingfish	KIN	All
Knobbed whelk	KWH	All
Leatherjacket	LEA	All
Ling	LIN	LIN1, 2
Paddle crab	PAD	All
Parore	PAR	All
Paua	PAU	All
Pilchard	PIL	All
Pipi	PPI	All
Porae	POR	All
Queen scallop	QSC	All
Red cod	RCO	All
Red snapper	RSN	All
Ribaldo	RIB	RIB1, 2, 9
Rig	SPO	All
Rock lobsters (incl. PHC)	CRA, PHC	All
Scallop	SCA	All
School shark	SCH	All
Sea cucumber	SCC	All
Sea perch	SPE	SPE1, 2, 8, 9
Skate, rough and smooth	RSK, SSK	All
Snapper	SNA	All
Spiny dogfish	SPD	SPD1, 3, 7, 8
Sprat	SPR	All
Stargazer	STA	All
Surf clams (all species)	DAN, DSU, MMI, MDI, SAE, PDO, BYA	All
Tarakihi	TAR	All
Trevally	TRE	All
Trumpeter	TRU	All
Tuatua	TUA	All
Yelloweyed mullet	YEM	All

FISHERIES MANAGEMENT - DEEPWATER

Common name	Code	Stock
Alfonsino	BYX	All
Barracouta	BAR	BAR4, 5, 7
Cardinalfish	CDL	All
Deepwater crabs (red crab, king crab, giant spider crab)	CHC, KIC, GSC	All
English mackerel	EMA	EMA3, 7
Frostfish	FRO	FRO3-9
Gemfish	SKI	SKI3, 7
Ghost shark, dark	GSH	GSH4-6
Ghost shark, pale	GSP	All
Hake	HAK	All
Hoki	HOK	All
Jack mackerel	JMA	JMA3, 7
Ling	LIN	LIN3-7
Lookdown dory	LDO	All
Orange roughy	ORH	All
Oreos	SSO, BOE, SOR, WOE, OEO	All
Patagonian toothfish	PTO	All
Prawnkiller	PRK	All
Redbait	RBT	All
Ribaldo	RIB	RIB3-8
Rubyfish	RBY	All
Scampi	SCI	All
Sea perch	SPE	SPE3-7
Silver warehou	SWA	All
Southern blue whiting	SBW	All
Spiny dogfish	SPD	SPD4, 5
Squid	SQU	All
White warehou	WWA	All

FISHERIES MANAGEMENT - HMS

Common name	Code	Stock
*Albacore tuna **	*ALB*	*All*
Bigeye tuna	BIG	All
Blue shark	BWS	All
Mako shark	MAK	All
Moonfish	MOO	All
Pacific bluefin tuna	TOR	All
Porbeagle shark	POS	All
Ray's bream	RBM	All
*Skipjack tuna **	*SKJ*	*All*
Southern bluefin tuna	STN	All
Swordfish	SWO	All
Yellowfin tuna	YFN	All

** non-QMS species*

INTL POLICY - FISHERIES MGMT

Common name	RFMO
Antarctic toothfish, Patagonian toothfish	CCAMLR
Orange roughy	SPRFMO
Pacific HMS species *	WCPFC
Southern bluefin tuna	CCSBT

Regional Fisheries Management Organisations (RFMOs)

CCAMLR - *Commission for the Conservation of Antarctic Marine Living Resources*

SPRFMO - *South Pacific Regional Fisheries Management Organisation*

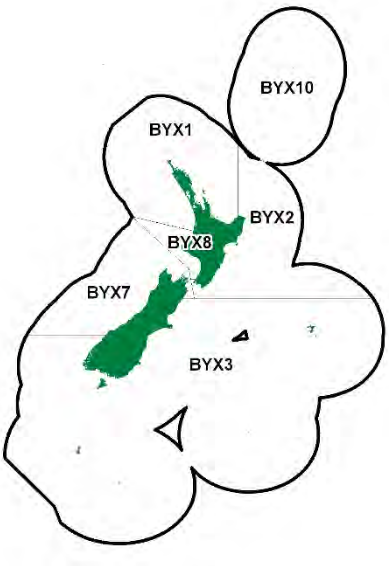
WCPFC - *Western and Central Pacific Fisheries Commission*

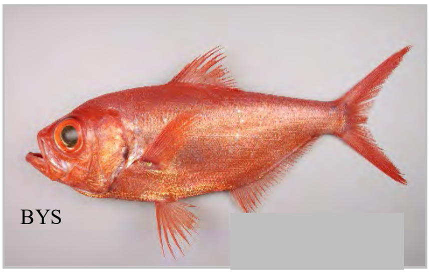
CCSBT - *Commission for the Conservation of Southern Bluefin Tuna*

** primarily ALB, BIG, SKJ, SWO and YFN*

ALFONSINO (BYX)

(*Beryx splendens*, *B. decadactylus*)





1. FISHERY SUMMARY

Alfonsino was introduced into the Quota Management System (QMS) on 1 October 1986. Current allowances, TACCs and TACs are shown in Table 1.

Table 1: Recreational and Customary non-commercial allowances, TACCs and TACs for alfonsino by Fishstock for 2020–21.

Fishstock	Recreational Allowance	Customary non-commercial allowance	TACC	TAC
BYX 1	2	2	300	304
BYX 2	-	-	1 575	1 575
BYX 3	-	-	1 010	1 010
BYX 7	-	-	80.5	80.5
BYX 8	-	-	20	20
BYX 10	-	-	10	10

1.1 Commercial fisheries

Alfonsino has supported a major mid-water target trawl fishery off the east coast of the North Island since 1983 and is a minor bycatch of other trawl fisheries around New Zealand. The original gazetted TACs were based on the 1983–84 landings except for BYX 10 which was administratively set. Recent reported domestic landings and actual TACCs are shown in Table 2, while Figure 1 shows the historical landings and TACC values for the main BYX stocks.

Alfonsino landings in New Zealand consist almost entirely of one species, *Beryx splendens*: the other species, *B. decadactylus*, is thought to make up less than 1% of landings. Before 1983 alfonsino were virtually unfished, but two main fisheries now exist in New Zealand. The first to develop was the lower east coast North Island fishery (BYX 2), which developed in the mid-1980s. The other is the eastern Chatham Rise fishery (BYX 3), which developed in the mid-1990s. Alfonsino are caught throughout the New Zealand EEZ but only in small quantities outside of the east coast North Island and eastern Chatham Rise fisheries.

In BYX 1, alfonsino is mainly caught as a target species by bottom trawl within QMA 1. A smaller amount is taken as bycatch by bottom longline in the bluenose target fishery. The TACC for BYX 1 was increased for the 2001–02 fishing year from 31 t to 300 t when it was included in the adaptive management programme, and allocated 2 t for both customary and other mortality increasing the TAC to a total of 304 t. The new TACC was attained for the first time in 2004–05 and has been under-caught since then.

Table 2: Reported domestic landings (t) of alfonsino by Fishstock from 1985–86 to present and actual TACCs (t) from 1986–87 to present. QMS data from 1986–present.

Fishstock	BYX 1		BYX 2		BYX 3		BYX 7	
FMA (s)	1 & 9		2		3, 4, 5 & 6		7	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1985–86*	11	-	1 454	-	3	-	1	-
1986–87	3	10	1 387	1 510	75	220	4	30
1987–88	8	27	1 252	1 511	101	1 000	2	30
1988–89	6	27	1 588	1 630	64	1 000	4	30
1989–90	24	31	1 496	1 274	147	1 007	21	80
1990–91	17	31	1 459	1 274	202	1 007	26	81
1991–92	7	31	1 368	1 499	264	1 007	2	81
1992–93	6	31	1 649	1 504	113	1 007	12	81
1993–94	7	31	1 688	1 569	275	1 007	31	81
1994–95	11	31	1 670	1 569	482	1 010	59	81
1995–96	11	31	1 868	1 569	961	1 010	66	81
1996–97	39	31	1 854	1 575	983	1 010	77	81
1997–98	14	31	1 652	1 575	1 164	1 010	67	81
1998–99	37	31	1 658	1 575	912	1 010	13	81
1999–00	25	31	1 856	1 575	743	1 010	24	81
2000–01	25	31	1 665	1 575	890	1 010	21	81
2001–02	123	300	1 574	1 575	1 197	1 010	10	81
2002–03	136	300	1 665	1 575	1 118	1 010	7	81
2003–04	219	300	1 468	1 575	884	1 010	11	81
2004–05	300	300	1 669	1 575	1 067	1 010	14	81
2005–06	195	300	1 633	1 575	1 068	1 010	7	81
2006–07	66	300	1 644	1 575	945	1 010	21	81
2007–08	154	300	1 532	1 575	1 030	1 010	32	81
2008–09	172	300	1 589	1 575	895	1 010	18	81
2009–10	185	300	1 643	1 575	1 016	1 010	21	81
2010–11	48	300	1 686	1 575	1 084	1 010	17	81
2011–12	45	300	1 603	1 575	1 037	1 010	14	81
2012–13	22	300	1 605	1 575	1 013	1 010	39	81
2013–14	29	300	1 551	1 575	930	1 010	58	81
2014–15	53	300	1 617	1 575	997	1 010	26	81
2015–16	24	300	1 573	1 575	1 104	1 010	27	81
2016–17	22	300	1 611	1 575	991	1 010	29	81
2017–18	73	300	1 692	1 575	754	1 010	12	81
2018–19	11	300	1 514	1 575	807	1 010	11	80
2019–20	3	300	1 673	1 575	713	1 010	3	81
2020–21	10	300	1 594	1 575	427	1 010	6	81

Fishstock	BYX 8		BYX 10			
FMA (s)	8		10		Total	
	Landings	TACC	Landings	TACC	Landings	TACC
1985–86*	0	-	0	-	1 469	-
1986–87	1	20	0	10	1 470	1 800
1987–88	1	20	0	10	1 364	2 598
1988–89	0	20	1	10	1 663	2 717
1989–90	< 1	20	0	10	1 688	2 422
1990–91	0	20	0	10	1 664	2 423
1991–92	< 1	20	< 1	10	1 641‡	2 648
1992–93	< 1	20	< 1	10	1 780‡	2 653
1993–94	< 1	20	0	10	2 001‡	2 718
1994–95	< 1	20	0	10	2 223‡	2 721
1995–96	< 1	20	0	10	2 906‡	2 721
1996–97	< 1	20	0	10	2 953‡	2 727
1997–98	< 1	20	0	10	2 898‡	2 727
1998–99	3	20	0	10	2 624‡	2 727
1999–00	< 1	20	0	10	2 648‡	2 727
2000–01	< 1	20	0	10	2 601‡	2 727
2001–02	< 1	20	0	10	2 904‡	2 925
2002–03	< 1	20	0	10	2 927‡	2 925
2003–04	2	20	0	10	2 584‡	2 925
2004–05	2	20	0	10	3 052‡	2 925
2005–06	< 1	20	0	10	2 903‡	2 925
2006–07	< 1	20	0	10	2 677‡	2 925
2007–08	< 1	20	0	10	2 748‡	3 000
2008–09	< 1	20	0	10	2 674‡	3 000
2009–10	< 1	20	0	10	2 865‡	3 000
2010–11	< 1	20	0	10	2 836‡	2 996
2011–12	< 1	20	0	10	2 699‡	2 996
2012–13	< 1	20	0	10	2 679‡	2 996
2013–14	< 1	20	0	10	2 568‡	2 996
2014–15	< 1	20	0	10	2 693‡	2 996
2015–16	< 1	20	0	10	2 729‡	2 996
2016–17	< 1	20	0	10	2 653‡	2 996
2017–18	< 1	20	0	10	2 531‡	2 996
2018–19	< 1	20	0	10	2 342‡	2 986
2019–20	< 1	20	0	10	2 392‡	2 996
2020–21	< 1	20	0	10	2 038‡	2 996

*FSU data.

‡ Excludes catches taken outside the New Zealand EEZ.

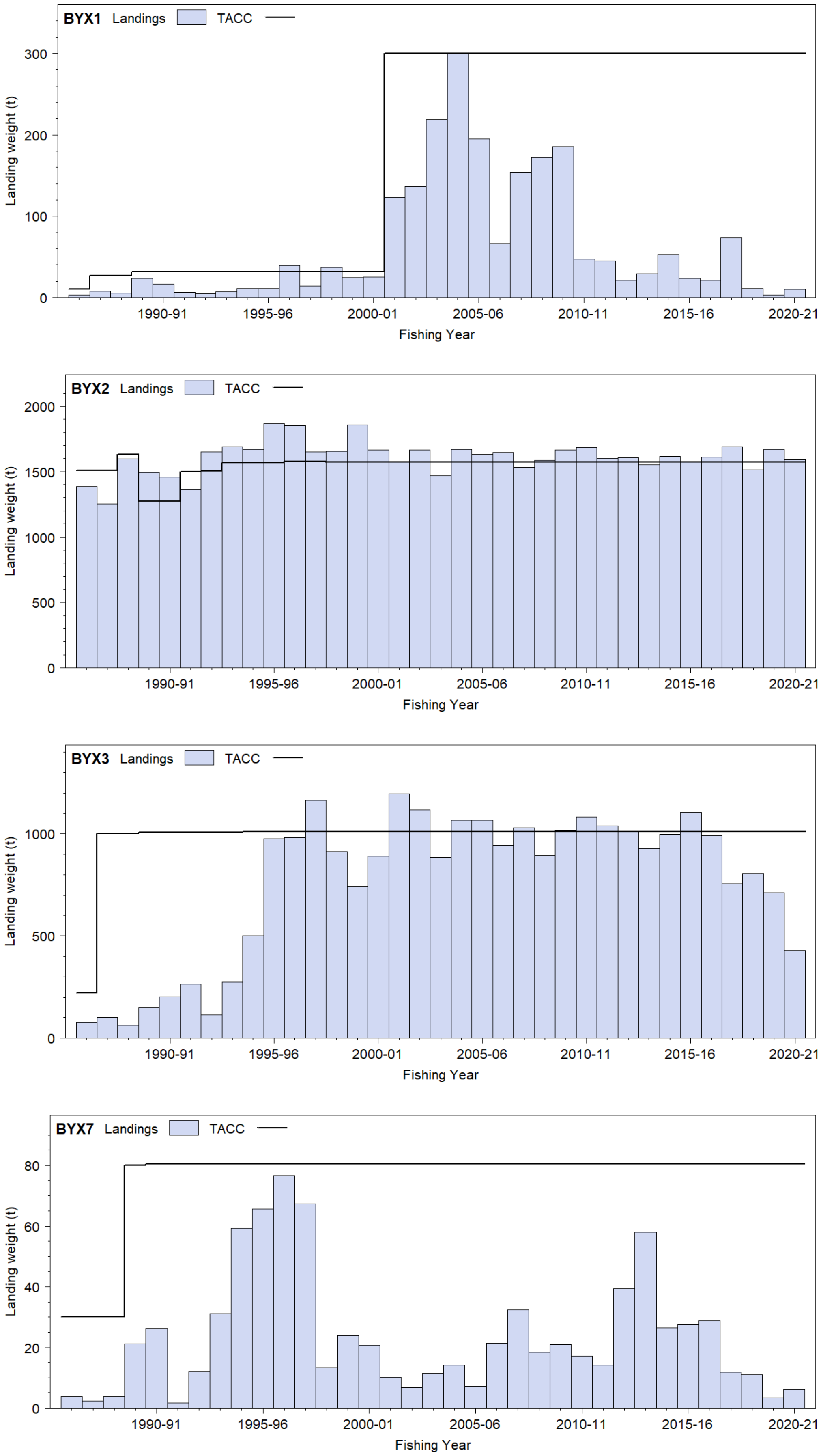


Figure 1: Reported commercial landings and TACC for the four main BYX stocks. Above: BYX 1 (Auckland) BYX 2 (Central East), BYX 3 (South East Coast, South East Chatham Rise, Sub Antarctic, Southland), and BYX 7 (Challenger). Note that these figures do not show data prior to entry into the QMS.

BYX 2 has historically been the major alfonsino fishery in the New Zealand EEZ. Prior to 1983, alfonsino was virtually an unfished resource. The domestic BYX 2 target fishery was developed during 1981, and was concentrated on the banks and seamount features off the east coast of the North Island, between Gisborne and Cape Palliser. Major fishing grounds included the Palliser Bank, Tuaheni Rise, Ritchie Banks and Paoanui Ridge. In more recent years, the alfonsino catch and effort has decreased from these areas, and an increasing proportion of the annual catch has been taken from the Madden Banks and Motukura Bank. Landings fluctuate around the TACC, which has been set at 1575 t since the 1996-97 fishing year.

In BYX 3 catches of alfonsino were low in the early 1990s and were mainly bycatch of the hoki fishery. The TACC for BYX 3 was increased for the 1987–88 fishing year from 220 t to 1000 t but annual landings remained low until 1993–94. However, the discovery of new grounds in the mid-1990s saw the rapid development of a target alfonsino fishery, most notably south-east of the Chatham Islands in Statistical Area 051. Annual landings are usually close to 1000 t, but were 754 t and 807 t in the 2017–18 and 2018–19 fishing years respectively. The vast majority of the BYX 3 alfonsino catch is targeted now, followed by bycatch in fisheries for orange roughy, bluenose, hoki and hake. Catches are made all year round but decrease during the winter months. Catches of alfonsino in the Southland and Sub-Antarctic regions of BYX 3 are negligible.

Catches of alfonsino in BYX 7 are small. They are mainly taken by vessels midwater trawling for spawning hoki in Statistical Areas 034 and 035 in winter. There is essentially no targeting of alfonsino in BYX 7. The TACC was increased from 30 t to 80 t in 1989 but the TACC has never been caught. Annual landings have been less than 15 t since 2017–18.

Landings have been reported from BYX 8 in only a few years. No targeting has ever been reported from this area. All catch has been from midwater trawls targeting jack mackerel and bottom longline targeting bluenose.

Catches of alfonsino from BYX 10 (Kermadec Region) are negligible. Apart from 1 t in 1989, and less than 1 t in each of 1992 and 1993, there have been no reported landings of alfonsino from this area.

1.2 Recreational fisheries

Occasional catches of alfonsino have been recorded from recreational fishers.

1.3 Customary non-commercial fisheries

No quantitative information on the level of customary non-commercial catch is available.

1.4 Illegal catch

No quantitative information on the level of illegal alfonsino catch is available.

1.5 Other sources of mortality

No qualitative information is available.

2. BIOLOGY

In New Zealand waters, most “alfonsino” landings are alfonsino *B. Splendens*, with landings of the red bream *B. decadactylus* accounting for less than 1% of the catch. These species are primarily associated with undersea structures such as the seamounts that occur off the east coast of the North Island and on the Chatham Rise, in depths from 300–600 m. They can be found all around New Zealand waters but occur in greatest numbers along the lower east coast North Island and south-east Chatham Rise. These two areas are essentially where the commercial fisheries for alfonsino in New Zealand are confined.

Alfonsino are widespread in tropical, subtropical and temperate waters from the Atlantic, Pacific, and Indian Oceans (Busakhin 1982). They have been recorded in depths ranging from 10–1200 m but are most commonly found at 200–800 m, on or close to the seabed, often in association with seamounts and other underwater features (Maul 1981, Vinnichenko 1997a, Vinnichenko 1997b).

Stock structure is not currently known for New Zealand alfonsino. Horn & Massey (1989) found substantial differences in length frequency distributions between commercially-caught alfonsino from the Palliser bank compared with those from other locations on the east coast North Island. These differences suggest that there may be some age-specific migration occurring.

It has been suggested that alfonsino could comprise widespread populations in large oceanic eddy systems (Alekseev et al 1986). If New Zealand alfonsino form part of such a system then the east coast North Island may be a vegetative, non-reproductive zone where fish grow and mature before leaving for a possible reproductive zone further east of the mainland (Horn & Massey 1989).

Alfonsino from Japan, northwest of Hawaii, and in the northeast of the Atlantic are known to spawn from August to October (Masuzawa et al 1975, Uchida & Uchihama 1986). In the southeast Atlantic, alfonsino spawn from January to March (Alekseev et al 1986) and from November to February in New Caledonian waters (Lehoday & Grandperrin 1994, Lehoday et al 1997). In New Zealand waters it has been suggested that alfonsino spawn from July to August (Horn & Massey 1989). This was based on observations of fish caught commercially from the lower east coast North Island that were ripening to spawn. However it is not known when and where spawning of alfonsino occurs in New Zealand waters. No running ripe fish were observed in regular samples taken over a 14-month period off the lower Wairarapa coast (Horn & Massey 1989).

Masuzawa et al (1975) estimated that the fecundity of a 40 cm female alfonsino from Japan to be 300 000–500 000 eggs. The fecundity of New Zealand alfonsino however has not been established because a full size range of ripening fish has not been observed (Horn & Massey 1989). Because of this the size and age at maturity cannot be determined precisely for either sex.

Tagging has been unsuccessful for alfonsino (Horn 1989). Being a moderately deepwater fish means that bringing them to the surface is not a viable option due to sudden and usually fatal changes in temperature, light, and particularly pressure. Horn (1989) evaluated the use of detachable hook tags using drop lines to tag alfonsino without bringing them to the surface. Only a small proportion of alfonsino tags were returned by commercial fishermen. This was thought to be due to a combination of low numbers being tagged to begin with (the tagging programme essentially targeted bluenose), low recapture rates, the loss of tags (either before or during capture by commercial fishermen), and possibly low rates of observation by fishermen.

Massey & Horn (1990) examined otoliths from commercially caught alfonsino from various alfonsino fishing grounds of the lower east coast of the North Island (BYX 2) from November 1985 to December 1986. They found evidence that one opaque and one hyaline zone (one ‘ring’) were formed annually (as did Lehodey & Grandperrin (1996)). They investigated the validity of zone counts by measuring the position of each ring and comparing it to the position of successive ring groups. They calculated the ‘marginal index’ of each otolith which was defined as the distance from the outer edge of the last hyaline ring to the otolith edge divided by the width of the last complete opaque and hyaline ring. They plotted the mean marginal indices of fish for each month over the study period and found that the index in every fishing ground dropped dramatically from June to December. This drop in mean marginal index meant that for most fish opaque material has started forming in June, and that the hyaline margin is probably laid down from March to May for most fish. Subsequent ageing has also shown the progression of relatively strong year classes between consecutive years of sampling, thus providing further support for the ageing method.

Massey & Horn (1990) observed very few fish younger than three years of age, and believed that full recruitment to the commercial fishery probably occurs at around five years of age. Size-at-sexual maturity is probably about 30 cm fork length (FL) at 4 to 5 years of age. Juvenile fish have been recorded in the pelagic and epipelagic zones in the North Pacific and Indian Oceans. Alfonsino less than 20 cm FL are seldom recorded in New Zealand waters. Differences in length-frequency distributions between fishing grounds off the east coast North Island suggest that some age-specific migration occurs. Fish probably recruit to these grounds at 28–31 cm FL.

Von Bertalanffy growth parameters were derived for alfonsino from BYX 2 by Stocker & Blackwell (1991) (Table 3). They found that females attain a larger size than males and are also larger at corresponding ages. Massey & Horn (1990) presented von Bertalanffy parameters separately by sex for three fishing grounds off lower east coast North Island.

Stocker & Blackwell (1991) used the equation $M = \log_e 100/\text{maximum age}$, where maximum age is the age to which 1% of the population survives in an unexploited stock. Using a maximum age of 20 years, they estimated M for both sexes as 0.23 for BYX 2.

Length-weight relationships are presented in Table 3. Parameters for the Chatham Rise are those reported by O'Driscoll et al (2011) for all fish from the summer Chatham Rise trawl survey time series from 1992–2010.

Table 3: Estimates of biological parameters for alfonsino.

Fishstock						**Estimate**	**Source**
1. Natural mortality (M)							
BYX 2						0.23	Stocker & Blackwell (1991)
2. Weight = $a(\text{length})^b$ (Weight in g, length in cm fork length).							
				Both Sexes			
				a		b	
BYX 2				0.0226		3.018	Stocker & Blackwell (1991)
BYX 3				0.019		3.049	O'Driscoll et al (2011)
3. Von Bertalanffy growth parameters							
	Females			Males			
	L_∞	k	t_0	L_∞	k	t_0	
BYX 2	57.5	0.08	-4.10	51.1	0.11	-3.56	Stocker & Blackwell (1991)

Horn et al (2010) examined stomach contents from *Beryx splendens* caught on three consecutive summer trawl surveys of the Chatham Rise (2005–2007). They found that alfonsino were moderately selective feeders that fed primarily in the mesopelagic layers. The most common prey items were crustaceans and mesopelagic fishes. By mass, the most important were prawns from the genus *Sergestes*, followed by the myctophid fish *Lampanyctodes hectoris,* and then prawns from the genus *Pasiphaea.*

Smaller crustaceans such as euphasiids and amphipods are most important in the diet of smaller alfonsino (17–26.5 cm fork length). Larger prawn species and mesopelagic fishes were more important for larger alfonsino (27–42 cm fork length). Horn et al (2010) postulated that they are selective feeders based on the observation that prey items such as squid and salps would be relatively abundant where alfonsino feed on the Chatham Rise, but are rarely taken.

3. STOCKS AND AREAS

No information is available as to whether alfonsino is a single stock in New Zealand waters. Overseas data on alfonsino stock distributions suggest that New Zealand fish could form part of a widely distributed South Pacific stock.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

i) BYX 1

Starr et al (2010) presented CPUE analyses from the bycatch of alfonsino in the east Northland and Bay of Plenty target longline fisheries for bluenose and hapuku. The two series showed no sign of decline up to 2007–08, but the indices were based on only 12% of the BYX catch from the area. The analyses have not been updated, and the catch of BYX has decreased to below 50 t for the last five years.

ii) BYX 2

A biomass index derived from a standardised CPUE (log linear, kg/day) analysis of the target trawl fishery represented by seven core vessels (Blackwell 2000) was calculated for BYX 2. However, the analysis was very uncertain, and the model accounted for only 25% of the variance in catch rates. The results of the standardised analysis were not accepted by the Inshore WG as indices of abundance.

The age composition of the commercial landings in BYX 2 was determined in 1998–99, 1999–00, and 2000–01 and 2002–03, 2003–04 and 2004–05. The commercial catch is dominated by 5–11 year old fish. Without linking age structure to specific fishing grounds the age structure of the catch is unlikely to monitor changes in the population.

iii) BYX 3

The potential to monitor trends in abundance using catch and effort data from the target BYX 3 fishery was investigated by Langley & Walker (2002b). However, it was concluded that the high variation in catch rates, the relatively small number of catch and effort records, and the complex nature of the fishery precluded the development of a reliable CPUE index.

4.2 Biomass estimates

Estimates of current biomass are not available.

4.3 Yield estimates and projections

4.3.1 Other yield estimates and stock assessment factors

Long-term sustainable yield using an $F_{0.1}$ fishing strategy was estimated for BYX 2 using the simulation model with alternative estimates of M. $F_{0.1}$ has been estimated as 0.25 and 0.32 for $M = 0.2$ and $M = 0.23$, respectively, for both sexes combined in BYX 2 (Stocker & Blackwell 1991). The biomass at this long-term equilibrium yield is about 35% B_0 and the $F_{0.1}$ yield is about 8–9% B_0.

4.4 Other factors

The most recent assessment for BYX 2 was based upon the historical fishery areas. In recent years the fishery has expanded to new areas not previously fished. Subsequent CPUE analyses have been rejected by Working Groups and it is no longer thought possible to monitor abundance in BYX 2 using trawl CPUE.

Current data on alfonsino movements are inconclusive. It is not known whether the fish on the east coast of the North Island spend some part of their life cycle in other New Zealand waters, or whether the east coast-Chatham Rise region is just one of several pre-reproductive regions. It is possible that the domestic trawl fishery may be exploiting part of a wider South Pacific stock. Catches may be maintained due to the discovery of new grounds. However, the potential for increased catches may be constrained by the availability of BNS 3 quota to cover likely bluenose bycatch.

5. STATUS OF THE STOCKS

Stock Structure Assumptions

No information is available as to whether alfonsino is a single stock in New Zealand fishery waters. Overseas data on alfonsino stock distributions suggest that New Zealand fish could form part of a widely distributed South Pacific stock. In addition to alfonsino (*Beryx splendens*) the BYX Fishstock includes landings of the red bream (*B. decadactylus*), however, red bream makes up less than 1% of the total landings.

BYX 1

Under the adaptive management programme the TACC was increased to 300 t in 2001−02, and catches increased for the next 9 years in the target trawl fishery. However, catches have been below 50 t since 2010–11 as target fishing in this fishery has waned.

BYX 2

Annual landings from 1986 to 2014–15 have remained reasonably stable at or above the level of the TACC. However, as the fishing grounds have extended throughout this time, it is not known if the recent catch levels or the current TACCs are sustainable.

BYX 3

Alfonsino on the Chatham Rise (BYX 3) were lightly fished prior to 1995–96 when catches increased to near the TACC, due to the development of new fishing grounds. Catch has fluctuated around the TACC since then. It is not known if the recent catch levels or the current TACCs are sustainable.

6. FUTURE RESEARCH CONSIDERATIONS

Neither CPUE nor trawl surveys are likely to provide an index of alfonsino abundance. The best method to determine the status of the stocks and to continue monitoring is likely to be a catch-at-age sampling programme. A large proportion of the alfonsino catch from the two main fisheries is still landed green which would allow for a land-based shed sampling programme for either area, although at-sea observer-based sampling would allow for the detection of any differences in sub-regions within the main fishery areas.

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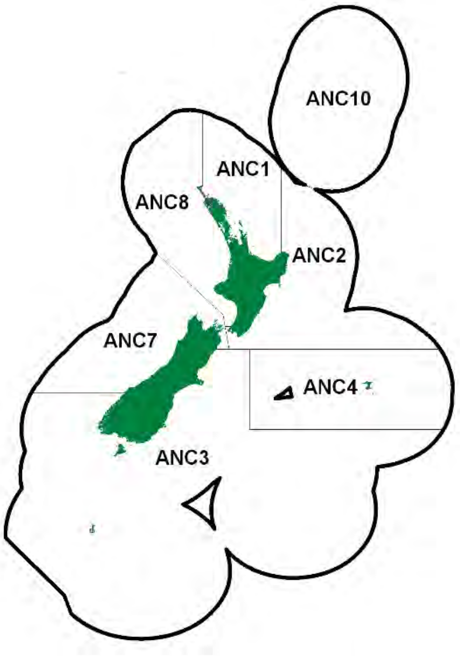
ANCHOVY (ANC)

(*Engraulis australis*)
Kokowhaawhaa



1. FISHERY SUMMARY

Anchovy were introduced into the QMS on 1 October 2002, with allowances, TACCs and TACs in Table 1. These have not changed.

Table 1: Recreational and Customary non-commercial allowances, TACCs and TACs for anchovy by Fishstock.

Fishstock	Recreational Allowance	Customary non-commercial allowance	TACC	TAC
ANC 1	10	5	200	215
ANC 2	10	5	100	115
ANC 3	2	1	50	53
ANC 4	3	2	10	15
ANC 7	10	5	100	115
ANC 8	10	5	100	115
ANC 10	0	0	0	0

1.1 Commercial fisheries

There is no information on catches or landings of anchovy prior to 1990, although sporadic catches were made in some years during exploratory fishing projects for small pelagic species, in the 1960s and 1970s. It is thought that anchovy were caught in most years, but were either not reported, reported as "bait", or included in the category "mixed species". Reported annual landings have fluctuated from less than 1 t to 21 t since 1990–91 (Table 2). Under-reporting is likely to have occurred due to misidentification of anchovy in pilchard and other mixed catches, as well as the low value of the species.

Historically most landings have been reported from northeastern New Zealand, ANC 1, with occasional small landings in ANC 3, 7 and 8.

The most consistent (though small) catches have been taken by purse seine. Very few catches have been reported as targeted; most anchovy appear to have been taken as non-target catch in the pilchard fishery. Up to four vessels reported a catch or landing in any one year.

Table 2: Reported catches or landings (t) of anchovy by fishstock from 1990–91 to present (prior to 2002–03 reported by FMA). MHR data from 2001–02 to present.

Fishstock	ANC 1	ANC 2	ANC 3	ANC 4	ANC 7	ANC 8	ANC 10	
FMA	1	2	3,5&6	4	7	8&9	10	Total
1990–91†	< 1	0	0	0	< 1	0	0	< 1
1991–92†	1	0	1	0	< 1	0	0	2
1992–93†	21	0	0	0	0	0	0	21
1993–94†	< 1	0	0	0	0	0	0	< 1
1994–95†	< 1	0	0	0	< 1	0	0	< 1
1995–96†	1	0	0	0	0	0	0	1
1996–97†	2	0	0	0	0	0	0	2
1997–98†	1	0	0	0	0	0	0	1
1998–99†	4	0	2	0	0	0	0	6
1999–00†	3	0	0	0	0	0	0	3
2000–01†	10	0	0	0	0	0	0	10
2001–02	7	0	0	0	0	0	0	7
2002–03	8	0	0	0	0	0	0	8
2003–04	4	0	0	0	0	10	0	15
2004–05	< 1	0	0	0	0	12	0	12
2005–06	10	0	0	0	0	< 1	0	10
2006–07	< 1	0	0	0	0	2	0	3
2007–08	< 1	0	0	0	< 1	< 1	0	< 1
2008–09	< 1	0	0	0	< 1	< 1	0	2
2009–10	6	0	0	0	6	0	0	12
2010–11	1	0	< 1	0	< 1	< 1	0	1
2011–12	< 1	0	0	0	0	0	0	< 1
2012–13	0	0	< 1	0	< 1	< 1	0	< 1
2013–14	2	0	< 1	0	< 1	< 1	0	2
2014–15	1	0	< 1	0	0	< 1	0	< 1
2015–16	< 1	0	0	0	11	0	0	11
2016–17	< 1	0	0	0	5	0	0	5
2017–18	< 1	0	0	0	< 1	0	0	< 1
2018–19	3	< 1	< 1	0	0	0	0	4
2019–20	0	< 1	< 1	0	0	< 1	0	< 1
2020–21	1	< 1	< 1	0	1	2	0	5

† CELR

1.2 Recreational fisheries

There is no known recreational fishery, but small numbers are caught in small-mesh setnets and beach seines. An estimate of the recreational harvest is not available.

1.3 Customary non-commercial fisheries

An estimate of the customary non-commercial catch is not available.

1.4 Illegal catch

There is no known illegal catch of anchovies.

1.5 Other sources of mortality

Some accidental captures of anchovy by vessels purse seining for other small pelagic species may be discarded if no market is available.

2. BIOLOGY

The single anchovy species, *Engraulis australis*, found in New Zealand also occurs around much of the Australian coast. In New Zealand, it occurs around most of the coastline, but is absent between Banks Peninsula and Foveaux Strait. It is found mostly inshore, particularly in gulfs, bays, harbours, and some large estuaries. In Australia it tends to move seaward in winter, returning closer inshore during spring and the same pattern is likely to occur in New Zealand. Its vertical distribution in the water column is not known, but it seems likely that it occurs at all depths between the surface and the coastal seafloor.

Anchovy are planktivorous, feeding mainly on copepods. They form compact schools, particularly during the warmer months and larger fishes, seabirds, and marine mammals prey heavily upon these schools. Although they generally form single-species schools, anchovies are closely associated with other small pelagic fishes, particularly pilchard and sprats.

The reproductive cycle is not well known. The main spawning season appears to be spring-summer, but in northern regions spawning may occur through much of the year. Spawning grounds extend from shallow water out to mid-shelf. The eggs are pelagic.

No reliable ageing work has been undertaken in New Zealand, but some information is available for this species in Australia where it reaches 16 cm at age 6, and matures at age 1. In northeastern New Zealand, the main size range of anchovy is 8–14 cm, which are likely to be 2–5 year old fish.

There have been no biological studies that are directly relevant to the recognition of separate stocks, or to yield estimates. Consequently no estimates of biological parameters are available. There is extensive international literature on similar species of anchovy, but the relevance of this to the New Zealand species is unknown.

3. STOCKS AND AREAS

No biological information is available on which to make an assessment on whether separate anchovy stocks exist in New Zealand. If spawning is as widespread as the fragmentary accounts suggest and if there is limited migration between regions, there is potential for localised depletion.

Anchovy and pilchard are often caught together. Anchovy fishstock boundaries are fully aligned with those for pilchard.

4. STOCK ASSESSMENT

There have been no stock assessments of New Zealand anchovy.

4.1 Estimates of fishery parameters and abundance

No fishery parameters are available.

4.2 Biomass estimates

No estimates of biomass are available.

4.3 Yield estimates and projections

MCY cannot be determined.

Current biomass cannot be estimated, so *CAY* cannot be determined.

4.4 Other yield estimates and stock assessment results

No information is available.

4.5 Other factors

Ichthyoplankton surveys show anchovy to be locally abundant. However, it is unlikely that the biomass is comparable to the very large stocks of anchovy in some oceans where strong upwelling promotes high productivity. It is more likely that New Zealand anchovy comprise abundant but localised coastal populations.

It is not known whether the biomass of anchovy is stable or variable, but the latter is considered more likely.

In some localities anchovy are a major food source for many fish, seabirds, and marine mammals (e.g., a major component of fur seal diet in May–August at Cape Foulwind). Excessive localised harvesting may disrupt ecosystems.

5. STATUS OF THE STOCKS

No estimates of current biomass are available. At the present level of minimal catches, stocks should be at or close to their natural level. This is nominally a virgin biomass, but not necessarily a stable one. It is not yet possible to estimate a long-term sustainable yield for anchovy.

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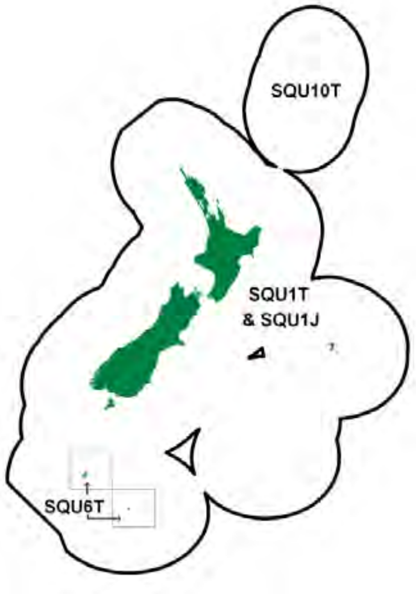
ARROW SQUID (SQU)

(*Nototodarus gouldi*, *N. sloanii*)
Ngū/Wheke



1. FISHERY SUMMARY

Arrow squid was introduced into the Quota Management System (QMS) on 1 October 1986. Current allowances, TACCs, and TACs are given in Table 1.

Table 1: Recreational and customary non-commercial allowances, TACCs, and TACs (t) for arrow squid by Fishstock.

Fishstock	Recreational Allowance	Customary non-commercial allowance	Other sources of mortality	TACC	TAC
SOU 1J	10	10	10	5 000	5 030
SQU 1T	0	0	0	44 741	44 741
SQU 6T	0	0	0	32 369	32 369
SQU 10T	0	0	0	10	0

1.1 Commercial fisheries

The New Zealand arrow squid fishery is based on two related species. *Nototodarus gouldi* is found around mainland New Zealand north of the Subtropical Convergence, whereas *N. sloanii* is found in and to the south of the convergence zone. The two species are both found off the northern part of the South Island west coast (Smith et al 1987, Uozumi 1998).

Except for the Southern Islands fishery (SQU 6T), for which a separate TACC is set, the two species are managed as a single fishery within an overall TACC. The Southern Islands fishery (SQU 6T) is almost entirely a trawl fishery. Although the species (*N. sloanii*) is the same as that found around the south of the South Island, there is evidence to suggest that the Auckland Island Shelf stock is different from the mainland stocks. Because the Auckland Island Shelf squid are readily accessible to trawlers, and because they can be caught with little finfish bycatch and are therefore an attractive resource for trawlers, a quota has been set separately for the Southern Islands. Total reported landings and TACCs for each stock are shown in Table 2, and historical landings and TACCs are depicted in Figure 1.

The New Zealand squid fishery began in the late 1970s and reached a peak in the early 1980s when over 200 squid jigging vessels came to fish in the New Zealand EEZ. The discovery and exploitation of the large squid stocks in the southwest Atlantic substantially increased the supply of squid to the Asian markets causing the price to fall. In the early 1980s, Japanese squid jiggers would fish in New Zealand for a short time before continuing on to the southwest Atlantic. In the late 1980s, the jiggers stopped transit fishing in New Zealand and the number of jiggers fishing declined from over

200 during the 1983–84 fishing year to 5 or fewer vessels from 2006–07. There has been no jig fishery operating since 2016–17. The jig landings in SQU 1J declined from a peak of 53 872 t in 1988–89 to under 1000 t per year by 2012–13. In 2016–17 the TACC was reduced from 50 212 t to 5000 t to reflect these changes within this fishery. Since the 2016–17 fishing year annual landings of less than 1 t have been recorded.

From 1987 to 1998 trawl landings fluctuated between about 30 000 and 70 000 t, but in SQU 6T the impact of management measures to protect the New Zealand sea lion *(Phocarctos hookeri*) restricted the total catch in some years between 1999 and 2005. Landings have remained below the TACC in SQU 6T since 2004, with only just over 11 000 t landed in 2020–21.

Catch and effort data from the SQU 1T fishery show that the catch occurs between December and May, with peak harvest from January to April. The catch has been taken from the Stewart-Snares shelf off the south coast of the South Island north to the Mernoo Bank (off the east coast South Island), but Statistical Area 028 (southern Stewart-Snares shelf and Snares Island region) has accounted for over 77% of the total in recent years. Based on observer data, squid accounts for 67% of the total catch in the target trawl fishery, with bycatch principally of barracouta, jack mackerel, silver warehou, and spiny dogfish.

For 2005–06, a 10% in-season increase to the SQU 1T TACC was approved by the Minister of Fisheries. The catch for December–March was 40% higher than the average over the previous eight years and catch rates were double the average, indicating an increased abundance of squid. Previously, in 2003–04, a 30% in-season increase to the TACC was agreed, but catches did not reach the higher limit. In both instances the TACC automatically reverted to the original value at the end of the fishing year.

Recent landings have remained below the TACC in both SQU 1 T and SQU 6T. The landings for these areas in 2020–21 totalled 30 081 t.

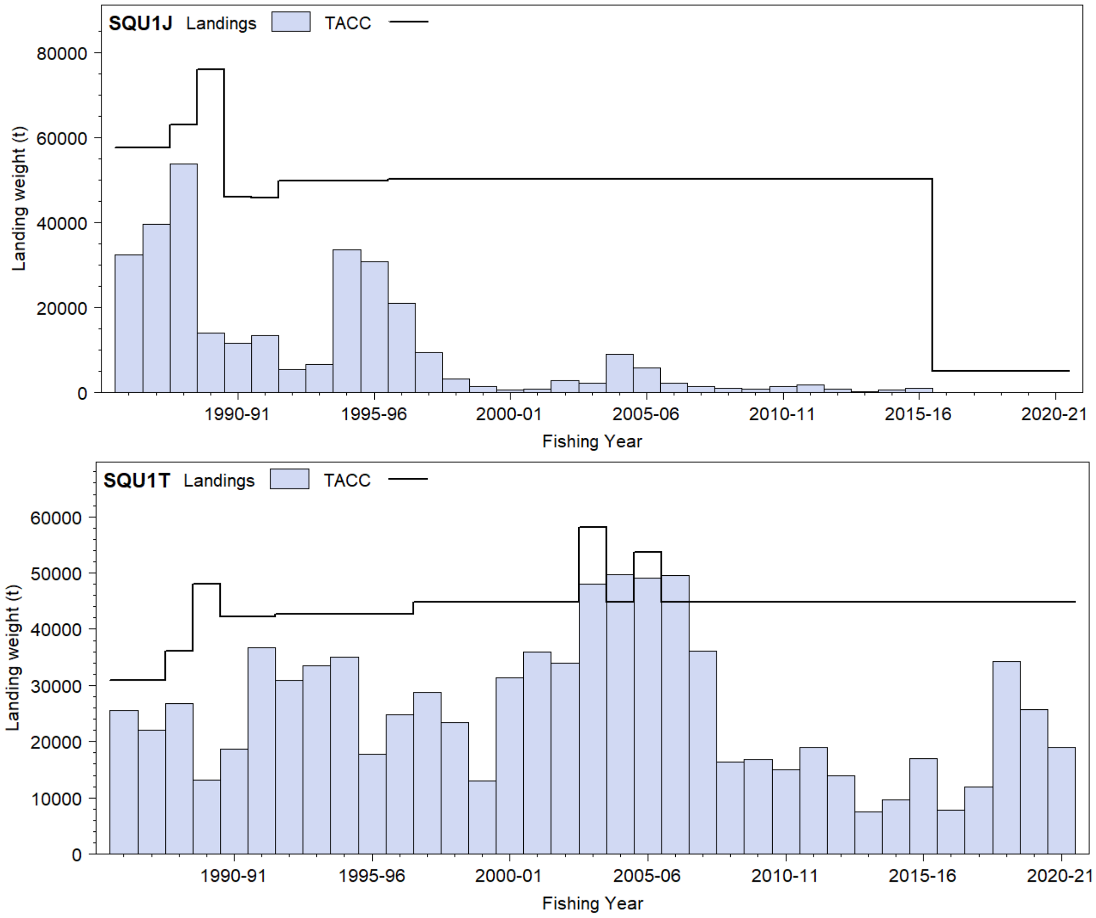


Figure 1: Reported commercial landings and TACC for the three main SQU stocks. Top to bottom: SQU 1J (all waters except 10T and 6T, jigging) and SQU 1T (all waters except SQU 10T and SQU 6T, all other methods). Note that these figures do not show data prior to entry into the QMS. [Continued on next page]

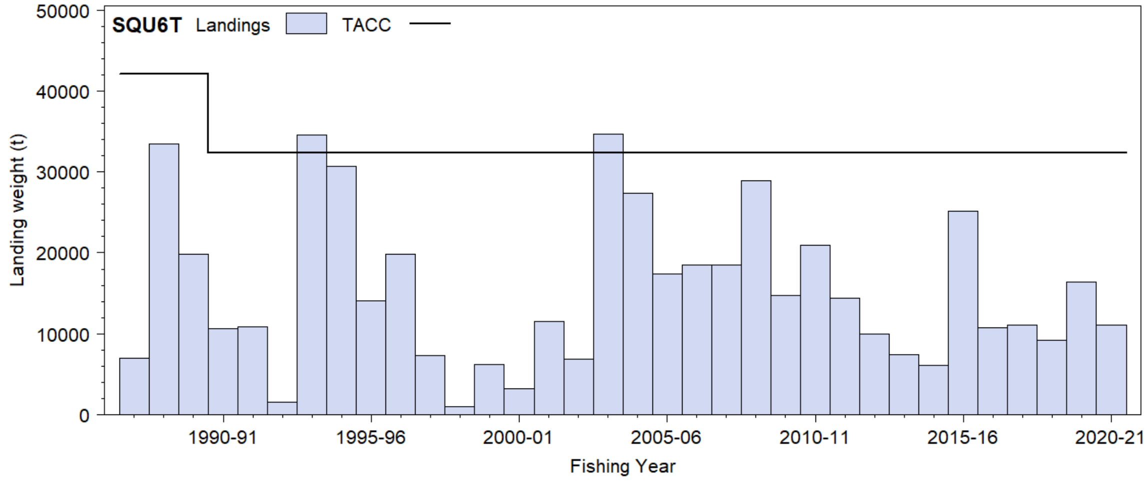


Figure 1: [Continued] Reported commercial landings and TACC for the three main SQU stocks. SQU 6T (Southern Islands, all methods). Note that these figures do not show data prior to entry into the QMS.

Table 2: Reported catches (t) and TACCs (t) of arrow squid from 1986–87 to present. Source - QMS.

Fishstock	SQU 1J*		SQU 1T*		SQU 6T†		SQU 10T‡		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1986–87	32 394	57 705	25 621	30 962	16 025	32 333	0	10	74 040	121 010
1987–88	40 312	57 705	21 983	30 962	7 021	32 333	0	10	69 316	121 010
1988–89	53 872	62 996	26 825	36 081	33 462	35 933	0	10	114 160	135 080
1989–90	13 895	76 136	13 161	47 986	19 859	42 118	0	10	46 915	166 250
1990–91	11 562	46 087	18 680	42 284	10 658	30 190	0	10	40 900	118 571
1991–92	12 985	45 766	36 653	42 284	10 861	30 190	0	10	60 509	118 571
1992–93	4 865	49 891	30 862	42 615	1 551	30 369	0	10	37 278	122 875
1993–94	6 524	49 891	33 434	42 615	34 534	30 369	0	10	74 492	122 875
1994–95	33 615	49 891	35 017	42 741	30 683	30 369	0	10	99 315	123 011
1995–96	30 805	49 891	17 823	42 741	14 041	30 369	0	10	62 668	123 011
1996–97	20 792	50 212	24 769	42 741	19 843	30 369	0	10	65 403	123 332
1997–98	9 329	50 212	28 687	44 741	7 344	32 369	0	10	45 362	127 332
1998–99	3 240	50 212	23 362	44 741	950	32 369	0	10	27 553	127 332
1999–00	1457	50 212	13 049	44 741	6 241	32 369	0	10	20 747	127 332
2000–01	521	50 212	31 297	44 741	3 254	32 369	< 1	10	35 071	127 332
2001–02	799	50 212	35 872	44 741	11 502	32 369	0	10	48 173	127 332
2002–03	2 896	50 212	33 936	44 741	6 887	32 369	0	10	43 720	127 332
2003–04	2 267	50 212	48 060	#58 163	34 635	32 369	0	10	84 962	127 332
2004–05	8 981	50 212	49 780	44 741	27 314	32 369	0	10	86 075	127 332
2005–06	5 844	50 212	49 149	#49 215	17 425	32 369	0	10	72 418	127 332
2006–07	2 278	50 212	49 495	44 741	18 479	32 369	0	10	70 253	127 332
2007–08	1 371	50 212	36 171	44 741	18 493	32 369	0	10	56 035	127 332
2008–09	1 032	50 212	16 407	44 741	28 872	32 369	0	10	46 311	127 332
2009–10	891	50 212	16 759	44 741	14 786	32 369	0	10	32 436	127 332
2010–11	1 414	50 212	14 957	44 741	20 934	32 369	0	10	37 304	127 332
2011–12	1 811	50 212	18 969	44 741	14 427	32 369	0	10	35 207	127 332
2012–13	741	50 212	13 951	44 741	9 944	32 369	0	10	24 637	127 332
2013–14	167	50 212	7 483	44 741	7 403	32 369	0	10	15 053	127 332
2014–15	513	50 212	9 668	44 741	6 127	32 369	0	10	16 310	127 332
2015–16	937	50 212	17 018	44 741	25 172	32 369	< 1	10	43 127	127 332
2016–17	1	5 000	7 735	44 741	10 726	32 369	0	10	18 462	82 120
2017–18	< 1	5 000	11 983	44 741	11 086	32 369	< 1	10	23 069	82 120
2018–19	< 1	5 000	34 217	44 741	9 180	32 369	0	10	43 397	82 120
2019–20	< 1	5 000	25 638	44 741	16 393	32 369	< 1	10	42 032	82 120
2020–21	< 1	5 000	19 006	44 741	11 074	32 369	< 1	10	30 081	82 120

* All areas except Southern Islands and Kermadec.
† Southern Islands.
‡ Kermadec.
# In-season increase of 30% for 2003–04 and 10% for 2005–06.

1.2 Recreational fisheries

The amount of arrow squid caught by recreational fishers is not known.

1.3 Customary non-commercial fisheries

No quantitative information is available on the current level of customary non-commercial take.

1.4 Illegal catch

There is no quantitative information available on the level of illegal catch.

1.5 Other sources of mortality

No information is available on other sources of mortality.

2. BIOLOGY

Two species of arrow squid are caught in the New Zealand fishery. Both species are found over the continental shelf in waters to 500 m depth, though they are most prevalent in waters less than 300 m depth. Both species are sexually dimorphic, though similar in biology and appearance. Individuals can be identified to species level based on sucker counts on arm I and differences in the hectocotylised arm of males.

Recent work on the banding of statoliths from *N. sloanii* suggests that the animals live for around one year. Growth is rapid. Modal analysis of research data has shown increases of 3.0–4.5 cm per month for Gould's arrow squid measuring between 10 and 34 cm dorsal mantle length (DML).

Estimated ages suggest that *N. sloanii* hatches in July and August, with spawning occurring in June and July. It also appears that *N. gouldi* may spawn one to two months before *N. sloanii*, although there are some indications that *N. sloanii* spawns at other times of the year. The squid taken by the fishery do not appear to have spawned.

Tagging experiments indicate that arrow squid can travel on average about 1.1 km per day with a range of 0.14–5.6 km per day.

Biological parameters relevant to stock assessment are shown in Table 3.

Table 3: Estimates of biological parameters.

Fishstock			Estimate	Source
1. Weight = a (length)^b (Weight in g, length in cm dorsal length)				
		a	b	
N. gouldi	≤ 12 cm DML	0.0738	2.63	Mattlin et al (1985)
N. sloanii	≥ 12 cm DML	0.029	3	
2. von Bertalanffy growth parameters				
	K	t_0	$L\infty$	
N. gouldi	2.1–3.6	0	35	Gibson & Jones (1993)
N. sloanii	2.0–2.8	0	35	

3. STOCKS AND AREAS

There are no new data which would alter the stock boundaries given in previous assessment documents. It is assumed that the stock of *N. gouldi* (the northern species) is a single stock, and that *N. sloanii* around the mainland comprises a unit stock for management purposes, although the detailed structure of these stocks is not fully understood. The distribution of the two species is largely geographically separate but those occurring around the mainland are combined for management purposes. The Auckland Islands Shelf stock of *N. sloanii* appears to be different from the mainland stock and is managed separately.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

Tables and text for this section were last updated for the 2021 Fishery Assessment Plenary. A more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021), available online at https://www.mpi.govt.nz/dmsdocument/51472-Aquatic-Environment-and-Biodiversity-Annual-Review-AEBAR-2021-A-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment. Some tables in this section have not been updated because data were unavailable at the time of publication.

4.1 Role in the ecosystem

Arrow squid are short-lived and abundance is highly variable between years (see Biology section). Hurst et al (2012) reviewed the literature and noted that arrow squid are an important part of the diet for many species. Stevens et al (2011) reported that, between 1960 and 2000, squids (including arrow squid) were important in the diet of banded stargazer (59% of non-empty stomachs), bluenose (26%), giant stargazer (34%), gemfish (43%), and hāpuku (21%), and arrow squid were specifically recorded in the diets of alfonsino, barracouta, hake, hoki, ling, red cod, red gurnard, sea perch, and southern blue whiting. In a detailed study on the Chatham Rise (Dunn et al 2009), cephalopods were identified as prey of almost all demersal fish species, and arrow squid were identified in the diet of hake, hoki, ling, Ray's bream, shovelnose spiny dogfish, sea perch, smooth skate, giant stargazer, and silver warehou and were a significant component (over 10% prey weight) of the diet of barracouta and spiny dogfish.

Arrow squid have been recorded as important in the diet of marine mammals such as New Zealand fur seals and New Zealand sea lions, particularly during summer and autumn (Fea et al 1999, Harcourt et al 2002, Chilvers 2008, Boren 2008) and in the diet of common dolphins (Meynier et al 2008, Stockin 2008). They are also important in the diet of seabirds such as shy albatross in Australia (Hedd & Gales 2001) and Buller’s albatross at the Snares and Solander islands (James & Stahl 2000). Cephalopods in general are important in the diet of a wide range of Australasian albatrosses, petrels, and penguins (Marchant & Higgins 2004).

Arrow squid in New Zealand waters have been reported to feed on myctophids, sprats, pilchards, barracouta, euphausiids, mysids, isopods, and squid, probably other arrow squid (Yatsu 1986, Uozumi 1998). Uozumi (1998) found that the importance of various food items changed between years, and the percentage of empty stomachs was influenced by area, season, size, maturation, and time of day. In Australia, *N. gouldi* was found to feed mostly on pilchard, barracouta, and crustaceans (O’Sullivan & Cullen 1983). Cannibalism was also recorded.

4.2 Bycatch (fish and invertebrate)

Based on models using observer and fisher-reported data, total non-target fish and invertebrate catch in the arrow squid trawl fishery ranged between 8900 t and 39 800 t per year between 2002–03 and 2015–16 and has shown a significant decreasing trend since 2005–06 (Anderson & Edwards 2018). Over that time period arrow squid comprised 79% of the total estimated catch recorded by observers in this fishery. Nearly 600 non-target species or species groups were recorded, with QMS species making up most non-target catch (over 85%) in each year. The remainder of the observed catch comprised mainly the QMS fish species barracouta (9.1%), silver warehou (3.3%), and spiny dogfish (1.7%). Invertebrate species made up a much smaller fraction of the bycatch overall (1.3%), but crabs (1.2%), especially the smooth red swimming crab (*Nectocarcinus bennetti*, 0.85%), were frequently caught.

Estimated total annual discards showed a decreasing trend over time, from 16 300 t in 2002–03 to about 1500 t in 2013–14 (Anderson & Edwards 2018). Quota management species accounted for 44% of discards over all years, followed by non-QMS species (41%), invertebrate species (15%), and arrow squid (8%). Target species discards were relatively low, and annual discards of non-QMS species were overall at a similar level to QMS discards. The species discarded in the greatest amounts were spiny dogfish (80%), redbait (34%), silver dory (87%), and rattails (88%). From 2002–03 to 2015–16, the overall discard fraction value was 0.12, with little trend over time. Discards ranged from 0.05 kg of discarded fish for every 1 kg of arrow squid caught in 2007–08 to 0.43 kg in 2002–03.

Finucci et al (2019) analysed bycatch trends in deepwater fisheries, including arrow squid trawl fisheries, from 1990–91 to 2016–17. They found that the most common bycatch species by weight were barracouta (*Thyrsites atun*, BAR), silver warehou (*Seriolella punctata*, SWA), and spiny dogfish (*Squalus acanthias*, SPD). Moreover, of the 347 fish and invertebrate species caught as bycatch in this fishery and examined in this study, 68 showed a decrease in catch over time (15 were significant) and 81 showed an increase (29 were significant). Species showing the greatest decline were jack mackerels (*Trachurus* spp., JMA) and thresher shark (*Alopias vulpinus*, THR); and species showing the greatest increase were giant spider crab (*Jacquinotia edwardsii*, GSC) and beaked sandfish (*Gonorynchus forsteri* & *G. greyi*, GON). A change in code between paddle crab (*Ovalipes catharus*, PAD) and smooth red swimming crab (*Nectocarcinus bennetti*, NCB) resulted in a decline of the former and an increase of the latter in bycatch records.

4.3 Incidental Capture of Protected Species (mammals, seabirds, and protected fish)

For protected species, capture estimates presented here include all animals recovered to the deck (alive, injured, or dead) of fishing vessels but do not include any cryptic mortality (e.g., seabirds struck by a warp but not brought onboard the vessel, Middleton & Abraham 2007).

4.3.1 New Zealand sea lion captures

The New Zealand sea lion (rāpoka) *Phocarctos hookeri*, is the one of the rarest sea lions in the world. The estimated total population of around 11 800 sea lions in 2015 is classified by the Department of Conservation as 'Nationally Vulnerable' under the New Zealand Threat Classification System (Baker et al 2019). Pup production at the main Auckland Islands group rookeries showed a steady decline between 1998 and 2009 and has subsequently stabilised (details can be found in the Aquatic Environment and Biodiversity Annual Review 2021, Fisheries New Zealand 2021).

Sea lions forage to depths of 600 m and overlap with arrow squid trawling in depths to 500 m. Sea lions interact with some trawl fisheries which can result in incidental capture and subsequent drowning (Smith & Baird 2005a & b, 2007a & b, Thompson & Abraham 2010a, Abraham & Thompson 2011, Abraham et al 2016, Large et al 2019). Since 1988, incidental captures of sea lions have been monitored by government observers on-board an increasing proportion of the fishing fleet. Since the 2012–13 fishing year, more than 80% of fishing trawls in the SQU 6T fishery have been observed each year.

Beginning in 1992, the Ministry has imposed a fisheries-related mortality limit (FRML, previously referred to as a maximum allowable level of fisheries-related mortality or MALFiRM) to set an upper limit on the number of New Zealand sea lions that can be incidentally killed each year in the SQU 6T trawl fishery (Chilvers 2008). If this limit is reached, the fishery will be closed for the remainder of the season. Mortality limits and other management settings in this fishery from 1992 onwards are given in Table 4.

From 2017, advice to manage sea lion interactions in this fishery has been developed in consultation with the Squid 6T Operational Plan Technical Advisory Group (SqOPTAG), including representatives from government and stakeholder groups as well as technical experts and advisors. Under the Operational Plan adopted in December 2017, Fisheries New Zealand set an FRML (Table 4) for sea lions in the Auckland Islands squid trawl fishery (SQU 6T) based on estimation of a Population Sustainability Threshold (PST) using a Bayesian population dynamic model (Roberts & Doonan 2016). The PST represents the maximum number of anthropogenic mortalities that the population can sustain while still achieving a defined population objective. For the Auckland Islands sea lion population, the choice of population objective underlying the current PST is as follows: "Fisheries mortalities will be limited to ensure that the impacted population is no more than 5% lower than it would otherwise be in the absence of fishing mortality, with 90% confidence, over five years".

The SQU 6T Operational Plan was updated in 2019 to reflect the outcomes of the new scientific approach whereby interactions, captures, and deaths (including cryptic mortality) are estimated directly and observed captures are applied toward the adopted FRML without the need for a proxy effort limit. This Operational Plan will remain in place until 30 September 2023. The Operational Plan defines a new FRML to reflect updated population model outputs, including sensitivities reflecting the likelihood that critical demographic rates for Auckland Islands sea lions are affected by decadal scale climatic variations (Roberts 2019, above). The plan also sets a minimum observer coverage requirement of 90%, to ensure that sea lion captures are recorded and Sea Lion Exclusion Devices (SLEDs) are properly deployed.

SLEDs were first used on some vessels in the SQU 6T fishing fleet in 2001–02. SLED use increased in subsequent years, and, from 2007–08, a single standardised and audited SLED design was in use across the entire SQU 6T fleet. Initially, Fisheries New Zealand adopted a management regime whereby the total number of allowable squid fishery tows was limited, based on proxy assumptions about how often sea lions might enter the net (the 'strike rate'), and what proportion of those sea lions would be expected to exit the net and survive (the ‘discount rate’). The rate at which sea lions might die as a consequence of their interaction with the fishing gear without being captured, termed ‘cryptic mortality’, was highly uncertain.

From 2019 a new science approach was adopted for Auckland Islands sea lions, whereby captures are estimated directly, applying the Spatially Explicit Fisheries Risk Assessment method (SEFRA; see Large et al 2019) and cryptic mortality is estimated separately (Meyer 2019). With this approach it is now possible to evaluate performance against the FRML using observed captures directly, without the need for an effort limit proxy based on an assumed strike rate and associated SLED discount rate. Instead, total captures are monitored by fisheries observers and compared against the FRML as the season progresses. Cryptic deaths are estimated as a proportion of observable deaths, effectively adjusting the capture limit lower to account for sea lions that may die without being counted by fisheries observers.

Table 4: Fisheries-related mortality limit (FRML) from 1991 to 2018 (♀ = females; numbers in parentheses are FRMLs modified in-season). Direct comparisons among years are not useful because the assumptions underlying the FRML changed over time.

Year	FRML	Discount rate	Management actions
1991–92	16 (♀)		
1992–93	63		
1993–94	63		
1994–95	69		
1995–96	73		Fishery closed by MFish (4 May)
1996–97	79		Fishery closed by MFish (28 Mar)
1997–98	63		Fishery closed by MFish (27 Mar)
1998–99	64		
1999–00	65		Fishery closed by MFish (8 Mar)
2000–01	75		Voluntary withdrawal by industry
2001–02	79		Fishery closed by MFish (13Apr)
2002–03	70		Fishery closed by MFish (29 Mar), overturned by High Court
2003–04	62 (124)	20%	Fishery closed by MFish (22 Mar), overturned by High Court
2004–05	115	20%	Voluntary withdrawal by industry on reaching the FRML
2005–06	97 (150)	20%	FRML increased in mid-March due to abundance of squid
2006–07	93	20%	
2007–08	81	35%	
2008–09	113 (95)	35%	Lower interim limit agreed following decrease in pup numbers
2009–10	76	35%	
2010–11	68	35%	
2011–12	68	35%	
2012–13	68	82%	
2013–14	68	82%	
2014–15	68	82%	
2015–16	68	82%	
2016–17	68	82%	
2017–18	38	75%	
2017–18	38	75%	
2019–20	52	N/A	New approach whereby deaths are estimated directly as a function of captures, eliminating the need for an effort limit and discount rate setting.

Observed captures (both sexes) and predicted total deaths (females only, but including cryptic mortality), as estimated by Large et al (2019) and Meyer (2019), are shown in Table 5. Squid fishery impacts on Auckland Islands sea lions are estimated to have been highest in the mid-1990s, when effort levels were high and no SLEDs were used. Since the adoption of a standardised SLED design in 2008–09, estimated fisheries deaths in the SQU 6T fishery have declined to much lower levels. Elsewhere, the SQU 1T fishery (on the Stewart-Snares shelf) is estimated to capture roughly one sea lion per year in recent years.

Table 5: New Zealand sea lion captures (both sexes) in the SQU 6T fishery from 1993–93 to 2018–19, shown separately for bottom trawl and midwater trawl gear configurations, and total deaths (females only) combined for both gear configurations (from Large et al 2019). The 2019–20 data were unavailable at the time of publication. Columns denote annual fishing effort (number of tows), observer coverage (percentage of tows observed), number of observed captures (including both live and dead captures), and estimated fisheries deaths with 95% confidence interval (females only) combining both the midwater and bottom trawl gear configurations, and includes cryptic mortality as estimated by Meyer (2019). Estimates are based on methods described by Large et al (2019. Observed and estimated protected species captures in this table derive from the PSC database version PSCV4. Combined fishery death estimates for 2017–18 and 2018–19 (denoted by –) have not yet been generated; however, very high observer coverage in these years makes statistical estimation unnecessary. * denotes years in which SLEDS were deployed on a variable proportion of squid target trawls, in the absence of a standard design or systematic inspection and audit programme. + denotes years in which SLEDs were deployed universally on all squid target trawls, with a standard design and a systematic inspection and audit programme.

Fishing	Bottom trawl configuration			Midwater trawl configuration			Estimated deaths (females only)	
year	All effort	% obs	Captures	All effort	% obs	Captures	Median	95% c.i.
1992–93	86	10	0	568	33	5	10	5–16
1993–94	0	–	3	3 226	7	1	82	61–108
1994–95	0	–	3	2 633	7	5	74	54–97
1995–96	721	0	0	3 747	15	13	83	62–108
1996–97	0	–	9	2 177	25	19	51	36–70
1997–98	242	19	4	1 219	24	11	28	18–39
1998–99	89	33	1	313	41	4	6	3–12
1999–00	455	15	1	751	50	24	19	12–28
2000–01	173	99	10	410	99	29	8	4–14
2001–02*	498	21	2	1 149	40	19	23	14–32
2002–03*	738	34	3	728	23	8	22	14–32
2003–04*	1 452	17	4	1 142	47	12	31	21–44
2004–05*	1 375	21	7	1 318	39	2	37	25–51
2005–06*	1 905	13	3	554	55	7	35	22–50
2006–07*	732	43	3	585	38	4	17	10–25
2007–08*	634	43	4	631	50	1	17	10–26
2008–09+	1 068	34	2	857	46	0	5	2–11
2009–10+	1 026	23	2	162	41	1	4	1–8
2010–11+	1 218	30	0	365	49	0	4	1–9
2011–12+	973	34	0	308	78	0	3	0–6
2012–13+	813	83	3	214	100	0	3	0–6
2013–14+	477	83	2	260	87	0	1	0–4
2014–15+	328	92	0	305	84	1	1	0–4
2015–16+	822	87	0	543	100	0	2	0–6
2016–17+	1 090	67	2	204	78	1	3	1–7
2017–18+	987	88	2	143	100	0	–	–
2018–19+	712	96	7	94	88	0	–	–

4.3.2 New Zealand fur seal captures

The New Zealand fur seal was classified in 2008 as ‘Least Concern’ by IUCN and in 2009 as ‘Not Threatened’ under the New Zealand Threat Classification System (Baker et al 2019).

Vessels targeting arrow squid incidentally catch fur seals (Baird & Smith 2007a, Smith & Baird 2009, Thompson & Abraham 2010b, Baird 2011, Abraham et al 2016), mostly off the east coast South Island, on the Stewart-Snares shelf, and near the Auckland Islands. In the 2017–18 year there were 14 observed captures of New Zealand fur seal in squid trawl fisheries. The capture rate over the period 2002–03 and 2017–18 varied from 0.08 to 1.12 captures per hundred tows without obvious trend (Table 6).

4.3.3 Seabird captures

Vessels targeting arrow squid incidentally catch seabirds. Baird (2005a) summarised observed seabird captures in the arrow squid target fishery for the fishing years 1998–99 to 2002–03 and calculated total seabird captures for the areas with adequate observer coverage using ratio-based estimations. Baird & Smith (2007b, 2008) summarised observed seabird captures and used both ratio-based and model-based predictions to estimate the total seabird captures for 2003–04, 2004–05, and 2005–06. Abraham & Thompson (2011) summarised captures of protected species and used model-based and ratio-based predictions of the total seabird captures for 1989–90 to 2008–09.

A consistent modelling framework was developed to estimate the captures for ten species (and species groups), using hierarchical, mixed-effects, generalised linear models (GLM), fitted using Bayesian methods (Abraham et al 2016, Abraham & Richard 2017, 2018).

Table 6: Number of tows (commercial and observed) by fishing year, observed and estimated New Zealand fur seal captures and capture rate in squid trawl fisheries, 2002–03 to 2019–20 (Abraham et al 2021). Estimates are available online at https://protectedspeciescaptures.nz/PSCv6/released/. Observed and estimated protected species captures in this table derive from the PSC database version PSCV6

	Fishing effort			Obs. captures		Est. captures		Est. capture rate	
Fishing year	**Tows**	**No. Obs**	**% obs**	**Captures**	**Rate**	**Mean**	**95% c.i.**	**Mean**	**95% c.i.**
2002–03	8 410	1 308	15.6	8	0.61	101	50–180	1.20	0.59–2.14
2003–04	8 336	1 771	21.2	16	0.90	142	79–243	1.71	0.95–2.92
2004–05	10 489	2 512	23.9	15	0.60	150	78–270	1.43	0.74–2.57
2005–06	8 576	1 103	12.9	4	0.36	109	48–206	1.27	0.56–2.40
2006–07	5 906	1 289	21.8	9	0.70	78	39–141	1.32	0.66–2.39
2007–08	4 236	1 459	34.4	6	0.41	35	16–71	0.83	0.38–1.68
2008–09	3 868	1 299	33.6	1	0.08	24	7–53	0.61	0.18–1.37
2009–10	3 789	1 071	28.3	8	0.75	66	32–126	1.75	0.84–3.33
2010–11	4 212	1 263	30.0	8	0.63	34	17–61	0.81	0.40–1.45
2011–12	3 506	1 382	39.4	8	0.58	35	18–65	1.00	0.51–1.85
2012–13	2 644	2 271	85.9	7	0.31	9	7–14	0.34	0.26–0.53
2013–14	2 051	1 789	87.2	10	0.56	11	10–14	0.54	0.49–0.68
2014–15	1 950	1 694	86.9	19	1.12	25	19–41	1.27	0.97–2.10
2015–16	2 896	2 363	81.6	10	0.42	19	11–37	0.65	0.38–1.28
2016–17	2 595	1 926	74.2	17	0.88	23	17–36	0.88	0.66–1.39
2017–18	2 824	2 515	89.1	14	0.56	23	14–49	0.83	0.50–1.73
2018–19	4 464	3 709	83.1	24	0.65				
2019–20	5 220	4 145	79.4	22	0.53				

Total estimated seabird captures in squid trawl fisheries varied from 244 to 1252 between 2002–03 and 2019–20 at a rate of 9 to 21.4 captures per hundred tows without obvious trend (Table 7). These estimates include all bird species and should be interpreted with caution because trends by species can be masked. The average capture rate in squid trawl fisheries since 2002–03 is about 12.2 birds per 100 tows, a high rate relative to trawl fisheries for scampi (4.43 birds per 100 tows) and hoki (2.32 birds per 100 tows) over the same years.

Table 7: Number of tows by fishing year and observed seabird captures in squid trawl fisheries, 2002–03 to 2019–20. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows. Estimates are based on methods described by Abraham & Richard (2020) and are available online at https://protectedspeciescaptures.nz/PSCv6/released/. Observed and estimated protected species captures in this table derive from the PSC database version PSCV6..

	Fishing effort			Obs. captures		Est. captures		Est. capture rate	
Fishing year	**Tows**	**No. Obs**	**% obs**	**Captures**	**Rate**	**Mean**	**95% c.i.**	**Mean**	**95% c.i.**
2002–03	8410	1308	15.6	155	11.85	840	651-1071	9.99	7.74-12.73
2003–04	8336	1771	21.2	194	10.95	842	677-1042	10.10	8.12-12.5
2004–05	10489	2512	23.9	351	13.97	1252	1052-	11.94	10.03-14.14
2005–06	8576	1103	12.9	198	17.95	1214	936-1547	14.16	10.91-18.04
2006–07	5906	1289	21.8	127	9.85	532	412-679	9.00	6.98-11.5
2007–08	4236	1459	34.4	166	11.38	435	349-540	10.27	8.24-12.75
2008–09	3868	1299	33.6	259	19.94	626	515-760	16.18	13.31-19.65
2009–10	3789	1071	28.3	92	8.59	365	279-476	9.64	7.36-12.56
2010–11	4212	1263	30.0	142	11.24	537	418-684	12.74	9.92-16.24
2011–12	3506	1382	39.4	105	7.60	326	256-414	9.31	7.3-11.81
2012–13	2644	2271	85.9	449	19.77	506	475-551	19.15	17.97-20.84
2013–14	2051	1789	87.2	209	11.68	244	222-278	11.90	10.82-13.55
2014–15	1950	1694	86.9	384	22.67	417	394-456	21.41	20.21-23.38
2015–16	2896	2363	81.6	302	12.78	343	319-380	11.84	11.02-13.12
2016–17	2595	1926	74.2	265	13.76	344	306-396	13.25	11.79-15.26
2017–18	2824	2515	89.1	256	10.18	282	264-311	9.98	9.35-11.01
2018–19	4464	3709	83.1	347	9.36	405	375-446	9.07	8.4-9.99
2019–20	5220	4145	79.4	391	9.43	480	442-529	9.20	8.47-10.13

The squid target fishery contributes to the total risk posed by New Zealand commercial fishing to seabirds. The two species to which the fishery poses the most risk are southern Buller's albatross and New Zealand white-capped albatross, with this target fishery posing 0.050 and 0.030 of PST, respectively (Table 8). Southern Buller's albatross was assessed at high risk and white-capped albatross at medium risk (Richard et al 2020).

Observed seabird captures since 2002–03 have been dominated by four species: white-capped and southern Buller's albatrosses make up 83% and 13% of the albatrosses captured, respectively; and white-chinned petrels and sooty shearwaters make up 56% and 41% of other birds, respectively (Table 9). Most captures occur on the Stewart-Snares shelf (63%) or close to the Auckland Islands (36%). These numbers should be regarded as only a general guide on the distribution of captures because observer coverage is not uniform across areas and may not be representative.

Table 8: Risk ratio of seabirds predicted by the level two risk assessment for the squid target trawl fishery and all fisheries (TOTAL) included in the level two risk assessment, 2006–07 to 2016–17, showing seabird species with a risk ratio of at least 0.001 of Population Sustainability Threshold, PST (from Richard et al 2020, where full details of the risk assessment approach can be found). The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the PST. The DOC threat classifications are shown (Robertson et al 2017 at http://www.doc.govt.nz/Documents/science-and-technical/nztcs19entire.pdf).

		Risk ratio			
Species name	**PST (mean)**	**Squid target trawl**	**TOTAL**	**Risk category**	**DOC Threat Classification**
Southern Buller's albatross	1 360	0.050	0.37	High	At Risk: Naturally Uncommon
New Zealand white-capped albatross	10 800	0.030	0.29	Medium	At Risk: Declining
White-chinned petrel	25 800	0.009	0.07	Low	At Risk: Declining
Salvin's albatross	3 460	0.002	0.65	High	Threatened: Nationally Critical
Northern royal albatross	723	0.001	0.05	Low	At Risk: Naturally Uncommon

Mitigation methods such as streamer (tori) lines, Brady bird bafflers, warp deflectors, and offal management are used in the squid trawl fishery. Warp mitigation was voluntarily introduced from about 2004 and made mandatory in April 2006 (Ministry of Fisheries 2006). The 2006 notice mandated that all trawlers over 28 m in length use a seabird scaring device while trawling (being "paired streamer lines", "bird baffler" or "warp deflector" as defined in the notice). During the 2005–06 fishing year a large trial of mitigation devices was conducted in the squid fishery (Middleton & Abraham 2007). Eighteen vessels were involved in the trial which used observations of seabird heavily contacting the trawl warps ('warp strikes') to quantify the effect of using three mitigation devices; paired streamer/tori lines, four boom bird bafflers, and warp scarers. Few warp strikes occurred in the absence of offal discharge. When offal was present the tori lines were most effective at reducing warp strikes. All mitigation devices were more effective for reducing large bird warp strikes than small bird strikes. There were, however, about as many bird strikes on the tori lines as the number of strikes on unmitigated warps. The effect of these strikes has not been assessed (Middleton & Abraham 2007).

Before warp mitigation was made mandatory (start of the 2005–06 fishing year) the warp capture rate of white-capped albatross (84% of albatross observed caught in this fishery) was higher than 3 per 100 tows in squid target trawls. Since 2006–07, the warp capture rate has decreased to below 1 per 100 tows. Capture rates from nets has fluctuated over this time period, and now make up the majority (Figure 2).

Table 9: Number of observed seabird captures in squid trawl fisheries, 2002–03 to 2016–17, by species and area. The risk category is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (from Richard et al 2020, where full details of the risk assessment approach can be found). It is not an estimate of the risk posed by trawl fishing for squid alone. – risk category not defined for grouped species.

	Risk category	Auckland Islands	Chatham Rise	East Coast South Island	Fiordland	Stewart-Snares shelf	Sub-Antarctic	Total
New Zealand white-capped albatross	High	399		3	11	525		938
Southern Buller's albatross	High	46			8	98		152
Salvin's albatross	High	1		4		17	1	23
Southern Royal albatross	Negligible					6		6
Campbell black-browed albatross	Low	1						1
Albatross spp.	–	4				1		5
Black-browed albatross	–	1						1
Buller's albatross	–				1			1
Royal albatross spp.	–					1		1
Total albatrosses		**452**	**0**	**7**	**20**	**648**	**1**	**1 128**
White-chinned petrel	Negligible	493				633	2	1 128
Sooty shearwater	Negligible	177		22	5	618		822
Antarctic prion	Negligible	34						34
Common diving petrel	Negligible	6				3		9
Cape petrel	Negligible				1	1		2
Fairy prion	Negligible	2						2
Black-bellied storm petrel	Negligible	1						1
Grey petrel	Negligible			1				1
New Zealand white-faced storm petrel	Negligible					1		1
White-headed petrel	Negligible	1						1
mid-sized petrels & shearwaters	–	8				1		9
Giant petrel spp.	–					7		7
Grey-backed storm petrel	–	3						3
Gadfly petrels	–	1						1
Prion spp.	–	1						1
Seabirds	–					1		1
Total other birds		**727**	**0**	**23**	**6**	**1 265**	**2**	**2 023**

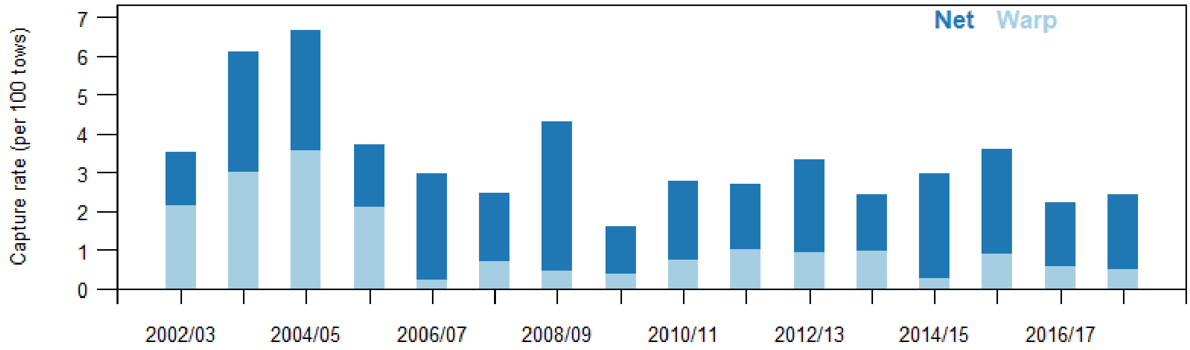


Figure 2: Capture rates of white-capped albatross in squid trawl fisheries for warp and net captures.

4.3.4 Protected fish species captures

Basking shark

The basking shark (*Cetorhinus maximus*) was classified as 'Endangered' by IUCN in 2013 and as 'Threatened – Nationally Vulnerable' in 2016, under the New Zealand Threat Classification System (Duffy et al 2018). Basking shark has been a protected species in New Zealand since 2010, under the Wildlife Act 1953, and is also listed in Appendix II of the CITES convention.

Basking sharks are incidentally caught in arrow squid trawls (Francis & Smith 2010). From 2010–11 to 2015–16, fishers reported catching 40 basking shark individuals (27 of which were reported by fisheries observers) in arrow squid fisheries. Little is known about the survival of released individuals, but it is assumed to be low. It is not known whether the low numbers of captures in recent decades are a result of different operational methods used by the fleet, a change in regional availability of sharks, or a decline in basking shark abundance (Francis 2017). Of a range of fisheries and environmental factors considered, vessel nationality stood out as a key factor in high catches in the late 1980s and early 1990s (Francis & Sutton 2012). Research to improve the understanding of the interactions between basking sharks and fisheries was reported by Francis & Sutton (2012) and updated by Francis (2017).

White pointer shark

The white pointer shark (*Carcharodon carcharias*, also known as great white shark) was classified as 'Vulnerable' by IUCN in 2019 and as 'Threatened – Nationally Endangered' in 2016, under the New Zealand Threat Classification System (Duffy et al 2018).

White sharks were protected in New Zealand waters in 2007, under the Wildlife Act 1953, but they are incidentally caught in commercial and recreational fisheries (Francis & Lyon 2012). Fishers reported catching a total of 20 white pointer shark individuals in arrow squid trawls since 2016, 3 of which were dead upon capture and the remainder were released alive. Little is known about the survival of released individuals, but it is assumed to be low.

4.4 Benthic interactions

The spatial extent of seabed contact by trawl fishing gear in New Zealand's EEZ and Territorial Sea has been estimated and mapped in numerous studies for trawl fisheries targeting deepwater species (Baird et al 2011, Black et al 2013, Black & Tilney 2015, Black & Tilney 2017, Baird & Wood 2018, and Baird & Mules 2019, 2021a, 2021b), species in waters shallower than 250 m (Baird et al. 2015, Baird & Mules 2021a, 2021b), and all trawl fisheries combined (Baird & Mules 2021a, 2021b). The most recent assessment of the deepwater trawl footprint was for the period 1989–90 to 2018–19 (Baird & Mules 2021b).

Numbers of bottom-contacting squid trawls used to generate the trawl footprint ranged from about 7000 to 10 000 tows during 1989–90 to 2005–06 and 2000–4000 during 2006–07 to 2018–19 (Baird & Mules 2021b). In total, about 183 000 bottom-contacting squid trawls were reported on TCEPRs, TCERs, and ERS for 1989–90 to 2018–19. The total footprint generated from these tows was estimated at about 41 850 km^2. This footprint represented coverage of 1.0% of the seafloor of the combined EEZ and the

Territorial Sea areas; 3.0% of the 'fishable area', that is, the seafloor area open to trawling, in depths of less than 1600 m. For the 2018–19 fishing year, 4280 squid bottom-contacting tows had an estimated footprint of 3925 km^2 which represented coverage of 0.1% of the EEZ and Territorial Sea and 0.3% of the fishable area (Baird & Mules 2021b).

The overall trawl footprint for squid (1989–90 to 2018–19) covered 9.7% of the seafloor in waters shallower than 200 m, 8.5% of 200–400 m seafloor, and 0.7% of the 400–1600 m seafloor (Baird & Mules 2021b). In 2018–19, the squid footprint contacted 1%, 1%, and < 0.1% of those depth ranges, respectively. The BOMEC areas with the highest proportion of area covered by the squid footprint were classes E (Stewart-Snares shelf), F (sub-Antarctic island shelves), I (Chatham Rise slope and shelf edge of the east coast South Island), and L (Southern Plateau waters). The 2018–19 arrow squid trawl footprint covered 2.5% of the 61 000 km^2 of class E, 2% of the 38 608 km^2 of class F, and 0.6% of the 52 224 km^2 of class I (Baird & Mules 2021b).

Bottom trawling for squid, like trawling for other species, is likely to have effects on benthic community structure and function (e.g., see Rice 2006 for an international review) and there may be consequences for benthic productivity (e.g., Jennings et al 2001, Hermsen et al 2003, Hiddink et al 2006, Reiss et al 2009). These are not considered in detail here but are discussed in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021).

4.5 Other considerations

A substantial decline in the west coast jig fishery for squid will have reduced any trophic implications of that fishery.

5. STOCK ASSESSMENT

Arrow squid live for one year, spawn once then die. Every squid fishing season is therefore based on what amounts to a new stock. It is not possible to calculate reliable yield estimates from historical catch and effort data for a resource which has not yet hatched, even when including data which are just one year old. Furthermore, because of the short life span and rapid growth of arrow squid, it is not possible to estimate the biomass prior to the fishing season. Moreover, the biomass increases rapidly during the season and then decreases to low levels as the animals spawn and die.

5.1 Estimates of fishery parameters and abundance

No estimates are available.

5.2 Biomass estimates

Biomass estimates are not available for squid.

5.3 Yield estimates and projections

It is not possible to estimate *MCY* and *CAY*.

5.4 Other yield estimates and stock assessment results

There are no other yield estimates of stock assessment results available for arrow squid.

5.5 Other factors

N. gouldi spawns one to two months before *N. sloanii*. This means that at any given time *N. gouldi* is older and larger than *N. sloanii*. The annual squid jigging fishery begins on *N. gouldii* and at some time during the season the biomass of *N. sloanii* will exceed that of *N. gouldi* and the fleet will move south. If *N. sloanii* are abundant the fleet will remain in the south fishing for *N. sloanii*. If *N. sloanii* are less abundant the fleet will return north and resume fishing *N. gouldi*.

6. STATUS OF THE STOCKS

No estimates of current and reference biomass are available. There is also no proven method at this time to estimate yields from the squid fishery before a fishing season begins based on biomass estimates or CPUE data.

Because squid live for about one year, spawn, and then die, and because the fishery is so variable, it is not practical to predict future stock size in advance of the fishing season. As a consequence, it is not possible to estimate a long-term sustainable yield for squid, nor determine if recent catch levels or the current TACC will allow the stock to move towards a size that will support the *MSY*. There will be some years in which economic or other factors will prevent the TACC from being fully taken, whereas in other years the TACC may be lower than the potential yield. It is not known whether New Zealand squid stocks have ever been stressed through fishing mortality.

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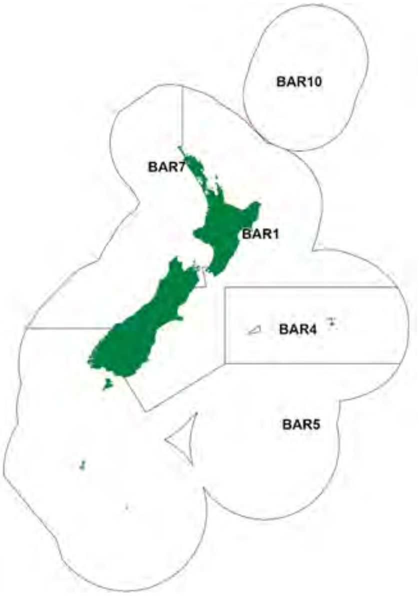
BARRACOUTA (BAR)

(*Thyrsites atun*)
Manga, maka



1. FISHERY SUMMARY

1.1 Commercial fisheries

Barracouta are caught in coastal waters around mainland New Zealand, Snares Islands, and Chatham Islands, down to about 400 m and have been managed under the Quota Management System since 1 October 1986. Historical catch summaries are given in Tables 1 and 2. Landings by New Zealand vessels increased significantly in the late 1960s and total annual landings peaked at about 47 000 t in 1977, with the addition of foreign vessels around New Zealand. Between 1983–84 and 2019–20, landings fluctuated between 18 000 and 30 000 t per annum (Table 3), at an average 25 000 t. Figure 1 shows the historical landings and TACC values for the main BAR stocks.

Table 1: Reported landings (t) for the main QMAs from 1931 to 1982.

Year	BAR 1	BAR 4	BAR 5	BAR 7	Year	BAR 1	BAR 4	BAR 5	BAR 7
1931–32	4	0	0	0	1957	163	0	20	80
1932–33	55	0	0	77	1958	146	0	15	78
1933–34	5	0	1	0	1959	139	0	18	71
1934–35	36	0	0	52	1960	117	0	13	90
1935–36	1	0	0	0	1961	187	0	22	68
1936–37	26	0	0	35	1962	104	0	25	44
1937–38	21	0	0	26	1963	63	0	4	20
1938–39	91	0	22	55	1964	66	0	4	21
1939–40	107	0	27	50	1965	111	0	1	76
1940–41	153	0	53	30	1966	62	0	1	116
1941–42	212	0	86	17	1967	53	0	1	178
1942–43	371	0	151	20	1968	10 113	0	3	1 196
1943–44	192	0	79	7	1969	8 499	0	2	5 756
1944	247	0	97	50	1970	12 984	0	2	3 960
1945	306	0	114	32	1971	11 327	0	191	4 006
1946	391	0	125	63	1972	29 307	2	86	3 487
1947	590	0	213	45	1973	14 856	0	79	4 698
1948	466	0	172	27	1974	23 420	0	106	9 028
1949	425	0	169	40	1975	8 985	0	855	6 257
1950	430	0	153	76	1976	19 124	5	495	6 795
1951	266	0	95	47	1977	6 981	9 095	2 041	33 266
1952	190	0	56	68	1978	6 833	17	1 162	6 918
1953	202	0	41	77	1979	6 474	4 057	3 380	5 263
1954	166	0	35	38	1980	5 649	1 854	7 867	5 146
1955	139	0	14	58	1981	6 993	2 030	8 311	11 141
1956	165	0	16	45	1982	5 393	787	6 909	7 064

Notes:

1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings. Data were aggregated to FMA using methods and assumptions described by Francis & Paul (2013).

Table 2: Reported landings (t) by nationality from 1977 to 1987–88.

Fishing	New Zealand		Foreign			Total	
Year	Domestic	Chartered	Japan	Korea	USSR	(FSU)	(QMS)
1977	4 697	0	34 357	8 109	0	47 163	-
1978–79	5 335	58	4 781	2 481	0	12 655	-
1979–80	7 748	6 679	4 339	3 879	47	22 922	-
1980–81	10 058	4 995	4 227	15	60	19 355	-
1981–82	12 055	11 077	2 813	373	0	26 328	-
1982–83	10 814	7 110	1 746	1 888	31	21 589	-
1983–83*	7 763	2 961	803	1 115	0	12 642	-
1983–84	12 390	10 226	1 786	4 355	0	28 757	-
1984–85	7 869	10 425	1 430	5 252	0	24 976	-
1985–86	8 427	7 865	1 371	815	0	18 478	-
1986–87	9 829	13 732	1 575	742	0	25 878	27 660†
1987–88	9 335	12 077	896	609	0	22 971	26 607†

* 6 month changeover in fishing years.

† The discrepancies between QMS and FSU total landings are due to under-reporting to the FSU.

Over 99% of the recorded catch is taken by trawlers. Major target fisheries have been developed on spring spawning aggregations (Chatham Islands, Stewart Island, west coast South Island, and northern and central east coast South Island) as well as on summer feeding aggregations, particularly around the Snares Islands and off the east coast of the South Island. Barracouta also comprise a significant proportion of the bycatch in the west coast North Island jack mackerel fishery, Stewart-Snares shelf squid fishery, and the east coast South Island red cod and tarakihi fisheries.

Landings in BAR 1 have been variable, but the lowest landing of the time series was recorded in 2018–19 (4209 t). The TACC in BAR 5 was increased to 8200 t in 2015–16, and landings have continued to fluctuate about the TACC. In BAR 7 the catch limit was exceeded in 2004–05 and 2006–07 (landings nearly reached 15 000 t in 2006–07), but landings have since decreased to well below the TACC, with the lowest landing reported in 2020–21 (3066 t).

Table 3: Reported landings (t) of barracouta by Fishstock from 1983–84 to present and actual TACCs (t) from 1986–87 to present. QMS data from 1986-present. [Continued on next page]

Fishstock	BAR 1		BAR 4		BAR 5		BAR 7	
FMAs	1, 2, 3		4		5 & 6		7, 8, 9	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	7 805	–	1 743	–	11 291	–	7 222	–
1984–85*	5 442	–	1 909	–	12 487	–	4 425	–
1985–86*	5 395	–	1 509	–	6 380	–	4 536	–
1986–87	8 877	8 510	3 084	3 010	7 653	9 010	8 046	10 510
1987–88	9 256	8 837	1 775	3 010	6 457	9 011	9 117	10 603
1988–89	5 838	9 426	946	3 010	5 323	9 011	8 071	10 702
1989–90	9 209	9 841	1 349	3 016	5 960	9 282	7 050	10 925
1990–91	9 401	9 957	1 399	3 016	8 817	9 282	7 138	10 925
1991–92	6 733	9 957	1 156	3 016	6 897	9 282	7 326	10 925
1992–93	9 032	9 969	2 251	3 016	7 019	9 282	10 141	10 925
1993–94	7 299	9 969	606	3 016	3 410	9 282	8 030	10 925
1994–95	10 023	9 969	331	3 016	2 645	9 282	9 345	10 925
1995–96	11 252	9 969	2 234	3 016	4 255	9 282	8 593	10 925
1996–97	11 873	11 000	1 081	3 016	2 839	9 282	10 203	10 925
1997–98	11 543	11 000	1 966	3 016	6 167	9 282	8 717	10 925
1998–99	9 229	11 000	459	3 016	7 302	7 470	4 427	10 925
1999–00	10 032	11 000	1 911	3 016	6 205	7 470	3 288	10 925
2000–01	7 118	11 000	2 122	3 016	6 101	7 470	6 890	10 925
2001–02	6 900	11 000	1 160	3 019	5 883	7 470	7 655	11 173
2002–03	7 595	11 000	573	3 019	7 843	7 470	9 025	11 173
2003–04	5 949	11 000	477	3 019	6 919	7 470	9 114	11 173
2004–05	6 085	11 000	98	3 019	8 593	7 470	12 156	11 173
2005–06	7 030	11 000	687	3 019	9 479	7 470	10 685	11 173
2006–07	5 351	11 000	3 233	3 019	6 334	7 470	14 698	11 173
2007–08	5 987	11 000	2 969	3 019	8 561	7 470	10 451	11 173
2008–09	8 861	11 000	968	3 019	7 659	7 470	8 955	11 173
2009–10	10 635	11 000	1 223	3 019	6 951	7 470	9 641	11 173
2010–11	11 420	11 000	1 190	3 019	8 199	7 470	6 128	11 173
2011–12	9 305	11 000	1 423	3 019	7 071	7 470	8 643	11 173
2012–13	9 740	11 000	706	3 019	7 931	7 470	6 897	11 173
2013–14	11 309	11 000	1 482	3 019	6 886	7 470	6 637	11 173
2014–15	6 902	11 000	3 671	3 019	6 779	7 470	6 974	11 173
2015–16	5 568	11 000	2 893	3 019	7 557	8 200	5 493	11 173
2016–17	9 520	11 000	2 606	3 019	8 916	8 200	7 127	11 173
2017–18	11 110	11 000	2 479	3 019	7 126	8 200	8 356	11 173
2018–19	4 209	11 000	2 016	3 019	8 141	8 200	4 053	11 173
2019–20	5 603	11 000	1 532	3 019	8 838	8 200	6 831	11 173
2020–21	8 918	11 000	775	3 019	8 638	8 200	3 066	11 173

Table 3: [Continued] Reported landings (t) of barracouta by Fishstock from 1983–84 to present and actual TACCs (t) from 1986–87 to present. QMS data from 1986-present.

Fishstock		BAR 10		
FMAs		10		Total
	Landings	TACC	Landings	TACC
1983–84*	0	–	28 061	–
1984–85*	0	–	24 263	–
1985–86*	0	–	17 820	–
1986–87	0	10	27 660	31 050
1987–88	0	10	26 605	31 471
1988–89	0	10	20 178	32 159
1989–90	0	10	23 568	33 073
1990–91	0	10	26 755	33 190
1991–92	0	10	22 212	33 190
1992–93	< 1	10	28 443	33 202
1993–94	0	10	19 345	33 202
1994–95	0	10	22 345	33 202
1995–96	0	10	26 334	33 202
1996–97	0	10	25 996	34 233
1997–98	0	10	28 393	34 233
1998–99	0	10	21 417	32 421
1999–00	0	10	21 436	32 421
2000–01	0	10	22 231	32 421
2001–02	0	10	21 598	32 672
2002–03	0	10	25 036	32 672
2003–04	0	10	22 459	32 672
2004–05	0	10	26 919	32 672
2005–06	0	10	27 881	32 672
2006–07	0	10	29 617	32 672
2007–08	0	10	27 968	32 672
2008–09	0	10	26 444	32 672
2009–10	0	10	28 451	32 672
2010–11	0	10	26 937	32 672
2011–12	0	10	26 442	32 672
2012–13	0	10	24 973	32 672
2013–14	0	10	26 313	32 672
2014–15	0	10	24 327	32 672
2015–16	0	10	21 511	33 402
2016–17	0	10	28 169	33 402
2017–18	0	10	29 071	33 402
2018–19	0	10	18 419	33 402
2019–20	0	10	22 804	33 402
2020–21	0	10	21 397	33 402

* FSU data.

1.2 Recreational fisheries

Barracouta are commonly encountered by recreational fishers in New Zealand, more frequently in the southern half of BAR 7 and BAR 1. Barracouta are typically harvested as bait for other fishing rather than for consumption. They are predominantly taken on rod and reel (97.9%) with a small proportion taken by net methods (1.7%). The catch is taken predominantly from fishers on boats (95.5%) with a small proportion from land based fishers (4.5%).

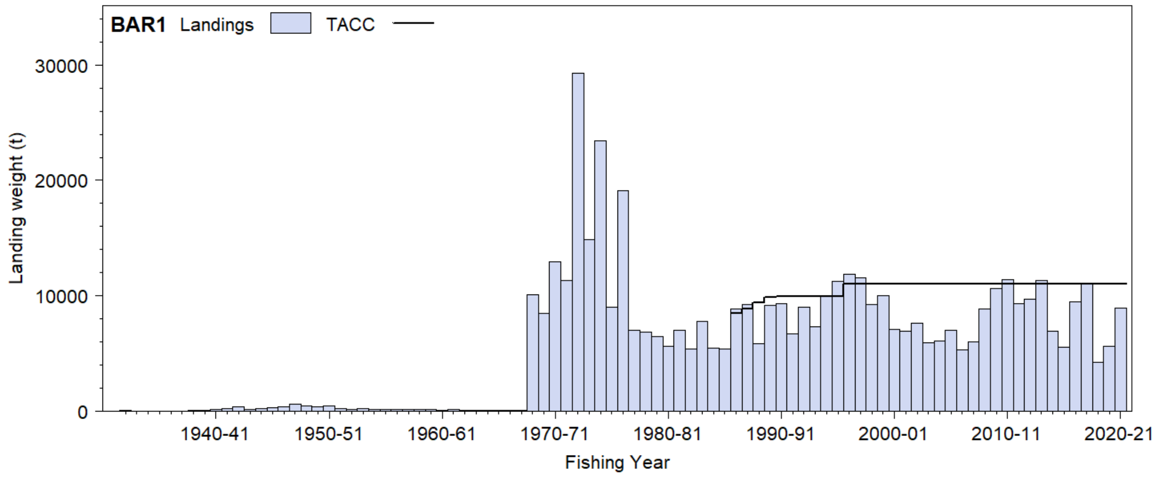


Figure 1:Reported commercial landings and TACC for the four main BAR stocks. BAR 1. [Continued on next page]

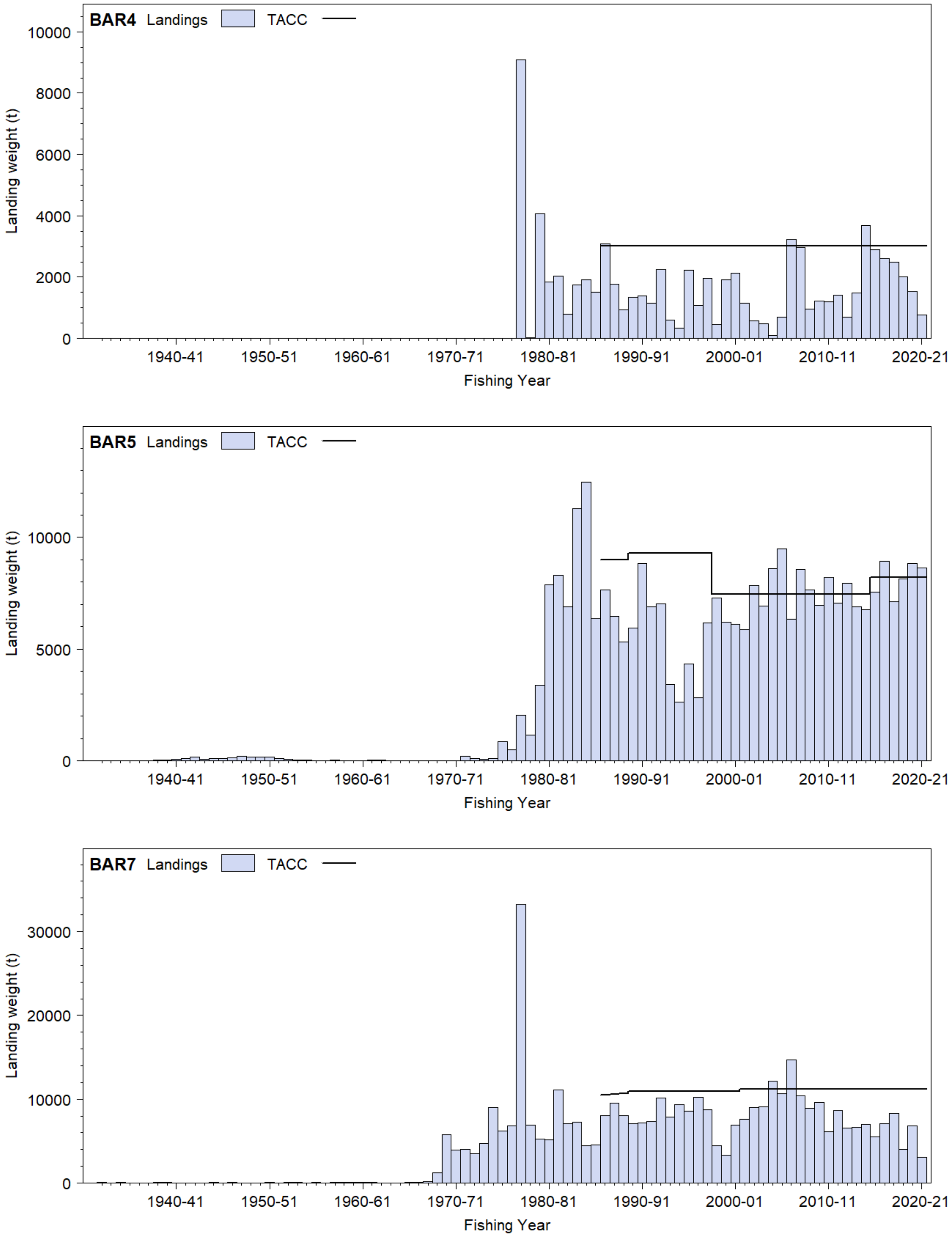


Figure 1: [Continued] Reported commercial landings and TACC for the four main BAR stocks. From top to bottom: BAR 4 (Chatham Rise), BAR 5 (Southland), and BAR 7 (Challenger).

1.2.1 Management controls

The main method used to manage recreational harvests of barracouta is daily bag limits. General spatial and method restrictions also apply. Fishers can take up to 30 barracouta as part of their combined daily bag limit in the Fiordland and Southland Fishery Management Areas. There is currently no bag limit in place in the other Fishery Management Areas.

1.2.2 Estimates of recreational harvest

There are two broad approaches to estimating recreational fisheries harvest: the use of onsite or access point methods where fishers are surveyed or counted at the point of fishing or access to their fishing activity; and offsite methods where some form of post-event interview and/or diary are used to collect data from fishers.

The first estimates of recreational harvest for barracouta were calculated using an offsite approach, the offsite regional telephone and diary survey approach. Estimates for 1996 came from a national telephone and diary survey (Bradford 1998). Another national telephone and diary survey was carried out in 2000 (Boyd & Reilly 2002). The harvest estimates provided by these telephone diary surveys (Table 4) are no longer considered reliable.

In response to the cost and scale challenges associated with onsite methods, in particular the difficulties in sampling other than trailer boat fisheries, offsite approaches to estimating recreational fisheries harvest have been revisited. This led to the development and implementation of a national panel survey for the 2011–12 fishing year (Wynne-Jones et al 2014). The panel survey used face-to-face interviews of a random sample of New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and catch information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 4. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

1.3 Customary non-commercial fisheries

Quantitative information on the current level of customary non-commercial take is not available.

1.4 Illegal catch

Quantitative information on the level of illegal catch is not available.

1.5 Other sources of mortality

There may have been considerable amounts of barracouta discarded prior to the QMS, either because of quota restrictions under the deepwater policy, low value, or undesirable small size fish. There is also likely to be some mortality associated with escapement from trawl nets. Some discarding may also have occurred in BAR 1 because of the lack of quota availability and the high deemed value in relation to the low value of the fish.

2. BIOLOGY

Barracouta spawn mainly in late-winter/spring (August–September) off the east coast of the North Island and west coasts of both the main islands, in late spring (October–December) off the east coast of the South Island and Southland, and in summer (December–February) on the Chatham Rise and around the Chatham Islands (Ballara & Holmes 2020). Sexual maturity is reached at about 50–60 cm fork length (FL) at about 2–3 years of age.

Juvenile barracouta have been recorded from inshore areas (less than 100 m depths) all around New Zealand and the Chatham Islands, although they appear to be less common off the west coast of the South Island. Adult fish are found down to about 400 m depth. Tagging experiments indicated that mature fish from the east coast South Island waters migrate after June to northern waters off the east coast North Island to spawn during August–September; research survey results and commercial fishing patterns show some consistency with this movement (see Hurst et al 2012).

Table 4: Recreational harvest estimates for barracouta stocks. Early surveys were carried out in different years in the regions: South in 1991–92, Central in 1992–93, and North in 1993–94 (Teirney et al 1997). The estimated Fishstock harvest is indicative in these surveys and made by combining estimates from the different years. Some early survey harvests are presented as a range to reflect the considerable uncertainty in the estimates. The telephone/diary surveys ran from December to November but are denoted by the January calendar year. The national panel surveys ran throughout the October to September fishing year but are denoted by the January calendar year. Mean weights of 2.14 kg and 2.40 kg were used for the 2011–12 and 2017–18 national panel surveys respectively.

Fishstock	Year	Survey	Number	CV	Total Survey harvest (t)
BAR 1	1992	South	27 000	47%	30–90
BAR 7	1992	South	2 100	44%	–
BAR 1	1993	Central	17 000	22%	25–35
BAR 7	1993	Central	15 600	24%	25–35
BAR 1	1996	National	68 000	8%	160–190
BAR 7	1996	National	74 000	15%	160–220
BAR 1	2000	National	156 000	35%	182 –377
BAR 5	2000	National	2 000	51%	2–7
BAR 7	2000	National	35 000	28%	68–120
BAR 1	2012	Panel survey	22 244	27%	47.7
BAR 5	2012	Panel survey	666	51%	1.4
BAR 7	2012	Panel survey	16 743	23%	35.9
BAR 1	2018	Panel survey	11 845	22%	28.4
BAR 5	2018	Panel survey	648	61%	1.6
BAR 7	2018	Panel survey	6 088	21%	14.6

No age data are available for the period prior to the onset of commercial fishing, which developed rapidly from 1968. Ageing studies carried out in the mid-1970s showed that the maximum age rarely exceeded 10 years.

M was estimated using the equation $M = \log_e 100$/maximum age, where maximum age is the age to which 1% of the population survives in an unexploited stock. Using 10 years for the maximum age suggests an M of up to 0.46. The effect of fishing on age structure prior to the mid-1970s is unknown, but M is unlikely to be less than 0.3, which has been assumed in previous stock assessments.

Biological parameters relevant to the stock assessment are shown in Table 5.

Table 5: Estimates of biological parameters.

Fishstock	**Estimate**	**Source**
1. Natural mortality (M)		Hurst (unpub. data)
All-both sexes	Less than 0.46 M = 0.30 considered best estimate for all areas for both sexes	

2. Weight = a(length)^b (Weight in g, length in cm fork length).

	Females		Males		
	a	b	a	b	
BAR 4	0.0074	2.94	0.0117	2.82	Hurst & Bagley (1992)
BAR 5	0.0075	2090	0.0075	2.90	Hurst & Bagley (1992)

3. von Bertalanffy growth parameters

	Both sexes				
	K	t_0	L_∞		Grant et al (1978)
Tasmania	0.45	0.166	91.17	(unconstrained)	
	0.42	-0.25	91.01	(constrained, t_0 fixed)	
Southland	0.336	-0.35	81.1	Male	Horn (2002)
	0.259	-0.60	89.3	Female	Horn (2002)

3. STOCKS AND AREAS

There are thought to be at least four main stocks, based on known spawning locations and movements. Stock boundaries are not well understood, but the Chatham Islands stock is probably separate. There may be some overlap between mainland stock management areas as currently defined from analysis of tagging data, commercial fishery data, biological data (i.e., length frequencies, otoliths, parasites, spawning areas, and seasons) and from seasonal relative biomass estimates. In particular, it appears that there is considerable overlap of Southland fish with other areas, probably the west coast of the South Island and possibly the east coast as well.

Spatial temporal changes in barracouta size, sex ratio, and spawning supported earlier hypotheses on population boundaries (Devine et al 2022). The barracouta around the Chatham Islands do not appear to be connected to the populations around the main islands, whereas fish on the western Chatham Rise are clearly connected to barracouta along the east coast of the South Island. Barracouta off Southland appear to be connected to fish off both the east and west coast of the South Island, and fish off the west coasts of both islands are not likely to be separate stocks (Devine et al 2022, Langley & Bentley 2002).

4. STOCK ASSESSMENT

There are no stock assessments available for any barracouta stocks and TACCs have remained constant in all stocks since 2001–02. Hurst et al (2012) provided a comprehensive characterisation of all barracouta stocks and provided CPUE indices for BAR 1 (east coast South Island), BAR 7 (west coast South Island), and BAR 5 for 1989–90 to 2007–08. McGregor (2020) characterised the fisheries and estimated CPUE indices for the WCNI and WCSI (BAR 7) fisheries and the southern Snares fishery (BAR 5). Baird (2016) provided indices for 1989–90 to 2013–14 for the ECNI and ECSI parts of BAR 1. Marsh & McGregor (2021) updated CPUE indices for BAR 5 to 2015. Ballara & Holmes (2020) updated the characterisation and CPUE indices from 1989–90 to 2017–18 for WCSI and WCNI (BAR 7) and developed a CPUE index for the ‘Chatham East’ area of BAR 4; no index for ‘Chatham Rise West’ was possible because effort was too sporadic.

4.1 BAR 1 Auckland (E), Central (E), South-East (Coast)

4.1.1 Estimates of fishery parameters and abundance

The results from trawl surveys carried out during the mid 1980s (sometimes from a variety of different vessels) were used to provide an approximate estimate of minimum absolute biomass. This approach required an assumption about catchability to convert the trawl survey catches to estimates of absolute biomass. This method is now considered obsolete and the estimates of absolute biomass have not been included.

4.1.2 Biomass estimates

There is no trawl survey series for BAR 1 off the east coast of the North Island. The trawl survey information discussed below is for the east coast of the South Island.

The ECSI winter surveys from 1991 to 1996 in 30–400 m were replaced by summer trawl surveys (1996–97 to 2000–01) which also included the 10–30 m depth range, but these were discontinued after the fifth in the annual time series because of the extreme fluctuations in catchability between surveys (Francis et al 2001). The winter surveys were reinstated in 2007 and this time included additional 10–30 m strata in an attempt to index elephant fish and red gurnard which were added to the list of target species. Only the 2007, 2012, 2014, 2016, and 2018 surveys provide full coverage of the 10–30 m depth range.

The 2014 barracouta biomass estimate was the highest recorded in the east coast South Island winter trawl survey time series core strata (30–400 m). Biomass in the east coast South Island winter trawl survey time series core strata steadily increased until 2014 when it was more than four-fold larger than the average biomass of the early 1990s, before a 57% decline in 2016 (Figure 2, Table 6). Biomass increased for the most recent (2018) survey and is close to the time series mean of 22 176 t. Biomass in the 10–30 m depth range accounted for 6% of the total biomass (core plus shallow, 10–400 m) but has at times accounted for up to 15% of the total biomass, indicating that shallow strata should continue to be monitored for this species.

A comparison of the pre-recruit and recruited biomass (where recruited fish are over 60 cm FL) for the ECSI winter survey, based on the core strata, is shown in Figure 3. During the 1991–93 surveys, the pre-recruit and recruited estimates were similar, but in 1994 and 1996 most of the total biomass was from recruited fish. For the renewed series, from 2007, the main increase has come from the recruited fish, with significantly higher biomass for recruited fish compared with pre-recruits in the 2009 and 2012 surveys. The 2014 survey indicated an increase in the pre-recruit biomass, although the uncertainty around this estimate is high, and in 2016 both recruited and pre-recruited biomass declined substantially. In 2018 both recruited and precrecruited fish have increased in abundance, with recruited fish accounting for most of the total biomass (MacGibbon et al 2019).

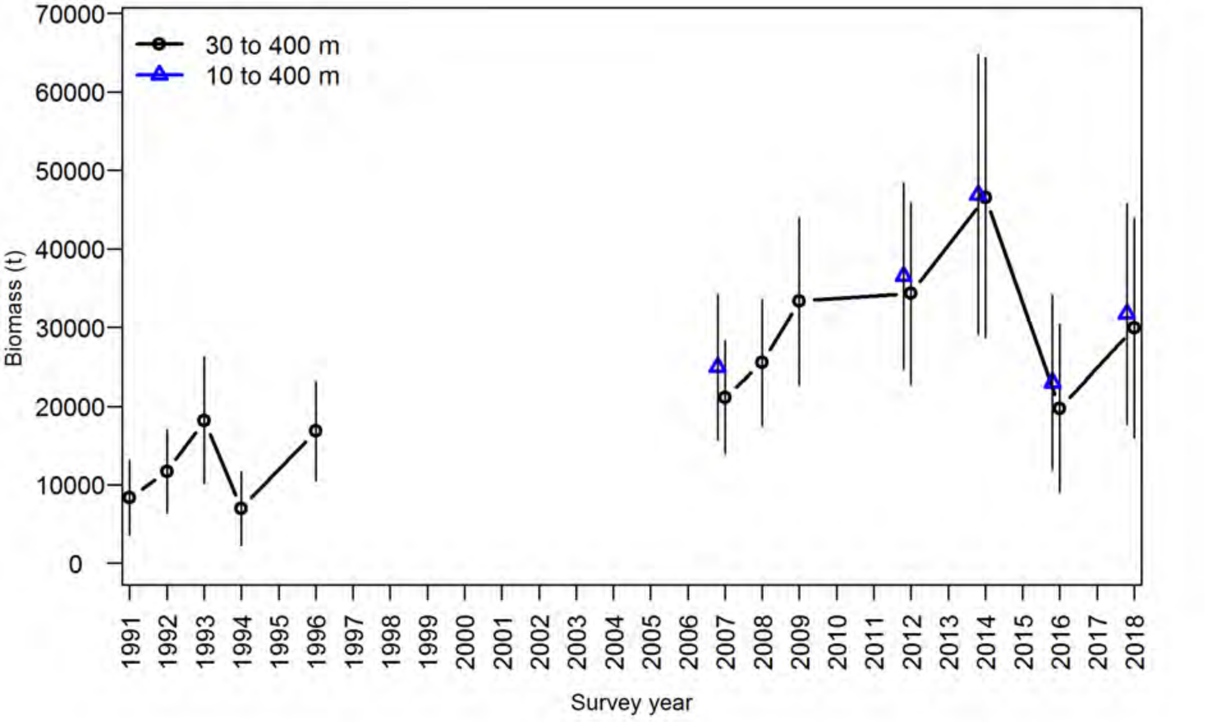


Figure 2: Barracouta total biomass and 95% confidence intervals for the all ECSI winter surveys in core strata (30–400 m) and core plus shallow strata (10–400 m) in 2007, 2012, 2014, 2016, and 2018.

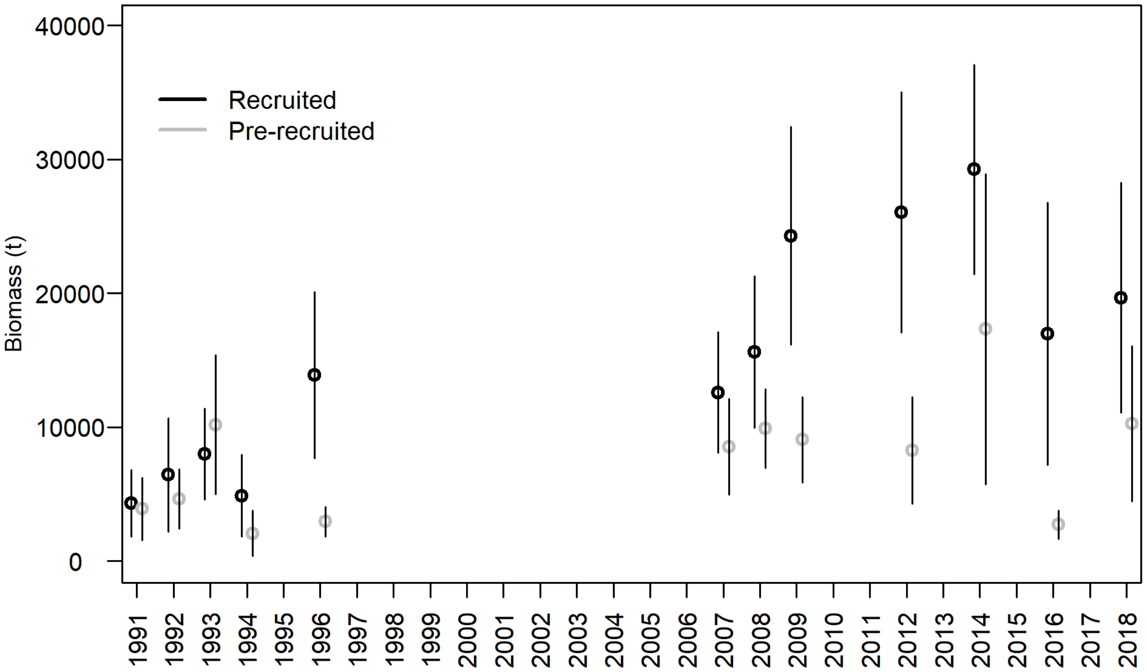


Figure 3: Barracouta pre-recruit and recruited biomass estimates and associated confidence intervals from the ECSI winter trawl survey core strata (30–400 m). Recruited fish were defined as fish over 60 cm fork length.

Table 6: Relative biomass indices (t) and coefficients of variation (CV) for barracouta for east coast South Island (ECSI) in winter, east coast North Island (ECNI), west coast South Island (WCSI), and Southland survey areas. Biomass estimates for ECSI in 1991 have been adjusted to allow for non-sampled strata (7 & 9 equivalent to current survey strata 13, 16, and 17) (see MacGibbon et al 2019). – , not measured; NA, not applicable.

Region	Fishstock	Year	Trip number	Total Biomass estimate	CV (%)	Total Biomass estimate	CV (%)
				30–400 m		10–400 m	
ECSI (winter)	BAR 1	1991	KAH9105	8 361	29	–	–
		1992	KAH9205	11 672	23	–	–
		1993	KAH9306	18 197	22	–	–
		1994	KAH9406	6 965	34	–	–
		1996	KAH9608	16 848	19	–	–
		2007	KAH0705	21 132	17	24 939	19
		2008	KAH0806	25 544	16	–	–
		2009	KAH0905	33 360	16	–	–
		2012	KAH1207	34 325	17	36 526	16
		2014	KAH1402	46 563	19	46 903	19
		2016	KAH1605	19 708	27	23 007	24
		2018	KAH1803	29 917	23	31 723	22
ECNI	BAR 1	1993	KAH9304	2 673	15	–	–
		1994	KAH9402	8 433	33	–	–
		1995	KAH9502	2 103	29	–	–
		1996	KAH9602	2 495	23	–	–
WCSI	BAR 7	1992	KAH9203	2 478	14	–	–
		1994	KAH9404	5 298	16	–	–
		1995	KAH9504	4 480	13	–	–
		1997	KAH9701	2 993	19	–	–
		2000	KAH0004	1 787	11	–	–
		2003	KAH0304	4 485	20	–	–
		2005	KAH0503	2 763	13	–	–
		2013	KAH1305	3 423	16	–	–
		2015	KAH1503	2 662	21	–	–
		2017	KAH1703	4 153	30	–	–
		2019	KAH1902	2 568	15	–	–
Southland	BAR 5	1993	TAN9301	11 587	18	–	–
		1994	TAN9402	6 151	20	–	–
		1995	TAN9502	4 539	17	–	–
		1996	TAN9604	7 693	19	–	–

4.1.3 Length frequency distributions

The length distributions from the east coast South Island winter trawl survey show at least three clear pre-recruit modes at about 20 cm, 35 cm, and 50 cm (combined males, females, and unsexed) consistent with ages of 0+, 1+, and 2+ (Figure 4). Length frequency distributions are consistent among the surveys, showing the presence of the pre-recruited cohorts, with indications that these could be tracked through time (modal progression) (Beentjes et al 2015, 2016). The addition of the 10–30 m depth range does not change the shape of the length distributions (not shown in Figure 4). The 0+ mode in 2018 is the strongest in the time series (Figure 4).

4.1.4 CPUE indices

Two sets of standardised CPUE indices were derived for BAR 1: one for the northern waters off the east coast of the North Island (ECNI) and one for the east coast South Island, ECSI (Baird 2016). Each set had three CPUE series defined by form type: a merged CELR/TCER day-level model for 1989–90 to 2013–14; a TCER tow-level model for 2007–08 to 2013–14; and a TCEPR tow-level model for 1989–90 to 2013–14. All ECNI series were rejected by the Working Group because of shifts in targeting through time, high inter-annual variability, and unacceptably low levels of data. Thus, the following sections on CPUE pertain to the ECSI waters only.

Three standardised CPUE series for the east coast South Island part of BAR 1 were prepared, as outlined above, using data from 1989–90 to 2013–14, with each series based on the catch of barracouta in bottom trawl fisheries defined by different target species, including barracouta (Baird 2016). Two CPUE series were rejected by the Southern Inshore (SINS) Working Group: the CPUE index based on the TCEPR data (targeting barracouta, red cod, and arrow squid), primarily because of inter-annual inconsistencies in the underlying catch and effort data; and the short TCER series with only seven years of data.

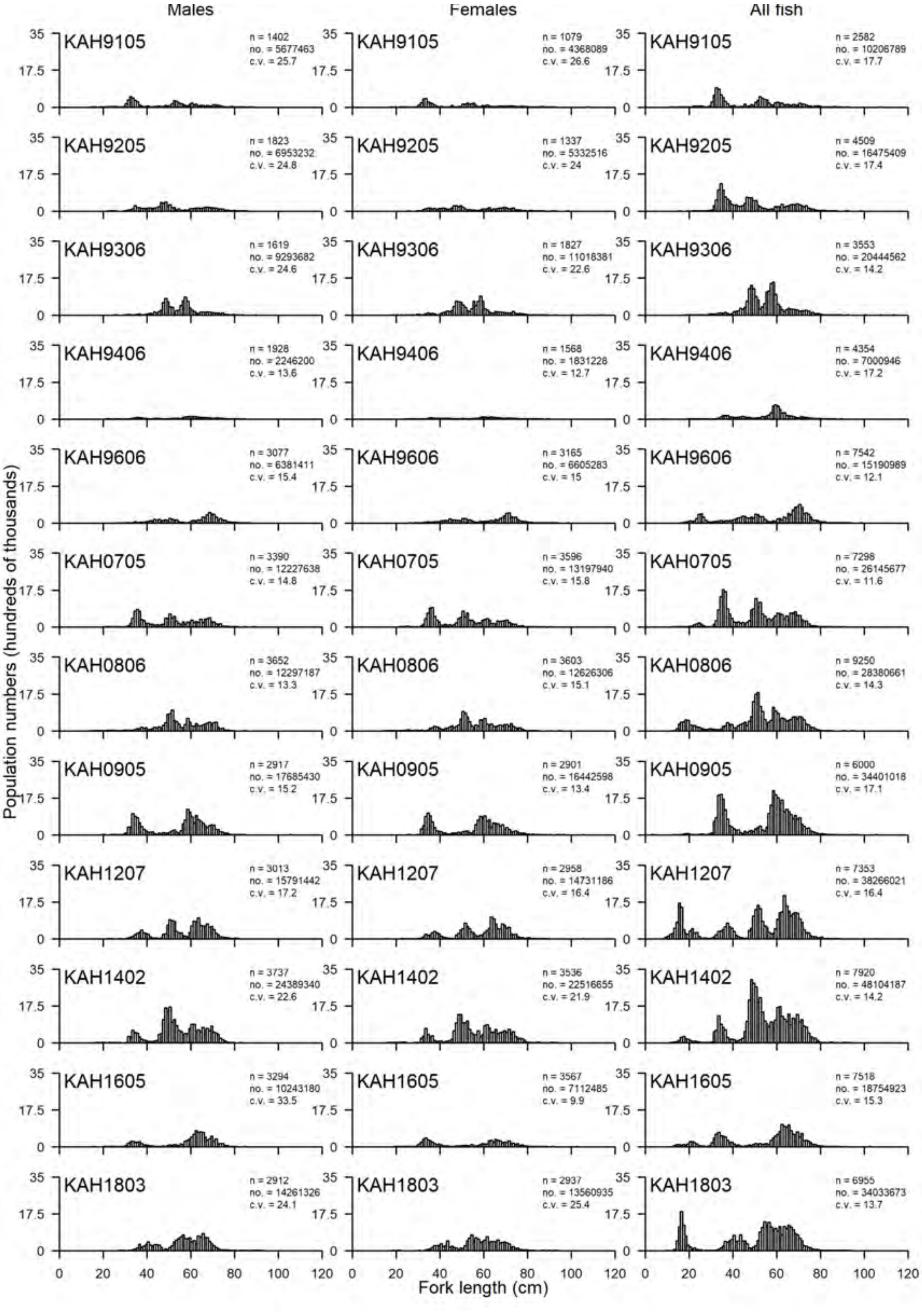


Figure 4:Scaled length frequency distributions for barracouta in core strata (30–400 m) for the ECSI winter surveys. n, number of fish measured; no., core strata population estimates; c.v., coefficient of variation.

The SINS Working Group accepted the combined index (delta lognormal model) series based on the 1989–90 to 2013–14 daily data from CELR and TCER forms (bottom trawls targeting barracouta, red cod, and tarakihi) as an index of abundance for BAR 1. This series has been updated to include data up to 2017 and combines the daily data from CELR, TCER, and TCEPR forms from vessels < 28 m

(Figure 5). After a peak period during 1996–97 and 1997–98, there was a period of relatively lower CPUE from 1998–99 to 2008–09, followed by an increase up to 2012–13, to a level similar to the earlier peak. In the following two years, the indices dropped to about the series mean. Subsequently, there was an increase and in 2016–17 the index was similar to that seen in 2013–14. The TCER tow-level CPUE series, for which additional explanatory variables were incorporated into the model, was similar to the CELR/TCER/TCEPR day-level series for the overlapping period (2007–08 to 2016–17). Figure 6 provides a comparison of the ECSI indices with the ECSI winter trawl survey indices. The increase in abundance measured by the trawl survey for 2007 onwards follows a similar trajectory to that for the ECSI CELR/TCER/TCEPR indices.

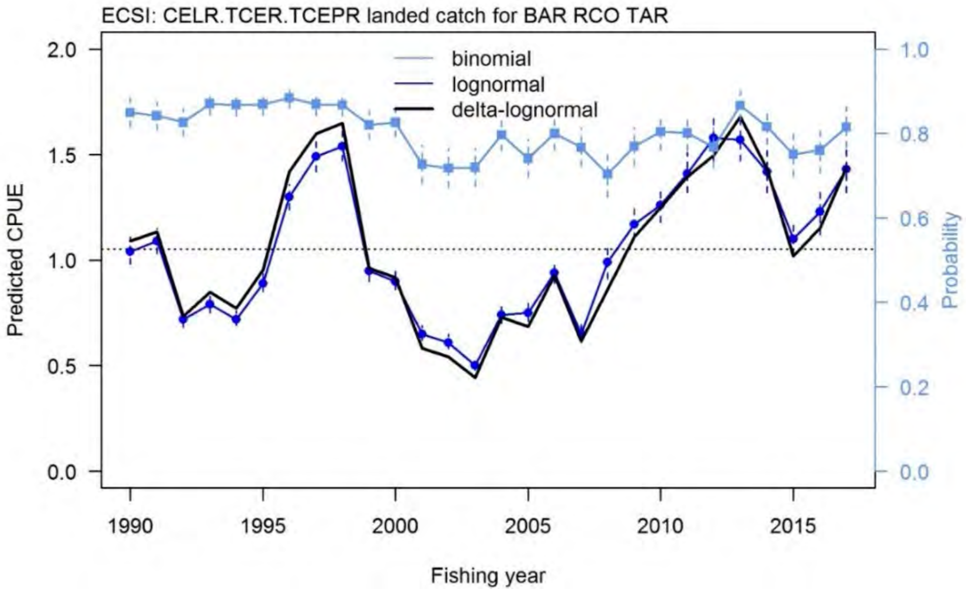


Figure 5: East coast South Island part of BAR 1 CPUE indices from the standardised lognormal, binomial, and the combined (delta lognormal) models, based on the merged day-level CELR, TCER, and small vessel (< 28m) TCEPR data for 1989–90 to 2016–17.

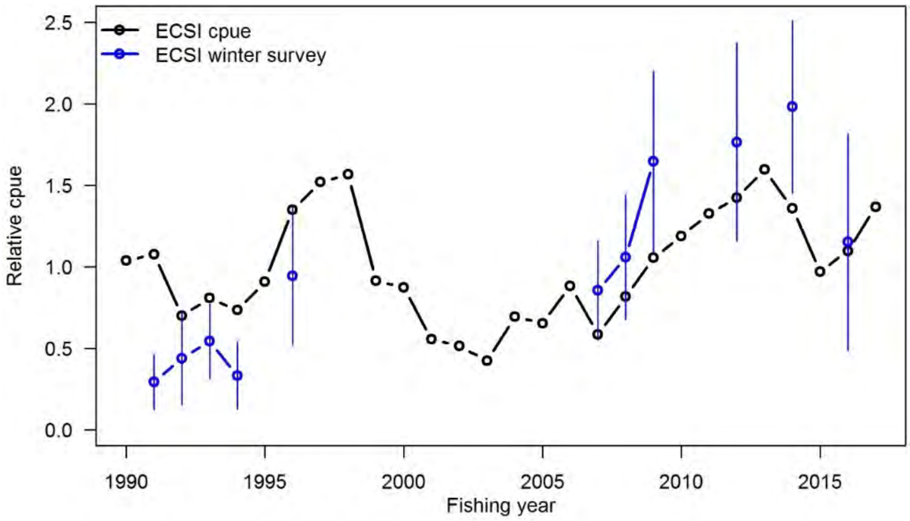


Figure 6: Comparison of the BAR 1 ECSI delta-lognormal CPUE series for 1990–2017 and the recruited biomass (and associated variance) from the ECSI winter trawl survey series from 1991–2016. The recruited biomass is based on fish over 60 cm fork length. Each series has been standardised to the mean for concurrent years.

Future research considerations

Review of the ECSI trawl survey for monitoring abundance of barracouta off the east coast of the South Island. This review should included an investigation of the timing of the survey in relation to a possible seasonal northward migration of barracouta off the east coast of the South Island.

4.2 BAR 4 Chatham Rise

Data available from fisheries on the Chatham Rise showed a clear separation of catches between the east and west, allowing a clearly defined split of the catches (see Ballara & Holmes 2020). A delta lognormal standardised CPUE index was derived for BAR 4 for the Chatham Rise East fishery, based on TCEPR and ERS-trawl tow-level data, restricted to the four statitistical areas immediately surrounding the Chatham Islands where barracouta are fished (Figure 7). The data included catches from bottom and midwater trawls and were not restricted based on target species. The CPUE series shows a slight increase until 2010, although the series is highly variable, with a slight decline in recent years. A fisheries-independent abundance index derived from the eastern strata of the *Tangaroa* Chatham Rise trawl survey is very noisy (Figure 8). Barracouta are a schooling species that are often found at depths shallower than the survey operates (200 m), which means that the bottom trawl survey does not adequately capture trends in abundance for this species. Therefore, it is not possible to make a meaningful comparison between the two series.

The Chatham Rise West is considered to be part of the BAR 1 Fishstock (Devine et al 2022). Creating an index for the Western Chatham Rise stock in BAR 4 was not considered appropriate without including data from the ECSI.

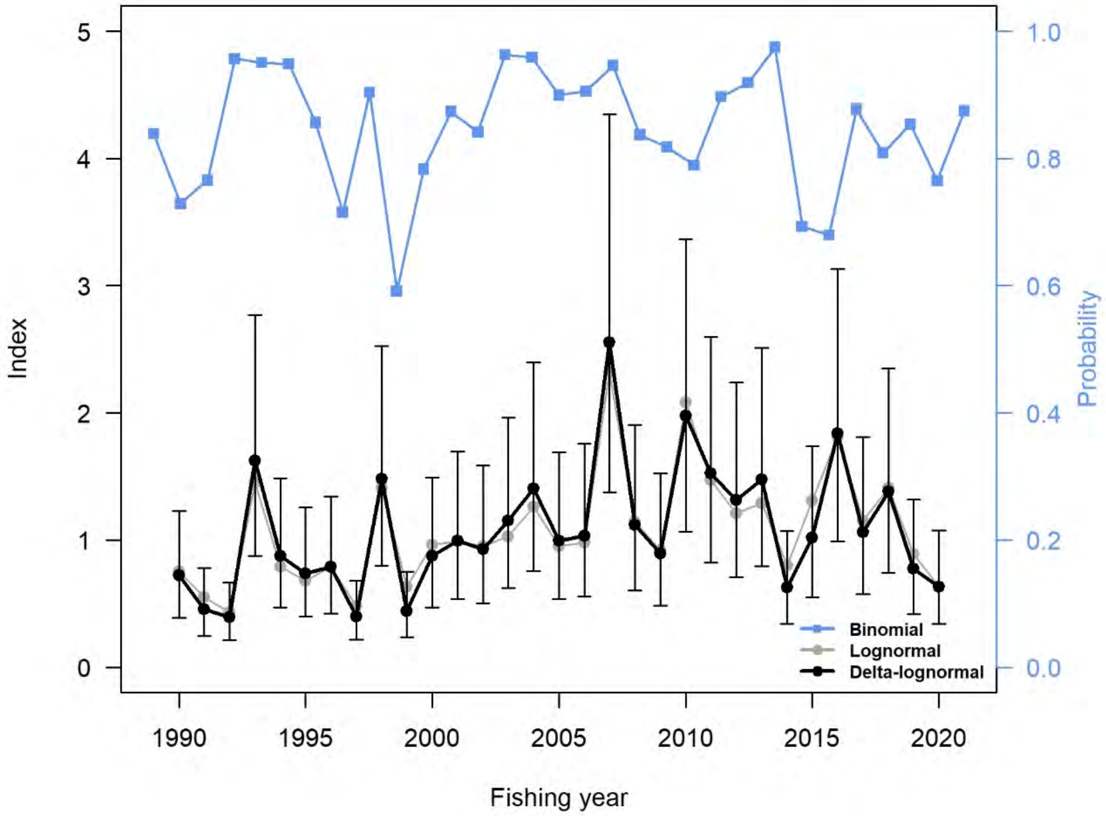


Figure 7: East Chatham Rise BAR 4 CPUE indices from the standardised lognormal (grey), binomial (blue), and the combined (delta lognormal) models with 95% confidence interval (black), based on the tow-by-tow TCEPR and ERS-trawl data for 1989–90 to 2019–20.

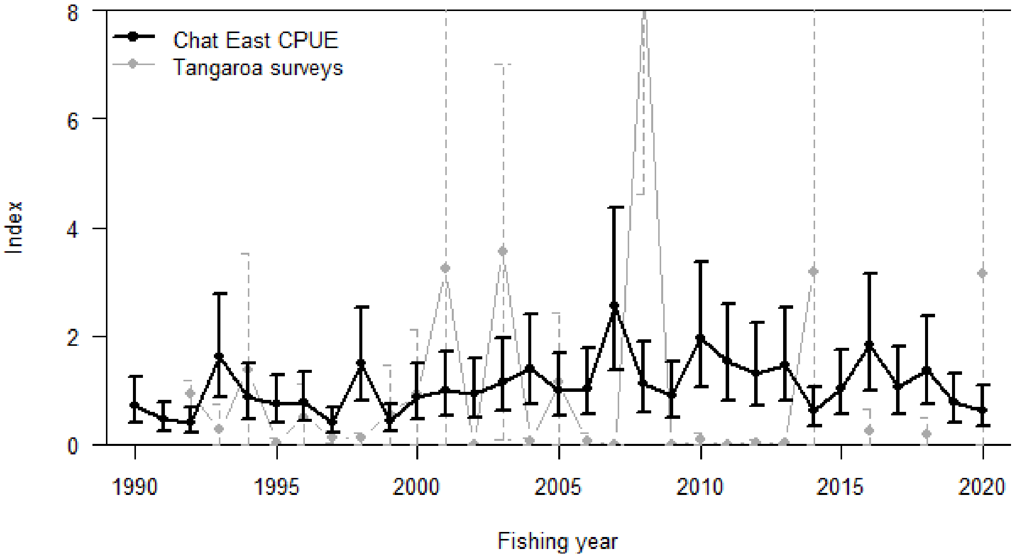


Figure 8:Comparison of Chatham Rise East CPUE standardised delta lognormal index (scaled to mean 1) and the *Tangaroa* survey index for the Chatham Rise East area. The fishing year is from October to September; 1990 is 1989–90 fishing year.

4.3 BAR 5 Southland, Sub-Antarctic

4.3.1 CPUE indices

A delta lognormal CPUE index for barracouta was created based on the squid target, tow-by-tow, TCEPR and ERS-trawl data (Devine et al 2022). Unlike the previous analysis (Marsh & McGregor 2021), data were not restricted to Statistical Area 028, but included from surrounding statistical areas, around the Auckland Islands group, and to the west of Stewart Island (Stewart-Snares shelf). The area for the analysis was expanded because, though barracouta are attracted to and prey upon squid in the directed fishery operating in Statistical Area 028, they are distributed throughout the Southland area. The index is variable, with several spikes (e.g., 1996, 2001), but has shown a general increase since 2007 (Figure 9). CPUE indices may be affected by fisher avoidance behaviour so as not to exceed ACE holdings.

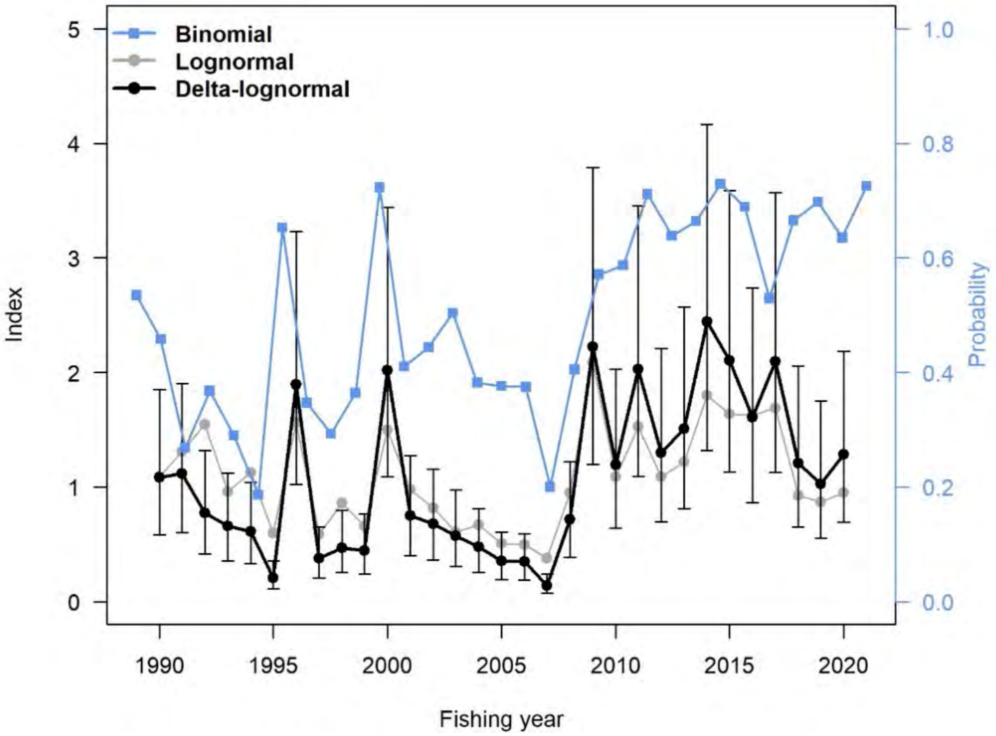


Figure 9:BAR 5 CPUE indices from the standardised lognormal (grey), binomial (blue), and the combined (delta lognormal) with 95% confidence interval (black), based on the tow-by-tow TCEPR and ERS-trawl data for 1989–90 to 2019–20.

Trawl surveys were carried out in the Southland area (QMA 5) in February–March from 1993 to 1996 and the Sub-Antarctic (deeper than 300 m) in November–December from 1991 to 1993 and then again from 2000 using *Tangaroa* (Table 6). The February–March series may have been able to provide additional information, had it not been discontinued, but the current survey does not adequately survey barracouta, most likely due to the depth of operation (300 m) and behavioral characteristics of barracouta (Figure 10). Trawl surveys off the east and west coasts of the South Island in autumn using *Kaharoa* may help interpret trends in biomass around the South Island because there are linkages in biological properties between fish off Southland and both coasts of the South Island (Devine et al 2022).

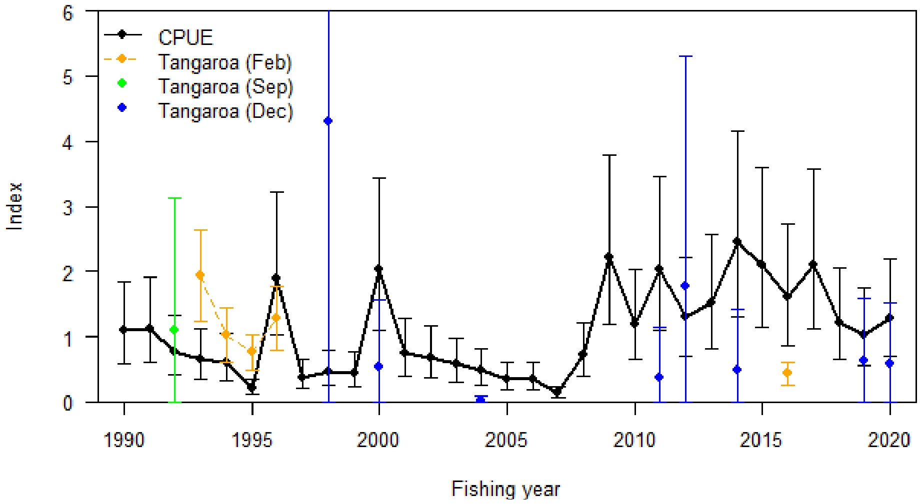


Figure 10: Comparison of BAR 5 CPUE standardised delta lognormal index (scaled to mean 1) and the *Tangaroa* surveys in the area. *Tangaroa* November–December surveys in 1991–1993 did not record any barracouta and were not included in the figure. The fishing year is from October to September; 1990 is 1989–90 fishing year.

4.4 BAR 7 Challenger, Central (W), Auckland (W)

4.4.1 Survey indices

Barracouta are a common catch of the west coast South Island (WCSI) inshore trawl surveys, with most tows containing barracouta. The biomass has varied almost three-fold during the time series but has not shown any consistent trend (Figure 11). More biomass has always come from the west coast strata compared with Tasman Bay and Golden Bay. Stevenson (2007) reviewed the WCSI time series up to 2007 and believed that the survey likely monitors juvenile and adult abundance of barracouta. The survey covers almost all of the species depth range, CVs are relatively precise, and biomass and length frequencies are reasonably consistent across years.

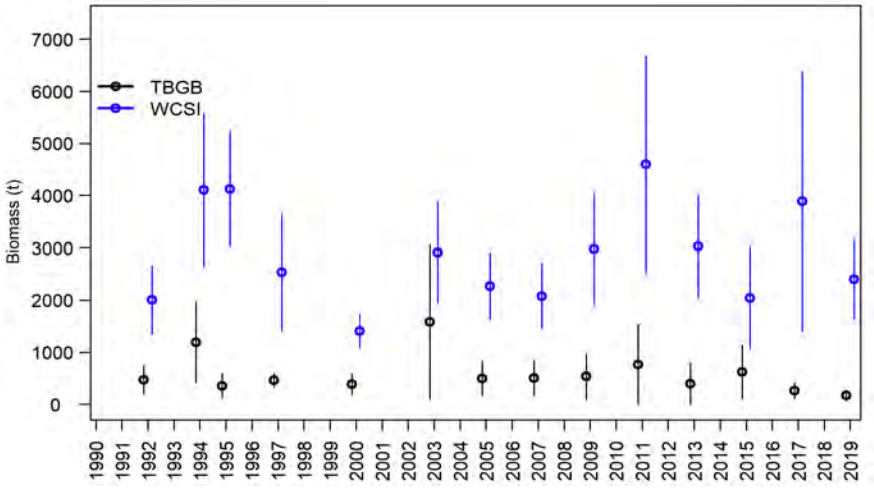


Figure 11: Barracouta biomass estimates from the WCSI inshore trawl survey core strata (20–400 m) for west coast strata and Tasman Bay and Golden Bay.

4.4.2 Length frequency distributions

There are distinct length modes that can be tracked through time in the WCSI time series (Figure 12). In most years that have a strong 0+ mode (centred around 20 cm), a large proportion of these fish were from the Tasman Bay and Golden Bay (TBGB) region, but in some years (e.g., 2000 and 2013) this small mode almost entirely comprised fish from off the west coast.

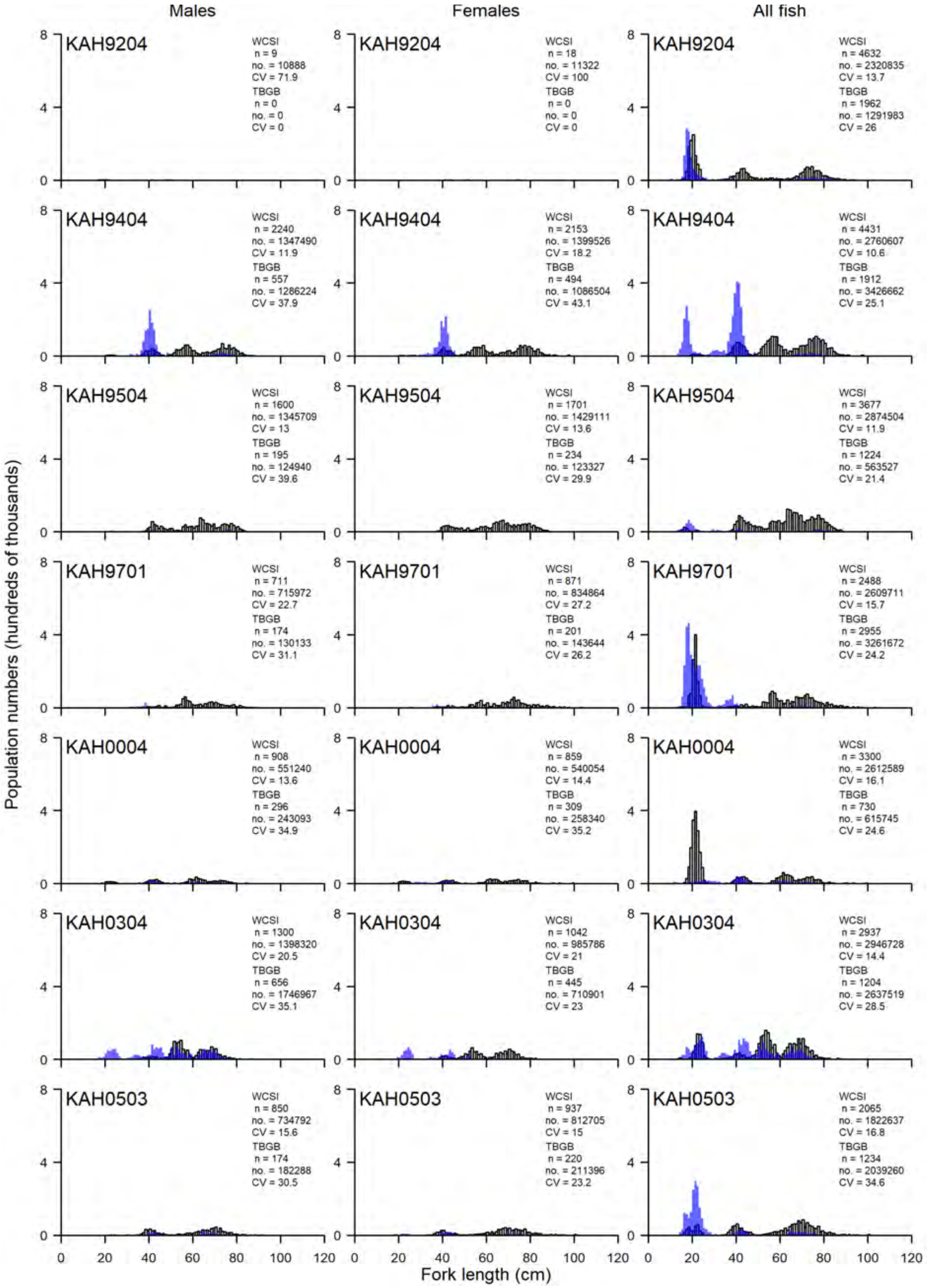


Figure 12: Length frequencies of barracouta from the WCSI (WCSI and TBGB) from *Kaharoa* (KAH) surveys, 1992-2005. Blue: TBGB; black: WCSI. The first two digits of the voyage code refer to the survey year. [Continued next page.]

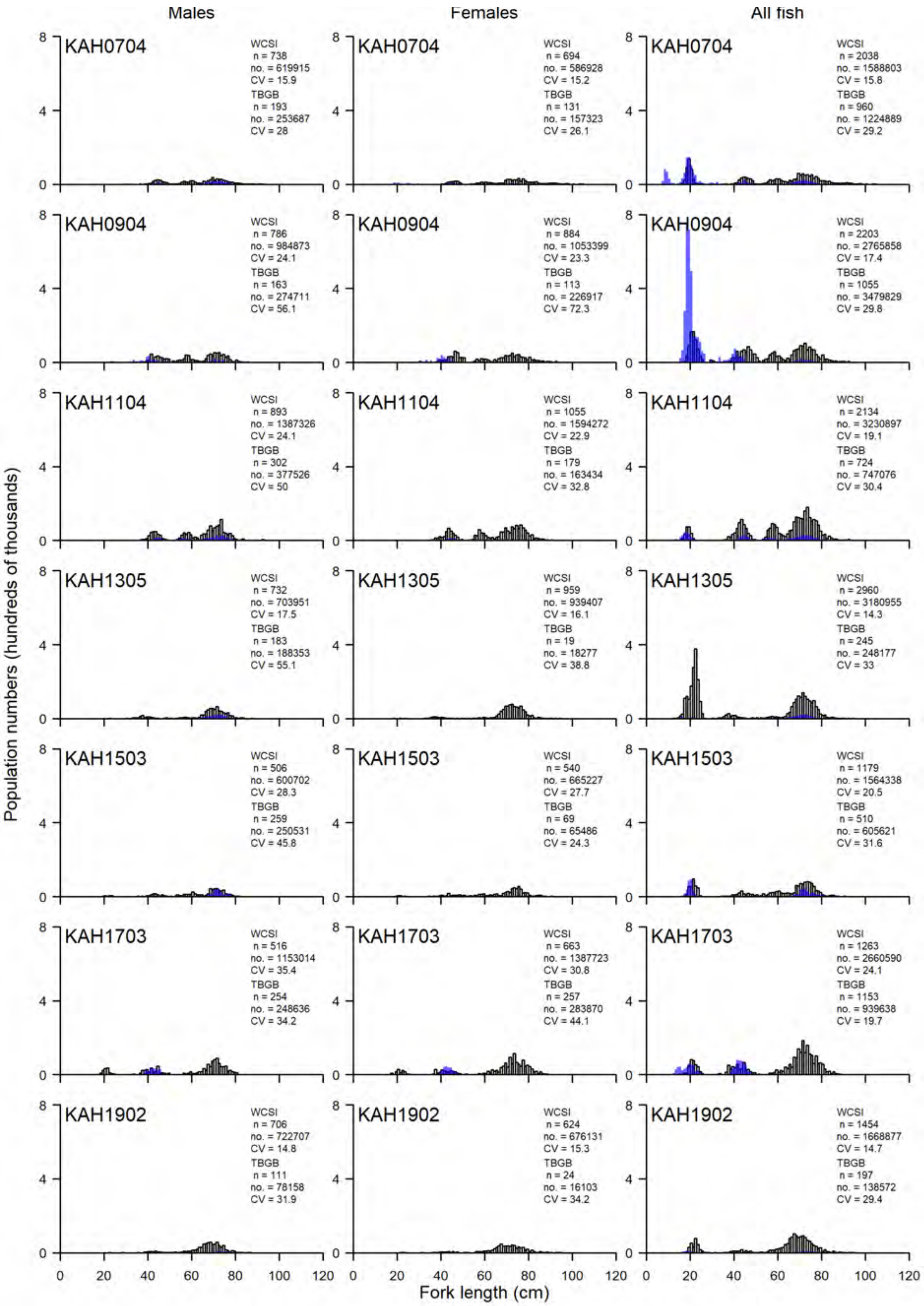


Figure 12: [Continued] Length frequencies of barracouta from the WCSI (WCSI and TBGB) from *Kaharoa* (KAH) surveys, 2007-2019. Blue: TBGB; black: WCSI. The first two digits of the voyage code refer to the survey year.

4.4.3 CPUE indices

Ballara & Holmes (2020) separated fisheries on the WCNI and WCSI. For WCNI, CPUE trends depended on the selection of input data. The model using tow-level TCEPR/ERS-trawl data (model 1) and the model using merged trip level TCEPR, TCER, CELR, and ERS-trawl (model 3) gave opposing long-term trends. The model using TCER data (model 2) showed the same pattern as model 3 between 2008–13, but then showed an increase in CPUE not seen from model 3, and opposite in direction to model 1. The TBGB *Kaharoa* trawl survey index shows large spikes in 1994 and 2003, and there is little agreement between the survey and any of the estimated CPUE indices. However, the survey in TBGB catches predominantly juveniles (Figure 13). There is a general rising trend in standardised CPUE up to 2010 and a subsequent decline (Figure 13). The DWWG considered that the TCEPR/ERS-trawl tow-level CPUE (model 1) comprised the best data to monitor this stock.

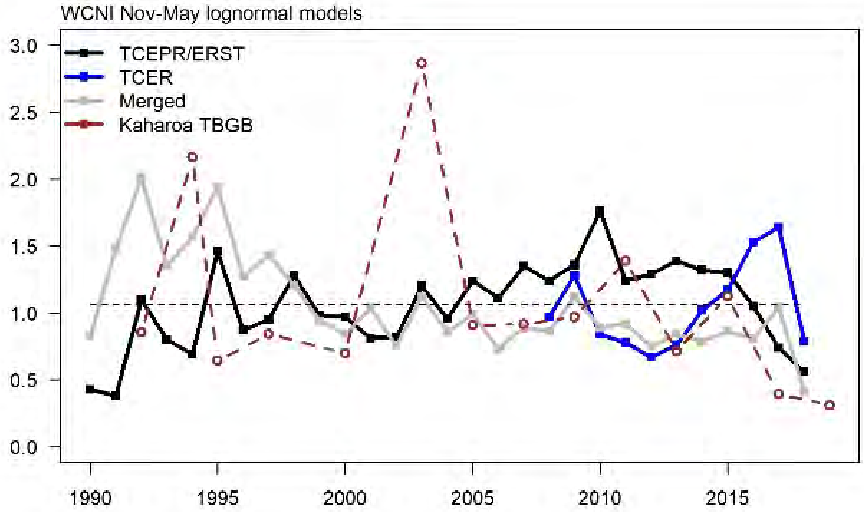


Figure 13: Comparison of WCNI CPUE indices (scaled to mean 1) for CPUE indices and *Kaharoa* survey indices for Tasman Bay, Golden Bay area. TCEPR/ERST:TCEPR and ERS-trawl tow level Nov–May (model 1); TCER: TCER tow level Nov–May (model 2); Merged: TCEPR, TCER, CELR, ERS-trawl trip level Nov-May (model 3).

CPUE indices for the WCSI fishery (from either tow- or trip-level models) were similar to the WCSI *Kaharoa* trawl survey series (Figure 14) and showed no long-term trend. The CPUE models were based on data from November to May, and the trawl survey takes place in April–May, the non-spawning season.

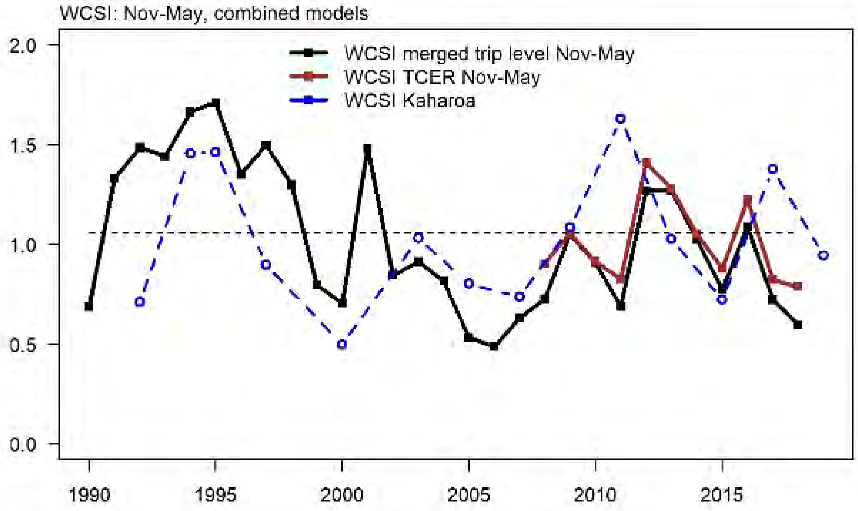


Figure 14: Comparison of WCSI CPUE indices (scaled to mean 1) and and *Kaharoa* survey indices for the WCSI area. TCER: TCER tow level Nov–May (model 2); Merged: TCEPR, TCER, CELR, ERS-trawl trip level Nov–May (model 3).

4.5 Yield estimates and projections

No estimates of biomass are available for any of the barracouta stocks.

4.6 Other factors

Barracouta are part of the shelf (30–300 m) mixed fishery and are usually the dominant catch species in these depths around the South Island (except perhaps in good red cod catch years in the Canterbury Bight). Any increase or decrease in barracouta quotas will have overflow effects onto bycatch species. The economics of targeting barracouta is likely to be affected by market demand and its availability relative to other more preferred species and this will, in turn, affect fishing patterns.

An analysis of trends in biomass of the Southland fishery suggests that recruitment may have been relatively low in the years after 1989 and that biomass may have declined between surveys by the *Shinkai Maru* (1981 and 1986) and the *Tangaroa* (annually 1993 to 1996). The scale of decline appeared to be greater than could be explained by different catching efficiencies of the two vessels.

4.7 Future research considerations

Recognising that CPUE will probably not provide a reliable relative abundance indicator for barracouta in isolation, and with the goal of developing a quantitative stock assessment in the future, the research and data collection needs for barracouta are as follows:

1. Development of age-based stock assessments for BAR 5 and BAR 7, incorporating inshore trawl survey biomass indices (and potentially survey length frequencies), commercial CPUE, and catch-at-age. Alternatively, length-based assessments could be attempted if no catch-at-age data are available.
2. Further investigation of stock relationships, focusing on the possible inter-relationship between BAR 5 with BAR 7 and BAR 1
3. Optimised otolith sampling and development of catch-at-age for BAR 5 and BAR 7 (focusing on the main fisheries areas - WCSI, WCNI, and South).
4. Further investigation of the linkages between the western part of BAR 4 and BAR 1 ECSI.
5. Continuation of development of spatio-temporal analyses to support further development of the CPUE time series and future stock assessments.
6. Ageing analysis of fish appropriate to the development of the stock assessment.
7. Collection of otolith samples from trawl surveys as well as the commercial fishery.

5. STATUS OF THE STOCKS

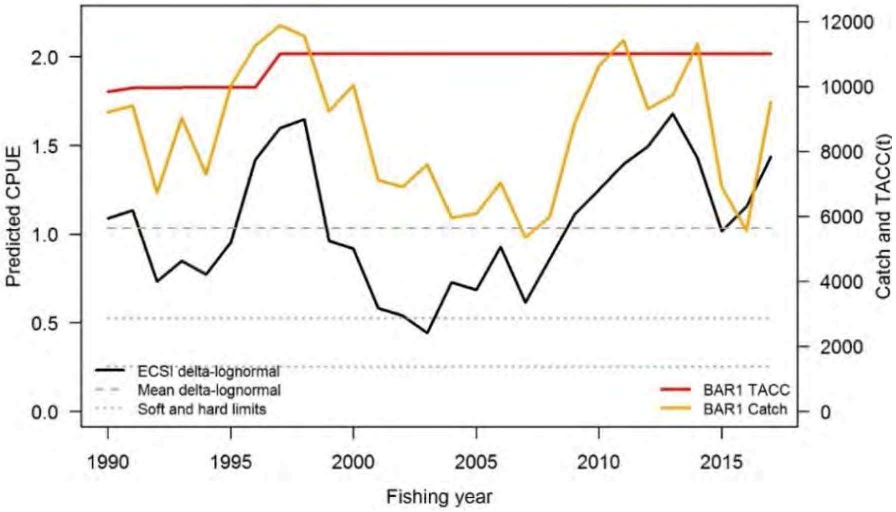
• BAR 1

The current understanding of the BAR 1 stock is that adult barracouta undertake an annual northward migration from the east coast of the South Island to spawn off the east coast of the North Island during July/August–September (see Hurst et al 2012). For the purposes of this analysis, barracouta in BAR 1 are assumed to comprise a single stock.

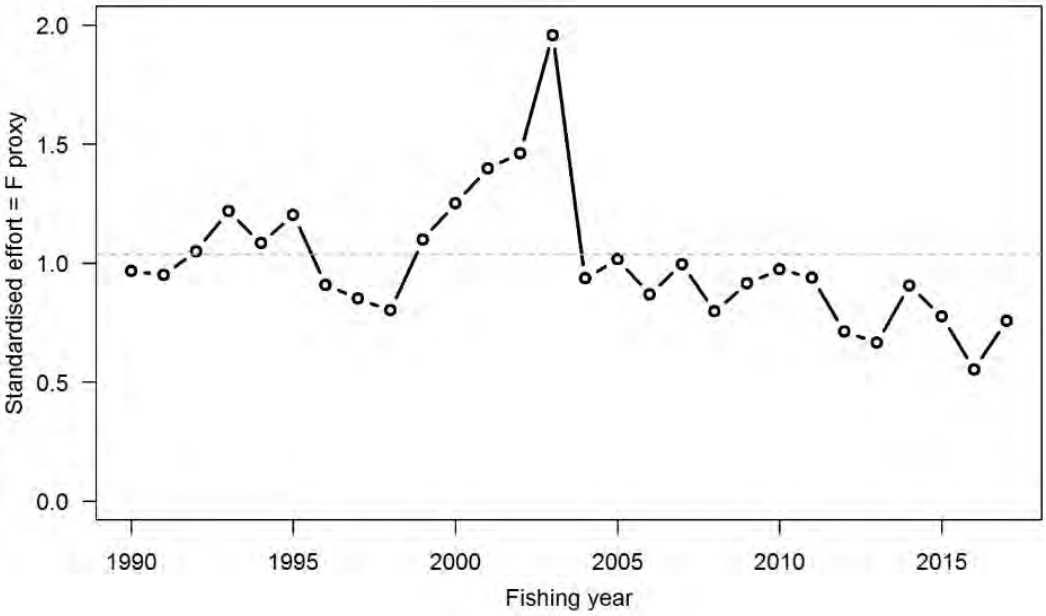
Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	BAR 1 ECSI CELR/TCER/small vessel TCEPR day-level series (target species BAR, RCO, TAR)
Reference Points	Interim Target: B_{MSY}-compatible proxy based on CPUE (average from 1989–90 to 2013–14 of the BAR 1 ECSI CELR/TCER/TCEPR model as defined by Baird (2019) Soft Limit: 50% of target Hard Limit: 25% of target Overfishing threshold: F_{MSY} (assumed)
Status in relation to Target	Likely (> 60%) to be at or above the target
Status in relation to Limits	Soft Limit: Very Unlikely (< 10%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Overfishing is Unlikely (< 40%) to be occurring

Historical Stock Status Trajectory and Current Status

CPUE, Catch and TACC Trajectories



Comparison of the ECSI CPUE series with the trajectories of catch (BAR 1 (QMR/MHR)) and TACCs from 1989–90 to 2016–17. Compare with the trawl survey trajectory shown in Figure 6.



Annual relative exploitation rate (catch/CPUE) for barracouta ECSI. The dotted line represents mean relative

Fishery and Stock Trends	
Recent trend in Biomass or Proxy	The BAR 1 CPUE series increased steeply from 2002–03 to a peak in 2012–13, dropped to the series mean in 2014–15, then increased.
Recent trend in Fishing Mortality or Proxy	Relative exploitation rate has declined gradually since 2005, and has been below the series mean (target) since 2012.
Other Abundance Indices	The winter ECSI trawl survey series for recruited fish has a trend that is similar to the BAR 1 CPUE index, with a peak in 2014 and a subsequent drop in 2016
Trends in Other Relevant Indicator or Variables	Recent landings (2008–09 to 2013–14) are at a similar level to those recorded during 1994–95 to 1999–2000.

Projections and Prognosis	
Stock Projections or Prognosis	Low pre-recruit biomass from the 2016 ECSI trawl survey suggests biomass may decline
Probability of Current Catch or TACC causing Biomass to remain below or decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE series	
Assessment Dates	Latest assessment: 2018	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data - Trawl survey biomass indices and associated length frequencies	1 – High Quality 1 – High Quality (used as supporting information)
Data not used (rank)	- TCEPR CPUE Series (ECSI)	3 – Low Quality: few vessels and highly variable CPUE
	- Standardised CPUE series (ECNI)	3 – Low Quality: insufficient data and high interannual variability
	- Summer ECSI trawl survey data	3 – Low Quality: variable catchability between years
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
-

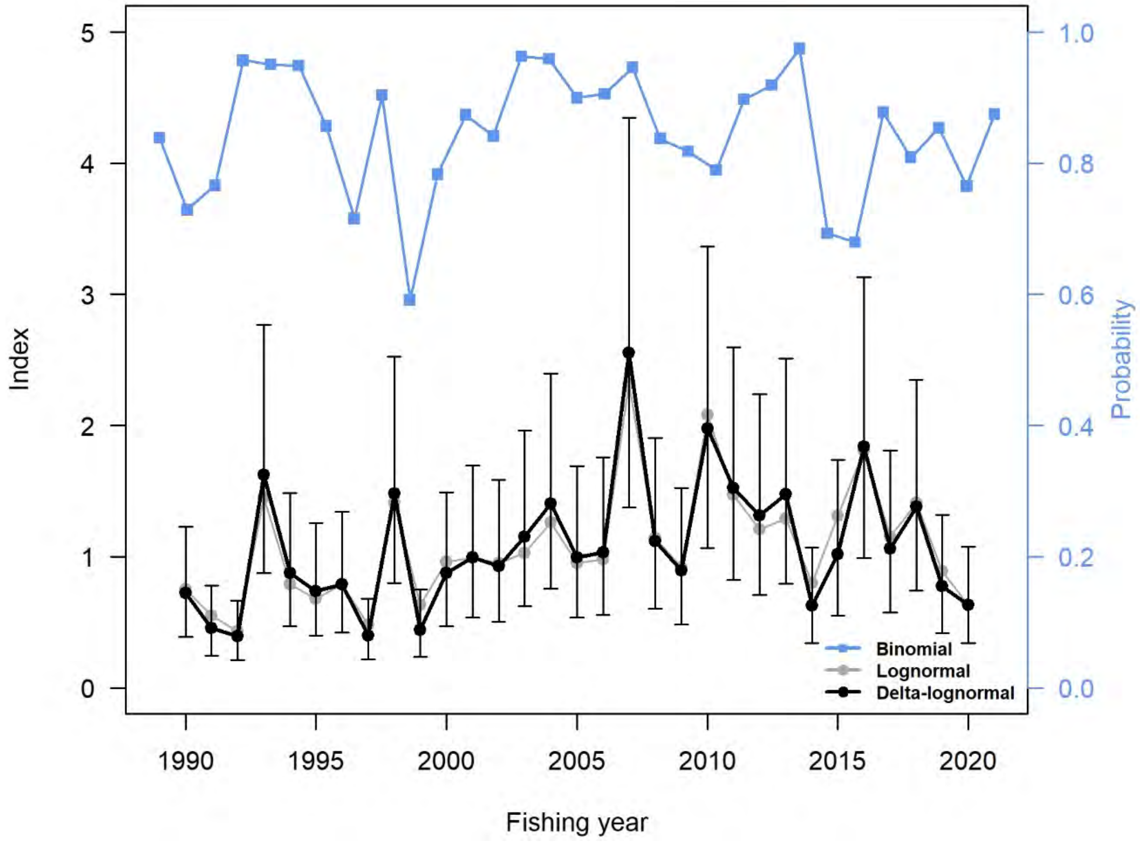
Fishery Interactions
Barracouta in the ECSI part of BAR 1 are taken as bycatch by inshore bottom trawl fisheries targeting, amongst others, red cod and tarakihi, and red cod and arrow squid by deepwater vessels. ECSI bycatch also comes from midwater effort targeting jack mackerels. In the ECNI part of BAR 1, most barracouta bycatch is from tarakihi and red gurnard effort; currently, there is little targeting of barracouta in this area.

- **BAR 4 (East Chatham Rise only)**

The relationships between the stock taken in this fishery and other barracouta stocks is uncertain.

Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Standardised CPUE Chatham East (tow-level)
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%B0}$
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Comparison of Chatham Rise East CPUE indices from the standardised lognormal (grey), binomial (blue), and the combined (delta lognormal) models with 95% confidence interval (black), based on the tow-by-tow TCEPR and ERS-trawl data for 1989–90 to 2019–20.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Recent trend is highly variable with no strong indication of an increase or decrease.
Recent Trend in Fishing Intensity or Proxy	-
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	-
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	Commercial CPUE (East)	2 – Medium or mixed Quality: the highly variable nature of this fishery makes interpretation of standardised CPUE difficult
Data not used (rank)	*Tangaroa* Chatham Rise trawl survey	3 – Low Quality: high interannual variability, doesn't cover depth range of species
Changes to Model Structure and Assumptions	-	
Major sources of Uncertainty	Changes in fish targeting have likely resulted in fluctuating catchability affecting the CPUE index over time.	

Qualifying Comments
-

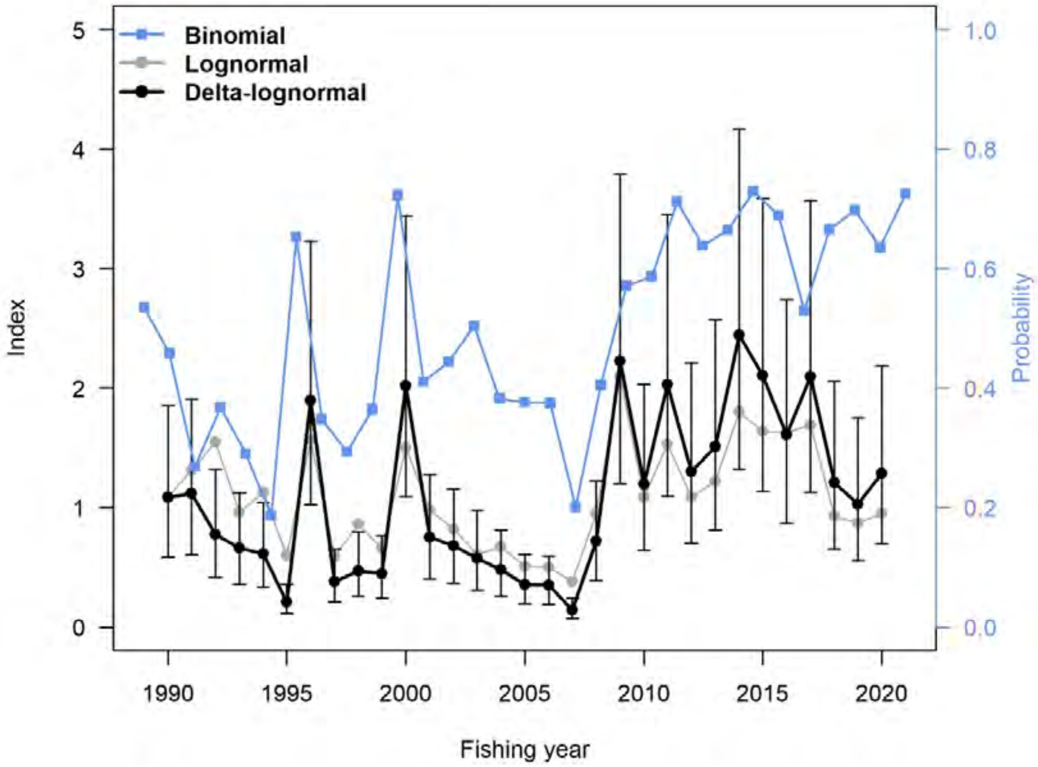
Fishery Interactions
Barracouta from Chatham Rise East are caught sporadically all year, but mainly in May–June, September, and/or December–January, by bottom or midwater trawls, mainly targeting barracouta. The trawl fishery in the ECSI area is subject to management measures designed to reduce interactions with endemic Hector's dolphins and seabirds. There is also a risk of incidental capture of sea lions from Otago Peninsula south.

- **BAR 5**

The relationship between these southern fisheries and the both coasts of the South Island is uncertain.

Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Standardised CPUE Sub-Antarctic (tow level)
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%B0}$
Status in relation to Target	Unknown
Status in relation to Limits	B_{2021} is Unlikely (< 40%) to be below the soft limit B_{2021} is Very Unlikely (< 10%) to be below the hard limit
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



BAR 5 CPUE indices from the standardised lognormal (grey), binomial (blue), and the combined (delta lognormal) with 95% confidence interval (black), based on the tow-by-tow TCEPR and ERS-trawl data for 1989–90 to 2019–20.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Recent trend is highly variable with no strong indication of an increase or decrease.
Recent Trend in Fishing Intensity or Proxy	-
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	-
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment.	
Assessment Method	Standardised CPUE	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Commercial CPUE	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major sources of Uncertainty	Changes to the squid fishery have likely resulted in fluctuating catchability, which affects the CPUE index.	

Qualifying Comments
-

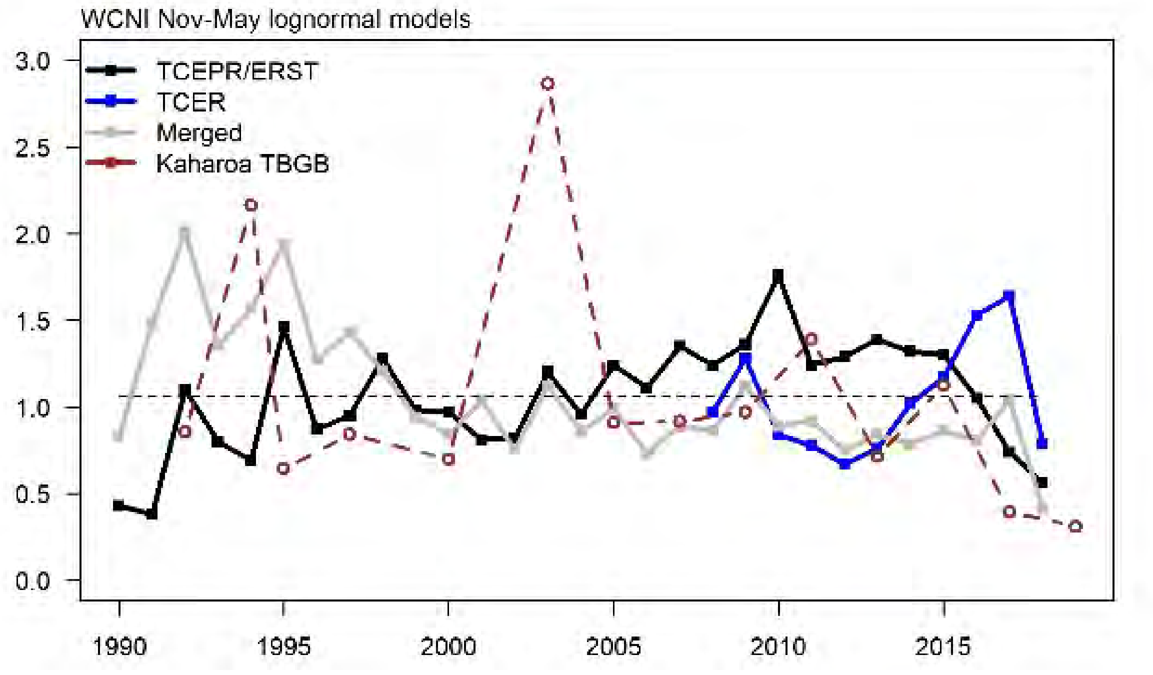
Fishery Interactions
Barracouta are taken mainly as a target species in BAR 5 and as bycatch in the squid fishery, but are also taken as bycatch in the jack mackerel, and warehou target fisheries.

- **BAR 7**

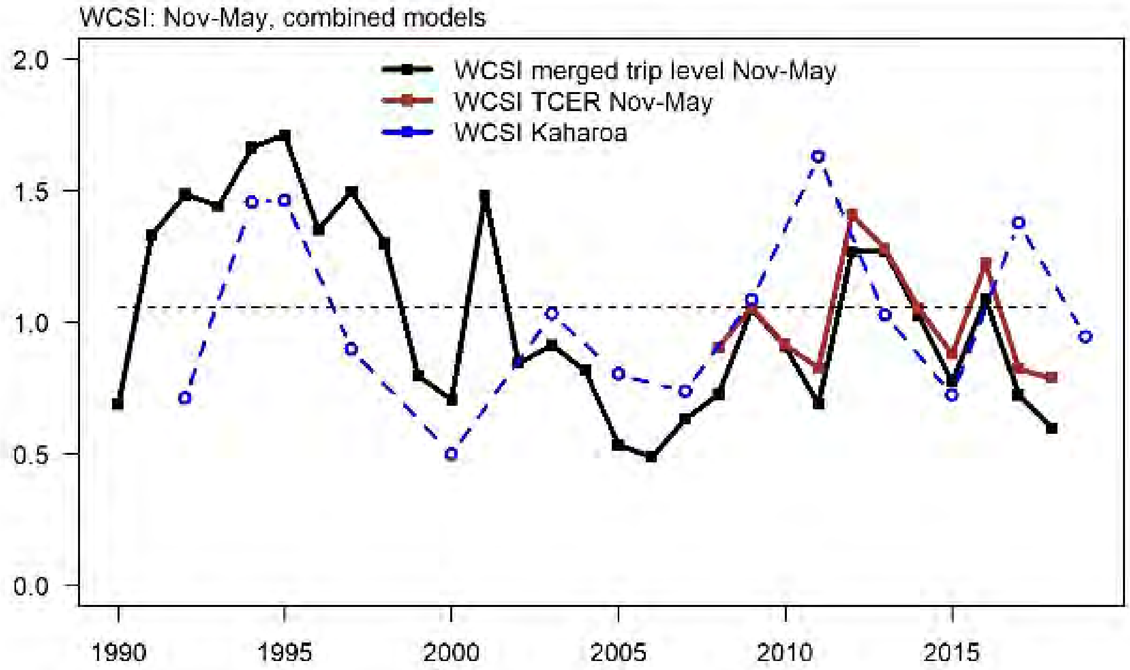
The relationship between the WCSI and the fisheries in BAR 5 is uncertain.

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE (tow level)
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%B0}$
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Comparison of WCNI CPUE indices (scaled to mean 1) for CPUE indices and *Kaharoa* survey indices for Tasman Bay, Golden Bay area. TCEPR/ERST: TCEPR and ERS-trawl tow level Nov–May (model 1); TCER: TCER tow level Nov–May (model 2); Merged: TCEPR, TCER, CELR, ERS-trawl trip level Nov-May (model 3).



Comparison of WCSI CPUE indices (scaled to mean 1) and and *Kaharoa* survey indices for the WCSI area. TCER: TCER tow level Nov–May (model 2); Merged: TCEPR, TCER, CELR, ERS-trawl trip level Nov-May (model 3). Trawl survey is based on fishing year.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	On the WCSI, CPUE is fluctuating with no clear trend. On the WCNI, CPUE has declined since 2010.
Recent Trend in Fishing Intensity or Proxy	-
Other Abundance Indices	The estimated biomass has varied almost three-fold during the *Kaharoa* WCSI time series but has not shown any consistent trend
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	-
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE	
Assessment Dates	Latest assessment: 2020	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Commercial CPUE - *Kaharoa* WCSI trawl survey biomass indices and associated length frequencies	1 – High Quality 1 – High Quality (used as supporting information)

Data not used (rank)	WCSI *Tangaroa* survey	3 – Low Quality: does not cover appropriate depth range
Changes to Model Structure and Assumptions	-	
Major sources of Uncertainty	-	

Qualifying Comments
Potential stock movement between FMA 5 and FMA 7 (or FMA 3) is unresolved. It is possible barracouta from other areas move into WCSI to spawn in winter.

Fishery Interactions
Barracouta in BAR 7 are taken both as a target in the WCSI fishery and as bycatch in the WCNI jack mackerel and WCSI hoki fisheries.

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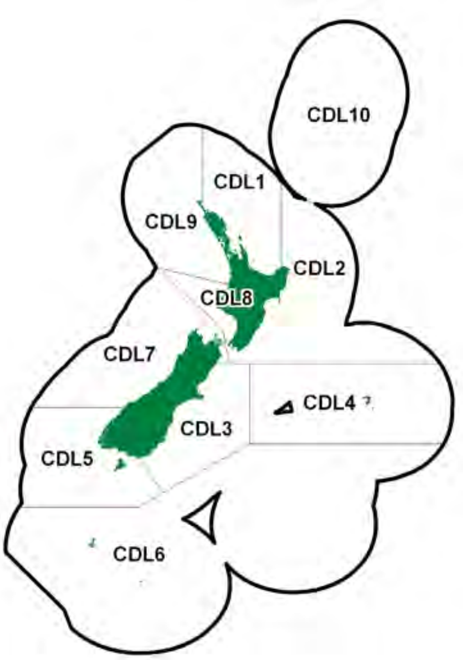
BLACK CARDINALFISH (CDL)

(*Epigonus telescopus*)
Akiwa



1. FISHERY SUMMARY

Black cardinalfish was introduced into the QMS on 1 October 1998 and quotas were set for QMAs 2–8. Quotas for QMAs 1 and 9 were subsequently set for 1999–00. TACCs were increased from 1 October 2006 in CDL 4 t to 66 t and in CDL 5 t to 22 t. In these stocks, landings were above the TACC for a number of years and the TACCs were increased to the average of the previous eight years plus an additional 10%. From 1 October 2009 the TACC was reduced in CDL 2 to 1620 t, then reduced to 1020 t in 2010–11, and further reduced to 440 t in 2011–12. The TACC of CDL 5 was increased from 22 t to 33 t on 1 October 2020. On 1 October 2021 the TACC of CDL 1 was reduced from 1200 t to 160 t to address potential sustainability concerns (Table 1).

Table 1: TACs (t), TACCs (t) and allowances (t) for black cardinalfish for the 2021-22 fishing year.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other sources of mortality	TACC	TAC
CDL 1	0	0	16	160	176
CDL 2	0	0	20	440	460
CDL 3	0	0	–	196	196
CDL 4	0	0	–	66	66
CDL 5	0	–	1	33	34
CDL 6	0	0	–	1	1
CDL 7	0	0	–	39	39
CDL 8	0	0	–	0	0
CDL 9	0	0	–	4	4
CDL 10	0	0	–	0	0
Total	0	0	37	939	976

1.1 Commercial fisheries

Several species of *Epigonus* are widely distributed in New Zealand waters, but only black cardinalfish (*E. telescopus*) reaches a marketable size and is found in commercial concentrations. It occurs throughout the New Zealand EEZ at depths of 300–1100 m, mostly in very mobile schools up to 150 m off the bottom over hills and rough ground. Black cardinalfish have been caught since 1981 by research and commercial vessels, initially as a bycatch of target trawling for other high value species. The preferred depth range of schools (600–900 m) overlaps the upper end of the depth range of orange roughy and the lower end of alfonsino and bluenose. The exploitation of these species from 1986 resulted in the development of the major cardinalfish fishery in QMA 2.

It is primarily sold domestically due to the short freezer life of fillets. The species has a section of dark flesh under the lateral line that has caused problems with overseas marketing. The fillets can be tainted if this flesh is not removed quickly.

Landings for 1998–99 to 2008–09 are from QMR totals following introduction of the species into the QMS for 1998–99. For the 1982–83 to 1985–86 fishing years, the best estimate of landings was the sum of the FSU Inshore and FSU Deepwater (i.e., FSU Total) catch returns. For 1986–87 to 1988–89 the best estimate was taken as the greater value of either the FSU Total or the LFRR. From the 1989–90 fishing year, the best estimate was taken as the higher of either the LFRR or the sum of the CLR and CELR Landed data.

The best estimate of total landings was split between the nine QMAs and ET (outside the EEZ) based on FSU and QMS data (Table 2). For FSU data (1982–83 to 1987–88 fishing years), catch where area was unknown was prorated to QMAs according to the catch level where area was reported. For QMS data (1988–89 to 1994–95 fishing years), catch by area in CELR Landed and CLR reports were scaled to equal the best estimate of the total catch. Commercial landings of black cardinalfish have been made in QMAs 1–9 and outside the EEZ (ET).

In most years since 1982 more than 65% of black cardinalfish landings were from the east coast of the North Island (QMA 2). The large increase in landings from this area in 1986–87 was associated with the development of the orange roughy fishery around the Ritchie Banks and Tuaheni High, and an increase in targeted fishing to establish a catch history when it was anticipated to become a quota species. The relatively large landings in 1990–91 were a combination of bycatch from the orange roughy fishery and target fishing for black cardinalfish. Landings from the Bay of Plenty (QMA 1) peaked at 2001 t in the fishing year 1996–97, but have remained well below the TACC since, with < 50 t of annual landings being recorded since 2014–15. Between 1991–92 and 2008–09 occasional catches were taken from outside the EEZ on the northern Challenger Plateau and the Lord Howe Rise. Figure 1 shows the historical landings and TACC values for the main CDL stocks.

1.2 Recreational fisheries

Recreational fishing for black cardinalfish is negligible.

1.3 Customary non-commercial fisheries

The level of this fishery is believed to be negligible.

1.4 Illegal catch

No information is available about illegal catch.

Table 2: Reported landings (t) of black cardinalfish by QMA and fishing year (1 October to 30 September) from 1982–83 to present. The data in this table have been updated from that published in the 1998 Plenary Report by using the data through to 1996–97 in table 32 on p. 262 of the "Review of Sustainability Measures and Other Management Controls for the 1998–99 Fishing Year - Final Advice Paper" dated 6 August 1998. Data for 1997–98 based on catch and effort returns, since 1998–99 on QMR records. [Continued on next page]

	QMA 1		QMA 2		QMA 3		QMA 4		QMA 5		QMA 6	
Year	Catch	TACC	Catch	TACC	Catch	TACC	Catch	TACC	Catch	TACC	Catch	TACC
1982–83	–	–	76	–	< 1	–	< 1	–	–	–	–	–
1983–84	–	–	212	–	7	–	< 1	–	–	–	–	–
1984–85	< 1	–	189	–	341	–	< 1	–	–	–	–	–
1985–86	< 1	–	238	–	50	–	3	–	2	–	–	–
1986–87	1	–	1 738	–	72	–	2	–	< 1	–	< 1	–
1987–88	3	–	1 556	–	28	–	1	–	3	–	–	–
1988–89	305	–	1 434	–	57	–	4	–	–	–	–	–
1989–90	613	–	1 718	–	20	–	18	–	–	–	–	–
1990–91	233	–	3 473	–	598	–	1	–	4	–	–	–
1991–92	7	–	1 652	–	146	–	3	–	< 1	–	2	–
1992–93	23	–	1 550	–	519	–	2	–	< 1	–	–	–
1993–94	364	–	2 310	–	277	–	10	–	5	–	–	–
1994–95	1 162	–	2 207	–	51	–	7	–	1	–	< 1	–

Table 2: [Continued]

	QMA 1		QMA 2		QMA 3		QMA 4		QMA 5		QMA 6	
Year	Catch	TACC	Catch	TACC	Catch	TACC	Catch	TACC	Catch	TACC	Catch	TACC
1995–96	1 418	–	2 621	–	57	–	4	–	10	–	–	–
1996–97	2 001	–	1 910	–	100	–	7	–	–	–	–	–
1997–98	995	–	1 176	–	40	–	351	–	–	–	–	–
1998–99	24	–	1 268	2 223	181	196	41	5	–	2	< 1	1
1999–00	980	1 200	2 158	2 223	215	196	36	5	< 1	2	< 1	1
2000–01	294	1 200	1 135	2 223	99	196	35	5	74	2	< 1	1
2001–02	455	1 200	1 693	2 223	146	196	29	5	18	2	< 1	1
2002–03	583	1 200	1 845	2 223	172	196	80	5	9	2	< 1	1
2003–04	481	1 200	966	2 223	96	196	148	5	27	2	< 1	1
2004–05	267	1 200	1 102	2 223	43	196	49	5	15	2	< 1	1
2005–06	643	1 200	2 153	2 223	50	196	53	5	< 1	2	< 1	1
2006–07	415	1 200	1 692	2 223	66	196	31	66	10	22	< 1	1
2007–08	202	1 200	861	2 223	7	196	23	66	20	22	< 1	1
2008–09	197	1 200	1 135	2 223	52	196	58	66	11	22	< 1	1
2009–10	49	1 200	1 046	1 620	45	196	15	66	3	22	< 1	1
2010–11	84	1 200	736	1 020	17	196	19	66	5	22	< 1	1
2011–12	148	1 200	376	440	79	196	44	66	93	22	< 1	1
2012–13	35	1 200	470	440	40	196	10	66	14	22	1	1
2013–14	160	1 200	282	440	68	196	11	66	19	22	< 1	1
2014–15	21	1 200	408	440	209	196	18	66	4	22	< 1	1
2015–16	35	1 200	299	440	136	196	30	66	15	22	1	1
2016–17	12	1 200	369	440	101	196	22	66	87	22	2	1
2017–18	2	1 200	236	440	131	196	13	66	6	22	1	1
2018–19	40	1 200	372	440	177	196	13	66	87	22	< 1	1
2019–20	2	1 200	341	440	103	196	8	66	2	22	1	1
2020–21	3	1 200	401	440	125	196	7	66	6	33	2	1

	QMA 7		QMA 8		QMA 9		Total (EEZ)		ET	Total
Year	Catch	TACC	Catch	TACC	Catch	TACC	Catch	TACC	Catch	Catch
1982–83	< 1	–	–	–	–	–	78	–	–	78
1983–84	< 1	–	–	–	–	–	220	–	–	220
1984–85	1	–	–	–	–	–	532	–	–	532
1985–86	< 1	–	–	–	45	–	292	–	–	292
1986–87	< 1	–	–	–	–	–	1 814	–	–	1 814
1987–88	2	–	< 1	–	< 1	–	1 638	–	–	1 638
1988–89	2	–	–	–	–	–	1 798	–	2	1 800
1989–90	15	–	–	–	–	–	2 385	–	< 1	2 385
1990–91	1	–	< 1	–	–	–	4 311	–	–	4 311
1991–92	11	–	–	–	–	–	1 821	–	17	1 838
1992–93	2	–	–	–	–	–	2 096	–	270	2 366
1993–94	6	–	–	–	–	–	2 972	–	829	3 801
1994–95	51	–	–	–	< 1	–	3 479	–	231	3 710
1995–96	26	–	–	–	–	–	4 150	–	340	4 490
1996–97	27	–	–	–	–	–	4 045	–	522	4 567
1997–98	76	–	–	–	108	–	2 338	–	405	2 743
1998–99	16	39	< 1	0	< 1	–	1 531	3 670	390	1 921
1999–00	27	39	0	0	< 1	4	3 415	3 670	962	4 377
2000–01	2	39	0	0	3	4	1 642	3 670	571	2 213
2001–02	3	39	0	0	5	4	2 349	3 670	490	2 839
2002–03	27	39	0	0	5	4	2 721	3 670	275	2 996
2003–04	2	39	0	0	6	4	1 727	3 670	58	1 785
2004–05	2	39	0	0	1	4	1 479	3 670	204	1 683
2005–06	1	39	0	0	2	4	2 901	3 670	44	2 945
2006–07	1	39	0	0	1	4	2 216	3 751	2	2 218
2007–08	2	39	< 1	0	19	4	1 134	3 751	1	1 135
2008–09	1	39	0	0	2	4	1 456	3 751	17	1 474
2009–10	< 1	39	0	0	5	4	1 163	3 148	–	–
2010–11	< 1	39	0	0	1	4	863	2 548	–	–
2011–12	< 1	39	0	0	< 1	4	742	1 968	–	–
2012–13	2	39	0	0	4	4	576	1 968	–	–
2013–14	1	39	0	0	< 1	4	542	1 968	–	–
2014–15	5	39	0	0	1	4	665	1 968	–	–
2015–16	3	39	0	0	2	4	522	1 968	–	–
2016–17	5	39	0	0	1	4	599	1 968	–	–
2017–18	11	39	0	0	1	4	401	1 968	–	–
2018–19	6	39	0	0	2	4	698	1 968	–	–
2019–20	7	39	0	0	2	4	467	1 968	–	–
2020–21	3	39	0	0	< 1	4	548	1 979	–	–

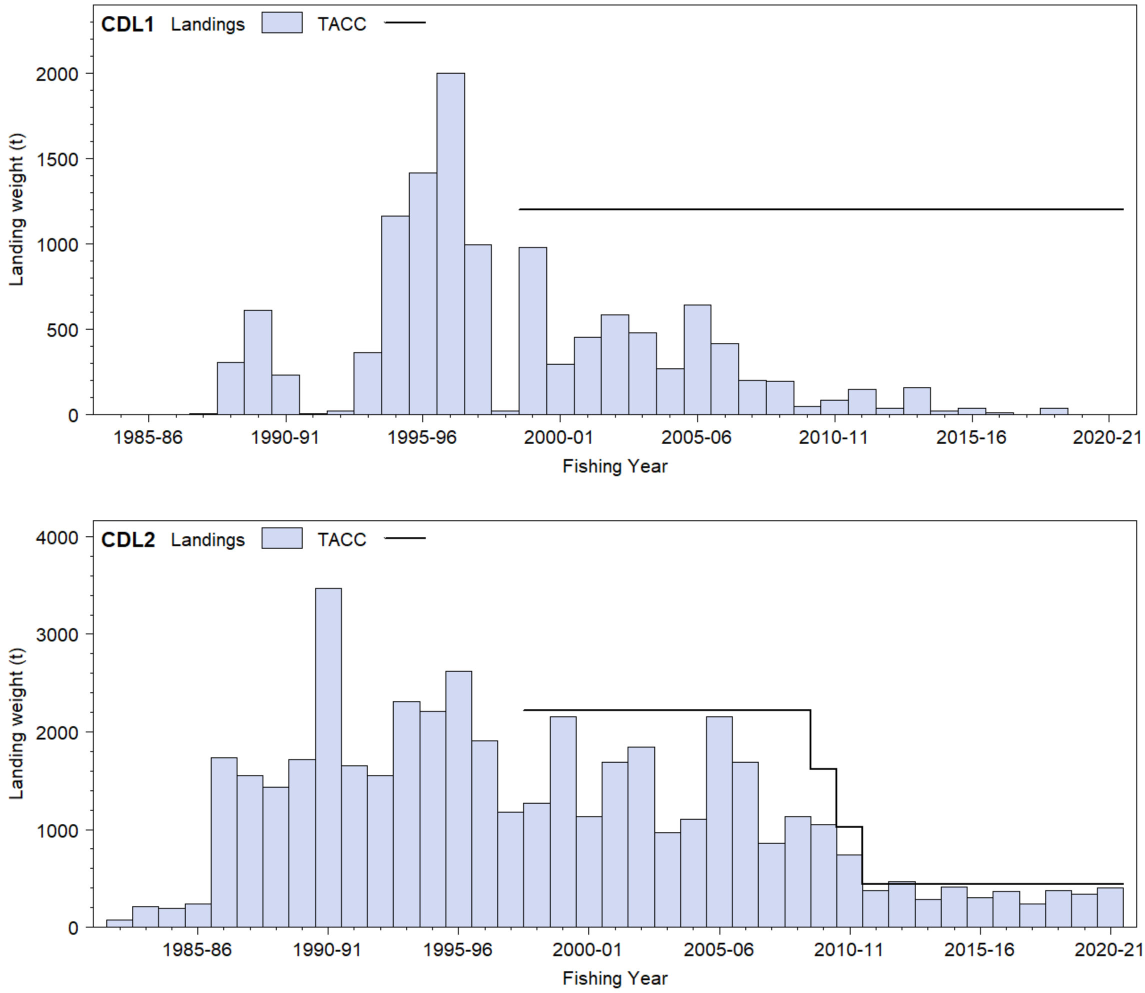


Figure 1: Reported commercial landings and TACC for the two main CDL stocks. CDL 1 (Auckland East) and CDL 2 (Central East).

1.5 Other sources of mortality

There has been a history of catch overruns (unreported catch) from loss of fish through burst nets, and the discarding at sea of this species while target fishing for higher value species. In the assessment presented here, the total removals were assumed to exceed reported catches by the overrun percentages in Table 3 (Dunn 2009). All yield estimates make an allowance for the current estimated level of overrun of 10%.

Table 3: Catch overruns (%) for CDL 2 by year.

Year	Overrun	Year	Over-run
1982–83	100	1991–92	30
1983–84	100	1992–93	30
1984–85	100	1993–94	30
1985–86	100	1994–95	20
1986–87	50	1995–96	20
1987–88	50	1996–97	20
1988–89	50	1997–98	20
1989–90	50	1998–99 and	10
1990–91	50	subsequently	–

2. BIOLOGY

The average size of black cardinalfish landed by the commercial fishery is about 50–60 cm fork length (FL). Length frequency distributions from research surveys are unimodal with a peak at 55–

65 cm FL. They reach a maximum length of about 75 cm FL. Otolith readings from 722 fish from QMA 2 have been validated using radiometric and bomb radiocarbon methods and indicated that this species is relatively slow-growing and long-lived (Andrews & Tracey 2007, Neil et al 2008). Maximum ages of over 100 years were reported, with the bulk of the commercial catch being between 35 and 55 years of age. The validation indicated that fish aged over 60 years tended to be under-aged, by up to 30%. This bias would be likely to have little impact on the estimated growth parameters but would influence the estimate of natural mortality (*M*). Life history parameters are given below in Table 4.

Table 4: Life history parameters for black cardinalfish. All estimates are for CDL 2, except the length-weight parameters which are for CDL 2–4.

Fishstock	Estimate	Source
1. Natural mortality (*M*)	0.034*	(Tracey et al 2000)
Age at recruitment (A_r)	unknown	
Gradual recruitment (A_m)	unknown	
Age at full recruitment	45	(Tracey et al 2000)
Age at maturity (A_s)	35	(Field & Clark 2001)
Gradual maturity (S_m)	13	(Field & Clark 2001)

2. Weight = $a(\text{length})^b$ (weight in g, fork length in cm).

Both sexes		
a	b	
0.113	2.528	Dunn (2009)

3. Von Bertalanffy growth parameters (Tracey et al 2000)

Both sexes			Female			Male		
L_∞	k	t_0	L_∞	k	t_0	L_∞	K	t_0
70.8	0.034	-6.32	70.9	0.038	-4.62	67.8	0.034	-8.39

* Because of uncertainties in ageing and *M*, the Deepwater Fisheries Assessment Working Group used a range of *M*s in the assessments.

The reproductive biology of black cardinalfish is not well known (Dunn 2009). Indications from research survey and Observer Programme data are that spawning may occur between November and July. Spawning locations have been identified in CDL 1, CDL 2, CDL 7, CDL 9, and outside the EEZ on the northern Challenger Plateau, Lord Howe Rise, and West Norfolk Ridge. A probit analysis of maturity at length indicated that fish became sexually mature at around 50 cm length, at an age of approximately 35 years (Field & Clark 2001). Maturity was also inferred to be between ages 26 and 44 years (mean 33 years) from changes in δ^{13}C in otoliths (Neil et al 2008).

Juveniles are thought to be mesopelagic until they reach a length of about 12 cm (5 years of age), after which they become primarily demersal (Neil et al 2008). Larger juveniles have been caught in bottom trawls at depths of 400–700 m, extending into deeper water as they grow, with adult fish caught primarily at 800–1000 m (Dunn 2009). Prey items from research trawl samples include mesopelagic fish, natant decapod prawns, and octopus.

Elevated levels of mercury (Hg) have been recorded in a sample of black cardinalfish from the Bay of Plenty (Tracey 1993).

3. STOCKS AND AREAS

The stock boundaries and number of black cardinalfish stocks in New Zealand are unknown. There are no data on genetics, or known movements of black cardinalfish which indicate possible stock boundaries.

There is evidence that spawning occurs in CDL 1, CDL 2, CDL 7, and CDL 9 and outside the EEZ (e.g., North Challenger, Lord Howe, and West Norfolk Ridge). In CDL 2, three geographically close spawning locations have been identified: Tuaheni High, Ritchie Bank, and Rockgarden (Dunn 2009). Juveniles of less than 30 cm have been infrequently identified in CDL 2 and more frequently found on the northern flanks of the Chatham Rise, which is south of the spawning grounds in CDL 2. No spawning grounds have been identified on the Chatham Rise, where adult fish are relatively rare.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was updated for the 2022 Fishery Assessment Plenary. A more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021), online at https://www.mpi.govt.nz/dmsdocument/51472-Aquatic-Environment-and-Biodiversity-Annual-Review-AEBAR-2021-A-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment.

4.1 Role in the ecosystem

Black cardinalfish is a part of the mid slope demersal fish assemblage identified by Francis et al (2002). It is widely distributed with a range centred on a depth of about 750 m and latitude about 39.4° S (i.e., central and northern New Zealand). It occupies depths intermediate between the shallower southern community dominated by hoki (about 620 m, 49.5° S) and the deeper southern black oreo (about 930 m, 45.5° S) and smooth oreo (about 1090 m, 44.6° S), and the deeper centrally located orange roughy (about 1090 m, 41.2° S) (Francis et al 2002). The role in the ecosystem is not well understood; and nor are the effects on the ecosystem of removing about an average of 2300 t of black cardinalfish per year between 1986–87 and 2010–11 from the New Zealand EEZ, mostly from the east coast of the North Island.

4.1.1 Trophic interactions

No detailed feeding studies for black cardinalfish have been documented for New Zealand waters. Prey items observed during research surveys in New Zealand waters include mesopelagic fish, particularly lighthouse fish (*Phosichthys argenteus*), natant decapod prawns, and cephalopods (Tracey 1993). Predators of black cardinalfish are not documented but predation is expected to vary with fish development.

4.1.2 Ecosystem indicators

Tuck et al (2009, 2014) used data from the Sub-Antarctic and Chatham Rise middle-depth trawl surveys to derive indicators of fish diversity, size, and trophic level. However, fishing for cardinalfish occurs mostly deeper than the depth range of these surveys and is only a small component of fishing in the areas considered by Tuck et al (2009, 2014).

4.2 Bycatch (fish and invertebrates)

Incidental catch and discards have not been estimated for the black cardinalfish target fishery. Anderson et al (2017) summarised the bycatch and discards from the target orange roughy and oreo trawl fisheries from 2000–01 to 2014–15. The bycatch of these fisheries may be similar to that of the cardinalfish fishery, although both occur somewhat deeper than cardinalfish and oreo fisheries are found further to the south.

4.3 Incidental capture of protected species (seabirds, mammals, and protected fish)

For protected species, capture estimates presented here include all animals recovered to the deck (alive, injured, or dead) of fishing vessels but do not include any cryptic mortality (e.g., seabirds struck by a warp but not brought onboard the vessel, Middleton & Abraham 2007).

4.3.1 Seabird captures

Annual observed seabird capture rates ranged from 0 to 0.9 per 100 tows in orange roughy, oreo, and cardinalfish trawl fisheries between 2002–03 and 2019–20 (Table 5). Capture rates have fluctuated without obvious trend at this low level. The average observed capture rate in deepwater trawl fisheries (including orange roughy, oreo, and cardinalfish) for the period from 2002–03 to 2019–20 is about 0.33 birds per 100 tows, a very low rate relative to other New Zealand trawl fisheries; e.g., for scampi (4.43 birds per 100 tows) and squid (13.79 birds per 100 tows) over the same years.

Table 5: Number of tows by fishing year and observed seabird captures in orange roughy, oreo, and cardinalfish trawl fisheries, 2002–03 to 2019–20. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows. Estimates are based on methods described by Abraham & Richard (2020) and are available online at https://protectedspeciescaptures.nz/PSCv6/released/. Observed and estimated protected species captures in this table derive from the PSC database version PSCV6.

	Fishing effort			Obs. captures		Est. captures		Est. capture rate	
Fishing year	Tows	No. Obs	% obs	Captures	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	8 871	1 384	15.6	0	0.00	36	17-60	0.40	0.19-0.68
2003–04	8 007	1 262	15.8	3	0.24	33	17-54	0.41	0.21-0.67
2004–05	8 420	1 619	19.2	7	0.43	44	25-68	0.52	0.3-0.81
2005–06	8 292	1 359	16.4	8	0.59	42	25-66	0.51	0.3-0.8
2006–07	7 365	2 324	31.6	2	0.09	22	10-40	0.30	0.14-0.54
2007–08	6 731	2 811	41.8	7	0.25	24	13-40	0.35	0.19-0.59
2008–09	6 130	2 372	38.7	8	0.34	26	15-42	0.42	0.24-0.69
2009–10	6 008	2 133	35.5	19	0.89	36	25-51	0.60	0.42-0.85
2010–11	4 178	1 205	28.8	1	0.08	17	7-33	0.42	0.17-0.79
2011–12	3 655	923	25.3	2	0.22	13	5-26	0.37	0.14-0.71
2012–13	3 098	346	11.2	2	0.58	15	6-30	0.50	0.19-0.97
2013–14	3 606	434	12.0	2	0.46	18	7-33	0.49	0.19-0.92
2014–15	3 814	978	25.6	0	0.00	15	5-30	0.40	0.13-0.79
2015–16	4 088	1 421	34.8	4	0.28	15	7-28	0.38	0.17-0.68
2016–17	3 962	1 226	30.9	2	0.16	14	5-26	0.35	0.13-0.66
2017–18	3 753	903	24.1	4	0.44	17	8-29	0.44	0.21-0.77
2018–19	3 906	1 190	30.5	9	0.76	21	13-34	0.55	0.33-0.87
2019–20	3 952	1 171	29.6	2	0.17	13	5-25	0.34	0.13-0.63

Table 6: Number of observed seabird captures in orange roughy, oreo, and cardinalfish fisheries, 2002–03 to 2019–20, by species and area. The risk category is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Thresholds, PST (from Richard et al 2017, where full details of the risk assessment approach can be found). It is not an estimate of the risk posed by fishing for black cardinalfish. Observed protected species captures in this table derive from the PSC database version PSCV6.

Species	Risk Category	Chatham Rise	East coast South Island	Fiordland	Sub-Antarctic	Stewart-Snares shelf	West coast South Island	West coast North Island	Total
Salvin's albatross	High	12	4	0	3	0	0	0	19
Southern Buller's albatross	High	3	0	1	0	0	0	0	4
Chatham Island albatross	Medium	11	0	0	1	0	0	0	12
New Zealand white-capped albatross	Medium	4	0	0	0	0	2	0	6
Gibson's albatross	High	1	0	0	0	0	0	0	1
Antipodean albatross	Medium	1	0	0	0	0	0	0	1
Northern royal albatross	Low	1	0	0	0	0	0	0	1
Southern royal albatross	Negligible	2	1	0	1	0	0	0	4
Albatrosses	–	2	1	0	0	0	0	0	3
Total albatrosses	–	37	6	1	5	0	2	0	51
Black petrel	Very High	0	0	0	0	0	0	1	1
Northern giant petrel	Medium	1	0	0	0	0	0	0	1
White-chinned petrel	Low	3	2	0	0	1	0	0	6
Grey petrel	Negligible	1	0	0	1	0	0	0	2
Sooty shearwater	Negligible	1	3	0	0	0	1	0	5
Common diving petrel	Negligible	3	0	0	0	0	0	0	3
White-faced storm petrels	Negligible	3	0	0	0	0	0	0	3
Cape petrel	–	8	1	0	0	0	0	0	9
Petrels, prions, and shearwaters	–	0	0	0	1	0	0	0	1
Total other birds	–	20	6	0	2	1	1	1	31

Salvin's albatross was the most frequently captured albatross (38% of observed albatross captures) but eight different albatross species have been observed captured since 2002–03. Cape petrels were the most frequently captured other taxon (29% of observed captures of taxa other than albatross, Table 6). Seabird captures in the orange roughy, oreo, and cardinalfish fisheries have been observed mostly around the Chatham Rise and off the east coast South Island. These numbers should be regarded as only a general guide on the distribution of captures because the observer coverage is not uniform across areas and may not be representative.

The deepwater trawl fisheries (including the cardinalfish target fishery) contribute to the total risk posed by New Zealand commercial fishing to seabirds (see Table 7). The two species to which the fishery poses the most risk are Chatham Island albatross and Salvin's albatross, with this suite of fisheries posing 0.06 and 0.022 of Population Sustainability Threshold (PST) (Table 7). Chatham Island albatross is assessed as at medium risk and Salvin's albatross as at high risk (Richard et al 2020).

Mitigation methods such as streamer (tori) lines, Brady bird bafflers, warp deflectors, and offal management are used in the orange roughy, oreo, and cardinalfish trawl fisheries. Warp mitigation was voluntarily introduced from about 2004 and made mandatory in April 2006 (Department of Internal Affairs 2006). The 2006 notice mandated that all trawlers over 28 m in length use a seabird scaring device while trawling (being "paired streamer lines", "bird baffler" or "warp deflector" as defined in the notice).

Table 7: Risk ratio of seabirds predicted by the level two risk assessment for the cardinalfish and all fisheries included in the level two risk assessment, 2006–07 to 2016–17, showing seabird species with a risk ratio of at least 0.001 of PST (from Richard et al 2020, where full details of the risk assessment approach can be found). The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the PST. 2018-19 and 2019-20 data were unavailable at time of publication. The DOC threat classifications are shown (Robertson et al 2017 at http://www.doc.govt.nz/documents/science-and-technical/nztcs19entire.pdf).

	PST	Risk ratio			
Species name	**(mean)**	**DPW Risk Ratio***	**Total**	**Risk category**	**DOC Threat Classification**
Chatham Island albatross	428	0.0602	0.28	Medium	At Risk: Naturally Uncommon
Salvin's albatross	3 460	0.0223	0.65	High	Threatened: Nationally Critical
Northern giant petrel	337	0.0052	0.15	Medium	At Risk: Naturally Uncommon
Northern Buller's albatross	1 640	0.0024	0.26	Medium	At Risk: Naturally Uncommon
Black petrel	447	0.0024	1.23	Very high	Threatened: Nationally Vulnerable
Antipodean albatross	369	0.002	0.17	Medium	Threatened: Nationally Critical
Gibson's albatross	497	0.0016	0.31	High	Threatened: Nationally Critical
Northern royal albatross	723	0.0013	0.05	Low	At Risk: Naturally Uncommon
Flesh-footed shearwater	1 450	0.0007	0.49	High	Threatened: Nationally Vulnerable
Southern Buller's albatross	1 360	0.0006	0.37	High	At Risk: Naturally Uncommon
Grey petrel	5 460	0.0003	0.03	Negligible	At Risk: Naturally Uncommon
Common diving petrel	137 000	0.0001	< 0.01	Negligible	At Risk: Relict
New Zealand white-faced storm petrel	331 000	0.0001	0.00	Negligible	At Risk: Relict
New Zealand white-capped albatross	10 800	0.0001	0.29	Medium	At Risk: Declining
Buller's shearwater	56 200	0	0.00	Negligible	At Risk: Naturally Uncommon
Westland petrel	351	0	0.54	High	At Risk: Naturally Uncommon
Sooty shearwater	622 000	0	0.00	Negligible	At Risk: Declining
Hutton's shearwater	14 900	0	0.00	Negligible	At Risk: Declining
Otago shag	283	0	0.13	Medium	Threatened: Nationally Vulnerable
White-headed petrel	34 400	0	0.00	Negligible	Not Threatened

* DPW Risk Ratio from Richard et al 2017.

4.4 Benthic interactions

The spatial extent of seabed contact by trawl fishing gear in New Zealand's EEZ and Territorial Sea has been estimated and mapped for trawl fisheries targeting deepwater species (e.g., Baird & Mules 2019, 2021a, 2021b), species in waters shallower than 250 m (Baird et al. 2015, Baird & Mules 2020a), and all trawl fisheries combined (Baird & Mules 2021a, 2021b). The most recent assessment of the deepwater trawl footprint was for the period 1989–90 to 2018–19 (Baird & Mules 2021b).

The Tier 2 species black cardinalfish is part of the deepwater fishery complex that includes orange roughy and oreo species. During 1989–90 to 2018–19, about 15 900 black cardinalfish bottom trawls were reported. These data show a gradual increase in tows a year to a relatively stable period during 1995–96 to 2006–07 (about 700–1100 tows annually), then a period of steady decline from 2007–08 onwards to a low of 82 tows in 2017–18, and an increase to 175 tows in 2018–19 (Baird & Mules 2021b). The annual trawl footprint from these tows increased to a peak of about 400 km^2 in 1998–99 and 1999–2000, ranged between 114 and 262 km^2 during 2000–01 and 2010–11, then declined steadily to 35 km^2 in 2017–18, increasing to 70 km^2 in 2018–19 (Baird & Mules 2021b). In total, the 1989–90 to 2018–19 footprint contacted 2213.6 km^2 of the seafloor which equates to 0.05% of the EEZ and Territorial Sea and 0.16% of the fishable area (the seafloor area in depths shallower than 1600 m that are open to fishing).

Trawling for orange roughy, oreo, and cardinalfish, like trawling for other species, is likely to have effects on benthic community structure and function (e.g., Rice 2006) and there may be consequences for benthic productivity (e.g., Jennings et al 2001, Hermsen et al 2003, Hiddink et al 2006, Reiss et al 2009). These consequences are not considered in detail here but are discussed in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021).

4.5 Other considerations

4.5.1. Spawning disruption

Fishing during spawning may disrupt spawning activity or success. Morgan et al (1999) concluded that Atlantic cod (*Gadus morhua*) “exposed to a chronic stressor are able to spawn successfully, but there appears to be a negative impact of this stress on their reproductive output, particularly through the production of abnormal larvae”. Morgan et al. (1997) also reported that “Following passage of the trawl, a 300-m-wide "hole" in the [cod spawning] aggregation spanned the trawl track. Disturbance was detected for 77 min after passage of the trawl.” There is no research on the disruption of spawning black cardinalfish by fishing in New Zealand. Spawning of this species appears to occur between February and July, peaking in April, and catches of black cardinalfish occur throughout the year (Dunn 2005).

4.5.2 Genetic effects

Fishing or environmental changes (including those caused by climate change or pollution) could alter the genetic composition or diversity of a species. There are no known studies of the genetic diversity of cardinalfish from New Zealand. Genetic studies for stock discrimination are reported under “stocks and areas”.

4.5.3 Habitat of particular significance to fisheries management

Habitat of particular significance for fisheries management (HPSFM) does not have a policy definition (Ministry for Primary Industries 2012). O’Driscoll et al (2003) reported spawning black cardinalfish mostly from around the North Island, but higher catch rates of juveniles on the northwest Chatham Rise and Puysegur area (O’Driscoll et al 2003). In both areas, sample sizes were small so these distributions should be treated with caution. It is not known if there are any direct linkages between the congregation of cardinalfish around features and the corals found on those features. Bottom trawling for cardinalfish has the potential to affect features of the habitat that could qualify as habitat of particular significance to fisheries management.

5. STOCK ASSESSMENT

A stock assessment for CDL 2–4 was completed in 2009. No assessments have been made for stocks in other areas. For the purposes of stock assessment, it has been assumed that black cardinalfish on the east coast North Island (CDL 2) are from the same stock as fish on the north Chatham Rise (CDL 3 and CDL 4).

5.1 Assessment inputs

The assessment inputs for CDL 2–4 were two CPUE indices (Table 8), catches adjusted by overruns (Table 9), and length frequency and maturity at length samples (Dunn 2009). The CPUE indices were derived from catch and effort data for fisheries focused on and around specific hill features in CDL 2 (Dunn & Bian 2009) with no overrun included. Although the CPUE indices accounted for a substantial proportion of the total catch (65–77%), the spatial extent of the fisheries was small compared with the overall area believed to be occupied by the stock. As a result, the indices may reflect local abundance, but it is less certain that they reflect overall stock biomass. The CPUE was split into two indices, before and after 1 October 1998, because of a change in reported fishing patterns in the late 1990s. This may have been caused, at least in part, by the introduction of the black cardinalfish TACC. The growth parameters used in the assessment are presented in Table 4. Length frequency samples were available for eight years between 1989–90 and 2007–08 from at-sea and market sampling. Maturity was input as the proportions mature at length from samples collected during research trawl surveys of the east coast North Island in 2001 and 2003.

Table 8: Standardised CPUE indices, and their calculated CVs, as used in the stock assessment.

Fishing year	Index a	CV (%)	Index b	CV (%)
1990–91	1.00	46	–	–
1991–92	0.73	43	–	–
1992–93	0.87	42	–	–
1993–94	0.58	46	–	–
1994–95	0.41	45	–	–
1995–96	0.26	39	–	–
1996–97	0.51	42	–	–
1997–98	0.29	47	–	–
1998–99	–	–	1.00	37
1999–00	–	–	0.57	32
2000–01	–	–	0.39	36
2001–02	–	–	0.50	35
2002–03	–	–	0.30	33
2003–04	–	–	0.26	38
2004–05	–	–	0.23	35
2005–06	–	–	0.34	34
2006–07	–	–	0.27	35
2007–08	–	–	0.17	37

Table 9: Estimated catches calculated by summing the CDL 2–4 catches from Table 2 (column 2), and increasing them by the overrun values in Table 3 (column 3), with the combined TACC for CDL 2–4 (column 4).

Year	Reported catch	Catch including overruns	TACC
1982–83	76	152	–
1983–84	219	438	–
1984–85	530	1 060	–
1985–86	291	582	–
1986–87	1 812	2 718	–
1987–88	1 585	2 378	–
1988–89	1 495	2 243	–
1989–90	1 756	2 634	–
1990–91	4 072	6 108	–
1991–92	1 801	2 341	–
1992–93	2 071	2 692	–
1993–94	2 597	3 376	–
1994–95	2 265	2 718	–
1995–96	2 682	3 218	–
1996–97	2 017	2 420	–
1997–98	1 567	1 880	–
1998–99	1 490	1 639	2 424
1999–00	2 409	2 650	2 424
2000–01	1 269	1 396	2 424
2001–02	1 868	2 055	2 424
2002–03	2 097	2 307	2 424
2003–04	1 210	1 331	2 424
2004–05	1 194	1 313	2 424
2005–06	2 256	2 482	2 424
2006–07	1 789	1 968	2 485
2007–08	891	980	2 485

5.2 Model structure and runs

Stock assessments were performed using the stock assessment program CASAL (Bull et al 2002) to estimate virgin and current biomass (Dunn 2009). Preliminary model runs were completed using all of the observational data. The key assumptions of the final model runs were:

- The biomass information in the data is primarily contained in the CPUE indices. Therefore, a two-step approach was used to produce the final model runs. In the final runs, selectivity and maturity were fixed at estimates from the preliminary runs and the length frequency and maturity data were not fitted. This ensured that any biomass signal from the length frequency data, potentially caused by errors in estimated growth and selectivity, did not dominate the signal from the CPUE trends.

- For runs assuming an M of 0.027, the selectivity and maturity estimates were similar; therefore the two were estimated separately in final runs.
- The base case with M set at 0.04 and vulnerability set equal to the MCMC median of maturity was considered to be the most credible.
- Runs where maturity and selectivity were estimated separately resulted in selectivity curves displaced to the right of the maturity ogive for $M = 0.04$ and $M = 0.06$, resulting in a proportion of the spawning stock not being available to the fishery (called "cryptic biomass"). The Deepwater Fisheries Assessment Working Group considered that it was unlikely that there existed mature biomass that was not vulnerable to the fishery, and the WG agreed that the age of vulnerability should be fixed to the age at maturity for the base case and for the case with $M = 0.06$. The WG agreed to present a sensitivity model run using $M = 0.04$ and with separately estimated maturity and selectivity to explore the implications of this scenario.

Four model runs are therefore presented, two with selectivity assumed to be the same as maturity and M assumed to be either 0.06 or 0.04, and two with selectivity and maturity fitted as separate ogives and M assumed to be 0.04 or 0.027 (Table 10).

Table 10: Four alternative assumptions to the stock assessment.

Model	M	Selectivity
Base	0.04	Equal to MCMC median maturity
Mat&sel	0.04	Estimated separately
M0.027	0.027	Estimated separately
M0.06	0.06	Equal to MCMC median maturity

The model was fitted using Bayesian estimation and partitioned the population by age (age-groups used were 1–90, with a plus group). The model assumed a single sex, with growth modelled using the von Bertalanffy growth function. The stock was considered to reside in a single area and have a single maturation episode, with maturation modelled by a logistic ogive which was estimated in preliminary model runs. Selectivity of the fishery was assumed to be equal to maturity, or modelled by a logistic ogive estimated in preliminary model runs. The catch equation used was the instantaneous mortality equation from Bull et al (2002), whereby half the natural mortality was applied, followed by the fishing mortality, then the remaining natural mortality. Deterministic recruitment was assumed. A Bayesian estimation procedure was used with a penalty function included to discourage the model from allowing the stock biomass to drop below a level at which the historical catch could not have been taken. Lognormal errors, with known (sampling error) CVs were assumed for the CPUE. In preliminary model runs, an additional process error was estimated and added to the length frequency distributions. Binomial errors were assumed for the proportions mature at length. The final model runs estimated virgin biomass, B_0, and two catchabilities. Confidence intervals were calculated from a posterior distribution of the model parameters, which was estimated using a Markov chain Monte Carlo technique.

5.3 Biomass estimates

Biomass estimates depended on the assumed M, with the M0.027 run resulting in a larger and less productive stock, and the M0.06 run in a smaller and more productive stock (Table 11, Figure 2). Estimates of current biomass were lowest in the Base case.

The Mat&sel run estimated cryptic spawning stock biomass, where vulnerability to the fishery took place after maturity, such that a median of 86% and 62% of the mature biomass was vulnerable to the fishery at virgin and 2009 biomass levels, respectively. It is unclear whether cryptic biomass could occur for black cardinalfish, and it is possible that this result is an artefact generated from the model assumptions. Cryptic biomass was not estimated when maturity and selectivity were estimated separately and M was assumed to be 0.027, and in sensitivity runs the level of cryptic biomass was found to increase as M increased. The wide confidence intervals reflect the uncertainty in the model, which was fitted to only relative biomass indices having relatively high CVs (see Table 8).

Table 11: Biomass estimates (medians rounded to the nearest 100 t, with 95% confidence intervals in parentheses) for the four model runs. $B_{CURRENT}$ is the mid-year biomass in 2009. $p(B_{2009} < 0.1\ B_0)$ is the probability of the mature biomass in 2009 being less than 10% of the virgin mature biomass (B_0). $p(B_{2009} < 0.2\ B_0)$ is the probability of the mature biomass in 2009 being less than 20% of the virgin mature biomass (B_0).

Run	B_0 (t)	$B_{CURRENT}$(t)	%B_0	$p(B_{2009} < 0.1\ B_0)$	$p(B_{2009} < 0.2\ B_0)$
Base	36 800 (32 800–95 400)	4 400 (1 900–60 400)	11.9 (5.9–63.3)	0.41	0.70
Mat&sel	40 800 (35 600–96 700)	7 300 (3 500–61 300)	17.8 (9.9–63.5)	0.13	0.56
*M*0.027	45 100 (39 500–93 500)	6 100 (2 000–53 000)	13.6 (5.0–56.6)	0.32	0.69
*M*0.06	33 800 (25 500–10 700)	8 200 (2 400–82 800)	24.2 (9.6–74.9)	0.16	0.43

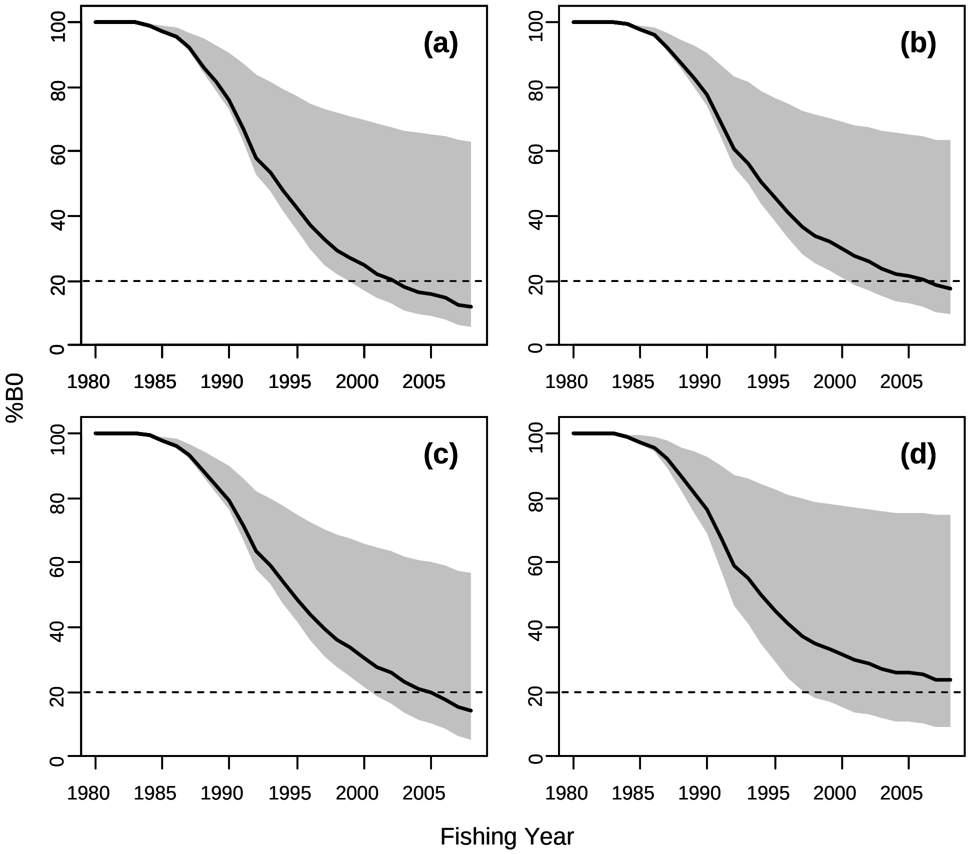


Figure 2: Estimated biomass trajectories (solid line) and 95% confidence intervals (shaded area) for the model runs (a) Base, (b) Mat&sel, (c) *M*0.027, (d) *M*0.06. The horizontal broken line indicates 20% B_0.

5.4 Sensitivity analyses

Several sensitivity analyses were conducted (reported in more detail by Dunn 2009). The assessment was found to be relatively insensitive to the assumed catch overruns. When overruns were either assumed to be zero, or were doubled for the period before 1998–99 (before the TACC was introduced), the mature stock in 2009 was estimated to be slightly less depleted compared with the Base case, at 13.5% (5.9–67.0%) B_0, and 12.2% (5.5–58.3%) B_0, respectively.

5.5 5-year projection results

Forward projections were carried out over a 5-year period using a range of constant catch options. A catch level of 180 t is approximately the level associated with $F = M$, a catch of 890 t is approximately the current (2007–08) catch and a catch of 2490 t is approximately the current (2007–08) TACC. In all projections overrun of 10% was assumed for future catches. For each catch option, three measures of fishery performance were calculated. The first one, %B_0, is the median biomass in 2009 as a percentage of B_0. The second one, $P_{0.1}$, is the probability that the biomass at the end of the 5-year period is less than 10%B_0. The third, $P_{0.2}$, is the probability that the biomass at the end of the 5-year period is less than 20% B_0. At high future catches the biomass may be reduced to such a low level that the catch is unlikely to be able to be taken (assumed to occur when the exploitation rate exceeds 0.9). This is indicated as P(no catch).

All projections indicate that the biomass would increase for all catch levels near or below the 2008–09 catch (890 t) and would continue to decline at catch levels of 1200 t in all runs except $M = 0.06$, where it would remain about the same (Table 12). In all runs the biomass would decline at catch levels equal to the current TACC (2490 t), and there was a 38–71% probability the biomass would decline to a level where the catch could not be taken.

Table 12: Results from forward projections to 2013 for the model runs. $P_{0.1}$ is the probability of the mature biomass in 2013 being less than 10% of the virgin mature biomass (B_0). $P_{0.2}$ is the probability of the mature biomass in 2013 being less than 20% of the virgin mature biomass (B_0). *P*(no catch) is the probability that the catch could not be taken, which is assumed to occur if the exploitation rate exceeds 90%. Current (2007–08) values of %B_0 are shown for each run in parentheses next to the measure. 95% confidence intervals are shown for the %B_0 estimates in 2013. A catch of 180 t is approximately *M* times the current biomass, 890 t is the current catch, and 2490 t is the current TACC.

		Future catch (t)					
Run	**Measure**	**0**	**180**	**530**	**890**	**1200**	**2490**
Base	%B_0 (11.9)	17.6	16.5	14.3	12.6	10.2	5.2
		(8.5–67.4)	(7.01–66.0)	(5.3–63.9)	(3.6–62.7)	(2.9–62.6)	(2.7–56.2)
	$P_{0.1}$	0.11	0.19	0.30	0.40	0.49	0.70
	$P_{0.2}$	0.57	0.60	0.65	0.71	0.74	0.83
	P(no catch)	0	0	0	0	0	0.38
Mat&sel	%B_0 (17.8)	24.5	23.6	20.4	18.6	16.2	9.5
		(14.0–68.8)	(12.9–67.8)	(10.2–65.5)	(8.0–63.4)	(6.5–61.7)	(5.5–57.8)
	$P_{0.1}$	0.00	0.00	0.06	0.14	0.22	0.53
	$P_{0.2}$	0.35	0.38	0.49	0.55	0.61	0.75
	P(no catch)	0	0	0	0	0	0.42
*M*0.027	%B_0 (13.6)	17.9	16.7	14.3	12.0	10.0	4.3
		(7.1–59.4)	(6.2–59.1)	(4.5–56.7)	(2.9–56.5)	(2.2–55.0)	(2.0–50.1)
	$P_{0.1}$	0.14	0.19	0.28	0.40	0.49	0.71
	$P_{0.2}$	0.57	0.60	0.67	0.71	0.75	0.84
	P(no catch)	0	0	0	0	0	0.41
*M*0.06	%B_0 (24.2)	33.6	31.4	29.8	26.3	24.6	17.4
		(13.0–80.2)	(12.5–79.2)	(10.6 –77.5)	(8.3–77.2)	(6.7–75.7)	(4.8–71.2)
	$P_{0.1}$	0.02	0.33	0.07	0.15	0.17	0.35
	$P_{0.2}$	0.27	0.29	0.35	0.40	0.42	0.54
	P(no catch)	0	0	0	0	0	0.71

5.6 Updated characterisation and CPUE analyses

A characterisation and CPUE analyses were conducted using catch and effort data to the end of the 2013–14 fishing year (Bentley & MacGibbon 2016). Catch and effort data were examined in each of nine “zones” which encompassed groups of underwater features where the majority of the cardinalfish catch has been taken: North Colville (NC), Mercury-Colville (MC), White Island (WI), East Cape (EC), Tuaheni High (TH), Richie-Rockgarden (RR), Madden (MD), Wairarapa (WA), and Kaikoura (KK). Within these zones, only tows in the depth range 470–980m (the 2.5th and 97.5th percentiles of the distribution of cardinalfish catch by depth) were considered when characterising effort and performing CPUE analyses.

Catches in each zone have generally declined or remained stable. In CDL 1, most of the catch has come from the Mercury-Colville zone since the early 2000s. In CDL 2, concurrent with a reduction in the TACC, catches have declined in the East Cape, Tuaheni High, and Richie-Rockgarden zones since 2010. In these zones, as in CDL 1, most of the cardinalfish is taken in target tows. In contrast, catches in the Wairarapa and Kaikoura zones have remained relatively constant during this period. In these southern two zones a greater proportion of the cardinalfish catch is taken as bycatch from tows that are targeting species other than cardinalfish and orange roughy. There was no evidence of substantial movement of fishing effort between features within zones.

A CPUE analysis was done using data from all nine zones and year effects estimated for each zone. This suggested that the CPUE trends in all zones were generally similar but that the Wairarapa and Kaikoura zones exhibited a flatter trend since 2000. On this basis, a final CPUE standardisation was done with separate year effects estimated for three regions North (zones North Colville, Mercury-Colville, and White Island; i.e., CDL 1), Central (zones East Cape, Tuaheni High, Richie-Rockgarden, and Madden; i.e., CDL 2 except for Wairarapa) and South (zones Wairarapa and Kaikoura). This standardisation model has the advantage over separate models for each region of using all the available data to estimate vessel coefficients.

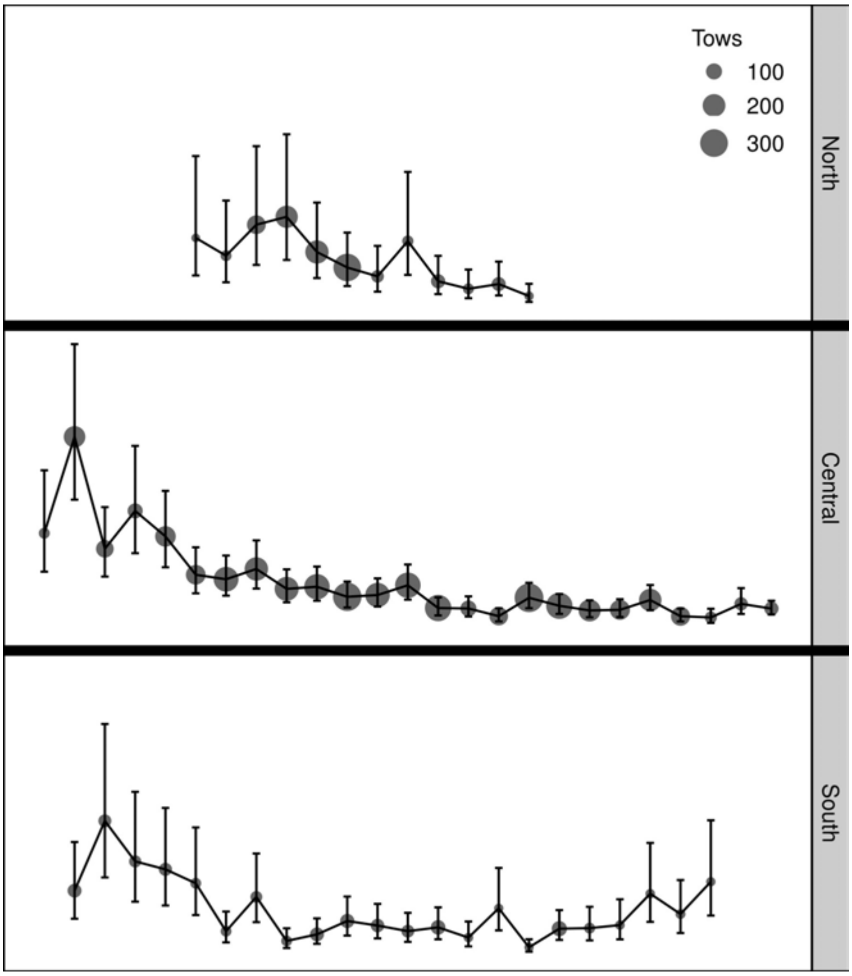


Figure 3: CPUE indices by region (see text for definitions of regions). Region/year combinations with less than 30 tows are not shown. Error bars indicate ± one standard error. Fishing years are indicated by the later calendar year.

6. STATUS OF THE STOCKS

Stock Structure Assumptions

The stock boundaries and number of black cardinalfish stocks in New Zealand is unknown. There are no data on genetics, or known movements of black cardinalfish which indicate possible stock boundaries.

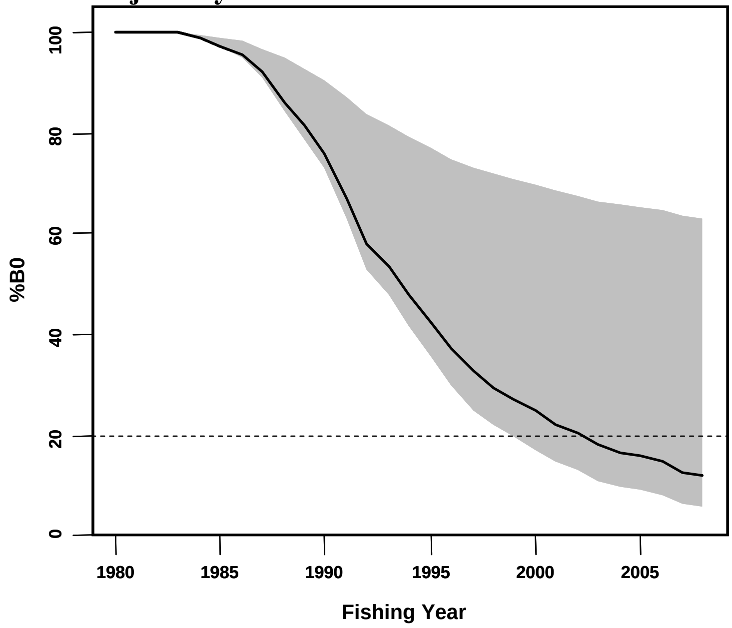
There is evidence that a spawning stock exists in CDL 2, with three geographically close spawning locations identified, on Tuaheni High, Ritchie Bank, and Rockgarden (Dunn 2009). Juveniles of less than 30 cm have been infrequently identified in CDL 2, and more frequently found on the northern flanks of the Chatham Rise, which is south of the spawning grounds in CDL 2. No spawning grounds have been identified on the Chatham Rise, where adult fish are relatively rare.

For the purposes of stock assessment, it has been assumed that black cardinalfish on the east coast North Island (CDL 2) are from the same stock as fish on the north Chatham Rise (CDL 3 and CDL 4).

CDL 2, 3 & 4

Stock Status	
Year of Most Recent Assessment	2009 full assessment 2014 CPUE updated
Assessment Runs Presented	One base case and three sensitivity runs Base case: $M = 0.04$; selectivity equal to maturity Sensitivity runs: various combinations of M and assumptions about the relationship between maturity and selectivity, considered to be less reliable than the base case
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%}$
Status in relation to Target	Very Unlikely (< 10%) to be at or above the target
Status in relation to Limits	Base case: B_{2009} was estimated to be 12% B_0; Likely (> 60%) to be below the Soft Limit and About as Likely as Not (40–60%) to be below the Hard Limit. Other model runs: The range of B_{2009} was estimated to be 14–24% B_0; About as Likely as Not (40–60%) or Likely (> 60%) to be below the Soft Limit and Unlikely (< 40%) to be below the Hard Limit.
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Estimated biomass trajectories (solid line) and 95% confidence intervals (shaded area) for the base case. The horizontal broken line indicates 20% B_0

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has been flat since 2008
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Model projections indicate that the biomass will increase at catch levels near or below the 2007–08 level but will decline sharply at catch levels equal to the TACC.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Likely (> 60%) Hard Limit: About as Likely as Not (40–60%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Soft Limit: Likely (> 60%) Hard Limit: Likely (> 60%)

Assessment Methodology and Evaluation		
Assessment Type	2009 Level 1 - Full Quantitative Stock Assessment 2014 Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2009	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Two commercial catch-per-unit-effort (CPUE) series from the trawl fishery up to 2008 - Estimates of biological parameters	1 – High Quality 1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	First accepted assessment for these stocks	
Major sources of Uncertainty	Major sources of uncertainty include the representativeness of the CPUE data, the relationship between CPUE and abundance, the assumption that recruitment has been constant throughout the history of the fishery, estimates of growth and natural mortality and the catch history.	

Qualifying Comments
The TACC was reduced from 2223 t in 3 stages to the level of 440 t in 2010–11. This level was the maximum annual catch required to rebuild the CDL 2 stock to 30%B_0 within the 24 year period specified in the Harvest Strategy Standard (twice T_{min}). CPUE since 2008 has been flat.

Fishery Interactions
Black cardinalfish is part of the deepwater trawl fishery complex that includes orange roughy and oreo species. Bycatch has not been characterised for the cardinalfish fishery, but is likely to be similar to that of orange roughy and oreo. Incidental captures of protected seabird species have been reported. Bottom trawling for cardinalfish is likely to have effects on benthic community structure and function.

Other QMAs

There is no information on the status of cardinalfish stocks in other QMAs.

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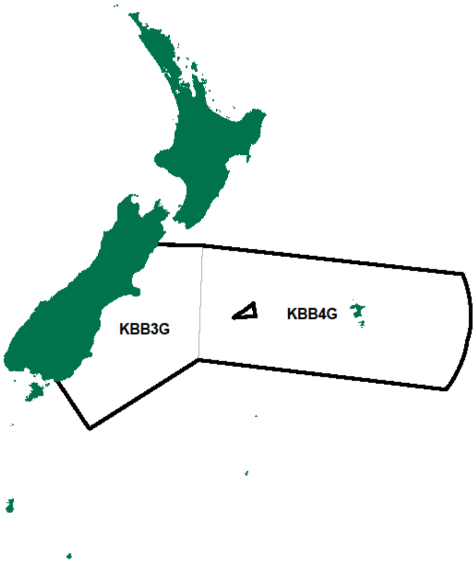
BLADDER KELP ATTACHED (KBB G)

(Macrocystis pyrifera)



1. FISHERY SUMMARY

Attached bladder kelp (KBB G) was introduced into the Quota Management System (QMS) on 1 October 2010, only within FMA 3 and FMA 4, which have the reporting codes KBB 3G and KBB 4G, respectively. The Total Allowable Catch (TAC), Total Allowable Commercial Catch (TACC), recreational, customary, and other mortality allowances issued to KBB G on entering the QMS remain unchanged and are presented in Table 1.

Bladder kelp, like all other large seaweeds, occurs in one of three states: attached (growing on the substrate), free-floating, and beach-cast. The attached growing state of bladder kelp is the only state managed under the QMS. Fisheries New Zealand will continue to monitor the use of beach-cast and free-floating seaweeds in FMAs 3 and 4 and will reconsider introducing these states into the QMS if sustainability and utilisation risks are identified in the future. Separate codes refer to beach-cast bladder kelp in FMA 3 (KBB 3B) and free-floating bladder kelp in FMA 3 and 4 (KBB 3F and KBB 4F). Unless explicitly stated, this section refers to only attached bladder kelp.

Table 1: Total Allowable Catch (TAC, t), Total Allowable Commercial Catches (TACC, t), customary non-commercial (t), recreational (t), and other mortality allowances (t) for attached bladder kelp on entering the QMS on 1 October 2010.

Fishstock	TAC	TACC	Customary non-commercial	Recreational	Other Mortality
KBB 3G	1 238	1 237	0.1	0.1	1.0
KBB 4G	274	273	0.1	0.1	

1.1 Commercial fisheries

Bladder kelp has been used for the production of potash, alginates, dietary supplements, and fertiliser, as well as for abalone and sea urchin feed, and it is also cultivated for bio-remediation purposes (Buschmann et al 2006, Gutierrez et al 2006, Barrento et al 2016, Correa et al 2016). There is current research evaluating the utilisation of bladder kelp as feed for other aquaculture species such as shrimps (Buschmann et al 2006, Cruz-Suárez et al 2009), as well as an evaluation as a possible feedstock for conversion into ethanol for biofuel use (Wargacki et al 2012, Camus et al 2016). Because of the growing demand for bladder kelp, Fisheries New Zealand considered that the bladder kelp resource requires active management to ensure its sustainable use, and that management under the QMS was the most appropriate mechanism. The fishing year for commercial harvest of KBB G is 1 October to 30 September, and catch is measured in greenweight (tonnes).

Restrictions on New Zealand harvests of KBB G have been based on the Californian fishery (where the majority of research into harvesting effects has been conducted) and modified to take into account differences between California and New Zealand. These differences include reduced nutrients in New Zealand waters, the shallower depth at which KBB G is harvested in New Zealand, and the lack of information on New Zealand stocks. Harvesting strategies for wild harvest of *Macrocystis* have also been developed in Chile where *Macrocystis* has a wide geographic range (e.g., Borras-Chavez et al 2012, Almanza & Buschmann 2013, Buschmann et al 2014b).

KBB G harvest is restricted to a maximum cutting depth of 1.2 m, implemented on introduction to the QMS on 1 October 2010. Also, harvest of attached kelp is prohibited within the East Otago Taiāpure.

Harvest of KBB G mainly occurs in QMA 3 and has varied since 2001–02 from 3 t to 105 t (Table 2 and Figure 1). Landings of KBB G in QMA 4 are minimal, with a total of only 2.49 t reported (Table 2).

Table 2: Reported landings for KBB G in greenweight (t) by fishing year. Blank cells indicate nil catches. Values above and below the horizontal line represent historical landings prior to QMS introduction and landings post QMS introduction, respectively. * Pre 2010 landings in KBB 3G include a combination of beach-cast, free-floating, and attached bladder kelp. Pre 2010 landings in KBB 4G may include a combination of free-floating and attached bladder kelp. Post 2010, the reported landings are for attached bladder kelp only.

Fishing Year	KBB 3G	KBB 4G
2001–02	104.50*	0.37*
2002–03	37.00*	
2003–04	7.53*	
2004–05	17.90*	
2005–06	2.82*	
2006–07	8.35*	
2007–08	6.43*	2.10*
2008–09	63.50*	
2009–10	28.37*	
2010–11	53.34	
2011–12	34.25	
2012–13	5.00	
2013–14	94.00	0.00
2014–15	62.00	0.02
2015–16	30.54	0.00
2016–17	41.77	0.00
2017–18	40.81	0.00
2018–19	67.24	0.00
2019–20	72.83	0.00
2020–21	94.00	0.00

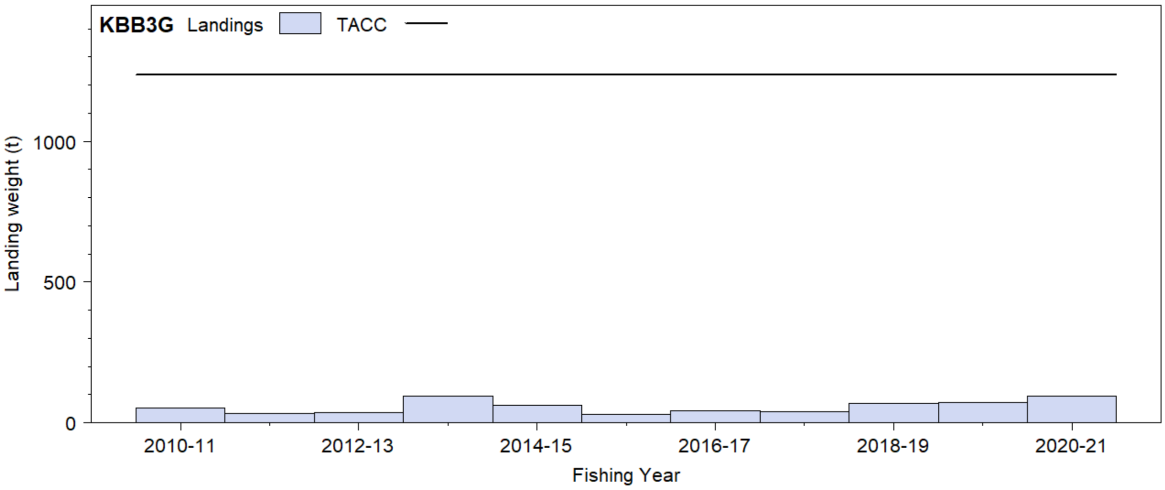


Figure 1: Reported commercial landings and TACC for KBB 3G (east coast, South Island). Note that this figure does not show data prior to entry into the QMS.

1.2 Recreational fisheries

There is no quantitative estimate of recreational harvest of bladder kelp at this time, although it is assumed to be restricted to the collection of beach-cast seaweed for composting. Consequently, recreational harvest of attached bladder kelp is assumed to be negligible.

1.3 Customary non-commercial fisheries

The customary harvest of bladder kelp is currently unrestricted. There is no quantitative information on the extent of customary harvest of attached bladder kelp (or any other state) in FMAs 3 and 4; however, the customary harvest of attached bladder kelp is likely to be negligible.

1.4 Illegal catch

There is some qualitative data to suggest illegal, unreported, unregulated activity in this Fishery.

1.5 Other sources of mortality

Hydrographic factors (e.g., tidal surge, nutrient limitation, temperature, and salinity stress) have been demonstrated to result in significant mortality of bladder kelp (Buschmann et al 2004, 2006, Schiel & Foster 2015). Wave action, both orbital size and velocity, has been shown to be a significant predictor variable for the distribution of kelp beds (Young et al 2015). Reductions in population densities of existing *M. pyrifera* populations have been linked to El Niño cycling and winter storm activity (Zimmerman & Robertson 1985, Seymour et al 1989).

Due to their large size and high drag, adult bladder kelp are vulnerable to removal by high water motion (Dayton et al 1984, Seymour et al 1989, Schiel et al 1995, Fyfe & Israel 1996, Graham et al 1997, Fyfe et al 1999), which is considered the primary agent of mortality. In 1994, Fyfe et al (1999) found that winter storms extensively removed floating surface canopies at Pleasant River (north of Dunedin), and, that by February 1995, 50% of surface canopies had reformed. High seasonal and year-to-year variability in wave intensity and plant biomass results in high intra- and inter-annual variability in mortality. In California, uprooted plants may become entangled with attached plants, increasing drag and the likelihood of detachment, which may result in a 'snowball effect' capable of clearing large swaths in the local population (Dayton et al 1984). For example, Seymour et al (1989) observed that mortality of bladder kelp in California due to storm-induced plant detachment and entangled was as great as 94%. Graham et al (1997) observed that bladder kelp holdfast growth in California decreased significantly along a gradient of increasing wave exposure, possibly due to greater disturbance to the bladder kelp surface canopy, which reduces holdfast growth (Barilotti et al 1985, McCleneghan & Houk 1985). Thus, increased water motion and decreased holdfast strength can act in combination to decrease plant survival.

Light is a key indicator for the distribution of *M. pyrifera* (e.g., Desmond et al 2015, Tait 2019, Tait et al 2021). Sedimentation (coastal erosion, land use changes) negatively affects both the settlement and survival of spores and early growth stages of *M. pyrifera* (e.g., Geange et al 2014, Glover 2020), but also influences the light environment, reducing productivity (e.g., Desmond et al 2015). Movement of bottom sediments can scour or bury bladder kelp spores and recruits, and the resuspension of sediments can reduce the amount of light reaching sub-canopy algae, preventing the attachment and development of spores, and inhibiting the growth of bladder kelp recruits (Dean & Jacobson 1984, Pirker 2002, Tait 2019). Research within the East Otago Taiāpure has demonstrated that kelp forests in the taiāpure are light limited for much of the year and that sediment run-off from the land can reduce their productivity and the extent of the kelp beds (Hepburn et al 2011, Pritchard et al 2013, Desmond et al 2015).

Temperature can influence the timing of the reproductive cycle in *M. pyrifera* (Kain 1982), as well as affecting the viability of different life stages (Kain 1982, Hay 1990, Ladah et al 1999). Over large spatial scales, elevated temperature also appears to be a major influence on bladder kelp mortality and is likely to limit the northern distribution of bladder kelp within New Zealand (Hay 1990). For example, Hay (1990) described an apparent retraction of the distribution of bladder kelp within Cook Strait since 1942, presumably due to increasing surface water temperatures. Cavanaugh et al (2011) compared changes in canopy biomass with oceanographic and climatic data in California. They revealed that winter losses of regional kelp canopy biomass were positively correlated with significant wave height, whereas spring recoveries were negatively correlated with sea surface temperature. On inter-annual timescales, regional kelp-canopy biomass lagged the variations in wave height and sea surface temperatures by 3 years, indicating that these factors affect cycles of kelp recruitment and mortality. The dynamics of kelp biomass in exposed regions were related to wave disturbance, whereas kelp dynamics in sheltered regions tracked sea surface temperatures more closely. In different parts of its geographic and ecological distribution, *M. pyrifera* shows morphological plasticity to different temperature ranges (e.g., Rothäusler et al 2011, Buschmann et al 2014a).

As well as warming oceans, marine heatwaves are being reported throughout the globe, becoming stronger and more frequent. The duration and intensity of these events influences their impacts, and there is strong evidence that these impacts are exacerbated by other stressors. Tait et al (2021) tested the association of surface canopy cover of *M. pyrifera* with sea surface temperature, temperature anomalies, chlorophyll a (a proxy for nutrient availability), and water clarity, using satellite imagery of surface canopies in 4 regions along the east and south coasts of New Zealand. They found a reduced cover of kelp across all regions during and after the marine heat wave of 2017/2018. The least impact was found in the southern region where water temperatures did not exceed 18°C. A very important observation was the significant interaction with water clarity: temperature-induced kelp loss was greater when water clarity was poor.

In Tasmania *Macrocystis* kelp beds were once sufficiently large to be commercially harvested but have declined by approximately half along the east coast since 1944 (Edyvane 2003) effectively being functionally extinct (Butler et al 2020). A further study of the extent of these *Macrocystis* beds, based on a time series of aerial photographs (1946–2007), showed an average canopy extent in the last decade of about 9% of the average canopy extent in the 1940s. The declines were estimated to be up to 95–98% in some locations. In general, declines were less pronounced in southern regions of Tasmania than in northern and eastern regions. The decline in *Macrocystis* has been linked with the progressive southward penetration of warm, salty, nutrient-poor EAC water, which has extended about 350 km further south than 60 years ago (Johnson et al 2011). Because of this decline and the ecosystem functions that this species provides, *Macrocystis* forests were declared an endangered ecological community under the federal Environmental Protection and Biodiversity Conservation Act 1999 in 2012. This dramatic loss of kelp forests is considered to have been driven by a combination of increasing temperature, decreasing nutrients, increased fishing, and increased herbivory by the expanding range of herbivores (Johnson et al 2011, Wernberg et al 2011, Butler et al 2020).

In New Zealand, with current seawater warming trends, including strong evidence of relatively rapid warming within southern waters (Shears & Bowen 2017), the cover of *Macrocystis* across much of its current range in southern New Zealand will be negatively affected. Although temperature was the major driver identified in *Macrocystis* canopy cover decline by Tait et al (2021), it is also evident that declining water clarity (high turbidity and low-light penetration) has negative effects on giant kelp (Desmond et al. 2015, Tait 2019, Tait et al. 2021).

Other human-induced threats include various pollutants that negatively affect bladder kelp. Leal et al (2016) examined the impact of exposure to chronic and high concentrations of copper in both *Macrocystis* and *Undaria* in New Zealand and found that there were differential impacts on meiospore germination, and arrested development of gametogenesis occurred in both species.

Coastal eutrophication has been shown globally to be a key stressor driving losses of major kelp forests (Wernberg et al 2011, Filbee-Dexter & Wernberg 2018). Glover (2020) discusses the impact of land conversion to pasture in New Zealand and the particular implications for increased phosphorous, nitrogen, and *Escherichia coli* (*E. coli*) in local bodies of water, with particular reference to East Otago. While seasonally nutrient concentrations can be limiting for *M. pyrifera* in New Zealand (e.g., Stephens & Hepburn 2016), the nutrients associated with land-use intensification can result in a system shift to turf-dominated ecosystems.

Although wave disturbance and sea surface temperature appear to be the predominant abiotic sources of bladder kelp mortality, there are no quantitative estimates for these sources of mortality available for New Zealand. Further, the relevance of results from studies conducted outside New Zealand may be limited due to differences in hydrographic environment between New Zealand and other locations.

In terms of biological processes, Californian and Chilean studies have shown that grazing by sea urchins can result in the detachment of adult plants and their removal from the population (Dayton 1985a, Tegner et al 1995), and/or the removal of recruits and juvenile plants (Dean & Jacobsen 1984, Dean et al 1988, Vásquez et al 2006). Wernberg et al (2011) discuss the interactions and roles of range extensions of herbivores, over harvest of predators, and introduction of non-indigenous species in conjunction with climate change stressors and the consequent negative impacts on ecological functioning and resilience of kelp forests. The invasive kelp *Undaria pinnatifida*, an opportunistic species that competes with *M. pyrifera* for space (Desmond et al 2019) but offers dramatically reduced ecosystem benefits (Suárez-Jiménez et al 2017, Desmond et al 2018), is also a significant stressor in parts of the kelp's range.

In Chile, infestations of bladder kelp holdfasts by crustaceans (e.g., amphipods and isopods) may increase mortality by decreasing attachment strength (Ojeda & Santelices 1984). Buschmann et al (2014b) summarise information about diseases, covering a range of pathogens and diseases known to occur in kelps, including prokaryotes, viruses, oomycetes, and fungi. Epiphytic and endophytic microscopic algae can also negatively affect kelp. Endophytic diseases can result in tumour-like growths, loss of photosynthetic tissue, and deformation of thalli.

2. BIOLOGY

Historically, two species of bladder kelp, *Macrocystis pyrifera* (Linnaeus) C.Agardh and *M. integrifolia* Bory, were reported from both Northern and Southern hemispheres, and *M. angustifolia* Bory and *M. laevis* Hay were reported from the Southern Hemisphere. However, *M. angustifolia, M. integrifolia,* and *M. laevis* are currently regarded as taxonomic synonyms of *M. pyrifera* (Graham et al 2007, Demes et al 2009). The four previously recognised species are referred to as bladder kelp, *Macrocystis pyrifera.* Macaya & Zuccarello (2010a, b) assessed the genetic structure of *M. pyrifera* across a broad latitudinal range in the southern hemisphere, finding low levels of genetic diversity.

In the 2019 evaluation of the threat status of New Zealand marine macroalgae, *Macrocystis pyrifera* was recorded as "At Risk, Declining", based on the information available at that time (Nelson et al 2019).

Bladder kelp is globally widespread. It is found in the Atlantic Islands (Baardseth 1941, Chamberlain 1965); North America from Alaska to California, Baja, and Mexico (e.g., Carr 1994, Graham et al 2007, Cavanaugh et al 2011); Central America (Taylor 1945); South America from Peru to Chile, Argentina, and Uruguay (e.g., Vásquez et al 2006, Thiel et al 2007, Macaya & Zuccarello 2010b); the Indian Ocean (Silva et al 1996); Tasmania (Cribb 1954, Womersley 1987); sub-Antarctic islands (Ricker 1987, John et al 1994); and New Zealand (Hay 1990, Fyfe & Israel 1996, Brown et al 1997, Hepburn et al 2007).

In New Zealand, bladder kelp has a broad latitudinal distribution (Figure 2), occurring around the southern North Island, the South Island, as well as Stewart, Chatham, Bounty, Antipodes, Auckland, and Campbell islands (Adams 1994, Harper et al 2012). According to Hay (1990) bladder kelp does not persist in New Zealand waters where maximum temperatures exceed 18–19 °C for several days. The northern limit of bladder kelp in the North Island has been reported to be between Castlepoint and Cape Turnagain on the east coast of the North Island, and Kapiti Island on the west coast. No *Macrocystis* has been seen at Castlepoint for at least 40 years, and there are no recent sightings of it at Kapiti Island. The current northern limit of the species appears to be on D'Urville Island in the western Marlborough Sounds (Desmond, pers. comm.), on the west coast of the North Island near Mana Island, and on the east coast of the North Island in Palliser Bay. Hay (1990) considered the distribution of bladder kelp corresponds to the Southland current, which brings cool nutrient-rich water north from the south. The distribution of bladder kelp is generally patchy, and there is both seasonal and inter-annual variation in abundance (Hay 1990, Pirker et al 2000). D'Archino et al (2019) evaluated the known distribution of *M. pyrifera* in the Wellington region, reports of declining populations over time, and methods to monitor populations of *Macrocystis*. The main drivers of retraction in range and declining populations are considered to be a combination of increased sea surface temperature, a combination of reduced light availability and increased sedimentation from terrestrial runoff, and, in some parts of its range, invasion by *Undaria pinnatifida* (Desmond et al 2015, 2018, 2019, Tait et al 2021).

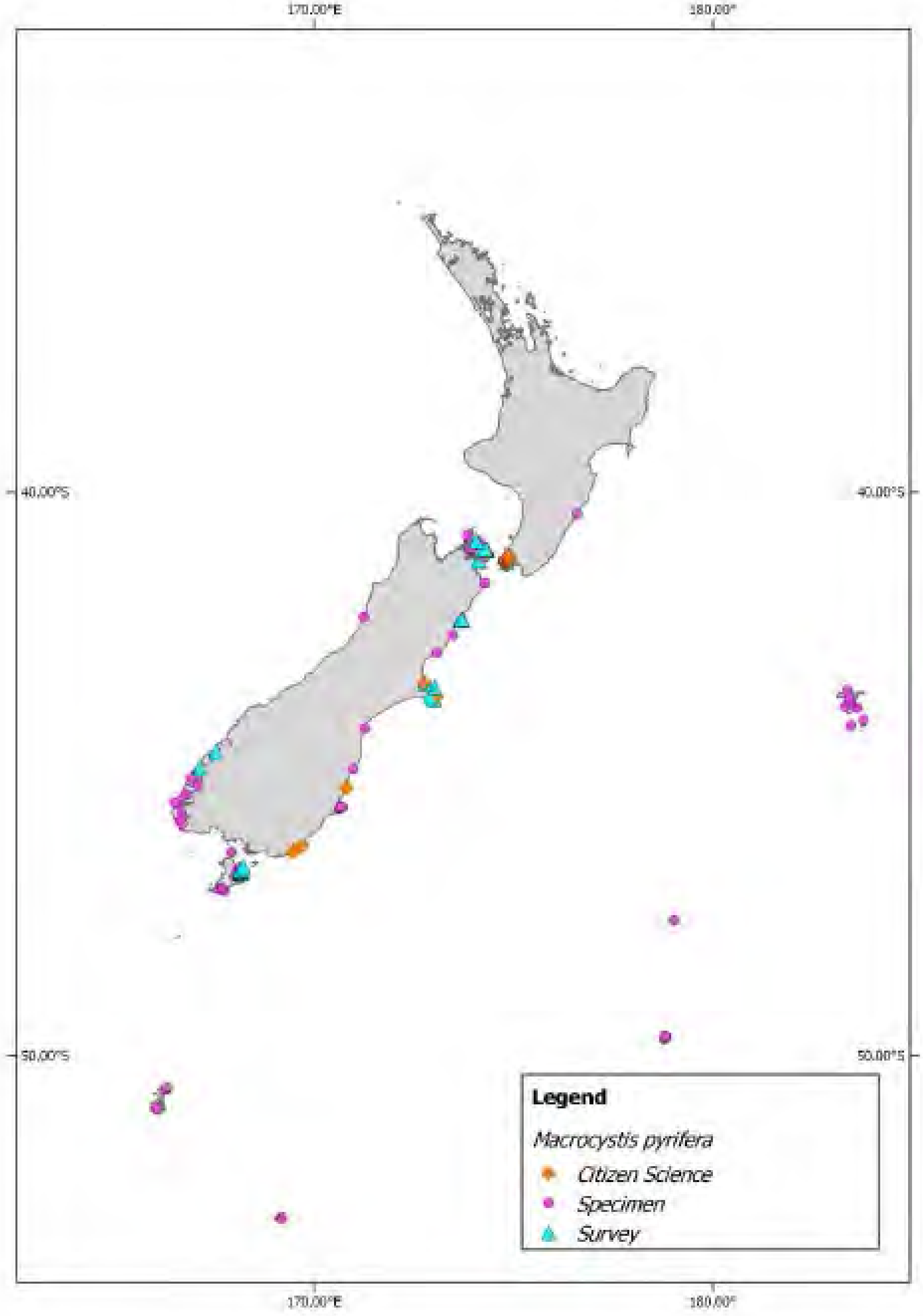


Figure 2: The New Zealand distribution of *Macrocystis pyrifera* (Laminariales) as recorded by citizen science, specimen, and survey records (D'Archino et al 2019).

Schiel & Foster (2015) published a detailed treatment of all aspects of the biology and ecology of *Macrocystis*. Bladder kelp is a large perennial kelp and can grow up to 45 m long in New Zealand, occurring in water 3–20 m deep. Where the bottom is rocky and affords places for it to anchor, bladder kelp grows in extensive beds with large floating canopies and frequently forms colonies or large populations in calm bays, harbours, or in sheltered offshore waters. It can tolerate a wide range of water motion in New Zealand, including areas where tidal currents reach 5–7 knots (Hay 1990). Smaller plants can be found in shallow pools and channels.

Macrocystis has a heteromorphic life history with a conspicuous kelp phase, the sporophyte, and microscopic gametophytes. Individuals of the kelp phase persist for up to five years in California (North 1994). The life history progresses from planktonic zoospores (less than three days longevity) to microscopic benthic gametophytes (7–30 days longevity) and finally macroscopic benthic sporophytes (the large plants visible along the coast) (Figure 3). Adult sporophytes typically consist of numerous vegetative fronds that arise from longitudinal splits in meristem tissue (undifferentiated plant tissue which gives rise to new cells) located just above the holdfast. Vegetative fronds consist of a stipe (stem) terminating in an apical meristem (the primary point of growth at the tip of a frond) which gives rise to new vegetative blades as the frond develops (Figure 3). Blades are attached to the stipe by a single pneumatocyst (gas bladder), which provides buoyancy to the frond. Continued elongation of the stipe, combined with the production of new blades by the apical meristem, results in elongation of the frond and increases in the number of blades. Fronds continue to grow after reaching the surface, forming canopies (Figure 3). Finally, meristem activity ceases in the apical blade and a terminal blade is formed. In California, frond elongation has been observed occurring at a rate of up to 30 cm per day, making bladder kelp one of the fastest growing organisms on earth. Reproductive blades (called sporophylls) are clustered above the holdfast, forming from the lowermost two to six blades on each frond (Figure 3). Sporophylls develop reproductive sporangia (spores) that are densely packed in sori (a cluster of sporangia) on the surface of the sporophylls. Californian studies have shown spores within sporangia take about 14 days to mature, with a mean residence time of about 30 days (Tugwell & Branch 1989). Each sporangium releases numerous mature zoospores that develop into gametophytes (North 1986).

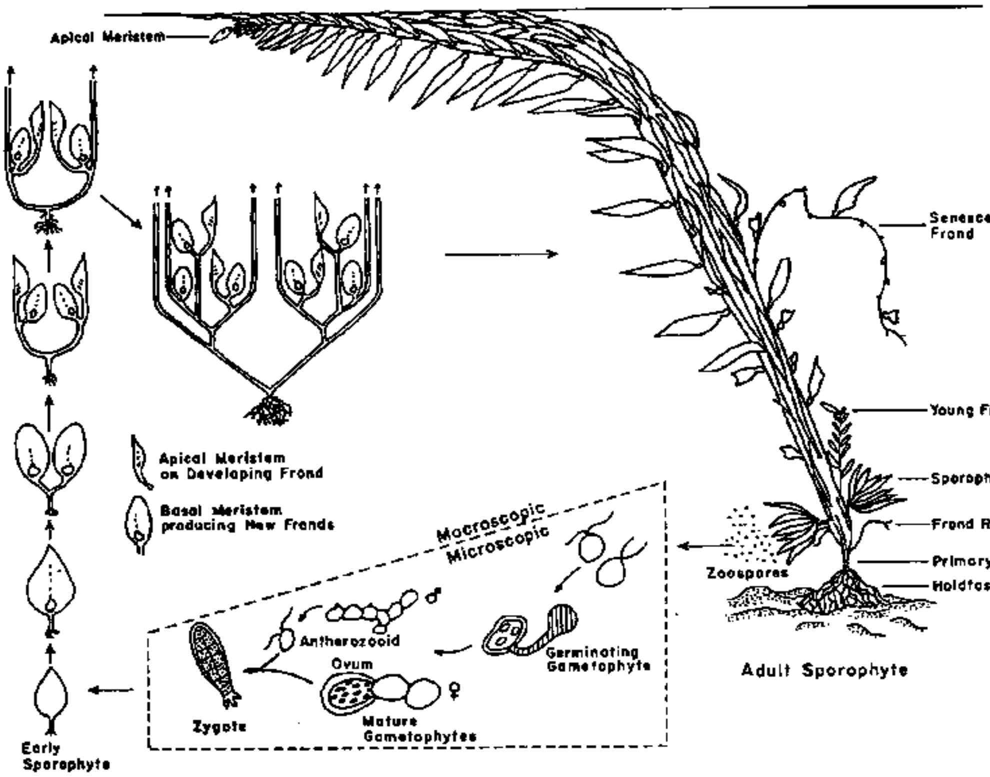


Figure 3: **Diagram of the bladder kelp life cycle showing (left side) development of the young diploid sporophyte, increasing frond numbers through production of basal and apical meristematic blades; (right side) growth habit of an adult diploid sporophyte about two years old, standing in 10 m of water depth, and liberating haploid zoospores; (below centre) development of haploid gametophytes from settled zoospores, proceeding to gametogenesis, and fertilisation yielding the zygote and, thence, a diploid embryonic sporophyte. From North (1986).**

A floating surface canopy consisting of numerous vegetative fronds characterises adult plants. In California, the floating surface canopy comprises 33–50% of total plant biomass and produces approximately 95% of organic production (Towle & Pearse 1973).

Unlike other perennial kelp genera, bladder kelp has limited nutrient and photosynthate storage capabilities, which in New Zealand is about 2 weeks (Brown et al. 1997); consequently, growth by young fronds, reproductive material, holdfasts, and other tissues near the base of the plant is supported by translocation of photosynthates from the canopy, which follows a source-sink relationship (North 1986). Mature canopy tissue exports both upward to the apical meristem at the frond apex, and downward to sporophylls, meristem tissue, holdfasts, and into apical regions of juvenile fronds (Schmitz & Lobban 1976, Lobban 1978, Manley 1984). The ability of bladder kelp to translocate photosynthates allows it to grow in dense aggregations with overlapping canopies that effectively shade out competitors on the bottom, yet support rapid growth by young fronds, sporophylls, holdfasts, and other tissues near the base of the plant. In a bed of *M. pyrifera* in Stewart Island, Stephens & Hepburn (2016) investigated how *in* *situ* pulses of nitrate (NO_3^-) affected the growth and nitrogen physiology of *M. pyrifera*, measuring multiple parameters (e.g., growth, pigments, soluble NO_3^-) in distinct tissues throughout entire fronds (apical meristem, stipe, adult blade, mature blade, sporophyll, and holdfast). Labelled ^{15}N was used to trace nitrogen uptake and translocation from nitrogen sources in the kelp canopy to sinks in the holdfast, 10 m below. Their research provided the first evidence of long-distance (> 1 m) transport of N in macroalgae.

Macrocystis pyrifera is a species that demonstrates high morphological, physiological, and life-history plasticity, allowing it to adapt to different nitrogen environments around the globe (refer Graham et al 2008, Buschmann et al 2014a, Schiel & Foster 2015). Patterns in physiological parameters suggest that *M. pyrifera* displays functional differentiation between canopy and basal tissues that may aid in nutrient-tolerance strategies, similar to those seen in higher plants and unlike those seen in more simple algae (i.e., non-kelps). In a study conducted at Stewart Island, Stewart (2015) showed that *M. pyrifera* growing on the edge of a kelp bed displayed higher growth rates and higher tissue carbon and nitrogen concentrations than kelp found in the interior of the same bed. He attributed these differences primarily to edge individuals receiving more light than interior individuals. Stephens & Hepburn (2014) examined intra-specific differences in kelp growth, physiology, and tissue chemistry and whether these can be attributed to differences in mass-transfer within the same bed. They investigated whether a mass transfer gradient across *M. pyrifera* kelp beds exists, and then whether this exposure gradient influences growth, erosion, pigment concentrations, tissue nitrogen, and C:N ratios. While variation in kelp growth has been previously demonstrated to occur between beds (Gerard & Mann 1979, Hepburn et al 2007), Stephens & Hepburn (2014) provided the first evidence that *M. pyrifera* growth within a singular site is not uniform and that the differences in growth rates presented here can be attributed to hydrodynamic gradients over relatively small spatial scales (tens of metres).

Macrocystis blades from wave-exposed locations have been found to have thicker tissue and are narrower than blades collected from wave sheltered locations (Hurd & Pilditch 2011). The blades from exposed sites exhibited surface corrugations, while those from sheltered sites were smooth, altering the diffusion boundary layer and modifying uptake of nutrients. Stephens & Hepburn (2016) found that nitrogen fertilisation did not enhance elongation rates within the frond, but instead thickness (biomass per unit area) increased in adult blades. They considered that increased blade thickness may enhance tissue integrity because fertilised kelp had lower rates of blade erosion.

The reliance on surface fronds for translocated photosynthate, combined with their vulnerability to disturbance, results in considerable spatial and temporal variability in bladder kelp productivity and size. For example, Graham et al (1997) observed that bladder kelp holdfast growth in California decreased significantly along a gradient of increasing wave exposure, possibly due to greater disturbance to the bladder kelp surface canopy. Similarly, Miller & Geibel (1973) and McCleneghan & Houk (1985) observed reduced holdfast growth in bladder kelp following the experimental removal of surface canopies in California. Reed (1987) demonstrated that a 75% thinning of vegetative fronds in California led to an approximate 75% decrease in the generation of reproductive blades.

Understanding the morphological variation and adaptation in *M. pyrifera* has important implications for understanding intra-site nutrient acquisition, the excretion of wastes, and, therefore, for primary productivity. Stephens & Hepburn (2014) showed that there is greater hydrodynamic variability within and across relatively small macroalgal beds than previously understood and this fine-scale variability also has important implications for key processes surrounding nutrient uptake and for photosynthesis and primary productivity.

Graham (2002) identified shifts in the reproductive condition of Californian bladder kelp from fertile to completely sterile in response to episodic, sub-lethal frond grazing by amphipods. This change in reproductive condition occurred despite relatively constant sporophyll biomass. Finally, in a New Zealand study, Geange (2014) identified an apparent trade-off between vegetative growth and the generation of reproductive sporophylls. Relative to controls, the removal of surface canopies did not result in decreased frond generation, despite an 86% reduction in the generation of reproductive blades. Geange (2014) also found that 89% of plants became completely sterile 50 days after canopy removal, with effects persisting for up to 83 days.

Growth of bladder kelp in New Zealand appears to be seasonal. Autumn and winter growth rates in 1988 in Otago Harbour were estimated at approximately 1–20 mm per day (Table 3, Brown et al 1997). Brown et al (1997) identified a seasonal pattern of blade relative growth rate (RGR) in Otago Harbour, where blade RGRs during 1986–87 were similar year-round, except for summer when lower rates were recorded. Brown et al (1997) concluded that sufficiently high irradiance levels and seawater nutrient concentrations support relatively constant growth throughout most of the year, but that growth was nutrient-limited during summer months when seawater nitrate levels decline. However, the research of Hepburn et al (2007) and Hurd (2017) showed growth rates to be enhanced by water velocity in modifying the seasonal pattern of *M. pyrifera* growth by ameliorating the negative effect of low seawater nitrogen concentrations during summer and autumn.

Table 3: Growth parameters for KKB G canopy (> 2.25 m) and submerged fronds at Aquarium Point, Otago Harbour during autumn (March/April/May) and winter (June/July/August) 1988. Adapted from Brown et al (1997).

	Frond type	
Growth parameter	**Canopy**	**Submerged**
Frond-elongation rate		
autumn	1.90 cm d^{-1}	1.20 cm d^{-1}
winter	2.00 cm d^{-1}	1.30 cm d^{-1}
Relative frond-elongation rate		
autumn	0.0065 d^{-1}	0.0080 d^{-1}
winter	0.0066 d^{-1}	0.0130 d^{-1}
Node-initiation rate		
autumn	0.33 nodes d^{-1}	0.28 nodes d^{-1}
winter	0.30 nodes d^{-1}	0.30 nodes d^{-1}
Relative node-initiation rate		
autumn	0.0047 d^{-1}	0.0064 d^{-1}
winter	0.0044 d^{-1}	0.0089 d^{-1}
Net blade-elongation rate		
autumn	9.40 cm d^{-1}	5.40 cm d^{-1}
winter	12.80 cm d^{-1}	12.10 cm d^{-1}
Elongation rate of immature blades		
autumn	0.22 cm d^{-1}	0.08 cm d^{-1}
winter	0.21 cm d^{-1}	0.10 cm d^{-1}
Relative elongation rate of immature blades		
autumn	0.0380 d^{-1}	0.0010 d^{-1}
winter	0.0360 d^{-1}	0.0010 d^{-1}

3. STOCKS AND AREAS

In New Zealand, patches of bladder kelp are typically small and discrete, usually less than 100 m^2, although large beds (less than 1 km^2) are found along the North Otago coast (Fyfe et al 1999). Although there are anecdotal accounts of changes in the distribution of *Macrocystis* in New Zealand, particularly in the northern portion of its range near Cape Campbell and in the Marlborough Sounds, and also in offshore Otago sites, baseline data are very limited, and the extent of population and distributional declines remain unclear (D'Archino et al 2019). Although there are currently no data evaluating stock structure for bladder kelp in New Zealand, Alberto et al (2010, 2011) found low, but significant, genetic differentiation over a 70 km stretch of coast in the Santa Barbara Channel in southern California. In a New Zealand context, where stands of bladder kelp are small and discrete, these results suggest that stocks may display strong spatial structuring; however, these results should be viewed with caution because current regimes in the Santa Barbara Channel are strongly unidirectional. Research conducted at University of Otago is currently investigating genetic structure of *M. pyrifera* around New Zealand (Desmond & Le pers. comm.).

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was first introduced to the May 2013 Plenary after review by the Aquatic Environment Working Group and has been updated subsequently as relevant research has been undertaken and published.

4.1 Role in the ecosystem

Macrocystis pyrifera is a large and complex organism that can alter the surrounding physical environment and buffer interior kelp individuals from wave and current movement. Forests of bladder kelp are amongst the most productive marine communities in temperate waters. They act as keystone species, altering the abiotic environment and providing vast amounts of energy and highly structured three-dimensional habitat (Foster & Schiel 1985, Graham 2004, Graham et al 2008, Schiel & Foster 2015, Hepburn 2019). Kelp forests provide a key habitat for reef fishes (Win 2011) and their canopy provides a surface for attachment for many organisms (Hepburn & Hurd 2005), providing physical habitat for organisms both above and below the benthic boundary layer (Foster & Schiel 1985). Kelp forests are key kōhanga (nursery) areas for fish (Win 2011) and are thought to allow for the settlement of larvae of kōura (crayfish, *Jasus edwardsii*) and perhaps pāua by slowing water flow, allowing passing larvae to reach the seabed and providing a refuge for newly settled recruits (Hinojosa et al 2015, Hesse et al 2016, Hepburn 2019).

In California, bladder kelp has been identified as altering abiotic and biotic conditions by dampening water motion and as a result may help prevent coastal erosion (Jackson & Winant 1983, Jackson 1998, Gaylord et al 2012), altering sedimentation (North 1971), shading the sea floor (Reed & Foster 1984, Edwards 1998, Dayton et al 1999, Clark et al 2004), scrubbing nutrients from the water column (Jackson 1977, 1998), and stabilising substrata (North 1971).

There are three primary components to the provisioning of habitat by attached bladder kelp: the holdfast, the midwater fronds, and the surface canopy (Foster & Schiel 1985). Studies from California, Canada, Chile, the Sub-Antarctic, Tasmania, and New Zealand have shown that a highly diverse assemblage of organisms colonises each of these three components. Holdfasts are primarily colonised by algae and invertebrates and encrusted with bryozoans and sponges. The midwater fronds and surface canopies are host to a variety of sessile and mobile invertebrates (e.g., amphipods, top snails, and turban snails), encrusting bryozoans, and hydroids. Juvenile and adult fishes may also associate with midwater and canopy fronds, although kelp-fish associations in New Zealand appear to be weaker than those reported in California.

Although the following associations are not exclusive, the major species associated with bladder kelp forests in New Zealand include: (i) understory brown algae, *Ecklonia radiata*, *Carpophyllum flexuosum*, *Marginariella boryana*, and *Cystophora platylobium*; (ii) a rich fauna of sessile invertebrates, including *Callana* spp*.*, *Calliostoma granti*, *Cookia sulcata*, *Evechinus chloroticus, Haliotis iris*, *Trochus* spp.; and (iii) fishes, including *Notolabrus celidotus*, *N. cinctus*, *Odax pullus*, and *Parika scaber* (Pirker et al 2000, Shears & Babcock 2007). Large stands of *Macrocystis pyrifera* play a particularly important role in supporting culturally and commercially important local fisheries species such as *Haliotis iris* (pāua), *Jasus edwarsii* (southern rock lobster), *Parapercis colias* (blue cod), *Evechinus chloroticus* (kina), and *Odax pullus* (greenbone) (Fyfe et al 1999, Hinojosa et al 2015). D'Archino et al (2019) present an example of a community food web based on survey data from the East Otago Taiāpure community, showing the relationships and patterns of association between species or among groups. The *Macrocystis* node was found to be strongly linked to other species, emphasising its role as a foundational member of the community.

A significant proportion of annual kelp production becomes free-floating and beach-cast in response to storm events, seasonal mortality, or ageing. Bladder kelp continues to provide habitat resources after detachment from the substratum. Studies from California, Chile, Macquarie Island, South Georgia, and Tasmania have shown that holdfasts, midwater fronds, and canopies can retain epifaunal fishes and mobile and sessile invertebrates when drifting long distances and play an important role in the dispersal of invertebrates and fishes (Edgar 1987, Vásquez 1993, Helmuth et al 1994, Hobday 2000a, b, c, Smith 2002, Macaya et al 2005, Thiel & Gutow 2005a, b). Mature free-floating individuals may also be important in the connectivity of bladder kelp populations and may explain low genetic diversity of bladder kelp over large geographic extents in the south-eastern Pacific (Thiel et al 2007, Macaya & Zuccarello 2010b).

The beach-cast state is either washed back into the sea over subsequent tidal cycles or remains in the beach environment. New Zealand and Californian studies demonstrate that it is incorporated into physical beach processes, or into the terrestrial or marine food webs through consumption and decomposition (Inglis 1989, Lastra et al 2008). In New Zealand, beach-cast material supports a diverse ecology of organisms through nutrient cycling and decomposition, including various micro- and macro-fauna (Inglis 1989, Marsden 1991) and, if washed up high enough on the beach, can aid sand dune formation.

4.2 Incidental catch (fish and invertebrates)

Small scale harvesting experiments carried out in Akaroa Harbour showed that harvesting canopy biomass had no measurable effect on bladder kelp and the dominant understorey species (Pirker et al 2000).

4.3 Incidental catch (marine mammals, seabirds, and protected fish)

None known.

4.4. Benthic interactions

None known.

4.5 Other considerations

None known.

5. STOCK ASSESSMENT

Currently there is insufficient information on canopy area and density to allow for a stock assessment for KBB G. Furthermore, due to large temporal and spatial variation in bladder kelp growth, estimates of biomass should be looked at conservatively when applying regional scale management.

Large spatial and temporal fluctuations in biomass within and between individual kelp forests necessitates the need for initial annual stock assessments of targeted beds to determine credible biomass and sustainable yield information to ensure long-term sustainability (Pirker et al 2000). A combination of aerial photography and *in situ* measurements provide a useful approach for assessing canopy biomass (Fyfe & Israel 1996, Fyfe et al 1999, Pirker et al 2000), although in some populations canopies are not present at the water surface and may remain undetected. Additional approaches to monitoring kelp beds are discussed by D'Archino et al (2019) and D'Archino & Piazzi (2021).

5.1 Estimates of fishery parameters and abundance

No estimates of fishery parameters or abundance are available at present.

5.2 Biomass Estimates

Maximum biomass occurs in winter (Cummack 1981, Pirker et al 2000). Growth rates and peaks in biomass can vary significantly over very short distances (i.e., kilometres) and temporal scales (i.e., seasonally) in response to changes in currents, light, nutrient levels, and other environmental factors. Fyfe et al (1999) found that the wet biomass of closed canopy at Pleasant River in KBB 3 fluctuated from an estimated 10 639 g m^{-2} (SE = 1566) in November 1995 to 3761 g m^{-2} (SE = 1237) in November 1996. Pirker et al (2000) noted that marked differences exist in the demography of bladder kelp at a spatial scale of only a few kilometres—and that beds decline and regenerate at different times. Because of the apparent rapid spatio-temporal fluctuations in biomass, the status of KBB 3G and KBB 4G biomass is unknown and unable to be reliably estimated using currently available information. Therefore, Fisheries New Zealand was unable to ascertain whether the current biomass of both attached bladder kelp stocks is stable, increasing, or decreasing.

There is some limited information on past harvestable bladder kelp biomass and potential yield at three sites in Akaroa Harbour (Wainui, Ohinepaka, and Mat White bays, located in KBB 3G) where Pirker et al (2000) estimated a combined annual harvestable canopy biomass of 377 tonnes for 1999. Further, Pirker et al (2000) concluded that at Akaroa Harbour sites no one forest was capable of supporting the removal of consistent amounts of canopy, although two harvests could be sustained per year—one in late spring/early summer just prior to frond senescence, and then another cut in late autumn/early winter. However, this estimate should be treated with caution; the survey provides only seasonal point estimates of harvestable biomass during the time the survey was conducted, with the 1999 estimate being the highest. Further, the 1999 estimate does not provide an indication of biomass at a QMA level.

There is also some limited information on the location of bladder kelp beds throughout KBB 3, although the biomass of floating surface canopies is unknown. In November 1995, Fyfe et al (1999) used aerial photography to quantify whole plant biomass (surface canopies and subsurface fronds) of bladder kelp forests at Pleasant River. They estimated 42 ha of closed bladder kelp canopy and 43 ha of broken canopy, with a combined biomass of 7900 tonnes (± 1300).

5.3 Yield estimates and projections

MCY cannot be estimated because absolute biomass has not been estimated.

CAY cannot be estimated.

5.4 Other yield estimates and stock assessment results

No information is available.

5.5 Other factors

It is not known whether the biomass of bladder kelp is stable or variable, but the latter is considered more likely.

6. STATUS OF THE STOCKS

KBB 3G

Stock Structure Assumptions
No information is currently available to determine biological stocks for bladder kelp. Therefore, where quota has been allocated this has been to existing fishery management areas (3 and 4).

Stock Status	
Year of Most Recent Assessment	1995 and 1999
Assessment Runs Presented	Survey biomass from different parts of KBB 3
Reference Points	Interim Target: 40% B_0 Interim Soft Limit: 20% B_0 Interim Hard Limit: 10% B_0 Interim Overfishing threshold: F_{MSY}
Status in relation to Target	Due to the relatively low levels of exploitation it is likely that all stocks are still effectively in a virgin state, therefore they are Very Likely (> 90%) to be at or above the target
Status in relation to Limits	Very Unlikely (< 10%) to be below the soft and hard limits
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status
-

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown
Recent Trend in Fishing Intensity or Proxy	Fishing is light in KBB 3G averaging 41 t since 2001–02, with a maximum of 104.5 t in 2001–02.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown

Probability of Current Catch or TACC causing Biomass to remain below, or to decline below, Limits	Current catches are Very Unlikely (< 10%) to cause declines below soft or hard limits
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Current catches are Very Unlikely (< 10%) to cause overfishing to continue or commence

Assessment Methodology and Evaluation		
Assessment Type	Level 2 Partial quantitative stock assessment	
Assessment Method	Ground-truthed remote sensing biomass surveys	
Assessment Dates	Latest assessment: 1995 and 1999 (in different areas of KBB 3)	Next assessment: Unknown
Overall assessment quality rank	1-High quality: it is very likely that fishing is light and having little impact	
Main data inputs (rank)	Biomass surveys	2 - Medium or mixed quality because surveys only cover part of the range and are dated
Data not used (rank)	-	-
Changes to Model Structure and Assumptions	-	-
Major Sources of Uncertainty	-	-

Qualifying Comments
There are large temporal and spatial fluctuations in biomass within and between beds; therefore, biomass estimates should be utilised conservatively.

Fishery Interactions
Bladder kelp plays an important role in structuring habitats and provides both dissolved and particulate carbon to nearshore food chains, and also contributes drift material that ends up in the deep ocean as well as being beach-cast (and potentially resuspended) with breakdown products contributing to both terrestrial and marine food webs. Effects of harvesting canopy biomass on associated or dependent species has not been measured in New Zealand and would be dependent upon the methods used and the quantities taken relative to the population size and standing crop.

KBB 4G

Stock Structure Assumptions

No information is currently available to determine biological stocks for bladder kelp. Therefore, where quota has been allocated this has been to existing fishery management areas (3 and 4).

Stock Status	
Year of Most Recent Assessment	None
Assessment Runs Presented	None
Reference Points	Interim Target: 40% B_0 Interim Soft Limit: 20% B_0 Interim Hard Limit: 10% B_0 Interim Overfishing threshold: F_{MSY}
Status in relation to Target	Due to the relatively low levels of exploitation it is likely that all stocks are still effectively in a virgin state, therefore they are Very Likely (> 90%) to be at or above the target
Status in relation to Limits	Very Unlikely (< 10%) to be below the soft and hard limits
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring
Historical Stock Status Trajectory and Current Status	
-	

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown
Recent Trend in Fishing Intensity or Proxy	Fishing is very light in KBB 4G with less than 3 t reported since 2001–02.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below, or to decline below, Limits	Current catches are Very Unlikely (< 10%) to cause declines below soft or hard limits
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Current catches are Very Unlikely (< 10%) to cause overfishing to continue or commence

Assessment Methodology and Evaluation		
Assessment Type	-	
Assessment Method	-	
Assessment Dates	-	Next assessment: Unknown
Overall assessment quality rank	-	
Main data inputs (rank)	-	-
Data not used (rank)	-	-
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
There are large temporal and spatial fluctuations in biomass within and between beds; therefore, any biomass estimates in the future should be utilised conservatively.

Fishery Interactions
Bladder kelp plays an important role in structuring habitats and provides both dissolved and particulate carbon to nearshore food chains, and also contributes drift material that ends up in the deep ocean as well as being beach-cast (and potentially resuspended) with breakdown products contributing to both terrestrial and marine food webs. Effects of harvesting canopy biomass on associated or dependent species has not been measured in New Zealand and would be dependent upon the methods used and the quantities taken relative to the population size and standing crop.

7. FUTURE RESEARCH CONSIDERATIONS

Future high priority research areas include: (i) updated (or new in the case of KBB 4G) biomass surveys; (ii) an evaluation of stock structure and inter-stock genetic differentiation; and (iii) quantitative estimates for different sources of mortality.

8. FOR FURTHER INFORMATION

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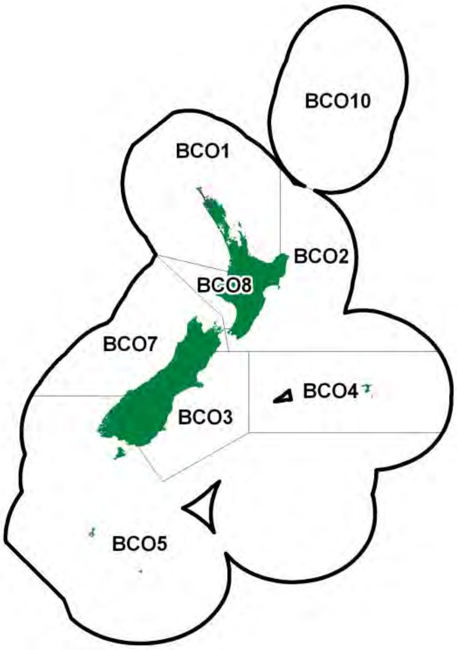
BLUE COD (BCO)

(Parapercis colias)
Rāwaru



1. FISHERY SUMMARY

Allowances, TACCs, and TACs are shown in Table 1.

Table 1: Recreational and Customary non-commercial allowances (t), other mortality (t), TACCs (t), and TACs (t) for blue cod by Fishstock as at 1 October 2021.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
BCO 1	2	2	–	46	50
BCO 2	–	–	–	10	10
BCO 3	83	20	10	130	243
BCO 4	20	10	40	759	829
BCO 5	85	20	20	800	925
BCO 7	–	–	–	70	–
BCO 8	188	2	2	34	226
BCO 10	–	–	–	10	10

1.1 Commercial fisheries

Blue cod is predominantly an inshore domestic fishery with very little deepwater catch. The major commercial blue cod fisheries in New Zealand are off Southland and the Chatham Islands, with smaller but regionally significant fisheries off Otago, Canterbury, the Marlborough Sounds, and Wanganui.

The fishery has had a long history. National landings of up to 2400 t were reported in the 1930s and landings of over 1500 t were sustained for many years in the 1950s and 1960s (see Table 2). Fluctuations in annual landings since the 1930s can be attributed to World War II, the subsequent market for frozen blue cod for a short period of time, and then the development of the rock lobster fishery. Annual landings of blue cod also vary with the success of the rock lobster season. Traditionally many blue cod fishers were primarily rock lobster fishers. Therefore, the amount of effort in the blue cod fishery tended to depend on the success of the rock lobster season, with weather conditions in Southland affecting the number of ‘fishable’ days.

The commercial catch from the BCO 5 fishery is almost exclusively taken by the target cod pot fishery operating within Foveaux Strait and around Stewart Island (Statistical Areas 025, 027, 029, and 030). Similarly, the BCO 3 commercial catch is dominated by the target pot fishery, although blue cod is also taken as a small bycatch of the inshore trawl fisheries operating within BCO 3. Most of the catch from BCO 3 is taken in the southern area of the Fishstock (Statistical Area 024). Catches from BCO 3 and

BCO 5 peak during autumn and winter and the seasonal nature of the fishery is influenced by the operation of the associated rock lobster fishery.

Total landings averaged 574 t in the 1970s before building up to 1546 t in 1985, the year before the QMS was implemented. Landings then declined to 1989 but have since increased, coinciding with a change in the main fishing method from hand lines to cod pots. Historical landings are given in Table 2, recent reported landings are given in Table 3, and Figure 1 shows the historical landings and TACC values for the five main BCO Fishstocks. FSU landings 1970 to 1983 are given in Table 4.

During the fishing years 1994–95 to 2017–18, total landings exceeded 2000 t annually, peaking at 2501 t in 2003–04. In 2018–19 landings dropped to 1844 t and in 2020–21, when the overall TACC was reduced to 1892 t, 1747 t were landed. Historically, the largest catches of blue cod have been taken in BCO 5 (1556 t in fishing year 2003–04). The total landings from this fishery remained relatively stable from 1982 to 1993 and subsequently increased to approach the level of the TACC in 1995–96. Landings have been declining since 2003–04, and the TACC was lowered to 1239 t in 2011–12. In 2018–19, less than 1000 t of landings were recorded for the first time since 1991–92; 926 t were landed in 2019–20. In 2020–21, the BCO 5 TACC was lowered to 800 t and 788 t were landed.

Table 2: Reported landings (t) for the main QMAs from 1931 to 1982.

Year	BCO 1	BCO 2	BCO 3	BCO 4	BCO 5	BCO 7	BCO 8
1931–32	29	0	55	148	719	4	4
1932–33	12	0	59	111	726	1	5
1933–34	24	5	26	1 055	792	3	2
1934–35	17	5	23	1 306	1057	0	4
1935–36	18	23	34	1 197	284	44	2
1936–37	3	7	27	755	113	61	0
1937–38	2	8	31	793	172	81	0
1938–39	2	3	19	686	94	57	0
1939–40	1	4	33	715	135	68	0
1940–41	3	7	39	320	177	72	0
1941–42	2	5	30	189	128	54	0
1942–43	3	5	20	204	139	65	0
1943–44	4	12	31	212	221	80	0
1944	3	10	38	216	552	88	0
1945	8	6	45	102	634	109	0
1946	11	9	43	175	715	116	2
1947	8	22	81	278	955	153	1
1948	7	24	74	623	852	88	2
1949	37	6	98	390	929	82	3
1950	5	5	66	485	1005	94	1
1951	4	9	51	494	873	74	2
1952	5	7	53	543	889	95	3
1953	7	20	62	682	414	114	2
1954	5	9	84	603	385	112	2
1955	4	8	83	355	405	79	3
1956	1	7	86	636	656	77	2
1957	2	5	63	1185	581	61	2
1958	2	4	57	892	542	71	2
1959	1	2	51	1158	492	71	1
1960	1	4	48	903	757	65	2
1961	1	2	43	871	590	55	3
1962	1	9	37	550	668	65	3
1963	1	12	46	633	621	60	4
1964	1	107	83	495	462	70	3
1965	1	18	55	742	296	59	2
1966	1	395	35	13	337	79	6
1967	1	437	34	0	518	74	5
1968	1	312	69	0	494	105	2
1969	6	232	92	8	361	60	1
1970	0	402	70	39	432	70	8
1971	1	105	81	36	375	44	2
1972	0	137	60	3	194	63	1
1973	1	127	65	4	571	68	11
1974	0	67	61	1	486	61	16
1975	0	5	42	2	232	58	14
1976	0	103	72	17	254	58	17
1977	2	3	21	46	208	87	19
1978	0	9	49	14	197	104	12
1979	0	17	74	13	217	98	16
1980	1	1	89	1	403	62	18
1981	1	2	69	40	494	79	23
1982	7	0	62	13	356	68	34

Table 3: Reported landings (t) of blue cod by Fishstock from 1983 to present and actual TACCs (t) from 1986–87 to present. QMS data from 1986 to present. FSU data cover 1983–1986. [Continued on next page]

Fishstock	**BCO 1**		**BCO 2**		**BCO 3**		**BCO 4**		**BCO 5**	
FMA (s)	**1 & 9**		**2**		**3**		**4**		**5 & 6**	
	Landings	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**
1983*	23	–	4	–	81	–	192	–	626	–
1984*	39	–	6	–	74	–	273	–	798	–
1985*	21	–	3	–	55	–	274	–	954	–
1986*	19	–	2	–	82	–	337	–	844	–
1986–87	8	30	1	10	84	120	417	600	812	1 190
1987–88	9	40	1	10	148	140	204	647	938	1 355
1988–89	8	42	1	10	136	142	279	647	776	1 447
1989–90	10	45	1	10	121	151	358	749	928	1 491
1990–91	12	45	< 1	10	144	154	409	757	1 096	1 491
1991–92	10	45	1	10	135	154	378	757	873	1 536
1992–93	12	45	4	10	171	156	445	757	1 029	1 536
1993–94	14	45	2	10	142	162	474	757	1 132	1 536
1994–95	13	45	1	10	155	162	565	757	1 218	1 536
1995–96	11	45	2	10	158	162	464	757	1 503	1 536
1996–97	13	45	2	10	156	162	423	757	1 326	1 536
1997–98	16	45	4	10	163	162	575	757	1 364	1 536
1998–99	12	45	2	10	150	162	499	757	1 470	1 536
1999–00	14	45	2	10	168	162	490	757	1 357	1 536
2000–01	15	45	2	10	154	162	627	757	1 470	1 536
2001–02	12	46	2	10	138	163	648	759	1 477	1 548
2002–03	11	46	4	10	169	163	724	759	1 497	1 548
2003–04	9	46	4	10	167	163	710	759	1 556	1 548
2004–05	9	46	5	10	183	163	731	759	1 473	1 548
2005–06	7	46	1	10	183	163	580	759	1 346	1 548
2006–07	6	46	4	10	177	163	747	759	1 382	1 548
2007–08	6	46	3	10	167	163	779	759	1 277	1 548
2008–09	7	46	8	10	158	163	787	759	1 391	1 548
2009–10	8	46	7	10	171	163	691	759	1 210	1 548
2010–11	7	46	8	10	183	163	781	759	1 296	1 548
2011–12	6	46	8	10	166	163	753	759	1 215	1 239
2012–13	9	46	7	10	170	163	739	759	1 207	1 239
2013–14	9	46	8	10	159	163	720	759	1 208	1 239
2014–15	11	46	7	10	175	163	796	759	1 132	1 239
2015–16	9	46	6	10	169	163	758	759	1 099	1 239
2016–17	12	46	10	10	170	163	741	759	1 152	1 239
2017–18	8	46	12	10	174	163	752	759	1 027	1 239
2018–19	9	46	9	10	177	163	744	759	827	1 239
2019–20	8	46	7	10	180	163	732	759	926	1 239
2020–21	8	46	7	10	183	163	703	759	788	800

Fishstock	**BCO 7**		**BCO 8**		**BCO 10**			
FMA (s)	**7**		**8**		**10**		**Total**	
	Landings	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**
1983*	91	–	53	–	0	–	1 070	–
1984*	129	–	56	–	0	–	1 375	–
1985*	169	–	70	–	0	–	1 546	–
1986*	83	–	42	–	0	–	1 409	–
1986–87	79	110	22	60	0	10	1 422	2 130
1987–88	78	126	44	72	0	10	1 420	2 400
1988–89	66	131	32	72	0	10	1 298	2 501
1989–90	75	136	34	74	0	10	1 527	2 666
1990–91	63	136	28	74	0	10	1 752	2 667
1991–92	57	136	25	74	0	10	1 480	2 722
1992–93	85	136	32	74	0	10	1 777	2 724
1993–94	67	95	21	74	0	10	1 852	2 689
1994–95	113	95	24	74	0	10	2 089	2 689
1995–96	65	70	31	74	0	10	2 234	2 664
1996–97	71	70	38	74	0	10	2 029	2 664
1997–98	60	70	15	74	0	10	2 197	2 664
1998–99	52	70	35	74	0	10	2 220	2 664
1999–00	28	70	30	74	0	10	2 089	2 664
2000–01	26	70	22	74	0	10	2 316	2 664
2001–02	30	70	17	74	0	10	2 319	2 680
2002–03	39	70	13	74	0	10	2 457	2 680
2003–04	45	70	10	74	0	10	2 501	2 680
2004–05	44	70	7	74	0	10	2 452	2 680
2005–06	50	70	20	74	0	10	2 184	2 680
2006–07	69	70	34	74	0	10	2 413	2 680
2007–08	59	70	22	74	0	10	2 313	2 680
2008–09	58	70	18	74	0	10	2 427	2 680
2009–10	59	70	16	74	0	10	2 162	2 680
2010–11	51	70	16	74	0	10	2 342	2 681
2011–12	54	70	10	34	0	10	2 214	2 332
2012–13	71	70	12	34	0	10	2 215	2 332
2013–14	58	70	12	34	0	10	2 174	2 332
2014–15	68	70	8	34	0	10	2 198	2 332
2015–16	60	70	4	34	0	10	2 096	2 332
2016–17	65	70	5	34	0	10	2 155	2 332

Table 3: [Continued]

Fishstock FMA (s)	BCO 7 7 Landings	 TACC	BCO 8 8 Landings	 TACC	BCO 10 10 Landings	 TACC	Total Landings	 TACC
2017–18	71	70	4	34	0	10	2 049	2 332
2018–19	64	70	14	34	0	10	1 844	2 332
2019–20	57	70	3	34	0	10	1 914	2 332
2020–21	55	70	3	34	0	10	1 748	1 893

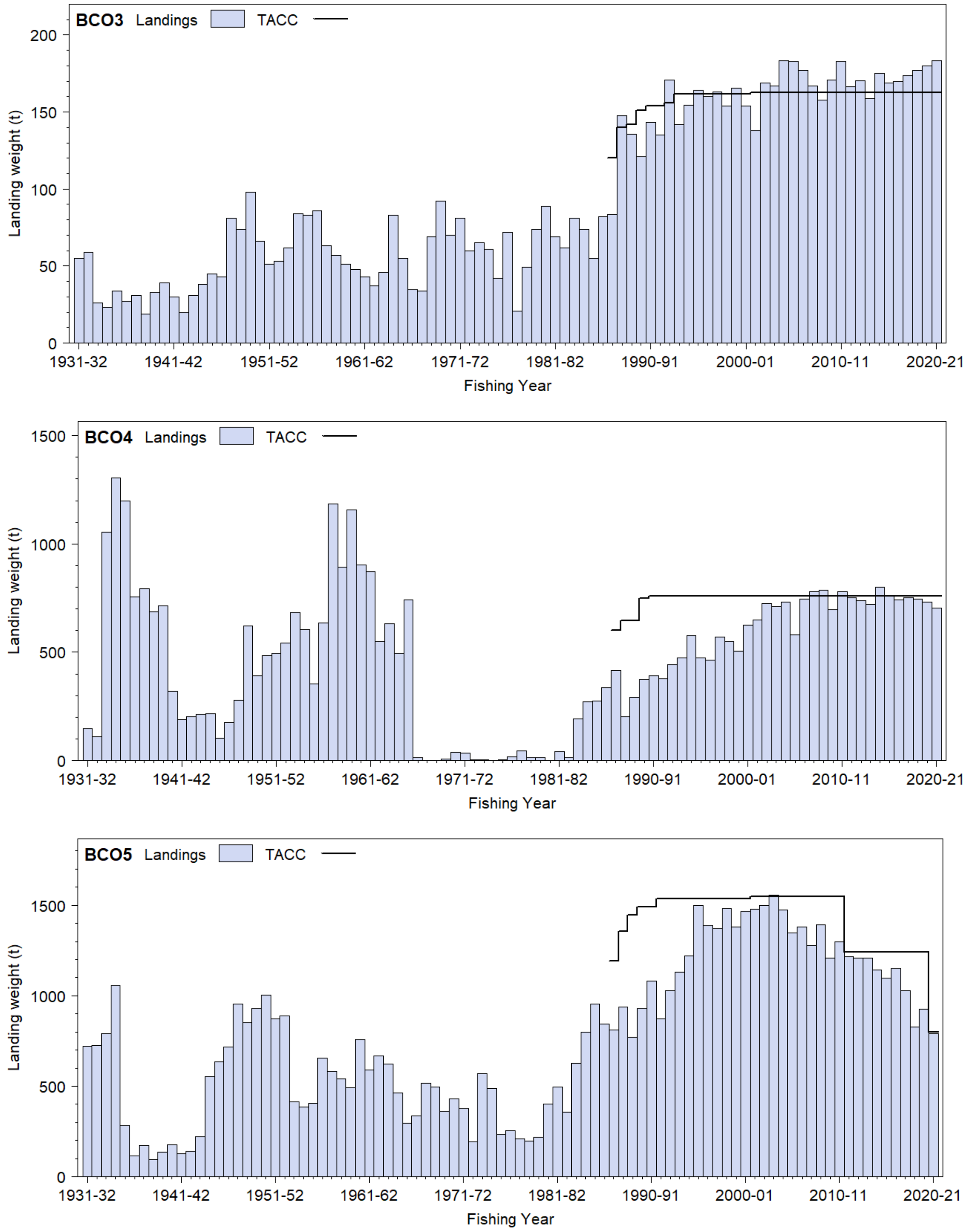
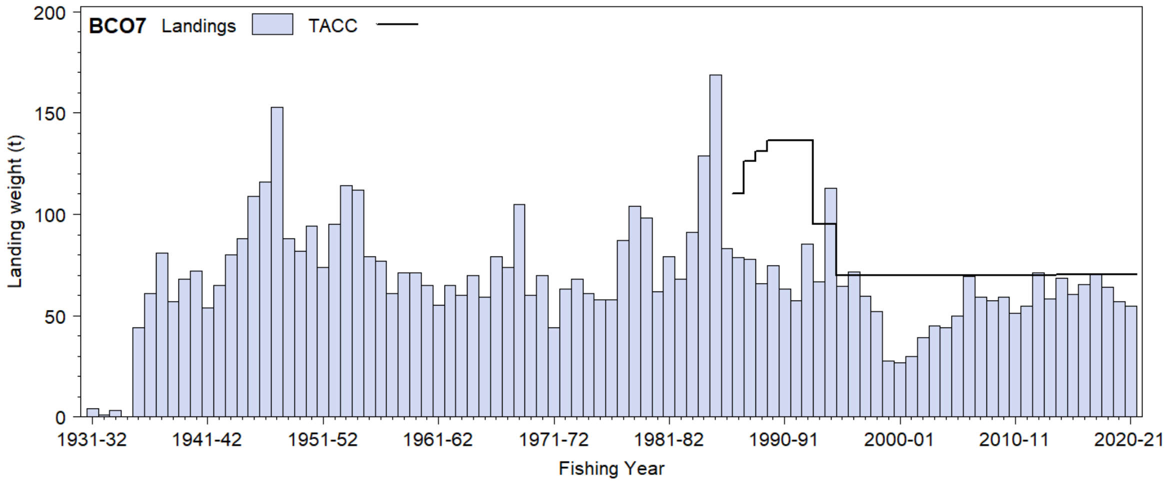


Figure 1: Reported commercial landings and TACC for the five main BCO stocks. From top: BCO 3 (South East Coast), BCO 4 (South East Chatham Rise), and BCO 5 (Southland). [Continued on next page]



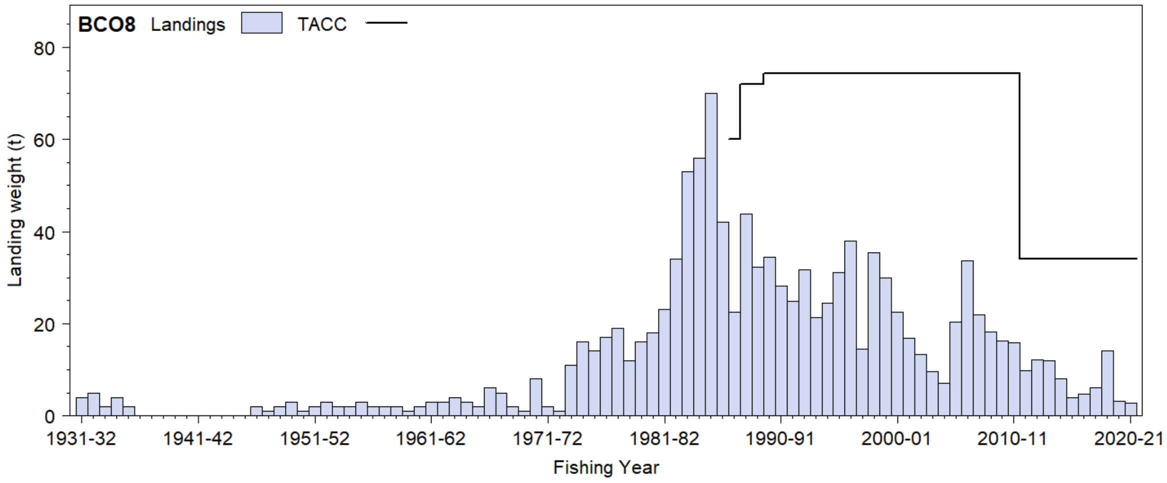


Figure 1: [Continued] Reported commercial landings and TACC for the five main BCO stocks. From top: BCO 7 (Challenger) and BCO 8 (Central Egmont).

Table 4: Reported total New Zealand landings (t) of blue cod for the calendar years 1970 to 1983. Sources MAF and FSU data.

Year	Landings
1970	1 022
1971	644
1972	459
1973	846
1974	696
1975	356
1976	524
1977	383
1978	378
1979	437
1980	536
1981	696
1982	539
1983	1 135

1.2 Recreational fisheries

Blue cod are generally the most important recreational finfish in Marlborough, Otago, Canterbury, Southland, and the Chatham Islands. Blue cod are taken predominantly by line fishing, but also by longlining, set netting, potting, and spearfishing. The current allowances within the TAC for each Fishstock are shown in Table 1.

1.2.1 Management controls

The main methods used to manage recreational harvests of blue cod are minimum legal size (MLS) limits, method restrictions, and daily bag limits. Daily bag limits are specified as either blue cod specific (DL) or a combined species limit (CDL). The main management controls have changed over time and vary by

Fishstock (Table 5). In addition, there have been temporary and seasonal closures in the Marlborough Sounds and several Fiordland sounds.

Table 5: Minimum legal size (MLS in cm), blue cod specific daily bag limit (DL), and combined species daily bag limit (CDL) by Fishstock from 1986 to present. Slot = slot limit (legal size range). * DS = Doubtful Sounds, TS = Thompson Sound, BS = Bradshaw Sound. C = inner sounds closed. # excluding Challenger East. ^bag limit of 6 inside Te Whaka ā Te Wera Mātaitai Reserve. There are two separate areas with different bag limits in each of BCO 3 South East and BCO 5 Southland (see text below for more detail).**

Fishstock	**BCO 1**		**BCO 2**		**BCO 3**		**BCO 3**		**BCO 3**		**BCO 4**	
Area					**South East**		**North**		**Kaikōura**		**South East**	
	Auckland		**Central (East)**		**(Otago)**		**Canterbury**		**Marine Area**		**(Chatham Is.)**	
	MLS	CDL	MLS	CDL	MLS	CDL	MLS	DL	MLS	DL	MLS	CDL
1986	30	30	30	30	30	30	30	30	N/A	N/A	30	30
1993	33	20	33	20	30	30	30	30	N/A	N/A	30	30
1994	33	20	33	20	30	30	30	30	N/A	N/A	30	30
2001	33	20	33	20	30	30	30	10	N/A	N/A	30	30
2008	30	20	33	20	30	30	30	10	N/A	N/A	30	30
2014	30	20	33	20	30	30	30	10	33	6	30	30
2017	30	20	33	20	30	30	30	10	33	6	30	30
2020	30	20	33	20	33	10/15	33	2	33	6	33	15

Fishstock	**BCO 5**		**BCO 5**		**BCO 5**		**BCO 5**		**BCO 7**		**BCO 7**	
Area	**Southland &**				**Fiordland**							
	Fiordland		**Paterson Inlet**		**internal (excl.**				**Challenger**		**Challenger East (incl.**	
	(External)		**^**		**DS, TS, BS*)**		**DS, TS, BS***		**West & South**		**Marlborough Sounds)**	
	MLS	CDL	MLS	DL	MLS	DL	MLS	DL	MLS	DL	MLS	DL
1986	30	30	30	30	33	20	33	20	30	30	30	12
1993	33	30	33	30	33	20	33	20	33	20	33	10
1994	33	30	33	15	33	20	33	20	33	20	28	6
2001	33	30	33	15	33	20	33	20	33	20	28	6
2003	33	30	33	15	33	20	33	20	33	20	30	3
2005	33	30	33	15	33	20	C**	C**	33	20	30	3
2008	33	30	33	15	33	20	C**	C**	33	20	C**	C**
2011	33	30	33	15	33	20	C**	C**	33	20	#SLOT 30–35	2
2014	33	20	33	15	33	20	C**	C**	33	20	#SLOT 30–35	2
2015	33	20	33	15	33	3	33	1	33	20	33	2
2017	33	20	33	15	33	3	33	1	33	20	33	2
2020	33	15/10	33	15	33	3	33	1	33	10	33	2

Fishstock	**BCO 8**		**BCO 10**	
Area	**Central (West)**		**Kermadec**	
	MLS	DL	MLS	CDL
1986	30	30	30	30
1993	33	20	33	20
2014	33	10	33	20
2017	33	10	33	20
2020	33	10	33	20

During 1992–93, the national minimum legal size (MLS) for blue cod increased from 30 cm to 33 cm for both amateur and commercial fishers, with the exception of BCO 3 and BCO 4 (South East management area). However, this was amended to 30 cm in 2008 for BCO 1, in response to a management review of blue cod in the area. Additionally, the Marlborough Sounds Area (part of BCO 7) had several MLS amendments between 1993 and 2015, including a closure in the inner sounds followed by a slot limit of 30–35 cm in response to differing management approaches in the Marlborough Sounds, before changing to an MLS of 33 cm and daily bag limit of 2 in 2015. In 2014, the Kaikōura Marine Area in BCO 3 was established and the MLS of blue cod in this area was set at 33 cm. In 2020, an MLS of 33 cm was adopted for all management areas out to 12 nm, apart from BCO 1 which remains at 30 cm.

In 2001, the recreational daily bag limit (DL) was reduced to 10 fish over the MLS in the North Canterbury area (BCO 3). In 2014, the DL was set at 6 in the newly established Kaikōura Marine Area (BCO 3), and the DL was reduced to 20 in Southland and the external waters of the Fiordland marine area (BCO 5). Before these changes, the DL in Paterson's Inlet (BCO 5) was reduced from 30 to 15 in 1994. In 2005, new commercial and recreational rules were introduced to the internal waters of the Fiordland Marine Area and Doubtful Sound, Thompson Sound, and Bradshaw Sound were closed to all blue cod fishing for 10 years. The closure was lifted in 2015 to allow recreational blue cod fishing and the new DL within Doubtful Sound was set at 1. The DL for the Challenger East area (BCO 7) has reduced from 10 to 2 since 1993 in response to differing management regimes in the area. In 2014, the DL in BCO 8 was reduced from 20 to 10.

On 1 July 2020, the DLs for South Island stocks out to 12 nm were revised (http://www.mpi.govt.nz/bluecod). In BCO 5 there are two areas with DLs of 10 and one with a DL of 15. The restrictions in the fiords and sounds remained unchanged. In BCO 3 the area south of Otago Harbour mouth has a DL of 15 and the area north to Banks Peninsula has a DL of 10. From the southern side of Banks Peninsula to the Conroy River, the DL is 2. North of the Conway River to the Clarence River, the DL is 10 and within the Kaikōura Marine Area the DL is 6. The BCO 7 Tasman area, including the Marlborough Sounds, has a DL of 2, whereas the Kahurangi area has a DL of 10 and the Westland area a DL of 15. The DL for the Chatham Islands is 15.

1.2.2 Estimates of recreational harvest

Recreational harvest estimates are given in Table 6. There are two broad approaches to estimating recreational fisheries harvest: the use of onsite or access point methods where fishers are surveyed or counted at the point of fishing or access to their fishing activity; and offsite methods where some form of post-event interview and/or diary are used to collect data from fishers.

The first estimates of recreational harvest for blue cod were calculated using an offsite approach, the offsite regional telephone and diary survey approach: MAF Fisheries South (1991–92), Central (1992–93), and North (1993–94) regions (Teirney et al 1997). Estimates for 1996 came from a national telephone and diary survey (Bradford 1998). Another national telephone and diary survey was carried out in 2000 (Boyd & Reilly 2004) and a rolling replacement of diarists in 2001 (Boyd et al 2004) allowed estimates for a further year (population scaling ratios and mean weights were not re-estimated in 2001).

The harvest estimates provided by these telephone diary surveys are no longer considered reliable for various reasons. With the early telephone/diary method, fishers were recruited to fill in diaries by way of a telephone survey that also estimated the proportion of the population that was eligible (likely to fish). A ‘soft refusal’ bias in the eligibility proportion arose if interviewees who did not wish to co-operate falsely stated that they never fished. The proportion of eligible fishers in the population (and, hence, the harvest) was thereby under-estimated. Pilot studies for the 2000 telephone/diary survey suggested that this effect could occur when recreational fishing was established as the subject of the interview at the outset. Another equally serious cause of bias in telephone/diary surveys was that diarists who did not immediately record their day’s harvest after a trip sometimes overstated their harvest or the number of trips made. There is some indirect evidence that this may have occurred in all the telephone/diary surveys (Wright et al 2004).

The recreational harvest estimates provided by the 2000 and 2001 telephone diary surveys are thought to be implausibly high, which led to the development of an alternative maximum count aerial-access onsite method that provides a more direct means of estimating recreational harvests for suitable fisheries. The maximum count aerial-access approach combines data collected concurrently from two sources: a creel survey of recreational fishers returning to a subsample of ramps throughout the day; and an aerial survey count of vessels observed to be fishing at the approximate time of peak fishing effort on the same day. The ratio of the aerial count in a particular area to the number of interviewed parties who claimed to have fished in that area at the time of the overflight was used to scale up harvests observed at surveyed ramps, to estimate harvest taken by all fishers returning to all ramps. The methodology is further described by Hartill et al (2007).

This aerial-access method was first employed, optimised for SNA, in the Hauraki Gulf in 2003–04. It was then extended to survey the wider SNA 1 fishery in 2004–05 and to other areas (SNA 8) and other species, including blue cod in BCO 7 in 2005–06 (Davey et al 2008). The estimates for BCO 7 in 2005–06 may not be accurate for two reasons. A large proportion of the fishing effort observed during aerial surveys of the outer Marlborough Sounds was from launches and other vessels that would not have returned to the surveyed boat ramps, because they would have returned to other access points and often on following days. A significant proportion of the boats fishing in the inner Marlborough Sounds may also have returned to a bach/crib rather than a surveyed ramp. For both these situations it was therefore necessary to assume that the catch and effort of these boats would have been the same as that reported by boats returning to surveyed boat ramps on the same day, which may not have been the case. A repeat aerial-access survey was conducted in BCO 7 over the 2015–16 fishing year (Hartill et al 2017) and this was considered by the Marine Amateur Fisheries Working Group to be more reliable than the initial survey because a greater number of days were surveyed in this year, and a pilot survey was undertaken to determine where boats fishing in the inner Marlborough Sounds had originated from, which led to interviews being conducted at two extra high traffic ramps in this area. The recreational harvest from BCO 7 in 2015–16 was about half that in 2005–06 (Table 6), almost with all the decrease being in the Marlborough Sounds.

In response to the cost and scale challenges associated with onsite methods, in particular the difficulties in sampling other than trailer boat fisheries, offsite approaches to estimating recreational fisheries harvest have been revisited. This led to the implementation of a national panel survey during the 2011–12 fishing year (Wynne-Jones et al 2014). The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 6. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 6: Recreational harvest estimates for blue cod stocks. The telephone/diary surveys and aerial-access survey ran from December to November but are denoted by the January calendar year. The national panel surveys ran throughout the October to September fishing years but are denoted by the January calendar year. Mean fish weights were obtained from boat ramp surveys (for the telephone/diary and panel survey harvest estimates).

Stock	Year	Method	Number of fish	Total weight (t)	CV
BCO 1	1996	Telephone/diary	34 000	17	0.11
	2000	Telephone/diary	37 000	23	0.31
	2012	Panel survey	17 463	1	0.20
	2018	Panel survey	13 276	6	0.18
BCO 2	1996	Telephone/diary	145 000	81	0.13
	2000	Telephone/diary	187 000	161	0.25
	2012	Panel survey	53 618	26	0.19
	2018	Panel survey	48 140	28	0.26
BCO 3	1996	Telephone/diary	217 000	151	0.11
	2000	Telephone/diary	1 026 000	752	0.29
	2012	Panel survey	212 184	101	0.20
	2018	Panel survey	202 765	99	0.18
BCO 5	1996	Telephone/diary	171 000	139	0.12
	2000	Telephone/diary	326 000	229	0.28
	2012	Panel survey	72 328	44	0.24
	2018	Panel survey	139 176	67	0.20
BCO 7	1996	Telephone/diary	356 000	239	0.09
	2000	Telephone/diary	542 000	288	0.20
	2006	Aerial-access	–	149	0.16
	2012	Panel survey	176 152	77	0.17
	2016	Aerial-access	–	75	0.15
	2018	Panel survey	129 038	63	0.12
BCO 8	1996	Telephone/diary	159 000	79	0.12
	2000	Telephone/diary	232 000	188	0.32
	2012	Panel survey	88 980	48	0.36
	2018	Panel survey	62 539	31	0.20

1.2.3 Charter vessel harvest

The national marine diary survey of recreational fishing from charter vessels in 1997–98 found blue cod to be the second most frequently landed species nationally and the most frequently landed species in the South Island. Results indicated that recreational harvests from charter vessels (Table 7) follow the same pattern as overall recreational harvest (Table 6). The estimated recreational harvests from charter vessels in BCO 7 exceeded the 1997–98 TACC and the commercial landings in QMA 7.

Table 7: Results of a national marine diary survey of recreational fishers from charter vessels, 1997–98 (November 1997 to October 1998).*

Fishstock	Number caught	CV	Estimated landings (number of fish killed)	Point Estimate (t)
BCO 1	430	0.18	2 500	2.4
BCO 2	34	0.50	300	0.2
BCO 3	17 272	0.29	72 000	58
BCO 5	16 750	0.36	63 000	51
BCO 7	32 026	0.13	110 000	76
BCO 8	2	–	–	0

*Estimated number of blue cod harvested by recreational fishers on charter vessels by Fishstock and the corresponding harvest tonnage. The mean weights used to convert numbers to harvest weight were considered the best available at the time (James & Unwin 2000).

1.3 Customary non-commercial fisheries

No quantitative data on historical or current blue cod customary non-commercial catch are available. However, bones found in middens show that blue cod was a significant species in the traditional Māori take of pre-European times.

1.4 Illegal catch

No quantitative data on the levels of illegal blue cod catch are available.

1.5 Other sources of mortality

Blue cod have in the past been used for bait within the rock lobster fishery. Pots are either set specifically to target blue cod or have a bycatch of blue cod that is used for bait. However, these fish are frequently not recorded and the quantity of blue cod used as bait cannot be accurately determined.

Cod pots covered in 38 mm mesh frequently catch undersized blue cod. It has been estimated that in Southland, 65% of blue cod caught in these pots are less than 33 cm. (The commercial MLS was increased from 30 cm to 33 cm in 1994.) When returned, the mortality of these fish can be high due to predation by mollymawks following commercial boats. It is estimated by the fishing industry that up to 50% of returned fish can be taken. To reduce the problem of predation of returned undersized fish, a minimum 48 mm mesh size was introduced to BCO 5 in 1994. However, no mesh size restrictions exist in any other area. An experiment conducted by Glen Carbines on commercial vessels in 2015 to quantify the reduction in undersized blue cod caught in pots with the alternative mesh size showed that almost all retained undersized fish were dead when returned to the water. Even though blue cod are not subject to barotrauma, because they have no swim bladders, the high mortality was the result of undersized blue cod being returned after the catch had been processed. In 2018 the mesh size in BCO 5 was increased to 54 mm, and on 1 July 2020 the mesh size for all areas was increased to 54 mm.

Recreational line fishing often results in the harvest of undersized blue cod. The survival of these fish has been shown to be a factor of hook size. A small-scale experiment showed that returned undersized fish caught with small hooks (size 1/0) experience 25% mortality, whereas those caught with large hooks (size 6/0) appear to have little or no mortality (Carbines 1999).

2. BIOLOGY

Blue cod is a bottom-dwelling species endemic to New Zealand. Although distributed throughout New Zealand near foul ground to a depth of 150 m, they are more abundant south of Cook Strait and around the Chatham Islands. Growth may be influenced by a range of factors, including sex, habitat quality, and fishing pressure relative to location (Carbines 2004a). Size-at-sexual maturity also varies according to location. In Northland, maturity is reached at 10–19 cm total length (TL) at an age of 2 years, whereas in the Marlborough Sounds it is reached at 21–26 cm TL at 3–6 years. In Southland, the fish become mature at 26–28 cm TL, at an age of 4–5 years. Blue cod have also been shown to be protogynous hermaphrodites, with some individuals over a large length range changing sex from female to male (Carbines 1998). Blue cod are a diandric species where males either develop directly from the undifferentiated state without sex inversion (primary males) or begin life as female and become male following sex inversion (secondary males) (Beentjes 2021). Validated age estimates using otoliths have shown that blue cod males grow faster and are larger than females (Walsh 2017). The maximum recorded age for this species is about 32 years.

An *M* of 0.17 was based on the empirical age distribution from the offshore Banks Peninsula survey in 2016, aged using the blue cod age determination protocol. The *M* estimate is based on the 1% tail of the distribution, which was 27 years, not the maximum age. The default *M* for blue cod was changed from 0.14 to 0.17 in April 2019 following the recommendation of the Inshore Working Group. Previous spawner-per-recruit ratio (SPR) analyses carried out using 0.14 are being updated following routine blue cod surveys.

Blue cod have an annual reproductive cycle with an extended spawning season during late winter and spring. Spawning has been reported within inshore and mid-shelf waters. It is also likely that spawning occurs in outer-shelf waters. Ripe blue cod are also found in all areas fished commercially by blue cod fishers during the spawning season. Batch fecundity was estimated by Beer et al (2013). Eggs are pelagic for about five days after spawning, and the larvae are pelagic for about five more days before settling onto the seabed. Juveniles (less than about 10 cm TL) are not caught by commercial potting or lining, and therefore blue cod are not vulnerable to the main commercial fishing methods until they are mature. Recreational methods do catch juveniles, but since this species does not have a swim bladder, the survival of these fish is good if they are caught using large hooks (6/0) (which do not result in gut hooking) and returned to the sea quickly (Carbines 1999).

Biological parameters relevant to stock assessment are shown in Table 8.

Table 8: Estimates of biological parameters for blue cod. These estimates are survey specific and reflect varying exploitation histories and environmental conditions. Only von Bertalanffy growth parameters derived from otoliths aged using the Age Determination Protocol for Blue Cod (Walsh 2017) are included in this table.

Fishstock	Estimate	Source
1. Natural mortality (*M*)		
All	0.17	Doonan (2020)

2. von Bertalanffy growth parameters

	Females			Males			
Survey/year	L_∞	*K*	t_0	L_∞	*k*	t_0	
Dusky Sound (2014)	46.7	0.129	-1.8	50.3	0.222	0.638	Beentjes & Page (2016)
Kaikōura (2015)	40.7	0.174	-1.12	52.3	0.171	-0.27	Beentjes & Page (2017)
Banks Peninsula (2016)	50.2	0.116	-2.07	58.7	0.134	-1.21	Beentjes & Fenwick (2017)
Marlborough Sounds (2017)	32.2	0.52	0.83	39.9	0.37	0.69	Beentjes et al (2018)
Paterson Inlet (2018)	40.0	0.20	-4.31	46.8	0.21	0.215	Beentjes & Miller (2020)

3. Weight = *a*(length)^b (Weight in g, length in cm total length).

Area			*a*	*b*	R^2	
Kaikōura	2011	Male	0.011793	3.09246	0.97	Carbines & Haist (2012b)
	2011	Female	0.007042	3.23949	0.95	
Motunau	2012	Male	0.01490	3.03796	0.98	Carbines & Haist (2012b)
	2012	Female	0.01384	3.05982	0.97	
Banks Peninsula	2012	Male	0.019138	2.98181	0.98	Carbines & Haist (2012a)
	2012	Female	0.016939	3.02644	0.96	
North Otago	2013	Male	0.01093	3.10941	0.98	Carbines & Haist (2014b)
	2013	Female	0.012023	3.09201	0.97	
South Otago	2013	Male	0.008472	3.19011	0.99	Carbines & Haist (2014c)
	2013	Female	0.008617	3.1863	0.99	
Fiordland	2002	Male	0.007825	3.1727	0.97	Carbines & Beentjes (2003)
(Dusky Sound)	2002	Female	0.00506	3.2988	0.98	
Stewart Island	2010	Male	0.00663	3.2469	0.98	Carbines & Haist (2014a)
(Paterson Inlet)	2010	Female	0.00663	3.2469	0.98	
Marlborough	2017	Male	0.00674	3.218	0.96	Beentjes et al (2018)
Sounds		Female	0.00648	3.238	0.94	

Tagging experiments carried out in the Marlborough Sounds in the 1940s and 1970s suggested that most blue cod remained in the same area for extended periods. A more recent tagging experiment carried out in Foveaux Strait (Carbines 2001) showed that although some blue cod moved as far as 156 km, 60% travelled less than 1 km. A similar pattern was found in Dusky Sound where from a total of 61 recaptures, four fish moved over 20 km but 65% had moved less than 1 km (Carbines & McKenzie 2004). The larger movements observed during this study were generally eastwards into the fiord. The inner half of the fiord was found to drain the outer strata and had 100% residency.

The preliminary results of a mitochondrial DNA analysis (Smith 2012) suggest that the Chatham Island blue cod are likely to be genetically distinct from mainland New Zealand fish. Over larger distances the mainland New Zealand blue cod appear to show a pattern of Isolation-by-Distance or continuous genetic change among populations. However, there is no evidence that blue cod are genetically distinct around the New Zealand mainland (Gebbie 2014).

3. STOCKS AND AREAS

The FMAs are used as a basis for Fishstocks, except FMAs 5 and 6, and FMAs 1 and 9, which have been combined. The choice of these boundaries was based on a general review of the distribution and relative abundance of blue cod within the fishery.

There are no data that would alter the current stock boundaries. However, tagging experiments suggest that blue cod populations may be geographically isolated from each other, and there may be several distinct sub-populations within each management area (particularly those occurring in sounds and inlets).

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

4.1.1 South Island blue cod potting surveys

Potting surveys are used to monitor blue cod populations supporting nine important recreational fisheries around the South Island (Figure 2). Surveys are generally carried out every four years and are used to monitor relative abundance and size, age, and sex structure of the nine geographically separate blue cod populations. The surveys also provide an estimate of fishing mortality (F) and associated spawner-per-recruit ratios. All potting surveys (except Foveaux Strait) originally used a fixed-site design, with predetermined (fixed) locations randomly selected from a limited pool of such sites. The South Island potting surveys were reviewed by an international expert panel in 2009, which recommended that blue cod would be more appropriately surveyed using random-site potting surveys (Stephenson et al 2009). A random site is any location (single latitude and longitude) generated randomly from within a stratum. Following this recommendation, all survey series began the transition to fully random survey designs with interim sampling of both fixed and random sites allowing comparison of catch rates, length and age composition, and sex ratios between the survey designs. Random sites were the only site type used in Foveaux Strait, and all other areas except Dusky Sound have now transitioned to solely random-site surveys.

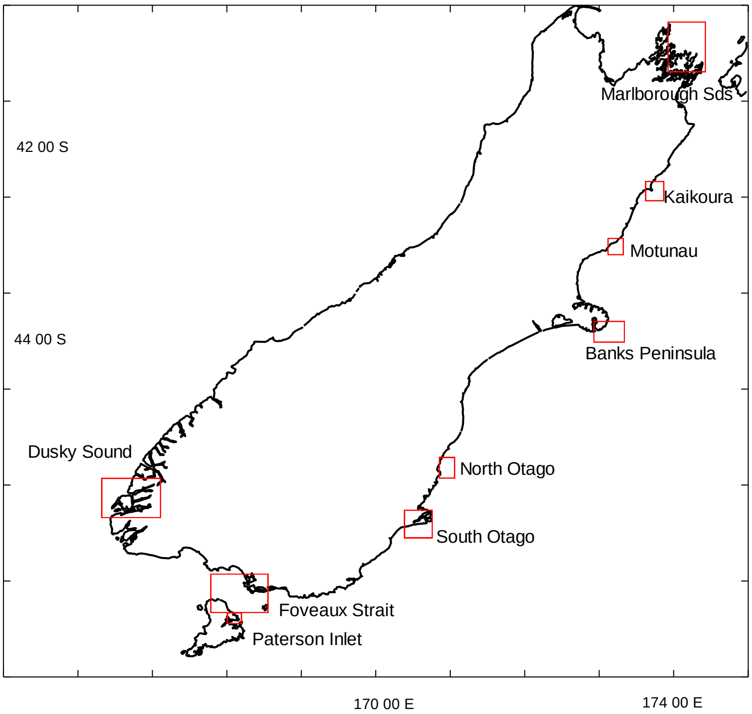


Figure 2: Map showing the nine South Island blue cod potting survey locations.

Marlborough Sounds

Fixed-site surveys were carried out using standardised cod pots (pot plan 1) between 1995 and 2017, either in all strata or partially, within five regions: Queen Charlotte Sound (QCH), Pelorus Sound (PEL), D'Urville Island (DUR), Cook Strait (CKST), and Separation Point (SEPR) (Table 9).

In 2010, experimental random sites using the same pot plan 1 were trialled in selected strata within Pelorus Sound, D'Urville Island, and the entire Cook Strait region (Table 9), and in 2013 and 2017 (Beentjes et al 2017, Beentjes et al 2018), full random-site and full fixed-site surveys were conducted concurrently. In 2021 the first solely random-site survey was carried out and this survey has now fully transitioned to the random-site design (Beentjes et al 2022a). The 2017 and 2021 random-site surveys also included Long Island Marine Reserve.

Table 9: Fixed-site and random-site blue cod potting survey time series in the Marlborough Sounds by region. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait; SEPR, Separation Point; LIMR, Long Island Marine Reserve; all, all strata surveyed; partial, not all strata surveyed; – no survey.

	Fixed-site surveys by region					Random-site surveys by region				
Year	QCH	PEL	DUR	CKST	SEPR	QCH	PEL	DUR	CKST	LIMR
1995	all	partial	–	–	–	–	–	–	–	–
1996	–	all	partial	–	–	–	–	–	–	–
2001	all	all	partial	–	–	–	–	–	–	–
2004	all	all	all	–	all	–	–	–	–	–
2007	all	all	all	–	all	–	–	–	–	–
2008	–	–	–	all	–	–	–	–	–	–
2010	all	all	all	–	–	–	partial	partial	all	–
2013	all	all	all	–	–	all	all	all	all	–
2017	all	all	all	–	–	all	all	all	all	all
2021	–	–	–	–	–	all	all	all	all	all

Fixed-site surveys

Throughout the fixed-site surveys, catch rates of total blue cod (all sizes) have tended to be highest around D'Urville Island (Figure 3, Table 10). In Queen Charlotte Sound catch rates progressively declined from 2.1 to 1.1 kg pot^{-1} (CV range 16 to 26%) between 1995 and 2007 before increasing markedly in 2010 to 1.75 kg pot^{-1} (Figure 3). From October 2008 to April 2011, the inner sounds were closed to recreational blue cod fishing and the 2010 potting survey increased abundance in Queen Charlotte Sound is attributed to the closure. In Pelorus Sound, total blue cod catch rates declined from 2.4 to 1.1 kg pot^{-1} (CV range 7 to 19%) over the same period, then increased again in 2010, to 2.9 kg pot^{-1} (Figure 3). Pelorus Sound showed a similar trend in catch rates to Queen Charlotte Sound, dropping markedly from 1996 to 2007 and increasing again in 2010 after two years of closure. The overall Marlborough Sounds fixed-site surveys catch rates from 2004 onward (where survey strata are consistent among surveys) showed the large increase in 2010, consistent with the closure of the inner sounds, and a second increase in 2017. In April 2011, a seasonal opening with a 'slot limit' (which allowed the take of blue cod between 30 and 35 cm) was introduced for the Marlborough Sounds Management Area, an area that includes inner and outer Queen Charlotte Sound and Pelorus Sound and east D'Urville. The slot limit was removed in December 2015. There was no closure or slot limit for Cook Strait.

The 2013 survey was carried out two years after the slot limit had been in place, with total blue cod catch rates for both Queen Charlotte Sound and Pelorus Sound declining relative to the 2010 survey, but remaining higher than 2001 to 2007 for Pelorus Sound when the fishery was open, and about the same magnitude as pre-closure for Queen Charlotte Sound (Figure 3). In the D'Urville Island strata, which have been fished continuously over the same period, catch rates for total blue cod between 2004 and 2013 have been stable, ranging from 3.9 to 4.44 kg pot^{-1} (CV range 8 to 18%) (Figure 3). D'Urville Island was not closed to fishing in October 2008, but the east side of the island was included in the management area where the 'slot limit' has been applicable since April 2011. Cook Strait has had only one fixed-site survey, in 2008.The proportion of the total biomass within the slot limit (30–35 cm) in 2013 was 45%, 49%, and 49% for QCH, PEL, and DUR regions, respectively, and proportions of biomass above the slot limit were 26%, 25%, and 22%, respectively. Sex ratios have been dominated by males in all regions over all fixed-site surveys (Table 10). The 2017 survey took place 2 years after the slot limit was removed and in the Marlborough Sounds Area the MLS was increased to 33 cm. In 2017, catch rates from the fixed-site survey in Queen Charlotte Sound were similar to those in 2013, in Pelorus Sound they were similar to 2010, and at D'Urville Island they were about 40% higher than in 2013 (Figure 3, Table 10).

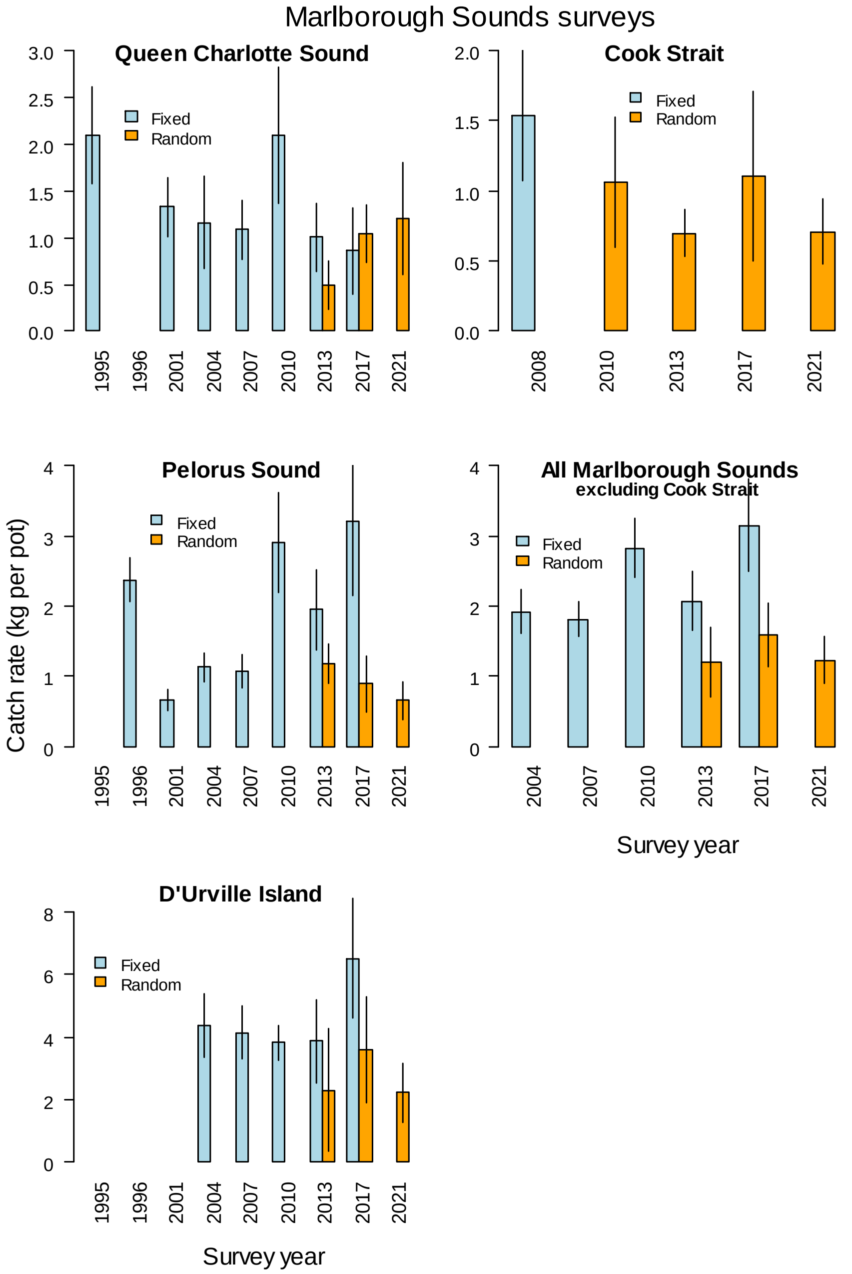


Figure 3: Marlborough Sounds fixed-site and random-site potting survey catch rates of all blue cod by survey year for each region and overall for the Marlborough Sounds. Error bars are 95% confidence intervals. There were no complete fixed-site surveys in Queen Charlotte Sound in 1996, Pelorus Sound in 1995, and D'Urville Island from 1995 to 2001 (see Table 9 above). For the overall Marlborough Sounds plot, the 2004 and 2007 fixed-site surveys exclude Separation Point, and the random-site surveys exclude Cook Strait, hence the strata are consistent among the surveys for fixed-site and random-site surveys.

Random-site surveys

The random-site surveys in 2013 and 2017 generally have lower catch rates than the concurrent fixed-site surveys, and, although the patterns among strata in each region are similar, they do not show the same overall trends as fixed sites by region and comparison between survey designs is problematic (Table 10, Figure 3). Queen Charlotte Sound random-site survey biomass increased markedly from 2013 to 2017 with no change in 2021;Pelorus Sound biomass shows a progressive decline between 2013 and 2021; D'Urville Island and Cook Strait show no trends. (Figure 3). Sex ratios have been dominated by males in all regions over all random-site surveys (Table 10). The Marlborough Sounds survey has now fully transitioned to random-site surveys and all future surveys will use the only the random-site design.

Table 10: Summary statistics from standardised blue cod fixed-site and random-site potting surveys in the Marlborough Sounds up to 2021 by region. Mean length and sex ratios are derived from the scaled population length distributions. Results for each region are shown only for surveys where strata have remained the same throughout the time series and results are for all blue cod. For the overall Marlborough Sounds (All MS), the 2004 and 2007 fixed-site surveys exclude Separation Point, and the random-site surveys exclude Cook Strait, hence the strata are consistent among the surveys for fixed-site and random-site surveys. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville; CKST, Cook Strait; LIMR, Long Island Marine Reserve; All MS, all Marlborough Sounds.

			Mean length (cm)			CPUE (kg pot^{-1})		Sex ratio
Region/stratum	**Year**	**Site type**	**Male**	**Female**	**unsexed**	**Overall**	**range (CV)**	**(% male)**
QCH	1995	Fixed	31.0	28.0		2.1	0.74–2.91 (12%)	59
	1996	–	–	–		–	–	–
	2001	Fixed	28.5	24.3		1.33	0.58–1.69 (12%)	61
	2004	Fixed	27.9	24.2		1.16	0.35–2.01 (22%)	51
	2007	Fixed	29.8	25.7		1.09	0.00–2.60 (15%)	69
	2010	Fixed	33.2	29.0		2.09	0.60–2.56 (18%)	71
	2013	Fixed	31.7	29.8		1.0	0.32–1.12 (18%)	62
		Random	32.1	30.3		0.49	0.22–1.07 (27%)	66
	2017	Fixed	32.2	29.6		0.86	0.18–1.95 (27.3%)	72
		Random	32.5	30.7		1.04	0.11–1.94 (15%)	73
	2021	Random	30.9	28.6		1.21	0.24–1.45 (25%)	74
QCH/LIMR	2017	Random	–	–	35.2	8.76	8.76 (14%)	–
	2021	Random	–	–	35.7	7.98	7.98 (13%)	–
PEL	1995	–	–	–		–	–	–
	1996	Fixed	29.8	26.2		2.4	1.00–3.30 (7%)	70
	2001	Fixed	27.8	22.2		0.67	0.19–1.46 (12%)	64
	2004	Fixed	28.2	23.5		0.96	0.20–2.70 (11%)	66
	2007	Fixed	29.2	24.5		1.07	0.28–3.24 (11%)	77
	2010	Fixed	32.8	28.3		2.9	1.60–3.86 (13%)	87
	2013	Fixed	31.3	27.2		1.95	3.30–4.94 (15%)	89
		Random	33.3	30.1		1.18	0.18–3.96 (12%)	77
	2017	Fixed	32.0	29.5		3.20	0.11–10.1 (17%)	86
		Random	32.4	29.8		0.90	0.07–2.77 (23%)	90
	2021	Random	31.9	29.2		0.66	0.19–1.19 (21%)	82
DUR	1995	–	–	–		–	–	–
	1996	–	–	–		–	–	–
	2001	–	–	–		–	–	–
	2004	Fixed	30.7	27.8		4.23	3.75–4.67 (11%)	50
	2007	Fixed	32.2	29.5		4.15	2.92–5.49 (10%)	71
	2010	Fixed	31.3	28.7		3.82	2.15–5.64 (8%)	64
	2013	Fixed	31.7	29.4		3.88	3.37–4.44 (18%)	70
		Random	32.8	29.9		2.31	1.42–3.28 (43%)	57
	2017	Fixed	32.9	30.6		6.52	4.50–8.70 (15%)	61
		Random	32.6	30.6		3.59	2.90–4.30 (24%)	65
	2021	Random	32.8	30.8		2.23	2.05–2.39 (21%)	63
CKST	2008	Fixed	31.9	26.4		1.50	0.30–4.20 (15%)	88
	2010	Random	30.5	25.6		1.06	0.11–1.74 (22%)	84
	2013	Random	31.7	28.4		0.70	0.14–1.62 (12%)	83
	2017	Random	32.3	28.2		1.10	0.08–2.67 (28%)	87
	2021	Random	32.3	27.5		0.71	0.07–2.13 (16%)	80
All MS	2004	Fixed	29.1	25.9		1.92	0.37–4.67 (8%)	54
	2007	Fixed	30.7	27.2		1.81	0.00–5.48 (7%)	72
	2010	Fixed	32.5	28.7		2.83	0.60–5.64 (7%)	75
	2013	Fixed	31.5	29.1		2.68	0.31–4.44 (10%)	76
		Random	32.9	30.0		1.20	0.22–3.96 (21%)	66
	2017	Fixed	32.4	30.2		3.15	0.11–8.73 (10%)	72
		Random	32.5	30.6		1.59	0.06–4.32 (14%)	72
	2021	Random	31.8	29.7		1.18	0.07–2.39 (13%)	72

Long Island Marine Reserve potting survey

Random-site surveys of Long Island Marine Reserve in 2017 and 2021, in which all fish were returned alive (unsexed), had mean catch rates of all blue cod of 8.76 kg pot^{-1} (CV of 15%) and 7.98 kg pot^{-1} (CV of 13%), respectively, and were 5.7 and 5.4 times higher than adjacent fished strata in Queen Charlotte Sound in 2017 and 2021, respectively (Table 10). In addition, the mean size was 3.2 cm (2017) and 5.2 cm (2021) greater in the marine reserve and length frequency distributions were bimodal in contrast to the unimodal distributions from adjacent strata in Queen Charlotte Sound. Blue cod were in better condition inside the marine reserve in 2021 with a mean Fulton condition factor (*K*) of 1.6, compared with 1.4 in adjacent strata.

Stock status

Growth rates and age compositions were similar for 2013 and 2017. Fixed-site survey Chapman-Robson total mortality estimates (*Z*) for males only, and for age at recruitment of 6 years, were 0.66 in 2013 and 0.77 in 2017 (Table 11). Similarly, random-site survey Chapman-Robson total mortality estimates (*Z*) at recruitment of 6 years were 0.60 in 2013 and 0.75 in 2017 (Table 11). In 2021, age compositions and *Z* estimates were similar to 2013 and 2017 random-site estimates (Z = 0.65), but growth was slightly faster in 2021.

The stock assessment plenary meeting on 18 July 2022 agreed that spawner-biomass-per-recruit (SPR) is not appropriate as a target reference point for blue cod in Marlborough Sounds for the following reasons:

1. As this species is a diandric protogynous hermaphrodite, with behavioural triggers for females changing to secondary males, it is difficult to reliably model this process, especially since the rate of sex change increases with the removal of dominant males by fishing, in an unpredictable manner.
2. Few females currently grow large enough to recruit to the fishery, presumably because the larger females change to males when dominant males are removed, so fishing mortality is mostly experienced by the males.
3. The standard spawner-per-recruit approach does not account for the reduction female spawner biomass resulting from the increased rate of sex change, implied by the sex ratio being heavily skewed to males.
4. Current growth rates of both males and females is likely to have been substantially modified by the increased rate of sex change induced by fishing. It is therefore not possible to estimate the growth rate of the virgin unfished population.

The Plenary recommended F=0.87M as an overfishing threshold for Marlborough Sounds blue cod, on the basis of Zhou et al (2012). Since none of the female age classes were fully recruited to the fishery, the Plenary recommend using the age composition of males for estimating total morality (*Z*). Table 11 was revised in July 2022; previous *SPR* results were removed and *Z* and *F* for males only are now presented, based on age at recruitment equivalent to age at which males reached minimum legal size, plus a one year to ensure more than 50% of males are recruited. The resulting high estimates of *F* (Table 11) are consistent with the relative catch rates inside and outside the Long Island Marine Reserve in adjacent Queen Charlotte Sound, where the catch rates outside were 18.6% and 17.5% of those inside the reserve, in 2017 and 2021, respectively.

Table 11: Mortality parameters (*Z*, *F*, and *M*) estimates for blue cod from the 2013, 2017, and 2021 Marlborough Sounds fixed-site and random-site potting surveys for all regions combined. *Z* (total mortality) and *F* (fishing mortality) estimates are for males 6 years and older. Otoliths from these surveys were aged using the Age Determination Protocol for blue cod (Walsh 2017). CIs, 95% confidence intervals;

Survey	Region	Site type	*M*	*Z* (CIs)	*F* (CIs)
2013	All regions combined	Fixed	0.17	0.66 (0.46–0.88)	0.49 (0.29–0.71)
2017			0.17	0.77 (0.54–1.03)	0.60 (0.37–0.86)
2013	All regions combined	Random	0.17	0.60 (0.42–0.81)	0.43 (0.25–0.64)
2017			0.17	0.75 (0.52–1.02)	0.58 (0.35–0.85)
2021			0.17	0.65 (0.43–0.90)	0.48 (0.26–0.73)

Banks Peninsula

There have been five fixed-site blue cod potting surveys off Banks Peninsula (2002, 2005, 2008, 2012, and 2016), split into geographically separate inshore and offshore areas (Beentjes & Carbines 2003, 2006, 2009, Carbines & Haist 2017, Beentjes & Fenwick 2017). In 2012 and 2016, concurrent random-site potting surveys were also carried out with the intention of replacing fixed-site surveys because the random-site surveys provide a more reliable indicator of stock status. The 2021 potting survey was the firstly solely random-site survey and the third in the time series (Beentjes et al 2022b).

Inshore survey. The most recent inshore random-site survey in 2021 recorded overall catch rates of 0.49. kg pot^{-1} (CV 20%), a sex ratio of 85% male, and mean lengths of 29 and 25 cm for males and females, respectively (Table 12) (Beentjes et al 2022b). The *SPR* ratio estimates from the 2016 and the current 2021 inshore random-site surveys were considered to be unreliable because of the poor estimates of *Z*, but they do reflect the extremely truncated nature of the age composition (oldest fish in 2021 was 6 years old) and indicate that *SPR* ratios are likely to be well below the target reference point of $F_{45\%SPR}$. This finding, together with the strongly skewed sex ratio toward males and very low catch rate estimates, indicates that the Banks Peninsula inshore blue cod population is heavily overfished. Further, as nearly all females and most males currently caught will be of sub-legal size (less than 33 cm), there is also likely to be significant mortality through catch and return of undersized fish. Notwithstanding the differences in catch rates ascribed to the survey design (fixed or random), there are strong indications that inshore blue cod biomass has declined substantially between 2005 and 2021 (Figure 4). For the 2012 random-site survey, sex ratios (all blue cod) were almost the same as those in fixed sites (about 70%), but in the 2016 random-site survey there were about 10% more males, increasing slightly in 2021 to 85% male; this indicates that male dominance in sex ratio may be increasing.

Offshore survey. The most recent offshore random-site survey in 2021 recorded overall catch rates of 1.90. kg pot^{-1} (CV 24%), a sex ratio of 66% male, and mean lengths of 37 and 34 cm for males and females, respectively (Table 12) (Beentjes et al 2022b). The 2016 and 2021 random-site survey spawner-per-recruit ratios were $F_{85\%SPR}$ and $F_{41\%SPR}$ indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit was reduced to 85% and 41% of the contribution in the absence of fishing. The level of exploitation (*F*) of offshore blue cod stocks has therefore increased substantially in five years, and in 2021 slightly exceeded the F_{MSY} target reference point of $F_{45\%SPR}$ (Table 12). Notwithstanding the differences in catch rates that can be ascribed to the survey design (fixed or random), there were no trends in abundance until the 63% decline between the 2016 and 2021 random-site surveys (Figure 4); this decline was largest in stratum 7 (Pompey's Rock) which is the more accessible of the two offshore strata. Length distributions had fewer larger male fish than in the 2021 compared with 2016 random-site surveys. Random-site surveys had similar sex ratios to overlapping fixed-site surveys in 2012 and 2016, but the 2021 survey had the highest proportion of males (66%) for any survey in the time series. There was clear evidence of modal progression of strong and weak ages classes from 2016 to 2021. The offshore blue cod population has historically been considered to be a healthy blue cod population, with a broad age structure, relatively high abundance, and a balanced sex ratio. However, between 2016 and 2021, abundance declined by 63%, age structure narrowed with fewer older age classes, there were fewer larger fish, *Z* increased, *SPR* ratio decreased, and the sex ratio is trending toward more males in the population. This indicates that the offshore blue cod population, and particularly Pompey's Rock, is now showing signs of overfishing.

Table 12: Summary statistics from standardised blue cod potting surveys of the northeast coast of the South Island (BCO 3). CPUE (catch rates) – catch per unit effort (kg pot^{-1}); CV – coefficient of variation (set based); mean length is from population scaled length. $M = 0.17$ in *SPR* analyses. All survey results shown are compliant with the blue cod potting manual, and the blue cod age determination protocol (Beentjes 2019, Beentjes & Page 2021, Beentjes & Miller 2021, Beentjes & Fenwick 2017, Beentjes et al 2022b, Walsh 2017). –, no valid ageing; NA, no valid SPR estimates in fixed sites.

	Mean length (cm)		Survey	CPUE stratum range (kg pot^{-1})	Sex ratio	
Area/Year	**Female**	**Male**	**(kg pot^{-1})**	**(CV) all**	**(% male)**	$F_{\%SPR}$
North Canterbury						
Kaikōura						
2004 (fixed sites)	30.3	32.5	2.62	0.60–7.97 (11.1%)	48.7	–
2007 (fixed sites)	29.8	32.5	5.00	1.91–20.45 (12.6%)	48.1	–
2011 (fixed sites)	27.5	29.1	3.66	2.14–11.44 (13.3%)	53.0	–
2011 (random sites)	28.5	29.5	2.64	0.61–8.22 (16.7%)	46.8	–
2015 (fixed sites)	25.9	27.0	2.25	1.58–5.07 (20.2%)	66.3	NA
2015 (random sites)	29.0	30.0	2.21	0.48–9.41 (18.9%)	51.7	72
2017 (random sites)	28.6	28.4	1.90	0.00–6.92 (15.9%)	44.8	42
2019 (random sites)	29.4	29.2	1.56	0.01–8.26 (10.4%)	50.0	62
Motunau						
2005 (fixed sites)	25.7	29.6	10.2	8.7–15.4 (11.4%)	76.6	–
2008 (fixed sites)	25.2	29.3	5.50	4.1–8.9 (16.1%)	77.9	–
2012 (fixed sites)	24.6	29.1	5.55	4.43–8.70 (11.8%)	71.9	–
2012 (random sites)	23.5	28.2	3.01	1.81–6.95 (19.5%)	72.1	–
2016 (fixed sites)	22.4	25.8	3.32	2.94–4.66 (12.7%)	75.5	NA
2016 (random sites)	22.2	26.5	2.48	1.10–7.24 (26.8%)	76.3	22.2
2020 (random sites)	20.2	24.8	2.07	1.41–4.54 (18.9%)	74.5	21.4
Banks Peninsula						
Inshore						
2002 (fixed sites)	25.4	28.3	1.12	0.04–2.61 (23.2%)	67.9	–
2005 (fixed sites)	27.2	32.7	2.78	1.02–4.16 (12.2%)	74.2	–
2008 (fixed sites)	25.5	29.8	1.08	0.07–2.30 (17.8%)	70.2	–
2012 (fixed sites)	24.7	28.8	1.35	0.60–1.88 (12.4%)	67.2	–
2012 (random sites)	22.8	27.3	1.23	0.33–2.89 (16.6%)	66.1	–
2016 (fixed sites)	23.2	26.5	1.26	0.57–2.12 (11.8%)	67.5	NA
2016 (random sites)	23.8	26.1	0.53	0.09–0.94 (22.2%)	81.3	NA
2021 (random sites)	25.0	29.3	0.49	0.0–0.79 (19.7%)	84.8	NA
Offshore						
2002 (fixed sites)	36.6	37.6	3.39	2.04–4.74 (19.9%)	41.8	–
2005 (fixed sites)	37.4	41.2	6.48	5.68–7.27 (9.4%)	57.2	–
2008 (fixed sites)	35.6	41.8	4.48	3.13–5.80 (13.8%)	49.8	–
2012 (fixed sites)	33.5	37.4	4.88	3.49–6.28 (17.0%)	55.9	–
2012 (random sites)	34.1	39.3	3.77	3.69–4.09 (36.2%)	59.0	–
2016 (fixed sites)	33.6	36.8	5.60	5.09–6.10 (14.1%)	65.2	NA
2016 (random sites)	36.1	41.3	5.08	5.21–4.54 (19.5%)	57.5	85.1
2021 (random sites)	33.6	36.8	1.90	1.50–3.20 (23.9%)	65.6	41.5

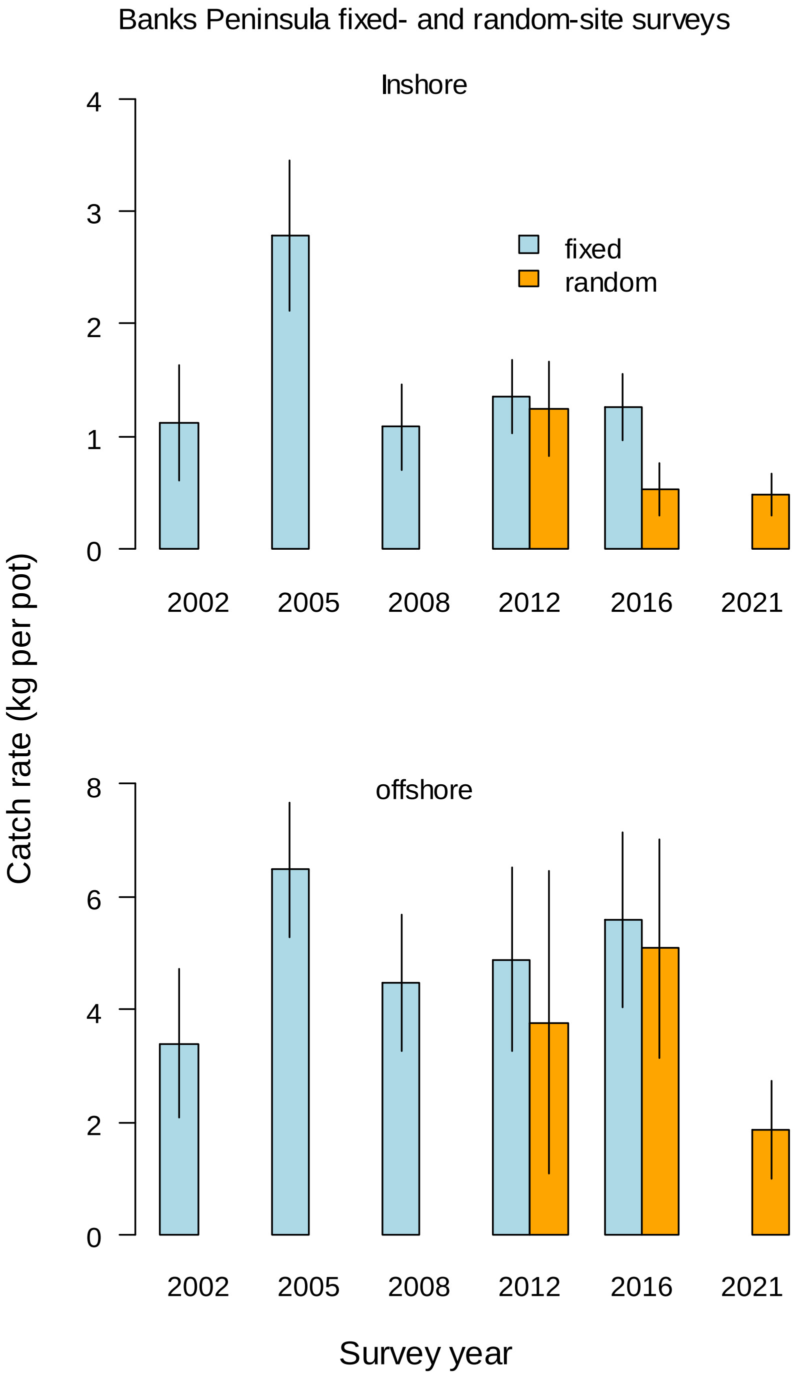


Figure 4: Banks Peninsula fixed-site and random-site potting survey catch rates of all blue cod by survey year shown for inshore and offshore populations. Error bars are 95% confidence intervals. Note the different y-axis scales for inshore and offshore (Beentjes et al 2022b).

North Canterbury

Kaikōura

There have been four fixed-site blue cod potting surveys off Kaikōura (2004, 2007, 2011, and 2015), (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2018a, Beentjes & Page 2017). In 2011 and 2015 concurrent random-site potting surveys were also carried out with the intention of replacing fixed-site surveys. Subsequently solely random-site surveys were carried out in 2017, earlier than the standard four-year cycle, to assess the impact of the November 2016 earthquake (Beentjes & Page 2018), and in 2019 (Beentjes & Page 2021). Random surveys provide a more reliable indicator of stock status than fixed-site surveys and will be used in future.

The most recent random-site survey in 2019 recorded catch rates of 1.56 kg pot^{-1} (CV 10%), sex ratio of 50% male, and mean lengths of 29.4 cm and 29.2 cm for males and females, respectively (Table 12). For the four fixed-site surveys, catch rates increased nearly two-fold from 2004 to 2007, and then declined in both 2011 and 2015, and catch rates from the last survey were the lowest of all four surveys (Table 12, Figure 5). For the four random-site surveys there was a slight decline over time with a statistically significant difference ($P<0.05$) between the mean pot catch of 2011 and 2019 surveys (Figure 5). Notwithstanding the differences in catch rates that can be ascribed to the survey design (fixed or random), blue cod biomass declined by around 50% between 2007 and 2019. The sex ratio for all blue cod was close to parity for all surveys (fixed and random), with the exception of the 2015 fixed-site survey where two-thirds of the blue cod were male (Table 12).

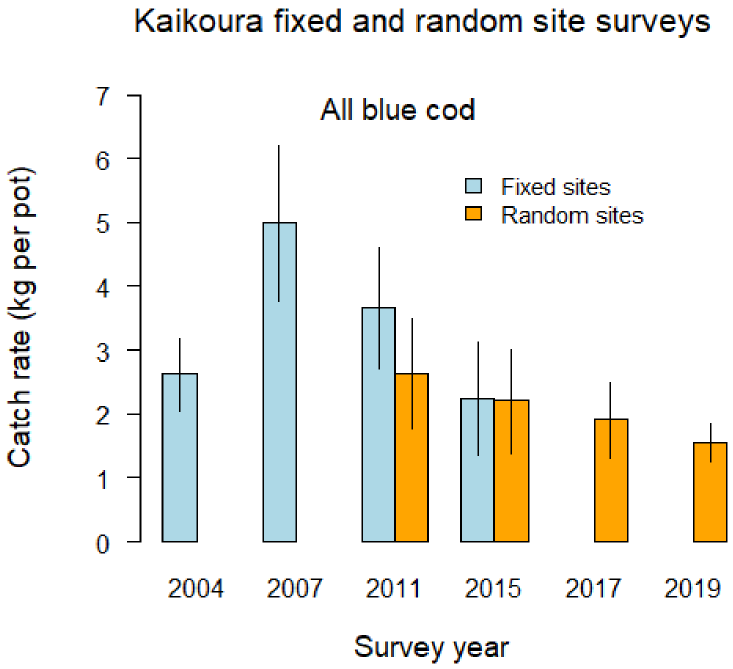


Figure 5: **Kaikōura fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals.**

Ageing is only valid for the 2015, 2017, and 2019 random-site surveys (i.e., compliant with the blue cod age determination protocol, Walsh 2017). Cohort progression of blue cod age classes is apparent over the three random-site surveys from 2015 to 2019, showing both nominally strong and weak year classes. Length frequency distributions and mean lengths were similar among the four random-site surveys with any differences due to the strong recruitment of mainly juvenile male blue cod in 2015, progressing through to strong modes in 2017 and 2019. In 2015 and 2019 the random-site survey spawner-biomass-per-recruit ratios were 72% and 62% indicating that the level of exploitation (F) of Kaikōura blue cod stocks was below the F_{MSY} target reference point of $F_{45\%SPR}$ (underexploited) (Table 12). In 2017 the random-site survey spawner-biomass-per-recruit ratio was 42%, indicating that the level of exploitation of Kaikōura blue cod stocks was above the F_{MSY} target reference point of $F_{45\%SPR}$ (over-exploited). However, because recruitment is not constant, and there are relatively few age classes represented above the age at recruitment, the point estimates of Z, F, and SPR should be treated with caution.

Motunau

There have been four fixed-site blue cod potting surveys off Motunau (2005, 2008, 2012, and 2016), (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2018a, Beentjes & Sutton 2017). In 2012 and 2016 concurrent random-site potting surveys were also carried with the intention of replacing the fixed-site surveys. Subsequently, a solely random-site survey was carried out in 2020 (Beentjes & Miller 2021). Random surveys provide a more reliable indicator of stock status than fixed-site surveys and will be used in future.

The most recent random-site survey in 2020 had catch rates of 2.1 kg pot^{-1} (CV 18.9%), sex ratio of 74% male, and mean lengths of 24.8 cm and 20.2 cm for males and females, respectively (Table 12).

For the four fixed-site surveys, catch rates decreased by about half in 2008 and then by half again in 2016 with a three-fold decline between 2005 and 2016 (Table 12, Figure 6). For the three random-site surveys there was a slight decline over time, but no statistically significant difference (P=0.19) between the mean pot catch of 2012 and 2020 surveys (Table 12, Figure 6). Notwithstanding the differences in catch rates that can be ascribed to the survey design (fixed or random), blue cod biomass appears to have declined by around 50% between 2005 and 2020. The sex ratio for all blue cod was around 75% male for fixed-site and random-site surveys with no trend (Table 12). Overall blue cod mean size shows a trend of declining size in both the fixed-site and random-site surveys.

Ageing is only valid for the 2016 and 2020 random-site surveys (i.e., compliant with the blue cod age determination protocol, Walsh 2017). Cohort progression of blue cod age classes is apparent from 2016 to 2020, showing both nominally strong and weak year classes. In 2016 and 2020 the random-site survey spawner-biomass-per-recruit ratios were 22% and 21% indicating that the level of exploitation (F) of Motunau blue cod stocks was well below the F_{MSY} target reference point of $F_{45\%\mathrm{SPR}}$ (overexploited) (Table 12). However, because recruitment is not constant, and there are relatively few age classes represented above the age at recruitment, the point estimates of Z, F, and SPR should be treated with caution.

The very high estimate of total mortality, truncated age composition, small size, strongly skewed sex ratio toward males, and a spawner-per-recruit ratio less than half the target indicates the current level of exploitation is unlikely to be sustainable. Further, as nearly all females and most males currently caught will be of sub-legal size (less than 33 cm from 1 July 2020), there is also likely to be significant mortality through catch and return of undersize fish.

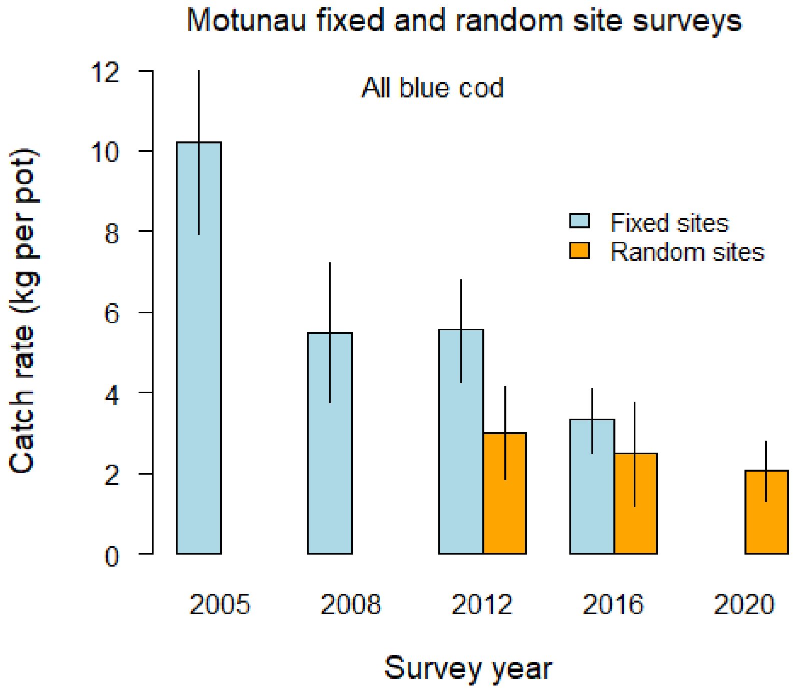


Figure 6: **Motunau fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals.**

North Otago

There have been four fixed-site blue cod potting surveys (2005, 2009, 2013, and 2018), and two random-site surveys off north Otago (2013 and 2018) (Beentjes & Fenwick 2019a). Random-site potting surveys are intended to replace fixed-site surveys, because they provide a more reliable indicator of abundance. The most recent random-site survey in 2018 recorded catch rates of 2.35 kg pot^{-1} (CV 18%), sex ratio of 87% male, and mean lengths of 30.2 cm and 26.7 cm for males and females, respectively (Table 13, Figure 7).

Table 13: Summary statistics from standardised blue cod potting surveys carried out in the southeast coast of the South Island (BCO 3). CPUE – catch per unit effort (kg pot^{-1}); CV – coefficient of variation; Mean length, from population scaled length. All north Otago survey outputs from Beentjes & Fenwick (2019a). South Otago survey 2010 outputs from Beentjes (2012) and subsequent surveys from Beentjes & Fenwick (2019b). *, no stratum 6 in 2005; **, only strata 1, 3, and 6 surveyed in 2010; –, no valid ageing.

	Mean length (cm)		Survey CPUE		Sex ratio	
Area/Year	**Female**	**Male**	**(kg pot^{-1})**	**CPUE range (CV)**	**(% male)**	**$F_{\%SPR}$**
North Otago						
2005 (fixed sites)*	27.8	32.8	10.2	7.49–14.5 (7.9%)	72.5	–
2009 (fixed sites)	27.4	32.3	11.5	6.21–19.88 (6.6%)	73.1	–
2013 (fixed sites)	27.5	31.7	5.0	2.72–8.07 (12.6%)	75.9	–
2013 (random sites)	27.5	30.7	4.2	0.94–7.46 (13.9%)	67.8	–
2018 (fixed sites)	26.3	30.4	3.55	2.24–5.30 (17.7%)	84.9	23
2018 (random sites)	26.7	30.2	2.35	0.33–4.12 (14.3%)	87.0	23
South Otago						
2010 (fixed sites)**	29.4	33.6	9.7	3.3–16.9 (17.1%)	74.5	–
2010 (random sites)**	23.7	29.0	4.4	1.2–6.0 (17.8%)	66.9	–
2013 (random sites)	25.5	31.9	6.2	0.8–7.4 (19.9%)	57.4	–
2018 (random sites)	24.9	29.0	1.52	0.17–3.79 (28.5%)	68.4	25

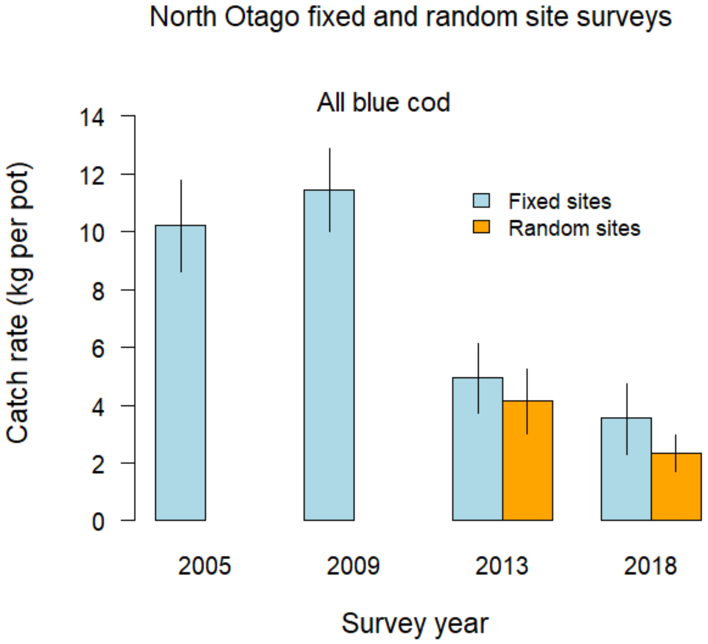


Figure 7: North Otago fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals. Surveys after 2005 include a new stratum (stratum 6).

For the four fixed-site surveys, catch rate was similar in 2005 and 2009, but in 2013 there was a decline with no overlap in the confidence intervals, and catch rates remained low in 2018 (Table 13, Figure 7). There are only two random-site surveys in the time series, but relative abundance showed a similar decline between 2013 and 2018 with no overlap in the confidence intervals. The sex ratio for all fixed-site surveys was 72–76% male for all blue cod with no trend, and 75–87% for the two random sites (Table 13). A preponderance of males is thought indicate high fishing intensity. The fixed-site scaled length frequency distribution shapes were similar for 2005 and 2009 but changed in 2013 and again in 2018 with the latter having relatively fewer larger fish than earlier surveys. For the two random-site surveys the length frequency distributions were similar between years, but overall blue cod were slightly smaller in 2018 than 2013. Ageing is currently only valid for the 2018 survey (i.e., compliant with the blue cod age determination protocol, Walsh 2017) and showed strong modes at three, five, and eight years for both sexes, but particularly for males. The 2018 random-site survey spawner-biomass-per-recruit ratio was 30% (assuming $M = 0.17$), indicating that the level of exploitation (F) of north Otago blue cod stocks was above the F_{MSY} target reference point of $F_{45\%SPR}$, in 2018 (over-exploited) (Table 13).

South Otago

There has been one fixed-site blue cod potting survey (2010), and three random-site surveys off south Otago (2010, 2013, and 2018) (Beentjes & Fenwick 2019b). The random-site surveys in 2013 and 2018 replaced fixed-site surveys. Random surveys provide a more reliable indicator of stock status and will be used solely in the future off south Otago. The first survey in 2010 was designed to compare fixed- and random-site potting survey designs and used only three of the six strata (Beentjes & Carbines 2011), with catch rates in fixed sites double that from random sites (Table 13, Figure 8). The most recent random-site survey in 2018 had catch rates of 1.52 kg pot^{-1} (CV 28%), a sex ratio of 68% male, and mean lengths of 29.0 cm and 24.9 cm for males and females, respectively (Table 13, Figure 8). There was a four-fold drop in catch rates between 2013 and 2018 random-site full strata surveys with no overlap in the confidence intervals, and this was largely mirrored in the three strata survey.

The sex ratio has varied from 60 to 70% male with no trend (Table 13) – a preponderance of males indicating high fishing pressure. The scaled length frequency distribution shapes for the random-site full strata surveys differed with 2013 having a strong juvenile mode and relatively more larger fish than 2018. Ageing is currently only valid for the 2018 survey (i.e., compliant with the blue cod age determination protocol, Walsh 2017) and showed strong modes at three, five, and eight years for both sexes, but particularly for males. This age structure mirrored that for north Otago in 2018. The 2018 random-site survey spawner-biomass-per-recruit ratio was 34% (assuming $M = 0.17$), indicating that the level of exploitation (F) of south Otago blue cod stocks was above the F_{MSY} target reference point of $F_{45\%SPR}$, in 2018 (over-exploited) (Table 13).

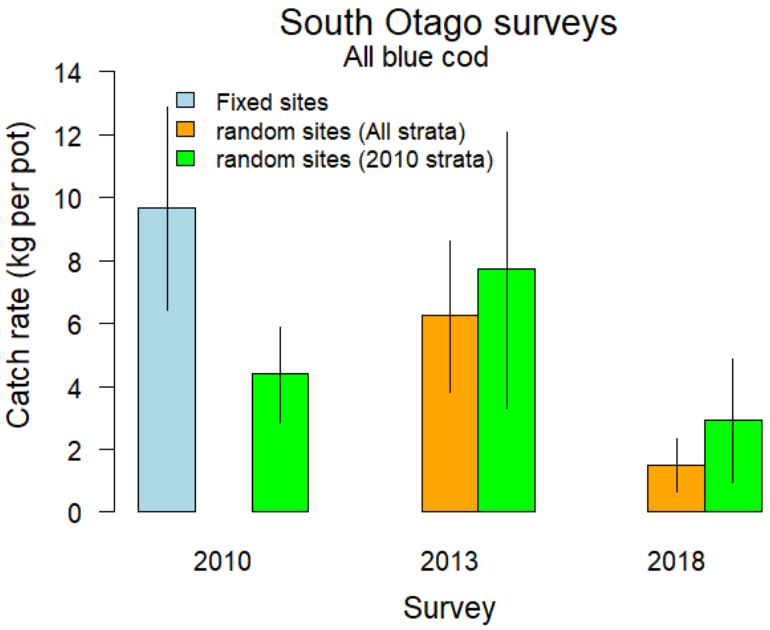


Figure 8: **South Otago fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals. The 2010 survey used three strata, and subsequent surveys used 6 strata. Catch rates are also shown for the three strata used in 2010 for the random-site surveys.**

Foveaux Strait

There have been three random-site surveys in Foveaux Strait (2010, 2014, and 2018) (Beentjes et al 2019). The most recent random-site survey in 2018 had catch rates of 5.66 kg pot^{-1} (CV 20%), sex ratio of 51% male, and mean lengths of 30.6 cm and 28.4 cm for males and females, respectively (Table 14, Figure 9). There is no clear trend in catch rates over the time series. Catch rates in Foveaux Strait, as of 2018, are the highest of all South Island random-site surveys.

Table 14: Summary statistics from standardised blue cod potting surveys carried out in the south and southwest coast of the South Island (BCO 5). $F_{\%SPR}$ estimated for age at full recruitment and M = 0.14 except Paterson Inlet where M is 0.17. Mean length, mean age, and sex ratios are from population scaled length and age. Foveaux Strait survey - all results from Beentjes et al (2019); Paterson Inlet survey excludes Ulva Island Marine Reserve –all results from Carbines (2007), Carbines & Haist (2014a), Carbines & Haist (2018c), Beentjes & Miller (2020); Dusky Sound excludes Five Fingers Marine Reserve – all results from Carbines & Beentjes (2003, 2011a) and Beentjes & Page (2016). Only mean ages and $F_{\%SPR}$ based on otoliths aged with the Age Determination Protocol (Walsh 2017) are included in this table. CPUE, catch per unit effort (kg pot^{-1}); CV, coefficient of variation.

	Mean length (cm)		Mean age (years)		CPUE	CPUE range (CV)	Sex ratio % male (MWCV around age)	$F_{\%SPR}$
Area/Year	Female	Male	Female	Male	(kg pot^{-1})	or set-based*		
Foveaux Strait								
2010 (random sites)	27.7	30.4	5.8	5.2	5.25	0.81–14.14 (12.7%)	47.2	26.9
2014 (random sites)	27.7	30.3	6.0	4.9	7.57	3.16–16.22 (12.9%)	48.0	27.6
2018 (random sites)	28.4	30.6	6.8	5.7	5.66	1.47–8.40 (20.5%)	50.7	21.8
Paterson Inlet								
2006 (fixed sites)	26.9	32.8			4.8	1.47 – 8.42 (11.9%)	55.5	
2010 (fixed	27.5	32.2			4.2	1.5 – 6.6 (11.1%)	75.1	
2010 (random sites)	25.9	29.0			0.82	0.23 – 1.4 (24.1%)	61.5	
2014 (fixed	26.9	32.3			4.8	1.05 – 7.66 (12.9%)	75.3	
2014 (random sites)	27.0	29.9			1.94	0.44 – 2.73 (19.9%)	67.5	
2018 (random sites)	27.2	29.6	6.1	5.3	1.51	0.59–2.72 (17.7%)	67.0	68.0
Dusky Sound								
2002 (fixed sites)	29.9	34.7			2.95	1.29–8.43 (10.8%)		
2008 (fixed	32.2	37.9			4.20	2.49 – 8.13 (5.8%)		
2014 (fixed sites)	32.6	35.2	8.1	6.9	3.22	1.87–9.2 (11.9%)		48.3
2014 (random sites)	32.3	33.8	8.2	6.5	2.61	2.04–4.99 (8.6%)		49.0

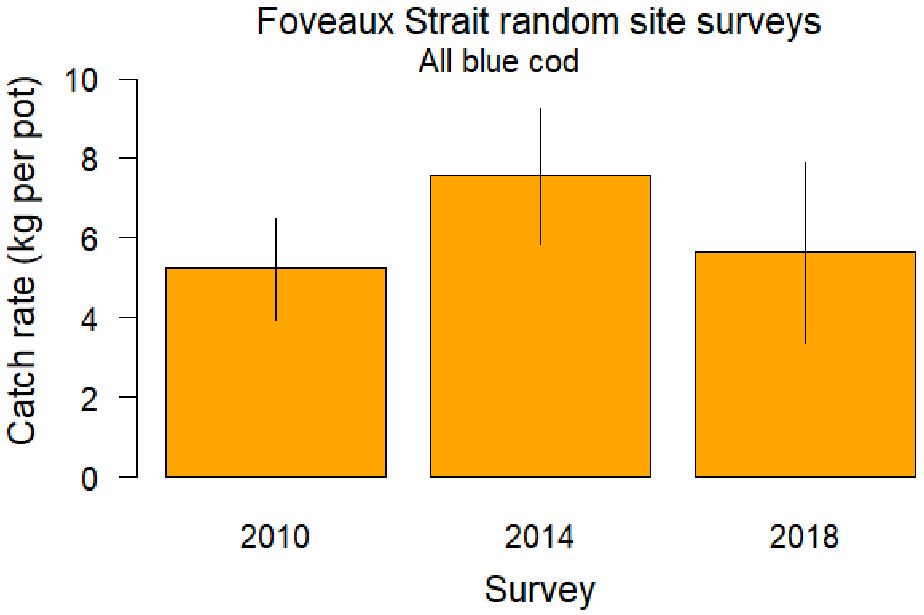


Figure 9: Foveaux Strait random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals.

The sex ratio has varied from 47 to 51% male with no trend (Table 14). The scaled length frequency distributions and mean length of all blue cod were remarkably similar for all three surveys. Ageing is valid for all three surveys (i.e., compliant with the blue cod age determination protocol, Walsh 2017). The age structure of both males and females was generally similar among the three surveys with minor differences in the strength of some cohorts. The spawner-biomass-per-recruit ratios were 27%, 28%, and 22%, for 2010, 2014, and 2018, respectively, indicating that the level of exploitation (F) of Foveaux Strait blue cod stocks was above the F_{MSY} target reference point of $F_{45\%SPR}$, in all three surveys (over-exploited) (Table 14). However, a cautious approach should be taken in interpreting *SPR* estimates when so few age classes are included in the recruited population.

Paterson Inlet

There have been three fixed-site (2006, 2010, 2014), and three random-site blue cod potting surveys in Paterson Inlet (2010, 2014, and 2018) (Carbines 2007, Carbines & Haist 2014a, 2018c, Beentjes & Miller 2020). Random-site potting surveys have replaced fixed-site surveys because they provide a more reliable indicator of abundance. All surveys have included the Ulva Island Marine Reserve as an additional stratum but all results given here exclude the marine reserve. The most recent random-site survey in 2018 recorded catch rates of 1.5 kg pot^{-1} (CV 18%), sex ratio of 67% male, mean lengths of 29.6 cm for males and 27.2 cm for females, and mean ages of 5.3 years males and 6.1 years for females. Neither the fixed-site nor random-site survey time series show any clear indications of a change in relative abundance, size, or sex ratio, although there was a large increase in abundance between 2010 and 2014 for the random-site series (Figure 10). More random-site surveys are required before trends can be reliably identified. Ageing is only valid for the 2018 random-site survey, which is compliant with the blue cod age determination protocol (Walsh 2017). In 2018, using a default *M* of 0.17, estimated fishing mortality (*F*) was 0.08, and the associated spawner biomass-per-recruit ratio (SPR) was 68% (95% confidence interval 49–100%) (Table 14). The point estimates of *Z*, *F*, and *SPR* in 2018 should be treated with caution because the traditional catch curve did not follow the ideal straight-line descending limb, suggesting that the assumption of constant recruitment had been violated.

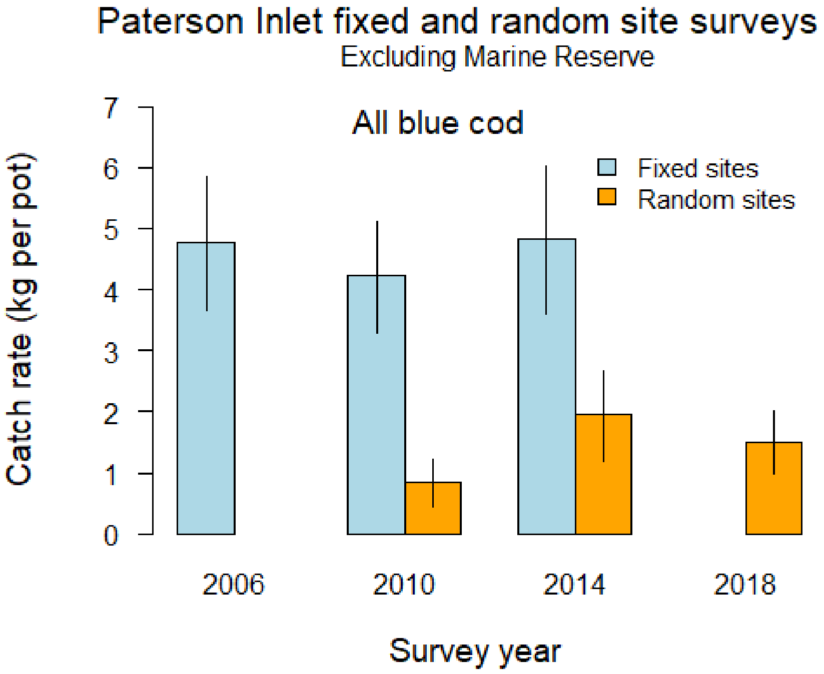


Figure 10: **Paterson Inlet random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals.**

Dusky Sound

Three blue cod potting surveys have been carried out in the Dusky Sound. The surveys in 2002 and 2008 were both fixed-site surveys, whereas, in 2014, independent fixed-site and random-site surveys were carried out concurrently.

In 2002 the overall mean catch rates for all blue cod from fixed sites were 2.65 kg pot^{-1} (CV = 9.2%) and 1.81 kg pot^{-1} for recruited blue cod $\geq$ 33 cm (CV = 8.7%). Catch rates were highest on the open coast (i.e., at the entrance to the sound, Carbines & Beentjes 2003). The 2008 fixed-site survey catch rates were 4.2 kg pot^{-1} (CV = 5.8%) for all blue cod and 3.15 kg pot^{-1} (CV = 5.9%) for recruited blue cod, considerably higher than in 2002 and again highest catch rates were in the open coast stratum (Carbines & Beentjes 2011a). In 2014 the fixed-site catch rates had declined to 3.22 kg pot^{-1} (CV = 11.9%) and 2.35 kg pot^{-1} (CV = 11.9%), respectively, with highest catch rates on the open coast. The 2014 random-site catch rates were less than from fixed sites and were 2.61 kg pot^{-1} (CV = 8.6%) for all blue cod and 1.92 kg pot^{-1} (CV = 9.6%) for recruited blue cod, also with catch rates highest on the open coast (Beentjes & Page 2017). Overall scaled length and age distributions were similar between the fixed- and random-site surveys but the sex ratio favoured females in fixed sites (39% male) and was close to parity in random sites (52% male). Fixed-site surveys may not be suitable for monitoring the Dusky Sound blue cod population, but at least one more dual fixed- and random-site survey is required before moving exclusively to random-site surveys.

Total mortality (*Z*) for blue cod from the 2014 random-site survey was estimated at 0.25 with spawner-biomass-per-recruit (full recruitment at 8 years for females) estimated at $F_{49\%}$. Mortality estimates from the 2002 and 2008 surveys should not be used due to a recent change in the age determination protocol for blue cod.

4.1.2 Trawl survey estimates

Relative abundance indices from trawl surveys are available for BCO 3, BCO 5, and BCO 7, but these have not been used because of the high variance and concerns that this method may not appropriately sample blue cod populations.

4.1.3 CPUE Analyses

BCO 3

A standardised CPUE analysis was conducted in 2019 on the target blue cod potting fishery operating in BCO 3. This fishery accounted for two-thirds of the total BCO 3 landings in the 29 years from 1989–90 to 2017–18, predominantly in the two southernmost BCO 3 Statistical Areas 024 and 026. Together these two areas represented about 90% of the total target blue cod potting fishery over the same 29 years (Figure 11). As found in the previous analyses, there was misreporting of RCO 3 landings as BCO 3, probably due to data entry errors (Starr & Kendrick 2010). This problem was again resolved before undertaking the CPUE analysis.

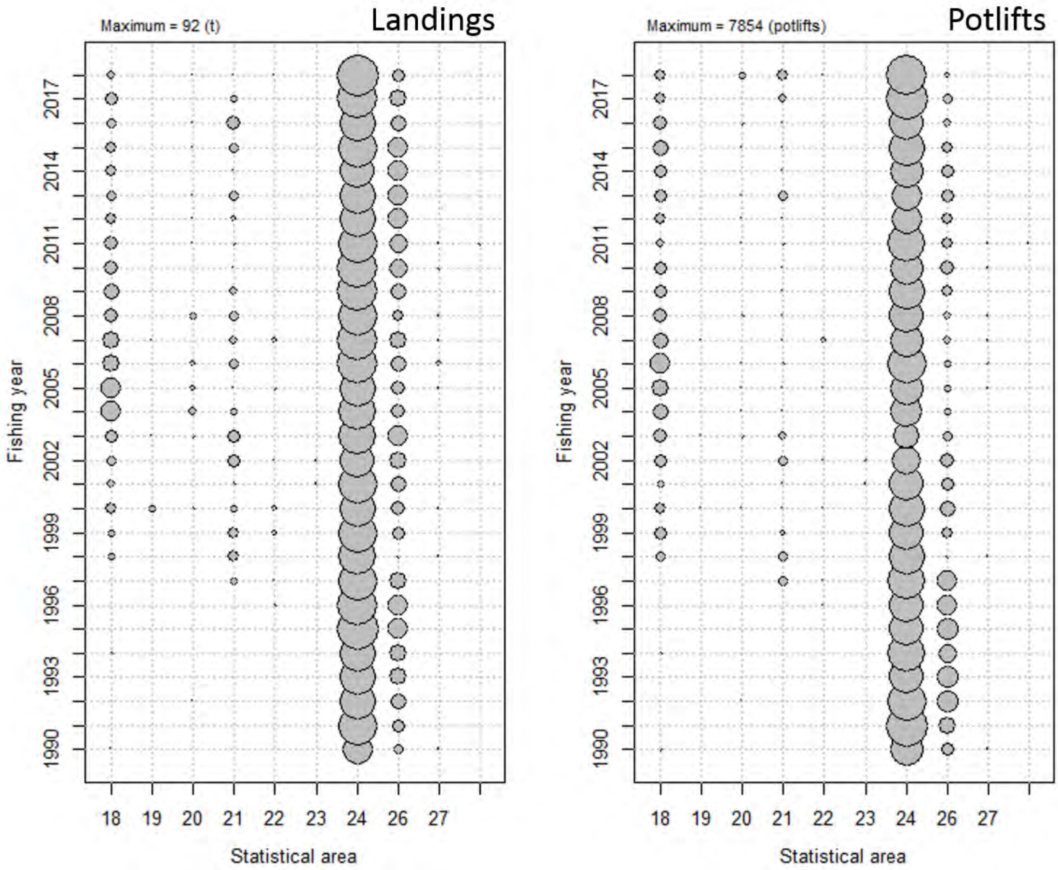


Figure 11: Distribution of landings and number of potlifts for the cod potting method by statistical area and fishing year from trips which landed BCO 3. Circles are proportional within each panel: [landings] largest circle = 92 t in 2011 for Statistical Area 024 (24); [number potlifts] largest circle = 7854 pots in 2006 for Statistical Area 024 (Holmes et al 2022a).

The effort data were matched with the landing data at the trip level and the 'trip-stratum' stratification inherent in the CELR data was maintained. The 2019 analysis used only data from Statistical Areas 024 and 026. The CPUE analysis was confined to a set of core vessels which had participated consistently in the fishery for a reasonably long period (5 trips in 3 years), resulting in keeping 61 vessels representing 94% of the landings. The explanatory variables offered to the model included fishing year (forced), month, vessel, statistical area, number of pots lifted in a day, and number of days fishing in the record. A log-logistic model (as used in the 2015 analysis) based on successful catch records was used because there were too few unsuccessful fishing events to justify pursuing a binomial model.

The log-logistic standardised model for BCO 3 (Figure 12) fluctuated without trend with the final data point close to the series mean. In the 2015 analysis, a model using estimated catches instead of scaled landings showed a similar trend up to 2012–13, when the series based on landed catch increased more rapidly than the estimated catch series. The Southern Inshore Working Group agreed in 2015 that the series based on landed catch was more reliable and consistent with other CPUE analyses done for the working group.

During 2002–03 to 2017–18, commercial catches in BCO 3 exceeded the TACC by 5%. The bulk of the total BCO 3 commercial catch (72%) was taken from Statistical Areas 024 and 026 (along with about 90% of the CPUE data). The CPUE series shown in Figure 12 is representative of the southern portion of BCO 3 (Statistical Areas 024 and 026) and is not applicable to those parts of BCO 3 north of Statistical Area 024.

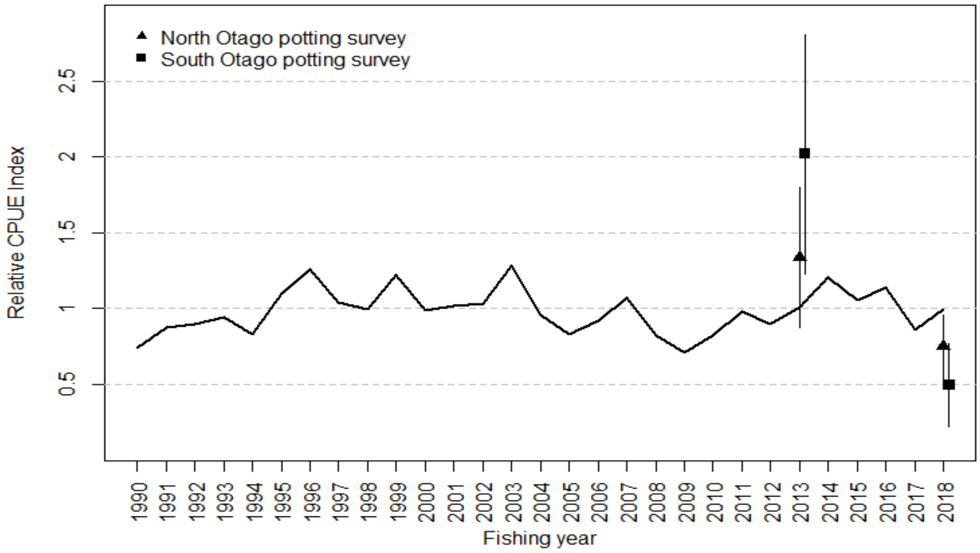


Figure 12: Comparison of BCO 3 standardised series (1989–90 to 2017–18) based on landed green weight catch data and the 2013 and 2018 observations from the north Otago and south Otago potting surveys conducted at random sites over all strata (Holmes et al 2022a). (Each relative series is scaled so that the geometric mean equals 1.0 from 2013 to 2018.)

Establishing B_{MSY} compatible reference points

In 2019, the Working Group accepted the mean CPUE from the target BCO cod potting series for the period 1994–95 to 2003–04 as the B_{MSY}-compatible proxy for BCO 3. This period was chosen because catches and CPUE were stable without trend and apparent productivity was good. This period was also used to determine average fishing intensity compatible with the selected B_{MSY}-compatible proxy. The Southern Inshore Working Group accepted the default Harvest Strategy Standard definitions for the Soft and Hard Limits at one-half and one-quarter the target, respectively. This conclusion was revisited in 2021 at which time the working group determined that it no longer had confidence in the consistency of the CPUE series, given that the series did not account for a 10 mm increase in the regulated mesh size (from 38 mm to 48 mm square mesh) in June 2009.

4.3 BCO 4

The cod potting fishery in BCO 4 is entirely targeted on blue cod and reported on the daily CELR form. The spatial resolution of the catch effort data is therefore defined by general statistical area and by day (or part of a day). CPUE was standardised for the cod pot fishery operating in Statistical Areas 049 to 052 up to 2017–18 (Holmes et al 2022b). The analysis was based on a Weibull model of positive allocated landed catches from a core fleet of vessels. This methodology follows that used in the previous CPUE standardisation (Bentley & Kendrick in prep). Detailed examination of model residuals and the distribution of catch per vessel day suggested that the Weibull distribution provided a better fit to the data than the lognormal distribution and other alternative distributions. The previous analysis found that there appears to have been a change in the underlying frequency distribution of catch categories in the late 1990s, which may be a result of several factors, including changes in the fleet composition, fishing methods, and/or reporting practices. Consequently, the indices for the fishing years up to, and including, 1996–97 are considered to be less reliable and may not be comparable with the indices from the latter part of the series. The working group considered that the current CPUE standardisation should only include analysis of the fishing years from 1997–98.

Overall, the annual indices from the standardisation model have fluctuated without trend since the late 1990s (Figure 13).

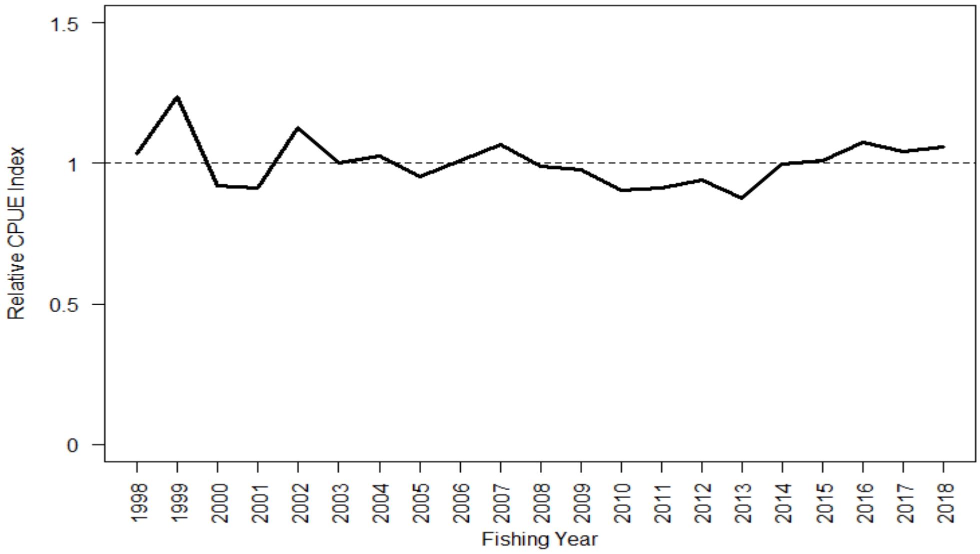


Figure 13: Standardised CPUE index for BCO 4 based on records of positive BCO catch by core vessels, 1997–98 to 2017–18 (Holmes et al 2022b).

4.4 BCO 5 (Southland)

The first fully quantitative stock assessment for blue cod in BCO 5 was carried out in 2013 (Haist et al 2013). A custom-built length-based model, which used Bayesian estimation, was fitted separately to data from Statistical Areas 025, 027, and 030. A second stock assessment was completed in 2019, but it switched to an age-based Bayesian model and the assessment was conducted using NIWA's CASAL2 assessment package (Doonan 2020). Again, the model was fitted separately to data from Statistical Areas 025, 027, and 030.

4.4.1 Methods

4.4.1.1 Model structure

The stock assessment model was aged-based with the population partitioned into six categories: male and female combined with three growth morphs (Doonan 2020). The growth morphs were fast, medium, and slow growth. Each morph had a normal length distribution at each age and they were constrained to combine into a normal length distribution-at-age with the same spread of length-at-age as observed in potting survey catches. Because fish cannot unambiguously be assigned to any one growth morph, observed data for each morph are not available. The pot fishery operates under a minimum legal size (MLS) and the morph construct helps the model 'remember' length distributional changes as a cohort grows past the MLS; i.e., once a cohort is completely recruited into the fishery, its length distribution is asymmetrical.

There are three fisheries: commercial line, commercial pot, and recreational line. Each fishery was modelled with a selectivity ogive and a retention ogive (Table 15), so catch data were a function of the selectivity ogive and landings data were a function of the product of selectivity and retention ogives. There were three time blocks for the pot fishery selectivity: pre-1994, 1994 to 2017, and 2018 onwards. These periods mirror the changes in regulations starting with the change in MLS (30 to 33 cm) in 1994, and the change in commercial pot mesh sizes in 2018. Discard mortality was assumed for fish that were caught but not landed.

Spawning stock biomass (*SSB*) is measured as the total mature biomass. A Beverton-Holt stock recruitment relationship was assumed. The CV of recruitment residuals was fixed at 0.6 and the steepness was assumed to be 0.75. Recruitment residuals were estimated for 1980 to 2014. Fish recruited to the model at age 1+ with 50% of fish recruiting as females. The populations were initialised at unexploited equilibrium conditions in 1900.

The informed prior distributions for model parameters are given in Table 16. Other parameters had uniform priors.

Table 15: Model selectivity and retention ogives by fishery, their parametric form, and parameter values if fixed or data fitted in the model to inform their estimation. AF, age frequency data; LF, length frequency data.

Ogives	Type	Parameters if fixed or data to inform
Selectivity		
Commercial line fishery	Logistic	50% selected at 280 mm; 95% selected at 305 mm
Commercial pot fishery ≤ 1993	Logistic	Mesh size trial LF
Commercial pot fishery 1994–2017	Logistic	Logbook sampling LF
Commercial pot fishery ≥ 2018	Logistic	2015 pot experiment & commercial AF
Recreational fishery	Logistic	Recreational catch LF
Survey	Logistic	Survey AF
Retention		
Commercial line fishery	Knife-edge	MLS (300 mm)
Commercial pot fishery ≤ 1993	Knife-edge	MLS (300 mm)
Commercial pot fishery 1994–2017	Knife-edge	MLS (330 mm)
Commercial pot fishery ≥ 2018	Knife-edge	MLS (330 mm)
Recreational fishery ≤ 1993	Knife-edge	MLS (300 mm)
Recreational fishery ≥ 1994	Knife-edge	MLS (330 mm)

Table 16: Assumed informed prior distributions for model parameters.

Model parameters	Distribution	Parameters/ bounds
Recruitment variation	Lognormal	CV: 0.60

As a sensitivity, sex change was modelled as a dynamic process, with the proportion of females transitioning to males as a function of age. Since there was little indication from the pot survey age data that sex change was occurring in the mature population, it was concluded that sex change probably occurred in the period before maturation. The sex ratio for mature fish was assumed to be 1:1.

4.4.1.2 Data

Separate data sets were compiled and analysed for Statistical Areas 025, 027, and 030. The data available for each of these areas differ, and few data were available for the remainder of the BCO 5 Statistical Areas. Data for Statistical Areas 025, 027, and 030, when combined, represent 92% of the recent commercial fishery landings. The general categories of data used in the stock assessment models included: landings, fishery length frequency data (LF), fishery and survey age frequency data (AF), abundance indices from standardised CPUE (all areas) and from fishery independent potting surveys (Statistical Area 025 only), and biological information on natural mortality, growth, and maturation.

Historical time series of BCO 5 landings were constructed for three gear types: commercial hand-line fishing, commercial pot fishing, and recreational line fishing. Additionally, non-reported blue cod catch used as bait in the CRA 8 rock lobster fishery was estimated and included with the commercial landings, and customary catch estimates were included with the recreational harvest. The constructed catch history prior to 2012 was the same as that used in the 2013 stock assessment (Haist et al 2013) and is presented in Figure 14.

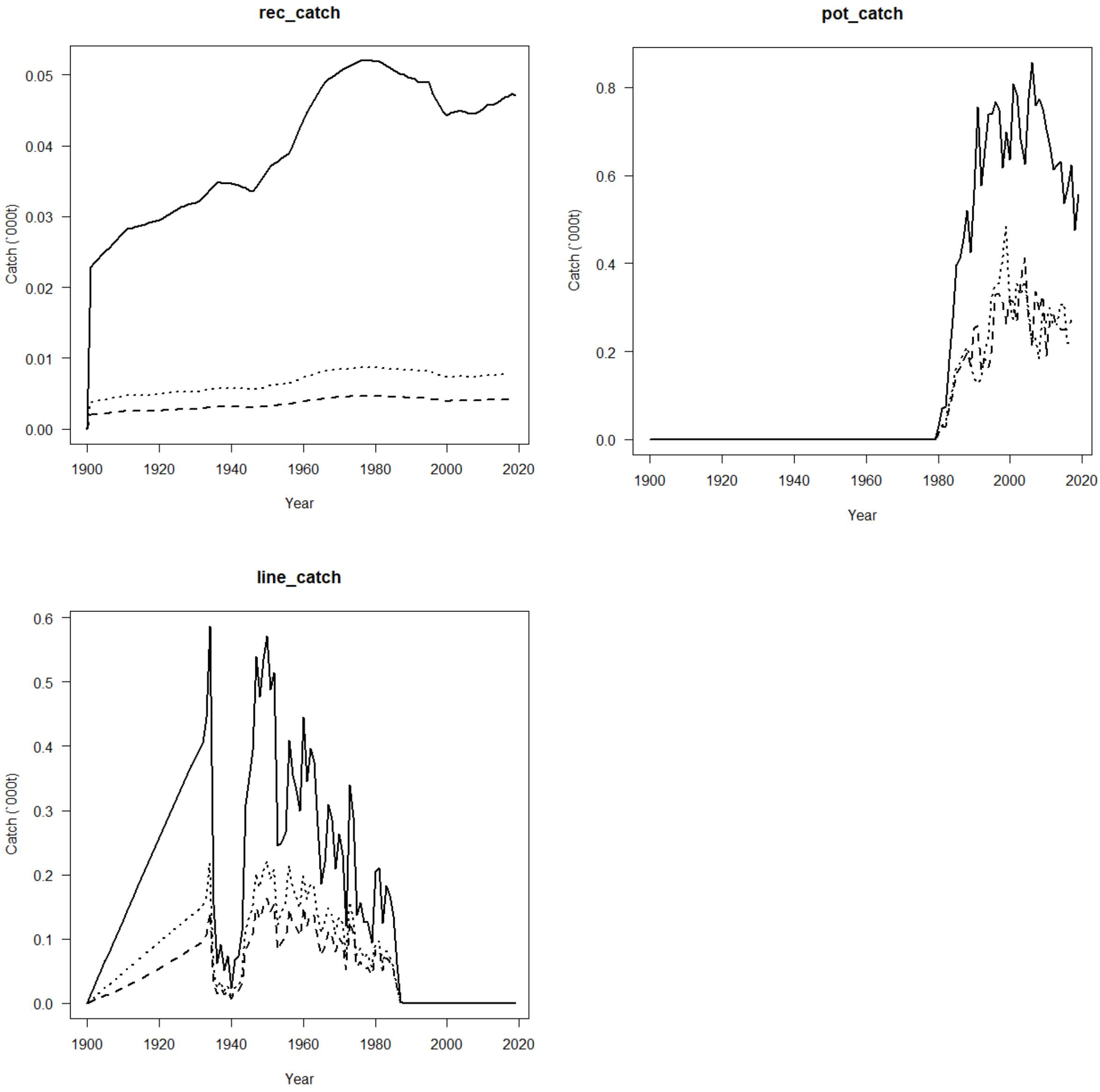


Figure 14: Constructed catch history used in the assessments by fishery and Statistical Areas 025 (solid line), 027 (dashed line), & 030 (dotted line).

Commercial landings data were available from 1931 (Warren et al 1997) and these were linearly decreased back to 1900, when the fishery was assumed to begin. The 1989–90 to 2011–12 average proportion of the total BCO 5 catch in each statistical area was used to prorate the earlier landings estimates to statistical area. A time series of non-reported blue cod used as bait in the rock lobster fishery was developed based on a 1985 diary study (Warren et al 1997), in conjunction with CRA 8 rock lobster landings.

A time series of recreational blue cod harvest was developed based on the 1991–92 and 1996 diary survey estimates of BCO 5 recreational catch. The average blue cod catch per Southland resident was estimated from the survey data and, assuming a constant per capita catch rate, was extrapolated to a time series using Southland District population census data.

Commercial fishery LF data were collected through a commercial fishers logbook project and a shed sampling project from 2009 to 2011. The shed sampling was sex-specific whereas the logbook sampling was not. Mean size of fish from the shed samples were smaller than those from the logbook programme (for Statistical Areas 025 and 027; there were no shed samples from Statistical Area 030), due to these data being from the last catch of the day, which was likely to be from inshore waters close to the sheds (so the fish would not spoil), where exploitation rates were higher. The logbook LF data were fitted to model predictions of the commercial catch size distribution for 2010, and, as a sensitivity, the logbook LFs were replaced by the shed LFs.

Recreational fishery LFs were obtained from a 2009–10 study of the Southland recreational blue cod fishery (Davey & Hartill 2011). This study included a boat ramp survey (Bluff, Riverton/Colac Bay, and Halfmoon Bay) and a logbook survey of charter and recreational vessels. Blue cod measured through the boat ramp programme were assumed to represent the landings, and fish measured through the logbook programme were assumed to represent the catch. Only the logbook data were fitted in the model.

Length frequency data from a blue cod mesh-size selectivity study, conducted by MAF in 1986 at Bluff and Stewart Island, were available. The LF from pots fitted with the then-standard 38 mm mesh were assumed to represent the size composition of the BCO 5 commercial pot fishery catch before the 1994 pot regulation changes. In preparation for a further change in mesh size regulations in 2018, different mesh sizes were trialled at various sites close to land in 2015 (Glen Carbines, pers. comm.). The data for the new mesh sizes were fitted to the 2018 size frequency. Both experiments did not catch a representative sample of the larger fish given the restricted range of sites used. Consequently, the model was fitted to just the left-hand limb (LHS) since its use was for catch selectivity estimation.

Length frequency data were also available from random stratified potting surveys conducted in Statistical Areas 025 and 030 in 2010, 2014, and 2018. These surveys also provide age frequency (AF) data by sex.

There are two stock abundance estimates: fishery-based standardised CPUE estimates (Table 17), and pot survey estimates of abundance.

The data fitted in the models for each statistical area are shown in Table 18, and the assumed error structure of each data series is shown in Table 19.

Table 17: Standardised CPUE indices for Statistical Areas 025, 027, and 030, for fishing years 1990–2018.

	Statistical Area		
Fishing Year	**025**	**027**	**030**
1990	1.01	0.59	1.04
1991	0.81	0.62	0.97
1992	0.79	0.66	1.00
1993	0.80	0.85	0.89
1994	0.81	0.61	0.65
1995	0.84	0.91	0.69
1996	0.97	1.07	0.70
1997	1.08	1.24	1.15
1998	1.06	1.13	1.20
1999	0.96	1.11	1.32
2000	1.12	1.32	1.13
2001	1.23	1.65	1.18
2002	1.31	1.75	1.35
2003	1.27	1.51	1.35
2004	1.23	1.63	1.23
2005	1.32	1.25	1.24
2006	1.26	1.18	1.27
2007	1.09	0.96	1.14
2008	1.02	0.88	0.95
2009	1.03	0.88	1.04
2010	0.90	0.82	1.01
2011	0.98	1.01	0.86
2012	0.98	0.98	0.81
2013	0.96	0.92	0.91
2014	1.00	0.84	0.96
2015	0.93	0.92	0.96
2016	0.92	0.97	0.85
2017	0.92	1.01	0.89
2018	0.76	0.90	0.82

Table 18: Data series fitted in the stock assessments for Statistical Areas 025, 027, and 030. AF is age frequency data; LF is length frequency data.

Data type	Series	Area 025	Area 027	Area 030
AF data				
	Survey	✓	–	–
	Pot fishery	✓	✓	✓
LF data:				
	Logbook	✓	✓	✓
	Mesh selectivity trials (1986)	data common to all areas		
	Recreational catch	data common to all areas		
	Mesh selectivity trials (2015)	data common to all areas		
Abundance Index:	CPUE	✓	✓	✓
	Survey	✓	–	–

Table 19: Assumed distributions for data fitted in the models. AF, age frequency data; LF, length frequency data. N, effective sample size.

Data type	Distribution	Parameters
Survey abundance	Lognormal	CV: 0.20
Survey AF	Multinomial	N: 100
Pot fishery AF 2018	Multinomial	N: 100
2019	Multinomial	N: 5
CPUE	Lognormal	CV: 0.10
Logbook LF	Multinomial	N: 100
Mesh size trials LF (1986)	Multinomial	N: 20
Mesh size trials LF (2015)	Multinomial	N: 20
Recreational catch LF	Multinomial	N: 100
Ages	Off-by-one, binominal	P: 0.086
Sensitivities		
Shed samples LF	Multinomial	N: 100

4.4.1.3 Further assumptions

Age data to estimate sex-specific von Bertalanffy growth parameters were available from the random-stratified potting surveys and the commercial AFs. The same growth model was assumed for all areas. For males, the L_∞ parameter was not well estimated because data were sparse at L_∞ due to fishing pressure. Male L_∞ was therefore estimated within the model. The potting surveys also had maturity data which gave maturity as logistic with A_{50} of 4.1 y and A_{50to95} of 2.47 y for both sexes.

4.4.1.4 Biomass estimates

The assessment was conducted in two steps. First, a set of initial exploratory model runs was carried out generating point estimates (MPD runs, which nominally estimate the mode of each posterior distribution). The purpose of the MPD runs was to decide which sets of assumptions should be carried forward to the final runs and to quantify the sensitivities of the MPD to the assumptions used. The final runs were fully Bayesian, estimating posterior distributions for all quantities of interest. The base-case model run consisted of separate stock assessments for Statistical Areas 025, 027, and 030, with the results combined to provide results for BCO 5. Natural mortality was fixed at 0.17.

The MPD $B_{CURRENT}$ ($\%B_0$) for the base case was estimated at 31.2%. When M was set at 0.15, $B_{CURRENT}$ was 29.4%, and when M was set to 0.19, it was 33.1%. The largest change occurred when the LF data from the logbook programme were replaced with that from the shed sampling programme; this reduced $B_{CURRENT}$ to 23.9%. The latter was considered unlikely, because the shed length data have a lower proportion of large fish than that from the logbook data because of the differences in the way the fish were sampled. The logbook length data were preferred by the working group. Other sensitivities model runs included:

Sensitivity	$B_{CURRENT}$ **(%** B_0**)**
Commercial discard mortality of 50%	31.6
Sex change in model (also single growth path)	32.0
Single growth path	31.6
Single stock assessment	33.0

Bayesian posterior distributions were estimated for the base-case model using a Markov chain Monte Carlo (MCMC) approach. For each run a chain of 1 million was completed and the chains thinned to produce a posterior sample of 1000. BCO 5 summary statistics are calculated by summing across Statistical Areas 025, 027, and 030, and BCO 5 catch is calculated assuming these areas account for 92% of the BCO 5 stock. The model estimates are summarised in Table 20 (estimates of spawning biomass), Figure 15 (biomass trajectories), and Figure 16 (recruitment trajectories).

Table 20: Estimates of BCO 5 unfished spawning stock biomass and current spawning stock biomass as a percentage of the unfished level for the final runs (medians of marginal posterior distributions, with 95% confidence intervals in parentheses). B_0 **is calculated assuming Statistical Areas 025, 027, and 030 represent 92% of the BCO 5 blue cod stock.**

Run	B_0 **(000 t)**	$B_{CURRENT}$ **(%**B_0**)**
base	21(20,23)	36 (31,41)

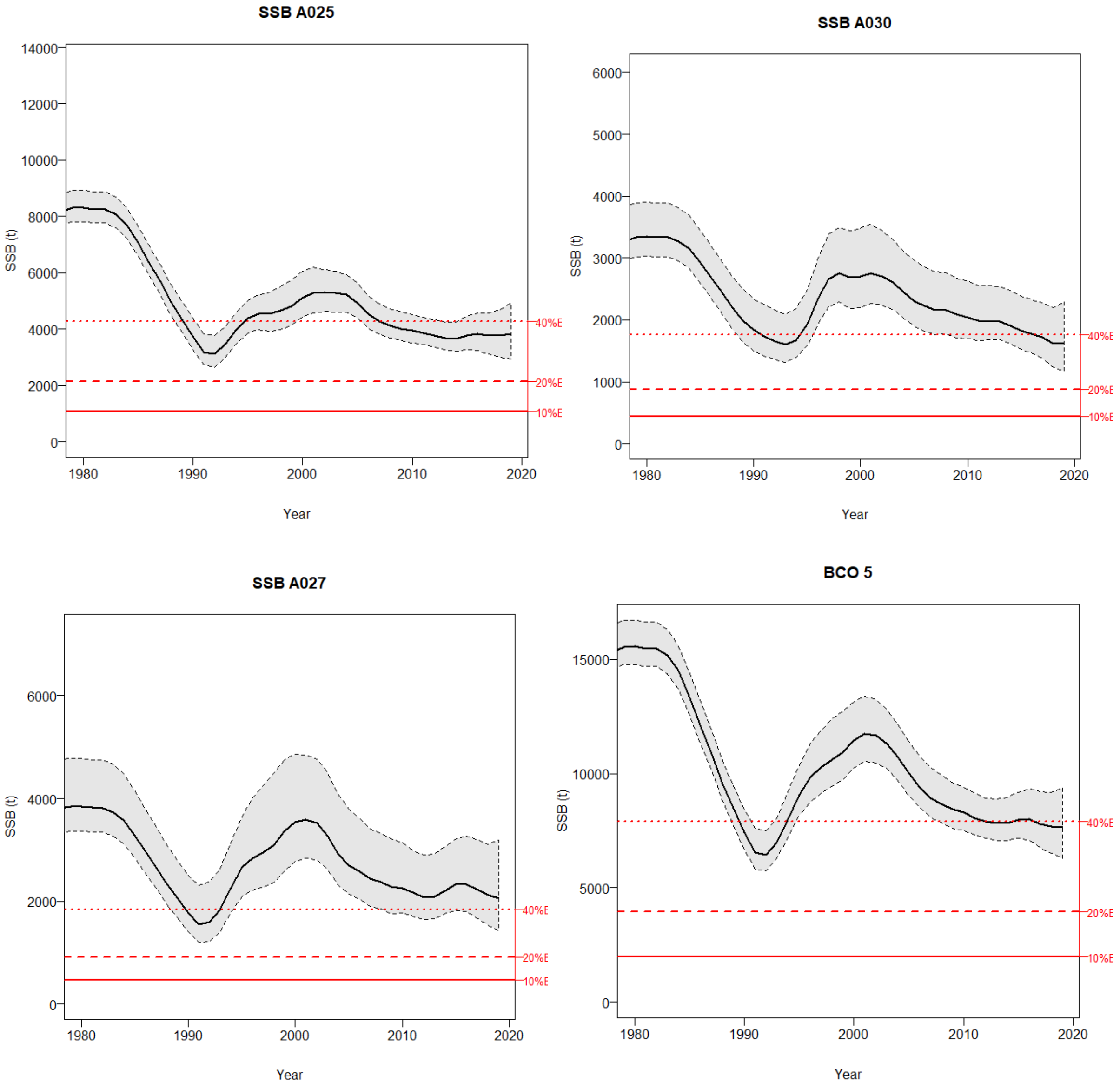


Figure 15: Median estimates of spawning biomass for Statistical Areas 025, 027, and 030, and the three areas combined, for the base-case model runs, 1980–2019.

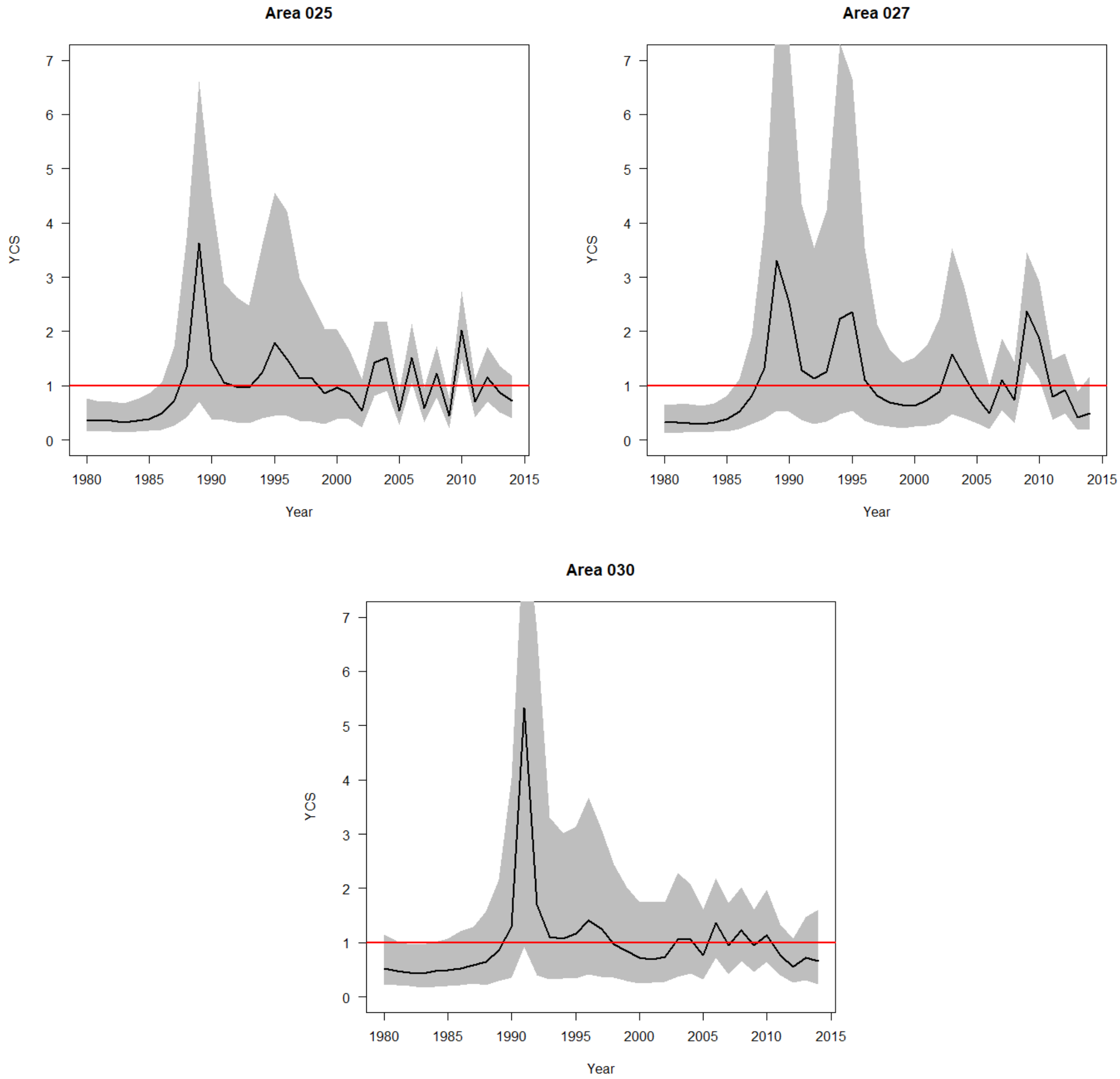


Figure 16: Year Class Strength (YCS) from the base-case runs for Statistical Areas 025, 027, and 030, for 1980–2014. Medians are shown by the black line and the shaded areas show the 95% range limits.

4.4.1.5 Yield estimates and projections

Ten-year stock projections were conducted for the three statistical areas at constant catch levels, with summary statistics calculated at the end of 5 and 10 years. These are based on the MCMC results.

In the stock assessment, the 2018–19 commercial catch level was set at the average of the years (2015–16, 2016–17, and 2017–18). This level of catch was also used in projections based on current catch for the years 2019–20 onwards, and the 2018–19 catch was recalculated based on returns-to-date (as of 8 November 2019) of 804.8 t, which was allocated to the assessment areas based on their fraction of catch to the total. An alternative catch scenario was simulated with commercial catch reduced by 20%.

Recruitment was simulated by randomly re-sampling (with replacement) from the 2005–14 recruitment deviates, applied to the stock-recruitment relationship. Summary statistics were calculated for the BCO 5 QMA by summing B_0 and projected biomass estimates across the three statistical areas.

The projections indicate that under the assumptions of commercial catch at current levels and recruitment at recent levels, the BCO 5 biomass is likely to decline gradually over the next 10 years (Figure 17). Although the spawning stock sex ratio is variable among the sensitivity trials, by 2013 and through the projection period, the sex ratio remains relatively constant.

The probabilities of the projected spawning stock biomass (2018 and 2023) being below the hard limit of 10% B_0 or the soft limit of 20% B_0, or above the target of 40% B_0, are presented in Table 21, for the base case model with recent recruitment for the sensitivity runs with recent recruitment and commercial catch at current levels and with a reduction of 20%. With catches at current levels, the probability of the stock being less than either the soft or hard limit over the next five years is negligible.

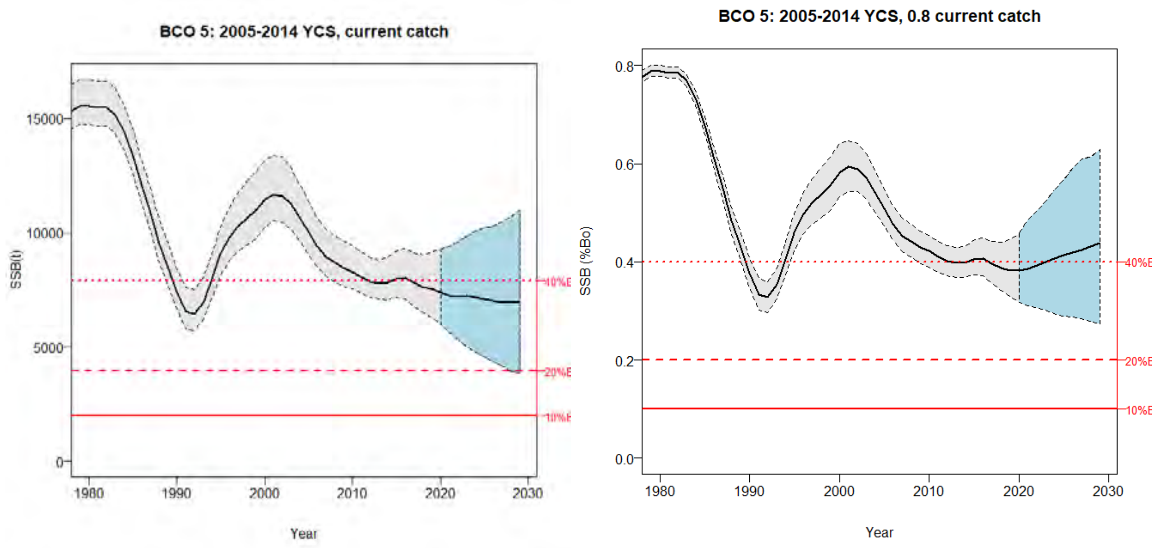


Figure 17: Projected BCO 5 spawning biomass (% B_0) assuming recent recruitment and catch at current levels and at 80% of current levels for the base case run. Median estimates are shown as solid lines and 95% confidence intervals as shaded polygons. Projections start in 2020.

Table 21: Probabilities of *SSB* being below B_0 reference levels in 2019, 2024, and 2029 at alternative catch levels for the base-case projections.

Run	**Base**		
Recruitment	**Recent**	**Recent**	**Recent**
Catch Level	TACC	Current	80% of Current
P(B_{2019}< 0.1 B_0)	NA	0	0
P(B_{2019}< 0.2 B_0)	NA	0	0
P(B_{2019}>= 0.4 B_0)	NA	0.279	0.269
5 year projection			
P(B_{2024}< 0.1 B_0)	NA	0	0
P(B_{2024}< 0.2 B_0)	NA	0.004	0
P(B_{2024}>= 0.4 B_0)	NA	0.286	0.535
10 year projection			
P(B_{2029}< 0.1 B_0)	NA	0	0
P(B_{2029}< 0.2 B_0)	NA	0.024	0.001
P(B_{2029}>= 0.4 B_0)	NA	0.301	0.69

4.5 Management procedure to set TACC

On the basis of the 2019 stock assessment (Doonan 2020), the TAC for BCO5 was reduced to 925 t, with a TACC of 800 t. Given recent poor recruitment and biomass declines estimated in the assessment model, a management procedure was developed in 2021 to monitor and manage the fishery between stock assessments on the basis of CPUE. According to the Medium Term Research Plan, the stock assessment for BCO 5 should be updated every 5 years. The harvest control rule was developed by industry stakeholders in consultation with Fisheries New Zealand and the Inshore Working Group, and robustness testing was undertaken using simulations based on the 2019 stock assessment model.

The harvest control rule relates CPUE (in kg per potlift) to TACC levels (Figure 18), leading to further reductions below the current 800 t TACC should CPUE decline further. The rule is meant to safeguard against further declines in biomass and minimise the risk of the fishery declining below limit reference points (i.e., 0.2 × SSB_0). Increases in catch include a latent year on CPUE increases; increases in CPUE from one year *y* to the next (*y*+1) are only realised if CPUE is still higher in the subsequent year (*y*+2). Any reductions in CPUE lead to immediate reductions in the TACC.

Simulation-testing of the control rule was carried out using a model that was modified from the 2019 stock assessment model to amalgamate all data (CPUE, composition data, catch) into a single area stock assessment. The revised operating model mirrored trends seen in the sum of the three single area models run by Doonan (2020), and the model was deemed adequate by the Plenary to test the robustness of the harvest control rule. The stakeholder-proposed rule was compared with a series of alternative control rules and constant catch levels to elicit its relative performance and risk. Recent estimated recruitment (2007–2016) was used as a basis for simulations, which represents some of the lowest recruitment in the model-estimated recruitment time series—simulation results could therefore be regarded as conservative because they assume that the recent low recruitment levels will continue.

Simulation testing concluded that the BCO 5 harvest control rule showed a low risk of reaching stock levels near limit reference points (Table 22, Figure 19), but also showed that the TACCs specified in the rule would lead to slow rebuilding of the stock based on the most recent 10 years of year class strength estimates, with a 46% change of rebuilding back to 40% SSB_0 by 2040 under the rule and recent recruitment.

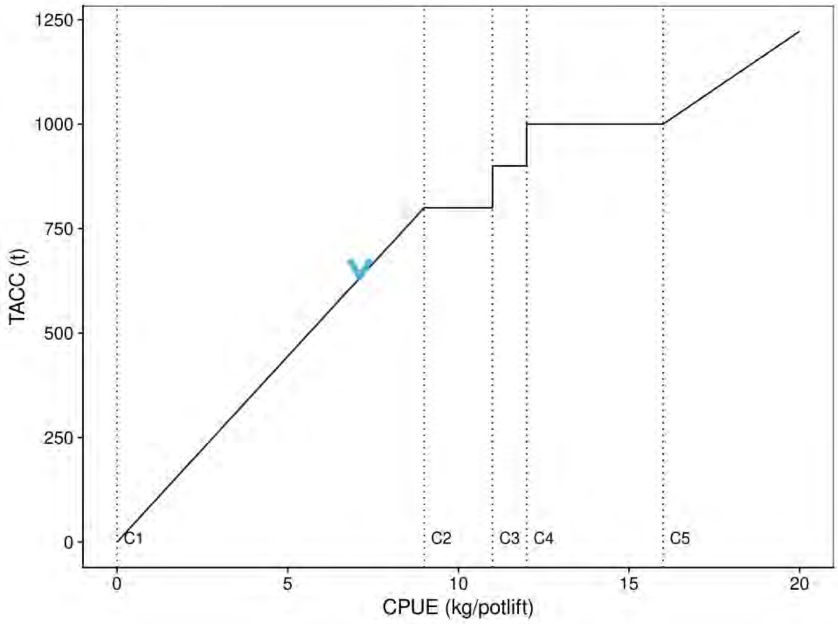


Figure 18: Harvest control rule relating the commercial TACC (t) to catch-per-unit-effort (CPUE, kg per potlift). The control rule is defined by CPUE parameters C1–C5 as well as corresponding TACC levels. The 2020 CPUE level is indicated by the light-blue arrow, suggesting a further reduction in TACC may be necessary to reduce fishing impacts under reduced current productivity.

Table 22: Probabilities of stock size being above 0.4 SSB_0 by 2025, 2030, and 2040, and the risk of the stock declining below 0.2 SSB_0 by 2025 or at any time between 2020 and 2040 under application of the harvest control rule using the 10 most recent years of estimated year class strengths.

	BCO 5 rule	TACC 800 t
P(SSB_{2025}>0.4 SSB_0)	0.23	0.15
P(SSB_{2030}>0.4 SSB_0)	0.37	0.26
P(SSB_{2030}>0.4 SSB_0)	0.46	0.32
P(SSB_{2025}<0.2 SSB_0)	<0.01	0.05
P(SSB_{2021}-SSB_{2040}<0.2 SSB_0)	<0.01	0.13

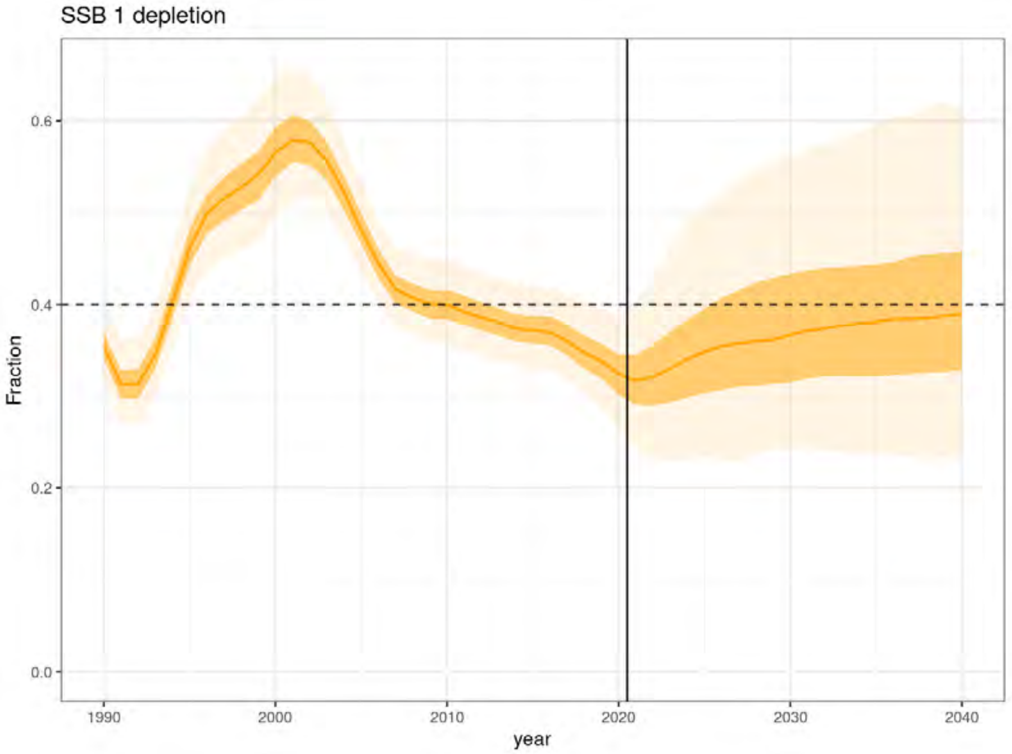


Figure 19: Stock trajectories estimated by the operating model used for harvest control-rule estimation up to 2020, with median (dark yellow), inter-quartile range (yellow), and 95% confidence bounds (tan). After 2020, trajectories show posterior medians of simulations under recent recruitment and application of the BCO 5 harvest control rule, compared with fixed total commercial catch (TCC) levels at the current TACC (800 t), recent catch (1000 t), and 600 t.

Breakout rules

To apply the harvest control rule, CPUE will be standardised and monitored annually, including standard diagnostics to ensure that changes in the fishery do not undermine the assumed relationship between CPUE and available biomass. Catch information will be used to monitor the spatial distribution of the fishery through time to determine whether this has changed. Trends and diagnostics will be presented annually to the Working Group to ensure that CPUE continues to reflect abundance and is therefore usable as input for the harvest control rule. The decision rule will be fully evaluated as part of the next stock assessment (2024). Catch and effort data collected from the recently-introduced Electronic Reporting System (ERS) will be monitored annually to determine whether there have been changes in reporting that affect the comparability of these data with data from CELR forms.

4.6 Other factors

Blue cod fishing patterns have been strongly influenced by the development and subsequent fluctuations in the rock lobster fishery, especially in the Chatham Islands, Southland, and Otago. Once a labour-intensive hand-line fishery, blue cod are now taken mostly by cod pots. The fishery had decreased in the past; however, with the advent of cod pots it rapidly redeveloped. Anecdotal information from recreational fishers suggests that there is local depletion in some parts of BCO 3, BCO 5, and BCO 7 where fishing has been concentrated. Blue cod abundance (Carbines & Cole 2009), catch (Cranfield et al 2001), and productivity (Jiang & Carbines 2002, Carbines et al 2004) may also be affected by disturbance of benthic habitat.

4.7 Future research considerations

All BCO stocks

- Explore the consequences of different mechanisms of sex change in blue cod in terms of how it might affect reference points as well as population parameters (Z, M, growth rates) through simulation studies.
- Explore the potential of tank experiments to understand the drivers of sex change in blue cod.

- Re-age otoliths from historical surveys (offshore Banks area) using new protocols with the aim to provide estimates of *M*.
- Investigate the potential of non-invasive approaches to sex blue cod from marine reserves (ultrasound, blood chemistry?).
- Investigate the potential for genetics for ageing (and sex) for marine reserves or closed areas.

BCO 3

- Account for the June 2009 regulatory mesh change in future CPUE analyses, probably by breaking the time series at 2010. A re-examination in 2021 of the BCO 3 standardised CPUE series that was accepted in 2019 resulted in the Inshore Working Group reassessing its utility given that this mesh size regulatory change had not been explicitly taken into account. A new reference period may also be required.
- More detailed analyses of the degree of representativeness of these surveys for the entire stock should be evaluated, with a view to combining them with other information (such as a reanalysed CPUE series) to determine whether a full stock assessment can be undertaken. An analysis of recently available high spatial resolution ERS commercial reporting data has shown that main BCO 3 commercial potting fishery more strongly coincides with the north Otago and south Otago fisheries-independent potting survey areas than previously thought.
- Analysis of fine scale effort data from the Electronic Reporting System should be included in planning for future surveys. Consideration should be given to adding additional strata if this would improve coverage of the commercial potting fishery.
- Estimates of recreational harvest should be provided for the different sub-areas in BCO 3.
- Further analyses to better estimate growth are needed. The %*SPR* estimates reported in the Status of Stocks tables are based on a single year of ageing in each survey, largely because ageing of otoliths from previous surveys before about 2015 was unreliable.
- Ageing more otoliths from earlier surveys and commercial catches (if available), obtaining survey-specific estimates of size or age at maturity, and refining other biological parameters should be considered before a full stock assessment would be feasible.

BCO 5

- Further examine the potting survey data to determine spatial structuring (e.g., using GAM surfaces).
- Try to find otoliths from early surveys or experiments and re-read using current protocols.
- Re-age otoliths from other early surveys in lightly fished areas to provide a better estimate of *M*.
- Obtain and examine market grading data. More commercial length and age data by area would be useful to determine spatial differences in size structure and growth.
- Re-examine the selectivity priors, including collecting more information about the effects of the 2018 mesh size regulations on fishing behaviour and CPUE. (This should also be done for other blue cod fisheries.)
- Consider interviewing fishers to ascertain changes in fishing behaviour that might affect the relationship between the CPUE indices and abundance. If there is evidence of increasing catchability, possible changes to the assessment include splitting vessel identifiers by time period(s) or including an additional parameter for representing increasing catchability.
- Evaluate the comparability of the ERS data to the CELR data, including potential changes in reporting behaviour.
- Use a wider range of values of *M* in sensitivities.
- Use empirical data for maturity rather than a logistic function.
- Conduct alternative runs to better understand the behaviour of the model: e.g., start estimating year classes earlier than 1980 to see how this affects early recruitments and the early part of the biomass trajectory; remove the age composition data to determine their relative influence.
- As part of next assessment, re-examine the magnitude of the catches outside the three main statistical areas to determine whether these should be included in the assessment, perhaps by merging them into adjacent statistical areas.

BCO 5 Control rule

- Consider a wider family of future harvest control rules.
- Try to define an optimal control rule based on input from stakeholders. Output a range of indicators of importance to stakeholders in a form that makes it easier to inform trade-offs.
- Explore other forms of breakout rules.

BCO 7

- Undertake a stock characterisation and CPUE analysis for BCO 7.
- Consider developing reference points from BCO 7 surveys once the time series are sufficiently long.
- Record width of blue cod habitat at each station within the BCO 7 potting surveys and explore the implications of scaling biomass to strata area rather than strata length.

5. STATUS OF THE STOCKS

For BCO 1 and 8 recent commercial catch levels are considered sustainable. The status of the remaining fish stocks is summarised below. A summary of TACCs and reported landings for blue cod from the most recent fishing year is given in Table 22.

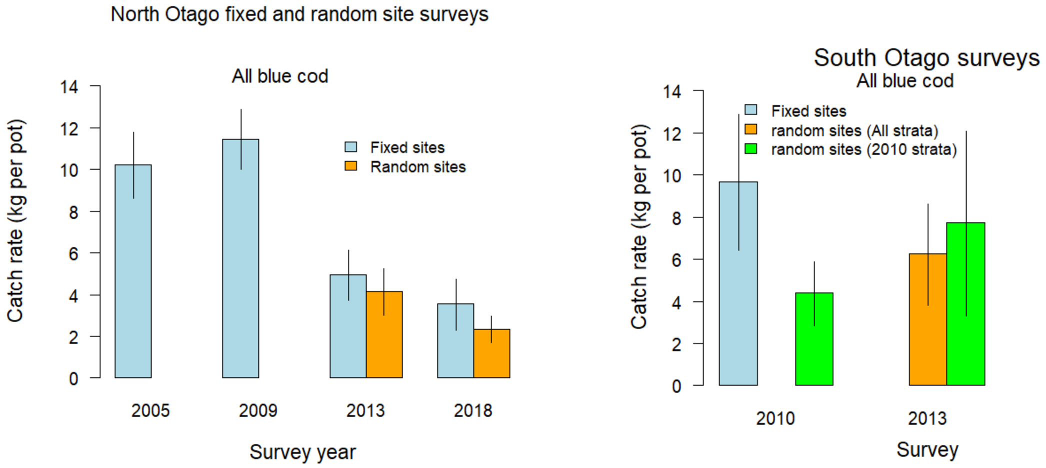
- **BCO 3 (Statistical Areas 024 and 026)**

Stock Structure Assumptions

Tagging experiments suggest that blue cod populations may be isolated from each other and there may be several distinct sub-populations within management areas. For the purposes of this summary, BCO 3 is split into two sub-areas along the Statistical Areas 022/024 boundary: Statistical Areas 018, 020, and 022 (Northern); and Statistical Areas 024 and 026 (Southern). There were insufficient data to produce a standardised CPUE series for the northern sub-area.

Stock Status	
Year of Most Recent Assessment	2019 (corrected 2021)
Assessment Runs Presented	North and south Otago potting surveys
Reference Points	Target: $SPR_{45\%}$ Soft Limit: $SPR_{22.5\%}$ Hard Limit: $SPR_{11.25\%}$ Overfishing Threshold: $F_{SPR45\%}$
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



North Otago and south Otago fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals. For north Otago, surveys after 2005 include a new stratum (stratum 6). For south Otago, the 2010 survey used three strata, and subsequent surveys used 6 strata. Catch rates are also shown for the three strata used in 2010 for the random-site surveys. Note that the fixed-site and random-site surveys are not directly comparable. Only the random sites are included for the status of stocks evaluation; however, the fixed sites are included because they provide context, particularly for north Otago.

Fishery and Stock Trends

Recent Trend in Biomass or Proxy	The north Otago and south Otago potting surveys each have two annual indices based on the random survey design, both of which have exhibited substantial declines between 2013 and 2018, particularly that for north Otago. There is good overlap between the survey areas and BCO commercial fishing grounds in Statistical Areas 024 and 026, where most of the BCO 3 commercial catch is taken. Earlier fixed station surveys also showed a decline for north Otago.
Recent Trend in Fishing Intensity or Proxy	-
Other Abundance Indices	Spawning biomass per recruit ratios were 30% and 34% for 2018 north and south Otago Potting surveys, respectively. These are above the soft and hard limits of 22.5% *SPR* and 11.25% *SPR*, respectively.
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis

Stock Projections or Prognosis	Current catch has exceeded the TACC since 2014–15, but there are anecdotal reports from both commercial and recreational fishers that blue cod catch rates in this area have declined.
Probability of Current Catch or TACC causing decline Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation

Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Fisheries-independent potting surveys	
Period of Assessment	Latest assessment: 2019 (2021 correction)	Next assessment: 2023

Overall Assessment Quality	1 – High Quality	
Main Data Inputs (Rank)	- Catch and effort data - North and south Otago potting surveys	1 – High Quality 1 – High Quality
Data not used	N/A	
Changes to Model Structure and Assumptions	- Use of the potting surveys to report stock status has replaced the previous CPUE series because pot mesh size changes in June 2009 will have impacted on the comparability of the CPUE indices over time.	
Major Sources of Uncertainty	- The degree of overlap between the potting surveys and the extent of the commercial fisheries and the stock needs further investigation. - The SPR estimates are based on one survey in each of the north and south Otago areas. - The impact of the change in mesh size for blue cod pots from 38 mm mesh to 48 mm mesh in 2009 on commercial CPUE is unknown, which means that the previously accepted CPUE index is no longer presented in the table.	

Qualifying Comments
Because the bulk of the commercial catch (72%) is taken from Statistical Areas 024 and 026, both CPUE and catch trends for BCO 3 are strongly influenced by catches in these areas. A June 2009 change in regulations governing commercial pots (change from 38 mm mesh to 48 mm square grids) will have affected CPUE indices and comparison of trends before and after this date. The impact of this regulation change is unknown, and it led to the CPUE index being excluded from this table.

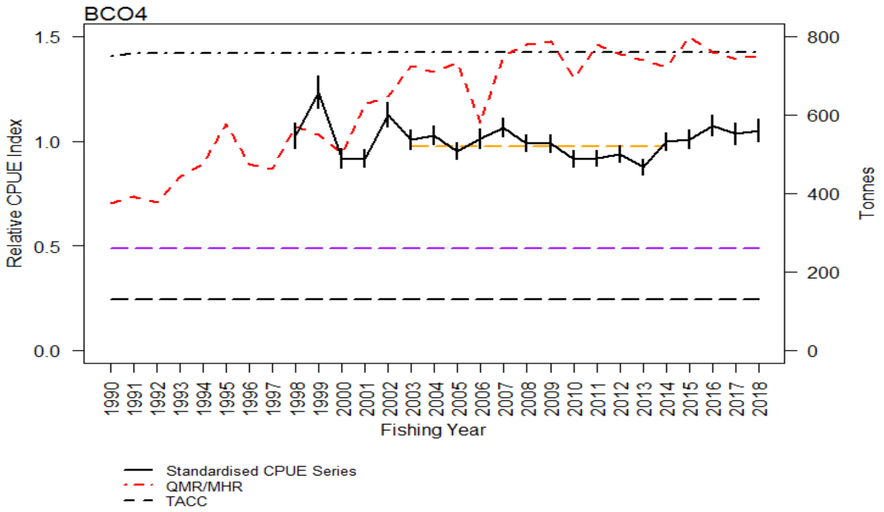
Fishery Interactions
Over two thirds of BCO 3 commercial catches are taken in a target cod-potting fishery which has very little interaction with other species. Most of the remaining BCO 3 catch is taken in the inshore bottom trawl fishery operating off the east coast of the South Island, largely directed at flatfish, red cod, and tarakihi.

- **BCO 4**

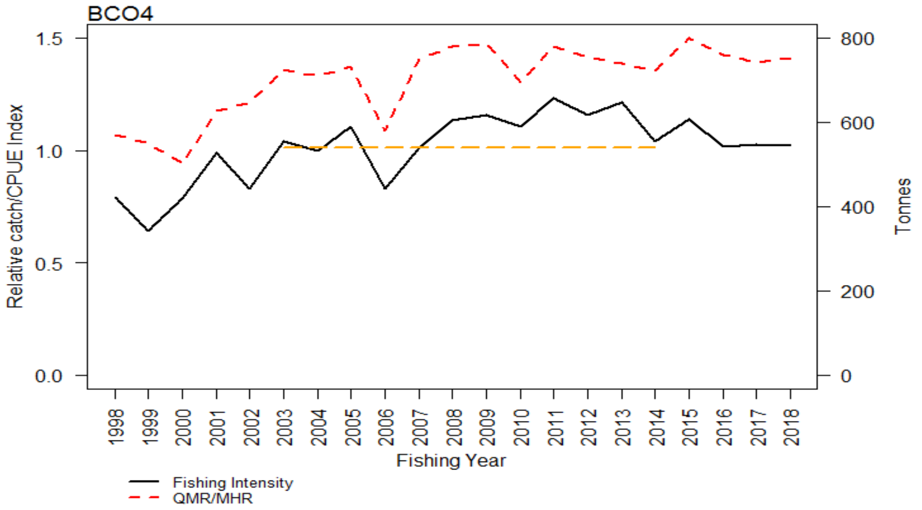
Stock Structure Assumptions
For the purposes of this summary BCO 4 is considered to be a single management unit.

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	CPUE index based on landed catch
Reference Points	Interim Target: B_{MSY} proxy based on mean CPUE for the period 2002–03 to 2013–14 (a period with high yield when both catch and CPUE were stable) Soft Limit: 50% B_{MSY} proxy Hard Limit: 25% B_{MSY} proxy Overfishing threshold: F_{MSY} proxy based on mean relative exploitation rate for the period 2002–03 to 2013–14
Status in relation to Target	Likely (> 60%) to be at or above the target
Status in relation to Limits	Soft Limit: Very Unlikely (< 10%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	About as Likely as Not (40–60 %) to be occurring

Historical Stock Status Trajectory and Current Status



BCO 4 standardised CPUE series for 1998–2018. Also plotted are the QMR/MHR landings and the BCO 4 TACC. The orange line represents the B_{MSY} proxy of mean CPUE from 2003 to 2014. The purple line is the Soft Limit=0.5*[B_{MSY} proxy] and the grey line is the Hard Limit=0.25*[B_{MSY} proxy].



BCO 4 fishing intensity (=catch/CPUE) plot based on the standardised CPUE series from 1997–98 to 2017–18 and the QMR/MHR landings. Horizontal orange line represents the mean 2003–2014 fishing intensity associated with the interim B_{MSY} proxy.

Fishery and Stock Trends

Recent Trend in Biomass or Proxy	CPUE has fluctuated without trend since 1997–98.
Recent Trend in Fishing Intensity or Proxy	Relative exploitation rate has declined since 2010–11 and in 2017–18 was near the overfishing threshold.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis

Stock Projections or Prognosis	The current catch and TACC are Unlikely (< 40%) to cause the stock to decline
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing overfishing to continue or to commence	-

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Fishery characterisation and standardised CPUE analysis	
Assessment Dates	Latest assessment: 2019	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and Effort 1997–98 to 2017–18	1 – High Quality
Data not used (rank)	- Catch and Effort 1989–90 to 1996–97	2 – Moderate or mixed Quality: compromised by changes in fleet composition and reporting practices
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
-

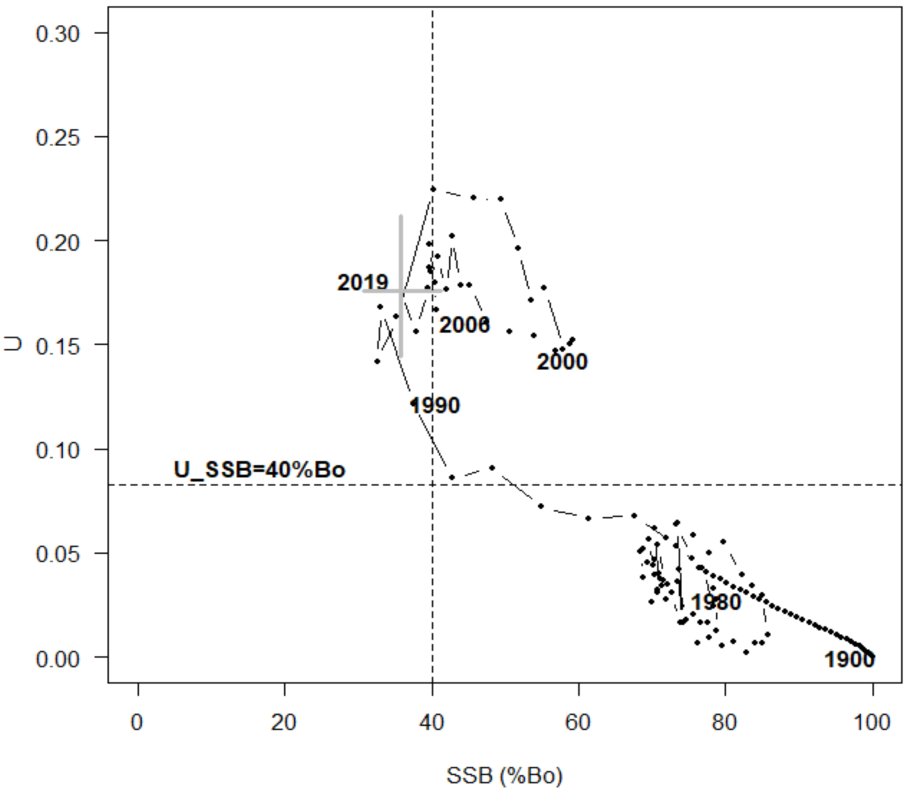
Fishery Interactions
The catch is almost entirely taken by target cod potting and there is little interaction with other species.

- **BCO 5**

Stock Structure Assumptions

Tagging experiments suggest that blue cod populations may be isolated from each other and there may be several distinct populations within management areas. For the purposes of this summary, blue cod in Statistical Areas 025, 027, and 030 of BCO 5 are treated as a unit stock. Dusky Sound and Paterson Inlet are assumed to contain discrete populations of BCO, which are monitored with potting surveys.

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	One base case model
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%SB}$
Status in relation to Target	B_{2019} was estimated to be 36% B_0; and is Unlikely (< 40%) to be at or above the Management Target
Status in relation to Limits	B_{2019} is Very Unlikely (< 10%) to be below the Soft Limit and Exceptionally Unlikely (< 1%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is Likely (> 60%) to be occurring

Historical Stock Status Trajectory and Current Status

Annual spawning biomass and fishing mortality compared with *SSB40%* and the corresponding fishing mortality reference.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has been decreasing since about 2000.
Recent Trend in Fishing Intensity or Proxy	The exploitation rate has been above the target since 1990.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	There have been three random-site potting surveys in Foveaux Strait (2010, 2014, and 2018) with no clear trend in catch rates over the time series.
Projections and Prognosis	
Stock Projections or Prognosis	BCO 5 biomass is expected to decline over the next 5 to 10 years at current catch levels.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For current catch in the next 3–5 years: Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	The current catch (average of 2015–16 to 2017–18), which is lower than the TACC, is Likely (> 60%) to cause overfishing to continue.

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-based model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2020	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- CPUE time series	1 – High Quality
	- Proportions-at-length and -age from commercial catch for 2017–18 and 2018–19	1 – High Quality

	-Proportions-at-length from commercial catch for 2010 - Relative biomass and proportions-at-length and at-age from potting surveys - Estimates of biological parameters - Potting survey abundance estimates	2 – Medium or Mixed Quality: sampling potentially unrepresentative 1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	Shed sampling LF by sex; only used in a sensitivity	3 – Low Quality: sampling potentially unrepresentative of the overall population
Changes to Model Structure and Assumptions	- Changed from length-based to age-based model - Maturity ogive age-based - *M* assumed to be 0.17 instead of 0.14 - No sex change assumed in base case	
Major Sources of Uncertainty	- Year classes prior to 2000 - Lack of adequate catch at age data - Lack of contrast in age data and CPUE - Relationship between abundance and sex change dynamics	

Qualifying Comments
There have been potential changes in fisher behaviour that are not captured in the assessment; for example, changes in responses to new pot mesh sizes and changes in areas fished (local versus long distance). Also, anecdotal information suggests some fishers have modified their fishing behaviour to maintain catch rates in a manner that cannot be standardised. Specifically, they move pots after each lift instead of re-setting them in the same place. It is not known to what degree this behaviour was adopted by core fleets in each statistical area, but this behaviour may have biased high recent CPUE, thereby masking declines in abundance.

Fishery Interactions
Historically, significant quantities of blue cod, taken by potting, were used as bait in the commercial rock lobster fishery. Since 1996, reporting of blue cod used for bait is mandatory and included as part of the commercial catch reporting. Some blue cod are landed as bycatch in rock lobster pots and oyster dredges.

- **BCO 7 - Marlborough Sounds only**

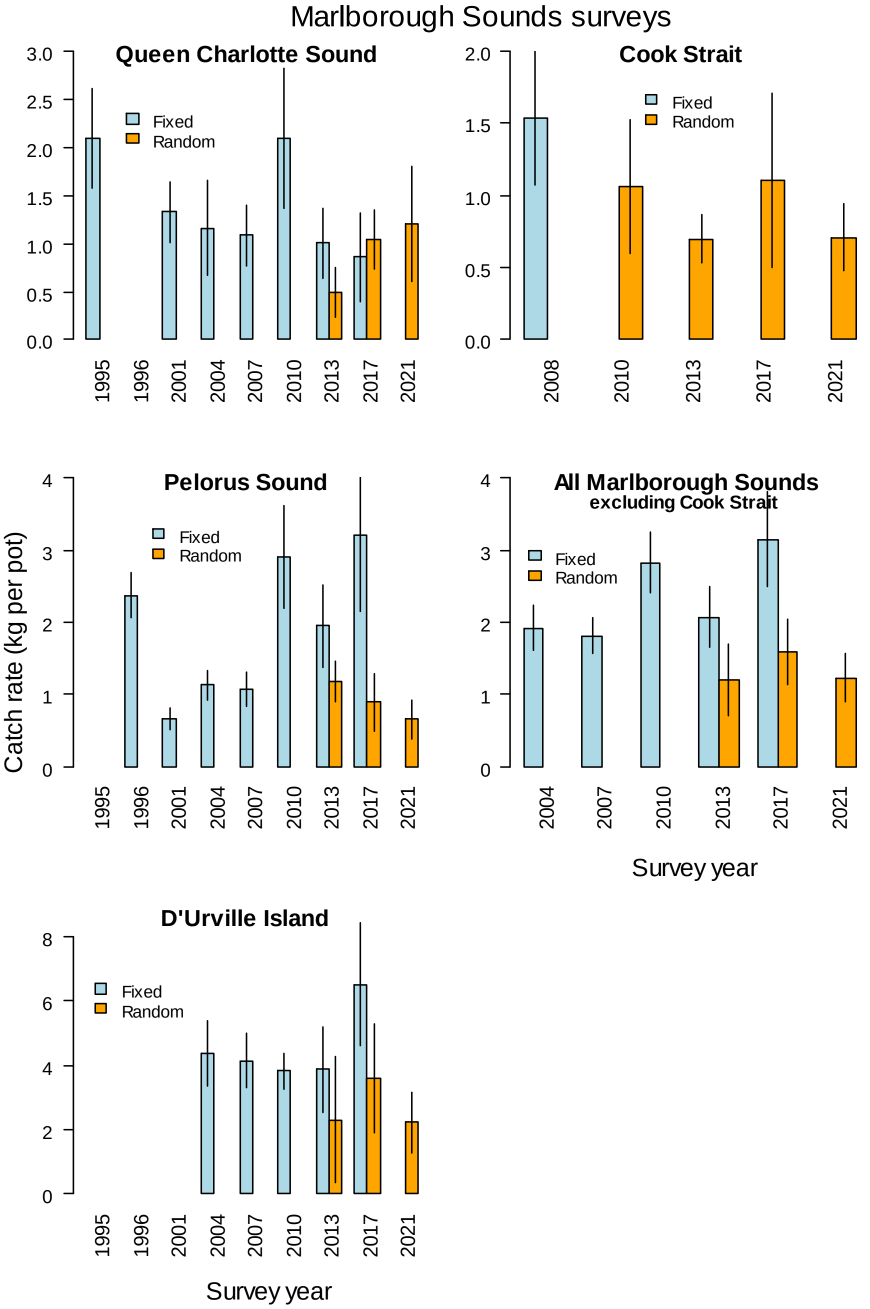
Stock Structure Assumptions

For the purposes of this summary BCO - Marlborough Sounds is considered to be a single management unit.

Stock Status	
Year of Most Recent Assessment	2022
Assessment Runs Presented	Catch rates and mortality estimates from random-site Marlborough Sounds potting surveys
Reference Points	Target1: B_{MSY}-compatible proxy based on the Marlborough Sounds potting survey (to be determined) Target 2: F=0.87, M = 0.15 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: F=0.87, M = 0.15
Status in relation to Target	F estimated at 0.48 is Very Unlikely (< 10%) to be at or below the target
Status in relation to Limits	Unknown

Status in relation to Overfishing	Overfishing is Very Likely (> 90%) to be occurring

Historical Stock Status Trajectory and Current Status



Marlborough Sounds fixed-site and random-site potting survey catch rates of all blue cod by survey year for each region and overall for the Marlborough Sounds. Error bars are 95% confidence intervals. There were no complete fixed-site surveys in QCH in 1996, PEL in 1995, and DUR in 1995, 1996, and 2001 (see Table 9). For the overall Marlborough Sounds plot, the 2004 and 2007 fixed-site surveys exclude Separation Point, and the random-site surveys exclude Cook Strait, hence the strata are consistent among the surveys for fixed-site and random-site surveys.

Fishery and Stock Trends

Recent Trend in Biomass or Proxy	The Marlborough Sounds fixed-site potting survey indices of abundance increased markedly in 2010 in the Queen Charlotte Sound and Pelorus regions following the closure of the fishery in the inner sounds in 2008 (QCH, PEL). The survey indices were stable in the D'Urville region where the fishery remained open (DUR). The QCH and PEL fisheries were reopened to a limited size range of blue cod (slot limit) in April 2011 and the estimated 2013 survey abundance in those regions declined, but no change

	was observed in DUR. In 2017, abundance in QCH was not different to 2013, whereas for PEL and DUR abundance was the highest of any of the surveys. The overall Marlborough Sounds catch rate from 2004 onward (where survey strata are consistent among surveys) indicates that blue cod were more abundant in 2017 than any of the previous surveys. Queen Charlotte Sound random-site survey biomass increased markedly from 2013 to 2017 with no change in 2021; Pelorus Sound biomass shows a progressive decline between 2013 and 2021; D'Urville Island and Cook Strait show no trends.
Recent Trend in Fishing Mortality or Proxy	Regulatory changes to the recreational fishery (e.g., fishery closures, changes to MLS, and daily bag limits) are likely to have resulted in a reduction in fishing mortality up to April 2011, after which mortality increased with the re-opening of the fishery. Fishing mortality was at least twice natural mortality for the random-site surveys in 2017 and 2021.
Other Abundance Indices	Blue cod catch rates in the open area of the Marlborough Sounds were 18.6% and 17.5% of those inside the Long Island Marine Reserve in 2017 and 2021, respectively. Mean length of BCO from the Marine Reserve was 5 cm longer than in the fished area.
Trends in Other Relevant Indicators or Variables	Sex ratio is strongly skewed in favour of males. For Marlborough Sounds overall, the percent male from random-site surveys was 72% in 2017 and 2021.

Projections and Prognosis	
Stock Projections or Prognosis	Biomass is expected to decrease under current management controls.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing overfishing to continue or to commence	Current catches are Very Likely (> 90%) to cause overfishing to continue.

Assessment Methodology and Evaluation		
Assessment Type	2 - Partial Quantitative Stock Assessment	
Assessment Method	Catch rates, mortality estimates, and sex ratios from fishery-independent potting surveys.	
Assessment Dates	Latest assessment: 2022	Next assessment: 2026
Overall assessment quality rank	2 – Medium Quality: mortality estimates compromised by regulation changes	
Main data inputs (rank)	- Potting survey catch rates from fixed-site and random-site surveys.	1 – High Quality
	- Length and age composition of catches from random-site and fixed-site potting surveys.	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Uncertainty in the estimate of *M*. - Frequent regulatory changes for this fishery are likely to have resulted in inconsistent fishing mortality over the lifetime of recent cohorts. - The predominance of males suggests fishing mortality may be higher than estimated.	

	-Lack of understanding about the triggers that drive sex change from female to male, as well as the degree, timing, and spatial nature of the sex change.

Qualifying Comments

Fishery Interactions
Most of the BCO catch is taken by recreational fishers using line methods. There is a reasonably high catch of associated species in this fishery, such as spotted and other wrasses as well as other targeted species such as tarakihi. Most of the commercial catch is taken by potting and has little bycatch. The recreational and commercial catches are of similar magnitude

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BLUE MACKEREL (EMA)

(*Scomber australasicus*)
Tawatawa

1. FISHERY SUMMARY

Blue mackerel were introduced into the QMS on 1 October 2002. Since then allowances, TACCs, and TACs (Table 1) have not changed.

Table 1: Recreational and Customary non-commercial allowances, TACCs, and TACs for blue mackerel by Fishstock.

Fishstock	Recreational Allowance	Customary Non-Commercial Allowance	TACC	TAC
EMA 1	40	20	7 630	7 690
EMA 2	5	2	180	187
EMA 3	1	1	390	392
EMA 7	1	1	3 350	3 352
EMA 10	0	0	0	0
Total	47	24	11 550	11 621

1.1 Commercial fisheries

Blue mackerel are taken by a variety of methods but for most of these methods the catches are very low. The largest and most consistent catches have been from the target purse seine fishery in EMA 1, 2, and 7, and as non-target catch in the jack mackerel midwater trawl fishery in EMA 7. Most catch is taken north of latitude 43° S (Kaikōura). Historical estimated and recent reported blue mackerel landings and TACCs are shown in Tables 2 and 3, and Figure 1 shows the historical landings and TACC values for these three main stocks. Since 1983–84 the catch of blue mackerel in New Zealand waters has grown substantially (Table 3), primarily in the purse seine fishery in EMA 1, and catches have averaged about 10 000 t annually since 1990–91.

Most blue mackerel purse seine catch comes from the Bay of Plenty (BoP) and East Northland, where it is primarily taken between July and December. Purse seine fishing effort on blue mackerel has been strongly influenced by the availability and market value of other pelagic species, particularly skipjack tuna and kahawai, with effort increasing as limits have been placed on the purse seine catch of kahawai. The purse seine fishery has accounted for more than 97% of annual EMA 1 landings since at least 1990, and about 90% of this was targeted (Ballara 2016).

Total blue mackerel landings peaked in 1991–92 at more than 15 000 t, of which 60–70% was taken by purse seine. More recently, commercial landings of over 12 500 t were taken in 2000–01 (13 100 t) and 2004–05 (12 750 t), with the highest landings recorded in EMA 1 and EMA 7 (MacGibbon 2021). EMA 1 landings exceeded the TACC in 2004–05, 2006–07, 2009–10, 2011–12, 2014–15, and 2017–18. The 2004–05, 2005–06, and 2008–09 EMA 7 landings also exceeded the TACC. EMA 7 landings have fluctuated in recent years, with the lowest landings since the mid-1980s recorded in 2016–17 (625 t) and landings increasing to just below the TACC in 2017–18 (3254 t). Landings from EMA 2 and 3 have been below the TACCs since the early to mid-1990s; they are mainly bycatch from purse seines (EMA 2) and trawlers (EMA 3).

The blue mackerel catch from EMA 7 is now principally non-target catch from the jack mackerel midwater trawl fishery. Purse seine catches are relatively minor in comparison to midwater trawl methods and have been declining since around 2000 (MacGibbon 2021). Highest catches are taken during June, July, and October in Statistical Areas 034 and 035 off the west coast South Island (WCSI)and Statistical Areas 041 and 801 further north (west coast North Island, WCNI). Fishing has shifted from south to north in the last decade. Since the late 1990s, a fleet of Ukrainian vessels has taken most of the catch in the JMA 7 target fishery and these vessels have taken the EMA as bycatch. Purse seine accounted for 17% of the EMA 7 catch between 1990 and 2018 (MacGibbon 2021).

A number of factors have been identified that can influence landing volumes in the blue mackerel fisheries. In the purse seine fishery, blue mackerel has become the second most preferred species because of decreased TACCs on kahawai. Skipjack tuna is the preferred species and blue mackerel will not be targeted once the skipjack season has begun in late-spring, early summer. Thus, early arrival of skipjack can result in reduced volumes of blue mackerel being landed.

Management of company quota is complicated by the relative timing of the fishing season and the fishing year and this, along with the timing of the main market, may influence whether the blue mackerel TACC can all be taken in a particular year. The fishing season usually begins in about July–August, runs through to the end-beginning of subsequent fishing years, and finishes in about November. The main market for blue mackerel purse seine catches takes up to 80% of the catch and requires premium fish to be available from early spring. To meet the demands of this market and to minimise the costs of storing fish from the previous season, fishing companies must carry over some proportion of their quota for a given year until fish become available the following season. If availability is delayed until after October 1, only 10% of the total quota can then be carried over into the new fishing year.

Table 2: Reported landings (t) for the main QMAs from 1931 to 1982.

Year	EMA 1	EMA 2	EMA 3	EMA 7
1931–32	0	0	0	0
1932–33	0	0	0	0
1933–34	0	0	0	0
1934–35	0	0	0	0
1935–36	0	0	0	0
1936–37	0	0	0	0
1937–38	0	0	0	0
1938–39	0	0	0	0
1939–40	0	0	0	0
1940–41	0	0	0	0
1941–42	0	0	0	0
1942–43	0	0	0	0
1943–44	0	0	0	0
1944	0	0	0	0
1945	0	0	0	0
1946	0	0	0	0
1947	0	0	0	0
1948	0	0	0	0
1949	0	0	0	0
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1966	0	0	0	0
1967	0	0	0	0
1968	0	0	0	0
1969	0	0	0	0
1970	0	0	0	0
1971	0	0	0	0
1972	0	0	0	0
1973	0	0	0	0
1974	38	8	0	6
1975	10	0	0	2
1976	50	49	0	0
1977	34	135	0	0
1978	14	55	0	128
1979	185	31	0	317
1980	752	32	0	407
1981	459	49	0	1 363
1982	305	0	0	791

Notes:
1. The 1931–1943 years are April–March, but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: Data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data include both foreign and domestic landings.

Because blue mackerel is taken principally as bycatch in the jack mackerel TCEPR target fishery in JMA 7, factors influencing the targeting of jack mackerel also affect blue mackerel landings. Other bycatch species taken in this fishery include barracouta, gurnard, John dory, kingfish, and snapper, and, although non-availability of ACE is unlikely to be constraining in the first three of these, the same is not true of kingfish and snapper. Fishing company spokespersons have stated that known hotspots of snapper are avoided. Other factors in this fishery include strategies to avoid the catch of marine mammals, and a code of practice operates in which gear is not deployed between 2 a.m. and 4 a.m. It is unknown whether this affects total landing volumes.

Table 3: Reported landings (t) of blue mackerel by QMA, and where area was unspecified (Unsp.), from 1983–84 to present. CELR data from 1986–87 to 2000–01. MHR data from 2001–02 to present.

	QMA						
Fishing year	**1**	**2**	**3**	**7**	**10#**	**Unsp**	**Total**
1983–84*	480	259	44	245	0	1	1 028
1984–85*	565	222	18	865	0	73	1 743
1985–86*	618	30	190	408	0	51	1 296
1986–87	1 431	7	424	489	0	49	2 399
1987–88	2 641	168	864	1 896	0	58	5 625
1988–89	1 580	< 1	1 141	1 021	0	469	4 211
1989–90	2 158	76	518	1 492	0	< 1	4 245
1990–91	5 783	94	478	3 004	0	0	9 358
1991–92	10 926	530	65	3 607	0	0	15 128
1992–93	10 684	309	133	1 880	0	0	13 006
1993–94	4 178	218	223	1 402	5	0	6 025
1994–95	6 734	94	154	1 804	10	149	8 944
1995–96	4 170	119	173	1 218	0	1	5 680
1996–97	6 754	78	340	2 537	0	< 1	9 708
1997–98	4 595	122	78	2 310	0	< 1	7 104
1998–99	4 505	186	62	8 756	0	4	13 519
1999–00	3 602	73	3	3 169	0	0	6 847
2000–01	9 738	113	6	3 278	0	< 1	13 134
2001–02	6 368	177	49	5 101	0	0	11 694
2002–03	7 609	115	88	3 563	0	0	11 375
2003–04	6 523	149	1	2 701	0	0	9 373
2004–05	7 920	9	< 1	4 817	0	0	12 746
2005–06	6 713	13	133	3 784	0	0	10 643
2006–07	7 815	133	42	2 698	0	0	10 688
2007–08	5 926	6	122	2 929	0	0	8 982
2008–09	3 147	2	88	3 503	0	0	6 740
2009–10	8 539	3	14	3 260	0	0	11 816
2010–11	6 630	2	9	1 996	0	0	8 638
2011–12	8 080	2	28	2 707	0	0	10 817
2012–13	7 213	3	100	2 401	0	0	9 716
2013–14	6 860	4	29	1 200	0	0	8 092
2014–15	8 134	16	87	892	0	0	9 129
2015–16	7 226	18	27	761	0	0	8 033
2016–17	7 551	83	126	625	0	0	8 385
2017–18	7 988	112	46	3 254	0	0	11 400
2018–19	7 630	12	32	2 626	0	0	10 300
2019–20	7 169	7	13	2 409	0	0	9 597
2020–21	8 002	129	3	2 832	0	0	10 966

* FSU data,
\# Landings reported from QMA 10 are probably attributable to Statistical Area 010 in the Bay of Plenty (i.e., QMA 1).

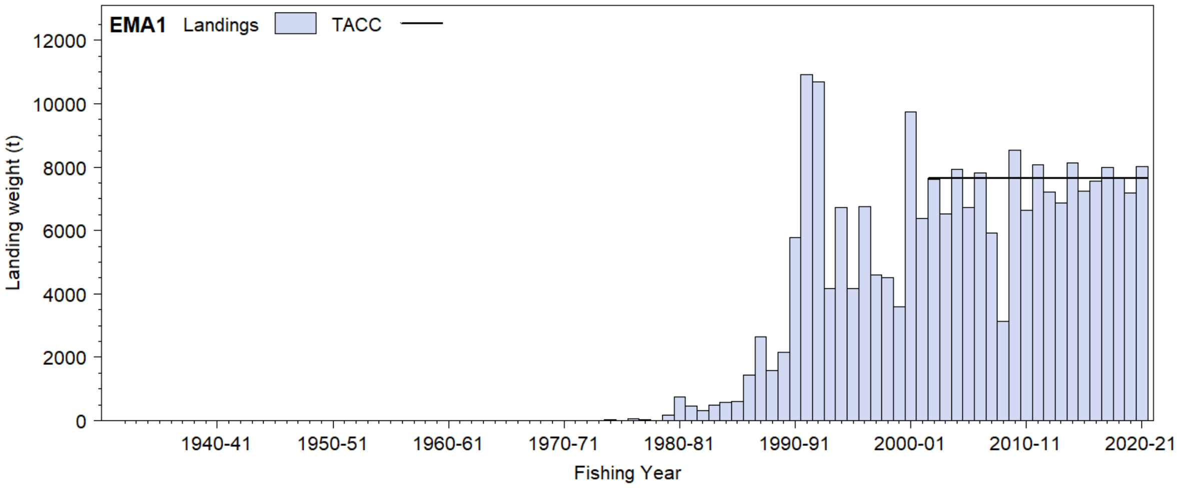


Figure 1: Reported commercial landings and TACC for the three main EMA stocks. EMA 1 (Auckland East). [Continued on next page]

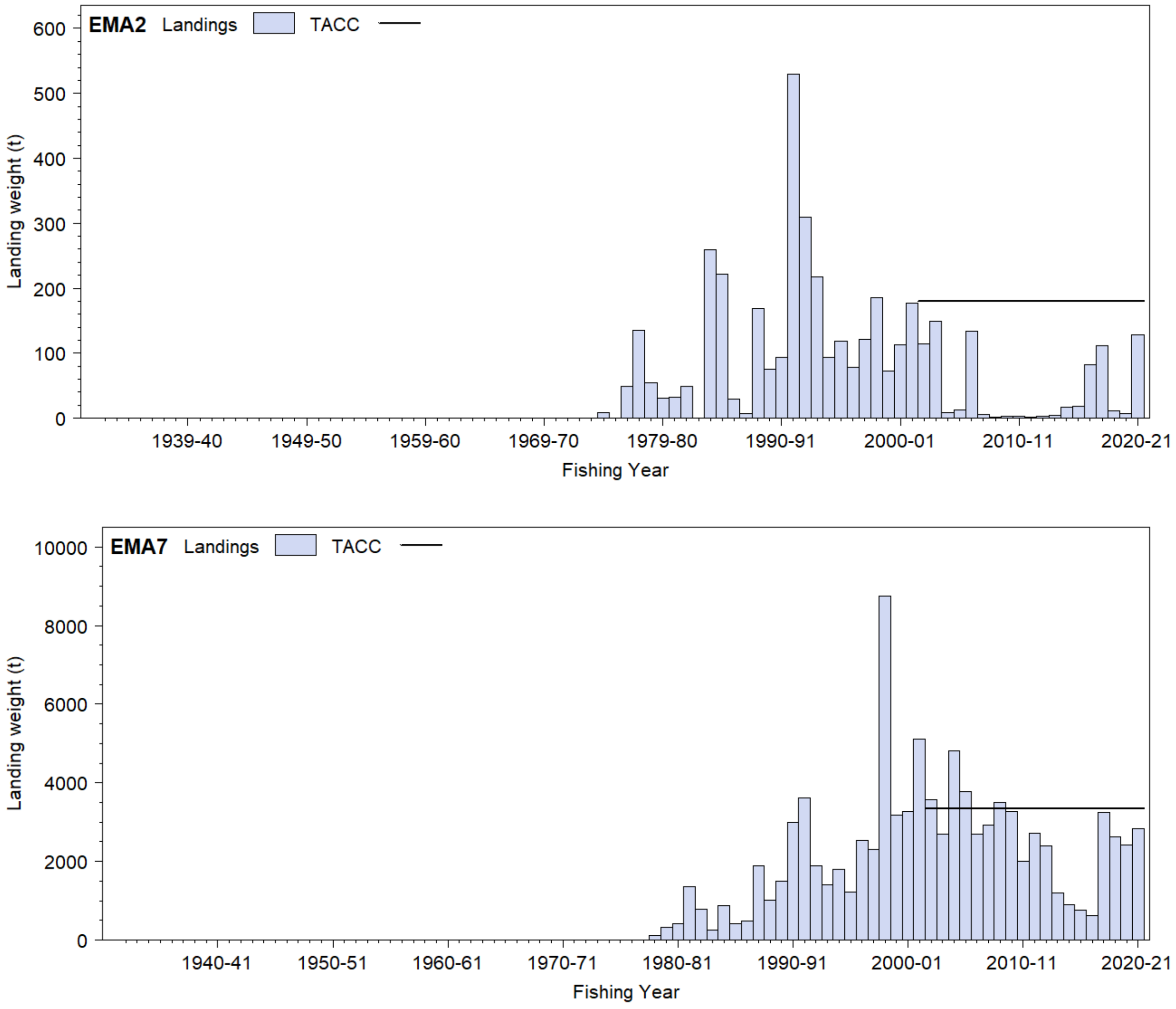


Figure 1: [Continued] Reported commercial landings and TACC for the three main EMA stocks. From top: EMA 2 (Central East) and EMA 7 (Challenger to Auckland West).

1.2 Recreational fisheries

Blue mackerel does not rate highly as a recreational target species although it is popular as bait. There is some uncertainty with all recreational harvest estimates for blue mackerel and there is some confusion between blue and jack mackerels in the recreational data.

Recreational catch in the northern region (EMA 1) was estimated at 114 000 fish by a diary survey in 1993–94 (Bradford 1996), 47 000 fish in a national recreational survey in 1996 (Bradford 1998), 84 000 fish (CV 42%) in the 2000 survey (Boyd & Reilly 2002), and 58 000 fish (CV 27%) in the 2001 survey (Boyd et al 2004). The surveys suggest a harvest of 35–90 t per year for EMA 1, insignificant in the context of the commercial catch. Estimates from other areas are very low (between 500 and 3000 fish) and are likely to be insignificant in the context of the commercial catch.

The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a national panel survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information was collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019).

Recreational catch estimates from the two national panel surveys are given in Table 4. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 4: Recreational harvest estimates for blue mackerel stocks (Wynne-Jones et al 2014, 2019). Mean fish weights were obtained from boat ramp surveys (Hartill & Davey 2015, Davey et al 2019).

Stock	Year	Method	Number of fish	Total weight (t)	CV
EMA 1	2011–12	Panel survey	18 438	19.2	0.36
	2017–18	Panel survey	15 036	17.3	0.50
EMA 2	2011–12	Panel survey	3 346	3.5	–
	2017–18	Panel survey	1 209	1.3	0.69
EMA 7	2011–12	Panel survey	11 194	11.6	0.42
	2017–18	Panel survey	4 375	4.5	0.45

1.3 Customary non-commercial fisheries

Quantitative information on the current level of customary non-commercial catch is not available.

1.4 Illegal catch

There is no known illegal catch of blue mackerel.

1.5 Other sources of mortality

There is no information on other sources of mortality.

2. BIOLOGY

The geographical distribution and habitat of blue mackerel vary with life history stage. Juvenile and immature blue mackerel are northerly in their distribution, with records from commercial and research catches around the North Island and into Golden Bay and Tasman Bay at the top of the South Island.

By contrast, adults have been recorded around both the North Island and South Island to Stewart Island and across the Chatham Rise almost to the Chatham Islands. Sporadic catches of small numbers of yearling blue mackerel have been made by bottom trawl in shallow waters.

The distribution of blue mackerel at the surface is seasonal and differs from its known geographical range. During summer, surface schools are found in Northland, BoP, South Taranaki Bight, and Kaikōura, but they disappear during winter, when only occasional individuals are found in Northland and the BoP. A possible corollary to this winter disappearance comes from the peak in bycatch of blue mackerel in the winter jack mackerel midwater trawl fishery in EMA 7. This suggests an increased partitioning of the population in deeper water at this time of the year, reflecting an observed behavioural characteristic of the related Atlantic species, *Scomber scombrus*. Summaries from aerial sightings data show that blue mackerel can be found in mixed schools with jack mackerel (*Trachurus* spp.), kahawai (*Arripis trutta*), skipjack tuna (*Katsuwonus pelamis*), and trevally (*Pseudocaranx dentex*), and that its appearance in mixed schools varies seasonally.

Observer data collected in EMA 7 between 1993 and 2019 suggest that blue mackerel spawn from spring into summer (Nov–Feb) (Kienzle in press). Observer data indicate that sexual maturity is reached at 33 cm fork length and 4.1 years for females (Table 5) and at a smaller size (about 28 cm) and presumably younger age for males (Kienzle in press).

Eggs are pelagic and development rate is dependent on temperature. In plankton surveys, blue mackerel eggs have been found from North Cape to East Cape, with highest concentrations from Northland, the Hauraki Gulf, and the western BoP. Eggs have been described throughout the Hauraki Gulf from November to the end of January, at surface temperatures in the range 15–23 °C. Individuals in spent or spawning condition have been taken in a few tows off Tasman Bay and Taranaki in EMA 7 and in the BoP in EMA 1.

Table 5: Proportion of female blue mackerel mature at age from South Taranaki Bight (EMA 7) (Kienzle in press).

Sex	Age group (y)	Age (y)	Fraction mature
female	1	0.50	0.01
female	2	1.50	0.03
female	3	2.50	0.10
female	4	3.50	0.29
female	5	4.50	0.61
female	6	5.50	0.86
female	7	6.50	0.96
female	8	7.50	0.99
female	9	8.50	1.00

Age and growth studies suggest a difference in the age structures of catches taken in the BoP (New Zealand, EMA 1) and New South Wales (Australia). For fish from the New South Wales study (Stewart et al 2001), a peak was found at 1 year that accounted for more than 55% of the fish sampled, with a maximum age of 7 years. The BoP results show a much broader distribution, with a maximum age of 24 years, and a mode in the data at around 8 to 10 years. Growth parameters estimated in the BoP study are given in Table 6. Following a quantitative test of competing growth models in the BoP study, no evidence was found of statistically significant differences in growth between the sexes in BoP blue mackerel.

Table 6: von Bertalanffy growth parameters for Bay of Plenty (EMA 1) blue mackerel (Manning et al 2006).

	Males	Females	Both sexes
L_∞	52.49	53.10	52.79
K	0.15	0.15	0.15
t_0	-3.29	-3.18	-3.19
Age range	1.8–21.9	1.8–21.9	1.8–21.9
N	240	269	509

Australian studies may underestimate the ages of larger, older blue mackerel in their catch. The Australian method for estimating blue mackerel ages is based on reading otoliths whole in oil, whereas the New Zealand method is based on otolith thin-sections (Marriott & Manning 2011). Results from the New South Wales study referred to above, suggest that blue mackerel 25–40 cm fork length may be 3–7 years old. Using the New Zealand method, fish in this length range could be as old as 16 years. Australian scientists, reading whole otoliths, may be missing opaque zones near the margin, which are visible in sectioned otoliths.

Although Australian scientists have validated the timing of the first opaque zone in blue mackerel otoliths, their results do not cover the complete life history defined using either the Australian or New Zealand method. A study attempting to validate the New Zealand age estimation method using lead-radium dating indicated that blue mackerel in New Zealand are a relatively long lived, small pelagic species, living to at least 17 to 49 years, with the real age most likely nearer the lower value (Marriott et al 2010). Although this range of age estimates is less than desirable for the validation of the growth zone counting method for this species, the findings are consistent with the New Zealand method where otolith ageing studies from commercial catches describe blue mackerel living to at least 24 years.

Instantaneous natural mortality (M) for male and female fish was estimated using Hoenig's method (Morrison et al 2001). Based on age estimates from otoliths collected during the mid-1980s, when fishing pressure was presumably light, natural mortality estimates of 0.22 yr^{-1} for males and 0.20 yr^{-1} for females were derived.

In New Zealand, the diet of blue mackerel has been described as zooplankton, which consists mainly of copepods, but also includes larval crustaceans and molluscs, fish eggs, and fish larvae. Feeding involves both filtering of the water and active pursuit of prey, with blue mackerel able to take much smaller animals than, for example, kahawai can.

3. STOCKS AND AREAS

Sampling of eggs, larvae, and spawning blue mackerel indicate at least three spawning centres for this species: Northland-Hauraki Gulf; western BoP; and south Taranaki Bight. Nothing is known of migratory patterns or the fidelity of fish to a particular spawning area. Examination of mitochondrial DNA shows no geographical structuring between New Zealand and Australian fish. Meristic characters show significant regional differentiation within New Zealand fisheries waters and, combined with parasite marker information, Smith et al (2005) sub-divided blue mackerel into at least three stocks in New Zealand fisheries waters: EMA 1, EMA 2, and EMA 7. No information is currently available on the stock affinity of fish in EMA 3.

4. STOCK ASSESSMENT

4.1 EMA 1

4.1.1 Estimates of fishery parameters and abundance

Analysis of aerial sightings data for east Northland (part of EMA 1) from 1985–86 to 2002–03 found no apparent trends in abundance, apart from a peak off east Northland in 1991–92 for both the number of schools and the estimated tonnage, and a further strong signal for the number of schools and the estimated tonnage from 2000–01 to 2002–03.

Using market and catch sampling data collected from 2002 to 2005, estimated numbers-at-length and numbers-at-age were calculated based on all available groomed length and length-at-age data (Manning et al 2007). These were done separately by sex and scaled to estimates of the total catch from the purse seine fishery. Results showed that the EMA 1 purse seine fishery was composed of fish between 2 and 21 years of age, although most were between 5 and 15 years.

4.2. EMA 7

4.2.1 Estimates of fishery parameters and abundance

A standardised CPUE analysis for EMA 7 was carried out using TCEPR tow-by-tow data from the midwater trawl jack mackerel target fishery up to 2017–18 (Ballara 2016, Kienzle in press). The initial dataset comprised tows that targeted jack mackerel with blue mackerel caught as bycatch. Tows that targeted blue mackerel were not considered because they constituted a small amount of catch and effort (about 30 tows each year for the last 10 years by all vessels) and they were confined to a few areas in the fishery and were directed at large sub-surface schools of blue mackerel. Tows that targeted jack mackerel but did not report any blue mackerel catch were also excluded. The data used for the CPUE analyses consisted of catch and effort by core vessels that targeted jack mackerel; core vessels were those participating in the fishery for five or more years, and reporting at least 20 tows per vessel-year. Estimates of relative year effects were obtained using a forward stepwise multiple regression method, where the data were fitted using binomial-lognormal model structure.

Separate standardisations were carried out for two subgroups of core vessels corresponding to an early and late period of the data series, respectively. CPUE indices were developed for the early time series from 1989–90 to 1997–98 using catch and effort by 12 core vessels (Fu & Taylor 2011) and the later time series from 1996–97 to 2017–18 using catch and effort by 7 core vessels (Table 7, Kienzle in press). The residual deviance explained was 33% for the early time series and 22% for the late time series. For both data series, the main terms selected by the models were statistical area, vessel, and month.

The early time series increased from 1990 to 1992 and was then relatively constant to 1998. The late time series showed a 70% decline in abundance from 1996–97 to 2004–05, followed by a period of stable abundance to 2017–18 (Figure 2).

The WG concluded that standardised CPUE series based on the blue mackerel bycatch in the WCNI and WCSI jack mackerel trawl fishery appears to provide a reliable index of abundance.

Table 7: Standardised lognormal CPUE catch/hr indices for the core west coast TCEPR tow-by-tow target JMA data indices for fishing years 1990–2018. The standardised CPUE indices for the early series were estimated for 1990 to 1998 (Fu & Taylor 2011), and a later series from 1997 to 2018 (Kienzle in press).

	ı & Taylor (2011)		Kienzle (in press)	
Year	**Indices**	**CV**	**Indices**	**CV**
1989–90	0.67	0.20	–	–
1990–91	0.87	0.10	–	–
1991–92	1.24	0.11	–	–
1992–93	1.01	0.13	–	–
1993–94	0.99	0.09	–	–
1994–95	1.05	0.07	–	–
1995–96	0.87	0.11	–	–
1996–97	1.34	0.08	2.43	0.09
1997–98	1.13	0.08	2.06	0.07
1998–99	–	–	2.29	0.05
1999–00	–	–	1.99	0.05
2000–01	–	–	1.65	0.05
2001–02	–	–	1.75	0.04
2002–03	–	–	1.18	0.05
2003–04	–	–	0.80	0.04
2004–05	–	–	0.70	0.04
2005–06	–	–	0.91	0.04
2006–07	–	–	0.66	0.04
2007–08	–	–	0.75	0.04
2008–09	–	–	0.92	0.04
2009–10	–	–	0.75	0.04
2010–11	–	–	0.86	0.04
2011–12	–	–	0.63	0.05
2012–13	–	–	0.63	0.05
2013–14	–	–	0.57	0.06
2014–15	–	–	0.68	0.08
2015–16	–	–	0.82	0.08
2016–17	–	–	0.81	0.08
2017–18	–	–	0.84	0.05

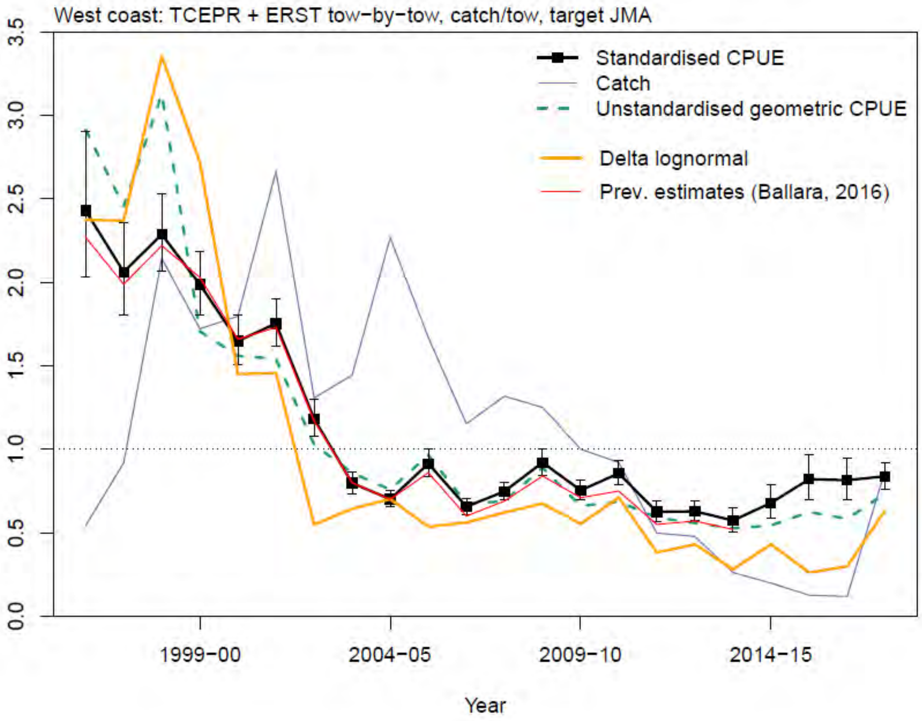


Figure 2: Blue mackerel CPUE for 1997–2018 fishing years for west coast areas WCSI and WCNI combined (EMA 7). Indices have been standardised to have the same geometric mean (Kienzle in press). The standardised CPUE index, accepted as an index of stock abundance by the WG, used only non-zero catch data (lognormal model).

Biological samples of blue mackerel collected by observers on board trawlers targeting jack mackerel were used to estimate an age-length key for 2017–18 (Horn & Ó Maolagáin 2019). This age-length key was applied to length frequency distributions to provide estimated age compositions for 2003–04 to 2005–06, 2013–14, and 2017–18 (Horn & Ó Maolagáin 2019). Blue mackerel had ages of between 1 and 25 years. The catch-at-age distributions showed no clear cohort progression and were not consistent from year to year, with 2017–18 being considerably different from earlier years (Figure 3).

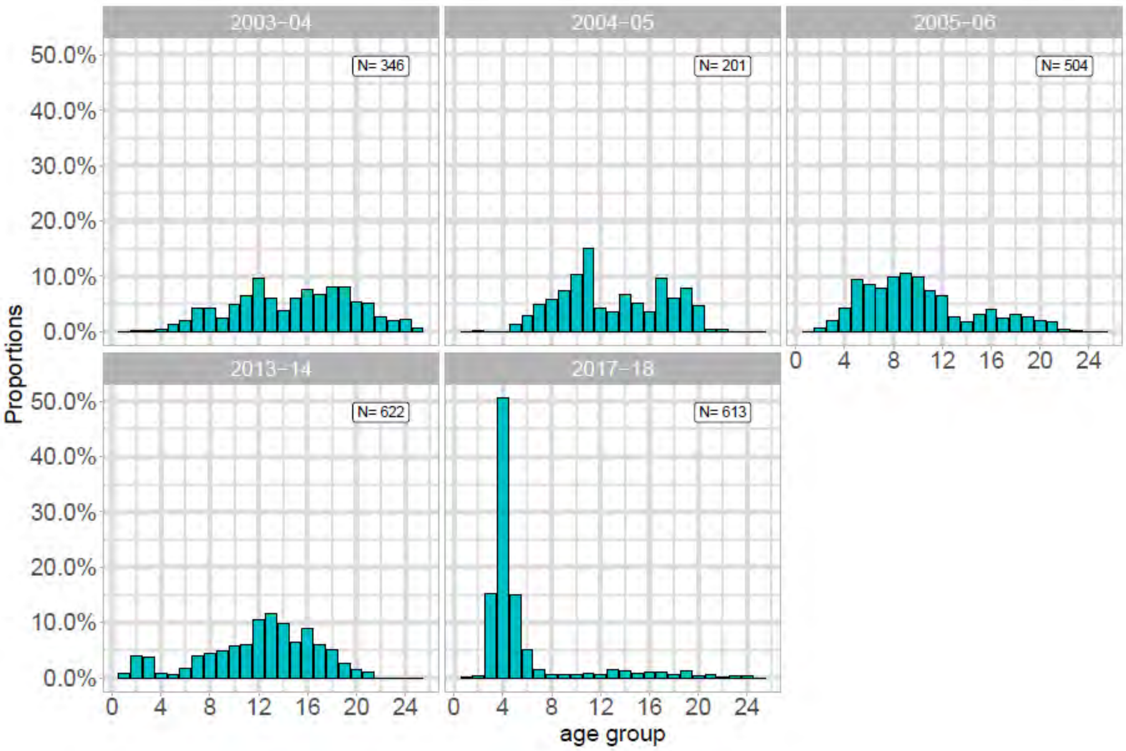


Figure 3: Blue mackerel scaled catch-at-age distributions. The number of age measurements (N) for each year is given in the top right-hand corner of each panel.

A stock assessment attempted in 2020 was rejected by the Working Group (Kienzle in press). This was because (a) there were sufficient concerns about the representativeness of the age data to preclude their usage in an age-structured model, and (b) the proposed model failed to adequately fit the observed data. Options to improve the assessment include:

- A more comprehensive analysis of the length and age data to determine sampling representativeness and the spatial and temporal patterns in length and age composition. This might include determining the appropriate sample size for annual otolith collection from the fishery.
- Explore whether a change in selectivity between 2013–14 and 2017–18 might have taken place.

4.3 Biomass estimates

No estimates of biomass are available for any blue mackerel stocks.

4.4 Other factors

Catch sampling in the period from 2002 to 2005 indicated that catch-at-length and catch-at-age is relatively stable between years in EMA 1. Although total mortality in EMA 1 is poorly understood, the relatively stable age-length composition between years and the number of year-classes that compose the catch-at-age within fishing years, suggested that blue mackerel may have been capable of sustaining the catch levels at that time in EMA 1.

5. STATUS OF THE STOCKS

Based on studies of stock structure within New Zealand waters blue mackerel may be sub-divided into at least three stocks: EMA 1, EMA 2, and EMA 7. No information is currently available on the stock affinity of fish in EMA 3.

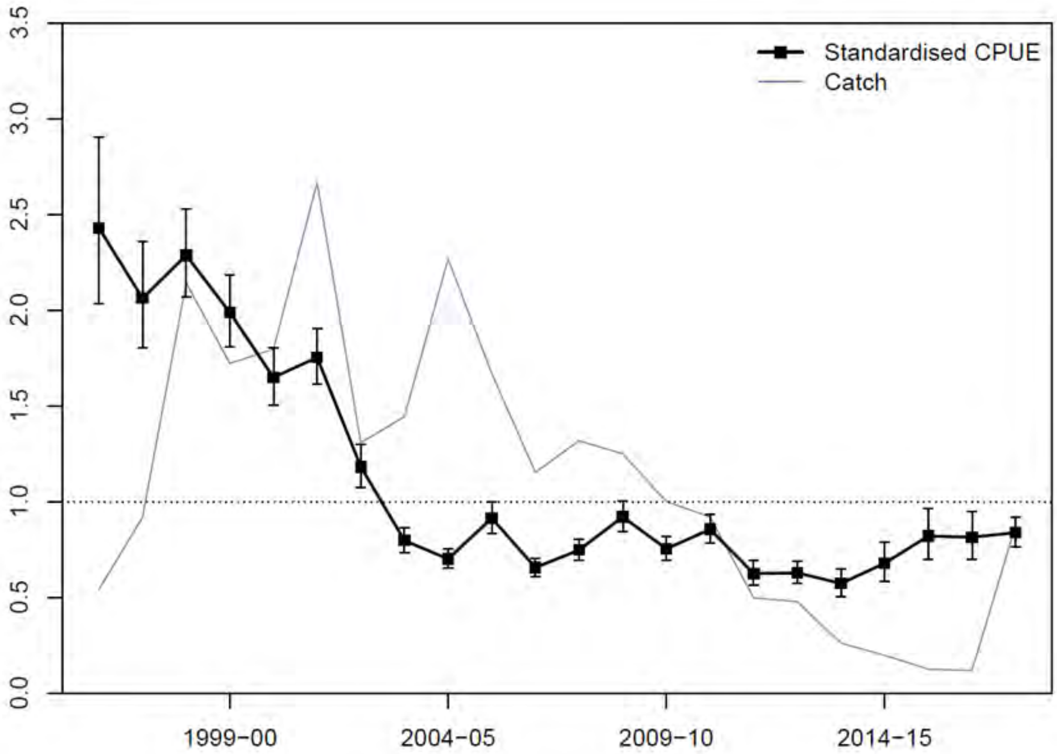
Little is known about the status of blue mackerel stocks and no estimates of current and reference biomass, or yield, are available for any blue mackerel area.

- **EMA 1**
  For EMA 1, the stability of the age composition data and the large number of age classes that comprise the catches suggests that blue mackerel may be capable of sustaining current commercial fishing mortality, at least in the short-term.

- **EMA 7**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised trawl CPUE
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%B0}$
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



West coast blue mackerel CPUE: Comparison of indices for the TCEPR tow-by-tow datasets for fishing years 1997 to 2018; CPUE indices from Ballara (2016) and Kienzle (in press). Standardised CPUE was the accepted biomass index. Indices have been standardised to have a mean of one.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has shown a modest increase in recent years and remains roughly constant from 2015–16 to 2017–18.
Recent Trend in Fishing Intensity or Proxy	
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Broad age structure of the trawl catch between 2003–04 and 2013–14 does not support a large decrease in biomass as suggested by the CPUE series

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE from the jack mackerel target fishery WCSI and WCNI	
Assessment Dates	Latest assessment: 2020	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Standardised CPUE - Proportions at age data from the commercial trawl fishery	1 – High Quality 1 – High Quality
Data not used (rank)		
Changes to Model Structure and Assumptions	-	
Major sources of Uncertainty	-	

Qualifying Comments

Fishery Interactions
There is a small target fishery for blue mackerel on the WCNI but the bulk of the catch is taken as bycatch in the jack mackerel mid-water trawl fishery on the WCSI and WCNI, which has a bycatch of kingfish and snapper. Incidental interactions and associated mortality of common dolphins occur in the jack mackerel fishery but have reduced considerably in recent years (see JMA chapter).

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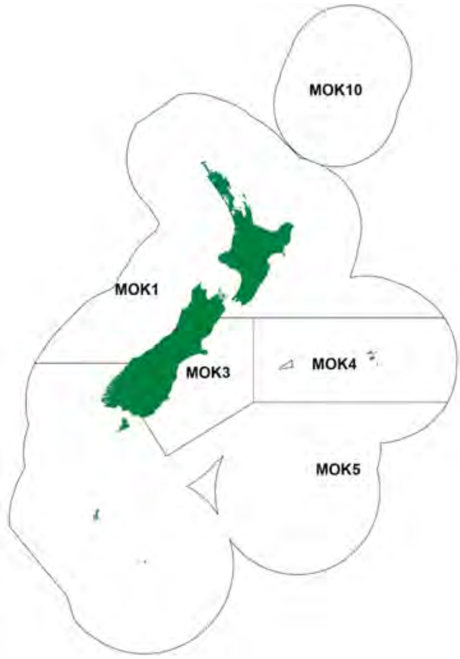
BLUE MOKI (MOK)

(*Latridopsis ciliaris*)
Moki



1. FISHERY SUMMARY

1.1 Commercial fisheries

Most blue moki landings are taken by set net or trawl off the east coast between the Bay of Plenty (BoP) and Kaikoura, although small quantities are taken in most New Zealand coastal waters. Although the proportions of the total commercial landings taken by set net and trawl have varied over time, set netting has been the predominant method, accounting for 50–60% of the annual catch during 1989–90 to 2011–12. The proportion of the catch taken by set net declined in the more recent years (to 2015–16) and catches by the two methods were at about parity during this period.

Reported landings and TACCs are given in Tables 1 and 2, and an historical record of landings and TACC values for the two main MOK stocks are depicted in Figure 1. Landings of blue moki peaked in 1970 and 1979 at about 960 t. Blue moki stocks appeared to have been seriously depleted by fishing prior to 1975 and this resulted in the sum of allocated ITQs being markedly less than the sum of the catch histories.

Table 1: Total reported landings (t) of blue moki from 1979 to 1985–86.

Year	1979*	1980*	1981*	1982*	1983†	1983–84†	1984–85†	1985–86†
Landings	957	919	812	502	602	766	642	636

*MAF data.
†FSU data.

Total annual landings of blue moki were substantially constrained when it was introduced into the QMS. In MOK 1, landings increased as the TACC was progressively increased. Since the TACC was set at 400 t (1995–96) landings have fluctuated around the TACC, which was subsequently increased to 403 t in 2001–02.

Landings from MOK 3 increased from the mid-2000s and exceeded the TACC of 127 t from 2010–11. The TACC was increased to 160 t in 2014–15, and landings have fluctuated around the TACC since. The combined MOK 1 and 3 catch fluctuated around 500 t per annum during 1994–95 to 2009–10. Since then annual landings have been about 550 t and peaked at over 600 t in 2017–18.

Annual landings from MOK 4 and 5 are generally < 10 t.

Table 2: Reported landings (t) and actual TACCs (t) of blue moki by Fishstock from 1986–87 to present. Source: QMS data. MOK 10 is not tabulated; no landings have ever been reported from MOK 10.

Fishstock	MOK 1		MOK 3		MOK 4		MOK 5			
FMA (s)	1,2,7,8,9		3		4		5 & 6		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1986–87	109	130	52	60	0	20	3	40	164	260
1987–88	183	142	95	62	0	20	2	40	280	274
1988–89	134	151	121	64	0	20	3	40	258	285
1989–90	202	156	89	65	11	25	1	43	303	299
1990–91	264	157	93	71	1	25	2	43	360	306
1991–92	285	157	66	71	2	25	2	43	355	306
1992–93	289	157	94	122	1	25	4	43	388	358
1993–94	374	200	102	126	4	25	5	43	485	404
1994–95	418	200	90	126	< 1	25	3	43	511	404
1995–96	435	400	91	126	1	25	3	43	530	604
1996–97	408	400	66	126	2	25	3	43	479	604
1997–98	416	400	78	126	3	25	2	43	500	604
1998–99	468	400	78	126	< 1	25	4	43	551	604
1999–00	381	400	56	126	1	25	5	43	443	604
2000–01	420	400	67	126	5	25	6	43	499	604
2001–02	365	403	77	127	8	25	2	44	451	608
2002–03	380	403	87	127	2	25	6	44	475	608
2003–04	372	403	60	127	2	25	6	44	440	608
2004–05	418	403	70	127	3	25	11	44	502	608
2005–06	408	403	69	127	1	25	5	44	483	608
2006–07	402	403	90	127	< 1	25	11	44	504	608
2007–08	401	403	125	127	< 1	25	8	44	533	608
2008–09	413	403	103	127	1	25	8	44	525	608
2009–10	386	403	129	127	< 1	25	6	44	521	608
2010–11	421	403	144	127	< 1	25	10	44	574	608
2011–12	427	403	137	127	< 1	25	6	44	571	608
2012–13	385	403	159	127	< 1	25	5	44	549	608
2013–14	393	403	134	127	< 1	25	7	44	535	608
2014–15	376	403	146	160	< 1	25	6	44	529	631
2015–16	395	403	183	160	< 1	25	8	44	587	631
2016–17	387	403	162	160	< 1	25	7	44	556	631
2017–18	435	403	178	160	< 1	25	7	44	620	631
2018–19	388	403	149	160	< 1	25	5	44	543	641
2019–20	384	403	167	160	< 1	25	2	44	553	641
2020–21	280	403	169	176	< 1	25	3	44	453	657

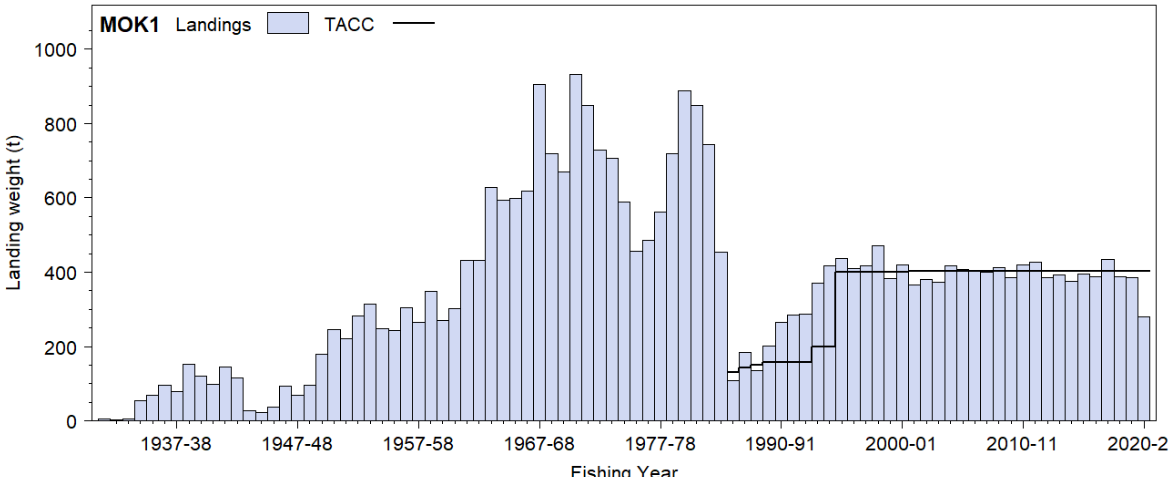


Figure 1: Reported commercial landings and TACC for the two main MOK stocks: MOK 1 (Auckland, Central, and Challenger). Note: these figures do not show data prior to entry into the QMS. [Continued on next page]

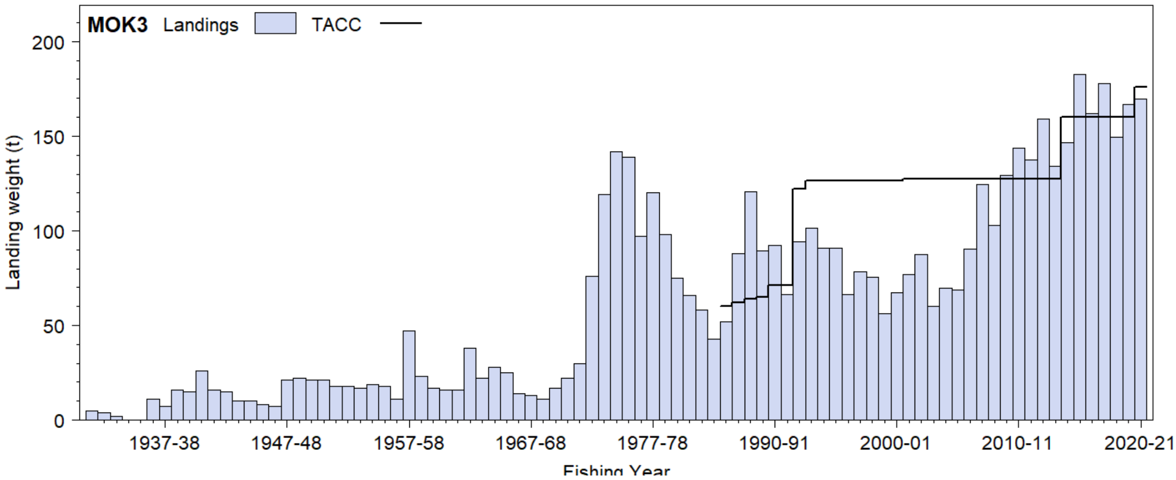


Figure 1 [Continued]: Reported commercial landings and TACC for the two main MOK stocks: MOK 3 (South East Coast). Note: these figures do not show data prior to entry into the QMS.

1.2 Recreational fisheries

Popular with recreational fishers, blue moki are taken by beach anglers, set netting, and spearfishing. Annual estimates of recreational harvest were obtained from diary surveys in 1991–94, 1996, and 1999–2000 (Tables 3a & 3b).

Table 3a: Estimated number and weight of blue moki harvested by recreational fishers by Fishstock and survey. Surveys were carried out in different years in the MAF Fisheries regions: South in 1991–92, Central in 1992–93, and North in 1993–94 (Teirney et al 1997).

Fishstock	Survey	Number	CV (%)	Survey harvest (t)
MOK 1	North	6 000	-	5–15
MOK 1	Central	38 000	28	40–80
MOK 1	South	2 000	-	0–5
MOK 3	South	31 000	33	40–70
MOK 5	South	7000	33	5–15

Table 3b: Estimates of annual number and weight of blue moki harvested by recreational fishers from national diary surveys in 1996 (Bradford 1998) and Dec 1999–Nov 2000 (Boyd & Reilly 2005). The mean weights used to convert numbers to catch weight are considered the best available estimates. Estimated harvest is also presented as a range to reflect the uncertainty in the point estimates.

Fishstock	Number caught	CV (%)	Estimated harvest range (t)	Point estimate (t)
				1996
MOK 1	63 000	14	80–110	93
MOK 3	16 000	18	20–30	24
MOK 5	9 000	–	–	–
				1999–2000
MOK 1	81 000	37	82–180	131
MOK 3	36 000	32	36–70	53
MOK 5	38 000	89	7–115	61

The harvest estimates provided by telephone/diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year (Wynne-Jones et al 2014). The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 4. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 4: Recreational harvest estimates for blue moki stocks (Wynne-Jones et al 2014, 2019). Mean fish weights were obtained from boat ramp surveys (Hartill & Davey 2015 and Davey et al 2019).

Stock	Year	Method	Number of fish	Total weight (t)	CV
MOK 1	2011–12	Panel survey	21 945	44.5	0.31
	2017–18	Panel survey	16 598	32.6	0.26
MOK 3	2011–12	Panel survey	5 739	11.6	0.53
	2017–18	Panel survey	8 324	16.3	0.29
MOK 5	2011–12	Panel survey	243	0.5	1.02
	2017–18	Panel survey	7 018	13.8	0.58

1.3 Customary non-commercial fisheries

A traditional Maori fishery exists in some areas, particularly the eastern Bay of Plenty and East Cape regions. No quantitative information is available on the level of customary non-commercial catch.

Iwi in the Cape Runaway area have a strong view that blue moki are of special significance in the history and life of the community. They believe that blue moki come to spawn in the waters around Cape Runaway and there are traditional fishing grounds, where in earlier years fishing took place in accordance with customary practices. In addition, these local Iwi consider the taking of blue moki by nets in this area to be culturally offensive.

Since September 1996, fishing by the methods of trawling, Danish seining, and set netting has been prohibited at all times within a two nautical mile wide coastal band beginning at the high water mark and extending from Cape Runaway to a stream tributary at Oruiti Beach. Note this is not a legal description, for full details please refer to the Fisheries Act (Auckland and Kermadec Areas Commercial Fishing Regulations 1986, Amendment No. 13).

1.4 Illegal catch

No quantitative estimates are available.

1.5 Other sources of mortality

Some blue moki caught for use as rock lobster bait have not been reported. Although little information is available, this practice appears to have been most common around Stewart Island and the Chatham Islands and may have accounted for about 45 t and 60 t from Stewart Island and Chatham Islands, respectively, in the past. The use of blue moki as bait has not been considered in the determination of *MCY*.

2. BIOLOGY

Blue moki grow rapidly at first, attaining sexual maturity at 40 cm fork length (FL) at 5–6 years of age. Growth then slows, and fish of 60 cm FL are 10–20 years old. Fish over 80 cm FL and 43 years old have been recorded (Manning et al 2009).

Many adults take part in an annual migration between Kaikoura and East Cape. The migration begins off Kaikoura in late April–May as fish move northwards. Spawning takes place in August–September in the Mahia Peninsula to East Cape region (the only known spawning ground), with the fish then returning south towards Kaikoura. The larval phase for blue moki lasts about 6 months.

Juvenile blue moki are found inshore, usually around rocky reefs, whereas most adults school offshore over mainly open bottom. Some adults do not join the adult schools but remain around reefs.

Biological parameters relevant to the stock assessment are shown in Table 5.

The estimate of natural mortality, given a maximum age of 43 years and using the equation $M = \log_e 100/\text{maximum age}$, is 0.1. Note that the maximum age for this calculation is meant to be the maximum age that 1% of the unfished population will reach, however, as this is not known, the maximum observed age was used here.

Table 5: Estimates of biological parameters for blue moki.

Fishstock				Estimate	Source
1. Natural mortality (*M*)					
All areas				0.14	Francis (1981b)
For maximum observed age of 33 yr.					
MOK 1				0.10	Manning et al (2009)
For maximum observed age of 44 yr.					
2. Weight = $a(\text{length})^b$ (Weight in g, length in cm fork length).					
		Both sexes			
	a		b		
All areas	0.055		2.713		Francis (1979)
3. von Bertalanffy growth parameters					
		Both sexes			
	L_∞	k	t_0		
All areas	66.95	0.208	-0.029		Francis (pers. comm.)

3. STOCKS AND AREAS

There are no new data which would alter the stock boundaries given in previous assessment documents.

Blue moki forms one stock around the North Island and the South Island north of Banks Peninsula. No information is available to indicate stock affiliations of blue moki in other areas (southern South Island and Chatham Rise) so these fish are currently divided into three Fishstocks.

4. STOCK ASSESSMENT

4.1 Estimates of fishing mortality

Estimates of total mortality (*Z*) for MOK 1 were obtained from catch curve analysis of catch sampling data collected during 2004–05 and 2005–06. Samples were taken from both the target set net fishery and from bycatch from the TAR 2 trawl fishery. When data were pooled across the two years, sexes and fishing methods, *Z* estimates ranged from 0.11 to 0.14, depending on assumed age-at-full recruitment (ages 4–12 years were tested). Assuming a value of natural mortality of 0.10 (based on a maximum age of 44 years), this suggests that recent fishing mortality is likely to be in the range of about 0.01 to 0.04. The Working Group considered that the most plausible age-at-full recruitment was 8 years. The estimate of Z and the bootstrapped 95% confidence intervals were 0.14 (0.12–0.16), giving rise to an *F* estimate of 0.04 (0.02–0.06). These estimates are well below the current assumed value of natural mortality (Manning et al 2009).

4.2 CPUE analyses

In 2017, a summary of the recent trends in catch from the MOK 1 and MOK 3 fisheries was presented to the Southern Inshore Fishery Assessment Working Group (Langley 2018). The analysis identified three main fisheries catching blue moki:

1. The bottom trawl fishery operating within the Gisborne-Mahia area (Statistical Area 013) throughout the year.
2. The target blue moki set net fishery operating between East Cape and Wairarapa (Statistical Areas 014–015) primarily during May–October.
3. The Kaikoura set net fishery (Statistical Area 018) operating during May–June and October.

For each fishery, a standardised CPUE analysis was conducted for 1989–90 to 2015–16. All three CPUE analyses modelled the positive catch of blue moki assuming a lognormal error structure, and the CPUE analysis of the tarakihi bottom trawl fishery (BT-TAR2-North) also modelled the presence of blue moki in the catch and derived delta-lognormal CPUE indices (Figure 2).

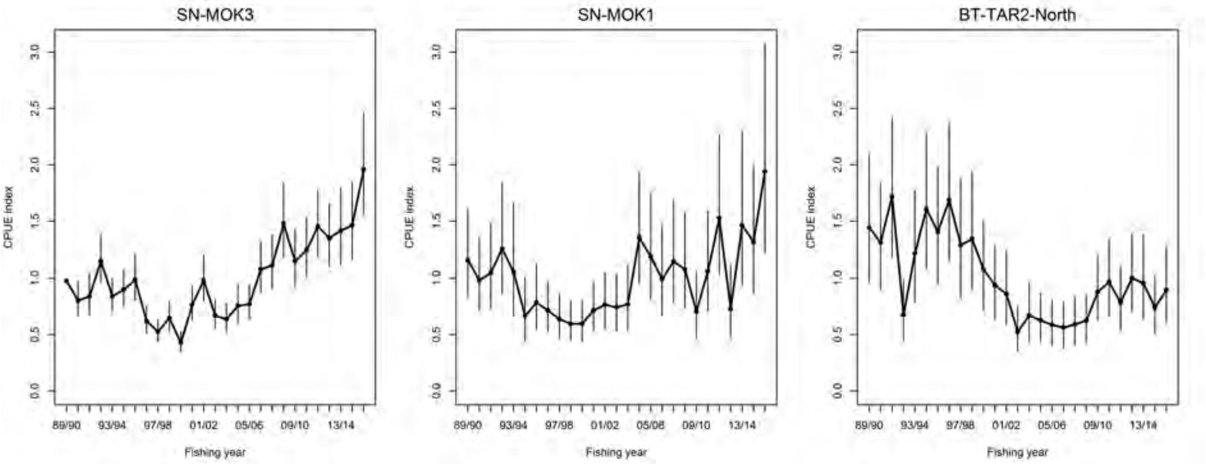


Figure 2: CPUE indices and 95% confidence intervals from the three main MOK 1 and MOK 3 fisheries.

The SN-MOK3 CPUE indices increased from a relatively low level in 1996–97 to 1999–2000 to reach the highest level of the time series in 2015–16. The SN-MOK1 CPUE indices increased during the same period although the CPUE indices are considerably more variable among years and are less well determined than the SN-MOK3 CPUE indices. The higher variability in the SN-MOK1 indices appears to be related to the inter-annual variation in the operation of the fishery (between Statistical Areas) and limited continuity in the core set of vessels participating in the fishery.

The SINSWG rejected the SN-MOK1 and SN-MOK3 CPUE indices as monitoring tools which could be used to determine stock status against Harvest Standard reference points, for the following reasons:

1. High inter-annual variation in the CPUE indices due to the low precision of CPUE indices derived from limited catch-effort data sets from these small fisheries and/or inter-annual variation in the catchability (availability) of migrating fish.
2. Possible hyperstability as a result of fishing directed at dense schools of migrating fish.

The WG nevertheless agreed that the SN-MOK1 and SN-MOK3 CPUE indices were likely to be broadly indicative of trends in abundance.

The two sets of SN CPUE indices are considered to represent the component (or components) of the blue moki stock migrating northward prior to spawning and then returning southward following spawning. These CPUE indices indicate that there has been a general increase in the abundance of adult blue moki within MOK 3 and the southern area of MOK 1 from the late 1990s. This is consistent with the estimates of total mortality derived from the population age structure in 2005–06 that indicated that fishing mortality on the adult population was less than natural mortality (*M*).

The BT-TAR2-North CPUE indices contrast the trend in the CPUE indices from the two set net fisheries. The BT-TAR2-North CPUE indices declined from 1996–97 to 2002–03 and remained at a relatively low level during 2002–03 to 2008–09. The index increased in 2009–10 and remained at about that level during 2010–11 to 2015–16. These recent indices are at a level considerably lower than the indices from 1989–90 to 1996–97 (with the exception of the low 1992–93 index).

The BT-TAR2-North CPUE indices are considered to predominantly comprise a component of the blue moki stock that remains in the Gisborne-Mahia area throughout the year. The trawl catch is probably comprises both immature and mature blue moki, although limited sampling of this component of the stock was conducted during the catch sampling programme. The SINSWG considered that the BT-TAR2-North CPUE series potentially provides an index of abundance for the resident portion of the population, but did not provide a monitoring tool for the entire population.

The contrasting trends in the CPUE indices (SN-MOK1 and SN-MOK3 versus BT-TAR-North) are indicative of differences in the stock dynamics (recruitment and/or exploitation) in the two components of the stock (resident and migrating). It was not considered feasible to amalgamate the three sets of CPUE indices to derive a composite set of abundance indices for the MOK 1&3 stock because the relative proportion of the stock biomass monitored by each CPUE series is unknown. Thus, the utility of the CPUE series is limited to the monitoring each component of the stock separately.

4.3 Biomass estimates

Estimates of current and reference biomass are not available.

4.4 Yield estimates and projections

MCY for all Fishstocks combined was estimated using the equation, $MCY = cY_{AV}$ (Method 4). The national catch, and probably effort, over the period 1961–86 varied considerably (annual landings ranged from 450 to 957 t with an average value of 705 t). However, no clear trend in landings over that period is apparent. The value of c was set equal to 0.9 based on the estimate of $M = 0.14$.

$$MCY = 0.9 * 705 \text{ t} = 635 \text{ t}$$

The level of risk to the stock by harvesting the population at the estimated *MCY* value cannot be determined.

Yield estimates for blue moki have been made using reported commercial landings data only and therefore apply specifically to the commercial fishery. Blue moki have been caught and used as bait and not reported. Therefore, the *MCY* estimates are likely to be conservative.

No estimate of *CAY* is available for blue moki stocks.

4.5 Other factors

CPUE data from the 1970s for the main northern blue moki stock indicated that the stock had declined to a level low enough to make recruitment failure a real concern. The 1986–87 TAC was set at a level considered low enough to enable some stock rebuilding.

Blue moki forms one stock around the North Island and the east coast of the South Island north of Banks Peninsula. As other stock boundaries are unknown, any interdependence is uncertain. If only one stock exists, then blue moki from the southern waters may be moving north and rebuilding the heavily exploited northern population.

5. STATUS OF THE STOCKS

Stock Structure Assumptions

Blue moki forms one stock around the North Island and the South Island north of Banks Peninsula. The bulk of the commercial catch is taken off the east coast between Banks Peninsula and East Cape, suggesting that this is where most of the blue moki stock resides.

MOK 1&3

Stock Status	
Year of Most Recent Assessment	2017
Assessment Runs Presented	2008 – Catch-at-age 2017 – Three CPUE series
Reference Points	Target: Not established but $F = M$ assumed Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Not established but $F = M$ assumed
Status in relation to Target	F is Very Likely (> 90%) to be below M
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unknown
Status in relation to overfishing	F is Very Unlikely (< 10%) to be above M

Historical Stock Status Trajectory and Current Status	-

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Catch curve analysis from catch sampling the migratory adult population (2004–05 and 2005–06) indicated that total mortality was low, with fishing mortality well below natural mortality. The general increase in CPUE from the SN-MOK1 and SN-MOK3 fisheries suggests that the biomass of migratory adults has increased since then.
Recent Trend in Fishing Intensity or Proxy	Low estimates of fishing mortality in 2005–06 and stable catches over the previous 14 years suggest that fishing mortality had been low for more than two decades. Recent increases in CPUE suggest that adult biomass has increased since the catch-at-age study, and together with constant catch suggests that fishing mortality remains below the target.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	CPUE indices from three fisheries are not considered to be sufficiently reliable to represent abundance indices for the stock. Rather, the indices are considered to be indicative of general trends in abundance for components of the stock. The SN-MOK1 and SN-MOK3 CPUE indices indicate that there has been a general increase in the abundance of adult blue moki within MOK 3 and the southern area of MOK 1 from the late 1990s. By contrast the BT-TAR2N series suggests that resident MOK in the northern part of FMA2 (Mahia Peninsula) declined to the mid-2000s and then increased to 2010–11, after which it fluctuated without trend at a level approximately half of that in the early 1990s.

Projections and Prognosis	
Stock Projections or Prognosis	If catches remain at current levels then fishing mortality should remain below the target.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Fishing mortality was estimated to be below the target fishing mortality level (M) in the mid-2000s. Since then, there has been a general increase in stock abundance of the migrating adult component of the stock (as indicated by the CPUE trends). It is therefore Unlikely (< 10%) that fishing mortality will exceeds the overfishing threshold at current catch levels.

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative stock assessment	
Assessment Method	Estimates of total mortality using Chapman-Robson estimator	
Assessment Dates	Latest assessment: 2017	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	

Main data inputs (rank)	- Age structure of setnet and trawl catches of blue moki made between Kaikoura and East Cape in 2004–05 and 2005–06 -Instantaneous rate of natural mortality (*M*) of 0.10 based on a maximum age of 44 years -CPUE indices for migrant components of the stock (SN-MOK1 and SN-MOK3 CPUE)	1 – High Quality 2 – Medium or Mixed Quality: uncertainty in estimate of M 2 – Medium or Mixed Quality: may not be fully representative
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	Uncertainty in the estimate of *M* Reliability of CPUE indices as indices of stock abundance.	

Qualifying Comments
-

Fishery Interactions
Interactions with other species are currently being characterised.

6. FOR FURTHER INFORMATION

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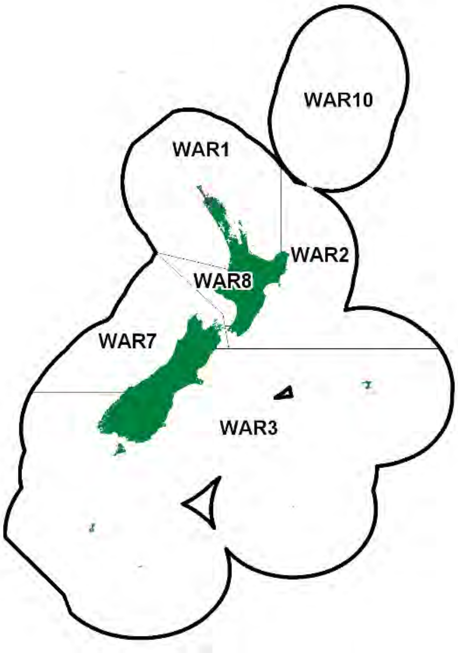
BLUE WAREHOU (WAR)

(Seriolella brama)
Warehou



1. FISHERY SUMMARY

Blue warehou was introduced into the Quota Management System (QMS) on 1 October 1986. Current allowances, TACCs and TACs are shown in Table 1.

Table 1: Recreational and Customary non-commercial allowances, TACCs and TACs for blue warehou by Fishstock.

Fishstock	Recreational Allowance	Customary non-commercial allowance	Other sources of mortality	TACC	TAC
WAR 1				41	
WAR 2				578	
WAR 3				2531	
WAR 7				1120	
WAR 8				233	
WAR 10				10	

1.1 Commercial fisheries

Blue (or common) warehou are caught in coastal waters of the South Island and lower North Island down to depths of about 400 m. Annual landings were generally less than 100 t up to the early 1960s, increased to about 1000 t by the early 1970s, and peaked at 4387 t in 1983–84 before declining steadily through to 1988–89 (Table 2). Figure 1 shows the historical landings and TACC values for the main WAR stocks.

The decline was most notable in WAR 3, from which most of the catch is recorded. A TACC reduction for WAR 3, from 3357 to 2528 t, was approved for the 1990–91 fishing year. In 1990–91, total catch increased substantially. The largest increase was in WAR 3 and catches in this area exceeded 2000 t for the following three years. There is no direct correlation between WAR 3 catches and fluctuations in effort in the Snares squid fishery where blue warehou is mostly taken as bycatch. In 1996–97, total catch increased again to 1990–91 levels and total catch has been maintained at this level since. Increased catches in WAR 2, 3 and 7 contributed to the increased total catch.

Until the mid 1980s, the main domestic fishing method used to catch blue warehou was gill-netting. The majority of the landings are now taken as a bycatch from trawling. Bull & Kendrick (2006) describe the commercial fishery from 1989–90 to 2002–03.

Table 2: Reported landings (t) of blue warehou by Fishstock 1983–84 to present and actual TACCs (t) from 1986–87 to present. QMS data from 1986–present. [Continued on next page.]

Fishstock		WAR 1		WAR 2		WAR 3		WAR 7
FMA		1 & 9		2		3, 4, 5 & 6		7
	Landings	TACC	Landings	TACC	Landings	TACC	Landings‡	TACC
1983–84*	13	-	346	-	3 222	-	702	-
1984–85*	5	-	278	-	1 313	-	478	-
1985–86*	15	-	185	-	1 584	-	955	-
1986–87	7	30	190	480	1 330	3 210	780	910
1987–88	7	41	204	560	976	3 223	685	962
1988–89	12	41	177	563	672	3 348	561	969
1989–90	17	41	201	570	814	3 357	607	1 047
1990–91	14	41	250	570	2 097	2 528	758	1 117
1991–92	25	41	235	570	2 514	2 528	1 001	1 117
1992–93	15	41	199	578	2 310	2 530	539	1 120
1993–94	16	41	233	578	688	2 530	436	1 120
1994–95	15	41	203	578	1 274	2 530	468	1 120
1995–96	32	41	368	578	1 573	2 530	756	1 120
1996–97	24	41	563	578	1 814	2 531	1 428	1 120
1997–98	20	41	402	578	2 328	2 531	860	1 120
1998–99	15	41	503	578	1 978	2 531	1 075	1 120
1999–00	9	41	422	578	2 761	2 531	1 147	1 120
2000–01	12	41	388	578	1 620	2 531	1 572	1 120
2001–02	7	41	294	578	1 614	2 531	1 046	1 120
2002–03	5	41	429	578	3 514	2 531	961	1 120
2003–04	6	41	392	578	3 539	2 531	755	1 120
2004–05	6	41	402	578	2 963	2 531	756	1 120
2005–06	4	41	293	578	3 505	2 531	691	1 120
2006–07	4	41	235	578	3 326	2 531	823	1 120
2007–08	7	41	198	578	684	2 531	569	1 120
2008–09	9	41	210	578	2 021	2 531	733	1 120
2009–10	6	41	204	578	2 601	2 531	414	1 120
2010–11	11	41	102	578	2 086	2 531	633	1 120
2011–12	13	41	131	578	2 425	2 531	714	1 120
2012–13	8	41	172	578	1 847	2 531	632	1 120
2013–14	17	41	153	578	1 819	2 531	551	1 120
2014–15	24	41	123	578	2 674	2 531	823	1 120
2015–16	5	41	167	578	1 861	2 531	764	1 120
2016–17	14	41	143	578	2 357	2 531	875	1 120
2017–18	13	41	88	578	1 468	2 531	772	1 120
2018–19	7	41	45	578	2 063	2 531	763	1 120
2019–20	3	41	55	578	1 971	2 531	639	1 120
2020–21	3	41	35	578	1 374	2 531	601	1 120

Fishstock		WAR 8		WAR 10		
FMA		8		10		Total
	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	104	-	0	-	4 387	-
1984–85*	91	-	0	-	2 165	-
1985–86*	43	-	0	-	2 782	-
1986–87	40	210	0	10	2 347	4 850
1987–88	43	218	0	10	1 915	5 014
1988–89	44	231	0	10	1 466	5 162
1989–90	57	233	0	10	1 696	5 459
1990–91	113	233	0	10	3 232	4 499
1991–92	132	233	<1	10	3 905	4 499
1992–93	152	233	<1	10	3 215	4 512
1993–94	126	233	0	10	1 500	4 512
1994–95	114	233	0	10	2 074	4 512
1995–96	186	233	0	10	2 913	4 512
1996–97	161	233	0	10	3 990	4 513
1997–98	111	233	0	10	3 720	4 513
1998–99	168	233	0	10	3 739	4 513
1999–00	116	233	0	10	4 455	4 513
2000–01	143	233	0	10	3 735	4 513
2001–02	146	233	0	10	3 107	4 513
2002–03	192	233	0	10	5 101	4 513
2003–04	129	233	0	10	4 821	4 513
2004–05	157	233	0	10	4 284	4 513
2005–06	76	233	0	10	4 569	4 513
2006–07	59	233	0	10	4 448	4 513
2007–08	72	233	0	10	1 530	4 513
2008–09	146	233	0	10	3 119	4 513
2009–10	159	233	0	10	3 384	4 513
2010–11	92	233	0	10	2 924	4 512

Table 2 [Continued]

Fishstock		WAR 8		WAR 10		
FMA		8		10		Total
	Landings	TACC	Landings	TACC	Landings	TACC
2011–12	97	233	0	10	3 381	4 512
2012–13	111	233	0	10	2 770	4 512
2013–14	161	233	0	10	2 701	4 512
2014–15	69	233	0	10	3 713	4 512
2015–16	95	233	0	10	2 891	4 512
2016–17	59	233	0	10	3 448	4 512
2017–18	134	233	0	10	2 476	4 512
2018–19	50	233	0	10	2 929	4 512
2019–20	71	233	0	10	2 738	4 512
2020–21	28	233	0	10	2 041	4 512

* FSU data.

‡ Includes landings from unknown areas before 1986–87.

Catches have fluctuated in most stocks but overall the total landings have increased. In 2002–03, total reported landings of blue warehou were the highest on record, with catches in WAR 3 exceeding the TACC by 983 t. From 2002–03 to 2006–07 catches in WAR 3 were well above the TACC as fishers landed catches well in excess of ACE holdings and paid deemed values for the overcatch. From 1 October 2007 the deemed values were increased to $0.90 per kg for WAR 3 and WAR 7 stocks and differential rates were also introduced. The differential rate applied to all catch over 110% of ACE holding at which point the deemed value rate increased to $2 per kg. The effect of these measures was seen immediately in 2007–08 as fishing without ACE was reduced and catch fell well below the TACC in WAR 3. Landings subsequently increased again and exceeded the TACC slightly in 2009-10 and 2014-15. In all other areas landings are below the TACCs.

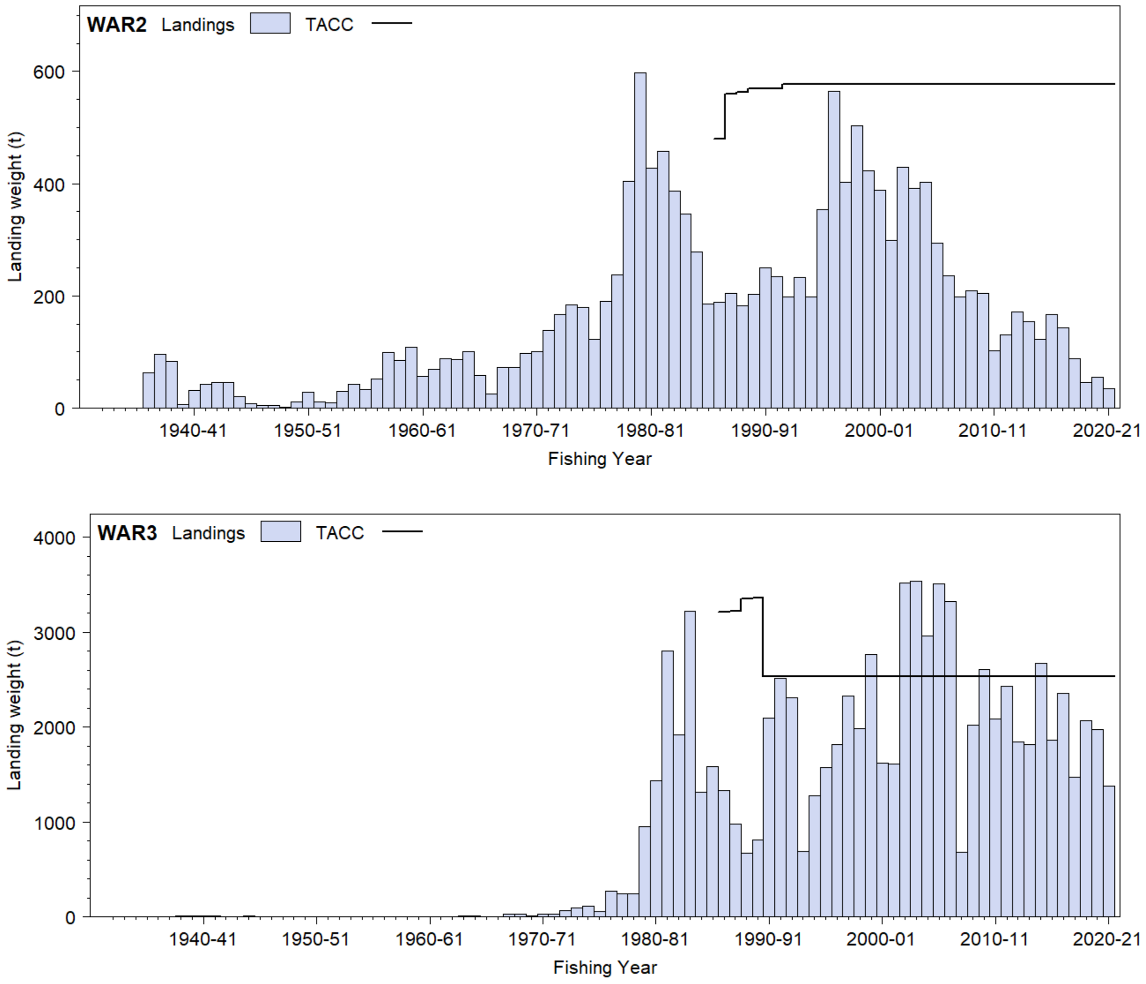
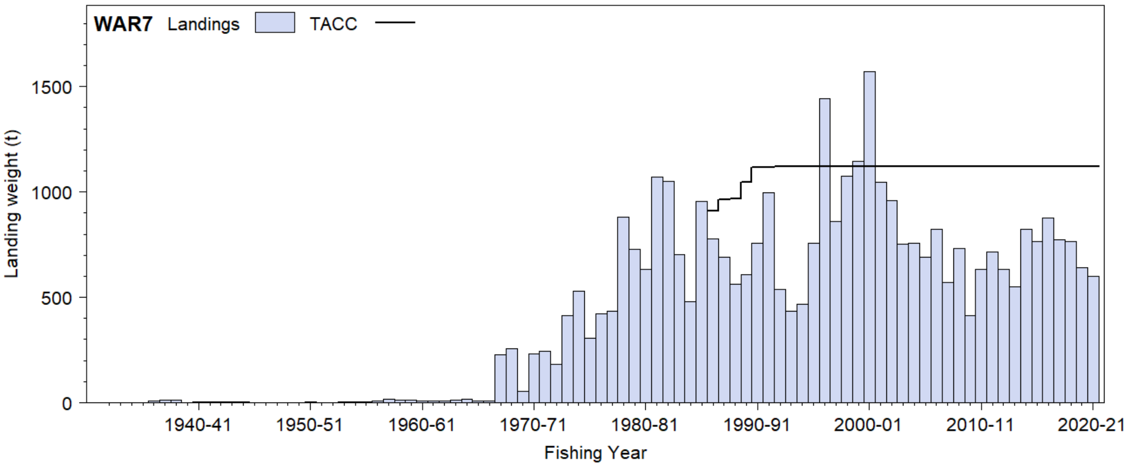


Figure 1: Reported commercial landings and TACC for the four main WAR stocks. WAR 2 (Central East) and WAR 3 (South East Coast) [Continued on next page].



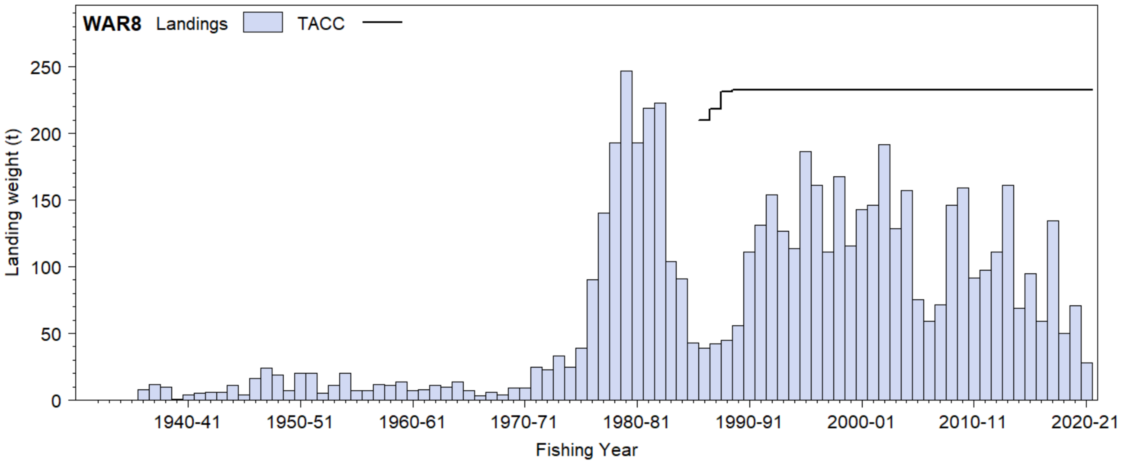


Figure 1 [Continued]: Reported commercial landings and TACC for the four main WAR stocks. WAR 7 (Challenger) and WAR 8 (Central Egmont).

1.2 Recreational fisheries

Estimates of recreational catch in the MAF Fisheries Central and South regions are shown in Table 3. Surveys in the North region in 1993–94 indicated that blue warehou were not caught in substantial quantities.

Table 3: Estimated harvest (t) of blue warehou by recreational fishers. Surveys were carried out in the MAF Fisheries Southern region in 1991–92 and in the Central region in 1992–93.

Fishstock	Survey	Estimated harvest	CV
1991–92			
WAR 3	Southern	10–20	-
1992–93			
WAR 2	Central	10.0	0.62
WAR 7	Central	1.7	0.65
WAR 8	Central	0.6	1.02

Blue warehou harvest estimates from the 1996 national survey were; WAR 2, 7000 fish; WAR 3, 3000 fish and WAR 7, 1000 fish. There are locally important fisheries which will not have been adequately sampled by these surveys.

The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 4 in numbers of fish (insufficient data are available to convert these numbers to catch weight). Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 4: Recreational harvest estimates for blue warehou stocks (Wynne-Jones et al 2014, 2019). Insufficient data on fish weights were obtained from boat ramp surveys to convert numbers caught to tonnes.

Stock	Year	Method	Number of fish	Total weight (t)	CV
WAR 2	2011–12	Panel survey	1 485	-	-
	2017–18	Panel survey	265	-	1.00
WAR 3	2011–12	Panel survey	483	-	-
	2017–18	Panel survey	206	-	1.00
WAR 8	2011–12	Panel survey	0	-	-
	2017–18	Panel survey	568	-	0.72

1.3 Customary non-commercial fisheries

No quantitative information is available on the current level of customary non-commercial take.

1.4 Illegal catch

No quantitative information is available on the level of illegal catch.

1.5 Other sources of mortality

No information is available on other sources of mortality.

2. BIOLOGY

Blue warehou average 40–60 cm fork length (FL) and reach a maximum of about 75 cm. Validated ageing of blue warehou shows rapid growth up to the time of first spawning (about 4–5 years), but negligible growth after about 10 years. Female blue warehou grow significantly faster and reach a larger size than males. Maximum recorded ages are 22 years for males, and 21 years for females. The best estimate of M is now considered to be 0.24 (Bagley et al 1998).

Blue warehou feed on a wide variety of prey, mainly salps but also euphausiids, krill, crabs and small squid.

Known spawning areas include the west coast of the South Island (in August–September), Kaikoura (in March, April, May), Southland (in November), and Hawke Bay (in September). Eggs are found in the surface plankton and juvenile fish are believed to occur in inshore areas.

Biological parameters relevant to the stock assessment are shown in Table 5.

Table 5: Estimates of biological parameters for blue warehou.

Fishstock							Estimate	Source
1. Natural mortality (M)								
WAR 3							0.24	Bagley et al (1998)
2. Weight = a(length)^b (Weight in g, length in cm total length).								
	Females			Males				
	a	b		a	b			
WAR 3	0.016	3.07		0.015	3.09			Bagley et al (1998)
3. Von Bertalanffy growth parameters								
	Females			Males				
	L_{∞}	k	t_0	L_{∞}	k	t_0		
WAR 3	66.3	0.209	-0.79	63.8	0.241	-0.46		Bagley et al (1998)
	Both Sexes							
WAR 1, 2, 7, 8 (part)	65.5	0.169	-1.35					Jones (1994)
WAR 8 (New Plymouth)	57.7	0.314	0.02					Jones (1994)

The seasonal pattern of landings suggest that there is a coastal migration of blue warehou. There is a winter/spring fishery for blue warehou at New Plymouth and north Wairarapa, a summer fishery with a small autumn peak at Wellington and a summer/autumn fishery along the east coast South Island. The west coast South Island has a fishery in August/September which picks up again in summer. There is a summer fishery in Tasman Bay.

3. STOCKS AND AREAS

No definite stock boundaries are known; however, Bagley et al (1998), after considering known spawning grounds and seasonal fishing patterns, suggested that there may be four stocks:

i. A southern population, mainly off Southland but perhaps extending into the Canterbury Bight. The main spawning time is November in inshore waters east and west of Stewart Island.
ii. A central eastern population, located on the northeast coast of the South Island and south east coast of the North Island (including Wellington), spawning mainly in the northern area in winter/early spring and also in autumn off Kaikoura.
iii. A south western population which spawns on the west coast of the South Island in winter.
iv. A north western population which may spawn off New Plymouth in winter/spring.

The proposed stock structure is tentative and there may be overlap between stocks. The available age and length frequency data are insufficient to compare by area and tagging studies have been minimal (about 150 fish tagged) with no returns.

For modelling WAR 3, the area on the east coast of the South Island south of Banks Peninsula including Southland was assumed to be a single stock. Movement between the west coast of the South Island and Southland is possible but there was no evidence for this from Southland seasonal trawl surveys. Also, the existence of two spawning periods, from August to September off the west coast of the South Island and from November to December in Southland, suggests two separate stocks.

4. STOCK ASSESSMENT

4.1 Estimation of fishery parameters and abundance

Biomass estimates are available from a number of early trawl surveys (Table 6) but the CVs are rather high for the *Shinkai Maru* data. From the age data from the *Tangaroa* Southland trawl surveys (1993–96) it appears that these surveys did not sample the population consistently, as apparently strong year classes did not follow through the time series of surveys.

Table 6: Trawl survey biomass indices (t) and coefficients of variation (CV) for recruited blue warehou.

Fishstock	Area	Vessel	Trip code	Date	Biomass (*t*)	CV (%)
WAR 3	Southland	*Shinkai Maru*	SHI8101	Jan–Mar 81	2 100	43
			SHI8201	Mar–May 82	800	62
			SHI8302	Apr–83	4 700	72
			SHI8601	Jun–86	2 000	59
WAR 3	Southland	*Tangaroa*	TAN9301	Feb–Mar 93	2 297	36
			TAN9402	Feb–Mar 94	1 629	38
			TAN9502	Feb–Mar 95	1 103	38
			TAN9604	Feb–Mar 96	1 615	40

4.2 Biomass estimates

Estimates of current and reference biomass are not available for any blue warehou Fishstocks.

4.3 Yield estimates and projections

MCY was estimated using the equation $MCY = cY_{AV}$ (Method 4) for all stocks. The value of c was set equal to 0.8 based on the revised estimate of M = 0.24 from the validated ageing work completed in 1997.

Auckland, Central (East) (WAR 1 and 2)
Average landings into Wellington over the period 1977 to 1983 were relatively stable at 300 t. Landings along the east coast of the North Island have shown large fluctuations. At Gisborne landings increased from 2 t in 1978 to 140 t in 1979 before declining to 2 t again in 1983. In Napier landings fluctuated from 1 t in 1960 to 87 t in 1972, decreased to less than 20 t in 1975 before peaking at 123 t in 1978 and then declining to 30–40 t. Y_{AV} for Central (East) (FMA 2) was estimated as 300–350 t.

$$\begin{aligned} MCY &= 0.8 \times (300\text{–}350\ t) \\ &= 240\text{–}280\ t \end{aligned}$$

South-east (south of Banks Peninsula), Southland, and Sub-Antarctic (WAR 3)
The catches from 1983–84 to 1985–86 were considered to be a sustainable level of catch. Y_{AV} = 2040 t

$$\begin{aligned} MCY &= 0.8 \times 2040\,t \\ &= 1630\ t \end{aligned}$$

Challenger (WAR 7)
The catches from 1983–84 to 1985–86 were considered to be a sustainable level of catch. Y_{AV} = 710 t.

$$\begin{aligned} MCY &= 0.8 \times 710\,t \\ &= 570\ t \end{aligned}$$

Central (West) (WAR 8)
The average domestic landings in the Central (West) zone from 1977 to 1983 were 70 t, and the average (declining) catch over 1983–84 to 1985–86 was 79 t. An *MCY* of 80 t is suggested for this area. New Plymouth has a peak seasonal catch in July, the season extending from June to September.

$$MCY = 80\ t$$

The level of risk to the stock by harvesting the population at the estimated *MCY* value cannot be determined.

CAY cannot be estimated because of the lack of current biomass estimates.

4.4 Factors modifying yield estimates
No information available.

5. STATUS OF THE STOCKS

Estimates of reference and current biomass are not available.

For all Fishstocks, it is not known if recent landings or TACCs are at levels which will allow the stocks to move towards a size that will support the maximum sustainable yield.

From 2002–03 to 2006–07 catches in WAR 3 were well above the TACC as fishers landed catches well in excess of ACE holdings. Deemed values were increased from 1 October 2007 and landings in WAR 3 in 2007–08 were much reduced to 684 t, well below the current TACC. WAR 3 landings have since increased to more than 2000 t.

6. FOR FURTHER INFORMATION

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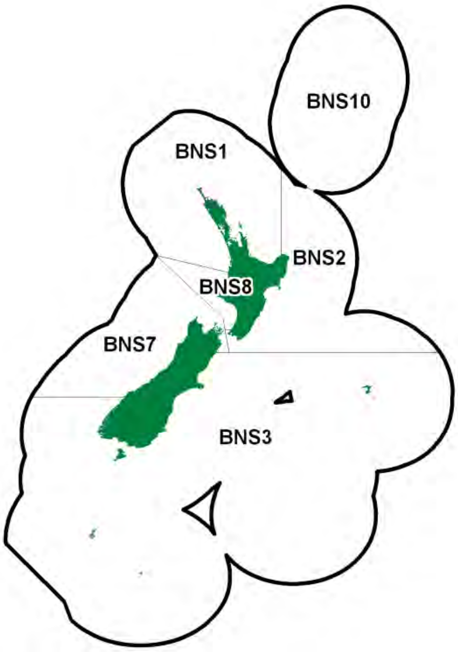
BLUENOSE (BNS)

(Hyperoglyphe antarctica)
Matiri



1. FISHERY SUMMARY

Bluenose were introduced into the QMS on 1 October 1986. A Total Allowable Catch (TAC) was set under the provisions of the 1983 Fisheries Act, initially at 1350 t. In 2010 new TACs were set for all BNS stocks along with recreational allowances, customary non-commercial allowances, and allowances for other sources of mortality. All current allowances, TACCs, and TACs are given in Table 1.

Table 1: Recreational and customary non-commercial allowances, TACCs, and TACs by Fishstock (t) for bluenose.

Fishstock	Recreational allowance	Customary allowance	Other mortality	TACC	TAC
BNS 1	15	2	8	230	251
BNS 2	25	2	9	247	279
BNS 3	18	2	3	93	114
BNS 7	3	2	2	34	40
BNS 8	2	1	1	16	20
BNS 10	–	–	–	10	10

1.1 Commercial fisheries

Bluenose have been landed since the 1930s, although the target line fishery for bluenose only developed in the late 1970s, with the trawl fishery off the lower east coast of the North Island developing after 1983, initially as a bycatch of the alfonsino fishery (Horn 1988a). The largest domestic bluenose fisheries occur in BNS 1 and 2. Historically, catches in BNS 2 were predominantly taken in the target alfonsino and bluenose trawl fisheries, but have been primarily taken by target bottom longline fishing in recent years. There is a target line fishery for bluenose in the Bay of Plenty and off Northland (both BNS 1). Target line fisheries for bluenose also exist off the west coast of the South Island (BNS 7) and the central west coast of the North Island (BNS 8). Bluenose in BNS 7 are also taken as bycatch in the hoki trawl and ling line fisheries. The BNS 3 fishery is focused on the eastern Chatham Rise where bottom longline catches were historically a bycatch of ling and hāpuku target fisheries. Target bluenose lining has predominated since 2003–04. There has been a consistent bycatch of bluenose in the alfonsino target bottom trawl fishery and bluenose have been targeted sporadically in a midwater trawl fishery in BNS 3 since the early 2000s. The bottom trawl fishery in BNS 3 has diminished. A small amount of target set net fishing for bluenose occurred in the Bay of Plenty until 1999 and again since 2012. Target bluenose set net fishing also occurs sporadically in the Wairarapa region of BNS 2. Set net catches off the east coast of the South Island have been a mix of target and bycatch in ling and hāpuku target sets. There was a dahn line fishery capturing between 9 and 65 tonnes/year of bluenose in Statistical Areas 031 and 032 (Fiordland) during the mid-1990s to the mid-2000s.

Reported landings and TACCs since 1981 are given in Table 2, and the historical landings and TACC for the main BNS stocks are depicted in Figure 1.

Table 2: Reported landings (t) of bluenose by Fishstock from 1981 to present and actual TACCs (t) from 1986–87 to present. QMS data from 1986 to present. [Continued on next page]

Fish stock	BNS 1		BNS 2		BNS 3		BNS 7		BNS 8	
FMA (s)	1 & 9		2		3, 4, 5 & 6		7		8	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1981*	146	–	101	–	36	–	12	–	–	–
1982*	246	–	170	–	46	–	22	–	–	–
1983†	250	–	352	–	51	–	47	–	1	–
1984†	464	–	810	–	81	–	30	–	1	–
1985†	432	–	745	–	73	–	26	–	1	–
1986†	440	–	1 009	–	33	–	53	–	1	–
1986–87	286	450	953	660	93	150	71	60	1	20
1987–88	405	528	653	661	101	166	104	62	1	22
1988–89	480	530	692	768	90	167	135	69	13	22
1989–90	535	632	766	833	132	174	105	94	3	22
1990–91	696	705	812	833	184	175	72	96	5	22
1991–92	765	705	919	839	240	175	62	96	5	22
1992–93	787	705	1 151	842	224	350	120	97	24	22
1993–94	615	705	1 288	849	311	350	79	97	27	22
1994–95	706	705	1 028	849	389	357	83	150	79	100
1995–96	675	705	953	849	513	357	140	150	70	100
1996–97	966	1 000	1 100	873	540	357	145	150	86	100
1997–98	1 020	1 000	929	873	444	357	123	150	67	100
1998–99	868	1 000	1 002	873	729	357	128	150	46	100
1999–00	860	1 000	1 136	873	566	357	114	150	55	100
2000–01	890	1 000	1 097	873	633	357	87	150	14	100
2001–02	954	1 000	1 010	873	+733	+925	70	150	17	100
2002–03	1 051	1 000	933	873	+876	+925	76	150	66	100
2003–04	1 030	1 000	933	873	915	925	117	150	96	100
2004–05	870	1 000	1 162	1 048	844	925	94	150	42	100
2005–06	699	1 000	1 136	1 048	536	925	84	150	20	100
2006–07	742	1 000	957	1 048	511	925	164	150	50	100
2007–08	585	1 000	1 055	1 048	660	925	145	150	53	100
2008–09	627	786	864	902	444	505	80	89	31	43
2009–10	665	786	845	902	419	505	94	89	36	43
2010–11	623	786	560	902	411	505	75	89	27	43
2011–12	417	571	431	629	256	248	94	89	20	43
2012–13	368	400	449	438	245	171	53	62	26	29
2013–14	382	400	435	438	248	171	60	62	28	29
2014–15	407	400	441	438	175	171	61	62	20	29
2015–16	344	400	386	438	172	171	52	62	7	29
2016–17	304	327	299	358	156	140	51	51	13	24
2017–18	208	230	267	247	139	93	38	34	4	16
2018–19	236	230	295	247	105	93	32	34	4	16
2019–20	199	230	289	247	96	93	29	34	4	16
2020–21	183	230	232	247	71	93	34	34	7	16

Fish stock	BNS 10			
FMA (s)	10		Total	
	Landings	TACC	Landings	TACC
1981*	0	–	295	–
1982*	0	–	484	–
1983†	0	–	701	–
1984†	0	–	1 386	–
1985†	0	–	1 277	–
1986†	0	–	1 536	–
1986–87	7	10	1 411	1 350
1987–88	10	10	1 274	1 449
1988–89	10	10	1 420	1 566
1989–90	0	10	1 541	1 765
1990–91	#12	#10	1 781	1 831
1991–92	#40	#10	2 031	1 837
1992–93	#29	#10	2 335	2 016
1993–94	#3	#10	2 323	2 023
1994–95	0	10	2 285	2 161
1995–96	0	10	2 351	2 161
1996–97	#9	#10	2 846	2 480
1997–98	#30	#10	2 613	2 480
1998–99	#2	#10	2 775	2 480
1999–00	#0	#10	2 731	2 480
2000–01	#0	#10	2 721	2 480
2001–02	#0	#10	2 784	3 048
2002–03	0	10	3 002	3 058
2003–04	0	10	3 091	3 058

Table 2 [Continued]

Fish stock	BNS 10			
FMA (s)	10		Total	
	Landings	TACC	Landings	TACC
2004–05	0	10	3 012	3 233
2005–06	0	10	2 475	3 233
2006–07	0	10	2 425	3 233
2007–08	0	10	2 498	3 233
2008–09	0	10	2 046	2 335
2009–10	0	10	2 059	2 335
2010–11	0	10	1 696	2 335
2011–12	0	10	1 218	1 590
2012–13	0	10	1 142	1 110
2013–14	0	10	1 153	1 110
2014–15	0	10	1 104	1 110
2015–16	0	10	960	1 110
2016–17	0	10	823	910
2017–18	0	10	656	630
2018–19	0	10	671	630
2019–20	0	10	616	630
2020–21	0	10	528	630

* MAF data.

† FSU data.

Includes exploratory catches in excess of the TAC.

+ An additional transitional 250 t of ACE was provided to Chatham Islands fishers, resulting in an effective commercial catch limit of 1175 t in 2001–02 and 2002–03.

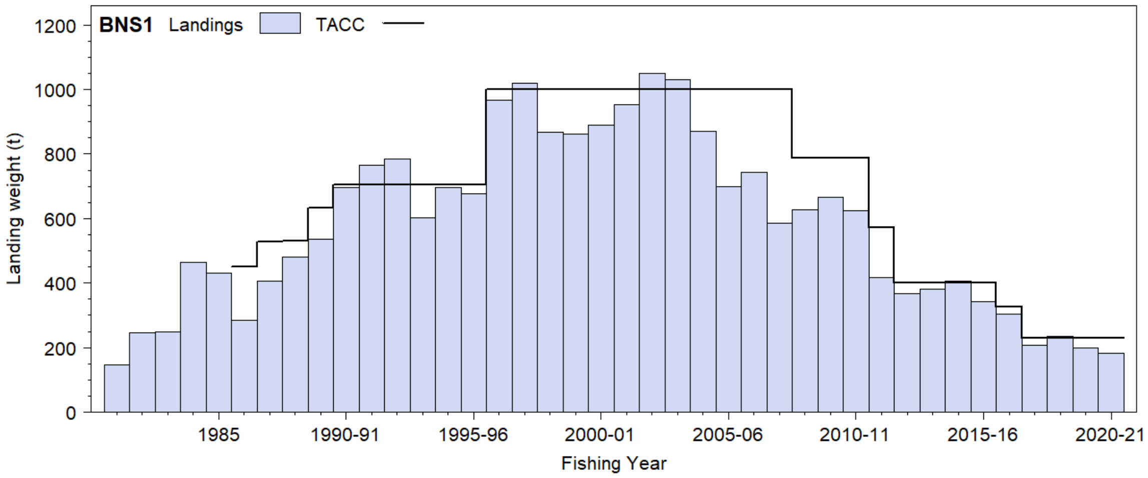
Bluenose landings prior to 1981 were poorly reported, with bluenose sometimes being recorded as bonita, or mixed with hāpuku/bass/groper, and foreign licensed and charter catches in the 1970s included bluenose catches as warehou and butterfish. Landings before 1986–87 have been grouped by statistical areas which approximate the current QMAs.

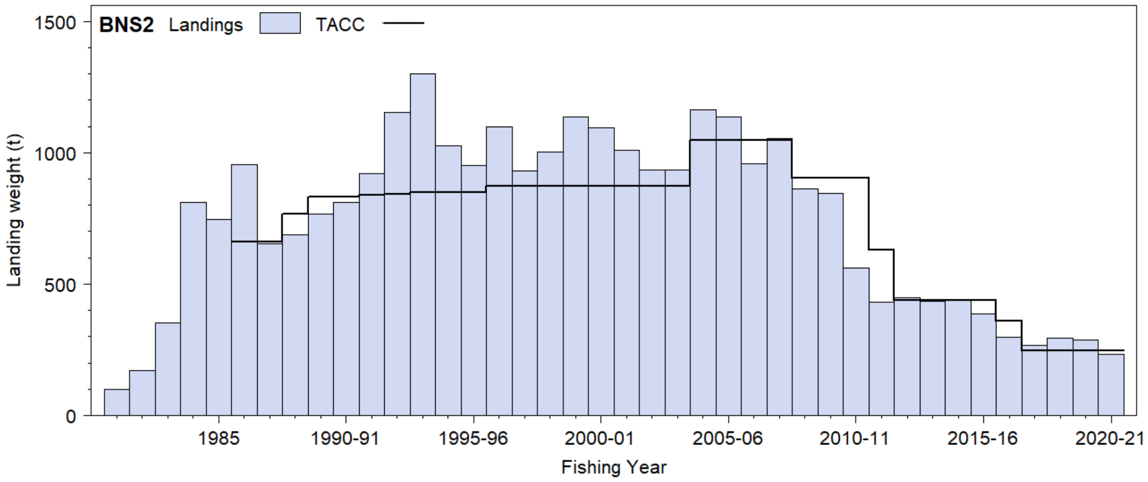
TACCs were first established for bluenose upon introduction to the QMS in 1986–87, with TACCs for all bluenose stocks totalling 1350 t. From 1992 to 2009 all bluenose fishstocks were included, for at least some of the time, in Adaptive Management Programmes (AMPs). BNS 3 was the first stock to enter an AMP in October 1992, with a TACC increase from 175 t to 350 t. This was further increased within the AMP to 925 t in October 2001, plus an additional transitional 250 t of ACE provided to Chatham Islands fishers in 2001–02 and 2002–03 only. BNS 7 (TACC increase from 97 t to 150 t) and BNS 8 (TACC increase from 22 t to 100 t) entered AMPs in October 1994. BNS 1, the second largest bluenose fishery, entered an AMP in October 1996, with a TACC increase from 705 t to 1000 t. BNS 2, the largest bluenose fishery, was the most recent entry into an AMP in October 2004, with a TACC increase from 873 t to 1048 t. TACCs for all bluenose stocks were reduced on 1 October 2008: 786 t (BNS 1), 902 t (BNS 2), 505 t (BNS 3), 89 t (BNS 7), and 43 t (BNS 8). AMP programmes were terminated on 30 September 2009.

Under a rebuild plan following the 2011 stock assessment, there have been further phased reductions to TACCs for bluenose stocks. On 1 October 2011, TACCs were reduced to: 571 t (BNS 1), 629 t (BNS 2), and 248 t (BNS 3); BNS 7 and BNS 8 were not reduced at that time. On 1 October 2012, TACCs were further reduced for all bluenose stocks to: 400 t (BNS 1), 438 t (BNS 2), 171 t (BNS 3), 62 t (BNS 7), and 29 t (BNS 8). The 2011 rebuild plan included a third phase of TACC reductions. For the 2016–17 fishing year, the Minister reduced the combined TACCs for bluenose stocks by 205 t as a further step towards ensuring the rebuild. He did not take stronger action because he wanted to provide the opportunity for a management procedure to be developed. As from October 2017, following the assessment being updated to include information up to the end of the 2015–16 year, the Minister noted that the stocks remained in a depleted state and he did not want to delay the rebuild any longer. Consequently, he reduced the TACCs for all BNS stocks further to ensure that BNS stocks rebuild towards the target at an appropriate rate consistent with the HSS guidelines.

As a result of the TACC increases under AMPs, the combined total TACC for all bluenose stocks increased from an initial 1350 t in 1986–87 to 3233 t by 2004–05. Reductions followed with the total TACC set to 1110 t by 2012–13, to 910 t in 2016–17, and finally to 630 t in 2017–18. Catch performance against the TACC has varied, with the combined TACC being under-caught by an average 9% (average landings 1504 t a year) over 1987–88 to 1990–91, over-caught by an average 11% (average landings 2501 t a year) over 1991–92 to 2000–01, and under-caught by an average 19%

(average landings 2180 t a year) from 2004–05 to 2011–12. More recently landings have fluctuated around the combined TACC, over-caught by an average of just 1% during 2012–13 to 2018–19.





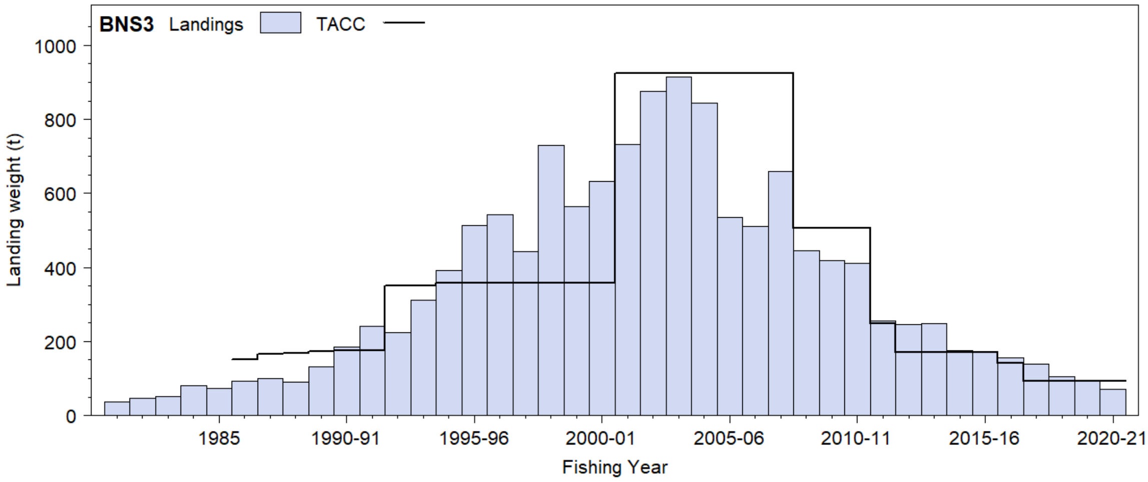
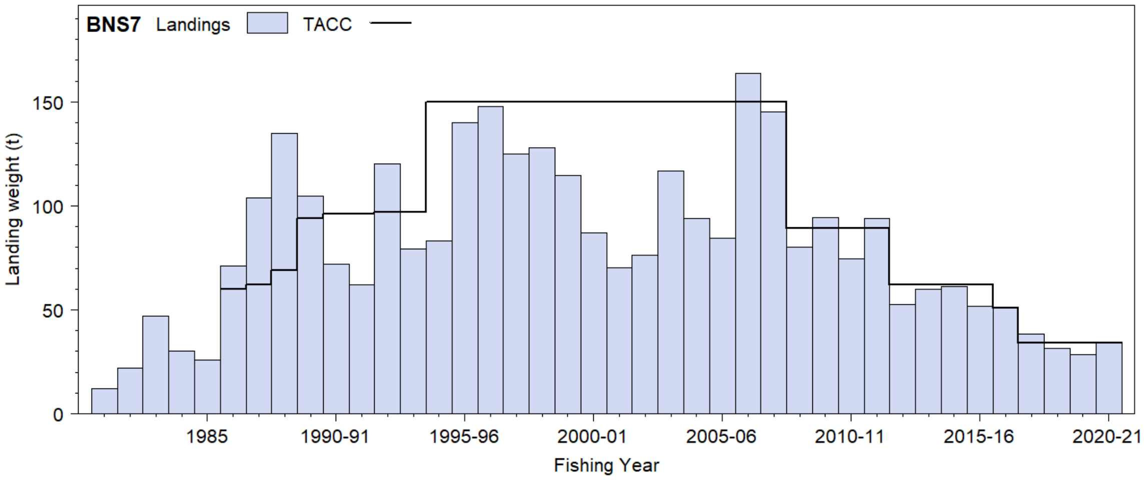


Figure 1: Reported commercial landings and TACC for the five main BNS stocks. BNS 1 (Auckland East), BNS 2 (Central East), BNS 3 (South East Coast) [Continued on next page]



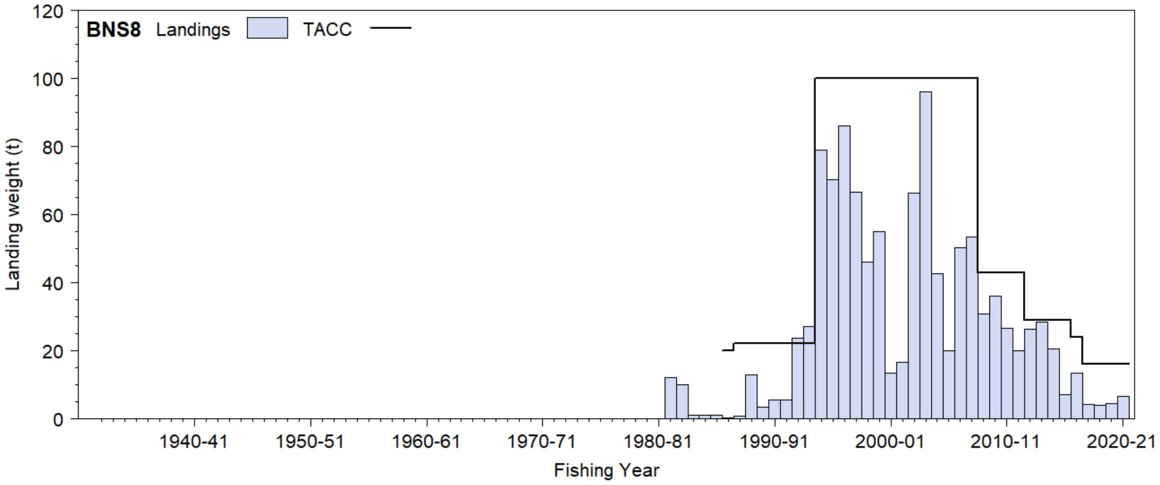


Figure 1: [Continued] Reported commercial landings and TACC for the five main BNS stocks. BNS 7 (Challenger), BNS 8 (Central Egmont).

1.2 Recreational fisheries

Bluenose is targeted by recreational fishers around deep offshore reefs. They are caught using line fishing methods, predominantly on rod and reel with some longline catch. The allowances within the TAC for each Fishstock are given in Table 1.

1.2.1 Management controls

From 2012 onwards the catch limit for recreational fishers in all areas has been up to 5 bluenose per person per day as part of their multi-species (combined) individual daily bag limit.

1.2.2 Estimates of recreational harvest

There are two broad approaches to estimating recreational fisheries harvest: the use of onsite or access point methods where fishers are surveyed or counted at the point of fishing or access to their fishing activity; and, offsite methods where some form of post-event interview and/or diary are used to collect data from fishers.

The first estimates of recreational harvest for bluenose were calculated using an offsite approach, the offsite regional telephone and diary surveys. Estimates for 1996 came from a national telephone and diary survey (Bradford 1998). Another national telephone and diary survey was carried out in 2000 (Boyd & Reilly 2002) and a rolling replacement of diarists in 2001 (Boyd et al 2004) allowed estimates for a further year (population scaling ratios and mean weights were not re-estimated in 2001). The annual recreational catch of BNS 1 was estimated from diary surveys to be 2000 fish in 1993–94 (Teirney et al 1997), 5000 fish in 1996 (Bradford 1998), and 11 000 fish in 1999–00 (Boyd et al 2004). The harvest estimates provided by these telephone/diary surveys are no longer considered reliable.

A new national panel survey was developed and was implemented in the 2011–12 fishing year (Wynne-Jones et al 2014). The panel survey used face-to-face interviews of a random sample of New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and catch information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 3. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 3: Recreational harvest estimates for bluenose stocks (Wynne-Jones et al 2014, 2019). Mean fish weights were obtained from boat ramp surveys; for bluenose the value used was 4.473 kg (Hartill & Davey 2015).

Stock	Year	Method	Number of fish	Total weight (t)	CV
BNS 1	2011–12	Panel survey	6 287	28.15	0.40
	2017–18	Panel survey	7 571	36.45	0.29
BNS 2	2011–12	Panel survey	444	1.99	0.48
	2017–18	Panel survey	1 298	6.12	0.43
BNS 3	2011–12	Panel survey	461	2.05	0.92
	2017–18	Panel survey	405	1.91	0.60
BNS 7	2011–12	Panel survey	456	2.02	1.00
	2017–18	Panel survey	355	1.67	0.60
BNS 8	2011–12	Panel survey	137	0.61	1.03
	2017–18	Panel survey	0	0	–

The recreational surveys indicate that the recreational harvest of bluenose is relatively small in areas other than BNS 1. There are some locally important fisheries which will not have been adequately sampled by the national panel survey.

1.3 Customary non-commercial fishing

No quantitative information on the level of customary non-commercial take is available.

1.4 Illegal catch

No quantitative information on the level of illegal catch is available.

1.5 Other sources of mortality

There have been reports of depredation by orca on bluenose caught by line fisheries.

2. BIOLOGY

Depth distribution

The depth distribution of bluenose extends from near-surface waters to about 1200 m. Research trawl surveys record their main depth range as 250–750 m, with a peak at 300–400 m, and they regularly occur to about 800 m (Anderson et al 1998). Commercial catches recorded in logbook programmes implemented for some of the bluenose stocks under AMPs, and catch-effort data for these fisheries, confirm that bluenose catches range in depth from less than 100 m to about 1000 m, depending on target species, but with a peak around 400 m for bluenose targeted fishing by any method.

The depth distribution of bluenose changes with size, with small juveniles known to occur at the surface under floating objects (Last et al 1993, Duffy et al 2000). Larger juveniles probably live in coastal and oceanic pelagic waters for one or two years. Fish 40–70 cm in length are caught between 200 m and 600 m, whereas larger fish, particularly those larger than 80 cm, are more often caught deeper than 600 m. A sequential move to deeper waters as bluenose grow has been confirmed by analysis of the stable radio-isotope ratios in otolith sections. Oxygen isotope ($\delta^{18}O$) ratios of bluenose otolith cores confirm residence of juvenile fish within surface waters. Changes in oxygen isotope ratios across otolith sections indicate changes in preferred mean depth with age of each fish (Horn et al 2008). That study hypothesised that the larger adults may be distributed below usually fished depths on underwater topographic features, but potentially available to fisheries as a result of regular vertical feeding migrations. The largest adults appear to reside in 700–1000 m; i.e., deeper than where most trawl or longline fishing for bluenose occurs. However, adult bluenose are also known to associate closely with underwater topographic features (hills and seamounts). Bluenose may undertake diurnal migrations into shallower depths to feed.

Age, growth, and natural mortality

Biological parameters for bluenose are summarised in Table 4. Recent ageing validation work by Horn et al (2008, 2010) substantially revised estimates of maximum age- and size-at-maturity for bluenose which were previously considered to be moderately fast growing (Horn 1988b). Radiocarbon (^{14}C) levels in core micro-samples from otoliths that had been aged using zone counts were compared with a bomb-radiocarbon reference curve which provided independent estimates of the age of the fish.

Table 4: Estimates of biological parameters for bluenose. Growth parameters from Dunn et al (2021) were used in the stock assessment, but only for ages five and older; growth for younger fish was assumed to be linear between the length at age five and t = -0.5.

Fishstock						**Estimate**	**Source**
1. Natural mortality (M)							
BNS						0.07–0.14	Horn & Sutton (2011)
2. Weight = a(length)^b (Weight in g, length in cm fork length).							
						Both sexes	
BNS 2				a = 0.00963		b = 3.173	Horn (1988a)
3. Von Bertalanffy growth parameters							
			Females			Males	
	K	t_0	L_∞	K	t_0	L_∞	
BNS 2	0.071	-0.5	92.5	0.125	-0.5	72.2	Horn et al (2010)
BNS 2	0.019	-20.9	120.4	0.046	-15.0	79.4	Dunn et al (2021)
3. Age at maturity (50%)							
			Females			Males	
a_{50} (a_{to95})			17 (11)			15 (6)	Horn & Sutton (2011)

Horn & Sutton (2010) estimated a maximum age of 71 years for bluenose from line fisheries in BNS 1. This maximum age is consistent with the maximum age of 85 years estimated for the closely related barrelfish (*Hyperoglyphe perciformis*) in the western North Atlantic, also determined, in part, using the bomb chronometer method (Filer & Sedberry 2008). Previous under-estimates of bluenose ages appear to have resulted from the incorrect interpretation of paired, fine ‘split rings’ as single growth zones, when they probably represent two separate growth zones. Horn & Sutton (2010) concluded M for bluenose would likely be in the range 0.09–0.15, based on 1% of the unfished population living to 30–50 years. However, they also noted that the true M for bluenose could be even lower than 0.09 given that the maximum recorded age was 71 years, and that old bluenose may be poorly sampled by the line fishery.

Horn & Sutton (2011) recorded a maximum age of 76 years for bluenose from trawl fisheries in BNS 2 and estimated total mortality (Z) to be in the range 0.11–0.26. Because bluenose had been only lightly exploited before the samples were taken (1984–86), these estimates of Z could be considered as reasonable proxies for natural mortality (M) because F would be very small. However, the Z estimates at the high end of the range are clearly inappropriate as M values for a species with a maximum age in excess of 50 years. Because of problems in obtaining a representative age sample of the population, Horn & Sutton (2011) favoured M estimation methods based simply on observed longevity. They concluded that a plausible range for M would be 0.07 to 0.14, with 0.10 as the best point estimate.

Previous stock assessments assumed an M of 0.08 as the best point estimate. From the range of estimates resulting from ageing, the working group concluded that M for bluenose was unlikely to be greater than 0.1. The M assumed in historical stock assessments was consequently 0.06, 0.08, or 0.1.

Maturity and reproduction

Little is known about the reproductive biology of bluenose. Maturity ogives derived from aged bluenose caught in BNS 1 from January to May indicated that ages at 50% maturity were about 15 and 17 years for males and females, respectively (Horn & Sutton 2011). Data from commercial logbook programmes implemented under AMPs indicate that bluenose sampled in QMAs 1, 3, 7, and 8 matured at between 60 cm and 65 cm. Analysis of gonad maturity stage proportions for bluenose sampled by Fisheries New Zealand observers and commercial logbook programmes, primarily in BNS 1, 7, and 8, indicate that spawning takes place over an extended period but peaks from February to April annually. No distinct spawning grounds have been described for bluenose in New Zealand waters. Most reproductively active fish have been sampled from locations in the Bay of Plenty, and in smaller numbers from several locations around the North Island, from northwest of Taranaki to East Cape, and off the south west coast of the South Island (Dutilloy et al 2020).

3. STOCKS AND AREAS

Stock boundaries are unknown, but similarity in trends in catch and CPUE across fisheries occurring in each of the five New Zealand BNS QMAs suggests the possibility that there may be a single BNS stock across all these areas, or of some close relationship between stocks in these QMAs. Tagging studies have shown that bluenose are capable of extensive migration, i.e., from the Wairarapa coast to Kāikoura, Bay of Plenty, and North Cape (Horn 2003). There is a possibility that the long period of relatively stable CPUE observations in the face of increasing catches before the period of decline may be evidence of hyper-stability caused by the replenishment of adult stocks on specific areas or features. Increases in BNS targeting in some areas, and increasing catches, could have exceeded the replenishment rate and caused the rapid and largely synchronous declines observed from about 2001–02 to 2011–12. Alternatively, there could be a simultaneous drop in recruitment due to coincident environmental factors. An environmental mechanism simultaneously affecting availability or catchability of BNS across all QMAs is considered to be less likely than the possibility of a single stock, or of correlated recruitment across sub-stocks in the various areas.

Analyses of length samples from research surveys and commercial catches indicated the smallest bluenose (predominantly juveniles) had been caught in relatively shallow water (shallower than 445 m) off the east coast of central and northern New Zealand, from Chatham Rise to East Northland, and the largest bluenose were caught off the south of the South Island and in the more northern parts of BNS 1 and in BNS 10 (Dutilloy et al 2020). Bottom longlines caught both the largest, and smallest, fish observed. Particle tracking studies, assuming that juvenile bluenose drift passively in ocean surface currents for the first year of life, suggested juveniles from spawning locations on both coasts of the North Island would accumulate on the east coast of central and northern New Zealand (Dutilloy et al 2020). Particles released off the west and south coasts of the South Island were predominantly retained in that area. Genetic analyses for the allied species hāpuku (*Polyprion oxygeneios*) found differences between fish from waters west of the South Island, and those from around the North Island and east of the South Island (Lane et al 2016). CPUE models were offered alternative spatial areas (to explain variability in bottom longline catch rates) and accepted the nine relatively fine-scale areas identified by Bentley (Bentley unpublished), but rejected other splits including separation of the west and south coast of the South Island from the rest of New Zealand (Dutilloy et al 2020). A single stock of bluenose around New Zealand remains most likely, although division into two stocks, separating the west and south coast of the South Island from the rest of New Zealand, remains possible.

4. STOCK ASSESSMENT

The most recent stock assessment modelling for bluenose was conducted in 2021. The model was implemented in the general-purpose Bayesian stock assessment program Casal2 V1.0.0 (CASAL2 Development Team 2021), with functionality added to allow fitting of weight composition data.

4.1 Methods

Model structure
The age-based model assumed a single New Zealand stock of bluenose, partitioned into two sexes, with 61 age groups (1–61 years with a plus group), and without maturity in the partition. The model had a single time step, four year-round fisheries (three line and one trawl), and mid-fishing-year

spawning. The stock was assumed to be at B_0 in 1915. All fishery and biological parameters were assumed to be constant. Recruitment was assumed to be deterministic with the Beverton and Holt stock recruit relationship.

The base model included two areas in the partition, a 'background' area where recruitment and the trawl fishery took place, and a 'features' area where the bluenose target line fisheries took place (Table 5). Fish were assumed to move from the background to the features at a constant rate-at-age (same rate for each age), which was estimated by the model. The rate parameter controls with partitioning of biomass between the two areas and, with catches partitioned by area, allows the biomass to potentially decline at different rates within each area.

Table 5: Bluenose 2021 stock assessment assumed fisheries, model area, total catch (1936–2021; assuming 'Mid' catches before 1990, see Table 6), selectivities, what composition data were used (LF, length frequency; AF, age frequency; WF, weight frequency), and whether CPUE indices were available. * Selectivity for East Northland, and Bay of Plenty and East Cape, were estimated to be similar and set to be the same in all final model runs.

Fishery	Area	Total catch (t)	Selectivity	Composition data	CPUE indices
Trawl	Background	22 870	Logistic	AF, and Observer LF	Yes
East Northland longline	Features	12 780	Double normal*	WF	Yes
Bay of Plenty & East Cape longline	Features	14 390	Double normal*	AF and WF	Yes
Wairarapa longline	Features	7 470	Double normal	WF	Yes
Other longline	Background	19 630	Logistic	WF	No

Data

The catch history in the model starts in 1936 when some bluenose were landed as groper or hāpuku. The main uncertainty in the catch history is the foreign catch just prior to the implementation of the EEZ in 1978. Foreign vessels recorded bluenose catch within mixed species groups, typically as part of a general warehou category. Catch data in the early 1980s were used to estimate the likely proportion of bluenose within a mixed warehou and bluenose group. Where possible, this was done on an area-specific basis and the proportions were applied to the pre-EEZ mixed species catches. Due to the uncertainties in species attributions mentioned above, alternative bluenose proportions were used to construct three alternative catch histories: low, mid (the base assumption), and high (Table 6).

The catch histories for the line and trawl fisheries from 1989–90 to 2006–07 were derived from the bluenose characterisations conducted for the 2008 AMP review. From 2007–08 onwards, the total recorded catch was split between line and trawl fisheries in roughly the same proportion as the catches from the 2006–07 year. The 2020–21 catch was assumed to be the same as that in 2019–20. Recreational and illegal catch were assumed to be zero.

Twelve standardised CPUE indices were fitted as indices of abundance. These were a single trawl bycatch index for 1989–90 to 2019–20 (bycatch in alfonsino, bluenose, and hoki target fishing), and eleven bottom longline bluenose target indices, which covered consistently fished features off (a) east Northland, (b) Bay of Plenty and East Cape, and (c) Wairarapa. The bottom longline indices were estimated for 1995–2002, 2003–2007, 2008–2012, and 2013–19. The index for Wairarapa for 1995–2002 was excluded because of insufficient data. Data prior to 1995 were excluded because of a potential bias in CPUE caused by the introduction of GPS in the early 1990s, and 2020 was excluded because concerns about potential biases following the widespread introduction of electronic reporting (which the WG considers can be resolved). The split between 2002 and 2003 was introduced because of the introduction of 3-D mapping around 2002, which was believed to have increased catch rates. The split between 2007 and 2008 was introduced because of a change in catch reporting forms. The split between 2012 and 2013 was introduced because the TACC reduction was believed to have modified fisher behaviour. An additional CV of 10–20% was added to the estimated lognormal error CVs for the CPUE indices, because they were considered unrealistically low (as is typical for indices estimated using a GLM approach). A CPUE series based on BNS catches in the HPB (hāpuka/bass) target longline fishery, was generated but not fitted. This series is assumed to index relative abundance of the background area and showed a similar trend to the trawl series. An alternative trawl index, estimated from alfonsino and bluenose target fishing only, was also used as a sensitivity.

Table 6: The three alternative catch (t) histories used in the BNS assessment model runs. Trawl catch prior to 1970 was assumed to be zero. Year represents fishing year (i.e., 2020 is the 2019–20 fishing year).

		Line				Line				Trawl	
Year	Low	Mid	High	Year	Low	Mid	High	Year	Low	Mid	High
1936	0	75	150	1963	0	59	119				
1937	0	75	150	1964	0	66	133				
1938	0	75	150	1965	0	64	128				
1939	0	75	150	1966	0	61	123				
1940	0	56	112	1967	0	65	129				
1941	0	50	100	1968	0	57	113				
1942	0	50	100	1969	0	55	111				
1943	0	50	100	1970	0	70	140	1970	0	0	0
1944	0	50	100	1971	0	69	138	1971	0	0	0
1945	0	50	100	1972	0	59	118	1972	0	45	78
1946	0	69	138	1973	0	63	126	1973	0	42	72
1947	0	75	150	1974	0	69	137	1974	0	68	117
1948	0	81	162	1975	111	182	252	1975	0	116	204
1949	0	95	189	1976	618	692	767	1976	0	112	211
1950	0	89	177	1977	821	913	1 004	1977	0	385	1 505
1951	0	74	147	1978	1	81	161	1978	0	0	0
1952	0	71	142	1979	9	92	176	1979	0	0	0
1953	0	70	141	1980	15	98	180	1980	0	0	0
1954	0	69	137	1981	235	300	365	1981	0	0	0
1955	0	66	132	1982	469	511	554	1982	0	0	0
1956	0	69	138	1983	730	755	780	1983	0	0	0
1957	0	69	138	1984	951	956	962	1984	324	324	324
1958	0	75	149	1985	1 013	1 013	1 013	1985	372	372	372
1959	0	68	137	1986	982	982	982	1986	605	605	605
1960	0	62	124	1987	744	744	744	1987	667	667	667
1961	0	60	121	1988	752	752	752	1988	522	522	522
1962	0	59	118	1989	797	797	797	1989	623	623	623

For all three catch histories

Year	Trawl	Line	Year	Trawl	Line
1990	730	808	2006	679	1 796
1991	572	1 204	2007	379	1 995
1992	559	1 472	2008	374	2 124
1993	721	1 590	2009	301	1 745
1994	870	1 450	2010	418	1 641
1995	841	1 443	2011	379	1 317
1996	793	1 558	2012	213	1 005
1997	1 061	1 690	2013	146	995
1998	814	1 732	2014	174	979
1999	860	1 867	2015	171	933
2000	983	1 693	2016	165	796
2001	1 118	1 589	2017	122	701
2002	1 393	1 374	2018	117	539
2003	1 294	1 642	2019	135	537
2004	934	2 157	2020	123	493
2005	1 069	1 943			

Observer length samples were used to construct annual length frequencies for the trawl fisheries for each year when there were more than 1000 fish measured (1997–98 to 1999–2000). For each sample, the length frequency was scaled to the numbers of fish in the sampled catch. Catch-weighted samples were then combined with no further scaling or stratification.

Fifteen age frequencies were fitted: three from trawl caught fish on the Palliser Bank, for the fishing years 1984–85, 1985–86, and 1986–87; and twelve for line caught fish in the Bay of Plenty and East Northland, for the fishing years 1996–97 to 2000–01, 2004–05 to 2006–07, and 2013–14 to 2016–17. Age samples were assumed to be random and scaled by catch. The age frequencies were the most direct estimates of selectivity-at-age and consequently were given higher effective sample sizes than the length and weight frequencies.

Weight compositions for bottom longline fisheries were also available from three Licensed Fish Receivers, derived from data on the number and total weight of bluenose in each pack sold. Data covered the same areas as assumed for CPUE analyses: east Northland (1997–98, 1998–99, and 2000–01 to 2019–20); Bay of Plenty and East Cape (2000–01 to 2002–03, 2004–05 to 2019–20); Wairarapa (2006–07, 2007–08, and 2012–13 to 2015–16); and also the west coast South Island (2015–16 to 2017–18; used to inform selectivity for all longline catches other than off the east coast North Island). The weight compositions were derived from mean weight data, which resulted in a spiky and variable appearance. Simulation exercises indicated that spikes were expected as a result of the way the pack data were collected. Although Casal2 was extended to account for the averaging of weights, the true statistics of the sample compositions were not known (such as the range of fish lengths that could occur in each pack), and these data could only be roughly fitted by the model.

All composition data were fitted assuming multinomial errors, with effective sample sizes scaled in accordance with observed sample sizes, then reduced to give primacy to fitting the CPUE indices. The length, age, and weight composition observations were often inconsistent from year-to-year and vary substantially on small spatial and temporal scales. Therefore, when evaluating model fits, the most importance was given to broadly capturing the shape of the frequency distributions, so that the age composition of catch removals would be approximately correct. The available composition data are inadequate to allow reasonable estimation of variation in year class strengths.

Fixed and estimated parameters

The estimated parameters were B_0 (uniform-log prior), logistic selectivity for the trawl fishery (two parameters), logistic selectivity for the east Northland, and Bay of Plenty and East Cape, CPUE and fisheries (two parameters), domed-selectivity for the Wairarapa CPUE and fishery (three parameters), logistic selectivity for other longline fisheries (two parameters), and the migration rate from background to features (one parameter). Priors on all parameters other than B_0 were uniform. Catchabilities (qs), for fitting the CPUE indices, were estimated as nuisance parameters.

The fixed parameters were year class strengths (i.e., recruitment was deterministic), growth, logistic maturation, stock-recruitment steepness (h), and natural mortality rate (M). The reference model assumed $M = 0.08$ yr^{-1} and $h = 0.84$.

Growth used empirical data of length at age rather than using the von Bertalanffy parameters (Table 4), because the latter did not adequately fit the observed pattern of length-at-age. The variability of length at age was assumed normal with CV = 7%, and variability of weight-at-length normal with CV = 10%. A normal ageing error with CV = 10% was assumed.

Model parameters were initially estimated as MPD, with MCMC used for final model runs.

Assessment runs

The working group agreed to present results from four final model runs; (1) a base model run, (2) a run assuming lower steepness (0.6), (3) a run excluding the weight composition data, and (4) a model run assuming a single area rather than two areas.

When the weight composition data were excluded, the selectivities were estimated from age and observer length frequency data only, and the Wairarapa longline fishery was set equal to that estimated for the Bay of Plenty and East Cape fishery, and the other longline selectivity set equal to the trawl fishery (the selectivity a_{50} for the Other Longline fishery being closer to the Trawl than Bay of Plenty & East Cape estimates in the two-area model).

The sensitivity model run assuming a single area used the same data, data weighting, and assumptions as the two-area base model run, except that the trawl fishery and CPUE had a double normal selectivity, and the Wairarapa longline fishery and CPUE had a logistic selectivity.

4.2 Results

The decline in standardised CPUE for the Bay of Plenty and East Cape, and east Northland, fisheries was almost twice that seen in the trawl fishery (Figure 2). Not all trends in the CPUE series were fitted well by the model. The best fit was to the east Northland indices, and the poorest to the Bay of Plenty and East Cape indices. The decline in Wairarapa CPUE, and Bay of Plenty and East Cape CPUE, between 2003 and 2007 was greater than could be explained by the catches. Fits to the CPUE series were constrained by the assumption of deterministic recruitment. The CPUE indices for the longline fisheries all indicated a biomass increase over the last three years, whereas a decline was seen in the trawl fishery.

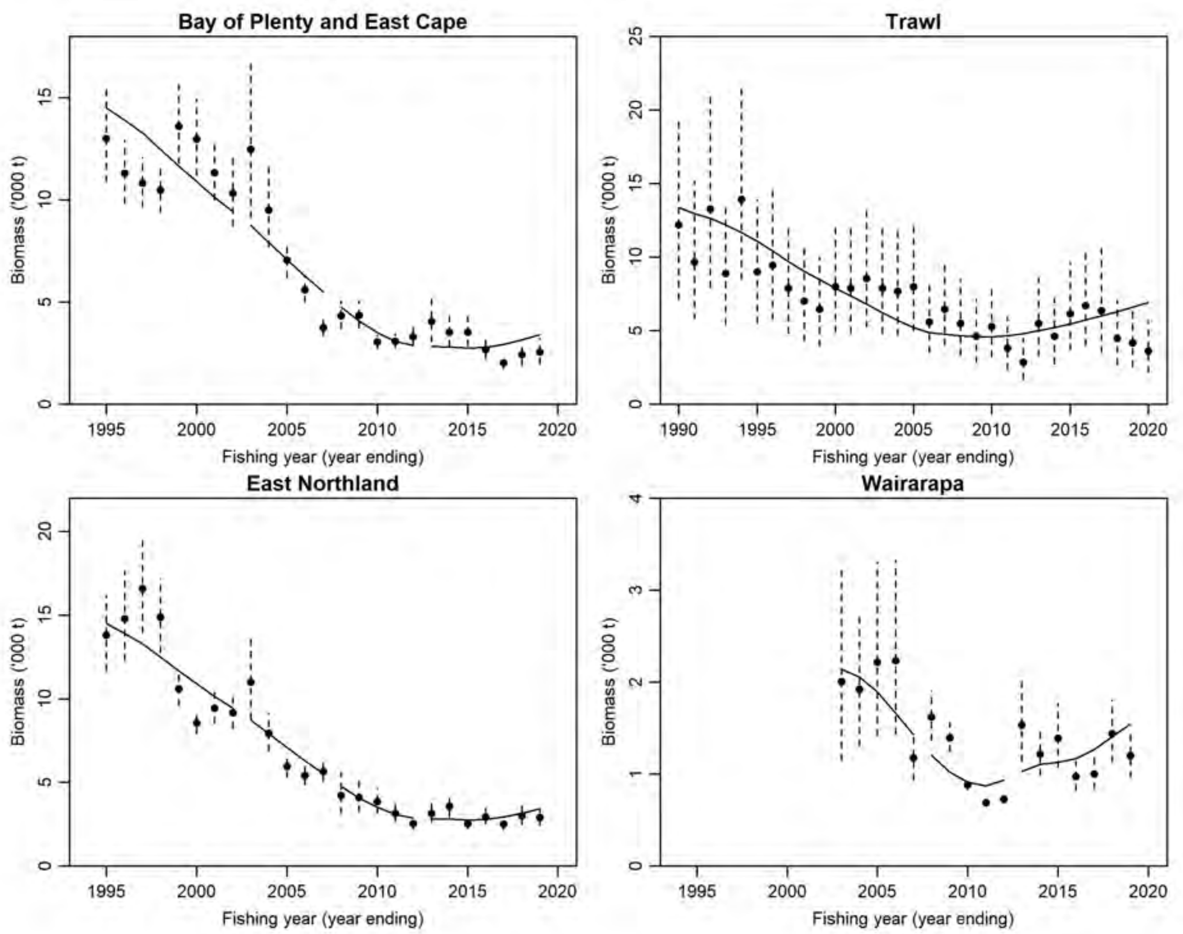


Figure 2: Bluenose CPUE indices (points, vertical broken lines indicate 95% CI) and base model run MPD fits (lines).

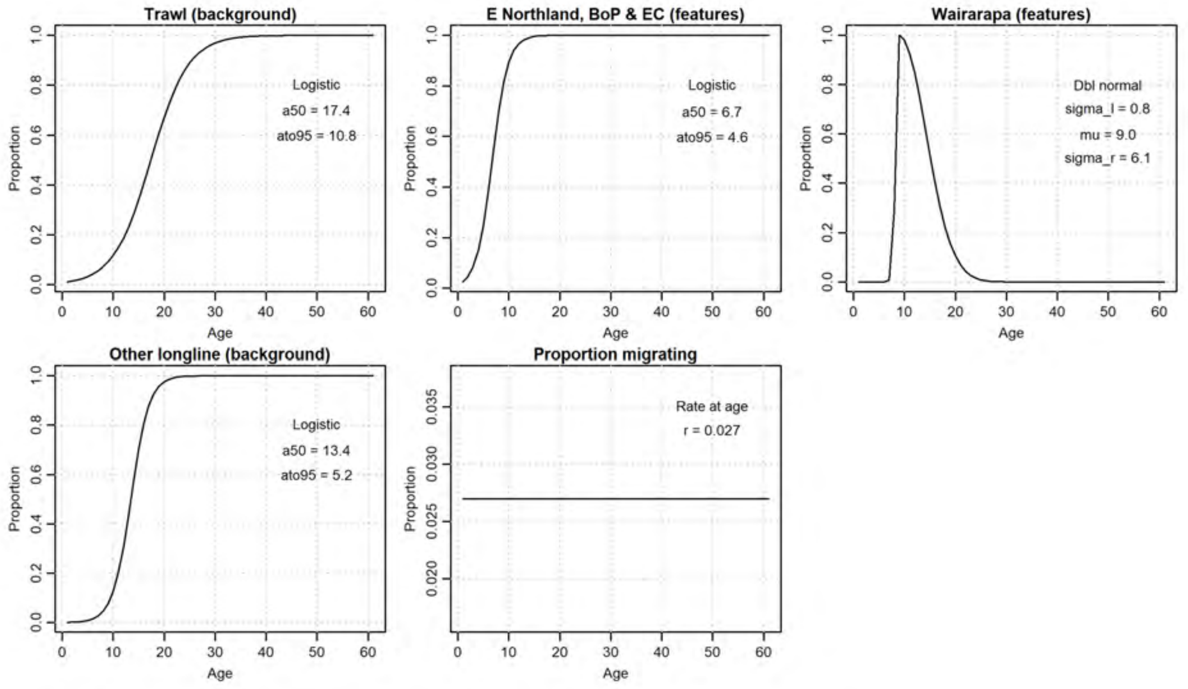


Figure 3: Bluenose estimated fishing selectivities and migration rate for the trawl and longline fisheries for the base model MPD run.

The youngest bluenose were taken by the Wairarapa longline fishery, then East Northland and Bay of Plenty and East Cape longline fisheries, then other longline fisheries (predominantly BNS 7 and BNS 3), and then the trawl fishery (Figure 3).

The model estimated age compositions for the catches that fitted the observations about as well as could be expected given the inconsistent shape of the age frequencies in the consecutive years (Figure 4). The base model run generally over-estimated the proportion of old fish in the plus group. The fits to the weight composition data were similarly variable, and those to the length frequencies were good.

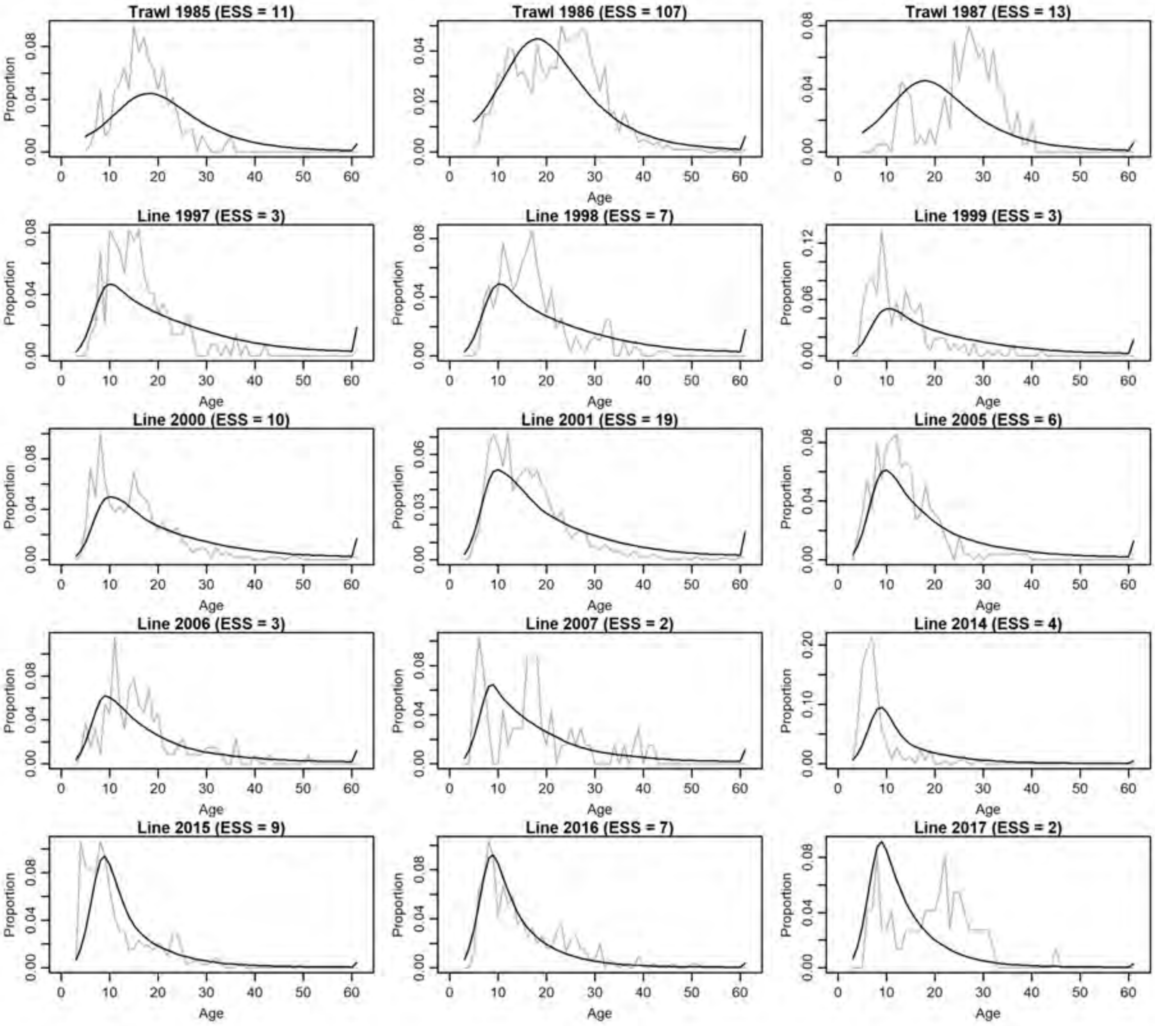


Figure 4: Bluenose observed age frequency samples (grey lines) and base model MPD fits (black lines) for the base model run. The model fit is focused on samples with higher effective sample sizes; effective sample sizes (ESS) are given in parentheses.

Sensitivity runs

A wide range of model sensitivity runs were completed. The assessment was particularly sensitive to natural mortality rate and stock-recruitment steepness. When a higher *M* was assumed (0.1 yr^{-1}) the stock was estimated to be smaller and less depleted and the fit to the composition data was improved (the proportion in plus group noticeably reduced), but the fit to the recent CPUE indices worsened. The reverse was obtained when a lower *M* (0.06 yr^{-1}) was assumed. When steepness was lower than the base case, the rate of the biomass rebuild was reduced, and the fit to the most recent CPUE indices improved, but the fit to the composition data worsened. The assessment model was less sensitive to changes in the shape of the selectivity ogives, alternative trawl CPUE indices, alternative catch histories, and whether the weight composition data were included.

When a single area was assumed, the spawning stock was estimated to have a similar B_0 but to be less depleted. This is most likely because the selectivity for the ‘features’ fishery was shifted towards older fish, primarily to reduce the vulnerable biomass to better fit the longline CPUE indices, but in doing so also reducing the vulnerable proportion of the *SSB*.

Final model runs

For the base model, and the selected sensitivity runs, MCMC diagnostics were acceptable. Although the stock size and status were relatively well determined (Table 7), some of the selectivity parameters had wide CI, most likely because of the inconsistencies in the composition data being fitted. Including the weight composition data reduced the uncertainty in longline selectivity parameters.

All model runs were indicative of a B_0 around 39 000 t, and current stock status close to, or just above, the soft limit and rebuilding. The base, excluding weight composition, and one area model runs, indicated a persistent *SSB* decline followed by a rebuild starting in 2012–13 (Figure 5). The lower steepness run estimated a *SSB* rebuild starting in 2013–14. The rate and timing of the rebuild in vulnerable biomass varied with the area and selectivity of the fishery (see Figure 2).

For the base model, there was a 97% probability that the stock was above 20% B_0 in 2021. For the sensitivity runs, the probability of being above 20% B_0 in 2021 was between 62% (lower steepness), and 100% (one area). For all model runs, the probability of being above the hard limit was 100%.

Table 7: Bluenose, MCMC estimates of virgin biomass (B_0), and stock status (B_{2021} as % B_0), with 95% CI in parentheses, for the base model and three sensitivity runs. Probability of being above the assumed target (40% B_0), soft limit (20% B_0) and hard limit (10% B_0) estimated from MCMC.

Model run	B_0 (000 t)	B_{2021} (%B_0)	p(B_{2021}>40% B_0)	p(B_{2021}>20% B_0)	p(B_{2021}>10% B_0)
Base	39 100	25.3	0.00	0.97	1.00
	(36 780 – 42 400)	(19.8 – 32.0)			
Lower steepness (h = 0.6)	40 900	20.9	0.00	0.62	1.00
	(39 200 – 43 500)	(16.4 – 26.7)			
Exclude weight frequency data	39 000	25.6	0.01	0.96	1.00
	(36 500 – 42 600)	(19.2 – 32.6)			
One area	38 600	31.6	0.04	1.00	1.00
	(35 400 – 44 300)	(24.4 – 41.1)			

For the base model run, the exploitation rate was estimated to be high enough to reduce the stock below the soft limit between 2002–03 and 2010–11, and then declined steadily, being close to the level associated with the biomass target since 2017–18 (Figure 6).

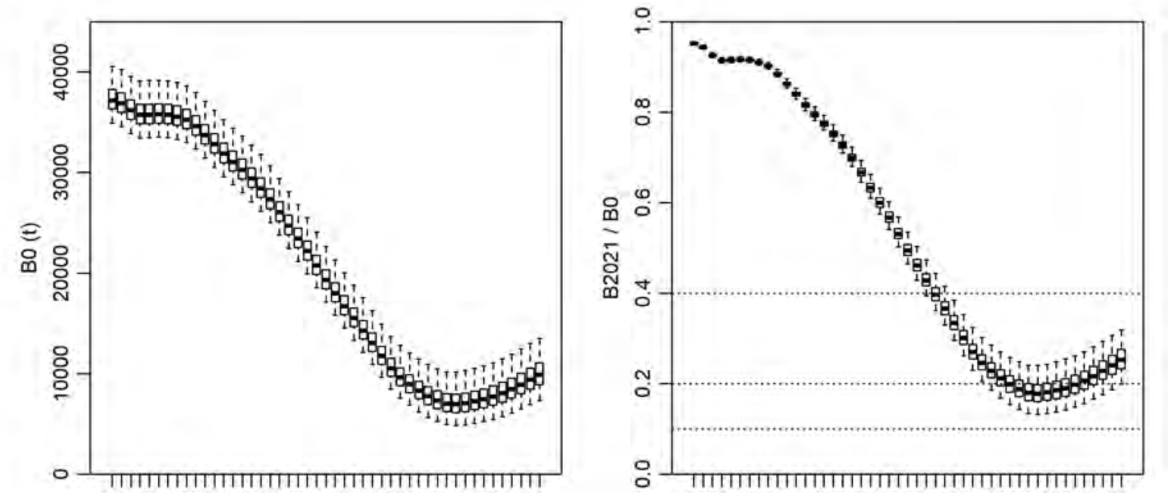


Figure 5: Bluenose Spawning Stock Biomass (*SSB*) trajectories and *SSB* as a proportion of B_0, for the base MCMC model run. Horizontal lines on the right panel indicate the assumed target (40% B_0), and soft (20% B_0), and hard (10% B_0) limit reference points. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

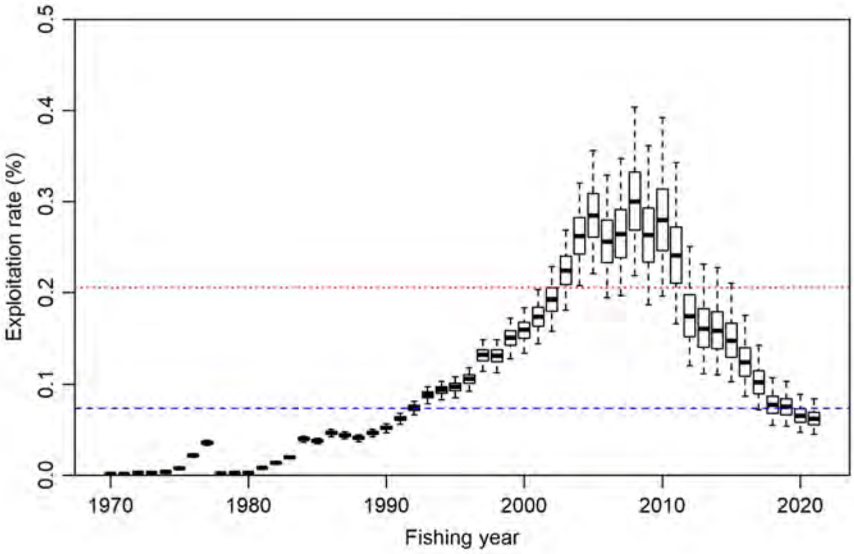


Figure 6: Bluenose MCMC estimated exploitation rate by fishing year for the base model run. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The exploitation rate associated with the soft limit of 20% *B0* is marked by the upper horizontal line, and that associated with the biomass target of 40% *B0* by the lower horizontal line.

4.3 Projections

Deterministic projections to 2041 using the base model run were carried out with constant future catches (2020–21 catch and TACC), maintaining the 2020–21 ratio between catches from the fisheries. The assumed constant future catches were: Northland and Bay of Plenty & East Cape longline, 287 t; Wairarapa longline, 79 t; Other longline, 126 t; Trawl, 124 t (total 616 t). The catches by fishery were prorated for projections with future constant catches at the TACC (630 t).

The stock was estimated to rebuild slowly and achieve a stock status of just above 30% B_0 within five years (Table 8). The rebuild would be very slightly slower if the future catches were at the current TACC rather than 2020–21 catch. The projected *SSB* achieved a 70% or greater probability of being at or above the target (40% B_0) in 2036–37 assuming the 2020–21 catch, or 2037–38 assuming the TACC.

Table 8: Bluenose, estimates from MCMC of the stock status (median and 95% CI) and probability of the *SSB* being greater than the target (40% *B0*), assuming constant future catches at the level of either the 2020–21 catch, or 2020–21 TACC, using the base model run.

	2020–21 catch		2020–21 TACC	
Fishing year	SSB_{year}/B_0	p(SSB>40% B_0)	SSB_{year}/B_0	p(SSB>40% B_0)
2021–22	26.5 (19.8–35.9)	0.01	26.5 (19.8–35.9)	0.01
2022–23	27.7 (20.8–37.3)	0.01	27.7 (20.8–37.3)	0.01
2023–24	28.9 (21.8–38.7)	0.02	28.9 (21.8–38.7)	0.02
2024–25	30.1 (22.8–40.1)	0.03	30.1 (22.8–40.0)	0.03
2025–26	31.3 (23.8–41.4)	0.04	31.2 (23.7–41.3)	0.04

4.4 Other factors

This assessment relies on standardised catch per unit effort as an index of abundance. In 2016 members of the fishing industry noted that bluenose fisheries have undergone a number of changes, not all of which are adequately captured in the statutory catch and effort data. These include changes in quota holdings, company structures and vessel operators, and shifts in fishing practice. The longline fishery data have been researched in most detail, and the splits in the time series used for assessment were a response to some of these issues. A further nearly 50% reduction in TACC occurred between 2015–16 and 2017–18, and future CPUE analyses should examine whether this cut may have caused further changes to fishing practice.

The base model predicted the biomass was rebuilding, but the most recent three years of the trawl CPUE declined, as did the HPB longline index. The alternative trawl CPUE index increased in 2019–20. It is suspected that trawl fishers may be avoiding areas where bluenose bycatch is relatively high due to the unavailability of ACE, which may bias the trawl CPUE low as the stock rebuilds.

More complex spatial structuring of bluenose populations and fisheries is also plausible and may be the cause of inconsistencies in the data, and some poor fits of the model. The plus group predicted by the model, not apparent in the data, may be because older fish move permanently to deeper water and become unavailable to the fishery; the assessment model assumes they are fully available. A sensitivity run with domed selectivity for the 'features' fishery allowed older fish to be unavailable, but it did not materially improve the fit. Assuming domed selectivity across all fisheries would allow an unverified and unavailable proportion of the mature biomass to exist (a 'cryptic spawning stock biomass'). If the misfit to the plus group is because (a) age-based cryptic biomass does exist, or (b) *M* is higher than assumed, then the current assessment stock status should be biased low and is precautionary.

In addition to cryptic biomass through age selectivity, cryptic biomass might also occur spatially. The assessment assumes all fish within the 'features' area are available. But if fish do not mix sufficiently, then areas may exist outside the main fisheries where bluenose are resident, and infrequently or not fished. There is evidence from fishery characterisation that such areas likely exist following the TACC, and targeted fishing effort, reduction. The limited tagging data, and similarity of some spatial CPUE trends, are supportive of mixing. However, if a spatial cryptic biomass of bluenose does exist, then the assessment stock status should again be biased low and is precautionary.

Variable YCS were not estimated. Ageing of bluenose is relatively difficult, life history and population parameters are not well known, and sampled age compositions are noisy. The steepness of the stock-recruitment relationship is unknown. The stock was estimated to have recently started rebuilding following a prolonged fish-down. The better fit to recent CPUE indices achieved with a lower assumed *h* could be, as assumed, due to relatively weak density-dependent compensation, but in this instance it might also be aliasing for a period of low recent YCS, perhaps resulting from unfavourable recent environmental conditions. Further observations of catch and CPUE, as the stock rebuilds, are required to better inform the productivity assumption.

5. FUTURE RESEARCH CONSIDERATIONS

- Incorporate estimated recreational catches in the assessment model.
- Continue to investigate how best to incorporate weight composition (packing) data in future stock assessments. Explore potential to collect this type of data more broadly if deemed to be useful. Explore the spatial pattern of data with stat areas, and the potential for length sampling of fish within the bin data.
- Create an age determination protocol, including creating a reference set of otoliths with agreed ages, to ensure that BNS ageing remains consistent over time.
- Develop otolith sampling programmes to obtain representative samples for estimating recruitment strength.
- Collect biological samples (including otoliths) from trawl vessels targeting BNS, BYX, and HOK.
- Revisit assumptions about historical catches, including the potential for under-reporting by trawlers in FMA 2 in the 1990s.
- Develop a programme to collect qualitative and quantitative data on changes in fishing behaviour both historically and in the future.
- Further investigate the comparability of *q*s between different CPUE series.
- Investigate changes in temporal and spatial trawl fishing patterns.

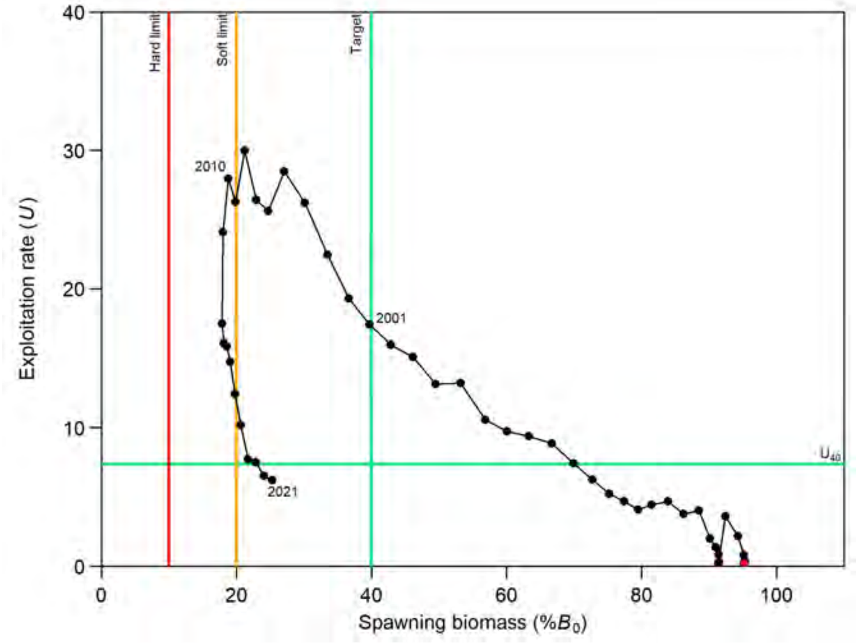
6. STATUS OF THE STOCKS

Stock Structure Assumptions
The assessment presented here assumes that bluenose in New Zealand waters comprise a single biological stock.

BNS 1, BNS 2, BNS 3, BNS 7, BNS 8, BNS 10

Stock Status	
Year of Most Recent Assessment	2021
Assessment runs presented	Base case
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	Very Unlikely (< 10%) to be at or above the target
Status in relation to Limits	Unlikely (< 40%) to be below the Soft Limit Very Unlikely (< 10%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is Unlikely (< 40%) to be occurring

Historical Stock Status Trajectory and Current Status



Historical trajectory of spawning biomass (% *B0*) and exploitation rate (%) (base model, medians of the marginal posteriors), from 1969–70 (red point) to 2020–21. The biomass target range of 40% *B0* and the corresponding exploitation rate range are marked in green. The soft limit (20% *B0*) is marked in orange and the hard limit (10% *B0*) in red.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	*SSB* was estimated to have been increasing slowly since 2012.
Recent Trend in Fishing Mortality or Proxy	Exploitation rates have declined since 2010.
Other Abundance Indices	A second standardised CPUE index based on the bycatch of bluenose in the HPB longline fishery had a trend that was very similar to the trawl index.
Trends in Other Relevant Indicator or Variables	-
Stock Projections or Prognosis	Deterministic projections predict that the *SSB* will slowly increase and reach the target around the mid 2030s.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured Casal2 model	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch history from statutory reporting	1 – High Quality
	- CPUE indices derived from statutory catch and effort reporting	1 – High Quality
	- Length frequency data distributions from observer data for the trawl fishery	2 – Medium or Mixed Quality: may not be representative
	- Age frequency distributions for the trawl and line fisheries	2 – Medium or Mixed Quality: may not be representative
	- Weight frequency distributions from commercial fish packing data for the longline fishery.	1 – High Quality
Data not used (rank)	- Length frequency distributions for the longline fishery collected under the AMP and from observer sampling. -	2 – Medium or Mixed Quality: may not be representative
	- HPB target BLL standardised CPUE index.	1 – High Quality
Changes to Model Structure and Assumptions	- the BLL CPUE indices for each of three fisheries were split after 2001–02, 2006–07, and 2011–12 - weight composition data from commercial LFR packing data were fitted - the assessment base model assumed two areas (background and features with a constant migration to the features) rather than one - empirical growth reformulated	
Major Sources of Uncertainty	- Deterministic recruitment is assumed; variations in year class strengths are not estimated, and therefore stock productivity is influenced only by *M* and *h*. - Stock structure and spatial dynamics are uncertain. - The selectivity of the longline fisheries appears to vary annually, making it difficult to estimate temporal changes in stock productivity (recruitment strength), which has resulted in an assessment with high uncertainty. - It is unclear whether the almost 50% reduction in TACC between 2015–16 and 2017–18 caused changes in fishing practices.	

Qualifying Comments
Because there are inconsistencies in the observed data, uncertainty in the bluenose stock assessment is high.

Fishery Interactions
Bluenose is taken in conjunction with alfonsino in target midwater trawl fisheries directed at the latter species. These fisheries are frequently associated with undersea features. Bluenose is also taken by target bottom longline fisheries throughout the New Zealand EEZ. Other commercially important species taken when longlining for bluenose are ling, hapuku, and bass.

7. FOR FURTHER INFORMATION

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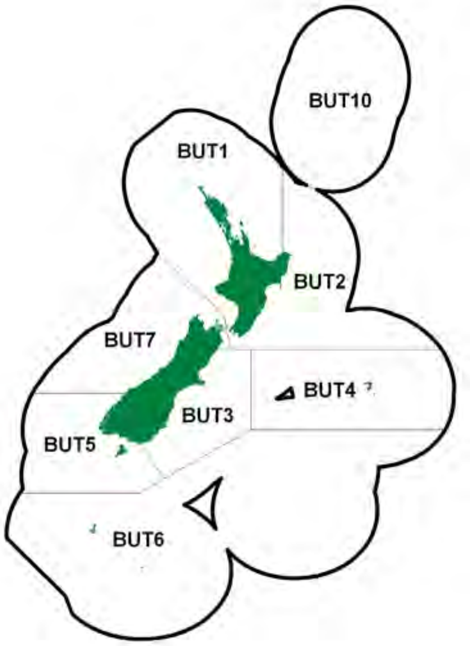
BUTTERFISH (BUT)

(*Odax pullus*)
Marari



1. FISHERY SUMMARY

Butterfish was introduced into the QMS in 1 October 2002 with allowances, TACCs and TACs as follows (Table 1).

Table 1: Summary of recreational and customary non-commercial allowances, TACs, and TACCs.

Fishstock	Recreational Allowance	Customary non-commercial Allowance	TACC	Other Mortality	TAC
BUT 1	10	10	3	1	24
BUT 2	80	80	63	2	225
BUT 3	65	65	3	1	134
BUT 4	4	4	10	0	18
BUT 5	10	10	45	1	66
BUT 6	0	0	0	0	0
BUT 7	15	15	38	1	69
BUT 10	0	0	0	0	0

1.1 Commercial fisheries

Butterfish is targeted by setnets in shallow coastal waters, principally around kelp-beds. The main fishery is centred on Cook Strait, between Tasman Bay, Castlepoint, and Kaikoura. There is also a smaller fishery around Stewart Island. A minimum setnet mesh size of 108 mm and a minimum fish size of 35 cm apply to commercial and recreational fishers; additional regional netting restrictions may also apply.

Hector's dolphin setnet closure areas were introduced on 1 October 2008 as part of the implementation of a Hector's and Maui dolphin Threat Management Plan. On 18 March 2011 the Minister decided to provide an exemption to the setnet prohibition on the East Coast South Island to allow commercial fishers targeting butterfish to use setnets in a defined area at the top of the East Coast South Island.

In line with the acceptable risk of mortality associated with butterfish fishing by commercial fisheries at the top of the East Coast of the South Island, given the type of fishing gear they use and the size of the area and the numbers of Hector's dolphins, recreational fishers are also allowed to target butterfish by method of set net from 1 January–30 April (inclusive). Set netting can only be undertaken if fishers stay with their nets at all times, the net is set no more than 200 m from the shore and it does not exceed 60 m in length.

Table 2: Reported domestic landings (t) and TACCs of butterfish by Fishstock from 2001–02 to present.

Fishstock	BUT 1		BUT 2		BUT 3		BUT 4		BUT 5	
FMA	1,8&9		2		3		4		5	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
2001–02	0.7	3	64	63	0.4	3	13	10	19	45
2002–03	2.0	3	58.2	63	2.8	3	4.0	10	34.6	45
2003–04	1.4	3	52.6	63	2.1	3	2.6	10	42.6	45
2004–05	1.5	3	62.9	63	2.4	3	5.3	10	35.4	45
2005–06	2.9	3	44.5	63	1.8	3	0.1	10	21.8	45
2006–07	2.4	3	55.5	63	1.8	3	0.1	10	30.1	45
2007–08	1.0	3	46.3	63	2.0	3	0	10	35.9	45
2008–09	2.1	3	55.5	63	0.6	3	0.6	10	36.9	45
2009–10	2.5	3	45.3	63	< 0.1	3	0.2	10	33.3	45
2010–11	3.1	3	42.4	63	0.1	3	0.2	10	47.0	45
2011–12	2.7	3	48.3	63	< 0.1	3	0.8	10	46.3	45
2012–13	2.1	3	53.8	63	0	3	0.1	10	34.5	45
2013–14	3.0	3	42.0	63	< 1	3	< 1	10	33.3	45
2014–15	2	3	36.3	63	< 1	3	0	10	37.1	45
2015–16	1.4	3	38.1	63	< 1	3	0	10	35.2	45
2016–17	2.8	3	44.4	63	< 1	3	0	10	48.9	45
2017–18	2.4	3	47.3	63	0.7	3	0	10	36.2	45
2018–19	1.6	3	48.0	63	< 0.1	3	0	10	37.1	45
2019–20	3	3	54	63	< 1	3	0	10	21	45
2020–21	2	3	29	63	< 1	3	0	10	31	45

Fishstock	BUT 6		BUT 7		BUT 10			
FMA (s)	6		7		10		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACCs
2001–02	0	0	25	38	0	0	121	162
2002–03	0	0	28.5	38	0	0	130.1	162
2003–04	0	0	24.8	38	0	0	126.1	162
2004–05	0	0	24.5	38	0	0	132.0	162
2005–06	0	0	23.7	38	0	0	94.8	162
2006–07	0	0	26.9	38	0	0	116.8	162
2007–08	0	0	29.4	38	0	0	114.6	162
2008–09	0	0	26.3	38	0	0	122.0	162
2009–10	0	0	16.5	38	0	0	97.9	162
2010–11	0	0	23.3	38	0	0	116.2	162
2011–12	0	0	21.4	38	0	0	119.5	162
2012–13	0	0	19.9	38	0	0	110.4	162
2013–14	0	0	16.7	38	0	0	95.1	162
2014–15	0	0	21.8	38	0	0	97.1	162
2015–16	0	0	19.3	38	0	0	94.5	162
2016–17	0	0	18.2	38	0	0	114.3	162
2017–18	0	0	18.7	38	0	0	102.9	162
2018–19	0	0	24.2	38	0	0	110.8	162
2019–20	0	0	26	38	0	0	105	162
2020–21	0	0	27	38	0	0	88	162

Total reported landings from 1982–83 to 2000–01 ranged between 105 and 193 t. Butterfish was introduced into the QMS in 2002. Reported landings and TACCs are given in Table 2, while Figure 1 shows the historical landings and TACC values for the main BUT stocks.

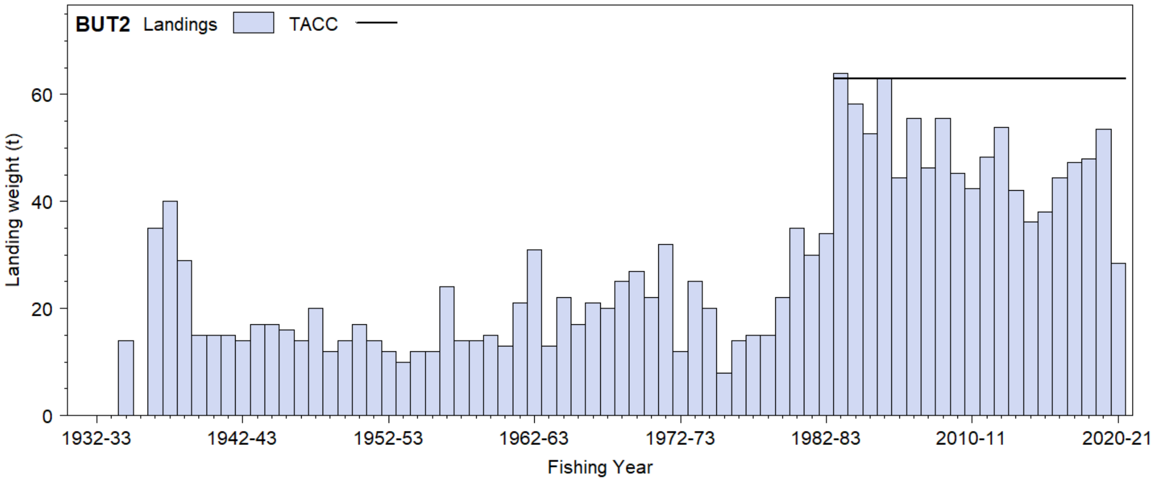


Figure 1: Reported commercial landings and TACC for the four main BUT stocks: BUT 2 (Central East). [Continued on next page]

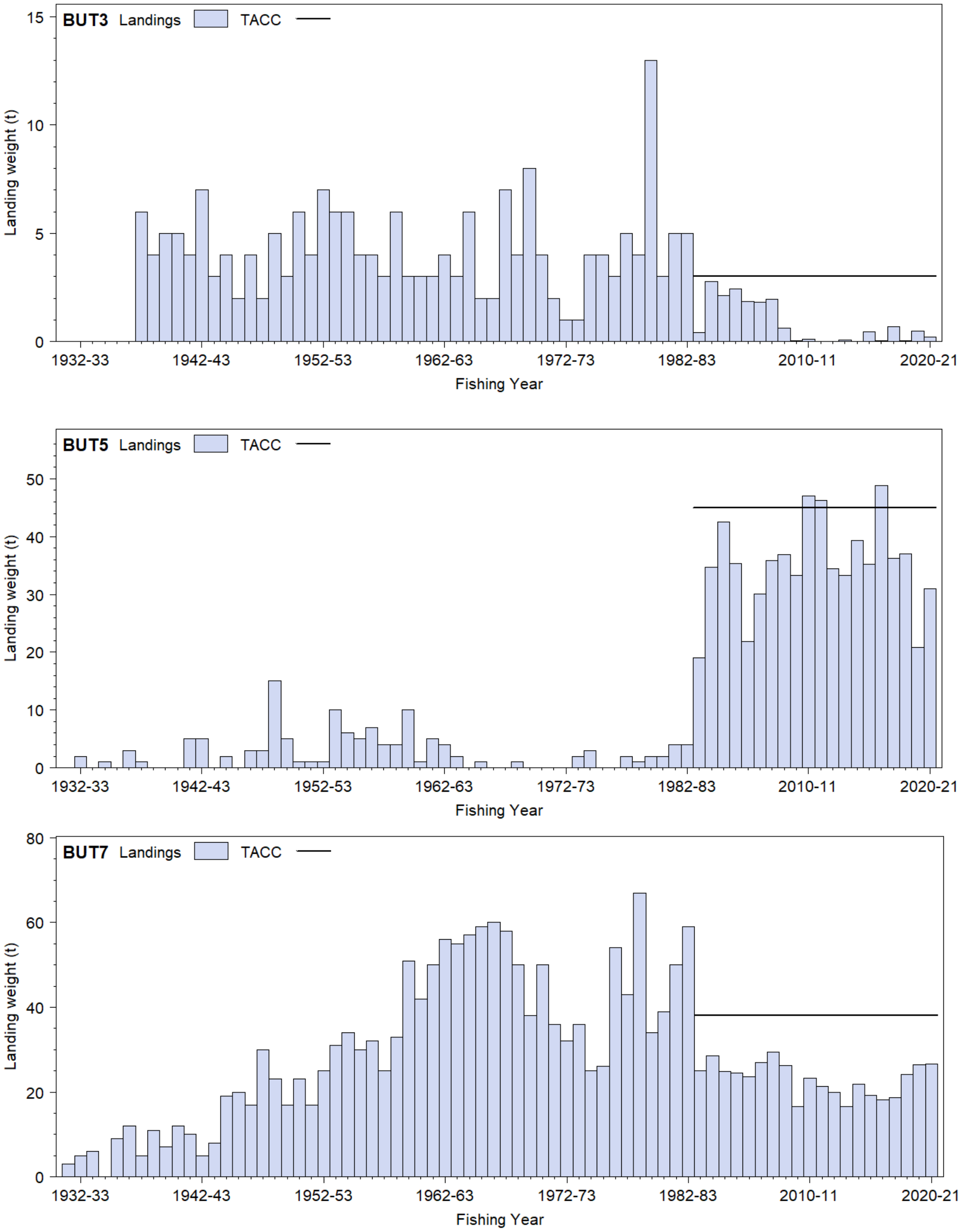


Figure 1 [Continued]: Reported commercial landings and TACC for the four main BUT stocks. From top, BUT 3 (South east coast), BUT 5 (Southland) and BUT 7 (Challenger).

From 2001–02 to 2018–19 total annual landings have averaged 112 t, with the highest proportion of landings being recorded for BUT 2, 5, and 7. Landings have consistently been below the TACC in all QMAs except for BUT 5, where landings slightly above the TACC of 45 t were recorded in 2010–11, 2011–12, and 2016–17.

1.2 Recreational fisheries

Butterfish is a popular recreational catch, and is taken mainly by setnet and spear. Recreational daily bag limits were set at 30 fish in 1986, but subsequently reduced to 20 for Northern and Central and Challenger (1995), and 15 for South (1993). Survey estimates indicate that the recreational catches appear to be of similar magnitude to those of the commercial fisheries in QMAs 1, 2, 5 and 7, and substantially higher in QMA 3 (Tables 3a and 3b).

Table 3a: Estimated recreational harvest of butterfish by QMA and survey.

QMA	Survey	Number caught	Survey harvest (t)	Fishstock harvest (t)
				1991–92
QMA 7	South	6 000	10	
QMA 7	South	4 000	5	15
QMA 3	South	36 000	65	65
QMA 5	South	8 000	10	10
				1993–93
QMA 2	Central	61 000	80	80
				1993–94
QMA 1 + 9	North	9 000	10	10
TOTAL		124 000		180

*Surveys were in different years: South 1991–92; Central 1992–93: and North 1993–94 (Teirney et al 1997). Many of these estimates have high CVs, and the estimate of total harvest is a guide only because of the different survey years. Line-caught ‘butterfish’ in QMA 3 and QMA 5 are excluded because of apparent species misidentification; these survey totals should be slightly higher.

Table 3b: Estimated number and weight of butterfish harvested by recreational fishers by Fishstock and survey. Surveys were carried out nationally in 1999–2000 (Boyd & Reilly 2002).

Fishstock	Survey	Number	CV%	Survey harvest (t)
BUT 1	National	1 000	71	< 1–3
BUT 2	National	23 000	39	16–36
BUT 3	National	45 000	47	27–76
BUT 5	National	17 000	42	11–27
BUT 7	National	18 000	41	12–29
BUT 8	National	1 000	100	0–2

The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 4. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 4: Recreational harvest estimates for butterfish stocks (Wynne-Jones et al 2014, 2019). Mean fish weights were obtained from boat ramp surveys (Hartill & Davey 2015, Davey et al 2019).

Stock	Year	Method	Number of fish	Total weight (t)	CV
BUT 1	2011–12	Panel survey	27 488	29.4	0.64
	2017–18	Panel survey	13 769	14.5	0.30
BUT 2	2011–12	Panel survey	13 892	15.6	0.33
	2017–18	Panel survey	20 478	25.8	0.30
BUT 3	2011–12	Panel survey	13 637	15.3	0.42
	2017–18	Panel survey	15 217	19.2	0.40
BUT 5	2011–12	Panel survey	188	0.2	0.74
	2017–18	Panel survey	8 411	10.6	0.65
BUT 7	2011–12	Panel survey	14 625	16.4	0.94
	2017–18	Panel survey	9 615	12.1	0.61

1.3 Customary non-commercial fisheries

There is no quantitative information on the current level of customary non-commercial catch.

1.4 Illegal catch

Because this is a localised small-scale fishery, some sales from fishers directly to retailers may have gone unreported, but no quantitative estimate of this are available.

1.5 Other sources of mortality

There is no quantitative information on other sources of mortality. In the past butterfish has been used as rock lobster bait and not reported.

2. BIOLOGY

Butterfish are endemic to New Zealand, and occur from North Cape to the Snares Islands. The species is also reported from the Chatham, Bounty and Antipodes Islands. Butterfish are more common from Cook Strait southwards. They inhabit rocky coastlines, and are commonly found among seaweed beds in moderately turbulent water. Their main depth range is 0–20 m. They occur shallower (to 10 m) in the north than in Cook Strait (to 20 m) and in southern waters they can be found as deep as 40 m.

Adult butterfish average 45–55 cm (FL) in length. Their maximum size is approximately 70 cm. Length/weight data are not available for whole fish, but as an interim measure a length/gutted weight relationship is given in Table 5.

Butterfish are almost exclusively herbivorous, feeding on several of the larger seaweeds. The diet of butterfish varies regionally and is largely determined by the species composition of the local seaweed beds. Feeding activity is greatest early in the day, and the tidal state controls the accessibility of intertidal seaweeds; fish were found to feed more actively in summer than winter (Trip 2009).

Fish were aged using sectioned sagittal otoliths, validated using daily growth (Trip 2009). Growth varies with latitude due to temperature difference, and local ecological factors such as diet and fish density.

Trip (2009) found that size and age differ significantly with latitude. Environmental temperature is the primary driver underlying the difference in life histories across latitudes, and affects growth rate, size-at-age and longevity. Butterfish living in colder temperatures (higher latitudes) grow slower, live longer, attain a greater average size and delay the onset of maturity (Trip 2009). Butterfish in Hauraki Gulf (BUT 1) reach 70% of their mean asymptotic size by the age of two, and have reached 90% of their maximum size by age 4. In the southern areas butterfish grow slower and reach a maximum size at about 75 % of their life span. The maximum age ranged from 11 years in the north (Hauraki Gulf) to 19 years in the south (Stewart Island) (Trip 2009). There are no significant differences in growth rates or mean adult body size between sexes, yet with the exception of the Hauraki Gulf, the oldest and largest fish (FL) sampled in all areas were females (Trip 2009).

Table 5: Estimates of biological parameters for butterfish.

Fishstock	**Estimate**	**Source**
1. Natural mortality (*M*)		
Cook Strait	0.30–0.45	Paul et al (2000)

2. Weight = a(length)^b (Weight in g, length in cm fork length).

	Females		Males		Juvenile		
	a	b	a	b	a	b	
Cook Strait	67.699	1 947.8	67.034	1 885.9	21.205	362.28	Ritchie (1969)
Hauraki Gulf							
Stewart Is.							

Linear regression, b = constant. Weight is gutted weight.

3. von Bertalanffy growth parameters

	Both sexes			
	K	t_0	L_∞	
Cook Strait	0.23	-1.7	51.8	Paul et al (2000)
Hauraki Gulf	0.517	-0.23	457.36	Trip (2009)

Butterfish start life as female, some, but not all, undergo sex change where an estimated 50% of mature females develop into males. The size at sex change ranges between 37 to 45 cm FL. The length at which sex change occurs does not seem to differ between geographical areas, but age-at-sex change varies geographically. The mean age-at-sex change was found to be significantly lower in warmer latitudes, 2.5 yrs at the Hauraki Gulf, in comparison to 7 years old at Stewart Island. At D'Urville Island, in-between the two, fish changed sex at 5 years old (Trip 2009).

In the warm waters of the north females mature early and of the samples collected in the Hauraki Gulf 95% of females are sexually mature by two years old (29.7 cm FL). Females sampled at Stewart Island show delayed maturity with only 50% mature at an average age of four (25.2 cm FL) (Trip 2009).

The depth distribution of butterfish differs by size and sex. Juveniles (less than 30 cm) occur in the shallow weed beds (less than 15 m) and (outside the breeding season) males occur in deeper waters than females. Consequently, sex ratios vary with locality, but females often outnumber males.

In the North the spawning season occurs between July and November, with a peak in August. The spawning season extends from July to March in Cook Strait, peaking in September and October. In southern New Zealand the spawning season appears to be shorter (August to January, peaking in October–January).

3. STOCKS AND AREAS

There is no clear information on whether biologically distinct stocks occur, although there is some evidence of regional variation in meristic characters which suggests some separation of populations. The time larval butterfish spend in the plankton before settling out into the adult habitats as postlarvae is relatively short, a factor that may cause a high level of stock separation around coastal New Zealand. The only information on movement relates to feeding behaviour involving small-scale movements within seaweed beds. There is no information on movement along the coastline within a weed-bed habitat, or potentially longer migration between such habitats separated by open coast. However, the latter seems unlikely on any substantial scale, and as a result butterfish populations are probably quite localised. Butterfish populations at offshore islands (Chatham, Antipodes, Bounties, and Snares), have not been studied but may be distinct from the mainland population(s) simply because of their isolation.

4. STOCK ASSESSMENT

A yield per recruit analysis was undertaken in 1997 (Paul et al 2000). This report derived new estimates of growth and natural mortality from the Cook Strait which were incorporated into this analysis. Stock status was not determined by this analysis.

4.1 Estimates of fishery parameters and abundance

No information is available.

4.2 Biomass estimates

No information is available.

4.3 Yield estimates and projections

The method *MCY* = *cYav* (Method 4) was evaluated. However, this method was rejected due to a lack of reliable information on changes in fishing effort and/or mortality over the history of the fishery. *MCY* for butterfish cannot be determined.

CAY cannot be determined.

4.4 Other yield estimates and stock assessment results

A study of setnet mesh selectivity in relation to the current legal minimum fish size showed that 108 mm mesh retained few undersized fish (immature). This provides a level of protection to butterfish stocks and their recruitment. A yield per recruit analysis showed that a modest yield increase could be obtained by using a smaller mesh and taking younger (2–3 year old) fish. However, this theoretical gain would be counter-balanced by the capture of relatively more juveniles and young females, and almost certainly a higher bycatch of other reef fishes. Butterfish populations are susceptible to localised depletion.

5. STATUS OF THE STOCKS

No estimates of current and reference biomass are available. It is not known whether recent catch levels will allow the stock to move towards B_{MSY}.

6. FOR FURTHER INFORMATION

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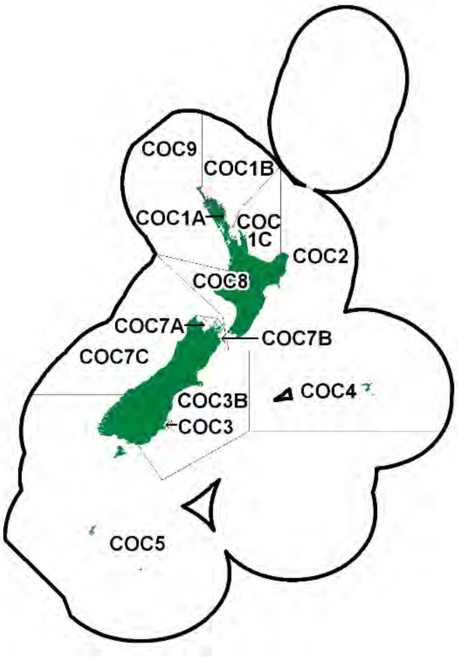
INTRODUCTION - COCKLES (COC)

(*Austrovenus stutchburyi*)
Tuangi



1. INTRODUCTION

Cockles are important shellfish both commercially and for non-commercial fishers. For assessment purposes, individual reports on the largest commercial fisheries have been produced separately:

1. Snake Bank, Whangarei Harbour, in COC 1A.
2. Papanui Inlet, Waitati Inlet, and Otago Harbour, Otago Peninsula in COC 3.
3. Tasman Bay and Golden Bay in COC 7A.

Since 1992, Fisheries New Zealand or its predecessors has commissioned biomass surveys for cockles and pipi in the northern North Island on beaches where there is known recreational and customary fishing pressure. The objective of the surveys is to determine the distribution, abundance, and size frequency of cockles and pipi on selected beaches in the Auckland Fisheries Management Areas (FMA 1 and FMA 2).

Over the years, a total of 35 beaches have been monitored. On average, 12 beaches are sampled each year. The last survey was conducted in 2021 (see Berkenbusch et al. 2021) and only eight sites were surveyed, with access to four of the usual 12 survey sites hampered during the field sampling by travel restrictions through Auckland (in response to COVID-19. Cockles were present at seven of the eight survey sites, and data from the field sampling were sufficient to provide cockle population estimates with relatively low uncertainty, i.e., with a CV of less than 20%. Cockle population densities exceeded 300 individuals per m^2 at all of the sites, with the highest density estimate of 884 cockles per m^2 at Whangapoua Harbour, on Coromandel Peninsula. The populations surveyed in 2020–21 contained few large individuals ($\geq$30 mm shell length): this size class was absent at Otūmoetai (Tauranga Harbour), and their densities were low (i.e. less than 10 large individuals per m^2) at Aotea Harbour and Whangapoua Harbour. Their highest density was 43 large cockles per m^2 (19.09%) at Whangamatā Harbour.

The tools employed to manage these fisheries include daily bag limits and seasonal, temporary, and permanent closures. Size limits are also an option, but these are not currently in use. Customary management tools such as 186A closures, taiāpure, and mātaitai may also be implemented at the request of tangata whenua.

The fishing pressure within greater Auckland and the depletion of some shellfish beds have led to the introduction of a range of the above measures at finer spatial scales. Temporary closures to shellfish harvesting under s186A of the Act have been implemented at the request of tangata whenua in the following locations: Marsden Bank and Mair Bank, Maunganui Bay, Te Mata and Waipatukahu Beaches and Umupuia Beach. Closures gazetted under s11 sustainability measures are in place for Ngunguru estuary, Whangateau harbour, and Cockle Bay. There are also permanent shellfish closures at Cheltenham, Eastern Beach, and Karekare.

1.1 Commercial fisheries

Information on cockles that applies to all stocks is included below rather than being repeated in the individual reports for each of the large commercial fisheries.

Cockles were introduced into the QMS on 1 October 2002. The fishing year runs from 1 October until September 30 and catches are measured in greenweight for all stocks. There is no minimum legal size for cockles in any stock. Cockles are managed under Schedule 6 of the Fisheries Act for all stocks listed in Table 1, which allows cockles to be returned to where they were taken as soon as practicable after the cockle is taken, as long as the cockle is likely to survive.

The landings, by stock, of these cockle fisheries are dominated by catch from COC 3 (Figure 1). Landings from COC 3 have been relatively stable since 2002–03; by contrast landings from COC 1A and COC 7A have generally declined during that time. However, it should be noted that since 2009, COC 3 has had access to additional substantial stocks within Otago Harbour.

Table 1: TACC, Recreational, customary, and other sources of mortality allowances, and TAC (t) for all cockle stocks.

Code	Description	TACC	Recreational allowance	Customary allowance	Other sources of mortality	TAC
COC 1A	Whangarei Harbour	346	25	25	4	400
COC 1B	East Northland	0	22	22	2	46
COC 1C	Hauraki Gulf and Bay of Plenty	5	32	32	3	72
COC 2	Central	0	2	2	1	5
COC 3	Otago	1 470	10	10	10	1 500
COC 3B	Part South East Coast	1	27	27	3	58
COC 4	South East (Chatham Rise)	0	1	1	1	3
COC 5	Southland and Sub-Antarctic	2	2	2	1	7
COC 7A	Nelson Bays	1 390	85	25	10	1 510
COC 7B	Marlborough	0	5	5	0	10
COC 7C	Part Challenger	0	3	3	1	7
COC 8	Central (Egmont)	0	1	1	1	3
COC 9	Auckland (West)	0	6	6	1	13

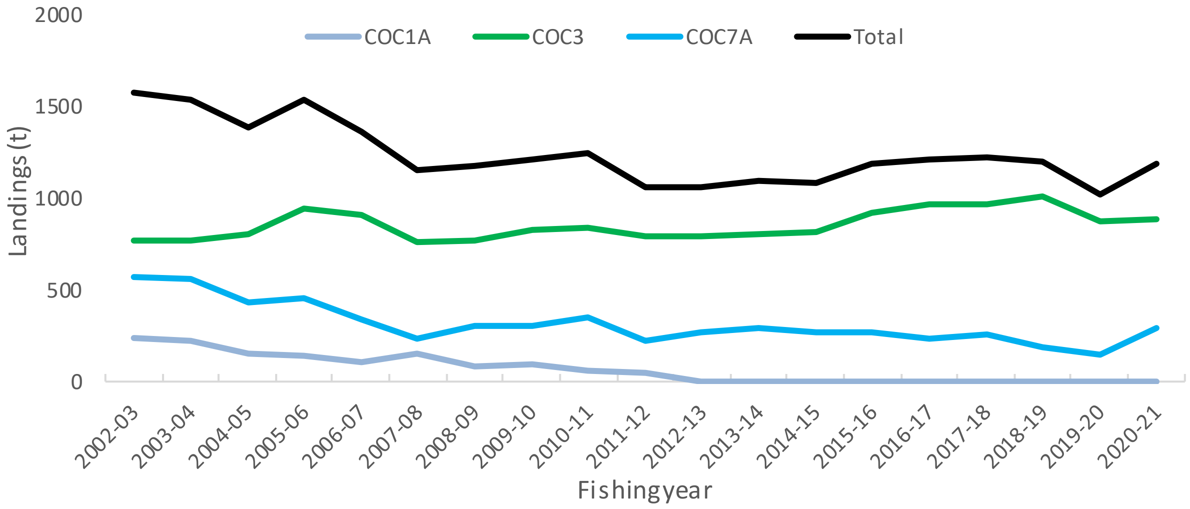


Figure 1: Commercial landings and the sum total (black line) of the three main commercial COC stocks from 2002–03 to present. Note that this figure does not show data prior to entry into the QMS.

New Zealand operates a mandatory shellfish quality assurance programme for all bivalve shellfish commercial growing or harvesting areas for human consumption. Shellfish caught outside this programme can only be sold for bait. This programme is based on international best practice and managed by Food Safety New Zealand in cooperation with the District Health Board Public Health Units and the shellfish industry[1] and is summarised below. Before any area can be used to grow or harvest bivalve shellfish, public health officials survey the water catchment area to identify any potential pollution issues and take samples of the water and shellfish over at least a 12-month period, so all seasonal influences are explored. This information is evaluated and, if suitable, the area is classified and listed by Food Safety New Zealand for harvest. There is then a requirement for regular monitoring of the water and shellfish flesh to verify levels of microbiological and chemical contaminants. Management measures stemming from this testing include closure after rainfall, to deal with microbiological contamination from runoff. Natural marine biotoxins can also cause health risks, therefore testing for these also occur at regular intervals. If toxins are detected above the permissible level the harvest areas are closed until the levels fall below the permissible level. Products are also traceable so that the source and time of harvest can always be identified in case of contamination.

1.2 Recreational fisheries

Cockles are taken by recreational fishers in many areas of New Zealand. The recreational fishery is harvested entirely by hand digging. Relatively large cockles are preferred.

Estimates of recreational harvest of cockles at the FMA level are available. Early estimates of the amateur cockle harvest are available from telephone-diary survey in 1992–93 (Teirney et al 1997), 1996 (Bradford 1998), and 2000 (Boyd & Reilly 2002). Harvest weights were estimated assuming a mean weight of 25 g per cockle (for cockles over 30 mm).

The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year (Wynne-Jones et al 2014). The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. A repeat of the National Panel Survey was conducted over the 2017–18 October fishing year (Wynne-Jones et al 2019). Results are given in Table 2.

Details for COC 1A, COC 3 and COC 7A can be found in the respective Working Group reports.

Table 2: Estimated numbers of cockles harvested by recreational fishers in each FMA for the 2017–18 fishing year, and the corresponding harvest weight based on an assumed mean weight of 25 g.

Stock	Harvest (number of cockles)	CV	Harvest (kg)
COC 1A	-	-	-
COC 1B	17 221	0.69	430.53
COC 1C	164 297	0.52	4 107.42
COC 2	1 492	0.80	37.30
COC 3, 3B	94 885	0.40	2 372.12
COC 3	8 475	0.67	211.86
COC 5	6 761	1.00	169.03
COC 7A	23 176	0.41	579.41
COC 7B	1 601	0.59	40.03
COC 7C	-	-	-
COC 8	-	-	-
COC 9	22 337	0.77	558.44

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[1] For full details of this programme, refer to the Animal Products (Regulated Control Scheme-Bivalve Molluscan Shellfish) Regulations 2006 and the Animal Products (Specifications for Bivalve Molluscan Shellfish) Notice 2006 (both referred to as the BMSRCS), at: https://www.mpi.govt.nz/food-business/food-monitoring-surveillance/seafood-monitoring-programmes/

1.3 Customary non-commercial fisheries

In common with many other intertidal shellfish, cockles are very important to Māori as a traditional food. Cockles form an important fishery for customary non-commercial, but the total annual catch is not known.

Māori customary fishers utilise the provisions under both the recreational fishing regulations and the various customary regulations. Many tangata whenua harvest cockles under their recreational allowance and these are not included in records of customary catch. Customary reporting requirements vary around the country. Customary fishing authorisations issued in the South Island and Stewart Island would be under the Fisheries (South Island Customary Fishing) Regulations 1999. Many rohe moana / areas of the coastline in the North Island and Chatham Islands are gazetted under the Fisheries (Kaimoana Customary Fishing) Regulations 1998 which require reporting on authorisations. In the areas not gazetted, customary fishing permits would be issued would be under the Fisheries (Amateur Fishing) Regulations 2013, where there is no requirement to report catch.

The information on Māori customary harvest under the provisions made for customary fishing can be limited (Table 3). These numbers are likely to be an underestimate of customary harvest as only the catch approved and harvested in kilograms and numbers are reported in the table.

Details are provided in the respective Working Group reports.

Table 3: Fisheries New Zealand records of customary harvest of cockles (approved and reported as weight (kg) and in numbers), since 2000–01. – no data.

		Weight (kg)		Numbers	
Stock	**Fishing year**	**Approved**	**Harvested**	**Approved**	**Harvested**
COC 1B	2008–09	120	120	450	450
	2009–10	440	440	–	–
	2010–11	340	340	–	–
	2011–12	400	400	–	–
	2012–13	280	280	–	–
COC 1C	2005–06	65	45	2 000	0
	2006–07	3 680	3 680	–	–
	2007–08	465	260	–	–
	2008–09	260	120	–	–
	2009–10	20	20	–	–
	2014–15	25	25	–	–
COC 2	2009–10	–	–	1 200	980
COC 3	2000–01	–	–	400	400
	2001–02	–	–	37	37
	2002–03	–	–	1 200	1 200
	2006–07	100	100	9 100	7 680
	2007–08	–	–	500	500
	2008–09	–	–	24 496	23 865
	2009–10	–	–	4 750	4 750
	2010–11	–	–	19 500	19 500
	2011–12	30	28	10 600	10 600
	2013–14	–	–	2 300	2 100
	2015–16	80	80	9 610	9 510
	2016–17	–	–	5 500	5 240
	2017–18	–	–	4 950	4 800
	2019–20	–	–	3 140	3 140
	2020–21	–	–	7 400	7 400
COC 3B	2006–07	–	–	156	156
	2007–08	–	–	5 000	5 000
	2008–09	–	–	1 250	750
	2011–12	–	–	500	340
	2015–16	–	–	500	100
	2017–18	–	–	2 250	1 433
	2018–19	–	–	1 500	1 356
	2019–20	–	–	2 450	1 640
	2020–21	–	–	670	570
COC 7C	2006–07	120	120	–	–
COC 9	2009–10	20	20	–	–
	2012–13	145	145	–	–
	2013–14	270	270	–	–
	2014–15	250	250	–	–

1.4 Illegal catch

No quantitative information on the level of illegal catch is available.

1.5 Other sources of mortality

No quantitative information is available on the magnitude of other sources of mortality. Harvesting implements, such as brooms, rakes, "hand-sorters", bedsprings and "quickfeeds" may cause some incidental mortality, particularly of small cockles, but this proposition has not been scientifically investigated. High-grading is often practiced with smaller sized clams being returned to the beds, potentially causing stress and related mortality, however no research has substantiated this.

2. BIOLOGY

The cockle, *Austrovenus stutchburyi*, formerly known as *Chione stutchburyi*, is a shallow-burrowing suspension feeder of the family Veneridae. It is found in soft mud to fine sand on protected beaches and enclosed shores around the North and South Islands, Stewart Island, the Chatham Islands, and the Auckland Islands (Morton & Miller 1973, Spencer et al 2002). Suspension feeders such as *A. stutchburyi* tend to be more abundant in sediments with a larger grain size. Cockles have been shown to be most abundant in sediments of below 12 percent mud in two separate studies (Thrush et al 2003, Anderson 2008). They are also common in eelgrass (e.g., *Zostera* sp.), which often co-occurs with sand flats.

Cockles are found from the lowest high-water neap tide mark to the lowest part of the shore. Larcombe (1971) suggested that the upper limit is found where submergence is only 3.5 hours per day. *A. stutchburyi* is often a dominant species and densities as high as 4500 per m^2 have been reported in some areas. In Pauatahanui Inlet the cockle biomass was estimated at 80% (5000 t) of the total intertidal biomass in 1976 (Richardson et al 1979). Calculations based on laboratory measurements of filtration rates suggested that cockles over 35 mm shell length were capable of filtering 1.1×10^6 m^3 of water or enough to filter all the water in Papanui Inlet every two tidal cycles (Pawson 2004).

Sexes are separate and the sex ratio is usually close to 1:1. Size at maturity has been estimated at about 18 mm shell length (Larcombe 1971). Spawning extends over spring and summer, and fertilisation is followed by a planktonic larval stage lasting about three weeks. Significant depression of larval settlement has been recorded for areas of otherwise suitable substrate from which all live cockles have been removed. This suggests the presence of some conditioning factor.

Work on Snake Bank also showed moderate differences among years in the level of recruitment of juveniles to the population. The variability of recruitment was estimated as $\sigma_R = 0.41$ using all available data (1983–1996) but as $\sigma_R = 0.31$ using data only from those years since the fishery has been considered to be fully developed (1991–96). Given the variability of most shellfish populations and the shortness of the time series, this is probably an underestimate of the real variability of recruitment in the Snake Bank population.

Small cockles grow faster than large cockles, but overall, maximum growth occurs on the first of January, and a period of no growth occurs at the beginning of July (Tuck & Williams 2012). Growth is slower in the higher tidal ranges and in high density beds. Significant increases in growth rates have been observed for individuals remaining in areas that have been 'thinned out' by simulated harvesting. Tagging work at Pakawau beach also highlighted the variability in growth that can occur within a beach (Osborne 2010).

Growth parameters and length weight relationships are listed in Table 4 (Stewart 2008, Williams et al 2009, Osborne 2010). However, considerable variability in growth has been seen in all three QMAs over time. At Snake bank (1A) growth to 30 mm has been estimated as taking between 2 and 5 years in separate studies (Martin 1984, Cryer 1997). Additional tagging work on Snake Bank from 2001 to 2010 showed that on average, cockles reach maturity (18 mm; Larcombe 1971) in their second year of growth, and recruit to harvestable size (about 28 mm SL) in about 3 to 4 years, although these results showed great variability in growth rate (tabulated in table 8, Tuck & Williams 2012). At Pakawau beach

(7A) K has varied between 0.36 and 0.41 and L_∞ between 47 and 49mm (Osborne 1992, 1999). The work of Breen et al (1999) in Papanui and Waitati Inlets, Purakanui and Otago Harbour showed no significant growth after one year and modes in the length frequency distributions did not shift when measured over four sampling periods within a year. They concluded that it was unlikely that average growth is really as slow as the results indicated, but there may be high inter-annual variability in growth.

Quite extensive movements of juveniles have been documented, but individuals over 25 mm shell length remain largely sessile, moving only in response to disturbance.

Given that cockles recruit to the spawning biomass at about 18 mm shell length, but do not recruit to commercial or non-commercial fisheries until closer to 30 mm shell length, there is some protection for the stock against overfishing, especially as the Snake Bank and Papanui and Waitati Inlet stocks are probably not isolated as far as recruitment of juveniles is concerned. However, this generality should be treated with some caution, given that some population of adults seems to be required to stimulate settlement of spat.

Natural mortality arises from a number of sources. Birds are a major predator of cockles (up to about 23 mm shell length). Other predators include crabs and whelks. Cockles are also killed after being smothered by sediments shifted during storms or strong tides. A mass mortality that killed an estimated 56–63% of all cockles and 80–84% of cockles over 30 mm in shell length (Fisheries New Zealand unpublished data) has been reported from sites within the Whangateau harbour (north of Auckland). This mortality was attributed to a potential weakening of cockles due to heat stress then mortality from a coccidian parasite and a mycobacterium. Sediments, both suspended and deposited, both impact upon cockle fitness or survival, with terrestrial sediments having greater effects than marine sediments (Gibbs & Hewitt 2004). Increasing suspended sediment concentrations have induced increased physiological stress, decreased reproductive status and decreased juvenile growth rates (Nicholls et al 2003, Gibbs & Hewitt 2004). Sediment deposition has also been shown to negatively impact upon densities of cockles (Lohrer et al 2004). The sum of these effects is seen in the distribution of cockles, which decline in abundance across a number of sites with increasing mud content in the sediments, either above zero or 11% mud content, depending upon the study (Thrush et al 2003, Anderson 2008).

Experimental work on Snake Bank led to estimates of absolute mortality of 17–30% per annum, instantaneous natural mortality (M) of 0.19–0.35, with a midpoint of $M = 0.28$. The estimated mortality rates for cockles of over 30 mm shell length were slightly greater at 19–37% per annum, (M of 0.21–0.46 with a midpoint of 0.33). This higher estimate was caused by relatively high mortality rates for cockles of over 35 mm shell length and, as these are now uncommon in the population, $M = 0.30$ (range 0.20–0.40) has been assumed for yield calculations across all three stocks (Table 4). Tagging (both notch and individual numbered tags) has been ongoing on Mair Bank from 2001 to 2009 and the last recoveries occurred in 2010 (Tuck & Williams 2012). Annualised mortality estimates (*M)* (averaged over 3, 6 and 9 month recoveries) were 0.356 and 0.465 from studies in 2008 and 2009.

Table 4: Biological parameters used for cockle assessments for different stocks. SL = shell length, within area 7A, P = Pakawau, FP = Ferry Point, TBR = Tapu Bay/Riwaka.

	1A	**3**	**7A**
1. Natural mortality (M)	0.3	0.3	0.3
2. Weight (grams)	$= a(\text{shell length})^b$	$= a(\text{shell length})^b + \text{b}$	$= a(\text{shell length})^b$
a	0.00014	0.7211	P = 0.000018, FP = 0.0002, TBR = 0.00015
b	3.29	11.55	P = 3.78, FP = 3.153, TBR = 3.249
3. von Bertalanffy growth parameters			Not used instead growth = $a(\text{Ln}(\text{age in years}))+b$
K	0.26	0.326	a = 11.452
L_∞(mm)	35	40.95	b = 16.425
SL at recruitment to the fishery (mm)	28	28	30

3. STOCKS AND AREAS

Little is known of the stock boundaries of cockles. Given the planktonic larval phase, many populations may receive spat fall from other nearby populations and may, in turn, provide spat for these other areas. In the absence of more detailed knowledge, each commercial fishery area is managed as a discrete population.

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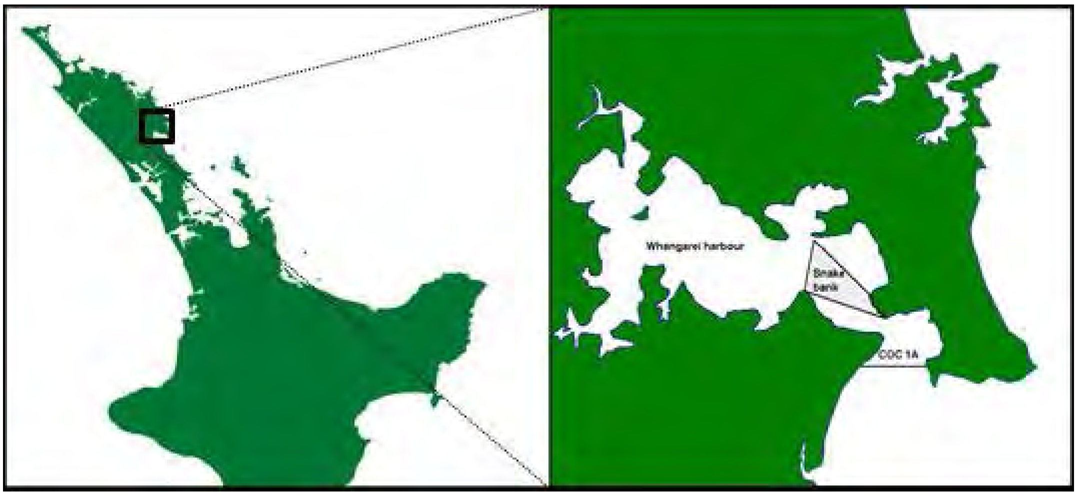
COCKLES (COC 1A) Snake Bank (Whangarei Harbour)

(*Austrovenus stutchburyi*)
Tuangi



1. FISHERY SUMMARY

COC 1A was introduced to the QMS in October 2002 with a TAC of 400 t, comprising a TACC of 346 t, customary and recreational allowances of 25 t each, and an allowance of 4 t for other fishing related mortality. These limits have remained unchanged since.

1.1 Commercial fisheries

Snake Bank is not the only cockle bed in Whangarei Harbour, but it is the only bed allowed for commercial fishing. Commercial fishers are restricted to hand gathering, but they routinely use simple implements such as ‘hand sorters’ to separate cockles of desirable size from smaller animals and silt. There are several other cockle beds in the harbour, some on the mainland and some on other sandbanks, notably MacDonald Bank. Fishing on these other beds should be exclusively non-commercial.

Commercial picking in Whangarei Harbour began in the early 1980s and was then undertaken year round, with no particular seasonality. Catch statistics (Table 1) are unreliable before 1986, although it is thought that over 150 t of Snake Bank cockles were exported in 1982. There was probably some under reporting of landings before 1986, and this may have continued since. Effort and catch information for this fishery has not been adequately reported by all permit holders in the past, and there are problems interpreting the information that is available. Landed weights reported on CELRs only summed to between 52 and 91% of weights reported on LFRRs during the years 1989–90 to 1992–93. CPUE data are available but have not yet been analysed for this fishery.

Before entry of this stock to the QMS there were eight permit holders, each allowed a maximum of 200 kg (greenweight) per day by hand-gathering. If all permit holders took their quota every day a maximum of 584 t could be taken in a 365-day year. Reported landings of less than 130 t before 1988–89 rose to 537 t in 1991–92 (about 92% of the theoretical maximum). Landings for the 1992–93 fishing year were much reduced (about 316 t) following an extended closure for biotoxin contamination. Landings averaged 462 t between 1993–94 and 2000–01. Landings have decreased substantially since COC 1A entered the QMS (average of 108 t). Due to low biomass, the fishery closed in November 2012 and has remained closed since.

The low catch in the last few years before the closure may partly reflect reduced effort on the bank because of temporary fishery closures during incidents of sewage and stormwater overflows which adversely affected harbour water quality. The fishery was closed for these reasons for 101, 96, 167, and

96 days for the 2006–07, 2007–08, 2008–09, and 2009–10 fishing years, respectively[1]. Figure 1 shows the commercial landings and TACC values of COC 1A since 1986.

The mean length of the commercial harvest was about 29.5 mm; cockles smaller than 25 mm were less attractive to both commercial and non-commercial fishers.

Table 1: Reported commercial landings and catch limits (t greenweight) of cockles from Snake Bank since 1986–87 (from QMR/MHR records)*.

Fishing year	Landings (t)	TACC (t)
1986–87	114	584
1987–88	128	584
1988–89	255	584
1989–90	426	584
1990–91	396	584
1991–92	537	584
1992–93	316	584
1993–94	**566	584
1994–95	501	584
1995–96	495	584
1996–97	457	584
1997–98	439	584
1998–99	472	584
1999–00	505	584
2000–01	423	584
2001–02	405	584
2002–03	237	346
2003–04	218	346
2004–05	151	346
2005–06	137	346
2006–07	111	346
2007–08	151	346
2008–09	88	346
2009–10	93	346
2010–11	64	346
2011–12	43	346
2012–13	0	346
2013–14	0	346
2014–15	0	346
2015–16	0	346
2016–17	0	346
2017–18	0	346
2018–19	0	346
2019–20	0	346
2020–21	0	346

*Before COC 1A entered the QMS, the fishery was restricted by daily catch limits which summed to 584 t in a 365 day year, but there was no explicit annual restriction. A TACC of 346 t was established in October 2002 when COC 1A entered the QMS.
** The figure of 566 t for 1993–94 may be unreliable.

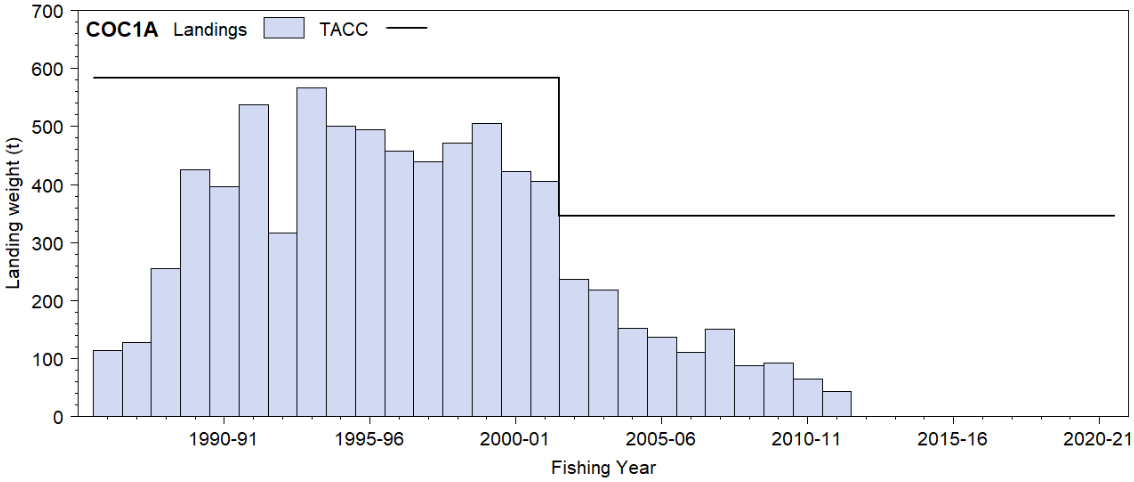


Figure 1: Reported commercial landings and TACC for COC 1A (Whangarei Harbour).

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[1] Statistics supplied by New Zealand Food Safety Authority in Whangarei.

1.2 Recreational fisheries

The recreational fishery is harvested entirely by hand digging, and large cockles (30 mm shell length or greater) are preferred. No recreational harvest estimates specific to the Snake Bank fishery are available.

History of the estimates of recreational catch is provided in the Introduction – Cockle chapter. Estimated numbers of cockles harvested by recreational fishers in QMA 1 are provided in Table 2.

Table 2: Estimated numbers of cockles harvested by recreational fishers in QMA 1, and the corresponding harvest tonnage based on an assumed mean weight of 25 g. Figures were extracted from telephone-diary surveys in 1993–94, 1996, 1999–00, and 2000–01 and the national panel survey in 2011–12 and 2017–18.

Survey	Numbers	CV (%)	Tonnes	Reference
1993–94	2 140 000	18	55	Bradford (1997)
1996	569 000	18	14	Bradford (1998)
1999–00	2 357 000	24	59	Boyd & Reilly (2002)
2000–01	2 327 000	27	58	Boyd et al (2004)
2011–12	299 765	68	7	Wynne-Jones et al (2014)
2017–18	0	0	0	Wynne-Jones et al (2019)

1.3 Customary fisheries

In common with many other intertidal shellfish, cockles are very important to Māori as a traditional food.

Māori customary fishers can utilise the provisions under both the Fisheries (Amateur Fishing) Regulations 2013 and the Fisheries (Kaimoana Customary Fishing) Regulations 1998 when their rohe moana is gazetted. Patuharakeke gazetted their rohe moana which covers the southern shoreline of the Whangarei harbour in 2009. When tangata whenua harvest cockles under their recreational allowance, these are not included in records of customary catch.

The Fisheries New Zealand customary catch database does not contain any record of Māori customary harvest of cockles from COC 1A.

1.4 Illegal catch

Anecdotal evidence suggests that there was a significant illegal catch from Snake Bank in the 1990s, with some fishers greatly exceeding their catch limits. Commercial landings, therefore, may have been under-reported. There is also good evidence that illegal commercial gathering has occurred on MacDonald Bank on a reasonable scale in the past, which could have resulted in some over-reporting of catch from Snake Bank in some years. However, no quantitative information on the level of illegal catch is available.

1.5 Other sources of mortality

For further information on other sources of mortality, please refer to the Introduction – Cockle chapter.

2. BIOLOGY

Biological parameters used in this assessment are presented in the Introduction – Cockle chapter.

3. STOCKS AND AREAS

This is covered in the Introduction – Cockle chapter.

4. STOCK ASSESSMENT

Stock assessment for Snake Bank cockles has been conducted periodically using absolute biomass surveys, yield-per-recruit (YPR), and spawning stock biomass-per-recruit (SSBPR) modelling. The stock assessments were used to estimate *CAY* and *MCY*. A length-based stock assessment model was developed for cockles but was not successful. The last stock assessment was conducted in 2009 and is now considered too old to inform the status of the stock.

4.1 Estimates of fishery parameters and abundance

Estimated and reference fishing mortality rates, estimates of total mortality and exploitation rate are available for Snake Bank (Table 3, Figure 2). Exploitation rate in 2012 and 2013 was 0% and had generally had a downward trend since 1991 (70%) except for a large peak around 2001 (93%). Exploitation rate is likely to be overestimated in the calculation below because the size of commercially harvested cockles is believed to have decreased from over 30 mm to over 28 mm shell length over time.

Table 3: Estimates of fishery parameters.

Population and years	**Estimate**	**Source**
1. Estimated Fishing Mortality (F_{est}, recruited size classes only)		
Snake Bank, 1991–92	1.55	Cryer (1997)
Snake Bank, 1992–93	0.62	Cryer (1997)
Snake Bank, 1995–96	0.50	Cryer (1997)
Snake Bank, 1991–96	0.89	Cryer (1997)
2. Reference Fishing Mortality (F_{ref}, recruited size classes only)		
Snake Bank, $F_{0.1}$	0.41	Cryer (1997)
Snake Bank, F_{max}	0.62	Cryer (1997)
Snake Bank, $F_{50\%}$	4.52	Cryer (1997)
3. Total Instantaneous Mortality (Z, all size classes)		
Snake Bank, 1992–93	0.46	Cryer & Holdsworth (1993)
4. Exploitation rate percentage (≥ 30 mm shell length)		

Year*	%
1991	71
1992	41
1995	34
1996	57
1998	54
1999	38
2000	74
2001	93
2002	51
2003	21
2004	28
2005	14
2006	14
2007	11
2008	8
2009	11
2012	0
2013	0

* Exploitation rate is only given in years when biomass surveys were completed and catch reporting was considered reliable (apart from in 2012 and 2013 when no catch was reported, therefore the exploitation rate percentage must be zero.

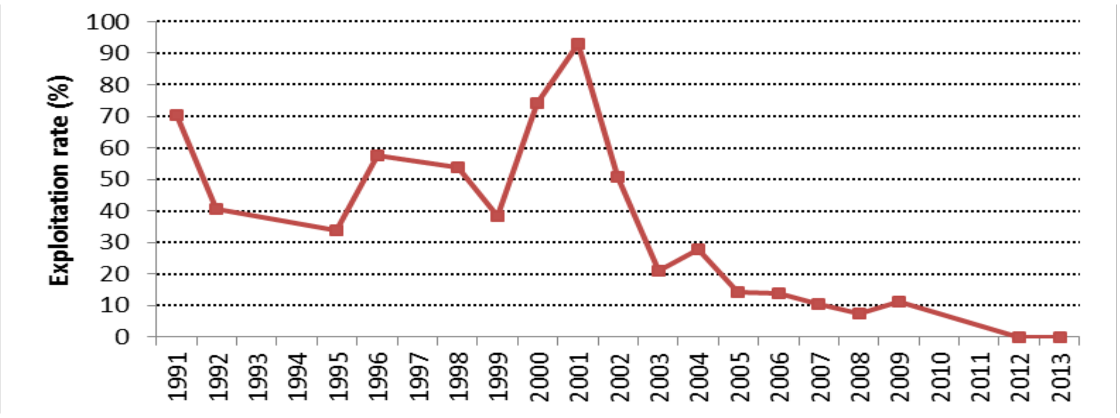


Figure 2: Exploitation rate (≥ 30 mm shell length).

4.2 Biomass estimates

Biomass estimates for the Snake Bank cockle population from 1982 to 1996 were made using grid surveys. Surveys done from 1998 used a stratified random approach (Table 4, Figure 3). The data given here differ from those in reports before 1997 because the assumptions made when estimating biomass have changed. The surveys conducted in 1985 and 1991 did not cover the whole area of the bank, and results from these surveys have been corrected in the table by assuming that the cockle population occupied the same area of the bank in these years as it did in 1982 (the first and largest survey). It has been further assumed for the estimation of variance for the grid-based surveys that samples have been taken at random from the bank, although variance estimators not requiring this assumption gave very similar results in 1995 and 1996. The post-1997 surveys also incorporated a large area of low density cockles not included in previous surveys, although this adds only a small tonnage of biomass to the total figure. In 1998 and 2000, biomass surveys were undertaken at MacDonald Bank using a stratified random approach (Table 5). Cryer et al (2003) reported biomass estimates for several locations in Whangarei Harbour in 2002, including a new MacDonald Bank stratum (Table 5). Northland Regional Council completed a survey in 2014 but only reported total biomass (Griffiths & Eyre 2014); this is included because it gives a recent indication of biomass in the absence of commercial fishing.

Virgin biomass, B_0, is assumed to be equal to the estimated biomass of cockles above a certain shell length in 1982. For example, if a length at recruitment of 30 mm or more was used, then a biomass of 2340 t resulted. This biomass was estimated using length frequency distributions, a length-weight regression, and a direct estimate of the biomass of cockles ≥ 35 mm shell length in 1982 (1825 t).

Between the start of the commercial fishery in 1982 and the survey in 1992, there was a consistent decline in the biomass of large cockles (≥ 30 mm shell length) on Snake Bank. The biomass of these large individuals declined to 33% of its virgin level in 1991. A decrease in the proportion and biomass of large, old individuals can be expected with the development of a commercial fishery. The biomass of mature cockles has fluctuated since then without trend between 63 and 19% of virgin levels. The recruited biomass is likely to be underestimated in the calculation below because the size of commercially harvested cockles is believed to have decreased from over 30 mm to over 28 mm shell length over time. There was no survey that has allowed calculation of percent B_0 since 2009.

Table 4: Estimates of biomass (t) of cockles on Snake Bank for surveys (*n*, number of stations) between 1982 and 2015. Biomass estimates for the ≥ 18 mm shell length component and those marked with an asterisk (*) were made using length frequency distributions and length-weight regressions; the other size fractions were generated by direct weighing of samples. Two alternative estimates are presented for 1988 because the survey was abandoned part-way through, 'a' assuming the distribution of biomass in 1988 was the same as in 1991, and 'b' assuming the distribution in 1988 was the same as in 1985. The 2001 result comes from the second of two surveys, the first having produced unacceptably imprecise results. The 2007 and 2008 results differ slightly from those reported previously because they were estimated using an analytical approach more consistent with that used in other years. The column '%$B_{recruited}$' compares the biomass in the ≥ 30 mm SL to the defined B_0 for that size (22 340 t in 1982).

		Total		≥ 18 mm SL		≥ 30 mm SL		≥ 35 mm SL		
Year	*n*	Biomass	CV	Biomass	CV	Biomass	CV	Biomass	CV	% $B_{recruited}$
1982	199	2 556	–	–	–	*2 340	–	1 825	~ 0.10	100
1983	187	2 509	–	2 460	0.06	*2 188	–	1 700	~ 0.10	94
1985	136	2 009	0.08	1 360	0.07	1 662	0.08	1 174	~ 0.10	71
1988 a	53	–	–	–	–	1 140	> 0.15	–	–	–
1988 b	53	–	–	–	–	744	> 0.15	–	–	–
1991	158	1 447	0.09	1 069	0.08	761	0.10	197	0.12	33
1992	191	1 642	0.08	1 355	0.07	780	0.08	172	0.11	33
1995	181	2 480	0.07	2 380	0.07	1 478	0.07	317	0.12	63
1996	193	1 755	0.07	–	–	796	0.08	157	0.11	34
1998	53	2 401	0.18	–	–	880	0.17	114	0.20	38
1999	47	3 486	0.12	2 645	0.11	1 321	0.14	194	0.32	56
2000	50	1 906	0.23	2 609	0.18	570	0.25	89	0.32	24
2001	51	1 405	0.17	1 382	0.17	435	0.17	40	0.29	19
2002	53	1 618	0.14	–	–	466	0.19	44	0.29	20
2003	60	2 597	0.11	2 385	0.31	1 030	0.12	121	0.14	44
2004	65	1 910	0.15	1 096	0.14	546	0.14	59	0.22	23
2005	57	2 592	0.18	2 035	0.15	967	0.20	111	0.20	41
2006	57	2 412	0.13	2 039	0.13	792	0.13	103	0.20	34
2007	73	2 883	0.13	2 681	0.13	1 434	0.15	329	0.42	61
2008	70	2 510	0.10	–	–	1 165	0.11	193	0.43	50
2009	75	1 686	0.15	–	–	815	0.13	88	0.19	35
2014	63	1 794	0.14	–	–	–	–	–	–	–

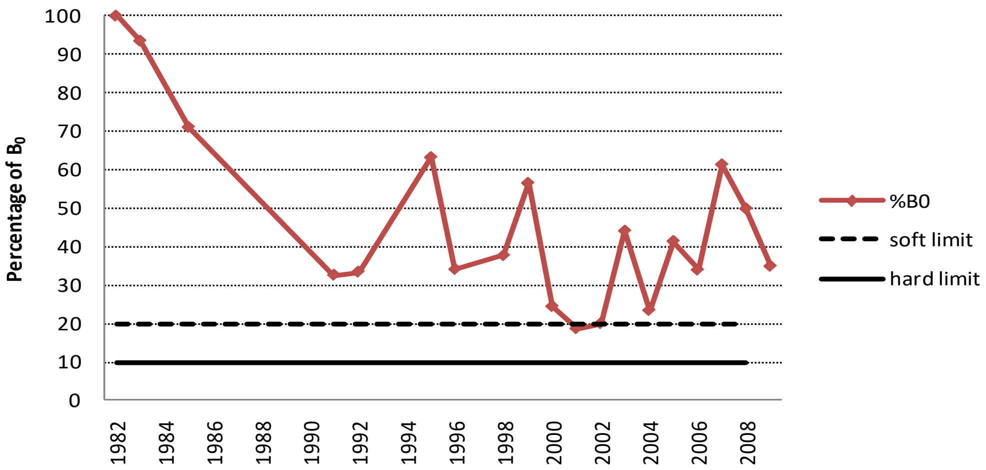


Figure 3: Recruited biomass (≥ 30 mm shell length) over time as a percentage of B_0 in relation to the hard and soft limits.

Table 5: Biomass estimates (t) and approximate CVs by shell length size classes for cockles on MacDonald Bank. *n* = the number of samples in the survey.

		Total		< 30 mm SL		≥ 30 mm SL		≥ 35 mm SL	
Year	*n*	Biomass	CV	Biomass	CV	Biomass	CV	Biomass	CV
1998	33	6 939	0.19	5 261	0.18	1 678	0.31	128	0.41
2000	30	6 037	0.28	4 899	0.29	1 137	0.30	34	0.37
2002	24	2 548	0.12	2 010	0.14	538	0.36	61	0.46

4.3 Yield estimates and projections

A range of sizes are taken commercially, selectivity seems to vary between years and *MCY* estimates are sensitive to the assumed size at recruitment to the fishery (Table 6). These are presented for two different shellfish lengths at recruitment into the fishery (when available): 30 mm, the historic size at recruitment; and 28 mm, the more recently accepted size at recruitment (Table 7). All these estimates include commercial and all non-commercial catch.

Because fishing is conducted year-round on Snake Bank, the Baranov catch equation is appropriate (Method 1, see Plenary introduction). This approach assumes that, between the start of the fishing year and when the biomass survey is started, productivity and catch cancel each other. The estimate includes non-commercial catch.

A range of sizes are taken commercially, selectivity seems to vary between years and *CAY* estimates are sensitive to the assumed size at recruitment to the fishery (Table 6). The level of risk to the stock by harvesting the population at the estimated *CAY* value cannot be determined.

Table 6: Sensitivity of biomass and *CAY* estimates to shell length at recruitment (L_{RECR}) for Snake Bank cockles.

L_{recr}(mm)	Rationale	B_{av} (1991–200) (t)	B_{curr}(2009) (t)	*M*	$F_{0.1}$	*MCY* (t)	*CAY* (t)
25	Smallest in catch	1 877	1 596	0.3	0.34	385	401
28	Fisher selectivity	1 409	1 265	0.3	0.38	289	349
30	Historical assumption	890	815	0.3	0.41	182	239
35	Largest cockles	145	88	0.3	1.00	30	49

4.4 Other yield estimates and stock assessment results

$F_{0.1}$ was estimated using a yield-per-recruit (*YPR*) model using quarterly (rather than the more usual annual) increments and critical sizes (rather than ages) for recruitment to the spawning stock and to the fishery. The following input information was used: growth rate parameters from a MULTIFAN analysis of 1991–96 length frequencies, an estimate of $M = 0.30$ (range 0.20–0.40) from a tagging study in 1984, length weight data from 1992, 1995, and 1996 combined, size at maturity of 18 mm, and size at recruitment of 30 mm from an analysis of fisher selectivity. For the base case analysis, $F_{0.1} = 0.41$. Estimates were neither sensitive to the length-weight regression used, nor to the value of *M* chosen

($F_{0.1}$ = 0.38–0.45 for M = 0.20–0.40), but were more sensitive to the assumed length at recruitment ($F_{0.1}$ = 0.34 for L_{recr} = 25 mm).

Table 7: *MCY* and *CAY* estimates (t) for different shell lengths at recruitment (L_{RECR}). *MCY* is calculated using the equation for developing fisheries before 1995 and developed fisheries after 1995. Year labels as given in Table 4.

Year	*MCY* ≥ 28 mm SL	*MCY* ≥ 30mm SL	*CAY* ≥ 28 mm SL	*CAY* ≥ 30mm SL
1982		240		687
1983		240		642
1985		240		488
1988 a		240		335
1988 b		240		218
1991		240		223
1992		240		229
1995		206		434
1996		196		234
1998		192		258
1999		206		388
2000		193		167
2001		180		128
2002		171		137
2003	269	175	255	302
2004		169		160
2005	238	171	389	284
2006	254	171	329	233
2007	243	179	516	421
2008	293	183	584	342
2009	268	182	349	239

4.5 Other factors

Biomass and yield estimates will differ for different sizes of recruitment. Māori and recreational fishers prefer cockles of 30 mm shell length and greater whereas commercial fishers currently prefer cockles of 25 mm and greater. Therefore, yield has been estimated for sizes of recruitment between 25 and 30 mm. Because cockles become sexually mature at around 18 mm, using a size of recruitment between 25 mm and 30 mm should provide some protection against egg overfishing under most circumstances. However, using the smaller size of recruitment to estimate yield will confer a greater risk of overfishing.

The Snake Bank cockle population may receive spat from spawning in other parts of Whangarei Harbour, and it may not be realistic to assume that the Snake Bank stock is discrete and that reduced egg production (as a result of heavy fishing mortality on medium and large sized individuals) would necessarily lead to recruitment overfishing. Spawning stock biomass-per-recruit (SSBPR) analysis suggests that $F_{50\%} > F_{max} > F_{0.1}$ ($F_{50\%}$ is that fishing mortality which would lead to egg production from the population at equilibrium being half of egg production from the virgin stock), except where the size at recruitment is reduced to 25 mm. Substantial reduction of egg production is therefore unlikely if fishing mortality is restrained to within $F_{0.1}$ or F_{max}, and the fishery concentrates on cockles over 30 mm in length.

However, it has been demonstrated for this bank that recruitment of juvenile cockles can be reduced by the removal of a large proportion of adult cockles from a given area of substrate. Conversely, there did not seem to be heavy recruitment to the population during the years when adult biomass was close to virgin (1982–85). This would suggest that there is some optimal level of adult biomass to facilitate recruitment, although its value is not known. It would appear prudent, therefore, to exercise some caution in reducing the biomass of adult cockles. If adult biomass is driven too low, then recruitment overfishing of this population could still occur despite high levels of egg production. In addition, sporadic recruitment of juveniles will probably lead to a fluctuating biomass, suggesting that a *CAY* approach may be more appropriate than a constant catch approach.

A length-based stock assessment model developed in 2000 allowed for more of the natural variability of the system to be incorporated in the stock assessment. This first model did not adequately capture the detail of cockle dynamics. Further work in 2002 (McKenzie et al 2003) did not resolve all these problems and substantial conflict remained in the model. Additional information on growth and the length frequency of cockles taken by the fishery was collected in 2003 and 2004 and updated in the model. Several additions and enhancements to the model were also made in an attempt to resolve the above-mentioned conflict (Cryer et al 2004, Watson et al 2005). As a result, the model showed an improved fit to the observed data. However, there still remained some conflict, primarily relating to annual variability in the growth increment data, in which only two years of observations were available (2002 and 2004). This was thought to be due to the existence of annual variability in recruitment, and possibly mortality, which are presently not explicitly modelled. Watson et al (2005) therefore concluded that no further development of the model should be undertaken for three to five years, and that resources be concentrated more on data collection, in particular, growth and recruitment data. Consequently, a tag-recapture experiment was started in March 2005, and additional large samples of cockles have been notch-tagged and released annually from 2005 to 2010. Tagged individuals were recovered and measured on a quarterly basis, and preliminary results suggested there may be strong seasonal variability in growth.

Although the Shellfish Working Group considered that the development of a length-based stock assessment model would be of considerable benefit to the stock assessment, the problems with the model were such that the current approach used to estimate yield for this fishery that had been agreed to by the Shellfish Fishery Assessment Working Group since 1992, would remain.

5. STATUS OF THE STOCKS

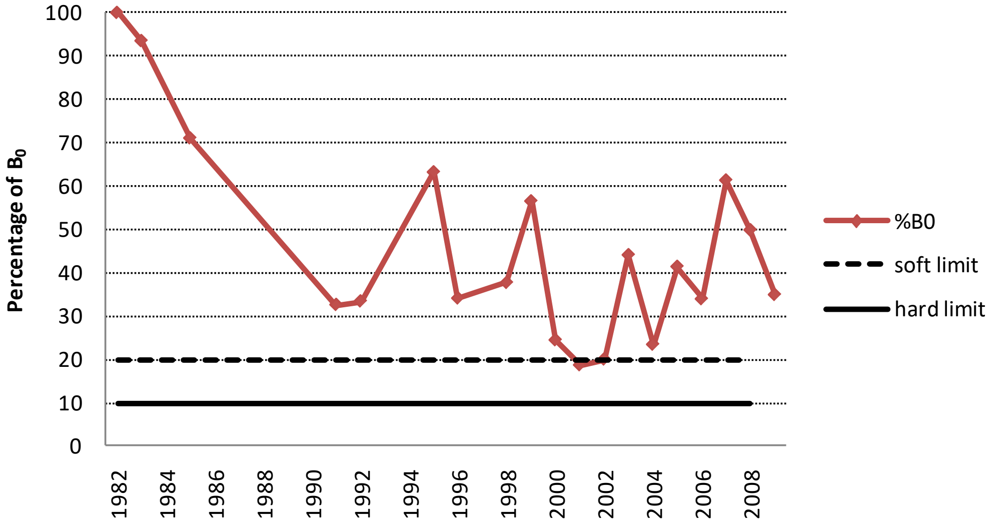
Stock structure assumptions
Snake Bank is assumed to be a single stock.

COC 1A

Stock Status	
Year of Most Recent Assessment	–
Assessment Runs Presented	–
Reference Points	Target: Not defined, but B_{MSY} assumed Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing Threshold: –
Status in relation to Target	Unknown
Status in relation to Limits	Unknown

Historical Stock Status Trajectory and Current Status

The current status is unknown



Recruited biomass (≥ 30 mm shell length) over time as a percentage of B_0 in relation to the hard and soft limits.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown

Recent Trend in Fishing Mortality or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	-
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	The commercial fishery has been closed since 2012.
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-

Assessment Methodology and Evaluation		
Assessment Type	–	
Assessment Method	–	
Assessment Dates	Latest assessment: 2009	Next assessment: Unknown
Overall assessment quality rank	–	
Main data inputs (rank)	–	
Data not used (rank)	–	
Changes to Model Structure and Assumptions	–	
Major sources of Uncertainty	–	

Qualifying Comments
Water quality issues have influenced the amount of time when cockles can be harvested from the bank in the past, e.g., the fishery was closed for 96 days in the 2009–10 year due to poor water quality.

Fishery Interactions
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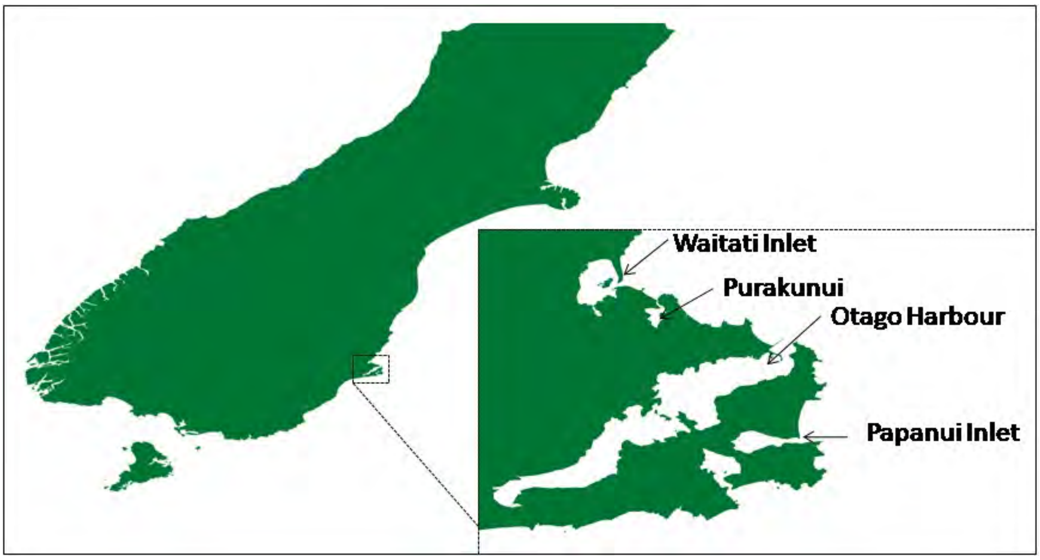
COCKLES (COC 3) Otago Peninsula

(*Austrovenus stutchburyi*)
Tuaki



1. FISHERY SUMMARY

COC 3 was introduced into the Quota Management System in October 2002 with a TAC of 1500 t, comprising a customary allowance of 10 t, a recreational allowance of 10 t, an allowance for other fishing related mortality of 10 t, and a TACC of 1470 t. Historical catch limits are shown in Table 1.

1.1 Commercial fisheries

Cockles are present at various locations around the Otago Peninsula but are only commercially fished from Papanui Inlet, Waitati Inlet, and Otago Harbour.

Commercial fishing in Papanui and Waitati Inlets began in 1983. A limit of 104 t was in effect for Papanui and Waitati Inlets combined from 1986–87 until 1991–92 (Table 1). From 1992–93 to 1998–99, separate catch limits were set for each inlet: 90 t for Papanui Inlet and 252 t for Waitati Inlet. In April 2000, based on new CAY estimates (Breen 1999) for each area, the catch limits were increased to 427 t for Papanui Inlet and 746 t for Waitati Inlet. In 2002 when cockles entered the QMS spatial restrictions upon harvest within COC 3 were removed.

From August 2009 until 31 January 2017, cockles were taken from Otago Harbour under a special permit in order to investigate the ecosystem effects of commercial cockle harvesting in this location (Table 1). This permit stated no explicit limit to the tonnage able to be taken but delimited the area where harvest would be taken. Subsequently, in November 2018, regulation 10 of the Fisheries (South-East Area Commercial Fishing) Regulations 1986 closing Otago Harbour to commercial shellfish harvest was amended to allow harvest from two beds corresponding to sanitation areas 1804 (Port Chalmers) and 1805 (Sawyers Bay).

Total landings have remained below the TACC since 2002–03, with the highest landings since the beginning of the time series recorded in 2018–19 (1008 t), but landings in 2019–20 declined slightly (872 t) to a value more similar to the recent average (Table 1, Figure 1).

In 1992, 35 mm shell length was the minimum size for commercial cockles. However, commercial fishers currently target the favoured market size of 28 mm or more.

Table 1: Reported landings (t) of cockles from Papanui and Waitati Inlets, Otago harbour (by each sanitation area and overall) and the entire FMA, since 1986–87 based on Licensed Fish Receiver Returns (LFRR). Catch splits are provided by Southern Clams Ltd. N/A = Not Applicable.

	Papanui Inlet		Waitati Inlet		Otago Harbour catch (t)			Total	
Year	catch (t)	limit (t)	catch (t)	limit (t)	Sanitation area, 1804	Sanitation area, 1805	Total	catch (t)	limit (t)
1986–87	14	–	–	–			–	14	104
1987–88	8	–	–	–			–	8	104
1988–89	5	–	–	–			–	5	104
1989–90	25	–	–	–			–	25	104
1990–91	90	–	16	–			–	106	104
1991–92	90	–	14	–			–	104	104
1992–93	90	90	92	252			–	182	342
1993–94	90	90	109	252			–	199	342
1994–95	90	90	252	252			–	342	342
1995–96	90	90	252	252			–	342	342
1996–97	90	90	252	252			–	342	342
1997–98	90	90	252	252			–	342	342
1998–99	90	90	293	252			–	383	342
1999–00	118	427	434	746			–	552	1 273
2000–01	90	427	606	746			–	696	1 273
2001–02	49	N/A	591	N/A			–	640	1 273
2002–03	52	N/A	717	N/A			–	767	1 470
2003–04	73	N/A	689	N/A			–	762	1 470
2004–05	91	N/A	709	N/A			–	800	1 470
2005–06	68	N/A	870	N/A			–	943	1 470
2006–07	0*	N/A	907	N/A			–	907	1 470
2007–08	–	N/A	760	N/A			–	760	1 470
2008–09	–	N/A	751	N/A	2	21	24	775	1 470
2009–10	–	N/A	379	N/A	188	253	441	820	1 470
2010–11	–	N/A	240	N/A	567	30	596	836	1 470
2011–12	–	N/A	358	N/A	153	284	437	795	1 470
2012–13	–	N/A	403	N/A	98	290	387	790	1 470
2013–14	–	N/A	438	N/A	201	161	362	800	1 470
2014–15	–	N/A	466	N/A	90	259	349	815	1 470
2015–16	–	N/A	453	N/A	193	276	469	923	1 470
2016–17	–	N/A	825	N/A	44	94	138	967	1 470
2017–18	48	N/A	906	N/A	0	0	0	954	1 470
2018–19	27	N/A	153	N/A	348	480	828	1 008	1 470
2019–20	0	N/A	417	N/A	205	250	455	872	1 470
2020–21	4	N/A	629	N/A	143	118	261	894	1 470

*No catches have been taken from Papanui Inlet between 2006–07 and 2016–17 because of water quality problems.

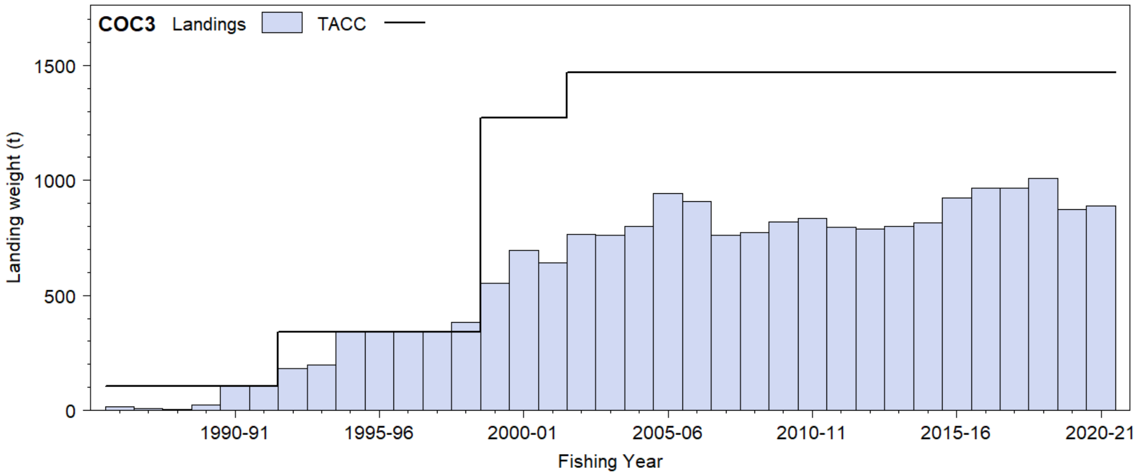


Figure 1: Reported commercial landings and TACC for COC 3 (Otago).

1.2 Recreational fisheries

Cockles are taken by recreational fishers in many areas of New Zealand. The recreational fishery is harvested entirely by hand digging.

No recreational harvest estimates specific to the COC 3 commercial fishery areas are available. History of the estimates of recreational catch is provided in the Introduction – Cockle chapter. Estimated numbers of cockles harvested by recreational fishers in QMA 3 are provided in Table 2.

Table 2: Estimated numbers of cockles harvested by recreational fishers in QMA 3, and the corresponding harvest tonnage based on an assumed mean weight of 25 g. Figures were extracted from telephone-diary survey in 1993–94, 1996 and 1999–00, and from the National Panel Survey in 2011–12 and 2017–18.

Survey	Numbers	% CV	Tonnes	Reference
1993–94 South	106 000	51	2.7	Teirney et al (1997)
1996	144 000	–	3.6	Bradford (1998)
1999–00	1 476 000	45	36.9	Boyd & Reilly (2002)
2011–12	300 158	67	7.5	Wynne-Jones et al (2014)
2017–18	103 359		2.6	Wynne-Jones et al (2019)

1.3 Customary non-commercial fisheries

Many intertidal bivalves, including cockles, are very important to Maori as traditional food, particularly to Huirapa and Otakou Maori in the Otago area. For information on customary catch regulations and reporting refer to the Introduction – Cockle chapter.

Estimates of customary catch under the provisions made for customary fishing for COC 3 are shown in Table 3. These numbers are likely to be an underestimate of customary harvest because only the approved and harvested catch in weight (kg) and in numbers are reported in the table. In addition, many tangata whenua also harvest cockles under their recreational allowance and these are not included in records of customary catch.

Table 3: Fisheries New Zealand records of customary harvest of cockles (reported as weight (kg) and numbers) in COC 3 since 2000–01. – no data.

	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
2000–01	–	–	400	400
2001–02	–	–	37	37
2002–03	–	–	1 200	1 200
2003–04	–	–	–	–
2004–05	–	–	–	–
2005–06	–	–	–	–
2006–07	100	100	9 100	7 680
2007–08	–	–	500	500
2008–09	–	–	24 496	23 865
2009–10	–	–	4 750	4 750
2010–11	–	–	19 500	19 500
2011–12	30	28	10 600	10 600
2012–13	–	–	–	–
2013–14	–	–	2 300	2 100
2014–15	–	–	–	–
2015–16	80	80	9 610	9 510
2016–17	–	–	5 500	5 240
2017–18	–	–	4 950	4 800
2018–19	–	–	–	–
2019–20	–	–	3 140	3 140
2020–21	–	–	7 400	7 400

On 1 October 2010, on the recommendation of the Taiāpure Committee, the Minister of Fisheries introduced new regulations for the East Otago Taiāpure[1]. These included a new amateur daily bag limit of 50 for shellfish, including cockles, and a ban on the commercial take of cockles from any part of the Taiāpure, except for the existing sanitation areas within Waitati Inlet. The new regulations reflect the Committee's concern about fishing pressure on shellfish stocks, including cockles, within the Taiāpure.

A long-running time series of surveys suggest that there are no sustainability concerns for cockles within the Taiāpure. However, they do indicate a shift in some beds towards smaller size classes of cockle.

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[1] The Kati Huirapa Runanga ki Puketeraki application for a taiāpure-local fishery was gazetted as the East Otago Taiāpure-Local Fishery in 1999. A management committee, made up of representatives from the Runanga and various recreational, environmental, commercial, community and scientific groups, was appointed in 2001.

The Committee hopes that reducing the bag limit and limiting the spatial extent of commercial harvest will lead to an increase in the number of large cockles.

The Ōtākou Mataitai Reserve was established over the outer Otago Harbour in 2016 in recognition of the importance of this area as a traditional customary food source.

1.4 Illegal catch

There is qualitative data to suggest illegal, unreported, unregulated (IUU) activity in this Fishery.

1.5 Other sources of mortality

For further information on other sources of mortality, please refer to the Introduction – Cockle chapter.

Other mortality sources would include predation from oystercatchers (*Haematopus ostralegus*) and other wading birds, and sediment burial via landslips or shifting sediments (Stephenson, 1981).

2. BIOLOGY

Biological parameters used in this assessment are presented in the Introduction – Cockle chapter.

3. STOCKS AND AREAS

Each inlet is assumed to be an independent fishery within the stock.

4. STOCK ASSESSMENT

Stock assessments for Papanui Inlet and Waitati Inlet have been conducted using absolute biomass surveys, yield-per-recruit analyses, and Method 1 for estimating CAY (See Introduction chapter of Plenary). From a 1998–99 survey, Breen et al. (1999) also estimated biomasses and yields and size composition for clams in Papanui Inlet and Waitati Inlet as well as five beds within Otago Harbour (Harwood, Aramoana, Port Chalmers, Sawyers Bay, and St Leonards), and Purakanui Inlet (Table 7). Stewart (2006, 2008a) estimated biomass and yields for Papanui and Waitati Inlets in 2004 and Waitati Inlet in 2007. Similarly, Jiang et al estimated biomass and yields for Papanui and Waitati Inlets in 2011 (Jiang et al 2011). Stewart (2017) also estimated the size structure and biomass for clams in part of Sanitation areas 1804 and 1805 in Otago Harbour in January 2007, 2012 and 2017. Miller & Black (2019) calculated MCY and CAY for the recruited biomass of commercial beds in Waitati Inlet using Method 1 and yield per recruit (YPR) values calculated by previous surveys. In 2020 the five Otago Harbour beds were resurveyed providing estimates of biomass and size composition (Beentjes 2021). Sanitation area 1804 includes the Port Chalmers bed, and Sanitation area 1805 the Sawyers Bay bed.

4.1 Estimates of fishery parameters and abundance

A project to estimate growth and mortality in Papanui and Waitati Inlets, Purakanui and Otago Harbour was undertaken in the late 1990s. Notched clams did not exhibit significant growth when recovered after one year, and modes in the length frequency distributions did not shift when measured over four sampling periods within a year (Breen et al 1999).

Yield-per-recruit modelling has been conducted for Papanui and Waitati inlets separately (Stewart 2006, 2008a, Jiang et al 2011, Miller & Black 2019) and for Otago harbour (Stewart 2017). The most recent parameters used in this modelling are detailed in table 2 of the cockle introductory section. Estimates of $F_{0.1}$ from these studies are given in Table 4. The exploitation rate has never exceeded 13% for Waitati, Papanui Inlet and Otago harbour sanitation areas (beds 1804 and 1805 combined and individually) (Table 5, Figure 2).

Table 4: Estimates of fishery parameters (recruitment to this fishery is at ≥ 28 mm)

M	$F_{0.1}$ 2004	$F_{0.1}$ 2007	$F_{0.1}$ 2011		$F_{0.1}$ 2017	$F_{0.1}$ 2019
			Waitati	Papanui	Otago harbour	Waitati
0.2	0.2321	0.2899	0.2600	0.2900	0.2899	0.2899
0.3	0.3412	0.3863	0.3900	0.4400	0.3863	0.3863
0.4	0.4767	0.5537	0.5300	0.6000	0.5537	0.5537

Table 5: Exploitation rate % as calculated by commercial landings divided by biomass (≥ 30 mm) from Papanui Inlet (whole inlet), Waitati Inlet (whole inlet) and Otago Harbour Sanitation areas (beds 1804 and 1805 combined)*.

Year	Papanui Inlet	Waitati Inlet	Otago Harbour		
			Sanitation areas combined	Sanitation area, 1804	Sanitation area, 1805
1998	2	3			
2002	1	8			
2004	2	9			
2007		13	0	0	0
2011	0	2	5	4	7
2017			2	1	4
2019		3			

* This measure is likely to overestimate exploitation as harvest occurs down to a size limit of 28 mm.

4.2 Biomass estimates

Biomass surveys have been undertaken periodically in COC 3 since 1984. The methods for the calculation of biomass have changed over time[2] which means that comparison of biomass values between times of different calculation methodologies should be conducted cautiously.

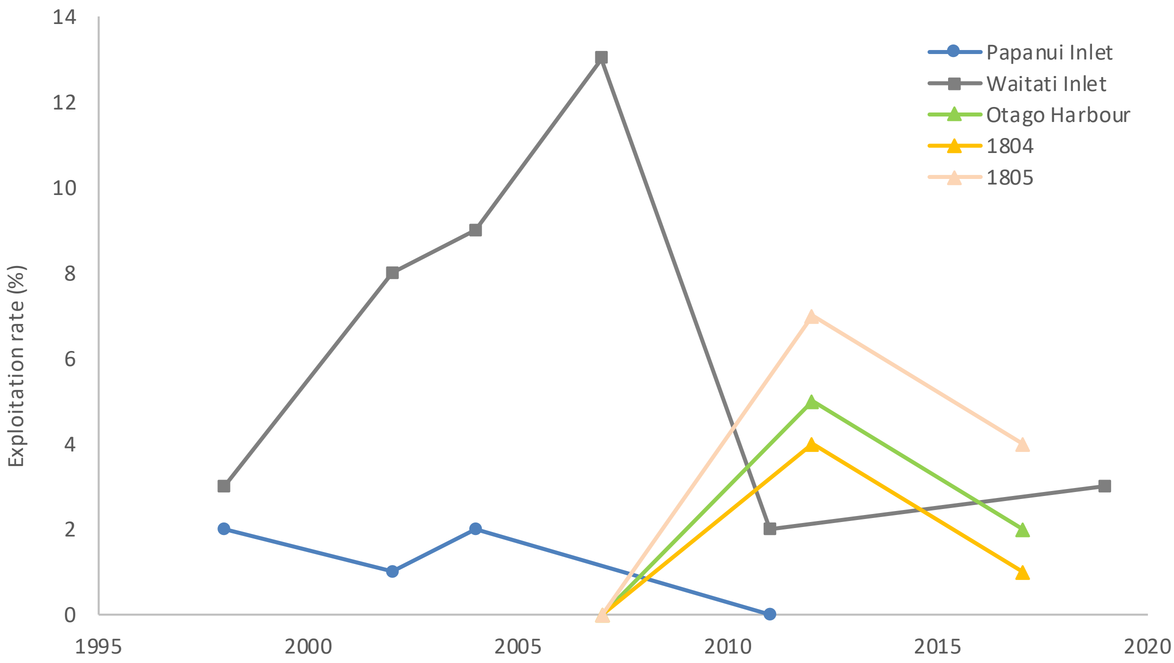

Figure 2: Exploitation rate (%) as calculated by commercial landings divided by biomass (≥ 30 mm) from Papanui Inlet (whole inlet), Waitati Inlet (whole inlet) and Otago Harbour Sanitation areas (beds 1804 and 1805 combined). Note: This measure is likely to overestimate exploitation as harvest occurs down to a size limit of 28 mm.

The spawning stock biomass (19 mm or more, shell length) was stable around the level of virgin biomass in Waitati Inlet until 2007 and has increased since (Table 6, Figure 3). In Papanui Inlet the spawning stock biomass (19 mm or more shell length) showed a trend of gradual decline from 1984 until 2011, when it was at 73% of virgin biomass. No commercial harvesting has occurred in Papanui

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[2] Wildish (1984a and b) and Stewart et al (1992) separated cockles by sieving into three size classes. Breen et al (1999) measured random samples of cockles from each inlet to calculate length-weight relationships. The first method only allows estimation of biomass from predetermined size classes. By calculating size structure of populations using length to weight data, a more flexible approach is allowed where data can be matched to current commercial needs as well as to future survey results. The 1998 survey used random samples from each inlet to calculate length to weight relationships (Breen et al 1999). This method was once again used in the 2002 survey (Wing et al 2002). In the 2004 and 2007 surveys random samples from each shellfish bed were weighed and their longest axis measured (Stewart 2006, 2008a). These data were then used to generate length to weight relationships. The 2017 survey replicated the method used in the 2004 and 2007 surveys. The 2020 survey of Otago Harbour followed the methods of Breen et al. 1999 (Beentjes 2021).

Inlet since 2006–07. The recruited biomass (30 mm or more shell length) in the sanitation areas (beds 1804 and 1805) in Otago Harbour decreased before the start of harvesting in 2008 and has decreased more since then (to 60% of virgin biomass). A new survey was conducted in January 2017. From 164 stations at bed 1804 and 176 stations at bed 1805 the total clam biomass for each bed was estimated to be 4549 tonnes for 1804 and 4829 tonnes for 1805.

Table 6: Survey biomass estimates (B in tonnes) and ± 95% confidence intervals (CI) from COC 3*.

Size classes	>2 to 18 mm (juveniles)		19 – 34 mm (adults)		≥ 30 mm		≥ 35 mm		Total (t)	
	B	± 95% CI	B	± 95% CI	B	± 95% CI	B	± 95% CI	B	± 95% CI
Papanui Inlet										
1984	65		3 705				2 370		6 140	
1992	139	41	3 721	852			1 706	635	5 567	1 058
1998	33	11	3 435	645	3 990	1 115	2 231	708	5 699	1 154
2002 (total inlet)	17	1.7	1 970	192	3 860	365	2 579	252	4 565	424
2002 (Commercial area)	8	1.2	888	111			1731	210	2 628	305
2004 (total inlet)	36	2.2	2 415	151	3 677	367	2 301	273	4 752	425
2004 (Commercial area)	13	1.3	825	88	2 420	271	1 847	208	2 685	298
2011 (total inlet)	8	1.4	1 400	168	4 025	542	3 048	429	4 457	601
2011 (Commercial area)	4		401				1 508		1 913	
Waitati Inlet**										
1984	619		7 614				3 844		12 080	
1992	1 210	115	5 198	363			4 620	596	11 027	707
1998	304	63	8 519	1 241	7 235	1 625	4 381	1 335	13 204	1 947
2002 (total inlet)	153	20	6 653	652	7 183	463	4 298	298	11 103	848
2002 (Commercial area)	26	1.8	2 622	168			3 630	260	6 278	410
2004 (total inlet)	257	14	7 272	403	7 993	720	4 535	508	12 064	925
2004 (Commercial area)	77	4	2 735	129	5 612	681	3 872	384	6 685	517
2007 (total inlet)	335	26	4 507	347$*^3$	7 106	548	3 941	462	11 948	921
2007 (Commercial area)	102	7.5	1 284	95$*^3$	4 726	352			6 112	456
2011 (total inlet)	220	14	7 348	501	11 441	946	6 323	643	13 892	1 149
2011 (Commercial area)	48		2 846		6 881		5 114		8 008	
2019 (total inlet)	885	67	5 403	369$*^3$	7 875	601			14 162	1 082
2019 (Commercial area)	105	7	1 677	109$*^3$	4 535	294			6 317	410
Purakunui Inlet										
1998					1 825					
Otago Harbour										
1998					32 975					
2020					20 606				22 978	
Otago Harbour Sanitation area, 1804										
1998					8 091$*^4$					
2007	208	15	472	35	5 473	402			6 153	452
2012	155	19	348	44	4 183	497			4 686	560
2017	312	42.35	148	20	4 100	554			4 550	616
2020					3 675$*^4$	1 374			3 715$*^4$	1 386
Otago Harbour Sanitation area, 1805										
1998					5 546$*^4$					
2007	375	41	3 387	367	3 526	382			7 288	790
2012	385	46	2 016	241	4 078	472			6 479	764
2017	1 106	201	1 465	271	2 258	416			4 829	888
2020					4 384$*^4$	978			5 353$*^4$	1 165

*Wildish 1984a; Stewart et al 1992; Breen et al 1999; Wing et al 2002; Stewart, 2006; Stewart 2008a (table 4.1.5), Stewart 2008b; Jiang et al 2011; Stewart 2013, Stewart 2017, Beentjes 2021. Area of current commercial beds, Papanui Inlet = 815 811 m^2. **Area of current commercial beds, Waitati Inlet = 943 986 m^2. $*^3$ = this value is only for ≥19 mm to <30 mm cockles. $*^4$ The surveys of Breen et al 1999 and Beentjes 2021 covered a larger extent of these beds than the three subsequent surveys in 2007–08, 2012 and 2017.

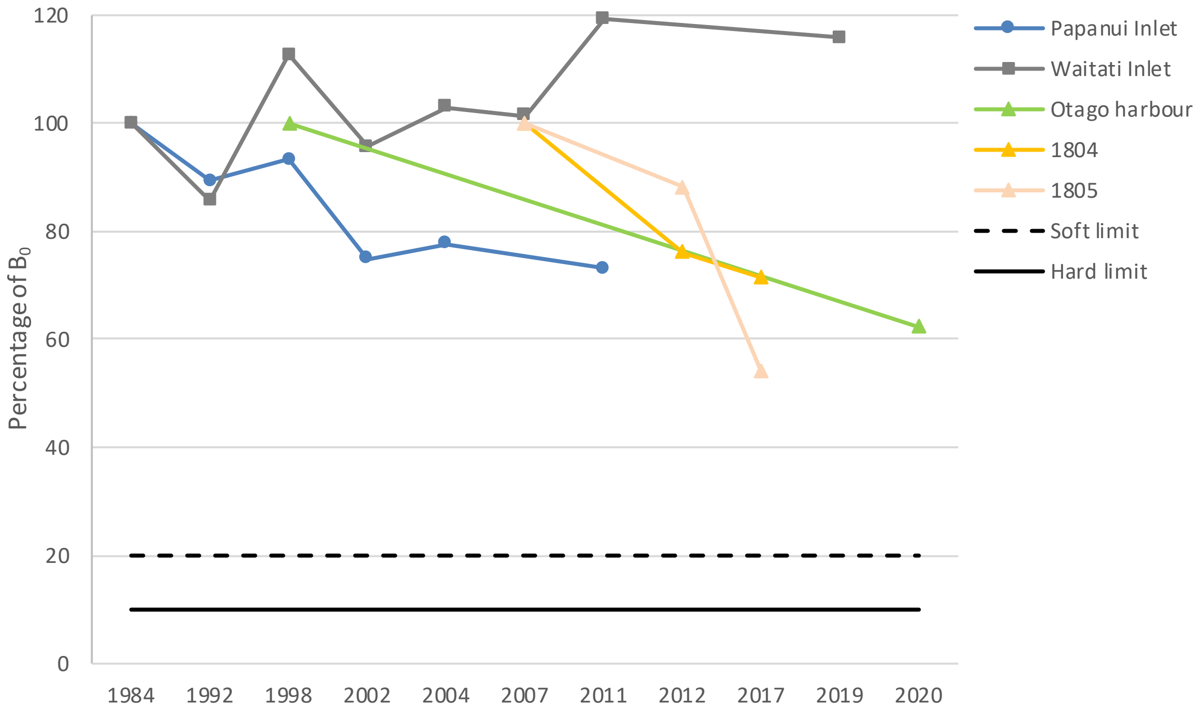


Figure 3: Biomass as a proportion of *B0*. For Papanui Inlet, Waitati Inlet, and the two sanitation areas (1804 and 1805) this is estimated for biomass ≥ 19mm. For Otago harbour, the estimates are for biomass ≥ 30 mm. For the 2020 Otago harbour survey, the biomass of the additional bed (Te Rauone, 69 t) was removed so the 1998 and 2020 surveys could be compared. Virgin biomass was taken as biomass estimated during the first survey for each area. Note: No catch has been taken from Papanui Inlet between 2006–07 and 2016–17.

4.4 Other factors

Commercial, customary and recreational fishers target different sized cockles. Biomass and yield estimates will differ for different sizes of recruitment to the fishery. Maori and recreational fishers prefer larger cockles (45 mm shell length and greater) whereas commercial fishers currently prefer cockles of around 28–34 mm. Commercial fishers currently target cockles 28 mm or more, therefore 28 mm is used as the effective minimum size in yield calculations; however, these estimates do not consider multiple fisheries preferring different sized cockles. Depending on the management approach taken in the future in COC 3, the appropriateness of the current methods to estimate yield may need to be reviewed.

The yield estimates use information from yield-per-recruit analyses that assume constant recruitment and constant growth and mortality rates. Yield estimates will be improved when growth, mortality and recruitment variation are better known.

As cockles become sexually mature at around 18 mm, using a size of recruitment of 30 mm should provide some protection against egg overfishing under most circumstances. Certainly the increase in the biomass of small cockles (2 to 18 mm) seen in both inlets in 2004 suggests that the very poor recruitment observed by Wing et al (2002) may have been due to natural variability, and supports the conjecture that significant recruitment might occur only sporadically in the Otago fishery, as suggested by John Jillett (*pers. comm.)* and Breen et al (1999). The possibility that fishing has an effect on recruitment remains an unknown.

In other cockle fisheries it has been shown that recruitment of juvenile cockles can be reduced by the removal of a large proportion of adult cockles from a given area of substrate. This would suggest that there is some optimal level of adult biomass to facilitate recruitment, although its value is not known. To date it has not been determined whether the cockles being targeted by commercial harvesting in the Otago fishery comprise the bulk of the spawning stock or if disturbance of the cockle beds is influencing settlement.

The distribution of very small size classes (2 to 10 mm) across the various beds is variable and no consistent differences exist for this size of shellfish between commercial and non-commercial beds (Stewart 2008a). A comparison of the size/frequency histograms with fishing history for each bed would be a worthwhile exercise and may reveal more. The fact that the relationship between spawning stock and recruitment in this fishery is poorly understood remains a concern.

The effects of the illegal catch, the Maori traditional catch and incidental handling mortality are unknown, although illegal catch is thought to be insignificant. The impacts of the recreational fishery are probably minor compared with those from the commercial fishery.

Table 7: *CAY* estimates (*t*) for COC 3. WI = Waitati Inlet, PI = Papanui Inlet, WIc and PIc are estimates for commercial areas only, B_{beg} = Projected biomass at the beginning of the fishing year. References: (a) Breen et al 1999, (b) Wing et al 2002, (c) Stewart 2006, (d) Stewart 2008a, (e) Jiang et al 2011 and (f) Miller & Black 2019.

				WI		WIc		PI		PIc		
Year	*M*	$F_{0.1}$	≥ SL (mm)	B_{beg}	*CAY*	B_{beg}	*CAY*	B_{beg}	*CAY*	B_{beg}	*CAY*	Reference
1999	0.2	0.258	30	7 235	1 498			3 990	826			(a)
1999	0.3	0.357	30	7 235	1 848			3 990	1 019			(a)
1999	0.4	0.457	30	7 235	2 221			3 990	1 225			(a)
2002	0.2	0.2017	30	7 183	1 193	5 364	891	3 860	641	2 322	386	(b)
2002	0.3	0.3015	30	7 183	1 627	5 364	1 215	3 860	874	2 322	526	(b)
2002	0.4	0.3956	30	7 183	1 960	5 364	1 464	3 860	1 053	2 322	634	(b)
2004	0.2	0.2321	30	9 399	1 771	6 081	1 146	4 119	776	2 454	462	(c)
2004	0.3	0.3412	30	9 399	2 367	6 081	1 532	4 119	1 038	2 454	618	(c)
2004	0.4	0.4767	30	9 399	2 984	6 081	1 930	4 119	1 308	2 454	779	(c)
2007	0.2	0.2899	28	8 378	1 920	5 261	1 206					(d)
2007	0.3	0.3863	28	8 378	2 342	5 261	1 471					(d)
2007	0.4	0.5537	28	8 378	2 990	5 261	1 878					(d)
2007	0.2	0.2899	30	7 106	1 629	4 725	1 083					(d)
2007	0.3	0.3863	30	7 106	1 986	4 725	1 321					(d)
2007	0.4	0.5537	30	7 106	2 536	4 725	1 686					(d)
2011	0.2	0.26	30	11 441	2 385	6 881	1 434					(e)
2011	0.3	0.39	30	11 441	3 223	6 881	1 938					(e)
2011	0.4	0.53	30	11 441	3 948	6 881	2 374					(e)
2011	0.2	0.29	30					4 026	923	1 784	409	(e)
2011	0.3	0.44	30					4 026	1 252	1 784	555	(e)
2011	0.4	0.60	30					4 026	1 527	1 784	677	(e)
2019	0.2	0.2899	28	9 330	2 138	5 089	1 166					(f)
2019	0.3	0.3863	28	9 330	2 608	5 089	1 423					(f)
2019	0.4	0.5537	28	9 330	3 330	5 089	1 816					(f)

5. STATUS OF THE STOCKS

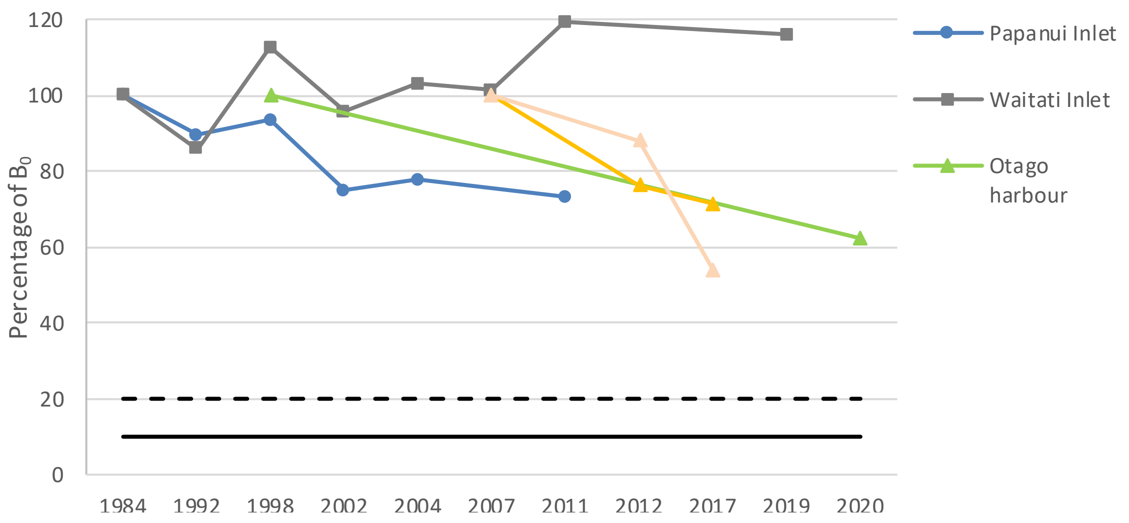
Stock structure assumptions

Each inlet is assessed separately.

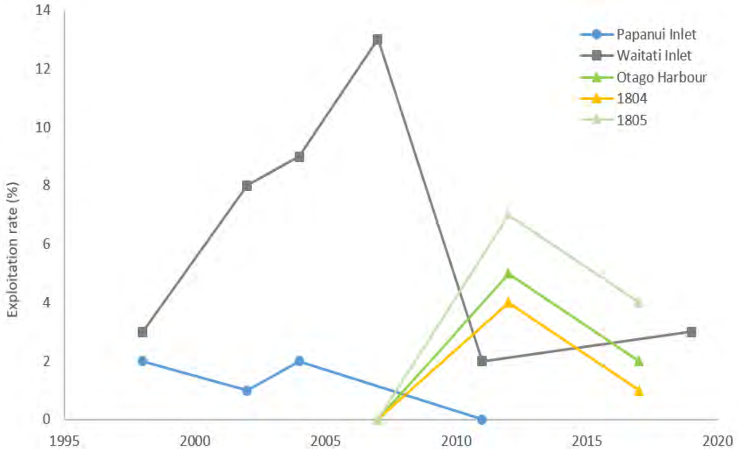
- **COC 3**

Stock Status	
Year of Most Recent Assessment	2020 - Otago harbour
Assessment Runs Presented	Survey biomass estimate for ≥ 19 mm shell length
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Not defined
Status in relation to Target	Likely (> 60%) to be at or above the target
Status in relation to Limits	For Papanui Inlet, Waitati Inlet, Otago harbour and each sanitation area (1804 and 1805): Very Unlikely (< 10%) to be below both soft and hard limits
Status in relation to overfishing	Exploitation rate has never exceeded 13% at any of the harvested sites. It is Very Unlikely (< 10%) that overfishing is occurring.

Historical Stock Status Trajectory and Current Status



Biomass as a proportion of B_0. For Papanui Inlet, Waitati Inlet, and the two sanitation areas (1804 and 1805); this is estimated for the biomass ≥ 19 mm. For Otago harbour, the estimates are for biomass ≥ 30 mm. For the 2020 Otago harbour survey, the biomass of the additional bed (Te Rauone, 69 t) was removed so the 1998 and 2020 surveys would be comparable. Virgin biomass was assumed as the biomass estimated during the first survey for each area. Note: No catch was taken from Papanui Inlet between 2006–07 and 2016–17.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The biomass at Waitati Inlet has been stable or increasing and has never decreased below 85% B_0. At Papanui Inlet, biomass generally decreased to approximately 70% of B_0 in 2004 but little commercial catch has come out of this inlet since. In Otago Harbour, recruited biomass has shown a declining trend in the commercially fished Sanitation bed 1804 (54% decline from 1999 to 2020), whereas in Sanitation bed 1805 it has been variable but stable from 1999 to 2020. The three other non-commercial beds in Otago Harbour showed declines of between 26% –65% between 1999 and 2020.
Recent Trend in Fishing Intensity or Proxy	Exploitation rate has never exceeded 13% at any of the harvested sites, and even the 13% rate was a single-year event that subsequently declined considerably. It is Very Unlikely (< 10%) that overfishing is occurring.  **Exploitation rate (%) as calculated by commercial landings divided by biomass (≥ 30 mm) from Papanui Inlet (whole inlet), Waitati Inlet (whole inlet) and Otago Harbour Sanitation areas (beds 1804 and 1805 combined).**
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	-
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Fishing at recent levels is Very Unlikely (< 10%) to cause declines below soft or hard limits
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (<10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Absolute biomass estimates from quadrat surveys	
Assessment Dates	Latest assessment: 2020	Next assessment: Unknown
Overall assessment quality rank	-	
Main data inputs (rank)	- Abundance survey - Length frequency	
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
For Papanui Inlet, the classification of this area changed from Conditionally Approved to Restricted on 9 June 2009. The Restricted classification allows for harvesting to take place under the following conditions: by a special permit as required for relaying, for depuration or for harvest treatment.

Fishery Interactions
Harvesting had a severe but short-lived impact on macroinfaunal community structure and no change in sediment structure was found after harvesting (Irwin 2004). Overall, adverse effects from harvesting at the current level appear to be no more than minor and of a transitory nature (Stewart 2017).

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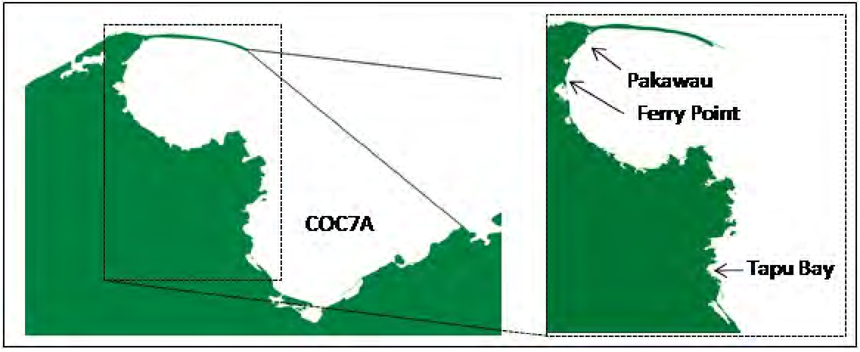
COCKLES (COC 7A) Tasman and Golden Bays

(*Austrovenus stutchburyi*)
Tuangi



1. FISHERY SUMMARY

COC 7A was introduced into the Quota Management System in October 2002 with a TAC of 1510 t which comprised a customary allowance of 25 t, a recreational allowance of 85 t, an allowance for other fishing related mortality of 10 t, and a TACC of 1390 t. These limits have remained unchanged since. The TACC was set higher than historical catch levels on the basis of the development potential of assessed beds.

1.1 Commercial fisheries

Commercial harvesting at Pakawau Beach in Golden Bay began in 1984, but with significant landings taken only since 1986. Harvesting at Pakawau Beach has occurred every year since 1984. Cockles have also been taken commercially from the Tapu Bay-Riwaka area (in Tasman Bay) since 1992–93, and Ferry Point (in Golden Bay) since 1998–99. Catch statistics (Table 1) are derived from company records and QMS returns. All commercial landings have been taken by mechanical harvester. Historical landings and TACC for this stock are depicted in Figure 1.

Table 1: Reported landings (t) of cockles from all commercially harvested areas in COC 7A. Landings from 1983–84 to 1991–92 are based on company records.

Fishing Year	Total Landings	TACC	Fishing Year	Total Landings	TACC
1983–84	2	225	2002–03	569	1 390
1984–85	38	225	2003–04	553	1 390
1985–86	174	225	2004–05	428	1 390
1986–87	230	225	2005–06	460	1 390
1987–88	224	225	2006–07	337	1 390
1988–89	265	300	2007–08	237	1 390
1989–90	368	300	2008–09	307	1 390
1990–91	535	300	2009–10	301	1 390
1991–92	298	300	2010–11	348	1 390
1992–93	300	336	2011–12	220	1 390
1993–94	440	336	2012–13	269	1 390
1994–95	326	336	2013–14	290	1 390
1995–96	329	336	2014–15	263	1 390
1996–97	325	336	2015–16	263	1 390
1997–98	513	949	2016–17	238	1 390
1998–99	552	1 130	2017–18	254	1 390
1999–00	752	1 130	2018–19	187	1 390
2000–01	731	1 134	2019–20	146	1 390
2001–02	556	1 134	2020–21	293	1 390

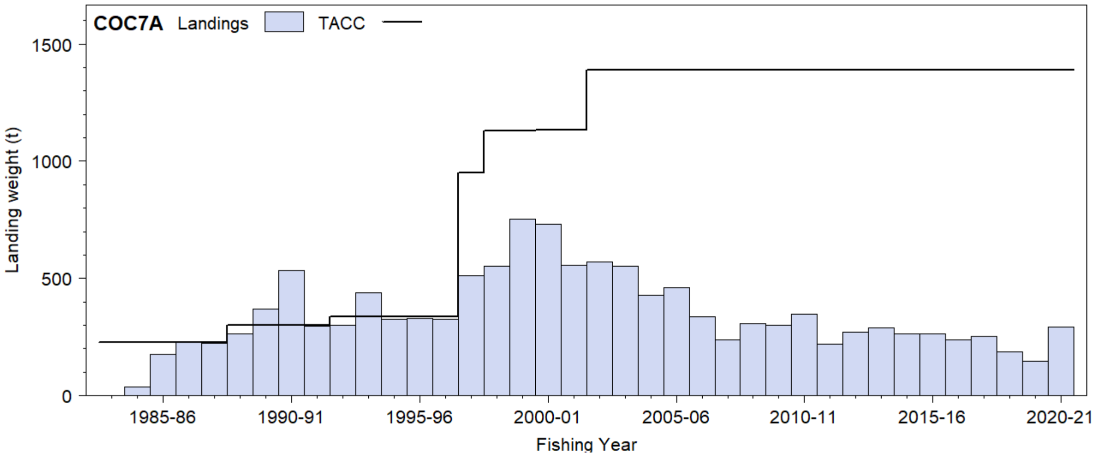


Figure 1: **Total reported landings and TACC for COC 7A (Nelson Bays) since 1983–84.**

1.2 Recreational fisheries

Cockles are taken by recreational fishers, generally by digging by hand. The catch limit is currently 150 cockles per person per day. Relatively large cockles (i.e., shell length over 30 mm) are generally preferred. Specific areas for recreational fishing are set aside from the commercial fishery by regulation and these include the area north of Ferry Point opposite Totara Ave and the area of Tapu Bay itself north of the fishery.

No estimates of recreational harvest of cockles from COC 7A are available. History of the estimates of recreational catch and their reliability is provided in the Introduction – Cockle chapter. Estimated numbers of cockles harvested by recreational fishers in QMA 7 are provided in Table 2.

Table 2: **Estimated numbers of cockles harvested by recreational fishers in QMA 7, and the corresponding harvest tonnage based on an assumed mean weight of 25 g. Figures were extracted from telephone-diary surveys in 1993–94, 1996, and 1999–2000, and from the national panel surveys in 2011–12 and 2017–18.**

Survey	Numbers	CV	Tonnes	Reference
1993–94	166 000	–	4.0	Teirney et al (1997)
1996	325 000	–	8.0	Bradford (1998)
1999–2000	499 000	–	12.5	Boyd & Reilly (2002)
2011–12	78 751	0.45	2.0	Wynne-Jones et al (2014)
2017–18	23 176	0.41	0.6	Wynne-Jones et al (2019)

1.3 Customary non-commercial fisheries

Cockles are an important Māori traditional food. Māori customary fishers can utilise the provisions under both the Fisheries (Amateur Fishing) Regulations 2013 and the Fisheries (South Island Customary Fishing) Regulations 1999. Many tangata whenua harvest cockles under their recreational allowance and these are not included in records of customary catch. There is no customary catch reported in COC 7A.

1.4 Illegal catch

No quantitative information on the level of illegal catch is available.

1.5 Other sources of mortality

The extent of any other sources of mortality is unknown. Incidences of unexplained large-scale die-off in localised areas have been noted (e.g., at Pakawau Beach and Ferry Point in 1999). Mortality of unrecruited cockles during the mechanical harvesting process was found to be very low (Bull 1984), and disturbance and mortality of other invertebrates in the harvested areas is slight (Wilson et al 1988). For further information on other sources of mortality, please refer to the Introduction – Cockle chapter.

2. BIOLOGY

All references to ‘shell length’ in this report refer to the maximum linear dimension of the shell (in an anterior-posterior axis). General cockle biology has been summarised earlier in this Plenary report. Some aspects of biology with particular relevance to COC 7A follow.

Estimates of growth and mortality have been made for cockles from Pakawau Beach (Osborne 1992, 1999, 2010), and the two early studies are summarised in Table 3. The 1992 investigation used a Walford plot of tag recapture data (Bull 1984) and measured growth after about 18 months on translocated cockles, to produce the growth parameters. A MIX analysis of the scaled length-frequency distribution from the 1992 survey enabled calculation of the proportional reduction of the 4+ and 5+ age classes to produce estimates of instantaneous natural mortality, M (after removal of estimated fishing mortality, F).

The 1999 investigation used a MIX analysis of length-frequency data from two strata in comparable surveys in 1997, 1998, and 1999 to estimate mean lengths (and proportion in the population) of the first 8-year classes. Von Bertalanffy parameters were estimated for each survey. Mean natural mortality rates were estimated (for age classes 4–7) between 1997 and 1998, and 1998 and 1999.

Table 3: Estimates of biological parameters.

Population & years			**Estimate**	**Source**
1. Natural mortality (M)				
Pakawau Beach (1992)			0.45 for 4+; 0.30 for 5+	Osborne (1992, 1999)
Pakawau Beach (1998)			0.4	Osborne (1999)
Pakawau Beach (1999)			0.52	Osborne (1999)
2. Weight = a (shell length)^b (weight in g, shell length in mm)				
	a		b	
Pakawau Beach (1992)	0.000017		3.78	Osborne (1992)
Ferry Point (1996)	0.00020		3.153	Forrest & Asher (1997)
Tapu Bay-Riwaka (1991)	0.000150		3.249	Stark & Asher (1991)
3. von Bertalanffy growth parameters				
	K	t_0	L_{∞}	
Pakawau Beach (1984–92)	0.36	0.3	49	Osborne (1992)
Pakawau Beach (1997)	0.38	0.68	48.3	Osborne (1999)
Pakawau Beach (1998)	0.4	0.68	47.4	Osborne (1999)
Pakawau Beach (1999)	0.41	0.66	47	Osborne (1999)

It was acknowledged that none of the MIX analyses converged, but the results presented were the best available fits (Osborne 1992, 1999). However, all four analyses produced very similar von Bertalanffy parameters. There is a trend of a reducing L_{∞} and increasing K over the period 1992–1999, which might be expected as a result of fishing. In 2009, growth was modelled by the equation $y = 11.452\mathrm{Ln}(x) + 16.425$, where y is shell width and x is age in years, this equation is only applicable to individuals 23–55 mm in shell width.

3. STOCKS AND AREAS

Little is known of the stock boundaries of cockles. The planktonic larval phase of this shellfish has a duration of about three weeks, so dispersal of larvae to and from a particular site could be considerable. Cockles are known to be abundant and widely distributed throughout Golden Bay and Tasman Bay, and, although nothing is known about larval dispersion patterns, cockles in these areas are likely to comprise a single stock. In the absence of any detailed information on stocks, the three currently fished sites in COC 7A are all managed as one stock.

4. STOCK ASSESSMENT

This report summarises estimates of absolute biomass and yields for exploited and unexploited cockle populations in Tasman Bay and Golden Bay. Stock assessments have been conducted using absolute biomass surveys, yield-per-recruit analyses, Methods 1 and 2 for estimating *MCY*, and Method 1 for estimating *CAY* (as documented in the Introductory section of the annual Plenaries).

Recruited cockles are considered to be those with a shell length of 30 mm or greater. This is the minimum size of cockles generally retained by the mechanical harvesters used in the COC 7A fishery. At present, most cockles in the fishery are > 35 mm shell length due to size grading by the fisher at Pakawau Beach who returns undersized cockles to the beach. However, the minimum size harvested has gradually declined as the proportion of smaller cockles in the population has increased and the density of large cockles has decreased. In the past, biomass occurring in areas of eel grass (*Zostera*) was not considered to be vulnerable to fishing because the mechanical harvesters cannot operate in areas of *Zostera*. However, it is now known that in the lower parts of the beach *Zostera* beds are periodically covered and re-exposed by moving waves of sand. When covered, cockles from the *Zostera* beds migrate vertically to the surface of the sand waves and become vulnerable to fishing. Also, since 2009, the location of all harvesting at Pakawau Beach has been precisely mapped, delineating the extent of harvestable areas. Biomass vulnerable to fishing has been redefined to include all that biomass 30 mm or greater shell length occurring within the defined extent of harvestable area.

4.1 Estimates of fishery parameters and abundance

None are available.

4.2 Biomass estimates

Biomass estimates from surveys are available for the three commercially fished areas and three other sites.

On Pakawau Beach, the surveys done in 1992 and 1997–2004 used a stratified random approach over a wide area of intertidal habitat (Table 4). An additional southern stratum was added to the survey area in 1997 after legal definition of the fishery area, accounting for the greater survey area relative to 1992. The surveys in 1984 and 1988 covered smaller areas still. Since 2008, the survey area has been modified to remove areas observed to be consistently unsuitable habitat for cockles or cockle harvesting (sand banks, soft mud, and *Zostera* areas). From 2014 to 2020, annual biomass surveys were conducted over a similar but slightly varying total area, but individual strata were varied depending on rotational fishing history. The area for which biomass was estimated included all areas known to be historically fished. By 2020, a set of strata were identified as suitable for standardising the time series into the future. Previous surveys were reanalysed with post-stratification (Osborne 2021). The 15 comparable surveys (1992–2020) show recruited biomass increased from 4400 t in 1992 to 7300 t by 2008, declined to 3800 t by 2014 (no intervening surveys), but increased steadily to almost 5100 t by 2020. The lowest value in this time series was recorded in 2014 (Table 4, Figure 2). Reference biomass levels used for *MCY* calculation are given in Table 4. In earlier years, B_{AV} was taken as the average vulnerable biomass (defined as that which was of minimum harvest size (30 mm) and outside *Zostera* beds). Most recently, B_{AV} was calculated as the average of post-stratified estimates of recruited biomass from the standard strata making up the area vulnerable to fishing (302 ha).

Estimates of biomass are available for Tapu Bay-Riwaka in 1991 using a fixed transect approach (Stark & Asher 1991) and Ferry Point in 1996 using a stratified random approach (Forrest & Asher 1997). Both these surveys were conducted about two years prior to the commencement of commercial harvesting in those areas. The cockle resource on three other beaches in Golden Bay was assessed using stratified random surveys in 1993 (Osborne & Seager 1994). Since then both Riwaka and Ferry Point have been surveyed in 2004 and 2008 using stratified random survey designs. Results from all these surveys are listed in Table 5. The biomass estimates at Riwaka and Ferry Point have generally decreased over time.

Table 4: Estimates of biomass with 95% confidence intervals where available for Pakawau Beach. Values are total biomass in the original area surveyed, a standardised series of post-stratified estimates from set strata, and reference levels of biomass used for calculating *MCY* (*B_0* virgin biomass, *B_{av}* average biomass). In 1992 and 2008 one of the six standard strata was not sampled so the area covered is less (the average biomass of the missing strata in other years was 260 tonnes). Prior to 2014 vulnerable biomass (averaged to give *B_{AV}*) was calculated differently (see Osborne 2014, 2021 for details).

	Total biomass in Original Survey strata				Standardised recruited biomass				Assessed reference levels		
	Area (ha)	tonnes	95% CI	CV	Area (ha)	tonnes	95% CI	CV	B_0	B_{av}	95% CI
1984	326	4 604	1 562	–	–	–	–	–	–	–	–
1988	510	5 640	–	–	–	–	–	–	–	–	–
1992	588	6 784	929	7.0	280	4 429	840	9.7	3 293	–	–
1997	642	9 331	1 749	9.6	302	6 230	1 319	10.8	–	3 655	134
1998	642	8 269	1 360	8.42	302	5 591	1 211	11.1	–	3 574	176
1999	642	8 666	1 425	8.4	302	5 087	883	8.9	–	3 445	282
2000	642	7 878	1 302	8.4	302	5 061	997	10.1	–	3 184	556
2001	642	10 255	1 629	8.1	302	6 537	1 272	9.9	–	3 172	455
2004	642	10 185	1 243	6.2	302	7 441	918	6.3	–	3 539	817
2008	407	9 212	1 674	9.3	280	7 307	1 328	9.3	–	3 716	788
2014	358	4 431	712	8.2	302	3 844	658	8.7	–	5 686	1 137
2015	196	3 128	563	9.2	302	4 050	758	9.5	–	–	–
2016	303	4 114	918	11.4	302	4 003	622	7.9	–	–	–
2017	381	5 345	997	9.5	302	4 721	757	8.2	–	–	–
2018	294	5 946	855	7.3	302	5 143	680	6.7	–	–	–
2019	294	5 273	784	7.6	302	4 730	689	7.2	–	–	–
2020	302	5 543	1 102	10.1	302	5 076	1 069	10.7	–	5 283	629

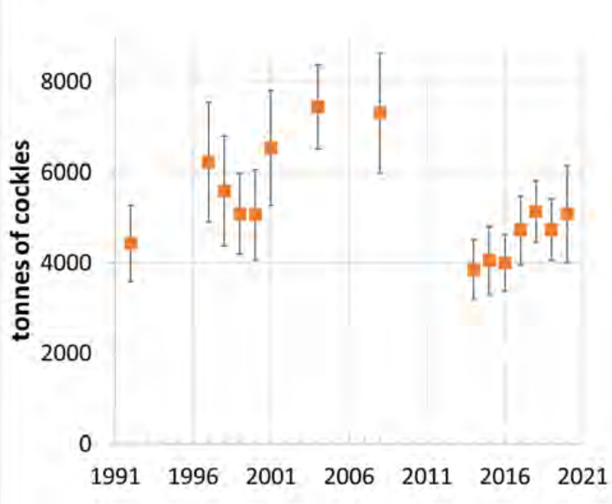


Figure 2: Recruited biomass (≥30 mm shell length) over time at Pakawau Beach from a standard set of strata covering 302 ha.

Surveys reporting on cockle abundance have also been produced for Motupipi, Golden Bay, in June 1995 (transect survey, 50 ha, 30 samples, mean density of 87 cockles per m^2, no sizes or weights recorded), and at various sites in the Marlborough Sounds in August 1986 (diver survey below mean low water only, 9 sites, main densities in Kenepuru and inner Pelorus sounds).

Table 5: Estimates of biomass (t) with 95% confidence intervals (CI) where available, and mean density (kg m^{-2}) for cockles at various sites in Golden Bay and Tasman Bay. Where possible, values are given for the total and recruited (≥ 30 mm) populations. *n* = number of samples in the survey.

Site	Date	Area	*n*	Total biomass			Recruited biomass		
		(ha)		t	CI	kg m^{-2}	t	CI	kg m^{-2}
Tapu Bay-Riwaka	Mar-91	306	321	~3 900	–	1.28	–	–	–
Riwaka	Feb-04	122.7	144	1 423	269	1.16	1 076	235.6	0.88
Riwaka	Mar-08	103	82	1475	257	1.44	939	178	0.9
Riwaka (excl. Tapu Bay)*	Mar-91	–	–	–	–	–	1 880	450	–
Ferry Point	Dec-96	40	552	2 617	190	5.99	2 442	191	5.6
Ferry Point	Feb-04	40	126	646	99.8	1.63	443	79	1.12
Ferry Point	Jan-08	28.2	75	662	112	2.35	470	83	1.7
Collingwood Beach	Mar-93	176	70	334	148	0.19	292	139	0.17
Takaka Beach	Mar-93	338	107	1 850	671	0.55	796	395	0.24
Rangihaeata Beach	Mar-93	197	75	473	345	0.24	438	320	0.22

* Recalculated by Breen (1996) from data in Stark & Asher (1991).

Absolute virgin biomass, B_0, is assumed to be equal to estimated biomass of cockles 30 mm or over shell length from surveys conducted before, or in the early stages of, any commercial fishing. These are listed above in Tables 4 and 5. Absolute current biomass can be estimated similarly from current surveys.

The biomass that will support the maximum sustainable yield (B_{MSY}) is not known for any of the areas fished in COC 7A. A preliminary deterministic length-based model suggests B_{MSY} is considerably lower than current biomass (Osborne 2021).

4.3 Yield estimates and projections

Estimates of *MCY* have been made for populations of cockles in various areas, and at various times, using the equation $MCY = 0.25 * F_{ref} * B_0$ (Method 1), where F_{ref} is either $F_{0.1}$ or F_{max}. This method applies to new fisheries, or to those with only very low past levels of exploitation. The value of F_{ref} is dependent on *M*, so, because of the uncertainty of *M*, a range of *MCY* estimates have been given for each stock (Table 6). For all estimates in Table 6, B_0 was taken as recruited biomass available for fishing (i.e., not in *Zostera* beds) in the survey area.

Estimates of *MCY* for Pakawau Beach have also been produced from $MCY = 0.5 * F_{REF} * B_{AV}$ (Method 2), using $F_{0.1}$, and with B_{AV} being the average of the available recruited biomass from the previous comparable surveys. For a range of *M* values, the latest estimates of *MCY* are as follows (for mean and upper and lower 95% confidence estimates of B_{AV}):

M	0.2	0.3	0.4
MCY	528 (465, 591)	792 (698, 887)	1057 (931, 1182).

Table 6: Estimates of *MCY* (t, using 0.25 * F_{REF} * B_0) for various cockle stocks in Tasman Bay and Golden Bay, assuming a range of values for *M*.

Site	Date	F_{ref}				*M*
			0.2	0.3	0.4	0.5
Pakawau Beach	1992	$F_{0.1}$	230	324	434	554
Pakawau Beach	1997	$F_{0.1}$	397	559	751	957
Pakawau Beach	2001	F_{MAX}	1 182	2 418	4 658	–
Pakawau Beach	2004	$F_{0.1}$	482	683	924	–
Pakawau Beach	2008	$F_{0.1}$	340	481	651	–
Pakawau Beach	2014	$F_{0.1}$	665	996	1 312	–
Pakawau Beach	2020	$F_{0.1}$	528	792	1 057	–
Ferry Point	1996	$F_{0.1}$	127	170	223	284
Ferry Point	1996	F_{MAX}	264	453	789	1 493
Ferry Point	2004	$F_{0.1}$	122	173	234	–
Ferry Point	2008	$F_{0.1}$	111	157	212	–
Riwaka	1991	$F_{0.1}$	167	224	286	–
Riwaka	2004	$F_{0.1}$	81	115	156	–
Riwaka	2008	$F_{0.1}$	118	167	226	–
Collingwood Beach	1993	$F_{0.1}$	20	28	37	48
Takaka Beach	1993	$F_{0.1}$	53	74	100	127
Rangihaeata Beach	1993	$F_{0.1}$	23	32	43	55

The level of risk of harvesting the populations at the estimated *MCY* levels cannot be determined for any of the surveyed areas. However, yield estimates are substantially higher when based on F_{MAX} than on $F_{0.1}$, so risk would be greater at *MCY*s based on F_{MAX}.

Estimates of *CAY* have been made in the past for cockle stocks at Pakawau Beach, Ferry Point, and Riwaka, using $CAY = F_{REF}/(F_{REF} + M) * (1 - e^{-(F_{REF} + M)}) * B_{BEG}$ (Method 1), where beginning of season biomass (B_{BEG}) is current recruited biomass available to the fishery, and F_{REF} is either $F_{0.1}$ or F_{max}. The most recent estimates of *CAY* available for all stocks are listed in Table 7.

4.4 Other yield estimates and stock assessment results

$F_{0.1}$ and *CAY* were estimated from a yield per recruit (YPR) analysis using the age and length-weight parameters for Pakawau Beach cockles from Osborne (2010) and assuming size-at-recruitment to the fishery of either 30, 35, or 37 mm shell length. A range of *M* values was used to produce the latest estimates in Table 8 (Osborne 2014). Yield per recruit increases with reduction in minimum size at harvest over this size range.

Table 7: Estimates of *CAY* (t) for various cockle stocks in Tasman and Golden Bays, assuming a range of values for *M*.

Site	Date	F_{REF}				M
			0.2	0.3	0.4	0.5
Pakawau Beach	2001	$F_{0.1}$	778	996	1 210	1 396
Pakawau Beach #	2001	$F_{0.1}$	1 964	2 514	3 053	3 522
Pakawau Beach	2004	$F_{0.1}$	1 202	1 555	1 910	
Pakawau Beach	2008	$F_{0.1}$	1 161	1 501	1 845	
Pakawau Beach	2014	$F_{0.1}$	638	844	1 040	
Pakawau Beach	2020	$F_{0.1}$	949	1275	1566	
Ferry Point	1996	$F_{0.1}$	407	501	600	696
Ferry Point	2004	$F_{0.1}$	69	89	109	
Ferry Point	2008	$F_{0.1}$	88	114	140	
Riwaka	1993	$F_{0.1}$	507	615	708	
Riwaka	2004	$F_{0.1}$	138	179	220	
Riwaka	2008	$F_{0.1}$	1 161	1 501	1 845	

Calculations using total recruited biomass, rather than available recruited biomass.

Table 8: Latest estimates of $F_{0.1}$ from a yield per recruit analysis and *CAY* at different levels of minimum size at harvest (MSH) and natural mortality (*M*) (Osborne 2014).

					M
	MSH (mm)	B_{beg}	0.20	0.30	0.40
$F_{0.1}$	30		0.23	0.34	0.46
CAY		3 363	638	844	1 040
$F_{0.1}$	35		0.28	0.40	0.54
CAY		2 409	541	696	838
$F_{0.1}$	37		0.31	0.43	0.56
CAY		2 026	489	617	732

The annual exploitation rate (u) corresponding to $F_{0.1}$ values for minimum size at harvest of 30 mm over the plausible range of M values are as follows:

M	0.2	0.3	0.4
$F_{0.1}$	0.23	0.34	0.46
u	19%	25%	31%

4.5 Other factors

The areas of Golden Bay and Tasman Bay currently commercially fished for cockles are very small with respect to the total resource. Recruitment overfishing is unlikely because of the extent of the resource protected from the fishery in *Zostera* beds, in sub-tidal areas, and in the protected areas adjacent to Farewell Spit and in other areas of Golden Bay. Cockle larvae are planktonic for about three weeks, so areas like Golden Bay and Tasman Bay probably constitute single larval pools.

Consequently, fisheries in relatively small areas (like Pakawau Beach) are likely to have little effect on recruitment. It is noted, however, that recruitment of juvenile cockles can be reduced by the removal of a large proportion of adult cockles from the area (i.e., successful settlement occurs only in areas containing a population of adult cockles).

It is also likely that growth and mortality of cockles are density-dependent. A reduction in density due to fishing could enhance the growth and survival of remaining cockles.

Because cockles begin to spawn at a shell length of about 18 mm, and the larval pools in Tasman Bay and Golden Bay are probably massive and derive from a wide area (most of which is closed to commercial fishing), there is a low risk of recruitment overfishing at any of the exploited sites.

5. STATUS OF THE STOCKS

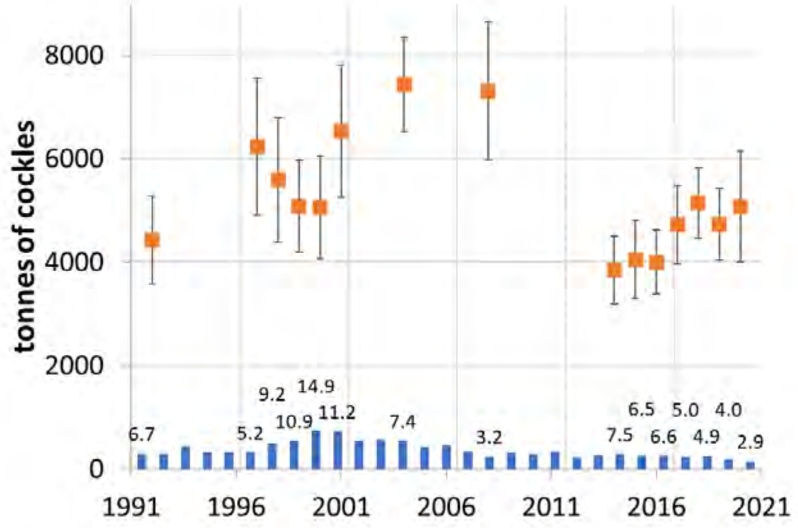
Stock structure assumptions

Little is known of the stock boundaries of cockles. Given differences in growth and mortality within and between different beds and in the absence of more detailed knowledge regarding larval connectivity, this commercial fishery area is managed as a discrete population.

COC 7A

Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Survey biomass estimates for ≥ 30 mm shell length
Reference Points	Target(s): Not defined, but B_{MSY} assumed Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: - Undefined
Status in relation to Target	Likely (> 60%) to be at or above the target (except for local depletion is some bays)
Status in relation to Limits	Unlikely (< 40%) to be below the soft limit and Very Unlikely (< 10%) to be below the hard limit
Status in relation to Overfishing	Overfishing is Very Unlikely (<10%) to be occurring

Historical Stock Status Trajectory and Current Status



Recruited biomass (≥ 30 mm shell length) over time at Pakawau Beach (± 95% CI) and catch (bars) labelled with exploitation rate (catch as a percentage of biomass estimated in the same year).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The recruited biomass estimates of cockles from Pakawau Beach have shown periods of increase and decline since 1992, peaking in 2004, a marked decline after 2008 to a historical low in 2014, and a steady increase again since then. Two other areas open for commercial fishing within COC 7A are not commercially fished.
Recent Trend in Fishing Mortality or Proxy	Landings since 2004–05 are intermediate compared with the history of the fishery and have fluctuated without trend between 146 and 460 t. Exploitation rate over the same period has ranged from 2.9% to 7.5% measured in years where biomass estimates area available. The exploitation rate corresponding to $F_{0.1}$ ranges from 19% to 31% over the range of plausible M values. Therefore, the fishery exploitation rate is relatively low in comparison to $F_{0.1}$. Exploitation rate (catch / biomass) has declined in recent years and is currently very low (< 3%).
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	-
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Fishing at present levels is Very Unlikely (< 10%) to cause declines below the soft or hard limits.
Probability of Current Catch or TACC causing Overfishing	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial quantitative stock assessment	
Assessment Method	Absolute biomass estimates from quadrant surveys	
Assessment Dates	Latest assessment: 2021	Next assessment: 2028
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Abundance survey - Length frequency	1 – High Quality 1 – High Quality
Data not used (rank)		
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
Water quality issues have influenced the amount of time when cockles can be harvested from Ferry Point in recent years.

Fishery Interactions
Cockles are an important food source for shorebirds including oyster catchers and godwits. Pakawau Beach is classed as a site of international importance for the South Island Pied Oystercatcher. Monitoring population sizes has shown that South Island Pied Oystercatcher (nationally at risk, declining) and Variable Oystercatcher (nationally at risk, recovering) have been stable or increased in numbers in Golden Bay over the period 1983 to 2012.

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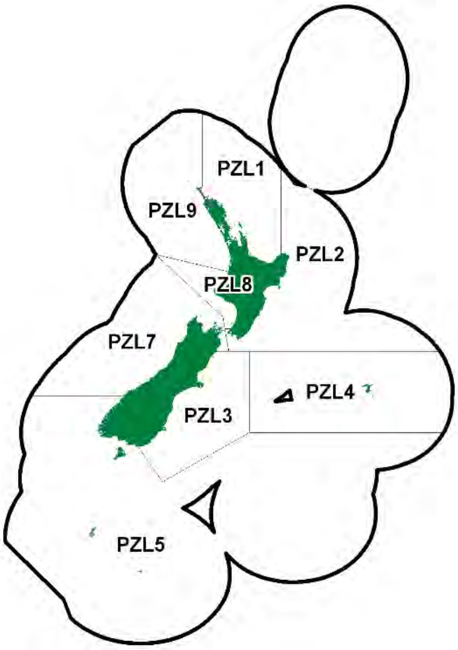
DEEPWATER (KING) CLAM (PZL)

(*Panopea zelandica*)
Hohehohe



1. FISHERY SUMMARY

Deepwater clams (*Panopea zelandica*), commonly referred to as geoducs, geoducks, or New Zealand king clams, were introduced into the Quota Management System on 1 October 2006 with a total TAC of 40.5 t, consisting of 31.5 t TACC and a 9 t allowance for other sources of mortality (Table 1). Most TACs have remained unchanged since entering the QMS, however, the TAC for PZL 7 was increased on 1 October 2020. The fishing year is from 1 October to 30 September and commercial catches are measured in greenweight. Deepwater clams are harvested by divers using underwater breathing apparatus and a hydraulic probe.

Table 1: Current TAC, TACC, and allowances for other sources of mortality for *Panopea zelandica*.

Fishstock	TAC (t)	TACC (t)	Other sources of mortality
PZL 1	1.5	1.2	0.3
PZL 2	1.5	1.2	0.3
PZL 3	1.5	1.2	0.3
PZL 4	1.5	1.2	0.3
PZL 5	1.5	1.2	0.3
PZL 7	114.0	80.0	32.0
PZL 8	1.5	1.2	0.3
PZL 9	1.5	1.2	0.3
Total	124.5	88.4	9.0

1.1 Commercial fisheries

The large landings reported between 1989 and 1992 (Table 2), were almost all taken in the Nelson-Marlborough region under a special permit for investigative research. Targeted fishing was also carried out under a special permit in PZL 7 between 2004 and 2005. Rare catches have also been made by trawlers. Annual catches averaged about 5 t between 2008–08 and 2018–19, but increased to almost 38 t by 2020–21, taken from the Nelson-Marlborough region (Table 2). Nationally, the deepwater clam fishery is undeveloped but is recognised as having significant potential.

The TAC increase for PZL 7 (30 to 114 t) was the outcome of a biomass survey conducted in 2017 under a further special permit. Current quota holders for PZL 7, including Te Tau Ihu iwi and Te Ohu Kaimoana, are progressing a fisheries development research plan to ensure co-ordinated, sustainable and well researched growth of the fishery. PZL 7 commercial fishers have agreed not to fish within the Marlborough Sounds.

Table 2: TACCs and reported landings (t) of deepwater clam by Fishstock from 1989–90 to present, taken from CELR and CLR data. There have never been any reported landings in PZL 2, 4, 5, 8, or 9.

	PZL 1		PZL 3		PZL 7		Total	
Fishing year	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1989–90	0.315	–	0	–	95.232	–	95.547	–
1990–91	0	–	0	–	29.293	–	29.293	–
1991–92	0	–	0.725	–	31.394	–	32.119	–
1992–93	0	–	0.053	–	0	–	0.053	–
1993–94	0	–	0	–	0	–	0	–
1994–95	0	–	0	–	0	–	0	–
1995–96	0	–	0	–	0	–	0	–
1996–97	0	–	0	–	0	–	0	–
1997–98	0	–	0	–	0	–	0	–
1998–99	0	–	0	–	0	–	0	–
1999–00	0	–	0	–	0	–	0	–
2000–01	0	–	0.146	–	0	–	0.146	–
2001–02	0.003	–	0.068	–	0	–	0.071	–
2002–03	0	–	0.001	–	0	–	0.001	–
2003–04	0	–	0	–	1.444	–	1.444	–
2004–05	0	–	0	–	2.944	–	2.944	–
2005–06	0	–	0	–	0	–	0	–
2006–07	0	1.2	0	1.2	0	23.1	0	31.5
2007–08	0	1.2	0.132	1.2	0.320	23.1	0.450	31.5
2008–09	0	1.2	0.016	1.2	5.100	23.1	5.116	31.5
2009–10	0	1.2	0	1.2	4.578	23.1	4.578	31.5
2010–11	0	1.2	0.076	1.2	7.880	23.1	7.956	31.5
2011–12	0	1.2	0.036	1.2	10.849	23.1	10.885	31.5
2012–13	0	1.2	0	1.2	1.746	23.1	1.746	31.5
2013–14	0	1.2	0	1.2	6.072	23.1	6.072	31.5
2014–15	0	1.2	0.003	1.2	3.927	23.1	3.93	31.5
2015–16	0	1.2	0	1.2	4.686	23.1	4.686	31.5
2016–17	0	1.2	0	1.2	3.260	23.1	3.260	31.5
2017–18	0	1.2	0	1.2	6.720	23.1	6.720	31.5
2018–19	0	1.2	0	1.2	6.294	23.1	6.294	31.5
2019–20	0.21	1.2	0	1.2	13.357	23.1	13.567	31.5
2020–21	0	1.2	0.010	1.2	37.972	80.0	37.982	88.4

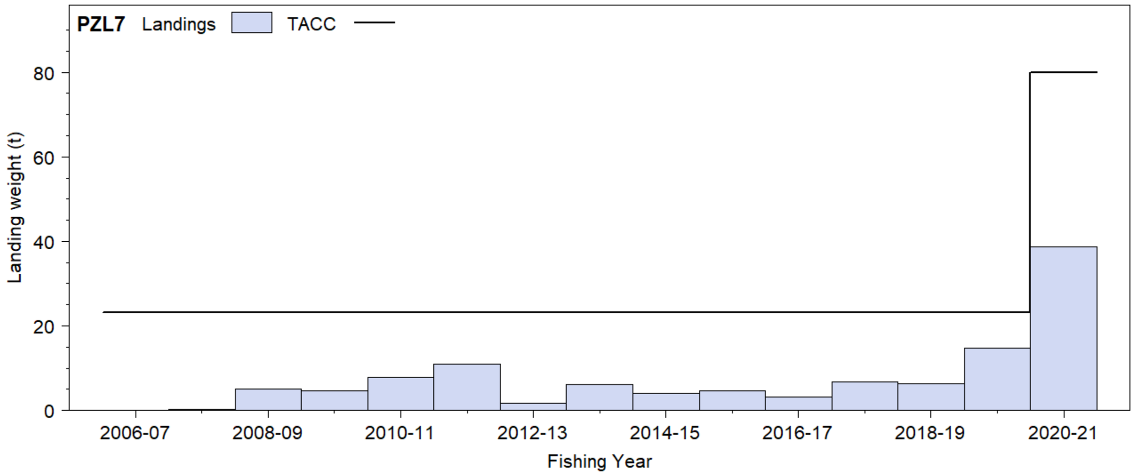


Figure 1: Reported commercial landings and TACCs for the main PZL stock: PZL 7 (Challenger).

1.2 Recreational fisheries

There are no estimates of recreational take for this clam. Recreational take is likely to be very small or non-existent however, some recreational take is recorded as section 111 landings.

1.3 Customary fisheries

This clam is harvested for customary use when washed ashore after storms but there are no estimates of this use of this clam. Customary take is likely to be very small or non-existent.

1.4 Illegal catch

There is no documented illegal catch of this clam.

1.5 Other sources of mortality

While there is little hard information on other sources of mortality, the clam has on rare occasions been captured during trawling operations.

Deepwater clams are extracted from the sediment using a hand-held water probe to liquefy the substrate, freeing the clam to be gathered. International research suggests the environment impacts of this method are similar to a storm event and disappear relatively quickly. However, damage to juvenile clams from this method is unknown and even adults show poor reburial after being dug out (Gribben & Creese 2005). Being cautious, the *other sources of mortality* allowance is set at 40% of the TACC.

2. BIOLOGY

There are two similar *Panopea* species in New Zealand: *P. zelandica*, also referred as geoduc, geoduck, and king clam; and *P. smithae*. Both are endemic and occur around the North, South, and Stewart islands. *P. smithae* has also been reported from the Chatham Islands. *P. smithae* is reported under the Fishstock code PSM and is not included in this Working Group report. Their distributions overlap, but *P. zelandica* occurs mainly in shallow waters (5–25 m) in sand and mud off sandy ocean beaches, whereas *P. smithae* lives mainly at greater depths (110–130 m) on coarse shell bottoms and is also thought to burrow deeper into the substrate. In samples of commercial and exploratory catches, *P. zelandica* is more abundant than *P. smithae*, and it comprises virtually all of the catch.

Deepwater clams are broadcast spawners with separate sexes. Protandric development (where an organism begins life as a male and then becomes a female) is considered likely for a proportion of the population (Gribben & Creese 2003). Fifty percent sexual maturity was calculated at 55 and 57 mm length for populations in Wellington and on the Coromandel Peninsula, respectively. Samples taken from three locations between the Coromandel Peninsula and Nelson showed spawning between spring and late summer (Gribben et al 2004a). Spawning may be controlled by temperature because it occurred at both the Coromandel and Wellington sites when water temperature reached approximately 15 °C (Gribben et al 2004a). The larval life is thought to be about two to three weeks (Gribben & Hay 2003), and there is evidence of significant recruitment variation between years.

The oldest *P. zelandica* based on annual ring counts in Golden Bay, Shelly Bay (Wellington), and Kennedy Bay (Coromandel) were 34, 34, and 85 years respectively (Breen 1991, Gribben & Creese 2005); ring counts were validated from Shelly Bay only. Growth in shell length appeared to be rapid for the first 10–12 years in these populations and total weight increased rapidly until at least 12–13 years of age. Differences in growth rates were seen between the Kennedy Bay and Shelly Bay populations: estimates of K varied between 0.16 and 0.29, t_0 between 1.67 and 3.8, and L_∞ between 103.6 mm and 116.5 mm, respectively (Breen 1991, Gribben & Creese 2005)[1]. The most recent estimate of K in Golden Bay was 0.11 (SE 0.027), L_∞ was 127.5 mm (SE 4.8 mm), and age-at-length-zero was -4.24 years (SE 2.15) (Slater et al 2017).

Estimates of M (instantaneous natural mortality) from catch curve analysis, estimates of maximum age, and the Chapman-Robson estimator from Kennedy Bay and Shelly Bay populations were all between 0.02 and 0.12 (Gribben & Creese 2005). The estimate by Breen (1991) for Golden Bay was 0.15, but in modelling this parameter was varied between 0.1 and 0.2.

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[1] No confidence intervals were available for these estimates.

3. STOCKS AND AREAS

For management purposes stock boundaries are based on FMAs, however, there is little information on stock structure, recruitment patterns, or other biological characteristics to determine fishstock boundaries.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

Estimates of total mortality (*Z*) for deepwater clam using Millar's method (2015) in a small part of Golden Bay (PZL 7) were obtained from a biomass survey conducted in 2014 (Slater et al 2017). In this analysis the first 8 age classes were removed because there is age-based selectivity bias. Estimated annual mortality was 0.189 (SE 0.042). The estimated instantaneous mortality *Z* (inclusive of both natural mortality and fishing mortality) was 0.209 (SE 0.047). This *Z* was similar to the upper value of instantaneous mortality *M* (0.20) estimated by Breen (1991) and higher than the *M* estimated for Kennedy Bay (0.05–0.07) and Shelly Bay (0.02–0.04) (Gribben & Creese 2005); the key difference being that the 2017 *Z* estimates were determined from both natural causes and fishing. The catch-curve analyses used by Breen (1991) and Gribben & Creese (2005) operate under two assumptions: firstly, recruitment rates are approximately constant during the time that aged deepwater clam were recruited; and secondly, mortality is similar for all age classes. Gribben & Creese (2005) concluded that catch-curve analyses may not be appropriate for estimating natural mortality in deepwater clam, and Millar (2015) suggested that general linear mixed modelling (GLMM) is superior in predicting mortality, due to the inclusion of recruitment involving annual variation and the substantial variability known to exist in population dynamics (Myers et al 1995).

The size and age data have been used for comparison with the age-weight growth curve and natural mortality values used in the study of deepwater clam sustainability by Breen (1994). When estimating recruitment, Breen (1994) used animals 8 years or older for recruited biomass, as did Slater et al (2017) because there appeared to be an age-based selectivity bias. The maximum realistic exploitation rate of 0.35 was based on Goodwin's (1977) show-factor and the disturbances created by the fishing method causing nearby individuals to retract their siphons. The upper bound of the 95% confidence interval for show-factor was 31%.

Slater et al (2017) fitted a von Bertalanffy growth curve to the aged individuals and estimated a L_{inf} of 127.5 mm (SE 4.8 mm), a growth rate (*K*) of 0.11 y^{-1} (SE 0.027), and an age-at-length-zero of -4.24 years (SE 2.15). These results were not dissimilar to earlier studies: a maximum theoretical length of 116.5 mm, $K = 0.16$ y^{-1}, and t_0 of –3.80 years (Breen 1991) and estimated asymptotes of 111.5 mm (Kennedy Bay) and 103.6 mm (Shelly Bay) (Gribben & Creese 2005).

4.2 Biomass estimates

Biomass has not been estimated for any deepwater clam stocks. Slater et al. (2017) estimated the biomass for a small area in Golden Bay (PZL 7).

Deepwater clam densities in North America are calculated by the use of established methods that include counting the siphon holes through which deepwater clam filter feed. Problematically, not all deepwater clam "show" their siphon holes at the same time and thus this method could lead to an erroneous population estimate (Hand & Dovey 1999).

This is solved by the use of a "show–factor" which is the number of deepwater clam siphons that are visible, or can be felt, versus the total number of individuals present in a given area. In North America, the number of deepwater clam that "show" their siphon holes is variable depending on different environmental and physiological factors; with more showing during the summer months during periods of feeding and breeding (Campbell et al 1998), and when local water currents are not overly severe with no mechanical disturbances of the bottom due to events such as storm activity (Goodwin 1977).

Gribben et al (2004b) investigated whether the North American methodology used for determining population abundance estimates is transferrable to New Zealand's *P. zelandica*. Experiments were conducted to determine how many deepwater clam were visible at a given point in time (show/no-show factors). Analysis of sediment samples indicated that *P. zelandica* were found in similar habitats to the American species *P. generosa.* There was no significant difference in the show-factor with regard to season or tidal height. A mean show-factor of 0.914 was used to adjust the density estimates from both populations which gave mean densities of 0.058 deepwater clam m^{-2} in Kennedy Bay and 0.489 deepwater clam m^{-2} in Wellington Harbour, with coefficients of variation generally less than 0.2. The density estimates for *P. zelandica* were much lower than those reported for *P. generosa.* But the authors suggested that the North American methodology for estimating deepwater clam populations was transferrable to *Panopea zelandica*.

Gribben & Creese (2005) reported mean maximum drained wet weights of 275.5 g in Kennedy Bay and 223.1 g in Shelly Bay. This would give 0.016 kg m^{-2} average density for Kennedy Bay and 0.109 kg m^{-2} for Shelly Bay. Slater et al (2017) calculated an average density of 0.0619 kg m^{-2} for the area surveyed in Golden Bay. Even accounting for water lost in draining, the Golden Bay area appears to have higher density than Kennedy Bay but not Shelly Bay. However, any difference in density could be explained by different measuring techniques or local environmental and productivity factors. Extrapolating this density to the area delineated in the study yields an estimate of total parent biomass of 1,334 t. By employing the very conservative upper confidence interval of 30.8% efficiency of the survey effort as a multiplier to the parent biomass in the surveyed area, a mean density of 0.201 kg m^{-2} and a parent biomass of 4,331.17 t would be estimated (Slater et al 2017).

4.3 Yield estimates and projections

MCY has not been estimated for any deepwater clam stocks. However, an age–structured stochastic model suggested that sustainable yields for this species, with realistic management constraints, appear to be on the order of 2% to 4% of virgin biomass (Breen 1994).

CAY has not been estimated for any deepwater clam stocks.

4.4 Future research considerations

Research should be conducted on:

- diver variability on counts of deepwater clam;
- the role that deepwater clam occurring deeper than 17 m perform; and
- the effect of geoduc density on fertilisation success.

5. STATUS OF THE STOCKS

PZL 7 – *Panopea zelandica*

Stock Status	
Year of Most Recent Assessment	A small area was surveyed in 2017 in Golden Bay
Assessment Runs Presented	–
Reference Points	Target: Not defined, but B_{MSY} assumed Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: –
Status in relation to Target	Because of the relatively low levels of exploitation of *P. zelandica* until 2018-19, it is likely that this stock is still effectively in a virgin state, therefore it is Very Likely (> 90%) to be at or above the target.
Status in relation to Limits	Because of the relatively low levels of exploitation of *P. zelandica* until 2018-19, it is likely that this stock is still effectively in a virgin state, therefore it is Very Unlikely (< 10%) to be below the soft or hard limits
Status in relation to Overfishing	Very Unlikely (<10%)

Historical Stock Status Trajectory and Current Status
Unknown

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown
Recent Trend in Fishing Mortality or Proxy	In 1989–92 the landings for PZL 7 averaged 52 t; however, since that time fishing has been light in all QMAs with a maximum of only 37.927 t taken across all QMAs in the 2020-21 fishing year.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	-
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Current catches are Very Unlikely (< 10%) to cause declines below soft or hard limits.
Probability of Current Catch causing Overfishing to continue or to commence	Very Unlikely (<10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 2: partial quantitative stock assessment	
Assessment Method	Biomass estimate from transects survey	
Assessment Dates	Latest assessment: 2014	Next assessment: unknown
Overall assessment quality rank	-	
Main data inputs (rank)	- Abundance survey - Length frequency	
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
Early surveys show that density is generally low compared with North American species but that productivity is higher.

Fishery Interactions
-

6. FOR FURTHER INFORMATION

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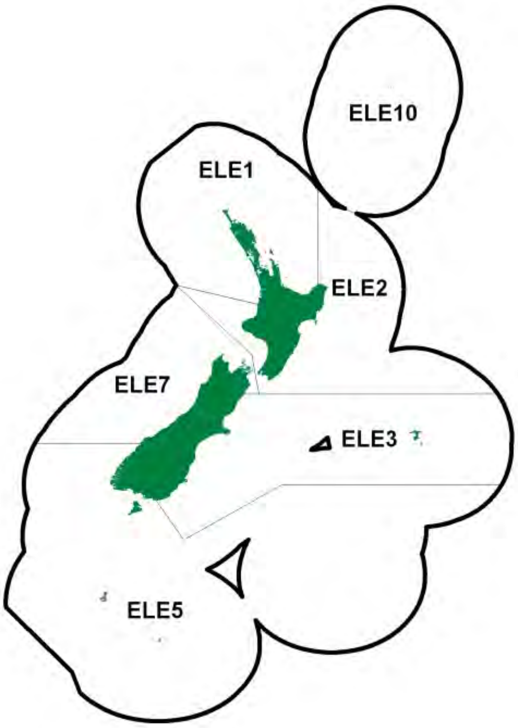
ELEPHANT FISH (ELE)

(*Callorhinchus milii*)
Reperepe



1. FISHERY SUMMARY

Elephant fish was introduced into the Quota Management System (QMS) on 1 October 1986. Current allowances, TACCs and TACs are shown in Table 1.

Table 1: Recreational and Customary non-commercial allowances, TACCs and TACs for elephant fish by Fishstock.

Fishstock	Recreational Allowance	Customary non-commercial allowance	Other sources of mortality	TACC	TAC
ELE 1				10	
ELE 2				22	
ELE 3	15	5	115	1 150	1 285
ELE 5	5	5	8.5	170	188
ELE 7	10	5	10	102	127
ELE 10				10	

1.1 Commercial fisheries

From the mid-1950s to the 1980s, landings of elephant fish of around 1000 t/year were common. Most of these landings were from the area now encompassed by ELE 3, but fisheries for elephant fish also developed on the south and west coasts of the South Island in the late 1950s and early 1960s, with average catches of around 70 t per year in the south (in the 1960s to the early 1980s) and 10–30 t per year on the west coast. Total annual landings of elephant fish dropped considerably in the early 1980s (between 1982–83 and 1994–95 they ranged between 500 and 750 t) but later increased to the point that they have annually exceeded 1 000 t since the 1997–98 fishing season. Reported landings since 1931 are shown in Tables 2 and 3, while an historical record of landings and TACC values for the three main ELE stocks are depicted in Figure 1. ELE 3 has customary, recreational and other mortality allowances of 5 t, 5 t, and 50 t respectively, and ELE 5 has allowances 5 t, 5 t, and 7 t respectively.

Table 2: Reported total landings of elephant fish for calendar years 1936 to 1982. Sources: MAF and FSU data.

Year	Landings (t)	Year	Landings (t)	Year	Landings (t)	Year	Landings (t)	Year	Landings (t)
1936	116	1946	235	1956	980	1966	1 112	1976	705
1937	184	1947	188	1957	1 069	1967	934	1977	704
1938	201	1948	230	1958	1 238	1968	862	1978	596
1939	193	1949	310	1959	1 148	1969	934	1979	719
1940	259	1950	550	1960	1 163	1970	1 128	1980	906
1941	222	1951	602	1961	983	1971	1 401	1981	690
1942	171	1952	459	1962	1 156	1972	1 019	1982	661
1943	220	1953	530	1963	1 095	1973	957		
1944	270	1954	853	1964	1 235	1974	848		
1945	217	1955	802	1965	1 111	1975	602		

The TACC for ELE 3 has, with the exception of 2002–03 and 2018–19, been consistently exceeded since 1986–87. The ELE 3 TACC was increased to 500 t for the 1995–96 fishing year, and then increased twice more under an Adaptive Management Programme (AMP): initially to 825 t in October 2000 and then to 950 t in October 2002. This new TACC combined with the allowances for customary and recreational fisheries (5 t each), increased the new TAC for the 2002–03 fishing year in ELE 3 to 960 t. For the 2009–10 fishing year, the TACC was increased from 960 t to 1000 t. This was followed by a further increase to 1150 t for the fishing year 2018-19. ELE 3 fishing is seasonal, mostly occurring in spring and summer in inshore waters. Most of the increase in catch from the early 2000s in the ELE 3 trawl fishery has been taken as a bycatch of the flatfish target fishery and an emerging target ELE fishery (Starr & Kendrick 2013). During the 1990s, the level of elephant fish bycatch from the RCO 3 trawl fishery increased from around 80 t/year to greater than 400 t in 2000–01 (Starr & Kendrick 2013). There was a steady increase in the level of ELE 3 bycatch from the FLA 3 trawl fishery, with catches increasing from around 70 t in 1994–95 to 300 t in 1999–00. There is also a significant setnet fishery in ELE 3, largely directed at rig and elephant fish.

The fishery in ELE 5 is mainly a trawl fishery targeted at flatfish and to a lesser extent giant stargazer. Very little catch in ELE 5 is taken by target setnet fisheries. Catches increased consistently from 1992–93 (39 t) to 2008-09 (208 t), before decreasing again. The TACCs were exceeded in most years from 1995–96 to 2011-12. The ELE 5 TACC was increased from 71 t to 100 t under an AMP in October 2001. The TACC was further increased under the AMP to 120 t in October 2004 and catches have exceeded this TACC by 70% in 2007–08 and 2008–09. For the 2009–10 fishing season, the TACC was increased by 17% up from 120 t to 140 t. All AMP programmes ended on 30 September 2009. The ELE 5 TACC was further increased to 170 t in 2012–13; landings have repeatedly remained below the TACC since, including in 2018-19 when just 104 t of elephant fish were landed.

From 1 October 2008, a suite of regulations intended to protect Maui's and Hector's dolphins was implemented for all of New Zealand by the Minister of Fisheries. For ELE 3, commercial and recreational set netting was banned in most areas to 4 nautical miles offshore of the east coast of the South Island, extending from Cape Jackson in the Marlborough Sounds to Slope Point in the Catlins. Some exceptions were allowed, including an exemption for commercial and recreational set netting to only one nautical mile offshore around the Kaikoura Canyon, and permitting setnetting in most harbours, estuaries, river mouths, lagoons and inlets except for the Avon-Heathcote Estuary, Lyttelton Harbour, Akaroa Harbour and Timaru Harbour. In addition, trawl gear within 2 nautical miles of shore was restricted to flatfish nets with defined low headline heights. For ELE 7, both commercial and recreational setnetting were banned to 2 nautical miles offshore, with the recreational closure effective for the entire year and the commercial closure restricted to the period 1 December to the end of February. The closed area extends from Awarua Point north of Fiordland to the tip of Cape Farewell at the top of the South Island. Some interim relief to these regulations was provided in ELE 5 from 1 October 2008 to 24 December 2009.

Table 3: Reported landings (t) for the main QMAs from 1931 to 1990.

Year	ELE 1	ELE 2	ELE 3	ELE 5	ELE 7	Year	ELE 1	ELE 2	ELE 3	ELE 5	ELE 7
1931–32	0	0	0	0	0	1957	0	2	992	28	46
1932–33	0	0	0	0	0	1958	0	0	1 140	47	51
1933–34	0	0	0	0	0	1959	0	0	1 066	37	44
1934–35	0	0	0	0	0	1960	0	1	1 099	38	27
1935–36	0	0	0	0	0	1961	0	0	913	43	27
1936–37	0	0	79	0	1	1962	0	4	1 066	73	14
1937–38	0	0	183	0	0	1963	0	2	976	111	8
1938–39	0	0	194	1	2	1964	0	3	1 109	107	16
1939–40	0	1	190	1	1	1965	0	7	983	88	34
1940–41	0	1	243	8	1	1966	0	1	985	99	27
1941–42	0	0	220	1	0	1967	0	1	812	77	45
1942–43	0	0	163	6	0	1968	0	1	757	54	52
1943–44	0	0	219	1	0	1969	0	1	824	75	33
1944	0	0	251	10	0	1970	0	3	987	87	53
1945	0	2	205	3	3	1971	0	0	1 243	103	37
1946	0	0	228	3	4	1972	0	0	928	70	15
1947	0	2	176	0	10	1973	0	0	864	73	21
1948	0	2	227	0	9	1974	0	0	766	97	41
1949	0	1	296	2	13	1975	0	1	557	55	28
1950	0	1	522	14	13	1976	0	0	622	91	52
1951	0	2	585	6	10	1977	0	0	601	114	45
1952	0	0	440	9	5	1978	0	0	552	49	26
1953	0	3	514	13	3	1979	0	0	661	63	18
1954	0	2	839	5	7	1980	0	0	794	129	34
1955	0	3	771	4	25	1981	0	1	543	114	16
1956	0	1	933	16	29	1982	0	0	584	85	34

Notes:

1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: Data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings. Data were aggregated to FMA using methods and assumptions described by Francis & Paul (2013).

Table 4: Reported landings (t) of elephant fish by Fishstock from 1983–84 to present and actual TACCs (t) from 1986–87 to present. QMR data from 1986 – present. No landings have been reported from ELE 10. [Continued on next page]

Fishstock		ELE 1		ELE 2		ELE 3		ELE 5		ELE 7		
FMA (s)		1 & 9		2 & 8		3 & 4		5 & 6		7		Total
	Landings		Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	< 1	-	5	-	605	-	94	-	60	-	765	-
1984–85*	< 1	-	3	-	517	-	134	-	50	-	704	-
1985–86*	< 1	-	4	-	574	-	57	-	46	-	681	-
1986–87	< 1	10	2	20	506	280	48	60	29	90	584	470
1987–88	< 1	10	3	20	499	280	64	60	44	90	610	470
1988–89	< 1	10	1	22	450	415	49	62	43	100	543	619
1989–90	< 1	10	3	22	422	418	32	62	55	101	510	623
1990–91	< 1	10	5	22	434	422	55	71	59	101	553	636
1991–92	< 1	10	11	22	450	422	58	71	78	101	597	636
1992–93	< 1	10	5	22	501	423	39	71	61	102	606	638
1993–94	< 1	10	6	22	475	424	46	71	41	102	568	639
1994–95	< 1	10	5	22	580	424	60	71	39	102	684	639
1995–96	< 1	10	7	22	688	500	72	71	93	102	862	715
1996–97	< 1	10	9	22	734	500	74	71	94	102	912	715
1997–98	< 1	10	12	22	910	500	95	71	66	102	1 082	715
1998–99	< 1	10	9	22	842	500	129	71	117	102	1 098	715
1999–00	< 1	10	6	22	950	500	105	71	87	102	1 148	715
2000–01	2	10	7	22	956	825	153	71	90	102	1 207	1 040
2001–02	< 1	10	9	22	852	825	105	100	88	102	1 053	1 057
2002–03	1	10	9	22	950	950	106	100	59	102	1 125	1 194
2003–04	< 1	10	10	22	984	950	102	100	42	102	1 139	1 194
2004–05	< 1	10	13	22	972	950	125	120	74	102	1 184	1 214
2005–06	< 1	10	14	22	1 023	950	147	120	76	102	1 260	1 214
2006–07	< 1	10	17	22	960	950	158	120	116	102	1 251	1 214
2007–08	< 1	10	16	22	1 092	950	202	120	125	102	1 435	1 214
2008–09	1	10	21	22	1 063	950	208	120	91	102	1 384	1 214
2009–10	< 1	10	21	22	1 089	1 000	176	140	86	102	1 372	1 274
2010–11	< 1	10	14	22	1 123	1 000	153	140	93	102	1 384	1 283
2011–12	< 1	10	16	22	1 074	1 000	157	140	130	102	1 377	1 283
2012–13	< 1	10	16	22	1 140	1 000	157	170	123	102	1 436	1 304
2013–14	< 1	10	16	22	1 110	1 000	173	170	96	102	1 394	1 304
2014–15	< 1	10	11	22	1 048	1 000	179	170	102	102	1 340	1 304
2015–16	< 1	10	9	22	1 159	1 000	137	170	95	102	1 400	1 304
2016–17	< 1	10	12	22	1 051	1 000	182	170	81	102	1 326	1 304
2017–18	< 1	10	8	22	1 098	1 000	126	170	113	102	1 346	1 304
2018–19	< 1	10	9	22	1 142	1 150	104	170	100	102	1 354	1 464

Table 4 [continued]

Fishstock FMA (s)	ELE 1 1 & 9 Landings	TACC	ELE 2 2 & 8 Landings	TACC	ELE 3 3 & 4 Landings	TACC	ELE 5 5 & 6 Landings	TACC	ELE 7 7 Landings	TACC	Total Landings	TACC
2019–20	< 1	10	6	22	1 133	1 150	111	170	109	102	1 359	1 464
2020–21	< 1	10	10	22	1 065	1 150	85	170	98	102	1 258	1 464

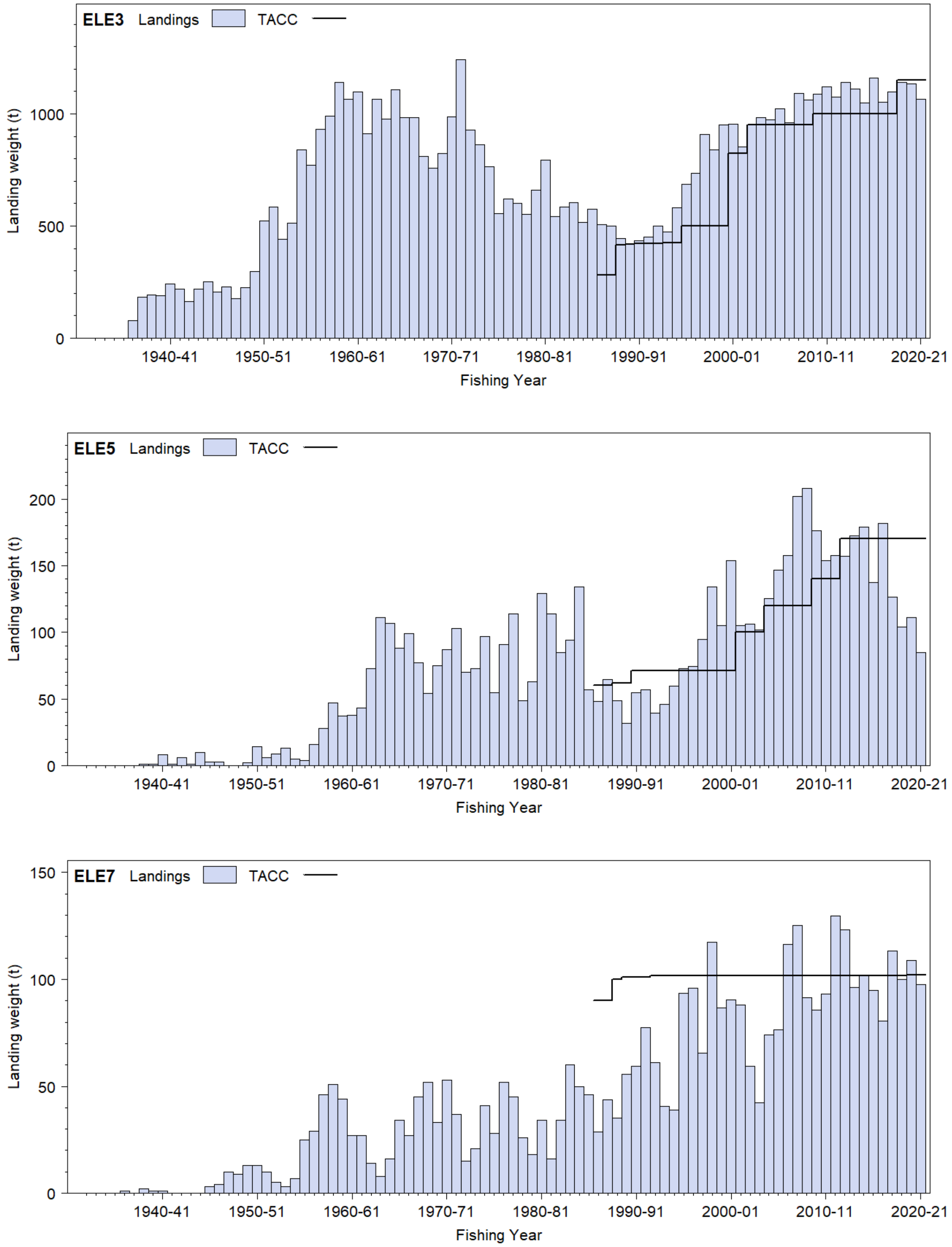


Figure 1: Reported commercial landings and TACC for the three main ELE stocks. From top: ELE 3 (South East Coast and Chatham Rise), ELE 5 (Southland and Sub-Antarctic), and ELE 7 (Challenger).

1.2 Recreational fisheries

Catches of elephant fish by recreational fishers are low compared with those of the commercial sector. Catches estimated using National Panel Surveys (NPS) in 2011–12 and 2017–18 (Wynne-Jones et al 2014, 2019) are shown in Table 5. Recreational catch exceeded 1000 fish only in ELE 3 in the two surveys and all estimates are quite uncertain. Regional surveys in the early 1990s (Teirney et al 1997) and national surveys in 1996, 1999, and 2000 (Bradford 1998, Boyd & Reilly 2002) showed similarly low number of fish harvested and similar geographical patterns. No estimates of mean weight are available to convert these estimates of harvested fish to harvested weights.

Table 5: Recreational harvest estimates for elephantfish stocks (Wynne-Jones et al 2014, 2019). In sufficient data on mean fish weights are available from boat ramp surveys to convert numbers to catch weights.

Stock	Year	Method	Number of fish	Total weight (t)	CV
ELE 2	2011–12	Panel survey	183	-	-
	2017–18	Panel survey	339	-	0.72
ELE 3	2011–12	Panel survey	4 853	-	-
	2017–18	Panel survey	2 458	-	0.36
ELE 5	2011–12	Panel survey	202	-	-
	2017–18	Panel survey	60	-	1.00
ELE 7	2011–12	Panel survey	960	-	-
	2017–18	Panel survey	189	-	0.39

1.3 Customary non-commercial fisheries

Quantitative information on the current level of customary non-commercial catch is not available.

1.4 Illegal catch

There are reports of discards of juvenile elephant fish by trawlers from some areas. However, no quantitative estimates of discards are available.

1.5 Other sources of mortality

The significance of other sources of mortality has not been documented.

2. BIOLOGY

Elephant fish are uncommon off the North Island and occur south of East Cape on the east coast and south of Kaipara on the west coast. They are most plentiful around the east coast of the South Island.

Males mature at a length of 50 cm fork length (FL) at an age of 3 years, females at 70 cm FL at 4 to 5 years of age. The maximum age of elephant fish is unknown. However, a tagged, 73 cm total length, Australian male was at liberty for 16 years, suggesting a longevity for males of at least 20 years (Coutin 1992, Francis 1997). Females probably also live to at least 20 years. A longevity of 20 years suggests that M is about 0.23. This results from use of the equation $M = \log_e 100/\text{maximum age}$, where maximum age is the age to which 1% of the population survives in an unexploited stock.

Mature elephant fish migrate to shallow inshore waters in spring and aggregate for mating. Eggs are laid on sand or mud bottoms, often in very shallow areas. They are laid in pairs in large yellow-brown egg cases. The period of incubation is at least 5–8 months, and juveniles hatch at a length of about 10 cm FL. Females are known to spawn multiple times per season. After egg laying the adults are thought to disperse and are difficult to catch; however, juveniles remain in shallow waters for up to 3 years. During this time juveniles are vulnerable to incidental trawl capture but are of little commercial value.

Von Bertalanffy growth curves based on MULTIFAN analysis of length-frequency data are available for Pegasus Bay and Canterbury Bight in 1966–68 and 1983–88. However, the ages of the larger fish were probably underestimated and the growth curves are only reliable to about 4–5 years (Francis 1997). New empirical growth curves were developed by fitting a Von Bertalanffy growth function to a dataset consisting of (a) the first six length-frequency modes from the study by Francis (1997) and (b) an approximate maximum size and age for male and female elephant fish. The latter points 'anchor' the curves at the right hand end and generate more plausible curve shapes, L_∞ estimates, and therefore length-at-age. The largest measured fish in the ELE 3 samples from 1966–68 and 1983–88 (i.e. 76 cm FL for males and 97 cm FL for females) were considered to be reasonable estimates of the mean maximum lengths of elephant fish in an unfished population. The following data points were therefore used in fitting the growth curves: 76 cm and 20 years for males, and 97 cm and 20 years for females. The best fitting growth model had separate male and female coefficients for K and L_∞ and a common coefficient for t_0 (M. Francis, unpubl. data).

Biological parameters relevant to the stock assessment are shown in Table 6.

Table 6: Estimates of biological parameters for elephant fish.

Fishstock	**Estimate**	**Source**
<u>1. Natural mortality (*M*)</u>		
All	0.23	See text

2. Weight = a (length)^b (Weight in g, length in cm fork length)

	Both sexes		
	a	b	
ELE 3	0.0091	3.02	Gorman (1963)

3. von Bertalanffy Growth Function

	Females			Males			
	L_∞	k	$t0$	L_∞	k	$t0$	
ELE 3	97.88	0.26	-0.55	75.03	0.34	-0.55	See text

3. STOCKS AND AREAS

There are no data that would alter the current stock boundaries. Results from tagging studies conducted during 1966–69 indicate that elephant fish tagged in the Canterbury Bight remained in ELE 3. Separate spawning grounds to maintain each 'stock' have not been identified. The boundaries used are related to the historical fishing pattern when this was a target fishery.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

4.1.1 Trawl survey biomass indices

ECSI Trawl Survey

The ECSI winter surveys from 1991 to 1996 in 30–400 m were replaced by summer trawl surveys (1996–97 to 2000–01) which also included the 10–30 m depth range, but these were discontinued after the fifth in the annual time series because of the extreme fluctuations in catchability between surveys (Francis et al 2001). The winter surveys were reinstated in 2007 and this time included additional 10–30 m strata in an attempt to index elephant fish and red gurnard which were officially included in the target species in 2012. Six surveys (2007, 2012, 2014, 2016, 2018 and 2021) provide full coverage of the 10–30 m depth range (Figure 2).

Total biomass in the core strata increased markedly in 1996 and although it has fluctuated since then it has remained high with the post-1994 average of 1032 t up to and including 2014, about three-fold greater than that of the early 1990s (Figure 2). The 2016 biomass was more than six-fold greater than this average, but the CV around the estimate was 68%, very high compared to previous surveys. The 2018 core strata estimate of 807 t is similar to the post-1994 average, whereas the 2021 biomass dropped to 83% below the average. In the core plus shallow strata, biomass followed the same trend as the core strata biomass. The additional elephant fish biomass captured in the 10–30 m depth range accounted for 44%, 64%, 41%, 7%, 28% and 74% of the biomass in the core plus shallow strata (10–400 m) for 2007, 2012, 2014, 2016, 2018 and 2021, respectively, indicating the importance of shallow strata for elephant fish biomass as well as variability in inshore-offshore spatial distribution at this time of year. (Table 7, Figure 2). Further, the addition of the 10–30 m depth range had a significant effect on the shape of the length frequency distributions with the appearance of strong 1+ and 2+ cohorts, otherwise poorly represented in the core strata, particularly in

2007,2012 and 2021. The proportion of pre-recruit biomass in the core plus shallow strata was also generally greater than that of the core strata alone, indicating that younger fish are more common in shallow water (Table 7). For the six core plus shallow strata surveys, the juvenile biomass (based on the length-at-50% maturity) was highly variable from 9–77%, and in 2021 it was 29%. The distribution of elephant fish hot spots varies, but overall this species is consistently well represented over the entire survey area from 10 to 100 m, but is most abundant in the shallow 10 to 30 m.

WCSI Trawl Survey

For WCSI Trawl Surveys, elephant fish (ELE 7) total biomass estimates are variable between successive surveys and the biomass estimates are frequently imprecise, particularly for the higher biomass estimates (Table 7). The last three trawl surveys (2009, 2011 and 2013) have estimated relatively high levels of recruited biomass compared to the biomass estimates from the earlier surveys (Figure 3). However, of the three recent surveys, only the 2013 survey provided a biomass estimate with a reasonable level of precision (CV 26%). The survey estimates of pre-recruit biomass are also poorly determined.

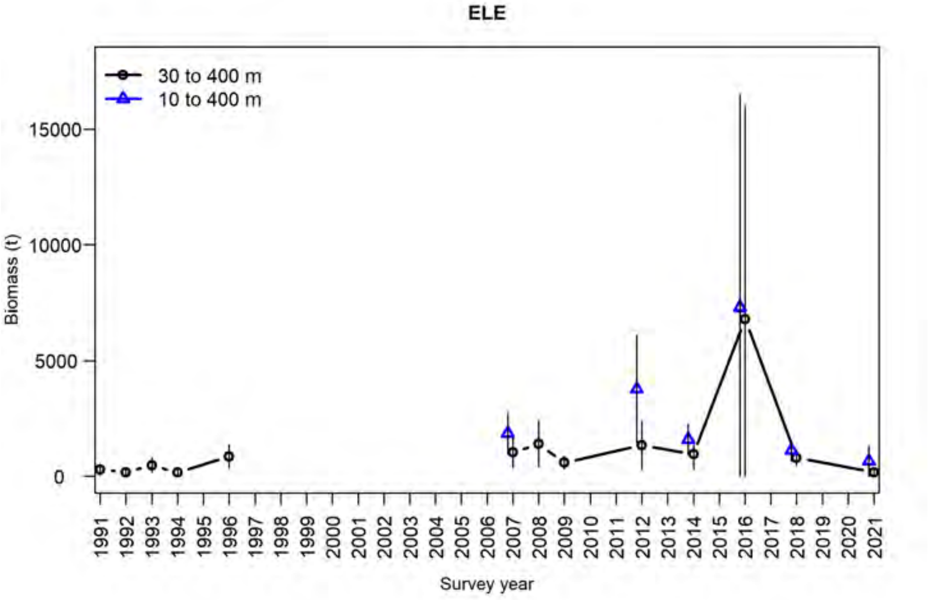


Figure 2: Elephant fish total biomass and 95% confidence intervals for all ECSI winter surveys in core strata (30–400 m), and core plus shallow strata (10–400 m) in 2007, 2012, 2014, 2016, 2018 and 2021.

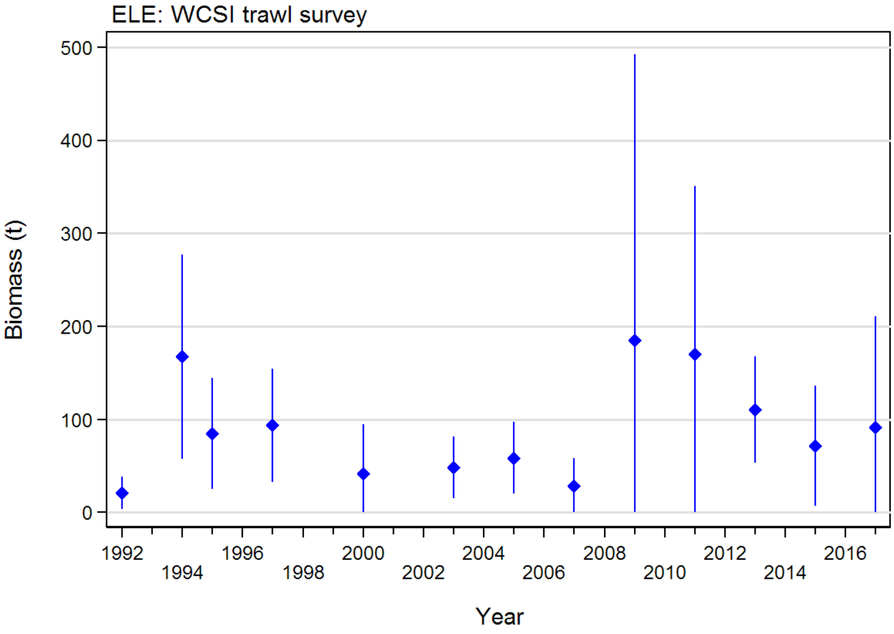


Figure 3: Elephant fish trawl survey total biomass estimates for the west coast South Island survey, with associated 95% confidence intervals.

Table 7: Relative biomass indices (t) and coefficients of variation (CV) for elephant fish for east coast South Island (ECSI) - summer and winter, west coast South Island (WCSI) and the Stewart-Snares Island survey areas*. Biomass estimates for ECSI in 1991 have been adjusted to allow for non-sampled strata (7 and 9 equivalent to current strata 13, 16 and 17). The sum of pre-recruit and recruited biomass values do not always match the total biomass for the earlier surveys because at several stations length frequencies were not measured, affecting the biomass calculations for length intervals. – , not measured; NA, not applicable. Recruited is defined as the size-at-recruitment to the fishery (50 cm).

Region	Fishstock	Year	Trip number	Total Biomass estimate	CV (%)	Total Biomass estimate	CV (%)	Pre-recruit	CV (%)	Pre-recruit	CV (%)	Recruited	CV (%)	Recruited	CV (%)
ECSI(winter)	ELE 3			30–400 m		10–400 m		30–400 m		10–400 m		30–400 m		10–400 m	
		1991	KAH9105	300	40	-	-	NA	NA	-	-	NA	NA	-	-
		1992	KAH9205	176	32	-	-	54	83	-	-	122	28	-	-
		1993	KAH9306	481	33	-	-	60	56	-	-	421	34	-	-
		1994	KAH9406	152	33	-	-	22	51	-	-	142	34	-	-
		1996	KAH9606	858	30	-	-	338	40	-	-	520	26	-	-
		2007	KAH0705	1 034	32	1 859	24	516	59	1 201	36	518	21	658	20
		2008	KAH0806	1404	35	-	-	627	57	-	-	777	27	-	-
		2009	KAH0905	596	23	-	-	210	38	-	-	387	25	-	-
		2012	KAH1207	1 351	39	3 781	31	66	46	581	25	1 285	39	3 199	36
		2014	KAH1402	951	34	1600	21	174	32	429	25	777	40	1 171	28
		2016	KAH1605	6 812	68	7 299	63	62	43	167	30	6 750	68	7 132	64
		2018	KAH1803	807	21	1 118	20	266	34	356	28	541	23	761	24
		2021	KAH2104	170	32	655	51	29	38	120	38	141	39	536	63
ECSI(summer)	ELE 3	1996–97	KAH9618	21	42	-	-	-	-	-	-	-	-	-	-
		1997–98	KAH9704	167	33	-	-	-	-	-	-	-	-	-	-
		1998–99	KAH9809	85	35	-	-	-	-	-	-	-	-	-	-
		1999–00	KAH9917	94	33	-	-	-	-	-	-	-	-	-	-
		2000–01	KAH0014	42	63	-	-	-	-	-	-	-	-	-	-
WCSI	ELE 7	1992	KAH9204	59	33	-	-	-	-	-	-	-	-	-	-
		1994	KAH9404	28	53	-	-	-	-	-	-	-	-	-	-
		1995	KAH9504	185	83	-	-	-	-	-	-	-	-	-	-
		1997	KAH9701	170	53	-	-	-	-	-	-	-	-	-	-
		2000	KAH0004	110	26	-	-	-	-	-	-	-	-	-	-
		2003	KAH0304	72	45	-	-	-	-	-	-	-	-	-	-
		2005	KAH0503	92	65	-	-	-	-	-	-	-	-	-	-
		2007	KAH0704	21	42	-	-	-	-	-	-	-	-	-	-
		2009	KAH0904	167	33	-	-	-	-	-	-	-	-	-	-
		2011	KAH1104	85	35	-	-	-	-	-	-	-	-	-	-
		2013	KAH1305	94	33										
		2015	KAH1503	42	63										
		2017	KAH1703	49	34										
Stewart-Snares	ELE 5	1993	TAN9301	219	33	-	-	-	-	-	-	-	-	-	-
		1994	TAN9402	177	47	-	-	-	-	-	-	-	-	-	-
		1995	TAN9502	69	49	-	-	-	-	-	-	-	-	-	-
		1996	TAN9604	137	46	-	-	-	-	-	-	-	-	-	-

*Assuming area availability, vertical availability and vulnerability equal 1.0. Biomass is only estimated outside 10 m depth except for COM9901 and CMP0001. Note: because trawl survey biomass estimates are indices, comparisons between different seasons (e.g., summer and winter ECSI) are not strictly valid.

4.1.2 CPUE biomass indices

ELE 3 and ELE 5

Three standardised CPUE series for ELE 3 were prepared for 2012, with each series based on the bycatch of elephant fish in bottom trawl fisheries defined by different target species combinations. Initially, the Working Group accepted a series based solely on the bycatch of elephant fish when targeting red cod. It then requested two further analyses: one [ELE 3(MIX)] where the target species definition was expanded to include STA, BAR, TAR, and ELE, as well as RCO, to investigate the effect of target species switching by explicitly standardising for target species effects. The second analysis [ELE 3(MIX)-trip] was done on all trips that targeted RCO, STA, BAR, TAR, and ELE at least once, then amalgamating all data to the level of a trip. This removed the differences between the TCEPR, TCER and CELR forms, but loses all targeting information.

The three sets of ELE 3 CPUE indices (ELE 3(RCO), ELE 3(MIX) and ELE 3(MIX)-trip) were very similar for the 1989–90 to 2010–11 years. The Working Group agreed in 2009 to drop the ELE 3-SN(SHK) and ELE 5-SN(SHK) (setnet with shark target species) indices because the setnet fisheries in these two QMAs have been substantially affected by management interventions (including measures to reduce the bycatch of Hector's dolphins) and no longer appeared to be an appropriate index of ELE abundance in either QMA.

In 2014, the ELE 3(MIX) CPUE model was updated to include additional data from 2011–12 and 2012–13 (Langley 2014). The resulting CPUE indices were very similar to the previous analysis for the comparable period. The indices were updated again in 2016, extending the time-series to 2014–15. Standardised CPUE has fluctuated without trend since 2009–10 and the 2014–15 data point is near the interim target (see below) (Figure 4).

An analysis of recent CPUE data suggested that bottom trawl fishing operations may be attempting to avoid larger catches of elephant fish. During 2012–13 to 2014–15, there was a lower probability of successive larger catches of elephant fish. This may have negatively biased the CPUE indices from 2012–13 to 2014–15 (Langley 2016 - presentation).

***B_{MSY}* conceptual proxy:** The Working Group proposed using the average of the ELE 3(MIX) series from 1998–99 to 2010–11 to represent a "B_{MSY} conceptual proxy" for the ELE 3 Fishstock. This period was selected because of its relative stability following a period of continuous increase. However, the Working Group has concerns about the reliability of this as a proxy and suggested that it only be used on an interim basis.

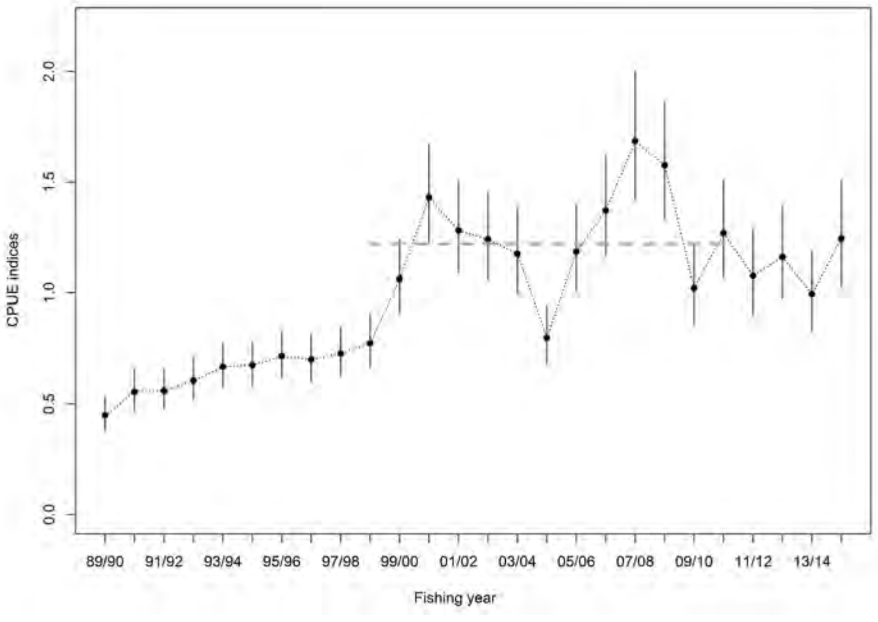


Figure 4: Standardised CPUE indices for the ELE 3 bottom trawl fisheries [ELE 3(MIX)]. The horizontal grey line is the mean of ELE 3(MIX) from 1998–99 to 2010–11 (B_{MSY} conceptual proxy). The CPUE series has been normalised to a geometric mean of 1.0. Error bars show 95% confidence intervals.

Two standardised CPUE series for ELE 5 were prepared for 2012 with each series based on the bycatch of elephant fish in the bottom trawl fisheries defined by target species combinations (Starr & Kendrick 2013). One of these series [ELE 5 BT(MIX)] is analogous to the MIX series developed for ELE 3, with the series defined by six target species in all valid ELE 5 statistical areas. The second ELE 5 analysis [ELE 5 BT(MIX)-trip] was a trip- based analysis using the same target species selection method as described for ELE 3-BT(MIX)-trip series. The two sets of indices were very similar.

In 2014, the ELE 5-BT(MIX) CPUE model was updated to include data from 2011–12 to 2012–13 (Langley 2014). This model used the "daily effort" method to prepare the data, whereby every record was reduced to a day of fishing, with the predominant statistical area and target species for the day assigned to the record. This method was accepted by the WG as the best procedure to follow when reducing event-based forms to match earlier daily forms. The two most recent indices were lower than the peak CPUE from 2008–09 to 2010–11, although CPUE has been maintained at a relatively high level compared to the 1990s–early 2000s (Figure 5). The ELE 5-BT(MIX) model was again updated in 2017, with data current to the end of 2015–16. Although the fishery definition and data preparation methods were unchanged, a binomial presence/absence series was added because of a declining trend in the proportion of days with zero catch. The Plenary accepted a revised index which combined the binomial and lognormal series using the delta-lognormal method (Starr & Kendrick, in prep). This was done because the Inshore WGs have adopted the standard of combining positive catch and fishing success models when there is a trend in the proportion zero catch. As well, simulation work has indicated that calculating a combined index may reduce bias when reporting small catch amounts (Langley 2015). Recent indices estimated by this updated series are lower than the peak observed at the end of the 2010 decade, but these indices remain above the long-term average CPUE (Figure 5).

***BMSY* conceptual proxy:** The Plenary agreed in 2017 to use the mean combined ELE5-BT(MIX) CPUE for the period 2005–06 to 2015–16 as a "BMSY conceptual proxy" for ELE 5. This period was selected because a plot of CPUE against catch (yield curve) appeared to have levelled out and is assumed to represent a stochastic equilibrium (Figure 6).

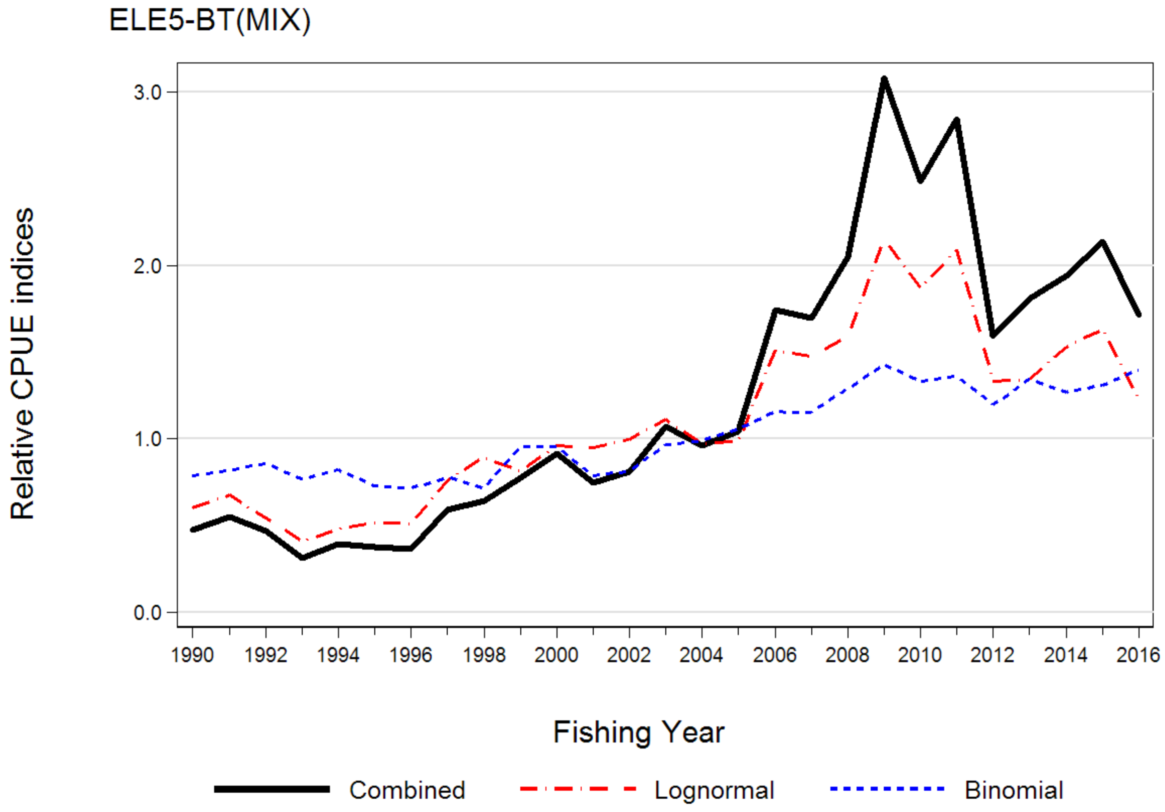


Figure 5: Plots of three ELE5-BT(MIX) CPUE series: a) positive catch (lognormal); b) presence/absence (binomial) and c) combined series using the delta-lognormal method.

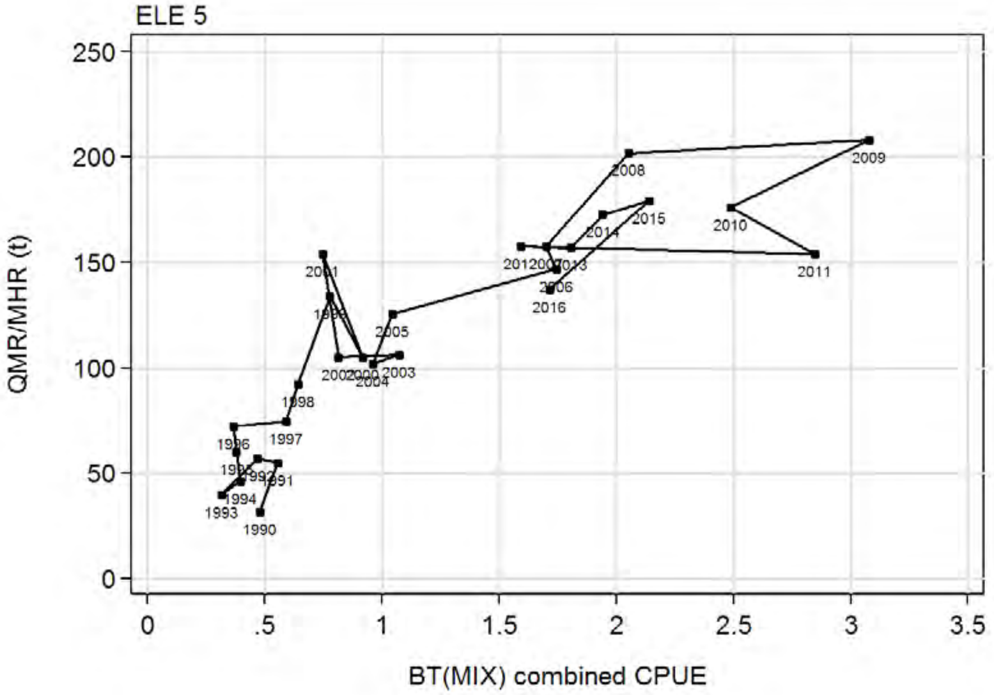


Figure 6: Trace yield plot for ELE 5, showing CPUE and QMR/MHR landings plotted sequentially by fishing year.

ELE 7

A preliminary CPUE analysis of the catch of elephant fish from the WCSI inshore trawl fishery was conducted in 2013 and updated in 2014 (Langley 2014). The analysis included all bottom trawl catch and effort data targeting either flatfish, red gurnard, red cod or elephant fish. These target trawl fisheries encompass almost all the trawl fishing effort within the depth range that encompasses most of the catch of elephant fish off the west coast of the South Island (5–80 m). The primary analysis was conducted based on catch and effort data from 1989–90 to 2012–13 aggregated in a format that was consistent with the CELR reporting format. The landed catch of elephant fish from each trip was apportioned to the effort records either based on the associated level of estimated catch or, where estimated catches were not recorded, in proportion to the number of trawls in each aggregated effort record.

The data set included a significant proportion of trip and effort records with no elephant fish catch, although the proportion of nil catch records decreased steadily over the study period. Thus, the overall CPUE for the fishery was modelled in two components: the binomial model of the proportion of positive catches and the lognormal model of the magnitude of the positive catch. The two components were combined to generate a time series of delta-lognormal CPUE indices. The sensitivity of the catch threshold used to define a positive catch (i.e. 0, 1 kg, 2 kg and 5 kg) was investigated. The resulting binomial and lognormal CPUE indices were sensitive to the applied catch threshold; however, the compensatory changes in the two sets of indices resulted in delta-lognormal indices that were relatively insensitive to the applied catch threshold.

The resulting CPUE indices fluctuated over the study period with a marked peak in CPUE in 1999–2000 and 2000–01 and low CPUE in 1997–98 and 2003–04 (Figure 7). The CPUE indices remained stable during 2007–08 to 2009–10, increased in 2010–11, increased markedly in 2011–12 and remained at the higher level in 2012–13. In 2014, the SINS WG concluded that the CPUE indices were unlikely to be a reliable index of stock abundance, primarily on the basis that the large inter-annual variations in the CPUE indices especially during the late 1990s and early 2000s were not consistent with the dynamics of the stock and may be attributable to changes in the operation of the WCSI trawl fishery at that time.

A separate delta-lognormal CPUE analysis was conducted for the location based TCER catch and effort data from 2007–08 to 2012–13 (Langley 2014). The resulting CPUE models incorporated a number of additional explanatory variables available in the high resolution data format. The TCER delta-lognormal CPUE indices were broadly similar to the CELR format CPUE indices for the comparative period The TCER indices exhibited a comparable increase in CPUE from 2009–10 to 2011–12, although the TCER indices were higher in 2007–08 to 2008–09 than the CELR format indices. In 2015, the TCER CPUE indices were updated to include the 2013–14 fishing year. The SINS WG concluded that the TCER CPUE indices represented the best available information for monitoring trends in ELE 7 stock abundance.

A "rapid update" of the ELE 7 tow-by-tow standardised CPUE analysis was reviewed and accepted by the SINS WG in 2019 (Starr & Kendrick 2019). This analysis duplicated the Langley (2014) analysis reported above, extending the analysis by four years as well as providing additional diagnostics supporting the standardisation procedure (Figure 7). The SINS WG agreed that this series indexed ELE 7 abundance, with the 2017–18 index near the series mean (Figure 7). In addition, the SINS WG agreed that the mean (2007–08 to 2017–18) index of this series could serve as a B_{msy} proxy target for this stock.

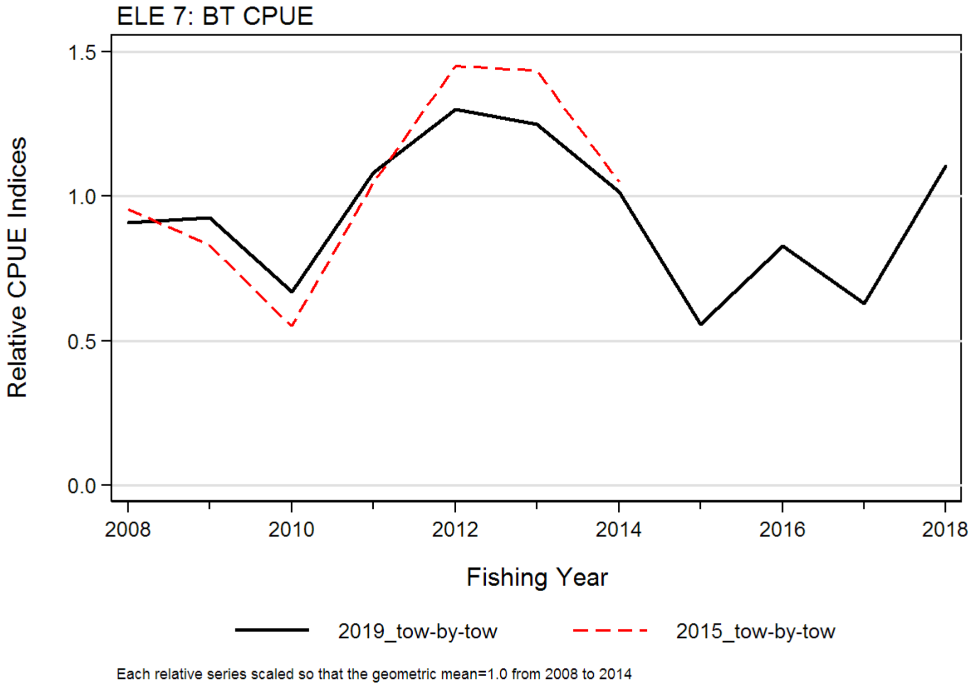


Figure 7. Standardised delta-lognormal CPUE indices for the ELE 7 inshore WCSI trawl fishery based on tow-by-tow TCER data. Two index series are presented: the updated 2019 series and the previously accepted 2015 series. Both sets of indices are normalised to the comparable time period (2007–08 to 2013–14).

4.2 Stock Assessment models

A preliminary stock assessment model was developed for ELE 3. Estimates of current and reference absolute biomass are not available for the other elephant fish stocks.

ELE 3

A stock assessment model was developed for ELE 3 in 2016 using the Stock Synthesis (3.24f) software to implement an age-structured population model. The data sets available for inclusion in the assessment model are, as follows.

- Annual reported catch of elephant fish (1931–2015). The historical catches were derived from Francis & Paul (2013). Additional unreported landed catches were included for the period prior to the introduction of the QMS. The level of unreported landed catch was assumed to represent a third of the reported catch. The magnitude of unreported landed catch was based on discussions with commercial operators in the ELE 3 fishery.
- A time-series of estimates of the magnitude of the discarded catch (unreported but not landed) of elephant fish (1931–2015). Based on the discussions with commercial operators it was assumed that the discarded (and unreported catch) represented 25% of total landed catch (reported and unreported combined). The discarded catch is comprised of smaller elephant fish, usually less than 50 cm FL.
- BT MIX CPUE indices 1989–90 to 2014–15 (26 observations).
- ECSI trawl survey pre-recruit (< 50 cm), recruited (50+ cm) and total biomass estimates from the time series of winter surveys, 30–400 m depth (11 observations).
- ECSI trawl survey length compositions (male and female); winter surveys, 30–400 m depth (11 observations).

- Aggregated length compositions (male and female) of the commercial trawl catch sampled by Scientific Observers during 2009–10.

Additional data are available from the summer ECSI trawl surveys. These data were not included in the analysis as it has previously been concluded that the summer survey series does not represent a reliable index of abundance for elephant fish. In recent years, the winter trawl survey has been extended to include the shallower areas of Canterbury Bight and Pegasus Bay (10–30 m), partly to improve the monitoring of the abundance of elephant fish. However, the time-series of surveys that includes this area is limited (four surveys).

Initial modelling results revealed that the scaled length compositions derived from the winter trawl surveys were highly variable (amongst surveys) and inconsistent with the other key input data sets. Further examination of the length composition data revealed that few elephant fish were caught and sampled during each survey and the scaled length compositions were typically dominated by the sampled catch from a limited number of trawls. The length and sex compositions of these larger catches were highly variable.

On that basis, it was concluded that the survey length compositions were unlikely to be representative of the length composition of the elephant fish population and these data were excluded from the final set of model options. Further, the estimates of trawl survey biomass for pre-recruit (<50 cm) fish are relatively imprecise (CVs 32–83%) and preliminary modelling indicated that these indices were not consistent with the other abundance indices (especially the CPUE indices). Thus, the pre-recruit trawl survey biomass indices were also excluded from the final set of model options.

Model configuration

The final assessment model was configured, as follows.

- Model period 1931–2015, terminal year represents 2014–15 fishing year.
- Age classes 0–19 and 20+ years, two sexes.
- Initial (1931) population age structure assumes equilibrium, unexploited conditions.
- Annual recruitment derived from Beverton and Holt stock-recruitment relationship; R0 parameter estimated (uninformative beta prior) and steepness fixed at 0.6 (base model option), recruitment deviates from SRR estimated for 1989–2013 assuming a SigmaR of 0.6.
- Sexual maturity (female fish) at 70 cm (FL).
- Two commercial fisheries: discard and retained catch. The selectivity of the commercial catch is assumed to be equivalent for the two main fishing methods (BT and SN).
- Commercial length composition data from 2009–10 are partitioned at 50 cm to characterise the length composition of discard (<50 cm) and retained (50+ cm) commercial catches. Both length compositions are assigned a relatively high weighting (ESS 100) to ensure that the model approximates these observations.
- The length-based selectivity of discard commercial fishery is parameterised using a double normal selectivity function (equivalent for both sexes). Selectivity is effectively truncated at about 50 cm (FL).
- Two alternative length-based selectivity options were adopted for the retained commercial fishery with selectivity parameterised using either a logistic or double normal function. Selectivity was allowed to vary by sex.
- The CPUE indices are assumed to represent the relative abundance of the component of the population that is vulnerable to the retained commercial fishery. The CPUE indices were assigned a CV of 20%.
- The ECSI recruited (50+ cm) total biomass estimates were assigned the native CVs from individual surveys. The length-based selectivity of the survey was assumed to be knife edge at 50 cm (FL) with full selectivity for all the larger length intervals.

Model options that assumed a logistic selectivity function for the (retained) commercial fishery resulted in a poor fit to the (retained) commercial length composition for male and female fish (from 2009–10). These models consistently over-estimated the number of larger male (>68 cm FL) and female (>90 cm FL) elephant fish in the commercial catch.

The alternative model option with selectivity parameterised by a double normal function resulted in a substantial improvement in the fit to the commercial length compositions (relative to the logistic selectivity model). The double normal selectivity model estimated selectivity for male and female fish started to rapidly decline above 70 cm and 85 cm FL, respectively. The lower selectivity of larger female fish meant that approximately 40–50% of the mature female population (by weight) is estimated to be invulnerable to the commercial fishery and, consequently, not monitored by the CPUE indices.

Separate model runs were conducted for the two selectivity options, each with three assumed values of SRR steepness: a base level of 0.6 bracketed by values of 0.5 and 0.7. MCMCs were conducted for the six model options. However, the results of the MCMCs were not satisfactory for the model options with the lowest value of steepness and, consequently, only MCMC results for the 0.6 steepness options are reported.

Model results

The overall fit to the CPUE indices was acceptable for all model options. The CPUE indices exhibit a general increase with marked peaks in the early and late 2000s. The models account for these trends by estimating higher recruitments for 1996–1998, 2004, and 2009. As previously noted, the double normal selectivity parameterisation substantially improved the fit to the retained commercial length composition data (compared to logistic selectivity). There was also a marginal improvement in the fit to the CPUE indices with the double normal selectivity.

All model options also estimated an increase in stock abundance that was consistent with the overall increase in the ECSI trawl survey recruited biomass estimates between the 1990s and the more recent period, although the fit to the individual biomass estimates is poor. The quality of the fit is consistent with the relatively low precision of the biomass estimates and the likelihood that the survey vulnerability of elephant fish varies amongst survey years (as indicated by the variability in the length composition of the survey catches).

Two indicators of stock status were derived from the assessment models: current (2014–15) female spawning (=mature) biomass relative to unexploited spawning biomass (SB_{2015}/SB_0), and current spawning biomass relative to the spawning biomass in 1985 (SB_{2015}/SB_{1985}). The latter metric provides an indication of the extent of the stock recovery from the period when the stock was estimated to be at the lowest level.

The MPD results indicate that stock abundance has increased considerably from a low level (approx. 10–20% SB_0) in 1985. The double normal selectivity model runs represent a somewhat more optimistic estimate of the current stock status relative to both SB_0 and SB_{1985}. MPD estimates of stock status tended to be near the lower bound of the MCMC confidence intervals, indicating that the MPD estimates are likely to represent minimum biomass levels consistent with the catch history.

Table 8: Estimates of stock status for the range of commercial selectivity and SRR steepness options (MPD estimates). MCMC estimates (median value and 95% confidence interval) are also presented for the two selectivity options with SRR steepness of 0.60.

Selectivity	Steepness		SB_{2015}/SB_0	SB_{2015}/SB_{1985}
Double normal				
	0.6	MPD	0.390	2.99
		MCMC	0.471	2.86
			(0.266–0.872)	(2.08–3.97)
	0.7	MPD	0.321	3.77
Logistic				
	0.6	MPD	0.279	2.50
		MCMC	0.386	2.63
			(0.217–0.651)	(1.86–3.61)
	0.7	MPD	0.229	3.03

The results are also sensitive to the assumptions regarding SRR steepness. Higher values of steepness correspond to lower estimates of SB_0 and a higher level of depletion by 1985, and while the relative level of recovery from 1985 is higher than for lower steepness options, the current level of stock biomass relative to SB_0 is lower.

The median estimates of SB_{2015}/SB_0 stock status from the MCMCs are more optimistic than the corresponding MPD results for the SRR steepness 0.60 model runs. The MCMC results also reveal that there is considerable uncertainty associated with the estimates of stock status, although the confidence intervals derived from the MCMCs suggest that current biomass is Likely to be above the default soft limit (20% SB_0) and About As Likely as Not to be at or above the default target biomass level (40% SB_0). However, the preliminary nature of the model precludes definitive statements about stock status.

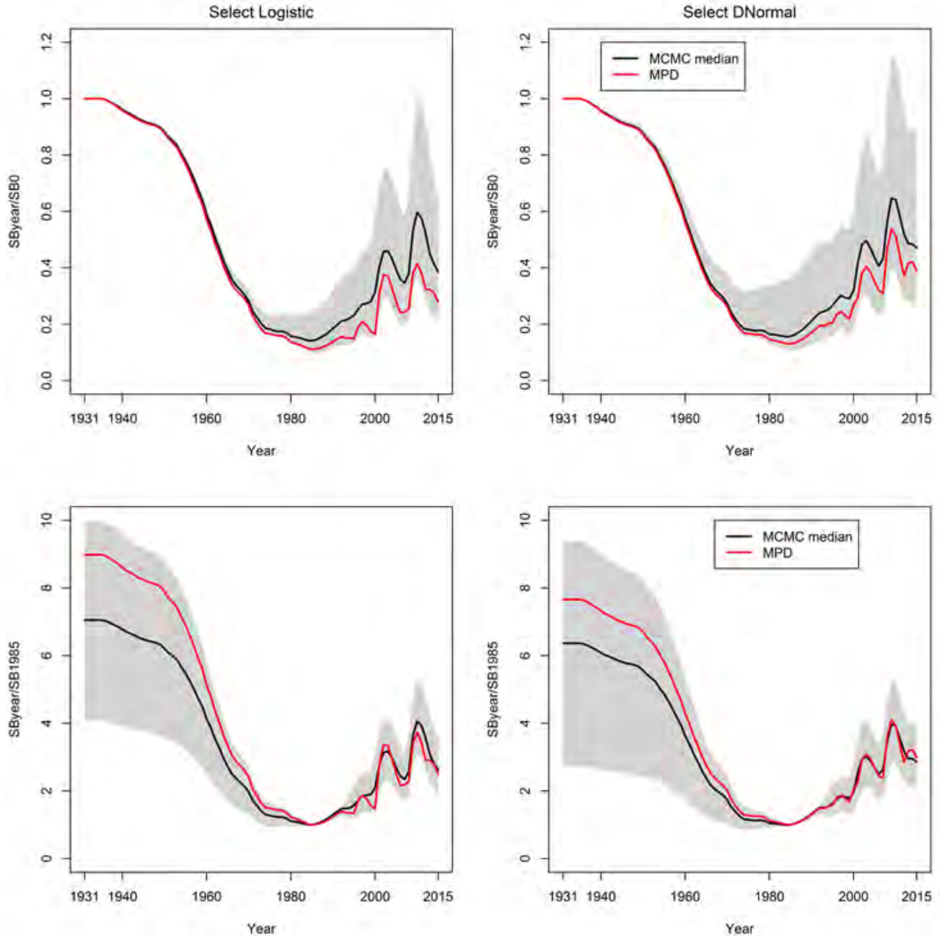


Figure 8: Stock trajectories for the spawning biomass relative to SB_0 (upper panels) and SB_{1985} (lower panels) for logistic (left panels) and double normal (right panels) selectivity options with SRR steepness 0.6. The black line represents the median of the McMCs (with 95% confidence interval) and the red line represents the MPD.

The Southern Inshore Working Group concluded that this preliminary model produced plausible biomass trajectories, but uncertainty about productivity and fits to commercial length data precluded acceptance of the model as a reliable estimator of current stock status.

These conclusions need to be tempered by the possibility that the models may be over-estimating recruitment in the more recent years. This may provide an explanation for the apparent over-estimation of the proportion of larger, older fish in the population in the late 2000s (that were not apparent in the commercial length composition). Conversely, the recent CPUE indices may be biased low (due to apparent avoidance behaviour) and consequently the model may under-estimate the current level of biomass.

Estimates of SB_{2015}/SB_0 stock status are also highly uncertain (and potentially biased) due to the assumptions associated with the estimation of historical, unexploited biomass.

4.3 Yield estimates and projections

No other yield estimates are available.

4.4 Other factors

A data informed qualitative risk assessment was completed on all chondrichthyans (sharks, skates, rays and chimaeras) at the New Zealand scale in 2014 (Ford et al 2015). Elephant fish was ranked fourth highest in terms of risk of the eleven QMS chondrichthyan species. Data were described as existing and sound for the purposes of the assessment and consensus over this risk score was achieved by the expert panel. This risk assessment does not replace a stock assessment for this species but may influence research priorities across species.

5. STATUS OF THE STOCKS

- **ELE 1**

No estimates of current and reference biomass are available.

- **ELE 2**

It is not known if recent catch levels or the current TACC are sustainable. The state of the stock in relation to B_{MSY} is unknown.

- **ELE 3**

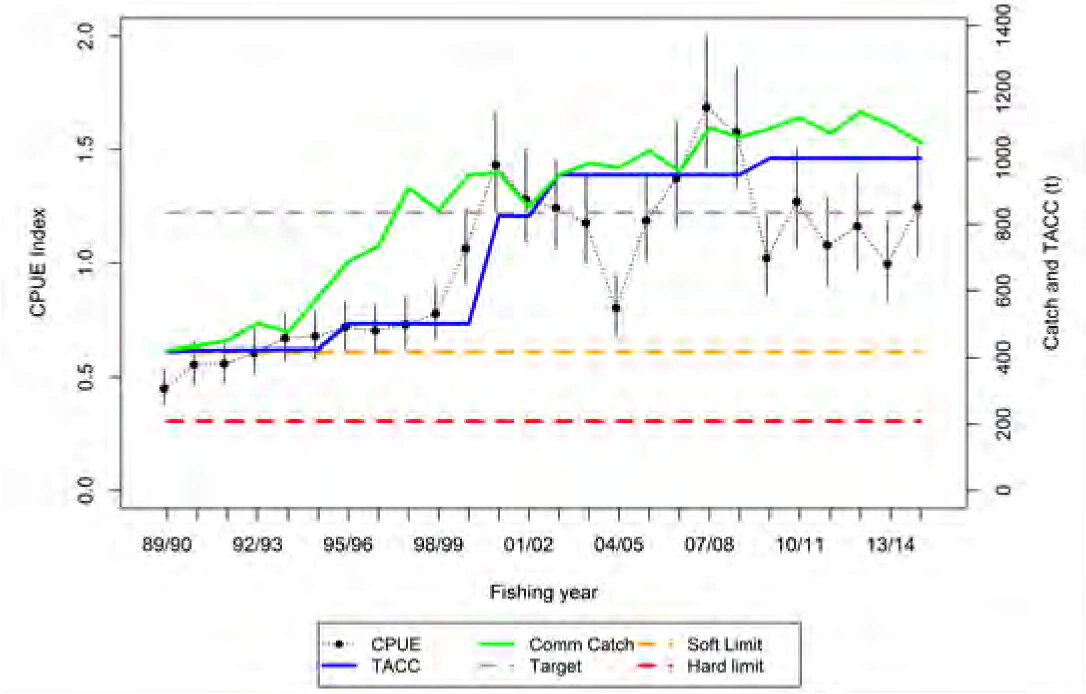
Stock Structure Assumptions

No information is available on the stock separation of elephant fish. The Fishstock ELE 3 is treated in this summary as a unit stock.

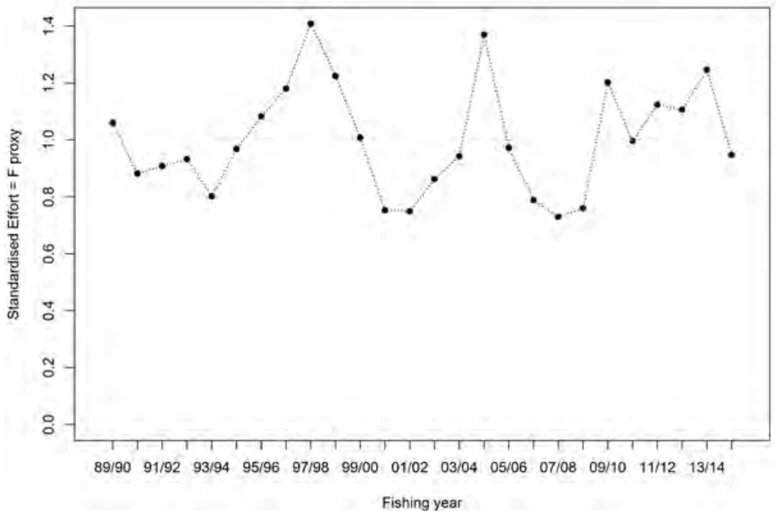
Stock Status	
Year of Most Recent Assessment	2016
Assessment Runs Presented	Update ELE 3 (MIX) CPUE series
Reference Points	Interim target: B_{MSY}-compatible proxy based on CPUE (average from 1998–99 to 2010–11 of the ELE 3(MIX) model as defined in Starr & Kendrick 2013) Soft Limit: 50% of target Hard Limit: 25% of target
Status in relation to Target	About as Likely as Not (40–60%) to be at or above the target
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Overfishing is About as Likely as Not (40–60%) to be occurring

Historical Stock Status Trajectory and Current Status

CPUE, Catch and TACC Trajectories



Comparison of the mixed target species bottom trawl CPUE series (ELE 3(MIX)) with the trajectories of catch (ELE 3(QMR/MHR)) and TACCs from 1989–90 to 2014–15. The dashed lines represent the interim target and corresponding soft limit and hard limit.

Fishery and Stock Trends	
Recent trend in Biomass or Proxy	The ELE 3(MIX) CPUE series, which is considered to be an index of stock abundance, showed a generally increasing trend from the beginning to reach a peak in 2007–08. CPUE indices have remained relatively stable below the peak level since 2009–10, remaining near the proposed target.
Recent trend in Fishing Intensity or Proxy	 **Fishing mortality proxy is Standardised Fishing Effort = Total catch/CPUE (normalised). Fishing mortality proxy has fluctuated about the average level and was at about the average in the most recent year.**
Other Abundance Indices	- Although there is high inter-annual variation, the winter ECSI trawl survey index shows a trend that is consistent with the ELE 3(MIX) CPUE index. - Preliminary stock assessment modelling for ELE 3 estimates that the stock abundance has increased substantially from a low level in the 1980s. The assessment models indicate that current biomass levels are probably at or about the default target biomass levels.
Trends in Other Relevant Indicator or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Quantitative stock projections are unavailable.
Probability of Current Catch or TACC causing decline Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	The TACC and current reported catches are About as Likely as Not (40–60%) to cause overfishing.

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Evaluation of agreed standardised CPUE indices which reflect changes in abundance.	
Assessment Dates	Latest assessment: 2016	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality. The Southern Inshore Working Group agreed that the ELE 3(MIX) CPUE index was a credible measure of abundance.	
Main data inputs (rank)	- Catch and effort data	1 – High Quality

Data not used (rank)	- Compass Rose trawl survey data - Summer ECSI trawl survey data and winter ECSI trawl survey data - Set net CPUE (shark)	3 – Low Quality: insufficient data 2 – Medium or Mixed Quality: variable catchability / selectivity between years 3 – Low Quality: Index compromised by area closures
Changes to Model Structure and Assumptions	None since 2012 assessment	
Major Sources of Uncertainty	- It is possible that fisher avoidance and discarding have biased (low) the CPUE trends reported for this fishery.	

Qualifying Comments
- Elephant fish have shown good recovery since apparently being at low biomass levels in the mid-1980s. - Preliminary stock assessment modelling results are consistent with assumed level of stock rebuilding, primarily reflecting the increase in the CPUE abundance indices. However, there are considerable uncertainties associated with key biological parameters (natural mortality and growth) and conflict amongst the main input data sets. The modelling results are not considered to be amply reliable to estimate current stock status (relative to MSY levels) and potential yields for the stock. With respect to the conceptual B_{msy} proxy, the Plenary had concerns about the reliability of this as a proxy and advised that it only be used in the interim. - Historical catches may be poorly estimated. Both current and historical estimates of landings exclude fish discarded at sea and the quantum of discards is unknown. Management interventions since the stock was introduced into the QMS may have influenced the rate of discarding and therefore the reliability of CPUE as a measure of relative abundance.

Fishery Interactions
Elephant fish in ELE 3 are taken as bycatch by bottom trawl fisheries targeting red cod, flatfish and barracouta. Targeting elephant fish in the bottom trawl fishery has increased to around 40% of the landings since 2004–05 when the deemed value regime changed. Around 15% of the ELE 3 landings are taken by setnet in a fishery targeted at a number of shark species, including rig, elephant fish, spiny dogfish and school shark. Both the trawl and setnet fisheries have been subject to management measures designed to reduce interactions with endemic Hector's dolphins. Bottom trawl fishers also have not trawled within one nautical mile of the coast (since 2001) in an effort to preserve ELE egg cases. This may have reduced juvenile and egg mortality in shallow water. Interactions with other species are currently being characterised.

- **ELE 5**

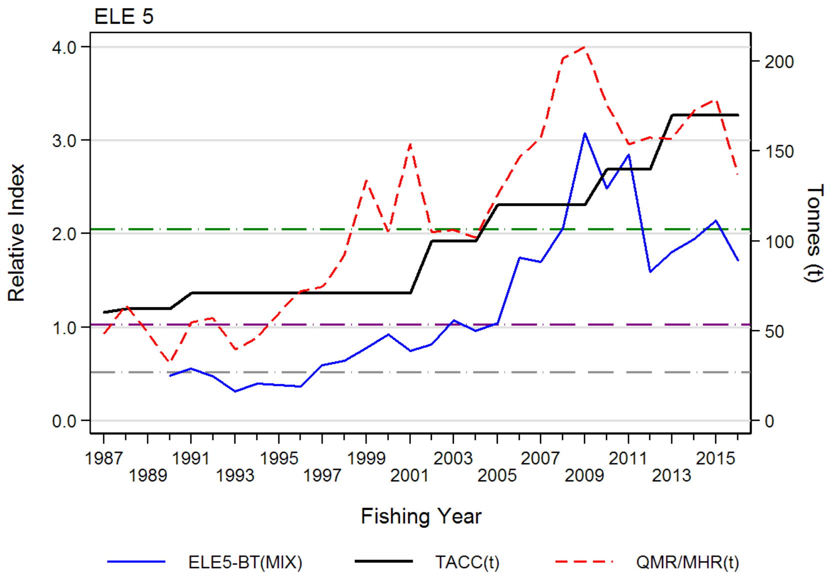
Stock Structure Assumptions

No information is available on the stock separation of elephant fish. The Fishstock ELE 5 is treated in this summary as a unit stock.

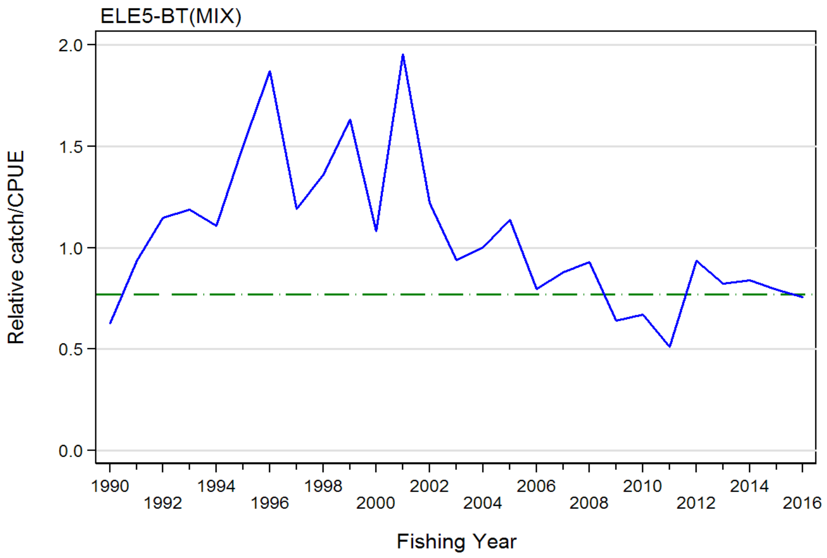
Stock Status	
Year of Most Recent Assessment	2017
Assessment Runs Presented	Standardised bottom trawl CPUE series based on mixed target species: combined delta-lognormal series
Reference Points	Target: B_{MSY}-compatible proxy based on mean ELE5-BT(MIX) standardised CPUE: 2005–06 to 2015–16 Soft Limit: 50% of Bmsy proxy Hard Limit: 25% of Bmsy proxy Overfishing threshold: Mean annual relative exploitation rate for the period: 2005–06 to 2015–16

Status in relation to Target	About as Likely as Not (40-60%) to be at or above Bmsy
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Overfishing is About as Likely as Not (40–60%) to be occurring

Historical Abundance and Catch Trajectories



Comparison of the ELE 5-BT(MIX) CPUE series with the TACC and QMR/MHR landings for ELE 5 The agreed *BMSY* proxy (geometric average: 2006–2016 ELE 5-BT(MIX) CPUE indices=2.051) is shown as a green line; the calculated Soft Limit (=0.5x*BMSY* proxy) is shown as a purple line; the calculated Hard Limit (=0.25x*BMSY* proxy) is shown as a grey line.



Relative fishing pressure for ELE 5 based on the ratio of QMR/MHR landings relative to the ELE5-BT(MIX) CPUE series which has been normalised so that its geometric mean=1.0. Horizontal green line is the geometric mean fishing pressure from 2006 to 2016.

Fishery and Stock Trends	
Recent trend in Biomass or Proxy	The ELE 5 (MIX) CPUE series increased up to a peak in 2008–09, dropped sharply in 2011–12 and has fluctuated without trend close to the target since then.
Recent Trend in Fishing Mortality or Proxy	Fishing mortality proxy has remained relatively stable or declining over the last 10 years.
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch and TACC causing biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Current Catch: About as Likely as Not (40–60%) TACC: About as Likely as Not (40–60%)

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Evaluation of agreed standardised CPUE indices	
Assessment Dates	Latest assessment: 2017	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- ELE 5 BT(MIX) CPUE series	1 – High Quality
Data not used (rank)	- Length frequency data summarised from setnet logbooks compiled under the industry Adaptive Management Programme	3 – Low Quality: data sparse and outdated
Changes to Model Structure and Assumptions	Addition of a binomial index to produce a combined CPUE series	
Major Sources of Uncertainty	It is possible that discarding and management changes (including changes in deemed values) in this fishery has affected CPUE estimates.	

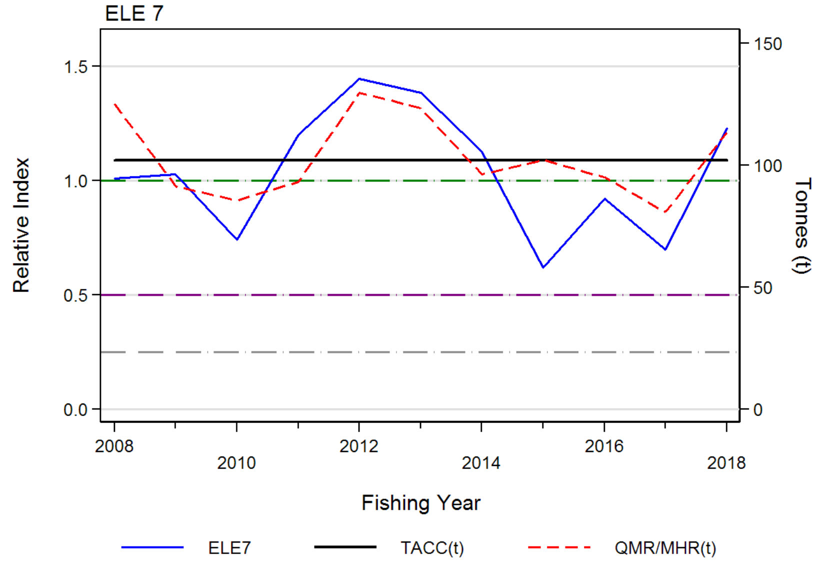
Qualifying Comments
Elephant fish have shown strong recovery since apparently being at low biomass levels in the mid-1980s. The historical catches may be poorly estimated. Both current and historical estimates of landings exclude fish discarded at sea and the quantum of discards is unknown. Confidence intervals for combined CPUE indices are not available.

Fishery Interactions
Elephant fish in ELE 5 are taken by bottom trawl in fisheries targeted at flatfish and stargazer. Targeting elephant fish in the bottom trawl fishery was low (average 14% from 1989–90 to 2015–16) but has increased to 19% of the landings since 2002–03. Around 12% of the ELE 5 landings are taken by setnet in a fishery targeted at rig and school shark. Incidental captures of seabirds and great white sharks occur, and there is a possibility of incidental capture of Hector's dolphins. However, both the trawl and setnet fisheries have been subject to management measures designed to reduce interactions with endemic Hector's dolphins. Interactions with other species are currently being characterised.

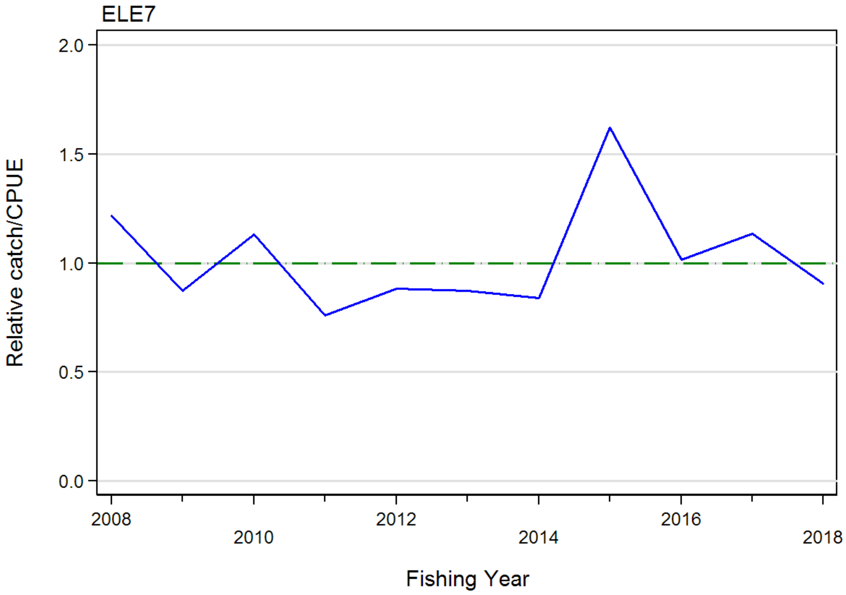
- **ELE 7**

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	ELE 7 tow-by-tow bottom trawl mixed target species standardised CPUE
Reference Points	Interim target: B_{MSY} proxy based on the mean of the CPUE series for the period: 2007–08 to 2017–18 Soft Limit: 50% of target Hard Limit: 25% of target Overfishing threshold: : Mean annual relative exploitation rate for the period: 2007–08 to 2017–18
Status in relation to Target	About as Likely as Not (40-60%) to be at or above B_{MSY}
Status in relation to Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)
Status in relation to Overfishing	Overfishing is About as Likely as Not (40–60%) to be occurring

Historical Stock Status Trajectory and Current Status



Comparison of the ELE 7-BT(tow-by-tow) CPUE series with the TACC and QMR/MHR landings for ELE 7. The agreed *BMSY* proxy (geometric average: 2008–2018 ELE 7-BT(tow-by-tow) CPUE indices=1.0) is shown as a green line; the calculated Soft Limit (=0.5x*BMSY* proxy) is shown as a purple line; the calculated Hard Limit (=0.25x*BMSY* proxy) is shown as a grey line.



Relative fishing pressure for ELE 7 based on the ratio of QMR/MHR landings relative to the ELE7-BT(tow-by-tow) CPUE series which has been normalised so that its geometric mean=1.0. Horizontal green line is the geometric mean fishing pressure from 2007–08 to 2017–18.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE was high from 2010–11 to 2012–13 followed by a period of low CPUE from 2014–15 to 2016–17. The 2017–18 CPUE was above the series mean.
Recent Trend in Fishing Intensity or Proxy	Relative exploitation rate has fluctuated about the series mean and in 2017-18 was lower than the overfishing threshold.
Other Abundance Indices	Trawl survey biomass trends for this stock are unreliably estimated by the West Coast South Island survey. However, recent biomass estimates have been relatively high compared to the long term average.
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Relative biomass is predicted to continue to fluctuate around the target level at the current catch.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Current catches and the current TACC are About as Likely as Not (40–60%) to cause overfishing.

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE index and relative biomass estimates from inshore WCSI trawl survey	
Assessment dates	Latest assessment: 2019	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Standardised CPUE (tow-by-tow) (from 2007–08)	1 – High Quality: The SINSWG had confidence in this part of the CPUE index as a credible measure of abundance
	- Standardised CPUE (MIX) (pre 2007–08)	2 – Medium or Mixed Quality: less catch (data) and lack of spatial resolution
Data not used (rank)	- Biomass estimates from inshore WCSI trawl survey	2 – Medium or Mixed Quality: low precision and high variability
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- It is possible that discarding and management changes in this fishery have biased the CPUE trends to be low.	

Qualifying Comments
The pre-QMS catches are not well reported. Both current and historical estimates of landings exclude fish discarded at sea and the quantum of discards is unknown.

Fishery Interactions
Trawl target sets for ELE 7 tend to be in shallow water mostly around 25 m. Elephant fish are landed with rig, school shark and spiny dogfish in setnets and in bottom trawls as bycatch in flatfish and red cod target sets. Incidental captures of seabirds occur and there is a possibility of incidental capture of Hector's dolphins. Interactions with other species are currently being characterised.

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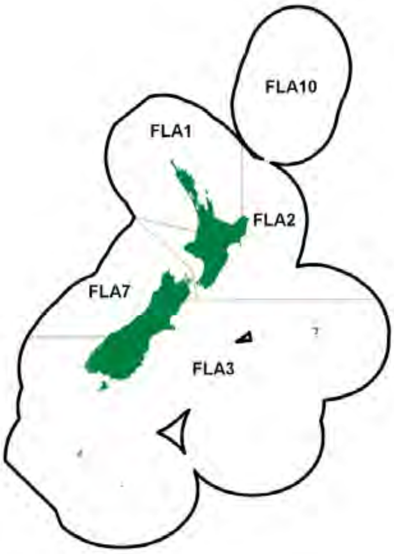
FLATFISH (FLA)

(*Rhombosolea leporina, Rhombosolea plebeia*, *Rhombosolea retiaria*, *Rhombosolea tapirina*, *Pelotretis flavilatus, Peltorhamphus novaezeelandiae*, *Colistium guntheri*, *Colistium nudipinnis*)
Patiki




SFL


GFL


BRI


YBF


ESO


BFL


TUR


LSO

1. FISHERY SUMMARY

1.1 Commercial fisheries

Flatfish Individual Transferable Quota (ITQ) provides for the landing of eight species of flatfish in the QMS. These are: the yellowbelly flounder, *Rhombosolea leporina* (YBF); sand flounder, *Rhombosolea plebeia* (SFL); black flounder, *Rhombosolea retiaria* (BFL); greenback flounder, *Rhombosolea tapirina* (GFL); lemon sole, *Pelotretis flavilatus* (LSO); New Zealand sole, *Peltorhamphus novaezeelandiae* (ESO); brill, *Colistium guntheri* (BRI); and turbot, *Colistium nudipinnis* (TUR). For management purposes landings of these species are combined.

Flatfish are shallow water species, taken mainly by target inshore trawl and Danish seine fleets around the South Island. Setnet and drag net fishing are important in the northern harbours and the Firth of Thames. Important fishing areas are:

Yellowbelly flounder	Firth of Thames, Kaipara, and Manukau harbours;
Sand flounder	Hauraki Gulf, Tasman Bay/Golden Bay, Bay of Plenty, Canterbury Bight, and Te Wae Wae Bay;
Greenback flounder	Canterbury Bight, Southland;
Black flounder	Canterbury Bight;
Lemon sole	west coast South Island, Otago, and Southland;
New Zealand sole	west coast South Island, Otago, Southland, and Canterbury Bight;
Brill and turbot	west coast South Island.

TACCs were originally set at the level of the sum of the provisional ITQs for each fishery. Between 1983–84 and 1992–93 total flatfish landings fluctuated between 2750 t and 5160 t; from 1992–93 to 1997–98, landings were relatively consistent, between about 4500 t and 5000 t per year. Landings declined to 2963 t in 1999–00, the lowest recorded since 1986–87, before increasing to a peak of 4051 t for the 2006–07 fishing year. Landings thereafter declined to just 1939 t in 2018–19, the lowest landings recorded since 1975. Historical estimated and recent reported flatfish landings and TACCs are shown in Tables 1 and 2, and Figure 1 shows the historical landings and TACC values for the main FLA QMAs.

Flatfish TACCs were first introduced in the fishing year 1986–87. After some minor increases TACCs remained unchanged for all FLA Fishstocks until the 1st October 2007, when a TAC and allowances were set for the first time in FLA 3. The FLA 3 TACC was reduced by 47% to 1430 t and a management procedure (MP) that recommended an in-season increase in the commercial catch allowance if supported by early CPUE data was implemented (see section 4.1 for a description of this procedure – this MP has been suspended, beginning in 2019–20). All FLA fisheries have been listed in Schedule 2 of the Fisheries Act 1996. Schedule 2 allows that, for certain 'highly variable' stocks, the TAC can be increased within a fishing season. Increased commercial catch is provided for through the creation of additional 'in-season' ACE. The base TACC is not changed by this process and the 'in-season' TAC reverts to the original level at the end of each season. The FLA 3 management procedure (section 4.1) is an implementation of this form of management. Landings have remained well below the TACC for FLA 1, FLA 2, and FLA 7, and the TACC for FLA 1 was reduced to 890 t from 2018–19.

From 1 October 2008, a suite of regulations intended to protect Māui and Hector's dolphins was implemented for all New Zealand by the Minister of Fisheries. Commercial and recreational set netting were banned in most areas to 4 nautical miles offshore of the east coast of the South Island, extending from Cape Jackson in the Marlborough Sounds to Slope Point in the Catlins. Some exceptions were allowed, including an exemption for commercial and recreational set netting to only one nautical mile offshore around the Kaikōura Canyon, and permitting set netting in most harbours, estuaries, river mouths, lagoons, and inlets, except for the Avon-Heathcote Estuary, Lyttelton Harbour, Akaroa Harbour, and Timaru Harbour. In addition, trawl gear within 2 nautical miles of shore was restricted to flatfish nets with defined low headline heights. The commercial minimum legal size for sand flounder is 23 cm, and for all other flatfish species is 25 cm.

Table 1: Reported landings (t) for the main QMAs from 1931 to 1982.

Year	FLA 1	FLA 2	FLA 3	FLA 7
1931–32	767	290	219	265
1932–33	958	219	61	276
1933–34	698	277	181	346
1934–35	708	203	83	195
1935–36	686	118	57	209
1936–37	438	127	139	139
1937–38	570	125	380	123
1938–39	717	83	639	94
1939–40	721	128	448	83
1940–41	1 004	180	494	101
1941–42	943	139	622	139
1942–43	591	192	594	154
1943–44	669	89	606	172
1944	441	104	783	78
1945	435	104	984	83
1946	392	168	1 264	146
1947	551	99	1 685	198
1948	433	93	1 494	214
1949	412	76	1 473	202
1950	284	31	1 446	176
1951	308	62	1 178	135
1952	349	94	1 117	166
1953	349	149	1 510	197
1954	376	112	1 184	213
1955	377	125	913	248
1956	308	106	772	190
1957	308	64	529	183
1958	362	59	989	321
1959	362	48	971	382
1960	410	58	1 257	361
1961	386	102	665	273
1962	383	156	584	228
1963	352	106	627	228
1964	499	134	879	350
1965	599	109	917	518
1966	547	222	1 141	496
1967	646	231	1 273	493
1968	541	139	973	311
1969	686	193	936	269
1970	557	262	1 027	471
1971	407	149	1 028	276
1972	475	114	548	166
1973	438	149	717	442
1974	503	147	637	748
1975	431	156	598	476
1976	548	132	802	929
1977	764	255	916	1 165
1978	706	202	1 730	1 225
1979	742	287	1 962	899
1980	906	219	1 562	459
1981	1 082	760	1 369	399
1982	934	650	1 214	468

1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data include both foreign and domestic landings.

Table 2: Reported landings (t) of flatfish by Fishstock from 1983–84 to present and actual TACCs (t) from 1986–87 to present. QMS data from 1986–present. [Continued on next page]

Fishstock	FLA 1		FLA 2		FLA 3		FLA 7		FLA 10			
FMA (s)	1 & 9		2 & 8		3, 4, 5 & 6		7		10		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	1 215	–	378	–	1 564	–	1 486	–	0	–	5 160	–
1984–85*	1 050	–	285	–	1 803	–	951	–	0	–	4 467	–
1985–86*	722	–	261	–	1 537	–	385	–	0	–	‡3 215	–
1986–87	629	1 100	323	670	1 235	2 430	563	1 840	0	10	‡2 750	6 050
1987–88	688	1 145	374	677	2 010	2 535	1 000	1 899	0	10	‡4 072	6 266
1988–89	787	1 153	297	717	2 458	2 552	757	2 045	0	10	4 299	6 477
1989–90	791	1 184	308	723	1 637	2 585	745	2 066	0	10	3 482	6 568
1990–91	849	1 187	292	726	1 340	2 681	502	2 066	0	10	2 983	6 670
1991–92	940	1 187	288	726	1 229	2 681	745	2 066	0	10	3 202	6 670
1992–93	1 106	1 187	460	726	1 954	2 681	1 566	2 066	0	10	5 086	6 670
1993–94	1 136	1 187	435	726	1 926	2 681	1 108	2 066	0	10	4 605	6 670
1994–95	964	1 187	543	726	1 966	2 681	1 107	2 066	0	10	4 580	6 670
1995–96	628	1 187	481	726	2 298	2 681	1 163	2 066	1	10	4 571	6 670
1996–97	741	1 187	363	726	2 573	2 681	1 117	2 066	0	10	4 794	6 670
1997–98	728	1 187	559	726	2 351	2 681	1 020	2 066	0	10	4 657	6 670
1998–99	690	1 187	274	726	1 882	2 681	868	2 066	0	10	3 714	6 670
1999–00	751	1 187	212	726	1 583	2 681	417	2 066	0	10	2 963	6 670
2000–01	792	1 187	186	726	1 702	2 681	447	2 066	0	10	3 127	6 670
2001–02	596	1 187	177	726	1 693	2 681	614	2 066	0	10	3 080	6 670
2002–03	686	1 187	144	726	1 650	2 681	819	2 066	0	10	3 299	6 670
2003–04	784	1 187	218	726	1 286	2 681	918	2 066	0	10	3 206	6 670
2004–05	1 038	1 187	254	726	1 353	2 681	1 231	2 066	0	10	3 876	6 670
2005–06	964	1 187	296	726	1 177	2 681	1 283	2 066	0	10	3 720	6 670
2006–07	922	1 187	296	726	1 429	2 681	1 419	2 066	0	10	4 066	6 670
2007–08	703	1 187	243	726	1 365	1 430	1 313	2 066	0	10	3 624	5 419
2008–09	639	1 187	214	726	1 544	**1 780	1 020	2 066	0	10	3 417	5 419
2009–10	652	1 187	212	726	1 525	**1 763	884	2 066	0	10	3 273	5 835
2010–11	486	1 187	296	726	1 027	1 430	659	2 066	0	10	2 467	5 509
2011–12	445	1 187	262	726	1 507	1 430	646	2 066	0	10	2 861	5 419
2012–13	480	1 187	274	726	1 512	**1 727	526	2 066	0	10	2 792	5 716
2013–14	511	1 187	216	726	1 377	1 430	568	2 066	0	10	2 672	5 419
2014–15	426	1 187	166	726	1 231	1 430	640	2 066	0	10	2 464	5 419
2015–16	277	1 187	238	726	1 622	**1 650	656	2 066	0	10	2 792	5 639
2016–17	421	1 187	136	726	1 421	*#2 065	873	2 066	0	10	2 851	6 054
2017–18	367	1 187	108	726	886	1 430	651	2 066	0	10	2 014	5 419
2018–19	435	890	82	726	968	1 430	454	2 066	0	10	1 940	5 122
2019–20	405	890	74	726	1 002	1 430	430	2 066	0	10	1 911	5 122
2020–21	392	890	78	726	870	1 430	474	2 066	0	10	1 814	5 122

* FSU data.
‡ Includes 11 t of turbot, area unknown but allocated to QMA 7.
§ Includes landings from unknown areas before 1986–87.
** Commercial catch allowance increased with additional 'in-season' ACE provided under S68 of Fisheries Act 1996.
*# The increase in commercial catch under S68 of Fisheries Act 1996 was not approved until late August 2017.

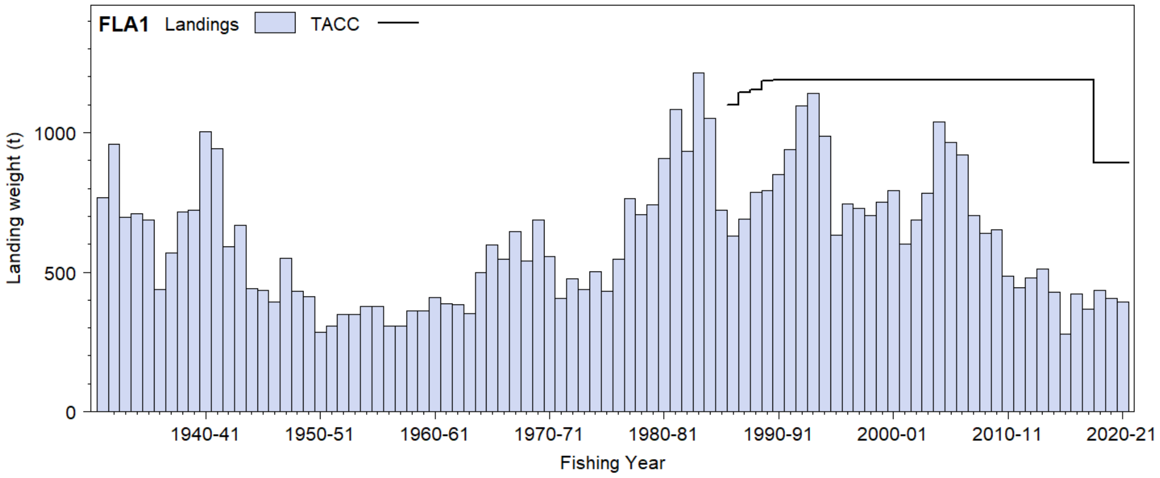


Figure 1: Historical landings and TACC for the four main FLA stocks. FLA 1 (Auckland). [Continued on next page]

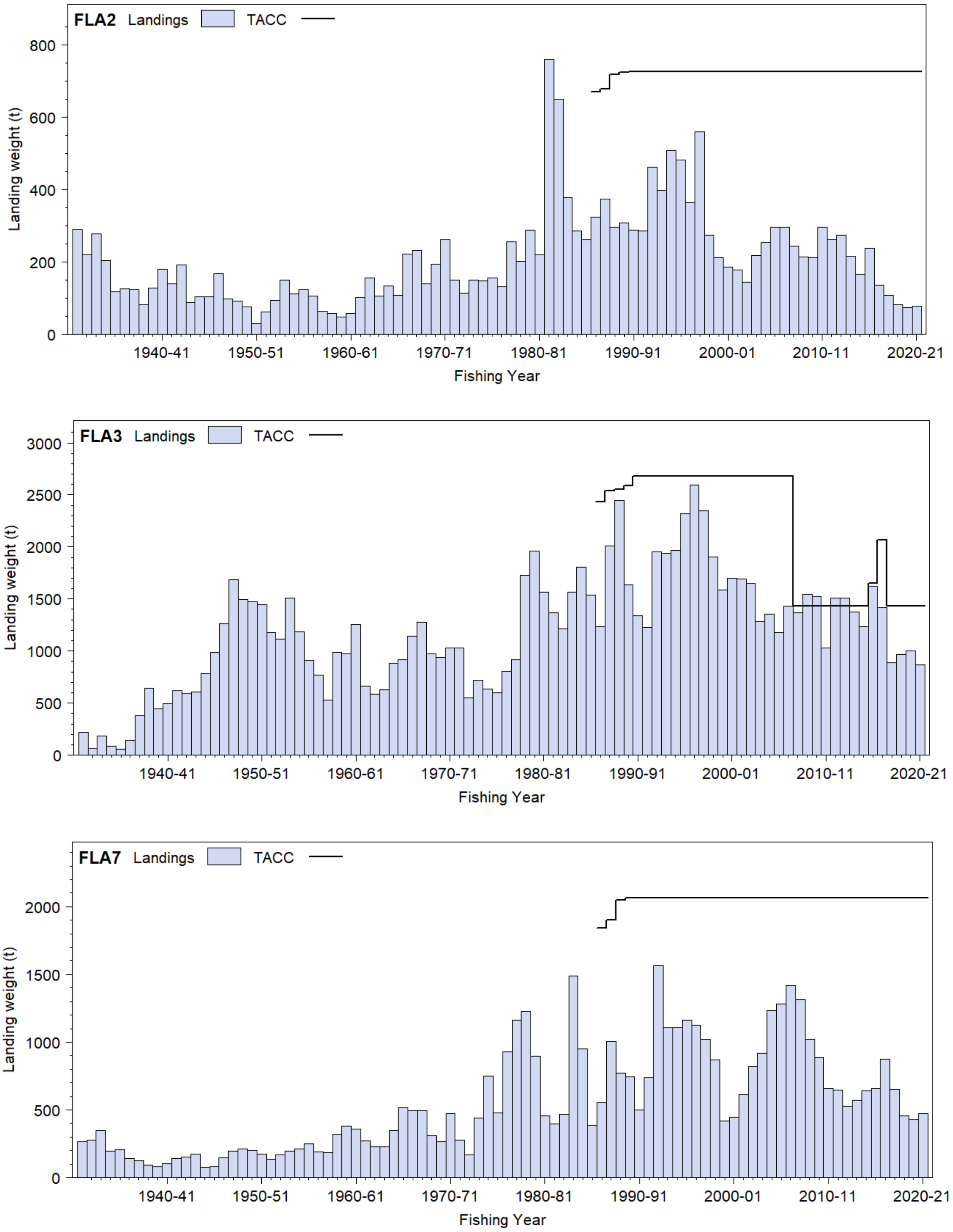


Figure 1 [Continued]: Historical landings and TACC for the four main FLA stocks. FLA 2 (Central), FLA 3 (South East Coast, South East Chatham Rise, Sub-Antarctic, Southland), and FLA 7 (West Coast South Island).

Fishers and processors are required to use a generic flatfish (FLA) code in the monthly harvest returns to report landed catches of flatfish species as well as in the landings section of the catch and effort forms. Fishers have been expected to use the specific flatfish species code when reporting estimated catches of flatfish since the 1990–91 fishing year. However, there is no penalty if fishers use the generic 'FLA' code, so reporting by species has been inconsistent across years and FLA QMAs. Starr & Kendrick (2019b) found that very few FLA 1 fishers reported species-specific catch. Bentley (2009, 2010), when initially developing the FLA 3 MP, introduced the concept of 'splitters', where derived species composition estimates were based on vessels which consistently reported estimated catches using species-specific species codes and avoided using the generic FLA code. Starr & Kendrick (2018) investigated four different definitions of 'splitters', demonstrating all were roughly equivalent, but settled on the 'trip splitter' definition, where every trip which did not use the FLA code for estimated catches, but which landed FLA, was used. They showed that this definition maximised the proportion of the total landings included in the splitter category, which varied between 42 and 77% for FLA 3 and 24 and 80% for FLA 7 (Figure 2). The percentage distribution of species-specific catch for FLA 3 and FLA 7, based on 'trip splitter' trips, is presented in Table 3.

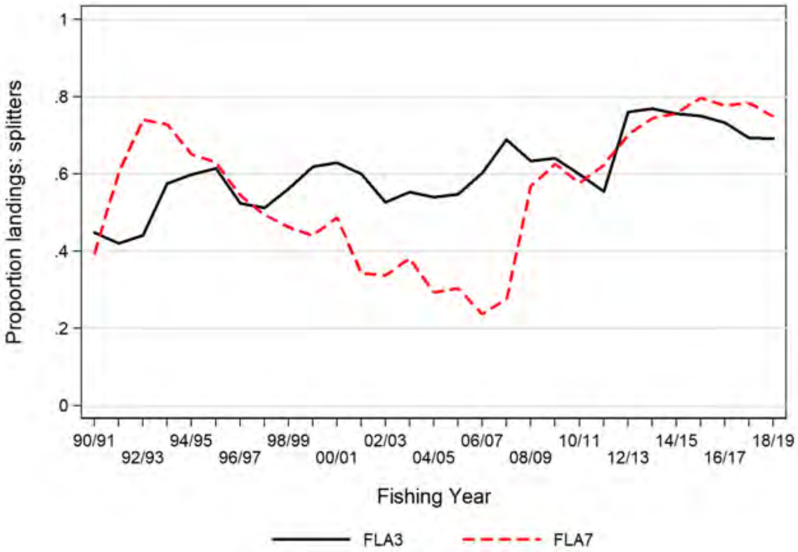


Figure 2: **Proportion of annual landings represented by 'splitter' trips in FLA 3 and FLA 7, where splitter trips are defined as those which reported FLA landings but did not use the generic FLA code to report estimated catches. FLA 3 annual percentages reported by Starr & Kendrick (2022a) and for FLA 7 by Starr & Kendrick (2022b).**

Table 3: **Percent flatfish catch by species in FLA 3 and FLA 7 for 'splitter' trips, which are trips which landed FLA but which did not use the generic FLA code in the estimated catch section of the catch/effort form. Trip estimated catches by species were scaled to the total FLA landings for the trip and summed for the period 1990–91 to 2018–19 (see Figure 2 for annual time series of splitter trips in FLA 3 and FLA 7).**

Species code	**Common name**	**FLA 3 (%)[1]**	**FLA 7 (%)[2]**
BFL	Black Flounder	3.6	0.3
BOT	Lefteye Flounders	<0.01	0
BRI	Brill	3.0	5.7
ESO	New Zealand Sole	27.6	35.8
GFL	Greenback Flounder	1.3	3.6
LSO	Lemon Sole	43.3	5.4
MAN	Finless Flounder	<0.01	<0.01
SDF	Spotted Flounder	<0.01	0
SFL	Sand Flounder	14.7	33.7
SLS	Slender Sole	<0.01	<0.01
TUR	Turbot	1.3	11.2
WIT	Witch	0.8	0.3
YBF	Yellowbelly Flounder	4.3	3.9

[1]Starr & Kendrick (2022a); [2]Starr & Kendrick (2022b)

1.2 Recreational fisheries

There are important recreational fisheries, mainly for the four flounder species, in most harbours, estuaries, coastal lakes. and coastal inlets throughout New Zealand. The main methods are set netting, drag netting (62.8% combined), and spearing (36.1%) (Wynne-Jones et al 2014). In the northern region, important areas include the west coast harbours, the lower Waikato, the Hauraki Gulf, and the Firth of Thames. In the Bay of Plenty, Ohiwa and Tauranga harbours are important. In the Challenger FMA, there is a moderate fishery in Tasman Bay and Golden Bay and in areas of the Mahau-Kenepuru Sound and in Cloudy Bay. In the South-East and Southland FMAs, flatfish are taken in areas such as Lake Ellesmere, inlets around Banks Peninsula and the Otago Peninsula, the Oreti and Riverton estuaries, Bluff Harbour, and the inlets and lagoons of the Chatham Islands (for further details see the 1995 Plenary Report).

1.2.1 Management controls

The main method used to manage recreational harvests of flatfish are minimum legal sizes (MLS) and daily bag limits. General spatial and method restrictions also apply, particularly to the use of set nets.

The flatfish MLS for recreational fishers is 25 cm for all species except sand flounder for which the MLS is 23 cm. Fishers can take up to 20 flatfish as part of their combined daily bag limit in the Auckland, Central, and Challenger Fishery Management Areas. Fishers can take up to 30 flatfish as part of their combined daily bag limit in the South-East, Kaikōura, Fiordland, and Southland Fishery Management Areas.

1.2.2 Estimates of recreational harvest

There are two broad approaches to estimating recreational fisheries harvest: the use of onsite or access point methods where fishers are surveyed or counted at the point of fishing or access to their fishing activity; and offsite methods where some form of post-event interview and/or diary are used to collect data from fishers. Harvest estimates are provided in Table 4.

Table 4: Estimated number and weight of flatfish, by Fishstock and survey, harvested by recreational fishers. Surveys were carried out in different years in the Fisheries regions: South in 1991–92, Central 1992–93, North 1993–94 (Teirney et al 1997) and nationally in 1996 (Bradford 1998) and 1999–00 (Boyd & Reilly 2004). (– Data not available). National panel surveys (Wynne-Jones et al 2014, 2019) were conducted from 1 October to 30 September and used mean weights for flatfish from boat ramp surveys (Hartill & Davey 2015, Davey et al 2019).

Fishstock	Survey	Number	CV	Harvest range (t)	Point estimate (t)
1991–92					
FLA 1	South	3 000	–	–	
FLA 3	South	15 200	0.31	50–90	
FLA 7	South	3 000	–	–	
1992–93					
FLA 1	Central	6 100	–	–	
FLA 2	Central	73 000	0.26	20–40	
FLA 7	Central	37 100	0.59	10–30	
1993–94					
FLA 1	North	520 000	0.19	225–275	
FLA 2	North	3 000	–	0–5	
1996					
FLA 1	National	308 000	0.11	95–125	110
FLA 2	National	67 000	0.19	13–35	24
FLA 3	National	113 000	0.14	30–50	40
FLA 7	National	44 000	0.18	10–20	16
1999–00					
FLA 1	National	702 000	0.25	203–336	–
FLA 2	National	380 000	0.49	82–238	–
FLA 3	National	395 000	0.33	128–252	–
FLA 7	National	114 000	0.53	23–73	–
2011–12					
FLA 1	Panel	64 999	0.37	–	27.2
FLA 2	Panel	12 885	0.31	–	5.4
FLA 3	Panel	53 475	0.31	–	21.7
FLA 7	Panel	12 259	0.37	–	4.7
2017–18					
FLA 1	Panel	37 289	0.28	–	15.2
FLA 2	Panel	22 324	0.41	–	9.1
FLA 3	Panel	23 316	0.38	–	9.5
FLA 7	Panel	12 930	0.43	–	5.3

The first estimates of recreational harvest for flatfish were calculated using an offsite regional telephone/diary survey approach. Estimates for 1996 came from a national telephone-diary survey (Bradford 1998). Another national telephone-diary survey was carried out in 2000 (Boyd & Reilly 2004). The harvest estimates provided by telephone/diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a national panel survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in

Table 4. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

1.3 Customary non-commercial fisheries

Quantitative information on the current level of customary non-commercial catch is not available.

1.4 Illegal catch

There is no quantitative information on the current level of illegal catch available.

1.5 Other sources of mortality

The extent of unrecorded fishing mortality is unknown.

2. BIOLOGY

Some New Zealand flatfish species are fast-growing and short-lived, generally only surviving to 3–4 years of age, with very few reaching 5–6 years. Others, such as brill and turbot, are longer lived, reaching a maximum age of 21 years and 16 years, respectively (Stevens et al 2001). However, these estimates have yet to be fully validated. Size limits (set at 25 cm for most species) are generally at or above the size at which the fish reach maturity and confer adequate protection to the juveniles.

Available biological parameters relevant to stock assessment are shown in Table 5. The estimated parameters in sections 1 and 3 of the table apply only to sand flounder in Canterbury and brill and turbot in west coast South Island — growth patterns are likely to be different for these species in other areas and for other species of flatfish.

Table 5: Estimates of biological parameters for flatfish.

Fishstock	Estimate	Source
1. Natural mortality (*M*)		
Brill - West coast South Island (FLA 7)	0.20	Stevens et al (2001)
Turbot - West coast South Island (FLA 7)	0.26	Stevens et al (2001)
Sand flounder - Canterbury (FLA 3)	1.1–1.3	Colman (1978)
Lemon sole - West coast South Island (FLA 7)	0.62–0.96	Gowing et al (unpub.)

2. Weight = $a(\text{length})^b$ (Weight in g, length in cm total length).

	Females		Males		
	a	*b*	*a*	*b*	
Brill (FLA 7)	0.01443	2.9749	0.02470	2.8080	Hickman & Tait (unpub.)
Turbot (FLA 7)	0.00436	3.3188	0.00571	3.1389	Hickman & Tait (unpub.)
Sand flounder (FLA 1)	0.03846	2.6584	-	-	McGregor et al (unpub.)
Yellowbelly flounder (FLA 1)	0.07189	2.5117	0.00354	3.3268	McGregor et al (unpub.)
New Zealand sole (FLA 3)	0.03578	2.6753	0.007608	3.0728	McGregor et al (unpub.)

3. von Bertalanffy growth parameters

	Females			Males			
	L_∞	k	t_0	L_∞	k	t_0	
Brill							
West coast South Island (FLA 7)	43.8	0.10	–15.87	38.4	0.37	38.4	Stevens et al (2001)
Turbot							
West coast South Island (FLA 7)	57.1	0.39	0.30	49.2	0.34	49.2	Stevens et al (2001)
Sand flounder							
Canterbury (FLA 3)	59.9	0.23	–0.083	37.4	0.781	37.4	Mundy (1968), Colman (1978)
Lemon sole							
West coast South Island (FLA 7)	26.1	1.29	–0.088	25.6	1.85	25.6	Gowing et al (unpub.)
Greenback flounder (FLA 5)	55.82	0.26	–1.06	52.21	0.25	–1.32	Sutton et al (2010)

Sutton et al (2010) undertook an age and growth analysis of greenback flounder. That analysis showed that growth is rapid throughout the lifespan of greenback flounder. Females reached a slightly greater maximum length than males, but the difference was not significant at the 95% level of confidence. Over 90% of sampled fish were 2 or 3 years of age, with maximum ages of 5 and 10 years being obtained for male and female fish, respectively. This difference in maximum age resulted in estimated natural mortalities using Hoenig's (1983) regression method, of 0.85 for males and 0.42 for females. It is suggested that 0.85 is the most appropriate estimate at this stage because only 1% of all fish exceeded 5 years. However, it was also noted that a complete sample of the larger fish was not obtained and as a result these estimates should be considered preliminary. Growth rings were not validated.

Flatfish are shallow-water species, generally found in waters less than 50 m depth. Juveniles congregate in sheltered inshore waters, e.g., estuarine areas, shallow mudflats, and sandflats, where they remain for up to two years. Juvenile survival is highly variable. Flatfish move offshore for first spawning at 2–3 years of age during winter and spring. Adult mortality is high, with many flatfish spawning only once and few spawning more than two or three times. However, fecundity is high, e.g., from 0.2 million eggs to over 1 million eggs in sand flounders.

3. STOCKS AND AREAS

There is evidence of many localised stocks of flatfish. However, the inter-relationships of adjacent populations have not been well studied. The best information is available from studies of the variation in morphological characteristics of sand flounders and from the results of tagging studies, conducted mainly on sand and yellowbelly flounders. Variation in morphological characteristics indicate that sand flounder stocks off the east and south coasts of the South Island are clearly different from stocks in central New Zealand waters and from those off the west coast of the South Island. There also appear to be differences between west coast sand flounders and those in Tasman Bay, and between sand flounders on either side of the Auckland-Northland peninsula. Tagging experiments show that sand flounders, and other species of flounder, can move substantial distances off the east and south coasts of the South Island. However, fish tagged in Tasman Bay or the Hauraki Gulf have never been recaptured very far from their point of release.

Thus, although the sand flounders off the east and south of the South Island appear to be a single, continuous population, fish in enclosed waters may be effectively isolated from neighbouring populations and should be considered as separate stocks. Examples of such stocks are those in Tasman Bay and the Hauraki Gulf and possibly areas such as Hawke Bay and the Bay of Plenty.

There are no new data which would alter the stock boundaries used in previous assessment documents.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

FLA 1

A standardised CPUE analysis of FLA 1 was conducted in 2022 (Moore et al in prep.) following previous analyses in 2019 (Starr & Kendrick 2019b), 2015 (Kendrick & Bentley 2015), 2012 (Kendrick & Bentley 2012), 2009 (Kendrick & Bentley 2011), and 2005 (Beentjes & Coburn 2005). Three standardised CPUE indices were generated using estimated catches as the dependent variable:

1. FLA(TOT) in Manukau Harbour (Statistical Area 043);
2. FLA(TOT) in Kaipara Harbour (Statistical Area 044);
3. FLA(TOT) in Hauraki Gulf (Statistical Areas 005, 006, and 007).

Each analysis was confined to a set of core vessels which had participated consistently in the fishery for a reasonably long period. The explanatory variables offered to each model included fishing year (forced), month, vessel, statistical area (Hauraki Gulf only), net length (summed), and duration of fishing (summed), with the estimated species catch used as the dependent variable. Following the 2019 analysis, the 2022 analyses also examined the use of a procedure (termed ‘F2’) which scales estimated catches to landings using a ‘vessel correction factor’. This procedure multiplies estimated catches with the ratio of landings to estimated catches for a vessel in a fishing year. A comparison of the two series for those records that had both landings and estimated catch data available showed no appreciable difference in output between the two procedures (Figure 3), even though the F2 procedure truncates the data set to avoid excessively large and small ratios. Accordingly, unscaled estimated catches were used in the final CPUE models (i.e., using all estimated catch records, including those without matched landings). Starr & Kendrick (2019b) also summed all flatfish estimated catches for the Manukau Harbour and Kaipara Harbour analyses to create a TOT category, a procedure that was replicated in the 2022 analyses. This was done because estimated catches of other flatfish species are negligible in these harbours (Table 6) and a comparison with 2015 series by Starr & Kendrick (2019b) showed no difference in the overlapping years.

Unlike previous analyses, species-specific CPUE indices were not generated for the Hauraki Gulf in 2022. This was because the SFL series of the 2019 analysis was rejected by the Northern Inshore Working Group (NINSWG) because it was noted that the reporting of SFL in the estimated catches fell away in the early to mid-2000s, which was also a period when the SFL CPUE dropped while, at the same time, there was little change in the species-specific reporting of YBF. Moreover, since the introduction of the ERS there has been a lack of species-specific reporting in all FLA 1 areas. These issues in reporting make the associated CPUE series unreliable, resulting in a recommendation from the NINSWG that the species-specific CPUE series for the Hauraki Gulf be replaced with a TOT series (which sums all flatfish species catch).

Less than half of the estimated FLA 1 flatfish catch since 1989–90 has been identified by species (Table 6), but most of the flatfish caught in FLA 1 West were likely to be yellowbelly flounder under the assumption that the flatfish reported using the generic ‘FLA’ code are YBF. This assumption is supported by the fact that the preferred muddy bottom habitat of yellowbelly flounder dominates the west coast harbours. Over 80% of the west coast catch is taken from Kaipara Harbour and Manukau Harbour (Table 6). Standardised CPUE trends were derived for these two areas using TOT (sum of all flatfish estimated catches). The NINSWG accepted the Manukau FLA(TOT) and Kaipara FLA(TOT) series as reflecting abundance. In spite of fluctuations, both the Manukau and Kaipara series show a long-term declining trend between 1990 and about 2010. Since then, both series have been generally stable and are currently 54% and 67% below the respective peaks in the early to mid-1990s (see Status of the Stocks section). Work by NIWA (McKenzie et al 2013) in the Manukau Harbour has linked the decrease in local CPUE with an increase in eutrophication, suggesting that there may be factors other than fishing contributing to the decline.

Table 6: Total FLA 1 estimated catches by declared flatfish species, summed over the period 1989–90 to 2020–21. From 2019 until 1 September 2021, after ERS was introduced, species-specific reporting was not accepted by many of the platforms.

	Manukau	Kaipara	Lower Waikato	Northwest	FLA 1 West	East Northland	Hauraki Gulf	Bay of Plenty	FLA 1 East	Total FLA 1
FLA	1 999.0	3 742.6	587.5	555.7	6 884.8	595.1	3 539.9	268.0	4 403.1	11 287.9
YBF	146.2	1 778.1	126.7	164.0	2 215.0	433.3	2669.7	137.7	3240.7	5 455.8
SFL	4.0	45.7	19.9	8.9	78.5	72.6	1271.2	310.0	1653.8	1 732.3
ESO	0.0	0.0	12.2	16.2	28.4	1.1	5.4	210.7	217.2	245.6
GFL	0.0	0.1	7.5	0.2	7.8	0.0	202.6	12.7	215.3	223.1
LSO	0.0	0.0	2.6	2.6	5.2	0.5	1.0	76.7	78.3	83.5
BRI	0.0	0.0	11.8	2.6	14.4	0.1	0.1	20.7	20.9	35.3
BFL	0.0	0.0	0.1	0.2	0.3	0.3	26.3	2.3	28.9	29.2
TUR	0.0	0.0	4.8	4.6	9.4	0.1	0.4	1.3	1.9	11.2
Total	2 149.3	5 566.5	773.1	754.9	9 243.8	1 103.3	7 716.7	1 040.2	9 860.2	19 103.9

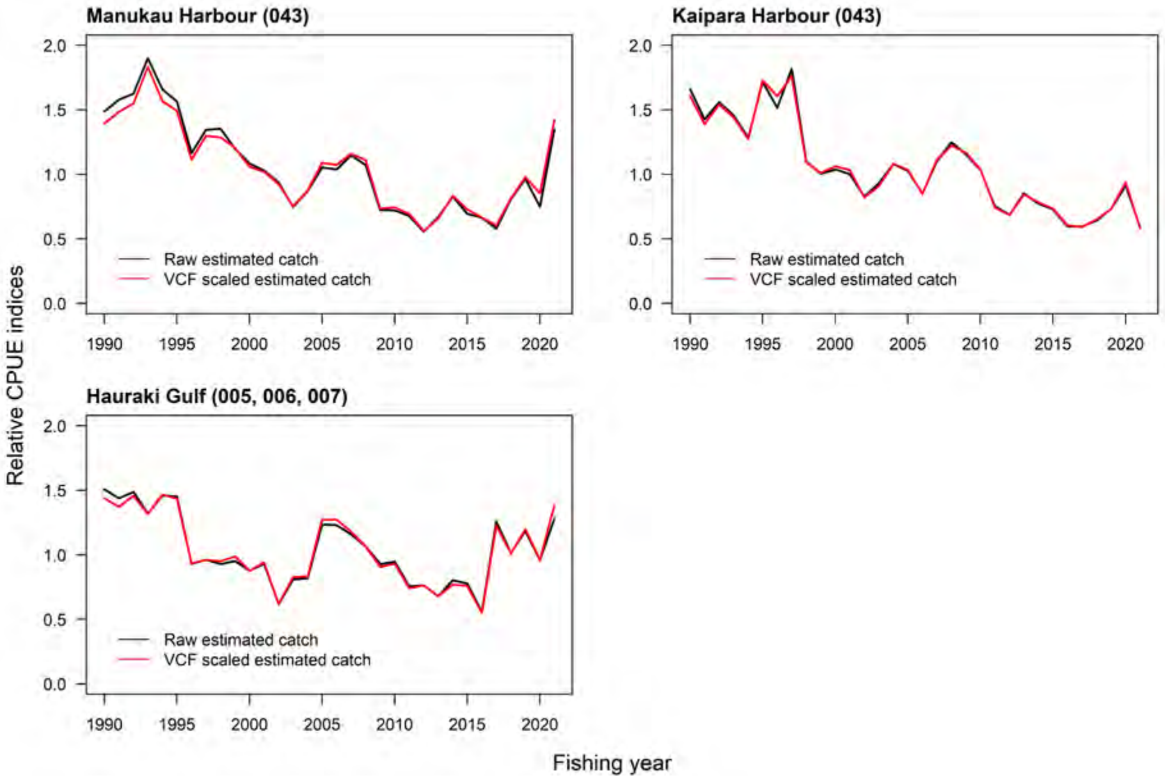


Figure 3: **Comparison of standardised CPUE indices for flatfish (all species) from models of catch rate based on raw estimated catches and estimated catches scaled by a 'vessel correction factor' (F2 procedure) for successful set net trips in Manukau Harbour, Kaipara Harbour, and the Hauraki Gulf.**

Seventy-eight percent of the flatfish catch from FLA 1 East, including a substantial and variable proportion of sand flounder, is taken in the Hauraki Gulf, particularly from the Firth of Thames (Statistical Area 007). The Hauraki Gulf FLA(TOT) series shows an overall declining trend except for a three-year increase from 2002 to 2005 and a single strong increase in the 2017 fishing year, which brought the series above the long-term average. Since then, the CPUE index has fluctuated around the series mean (see Status of the Stocks section).

FLA 2

In 2017, Schofield et al (2018a) provided standardised CPUE for FLA 2 (Figure 4) based on the flatfish target fishery in Statistical Areas 013 and 014. Estimated catches were allocated to daily aggregated effort using methodology described by Langley (2014) to improve the comparability between the data collected from two different statutory reporting forms (CELR and TCER). A core fleet of 15 vessels that had completed at least five trips per year in at least seven years was identified. The model, using a gamma error distribution adjusted for changes in duration, month, and vessel, accounted for 33% of the variance in catch. Area was not included in the model because the change in reporting forms appears to have influenced the catch split between Statistical Areas 013 and 014.

The NINSWG noted that most of the records in the aggregated data had catches of flatfish and that a binomial index was flat. As a result, the positive catch index was retained as the key monitoring series. The CPUE series exhibits moderate fluctuations around the long-term mean, with no overall trend up or down and appears currently to be in an increasing phase.

Characterisation using the estimated catch data suggests that the FLA 2 catch comprises mainly sand flounder (SFL) and New Zealand sole (ESO). CPUE indices for ESO and SFL were provided by Schofield et al (2018a) for 2008 to 2016 using the tow by tow data from vessels consistently estimating catches by flatfish species. Trends were apparent in the probability of catch, so combined (binomial and positive catch modelled with a gamma distribution) indices were produced. There is reasonable consistency between the species-specific indices and the overall FLA 2 index (Figure 4), noting that — because the FLA 2 fishery is small — the datasets for the individual species are small and the indices variable.

These indices were updated in 2018 (Schofield et al 2018b) to include data to 30 September 2017.

Establishing B_{MSY} compatible reference points

In 2014, the Working Group adopted mean CPUE from the bottom trawl flatfish target series for the period 1989–90 to 2012–13 as a B_{MSY}-compatible proxy for FLA 2. The Working Group accepted the default Harvest Strategy Standard definitions that the Soft and Hard Limits would be one half and one quarter the target, respectively.

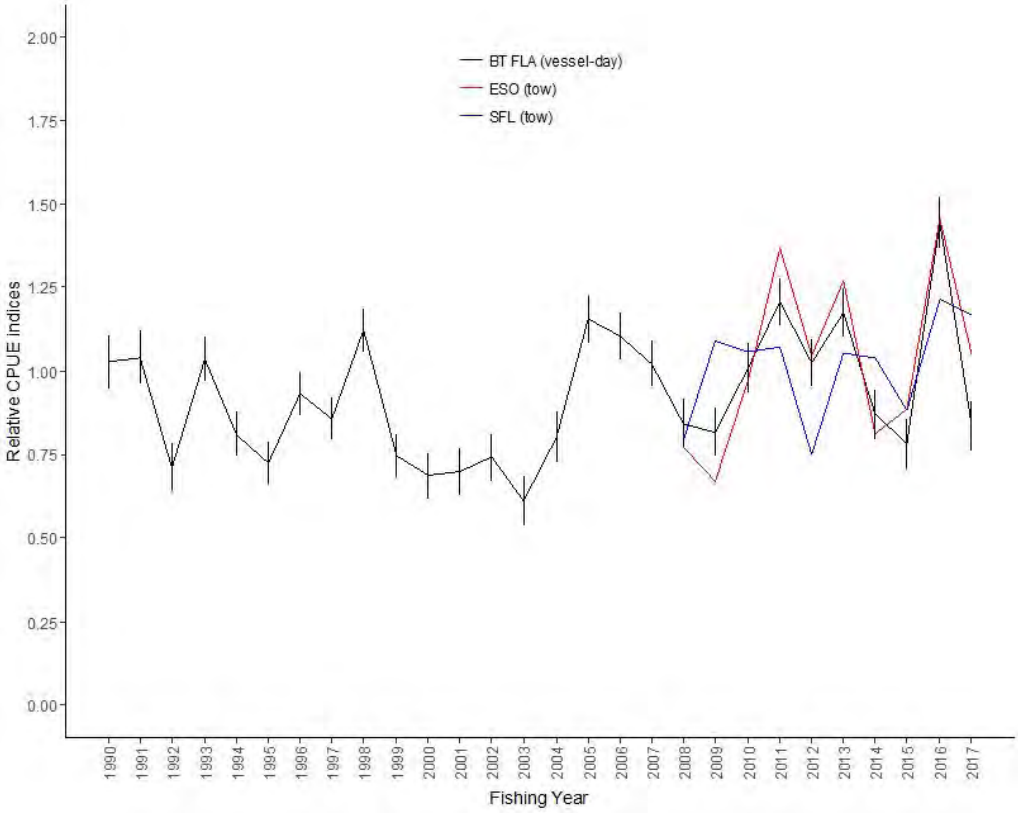


Figure 4: Standardised CPUE indices in FLA 2 for BT targeting all species of flatfish, (aggregated to combine data across form types, BT_flats(day)), and shorter combined series for sand flounder (BT_sfl(tow)) and New Zealand sole (BT_eso(tow)) based on tow by tow resolution data (Schofield et al 2018b).

FLA 3

CPUE trends

CPUE trends for the three principal FLA 3 species (New Zealand sole [ESO], sand flounder [SFL], and lemon sole [LSO]) and an aggregated catch landed to FLA [TOT], based on bottom trawl catch and effort data, were updated in 2020 (Starr & Kendrick 2022a). The species-specific catch data were based on 'splitter' trips, defined as trips which landed FLA 3 but which did not use the FLA code in the estimated catch section of the catch and effort form. Alternative definitions of 'splitters' based on vessel performance were investigated in 2015 (Starr & Kendrick 2018), but CPUE trends were found to be similar to those derived from the 'trip splitter' algorithm. The latter was selected because it retained the greatest amount of catch, particular in the early years of the series.

The CPUE data were prepared by matching the FLA landing data for a trip with the effort data from the same trip that had been amalgamated to represent a day of fishing. The procedure assigns the modal statistical area and modal target species (defined as the observation with the greatest effort) to the trip/date record. All estimated catches for the day were summed and the five top species with the greatest catch were assigned to the date. This 'daily-effort stratum' preparation method was followed so that the event-based data forms that are presently being used in these fisheries can be matched as well as possible with the earlier daily forms to create a continuous CPUE series. For this procedure to function correctly, given that there are multiple flatfish species in the estimated catches, the matching procedure with landings is done twice: first by summing all flatfish estimated catches into a single generic ‘flatfish’ category. The ratio of the total FLA landings relative to the sum of the estimated flatfish catches can then be used to scale each of the species-specific estimated catches on the same trip as the second step.

Each analysis was confined to a set of core vessels which had participated consistently in the fishery for a reasonably long period (5 trips for at least 5 years). The explanatory variables offered to each model included fishing year (forced), month, vessel, statistical area, number tows, and duration of fishing, with the scaled estimated species catch used as the dependent variable. The WG agreed to report only the lognormal series for these analyses because zero records only meant that the species had not been reported, rather than being a true zero. The WG also agreed to restrict all analyses to target FLA records and to the following six Statistical Areas: 020, 022, 024, 026, 025, and 030.

The estimated CPUE trends by species were used to evaluate the relative status of the three main species in the FLA 3 fishery. There were similarities among the three species-specific standardised CPUE indices (Figure 5), with all indices increasing in the early 1990s and peaking at some point in the early to mid-1990s. All indices then have a trough in the early- to mid-2000s, followed by an increase for LSO and SFL and a decrease for ESO, with the ESO and SFL indices showing similarity in their fluctuationsThe SFL index series gradually increased to a peak in the mid-2010s, after which it levelled out while neither the LSO or ESO series have returned to the levels seen in the 1990s. The LSO series has been without trend since 2008–09 while the ESO series has declined slowly from that year (Figure 5).

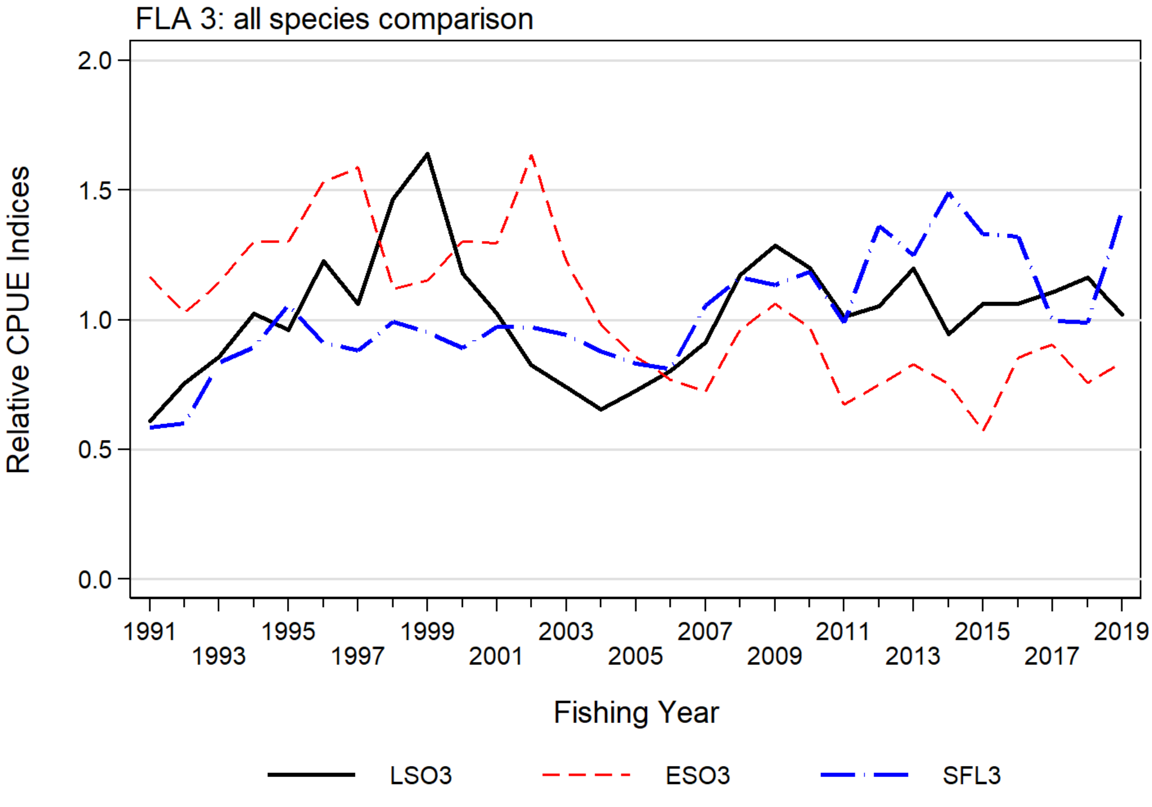


Figure 5:Comparison of standardised bottom trawl lognormal CPUE indices in FLA 3 for LSO (lemon sole), ESO (New Zealand sole), and SFL (sand flounder) (from Starr & Kendrick 2022a).

ECSI trawl survey biomass estimates for LSO, ESO, and SFL

Lemon sole biomass indices in the core strata (30–400 m) from the east coast South Island trawl survey (Table 7) show no trend (Figure 6). Coefficients of variation are moderate to low, ranging from 15 to 33% (mean 23%). The additional biomass captured in the 10–30 m depth range region accounted for 1% to 5% of the biomass in the core plus shallow strata (10–400 m) for the five years with usable biomass estimates in the 10–30 m region, indicating that the existing core strata time series in 30–400 m are more important for this species. A comparison of the LSO CPUE series with the LSO ECSI biomass indices shows that both series fluctuate without trend and show considerable variation (Figure 6). The correspondence between the two sets of indices is weak (rho=-0.342; R^2=12%).

The shallow 10–30 m region holds a substantial fraction of the biomass of the other two important FLA 3 species, ESO and SFL. This fraction ranges from 54% to 90% of the total annual ESO biomass whereas the equivalent range for SFL is 41–96% (Table 7). There is reasonable correspondence between the summed survey biomass estimates and the equivalent commercial CPUE series over the five overlapping years (Figure 7), although the CVs for these estimates are large for both species (Table 7).

Table 7: Relative biomass indices (t) and coefficients of variation (CV) for lemon sole (LSO). New Zealand sole (ESO), and sand flounder (SFL) from the east coast South Island (ECSI) - winter survey area. Biomass estimates are provided for the core (30–400 m) region and for the shallow (10–30 m) region introduced in 2007. NA: insufficient tows for shallow region.

Species	Year	Trip number	Total Biomass estimate (t)	CV (%)	Total Biomass estimate (t)	CV (%)
			30–400 m (core)		10–30 m	
LSO	1991	KAH9105	92	27	–	–
	1992	KAH9205	57	18	–	–
	1993	KAH9306	121	19	–	–
	1994	KAH9406	77	21	–	–
	1996	KAH9606	49	33	–	–
	2007	KAH0705	74	26	3	38
	2008	KAH0806	116	25	NA	NA
	2009	KAH0905	55	27	NA	NA
	2012	KAH1207	65	18	1	55
	2014	KAH1402	107	27	2	50
	2016	KAH1605	91	15	3	52
	2018	KAH1803	44	20	2	33
ESO	2007	KAH0705	5	51	19	72
	2008	KAH0806	6	38	NA	NA
	2009	KAH0905	2	48	NA	NA
	2012	KAH1207	15	82	17	38
	2014	KAH1402	13	41	22	29
	2016	KAH1605	4	64	23	31
	2018	KAH1803	3	60	32	40
SFL	2007	KAH0705	16	61	31	64
	2008	KAH0806	9	52	NA	NA
	2009	KAH0905	2	74	NA	NA
	2012	KAH1207	43	71	30	27
	2014	KAH1402	55	42	65	21
	2016	KAH1605	2	63	48	33
	2018	KAH1803	5	99	40	14

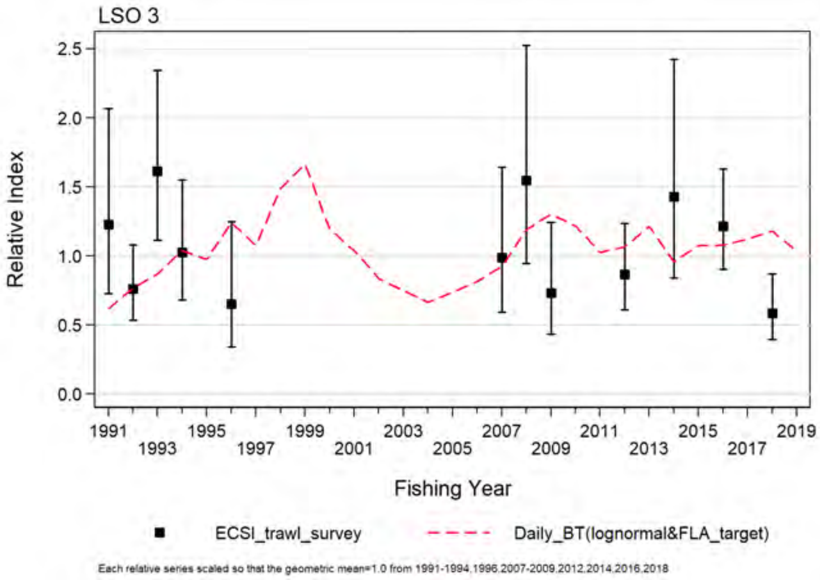


Figure 6:Lemon sole total biomass and 95% confidence intervals for the ECSI winter survey in core strata (30–400 m) plotted against the LSO bottom trawl CPUE series.

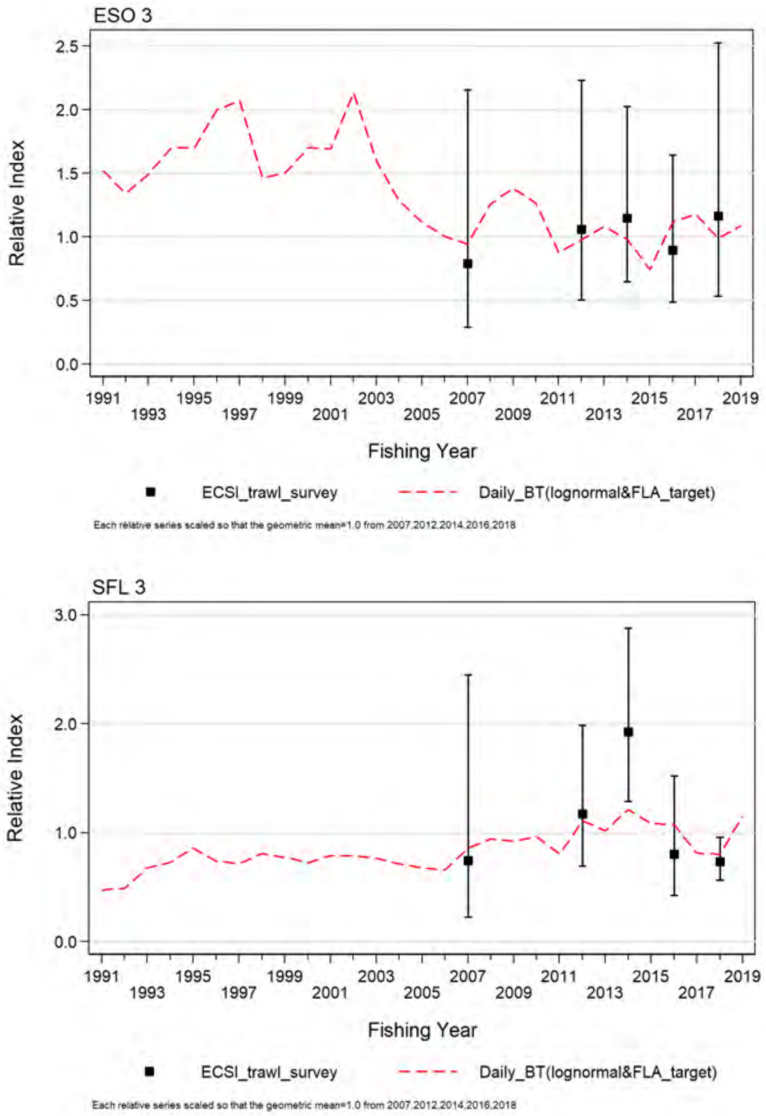


Figure 7: **New Zealand sole (ESO, top panel) and sand flounder (SFL, bottom panel) total biomass and 95% confidence intervals for the summed ECSI winter survey core + shallow strata plotted against the respective ESO and SFL bottom trawl CPUE series.**

In-season Management Procedure

In 2007 concerns were expressed about the sustainability of FLA 3 catches and the TACC was reduced from 2681 t to 1430 t from 1 October 2007. In the 2008–09 fishing year anecdotal information indicated an increase in abundance of lemon and New Zealand sole in the FLA 3 QMA above a level that fishers were able to utilise within the available TACC. It was considered that there was opportunity for increased utilisation that would not adversely impact on the long-term sustainability of the FLA 3 stock complex and for 2008–09 ‘in-season’ commercial allowances were set at 1780 t based on the 15 year average of commercial FLA3 catches.

In 2010, an ‘in-season’ Management Procedure (MP) was developed which has been used to inform in-season adjustments to the FLA 3 TACC since 2010–11 (Bentley 2009, 2010). This MP was updated and revised in 2015 (Starr et al 2018). It used the relationship between annual standardised CPUE for all FLA 3 species and the total annual FLA 3 landings to estimate an average exploitation rate which is then used to recommend a level of full-season catch based on an early estimate of standardised CPUE. Only the period 1989–90 to 2006–07 was used to estimate the average exploitation rate because this was the period before the TACC was reduced which allowed the fishery to operate at an unconstrained level. A partial year in-season estimate of standardised CPUE is used as a proxy for the final annual index, with the recommended catch defined by the slope of the regression line (Figure 8) multiplied by the CPUE proxy estimate (Figure 8 shows the outcome of this procedure for 2019).

The 2010 FLA 3 MP approximated the standardisation procedure by applying fixed coefficients to a data set specified by a static core vessel definition. This approach deteriorated over time as vessels dropped out of the core vessel fleet, thus reducing the available data set. The 2015 MP was based on a re-estimated standardisation procedure using a data set specified annually by a dynamic core vessel definition, allowing new vessels to enter the data set as they meet the minimum eligibility criteria. The 2015 MP was validated through a retrospective analysis which used the data available up to end of the previous year and the partial data in the final year to determine how the model performed across years (Figure 9). In most years, the MP performance was satisfactory after only two months of data were accumulated. The poor performance of the model in some years (e.g., 2012) persisted across all four early months, indicating that collecting additional data in those years would not have improved the recommendation (relative to the end of year recommendation).

Starr & Kendrick (2022a) repeated the 2015 evaluation of the capacity of the FLA 3 MP to estimate the final annual CPUE, given the accumulation of two to five months of data in the final (predictive) year. This evaluation was made retrospectively over 12 years of observations from 2007–08 to 2018–19, using partial year data to estimate the annual CPUE in the final year. They showed that the first two months of data (October, November) had an average absolute prediction error of 11% (range: 4.7% to 23.1%). This statistic dropped by less than 1% with the addition of data from the month of December and by less than another 2% after the addition of the January data. This relative insensitivity to adding additional months of data to the analysis indicates that the MP should be able to provide benefit to the fishery once the implementation difficulties are solved.

Table 8 shows the results of the operation of the FLA 3 in-season MP since the inception of the Schedule 2 programme. Five TACC in-season increases have been recommended since 2010 based on the operation of the MP (2009–10, 2010–11, 2012–13, 2015–16, and 2016–17; Table 8). However, MPI approval of the 2016–17 increase was delayed until late August, resulting in limited opportunity to take advantage of the increase in commercial catch allowance. The FLA 3 MP was suspended by Fisheries New Zealand from 2019–20 due to the long delays which are consequent to the consultation requirements attendant to catch limit changes, even if they are temporary. These delays resulted in reduced (or even eliminated) opportunities to catch the additional flatfish.

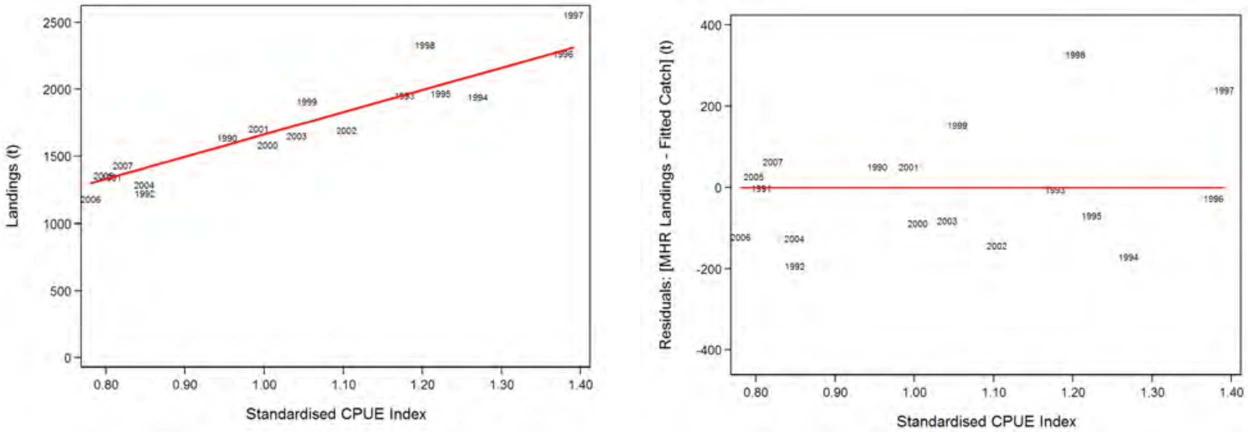


Figure 8: **Relationship between annual FLA 3 CPUE and total annual FLA 3 QMR/MHR landings from 1989–90 to 2006–07 (calculated for the 2019 in-season MP, the most recent year of the operation of this MP) [right panel]; residuals from the top panel regression [left panel].**

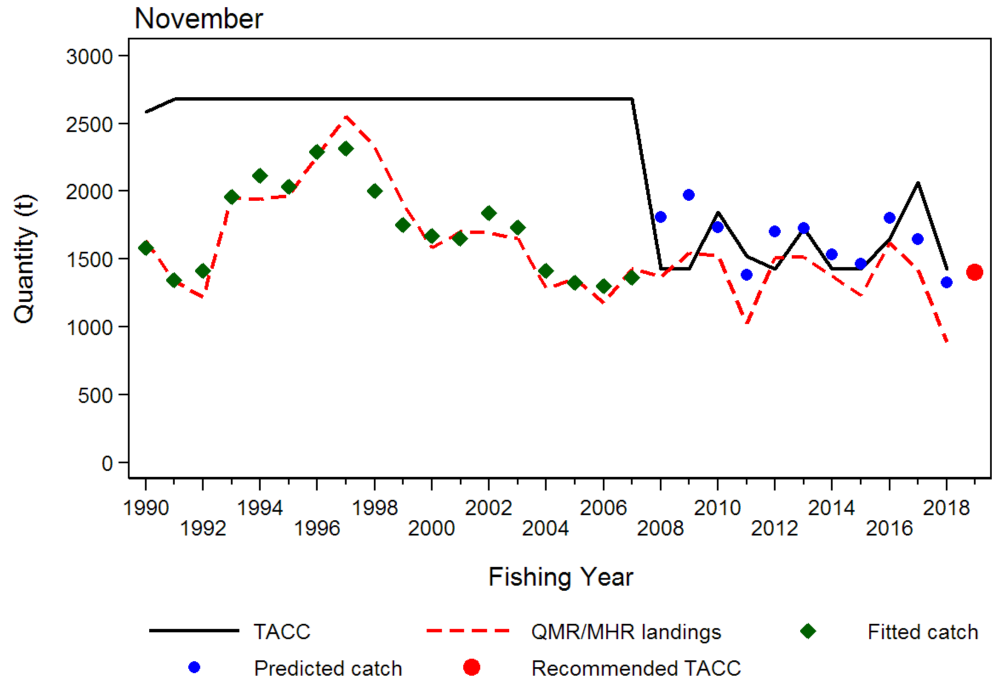


Figure 9: Operation of the 2015 FLA 3 MP in 2019 (the most recent year of operation), showing the relationship of the fitted catch estimates to the observed MHR/QMR landings and the annual recommended catches from 2008 onward based on the estimated standardised CPUE up to the end of November.

Table 8: Results of the operation of the FLA 3 MP by prediction year. NA: not available.

Prediction Year	Fishing Year	CPUE Prediction	CPUE Total year[1]	Recom-mended commercial allowance (t)	Approved commercial allowance (t)[2]	Annual catch (t)	Date of Approval[2]	Reference
2010*	2009–10	64.98 (kg/tow)	75.82	1 846	1 763	1 525	18 June 2010	Bentley (2010)
2011*	2010–11	59.83 (kg/tow)	58.76	1 520	1 430	1 027	–	Bentley (2011)
2012	2011–12	58.45 (kg/tow)	57.56	1 495	–	1 507	–	Bentley (2012)
2013*	2012–13	67.97 (kg/tow)	69.70	1 727	1 727	1 512	17 May 2013	Brouwer (2013)
2014	2013–14	NA	54.80	NA	–	1 377	–	NA
2015	2014–15	53.20 (kg/tow)	NA	1 362	1 352	1 231	–	Bentley (2015)
2016*	2015–16	0.984	1.048	1 650	1 650	1 622	15 July 2016	Starr et al (2016)
2017*	2016–17	1.215	0.978	2 065	2 065	1 421	23 Aug 2017	Starr & Kendrick (2017)
2018	2017–18	0.870	0.796	1 461	–	886	–	Starr & Kendrick (2018)
2019	2018–19	0.843	0.803	1 402	1 430	968	–	Starr & Kendrick (2019a)

[1] calculated in the year following.
[2] information provided by MPI.
* MP operation that resulted in a commercial catch allowance increase recommendation.

Establishing B_{MSY} compatible reference points

Given the large recruitment driven fluctuations in biomass observed for FLA, a target biomass is not meaningful. In-season adjustments are therefore based on relative fishing mortality for all FLA species combined, with increases made when this drops below the target value. F_{MSY} proxies accepted for FLA 3 are the relative fishing mortality values calculated by dividing the baseline TACCs by the corresponding CPUE values on the landings:CPUE regressions shown in Figure 8.

FLA 7

CPUE trends

CPUE trends for four principal FLA 7 species (New Zealand sole [ESO], sand flounder [SFL], brill [BRI], and turbot [TUR]), based on bottom trawl catch and effort data, were estimated in 2020 (Starr & Kendrick 2022b). The data preparation description given for FLA 3 [above] also applies to FLA 7, including the use of 'splitter' trips to estimate the time sequences of catch by species, the 'daily effort' amalgamation procedure, and scaling all species-specific catches to the total FLA landings in a trip. The same criteria were used to select core vessels (5 trips for at least 5 years) to screen data used in the analysis which consisted of offering six explanatory variables to each model, including fishing year (forced), month, vessel, statistical area, number of tows, and duration of fishing, using the scaled estimated species catch for the dependent variable. The WG agreed to report only the lognormal series for these species-specific analyses because zero records only meant that the species had not been reported, rather than being a true zero. The WG also agreed to restrict the analyses to target FLA records and to the following spatial restrictions: [SFL] Tasman Bay/Golden Bay (Statistical Area 038); [ESO, BRI, TUR] west coast South Island (Statistical Areas 032, 033, 034 and 035).

The estimated CPUE trends by species were used to evaluate the relative status of the four main species in the FLA 7 fishery. There are similarities in the fluctuations in the standardised CPUE series for ESO and SFL (Figure 10 [top panel]), with each species showing approximate decadal periodicity. They peak three times in the early- to mid-1990s, in the mid-2000s, and finally at the end of the 2010s. The final 'peak' is low relative to the two previous peaks, indicating that both these species are likely to be at below average levels at the end of the 2010–2019 decade (Figure 10 [top panel]). The more long-lived brill and turbot (Figure 10 [bottom panel]) show a nadir in the late-1990s to early 2000s, followed by an increasing trend and subsequent levelling of the series. Brill appear to be more ascendant at the end of the series when brill have the highest indices in the series, whereas turbot appear to be declining at the end of the 2010–2019 decade (Figure 10 [bottom panel]).

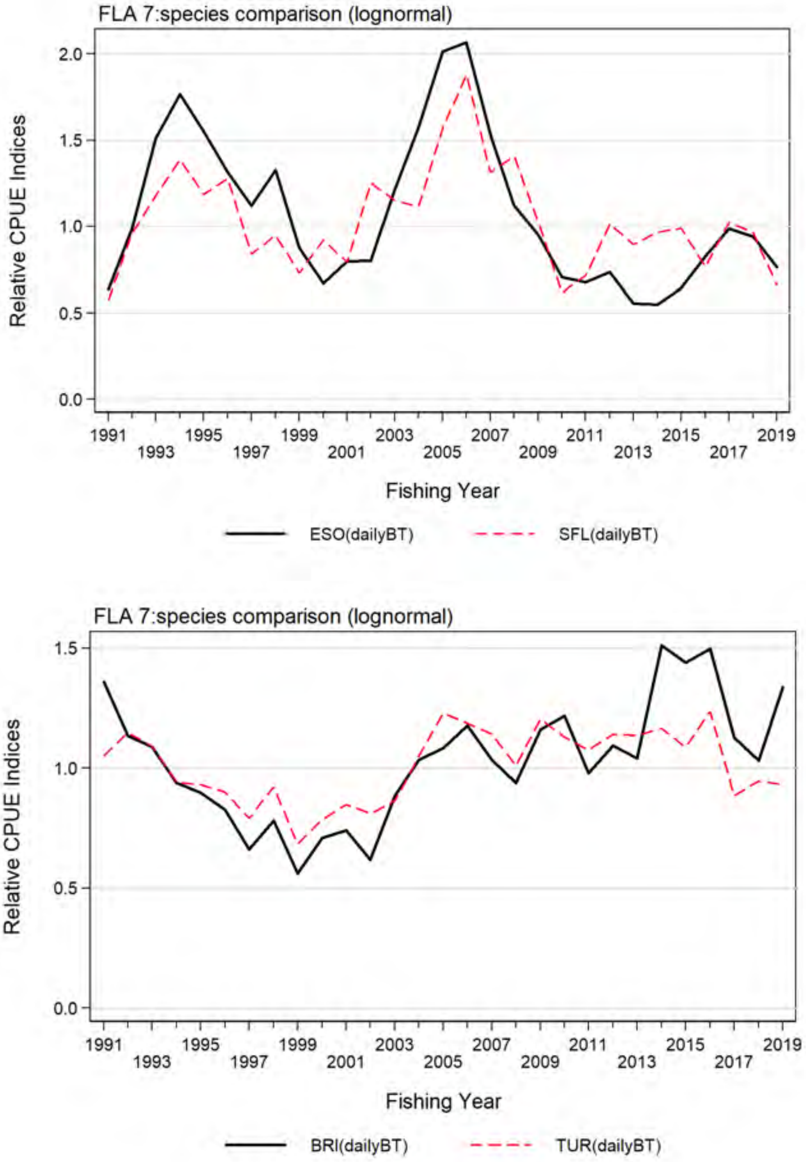


Figure 10: Comparison of FLA 7 standardised bottom trawl lognormal CPUE indices in FLA 7 for [top panel] SFL (sand flounder), ESO (New Zealand sole) [bottom panel] BRI (brill), TUR (turbot) (from Starr & Kendrick 2022b).

Establishing B_{MSY} compatible reference points
The WG discussed establishing B_{MSY} proxy reference points for the four FLA 7 species with CPUE index series. Given that there appeared to be about three decadal cycles in the ESO/SFL series (see Figure 10 [top panel]), the WG agreed to use the average over the entire series as the target. The same conclusion was made for turbot (Figure 10 [bottom panel]), given that this series appeared to be relatively stable across the 30 years of the time series, making the average of the series the B_{MSY} reference level. The B_{MSY} proxy for brill was based on mean standardised CPUE from 1990–91 to 2018–19 (Figure 10 [bottom panel]), which corresponded with a stable period of high abundance and catch.

4.2 Other Factors

The flatfish complex is comprised of QMS eight species although typically only a few are dominant in any one QMA and some are not found in all areas. For management purposes all species are combined to form a unit fishery. The proportion that each species contributes to the catch is expected to vary annually. It is not possible to estimate *MCY* for each species and stock individually.

Because the adult populations of most species generally consist of only one or two year classes at any time, the size of the populations depends heavily on the strength of the recruiting year class and is therefore thought to be highly variable. Brill and turbot are notable exceptions with the adult population consisting of a number of year classes. Early work revealed that although yellowbelly flounder are short-lived, inter-annual abundance in FLA 1 was not highly variable, suggesting that some factor, e.g., size of estuarine nursery area, could be smoothing the impact of random environmental effects on egg and larval survival. Work by NIWA (McKenzie et al 2013) in the Manukau Harbour has linked the decrease in local CPUE with an increase in eutrophication, suggesting that there may be factors other than fishing contributing to the decline.

Flatfish TACCs were originally set at high levels so as to provide fishers with the flexibility to take advantage of the perceived variability associated with annual flatfish abundance. This approach has been modified with an in-season increase procedure for FLA 3.

5. STATUS OF THE STOCKS

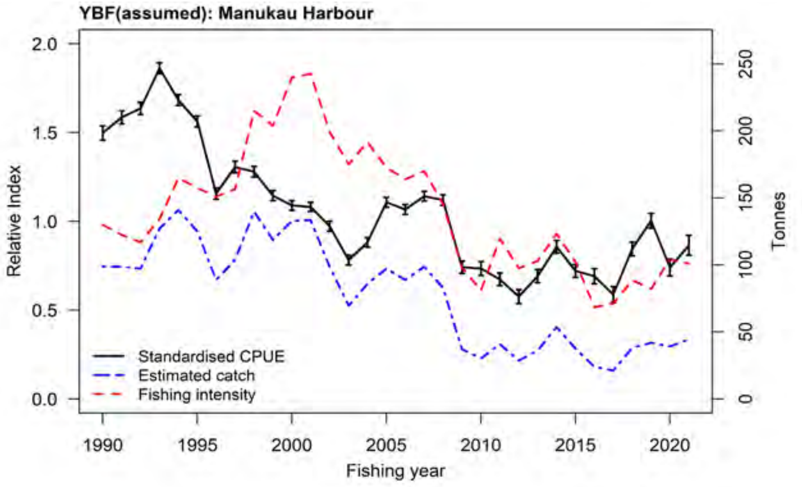
Estimates of current and reference biomass are not available.

- **Yellowbelly flounder in FLA 1**

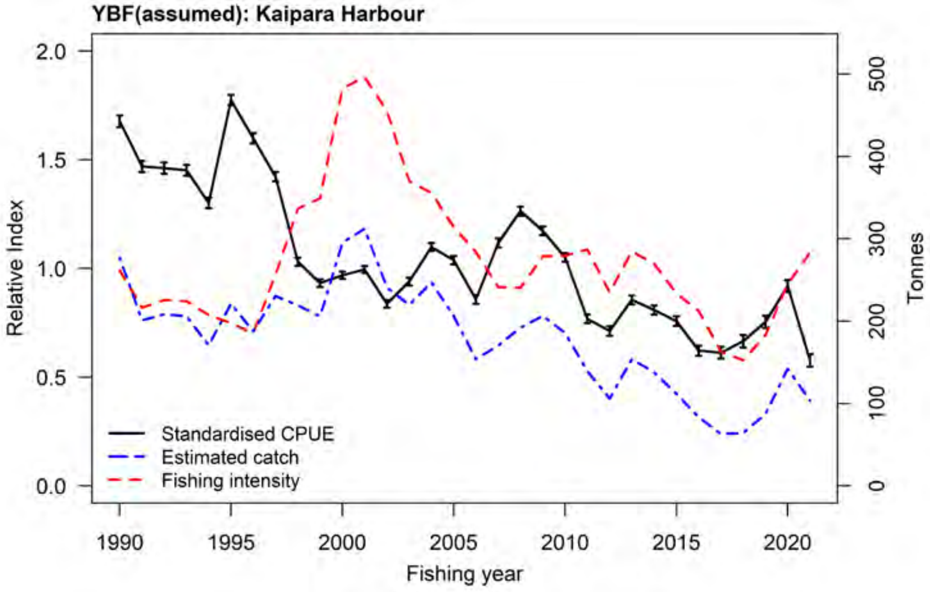
Stock Structure Assumptions
Based on tagging studies, yellowbelly flounder appear to comprise localised populations, especially in enclosed areas such as harbours and bays.

Stock Status	
Year of Most Recent Assessment	2022
Assessment Runs Presented	CPUE in Manukau and Kaipara harbours
Reference Points	Target: Not established but B_{MSY} assumed Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing Threshold: F_{MSY}
Status in relation to Target	Manukau: Unknown Kaipara: Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



CPUE (± standard error) and total annual estimated catches for YBF (assumed) in Manukau Harbour. Also shown is the fishing intensity (catch/CPUE), standardised relative to the geometric mean. Fishing year designated by second year of the pair.



CPUE (± standard error) and total annual estimated catches for YBF (assumed) in Kaipara Harbour. Also shown is the fishing intensity (catch/CPUE), standardised relative to the geometric mean. Fishing year designated by second year of the pair.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	In spite of fluctuations, both the Manukau and Kaipara series show a long-term declining trend. Both series have been stable since about 2010.
Recent Trend in Fishing Intensity or Proxy	Recent fishing intensity is relatively low in both of the west coast harbours.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or	Soft Limit: Unknown

TACC causing Biomass to remain below or to decline below Limits	Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches	
Assessment Dates	Latest assessment: 2022	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Lack of species-specific reporting until 2021. All FLA reported catch from Manukau and Kaipara harbours is assumed to be YBF.	

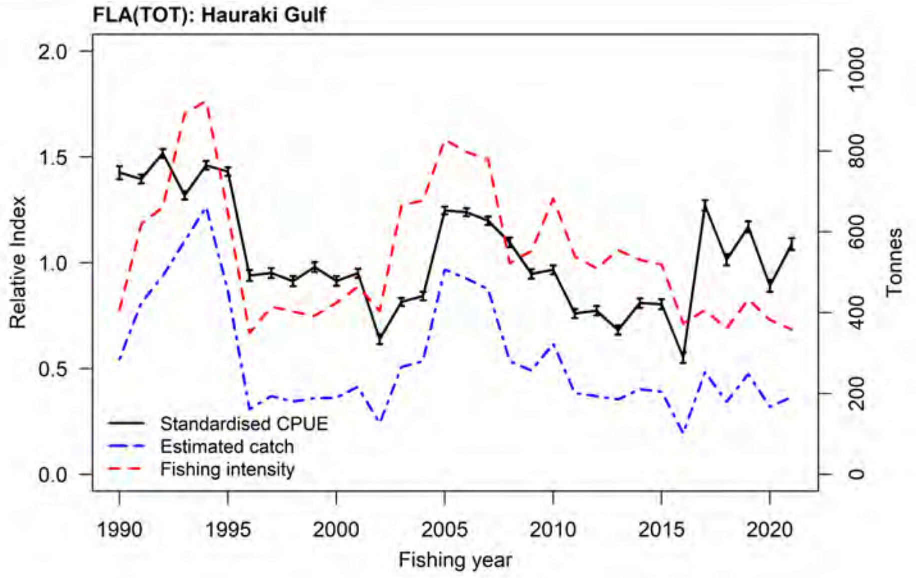
Qualifying Comments
The FLA catch in both the Kaipara and Manukau harbours is predominantly YBF. The lack of species-specific reporting for FLA stocks is limiting the ability to assess these stocks, as is the possible reduction in carrying capacity for Manukau Harbour and Kaipara Harbour.

Fishery Interactions
FLA 1 species are mostly targeted with set nets in harbours. Main QMS bycatch species in west coast harbours are rig, kahawai, parore, and grey mullet.

- **Total FLA 1 in Hauraki Gulf**

Due to a reduction in species-level reporting with the introduction of the ERS, species-specific assessments were not generated for the Hauraki Gulf during the 2022 analysis. Rather, a total FLA CPUE analysis is substituted, which will predominantly comprise mixed sand flounder and yellowbelly flounder.

Stock Status	
Year of Most Recent Assessment	2022
Assessment Runs Presented	Standardised CPUE for Hauraki Gulf
Reference Points	Target(s): Not established but B_{MSY} assumed Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Not established
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status

CPUE (± standard error) and total annual estimated catches for FLA(TOT) in the Hauraki Gulf. Also shown is the fishing intensity (catch/CPUE), standardised relative to the geometric mean. Fishing year designated by second year of the pair.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The Hauraki Gulf FLA(TOT) series shows an overall declining trend except for a three-year increase from 2002 to 2005 and a single strong increase in the 2017 fishing year, which brought the series above the long-term average. Since then, the CPUE index has fluctuated around the series mean.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity appears to be dropping after peaking in 2005.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches	
Assessment Dates	Latest assessment: 2022	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	Catch and effort data	1 – High Quality
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Uncertainty in the stock structure and proportion of catch by species.	

Qualifying Comments
The lack of species-specific reporting for FLA stocks limits the ability to assess these stocks. FLA in the Hauraki Gulf includes variable proportions of YBF and SFL.

Fishery Interactions
Main QMS bycatch species are kahawai, snapper, and rig.

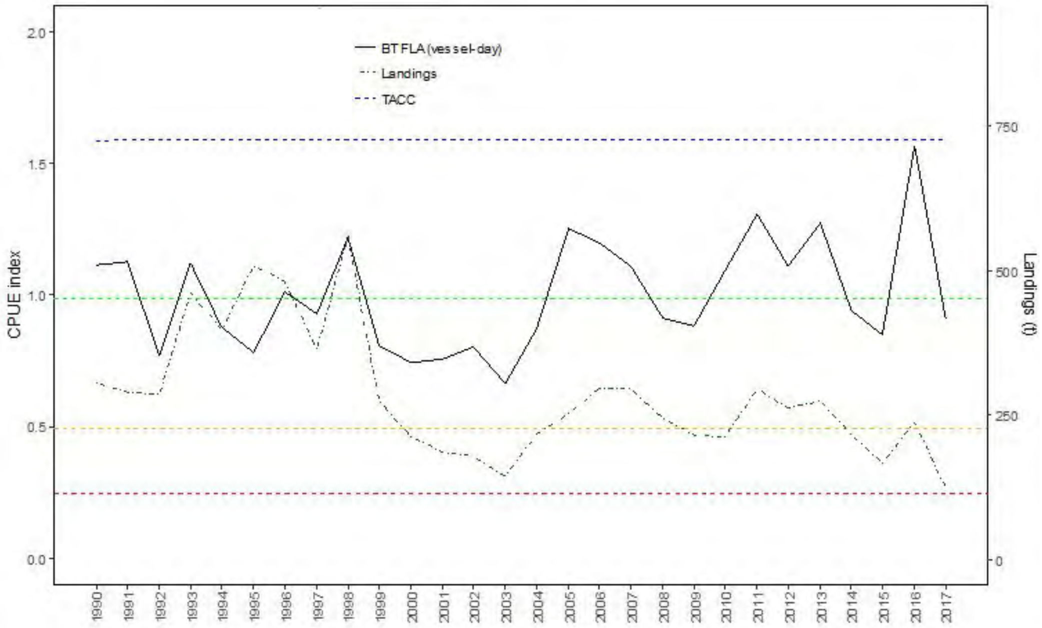
- **FLA 2**

Stock Structure Assumptions

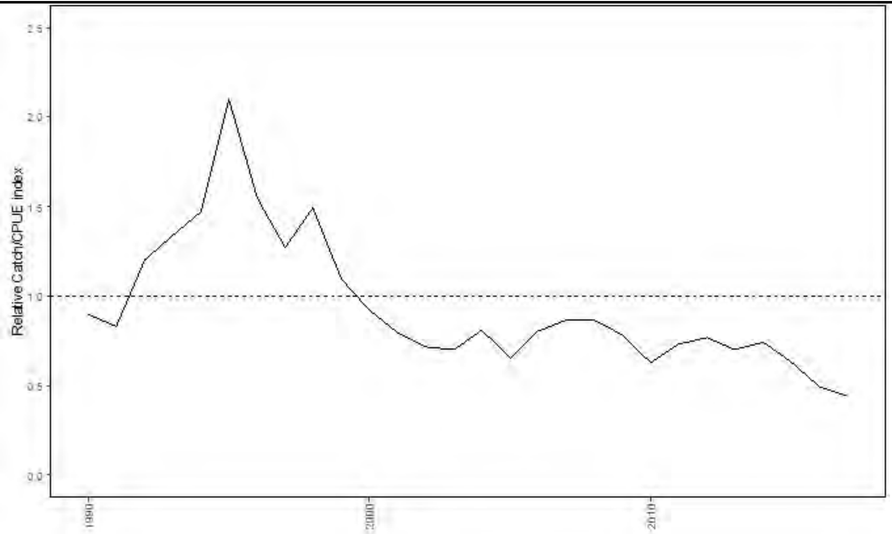
Sand flounder off the East Coast (FMA2) of North Island appear to be a single continuous population. The stock structure of New Zealand sole (ESO) is unknown.

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	Standardised CPUE for all flatfish combined in FLA 2
Reference Points	Target: B_{MSY}-compatible proxy based on the mean CPUE 1989–90 to 2012–13 for the bottom trawl flatfish target series Soft Limit: 50% of target Hard Limit: 25% of target Overfishing threshold: F_{MSY}
Status in relation to Target	About as Likely as Not (40–60%) to be at or above the target
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Annual landings and standardised CPUE index based on positive catches for BT_FLA, (all flatfish species combined) at day resolution (Schofield et al 2018b). Fishing years are labelled according to the second calendar year, e.g. ,1990 = 1989–90. Horizontal lines are the target and the soft and hard limits.



Annual relative exploitation rate for flatfish in FLA 2.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Relative abundance has fluctuated without trend since 1989–90 and is currently just below the target.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has trended down since the mid-1990s and is currently below the reference period (1990–2013) average.
Other Abundance Indices	Tow-based CPUE analysis for SFL and ESO from 2007–08 to 2016–17 data are reasonably consistent with the aggregated data index for combined species, although the decrease in abundance from 2016 to 2017 is more evident in ESO than SFL.
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Stock is likely to continue to fluctuate around current levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown for TACC; Unlikely (< 40%) for current catch Hard Limit: Unknown for TACC; Unlikely (< 40%) for current catch
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown for TACC; Unlikely (< 40%) for current catch

Assessment Methodology		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches	
Assessment Dates	Latest assessment: 2018	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
-

Fishery Interactions
The fishery is mainly confined to the inshore domestic trawl fleet except for a small incidental bycatch of soles, brill, and turbot by offshore trawlers. The main fisheries landing flatfish as bycatch in FLA 2 target gurnard, snapper, and trevally. Interactions with other species are currently being characterised.

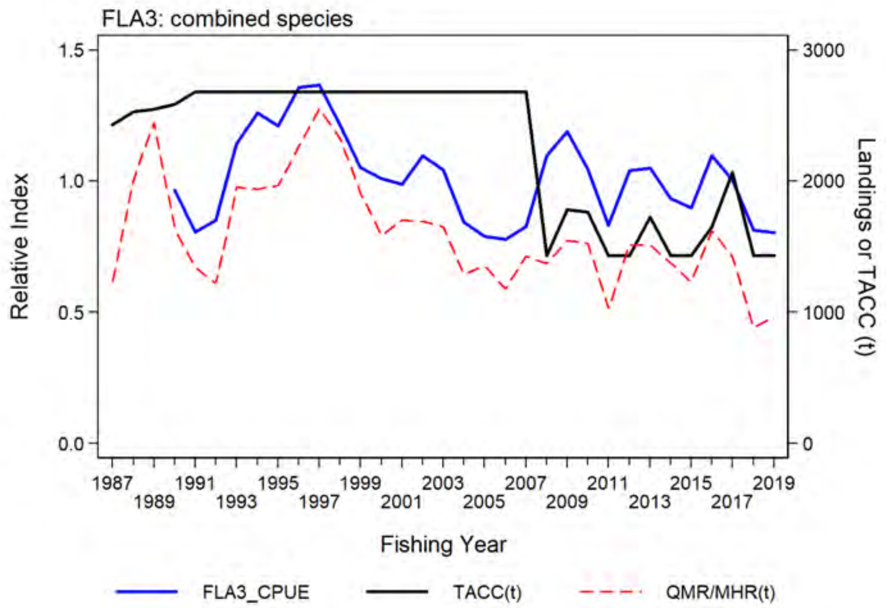
- **FLA 3 (all species combined)**

Stock Structure Assumptions

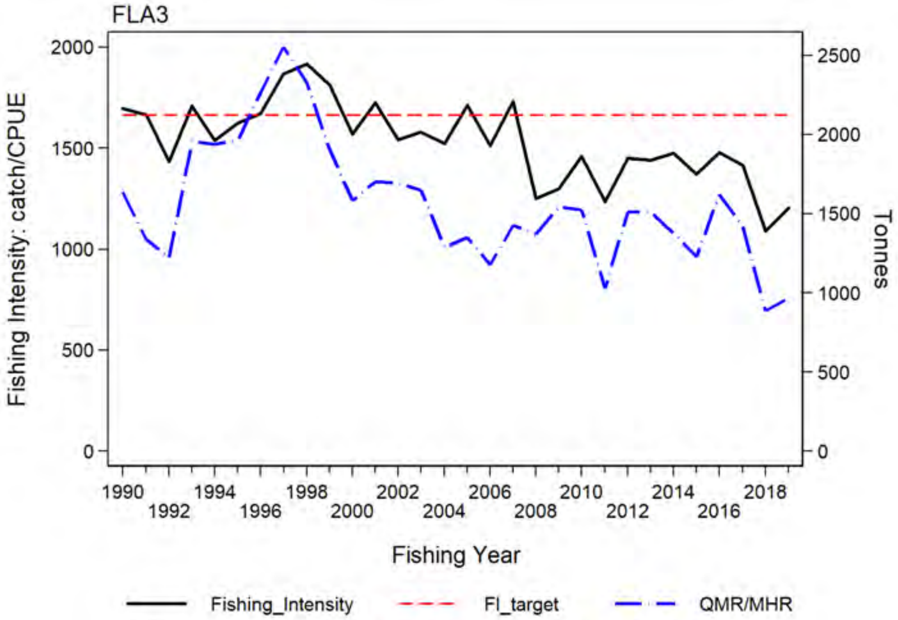
New Zealand sole and lemon sole appear to be a continuous population extending from Canterbury Bight to Foveaux Strait. Sand flounder off the east and south coasts of the South Island show localised concentrations that roughly correspond to the existing statistical areas. The stock relationships among these localised concentrations are unknown.

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised lognormal bottom trawl CPUE for all flatfish combined in FLA 3
Reference Points	Target: F_{MSY} proxy Soft Limit: to be determined Hard Limit: to be determined Overfishing threshold: F_{MSY} proxy
Status in relation to Target	Fishing mortality is Likely (> 60%) to be at or below the target
Status in relation to Limits	Soft limit: Not determined Hard Limit: Not determined
Status in relation to Overfishing	Unlikely (< 40%) that overfishing is occurring

Historical Stock Status Trajectory and Current Status



Standardised CPUE indices based on positive catches for all flatfish species combined (Starr & Kendrick 2022a). Also shown are the QMR/MHR declared FLA 3 landings and the annual FLA 3 commercial catch allowance. Fishing year designated by second year of the pair.



Fishing intensity (catch/CPUE) and a target fishing intensity calculated by dividing the base FLA 3 TACC by the CPUE associated with the base FLA 3 TACC from the catch/CPUE regression (top panel of Figure 8). Also plotted are the annual FLA 3 QMR/MHR landings. Fishing year designated by second year of the pair.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has fluctuated over the long-term near the 30-year mean.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has dropped since the reduction of the TACC in 2007–08 and the introduction of in-season variation to commercial catch allowance and remains below the F_{MSY} proxy.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Stock expected to vary in abundance around the long-term mean
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unlikely (< 40%) to cause overfishing

Assessment Methodology		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches	
Assessment Dates	Latest assessment: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Mixed species complex managed without explicitly considering each species - Uncertainty in stock structure assumptions	

Qualifying Comments
-

Fishery Interactions
The fishery is mainly confined to the inshore domestic trawl fleet except for a small incidental bycatch of soles, brill, and turbot by offshore trawlers. The main target species landing flatfish as bycatch in FLA 3 are red cod, barracouta, stargazer, gurnard, tarakihi, and elephantfish. Interactions with other species are currently being characterised.

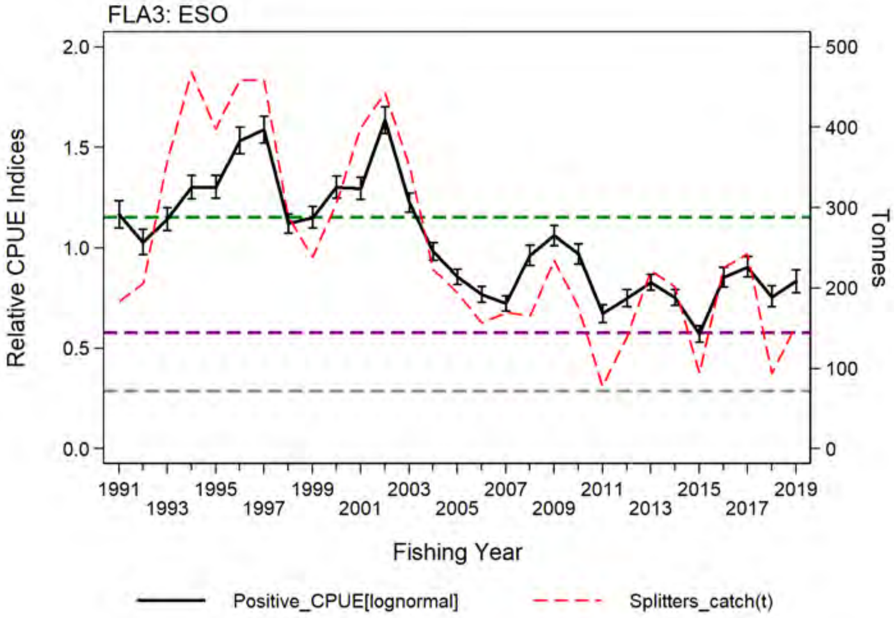
- **FLA 3: New Zealand (ESO) sole**

Stock Structure Assumptions

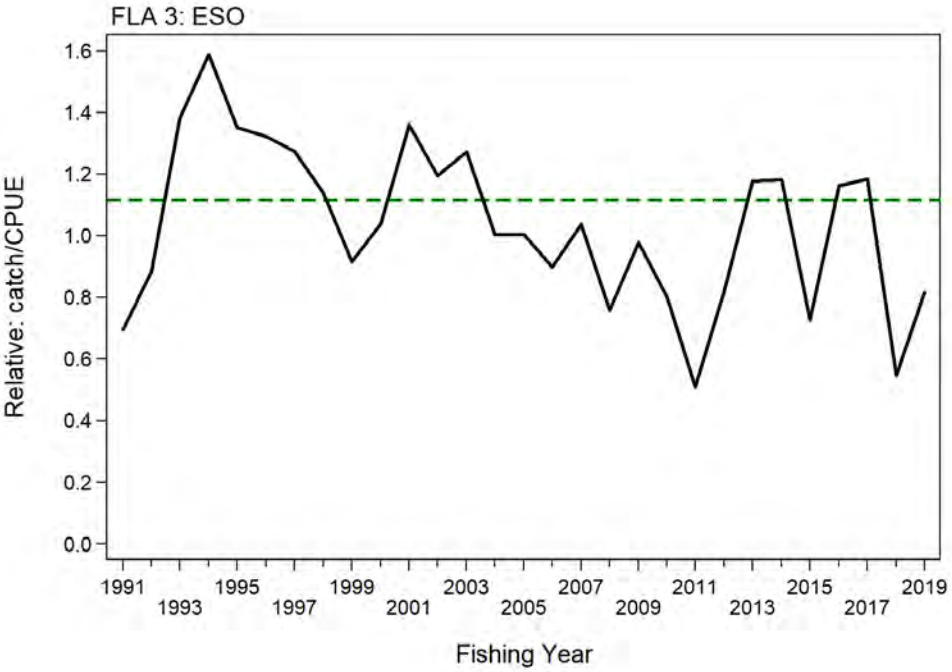
New Zealand sole appear to be a continuous population extending from Canterbury Bight to Foveaux Strait.

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised lognormal bottom trawl CPUE for ESO in FLA 3, based on trips which landed FLA 3 but which did not use the FLA species code
Reference Points	Interim Target: B_{MSY} proxy based on mean standardised CPUE from 1990–91 to 2006–07 (the final year of unconstrained catches) Soft Limit: 50% B_{MSY} proxy Hard Limit: 25% B_{MSY} proxy Overfishing threshold: F_{MSY} proxy based on mean relative exploitation rate for the period 1990–91 to 2006–07
Status in relation to Target	Unlikely (< 40%) to be at or above target
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Unlikely (< 40%) that overfishing is occurring

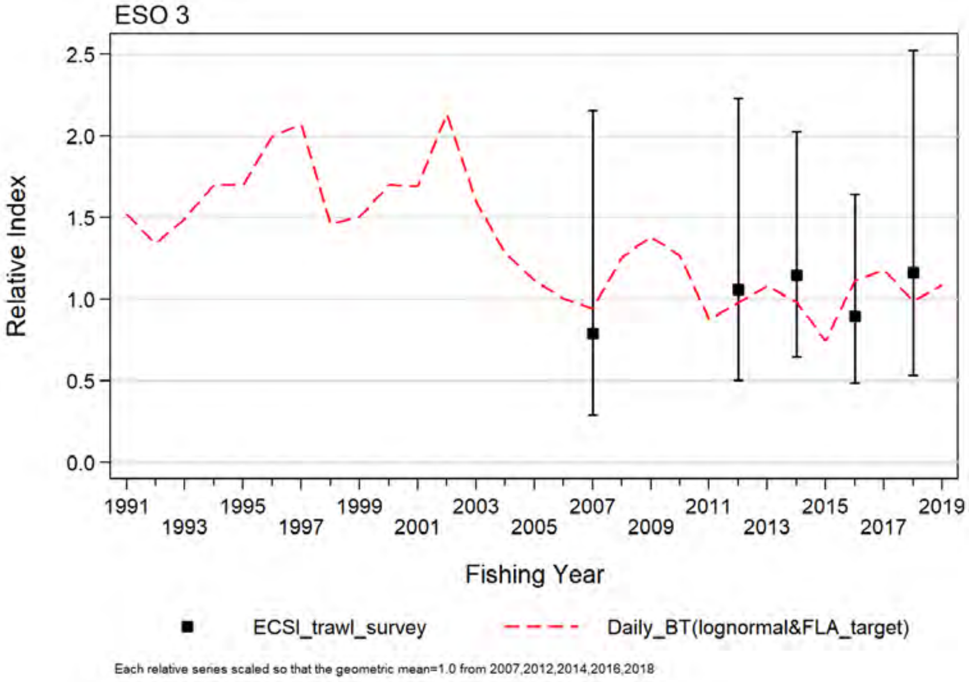
Historical Stock Status Trajectory and Current Status



Standardised CPUE indices based on lognormal CPUE series for New Zealand sole (ESO), showing the agreed B_{MSY} proxy (green dashed line: average 1990–91 to 2006–07 CPUE index) and the associated Soft (purple dashed line) and Hard (grey dashed line) Limits (Starr & Kendrick 2022a). Also shown is the ESO estimated catch by trips that landed FLA 3 but which did not use the FLA code. Fishing year designated by second year of the pair.



Relative fishing intensity for ESO in FLA 3, based on the ESO 'splitter' catch and the standardised lognormal ESO CPUE series. The horizontal dashed green line corresponds to the mean fishing intensity for the period 1991–2007.



Standardised indices based on the lognormal CPUE series for New Zealand sole (ESO), shown with the 5 total (core+shallow strata) trawl survey ESO biomass indices from the *Kaharoa* ECSI winter trawl survey.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has declined from a peak reached in 2001–02 but has remained above the Soft Limit since 2007–08.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has declined to below the target in the most recent two years.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to be at or above target
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) for current catch Hard Limit: Very Unlikely (< 10%) for current catch
Probability of Current Catch or TACC causing Overfishing to continue or to commence	As Likely as Not (40–60%) for current catch

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches	
Assessment Dates	Latest assessment: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- uncertainty in stock structure assumptions	

Qualifying Comments
The lack of historic species-specific reporting for FLA stocks limits the ability to assess the long-term trends in these stocks; there is an expectation that the adoption of Electronic Reporting of catch will improve the reporting of species-specific estimated flatfish catch.

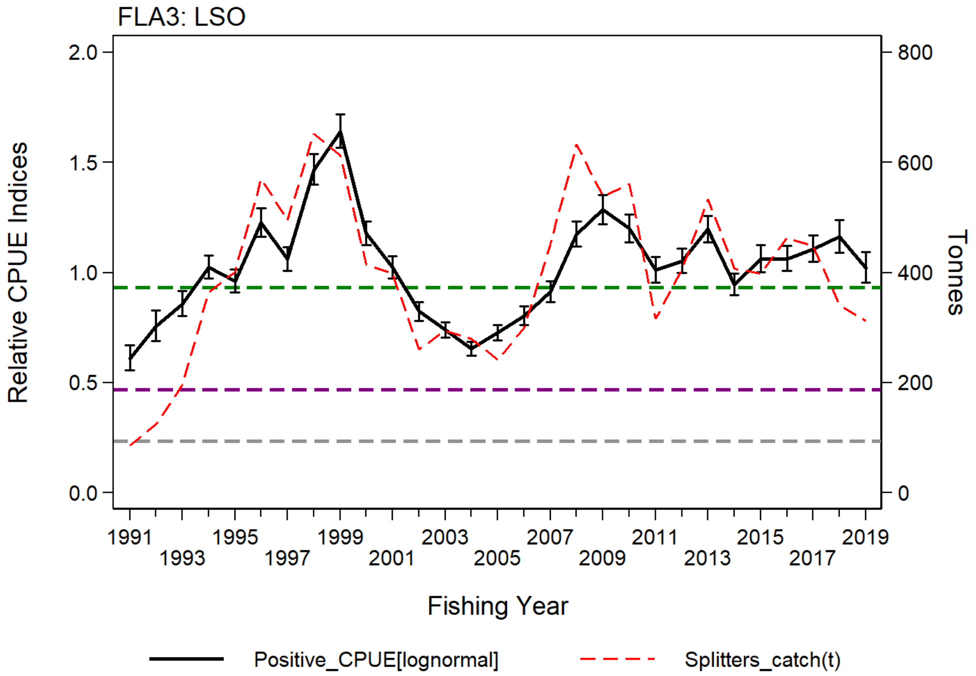
Fishery Interactions
The fishery is mainly confined to the inshore domestic trawl fleet except for a small incidental bycatch of soles, brill, and turbot by offshore trawlers. The main target species landing flatfish as bycatch in FLA 3 are red cod, barracouta, stargazer, gurnard, tarakihi, and elephantfish.

- **FLA 3: Lemon (LSO) sole**

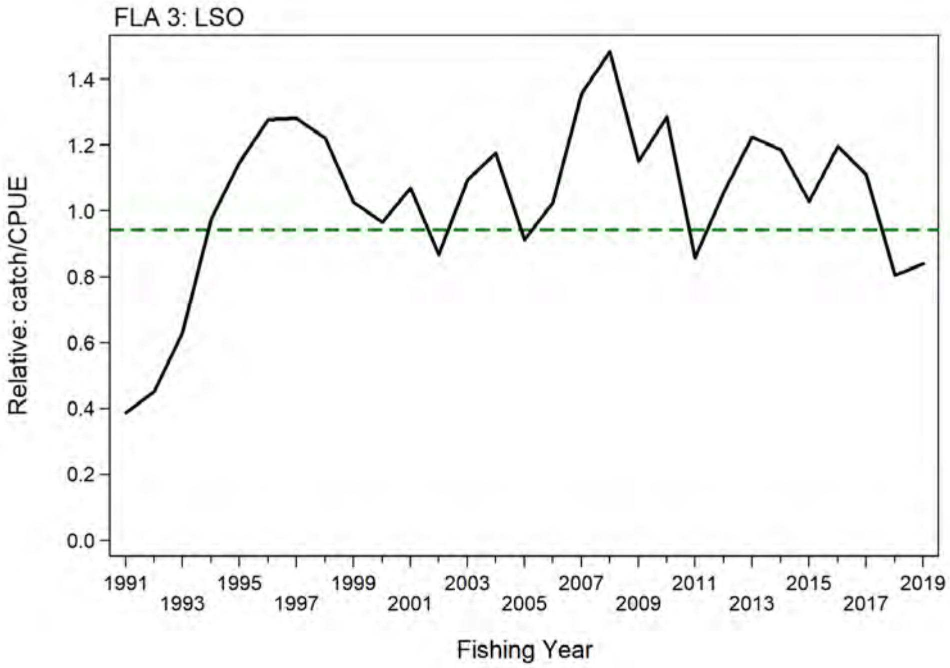
Stock Structure Assumptions
Lemon sole appear to be a continuous population extending from Canterbury Bight to Foveaux Strait.

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised lognormal bottom trawl CPUE for LSO in FLA 3, based on trips which landed FLA 3 but which did not use the FLA species code
Reference Points	Interim Target: B_{MSY} proxy based on mean standardised CPUE from 1990–91 to 2006–07 (the final year of unconstrained catches) Soft Limit: 50% B_{MSY} proxy Hard Limit: 25% B_{MSY} proxy Overfishing threshold: F_{MSY} proxy based on mean relative exploitation rate for the period 1990–91 to 2006–07
Status in relation to Target	About as Likely as Not (40–60%) to be at or above target
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	About as Likely as Not (40–60%) that overfishing is occurring

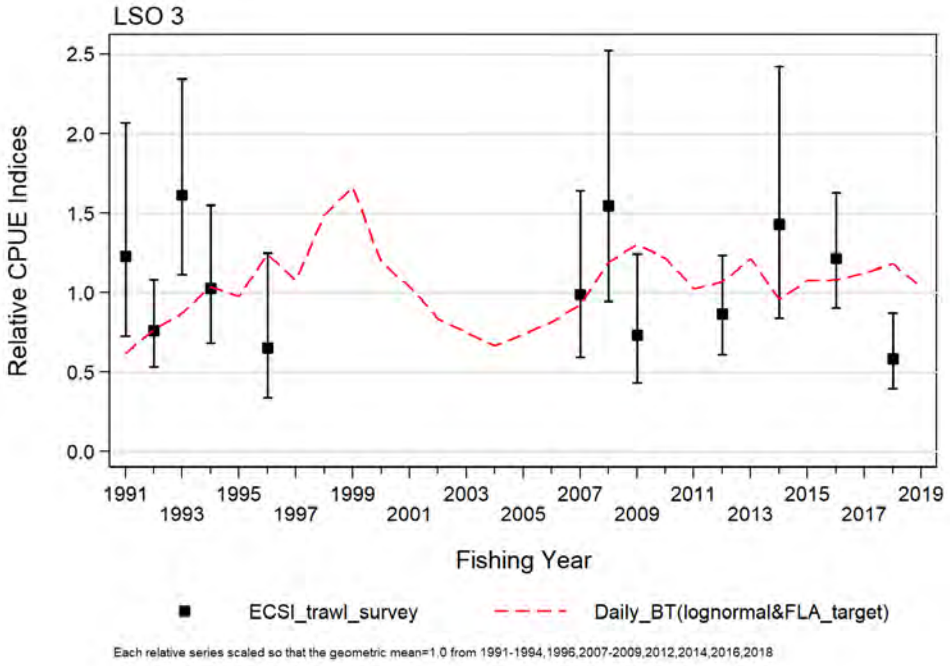
Historical Stock Status Trajectory and Current Status



Standardised indices based on lognormal CPUE series for Lemon sole (LSO), showing the agreed B_{MSY} proxy (green dashed line: average 1990–91 to 2006–07 CPUE index) and the associated Soft (purple dashed line) and Hard (grey dashed line) Limits (Starr & Kendrick 2022a). Also shown is the LSO estimated catch by trips that landed FLA 3 but which did not use the FLA code. Fishing year designated by second year of the pair.



Relative fishing intensity for LSO in FLA 3, based on the LSO 'splitter' catch and the standardised lognormal LSO CPUE series. The horizontal dashed green line corresponds to the mean fishing intensity for the period 1991–2007.



Standardised indices based on the lognormal CPUE series for Lemon sole (LSO) shown with the 12 trawl survey LSO core strata biomass indices from the *Kaharoa* ECSI winter trawl survey. Fishing year designated by second year of the pair.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE reached a nadir in 2003–04, but then climbed to a new level near the long-term mean in 2007–08 and has since remained at that level.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has fluctuated, mostly above the F_{MSY} proxy since 1994–95 but has dropped to just below target in 2017–18 and 2018–19.
Other Abundance Indices	Relative abundance from the ECSI winter trawl survey has fluctuated without trend since 1991.
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	About as Likely or Not (40-60%) to remain at or above the target
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For current catch, About as Likely as Not (40–60%) to occur

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches	
Assessment Dates	Latest assessment: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- uncertainty in stock structure assumptions	

Qualifying Comments
The lack of historic species-specific reporting for FLA stocks limits the ability to assess the long-term trends in these stocks; there is an expectation that the adoption of Electronic Reporting of catch will improve the reporting of species-specific estimated flatfish catch.

Fishery Interactions
The fishery is mainly confined to the inshore domestic trawl fleet except for a small incidental bycatch of soles, brill, and turbot by offshore trawlers. The main target species landing flatfish as bycatch in FLA 3 are red cod, barracouta, stargazer, gurnard, tarakihi, and elephantfish. Interactions with protected species are believed to be low. Incidental captures of seabirds occur.

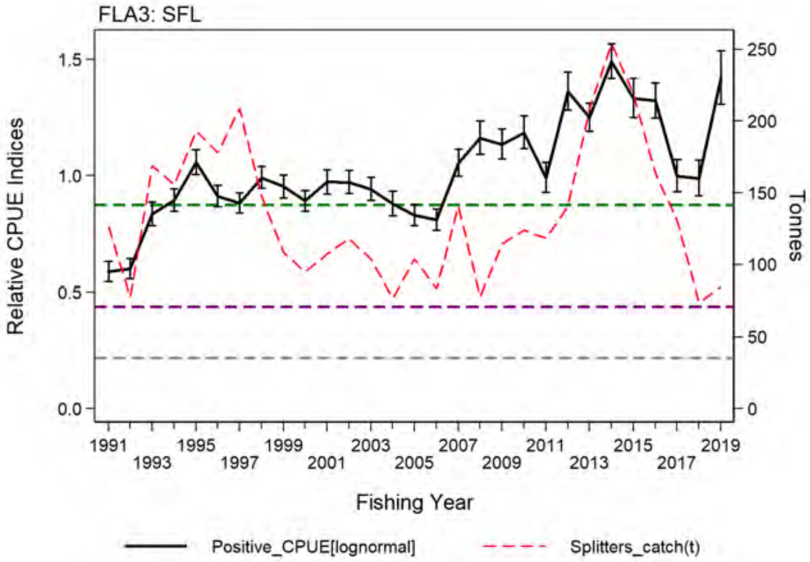
- **FLA 3: Sand Flounder (SFL)**

Stock Structure Assumptions

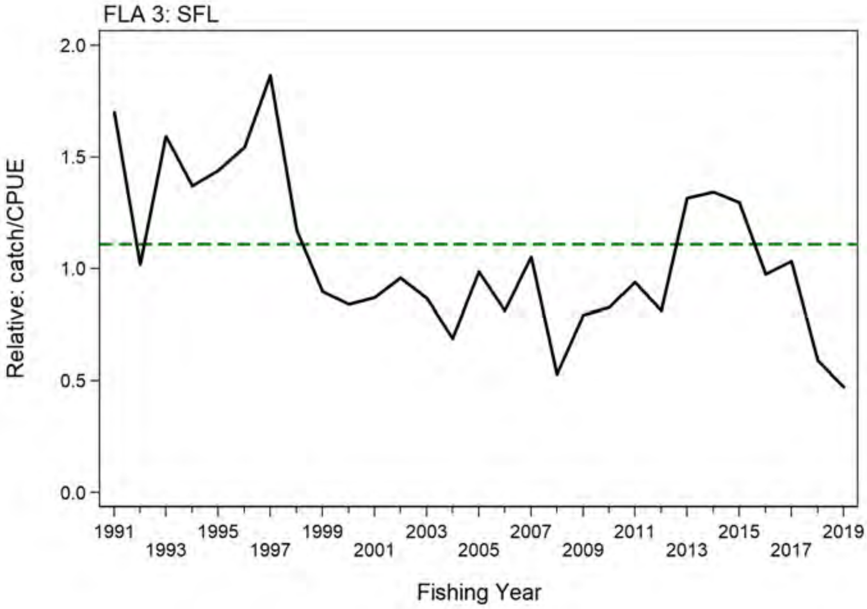
Sand flounder off the east and south coasts of the South Island show localised concentrations that roughly correspond to the existing statistical areas. The stock relationships among these localised concentrations are unknown.

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised lognormal bottom trawl CPUE for SFL in FLA 3, based on trips which landed FLA 3 but which did not use the FLA species code
Reference Points	Interim Target: B_{MSY} proxy based on mean standardised CPUE from 1990–91 to 2006–07 (the final year of unconstrained catches) Soft Limit: 50% B_{MSY} proxy Hard Limit: 25% B_{MSY} proxy Overfishing threshold: F_{MSY} proxy based on mean relative exploitation rate for the period 1990–91 to 2006–07
Status in relation to Target	Very Likely (> 90%) to be at or above target
Status in relation to Limits	Soft Limit: Very Unlikely (< 10%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Unlikely (< 40%) that overfishing is occurring

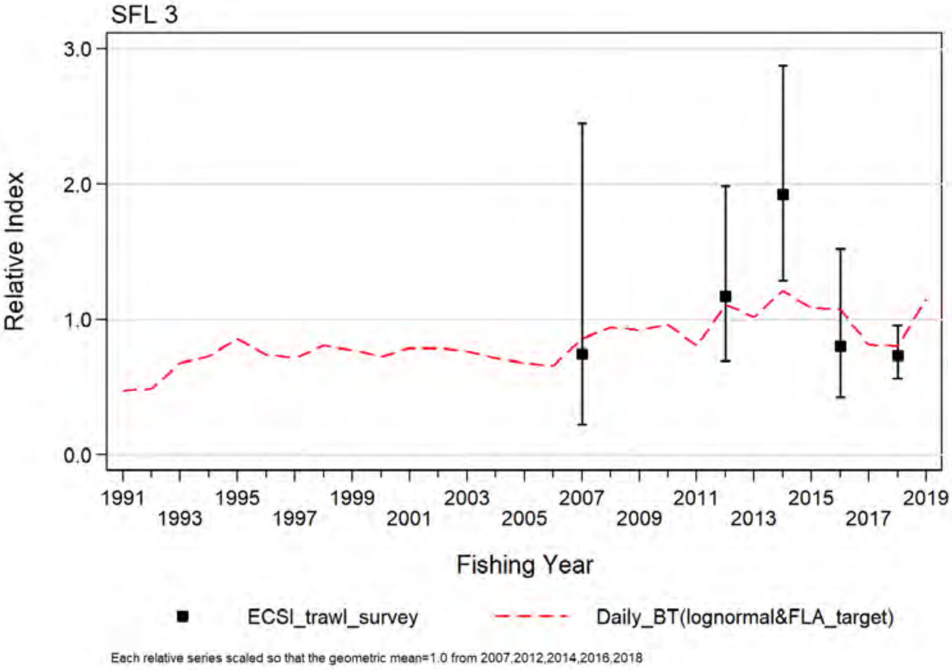
Historical Stock Status Trajectory and Current Status



Standardised indices based on lognormal CPUE series for Sand flounder (SFL), showing the agreed B_{MSY} proxy (green dashed line: average 1990–91 to 2006–07 CPUE index) and the associated Soft (purple dashed line) and Hard (grey dashed line) Limits (Starr & Kendrick 2018). Also shown is the SFL estimated catch by trips that landed FLA 3 but which did not use the FLA code. Fishing year designated by second year of the pair.



Relative fishing intensity for SFL in FLA 3, based on the SFL 'splitter' catch and the standardised lognormal SFL CPUE series. The horizontal dashed green line corresponds to the mean fishing intensity for the period 1991–2007.



Standardised indices based on the lognormal CPUE series for sand flounder (SFL), shown with the 5 total (core+shallow strata) trawl survey SFL biomass indices from the *Kaharoa* ECSI winter trawl survey.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE rose from a nadir in 2003–04 to above the long-term mean by 2007–08 and has fluctuated above this level since then.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has dropped steeply since 2014–15 and was well below the target in 2018–19.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	- Likely (> 60%) to remain at or above the target
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) for current catch Hard Limit: Very Unlikely (< 10%) for current catch
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unlikely (< 40%) for current catch

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches	
Assessment Dates	Latest assessment: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- uncertainty in stock structure assumptions	

Qualifying Comments
The lack of historic species-specific reporting for FLA stocks limits the ability to assess the long-term trends in these stocks; there is an expectation that the adoption of Electronic Reporting of catch will improve the reporting of species-specific estimated flatfish catch.

Fishery Interactions
The fishery is mainly confined to the inshore domestic trawl fleet except for a small incidental bycatch of soles, brill, and turbot by offshore trawlers. The main target species landing flatfish as bycatch in FLA 3 are red cod, barracouta, stargazer, gurnard, tarakihi, and elephantfish. Interactions with other species are currently being characterised.

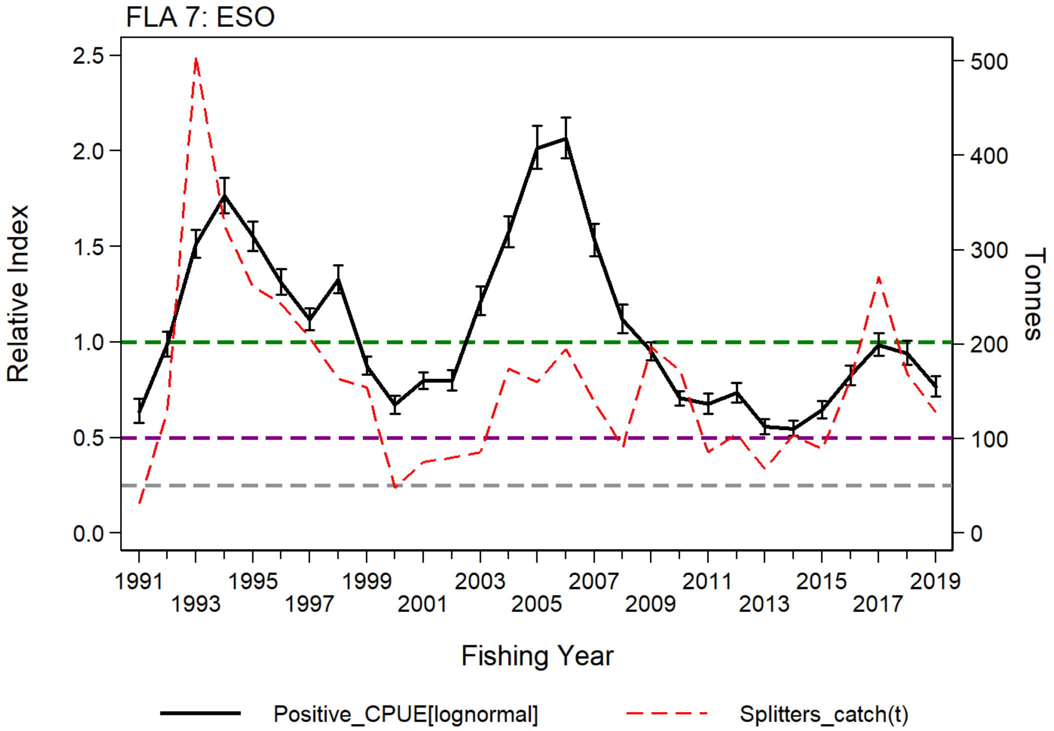
- **FLA 7: New Zealand (ESO) sole**

Stock Structure Assumptions

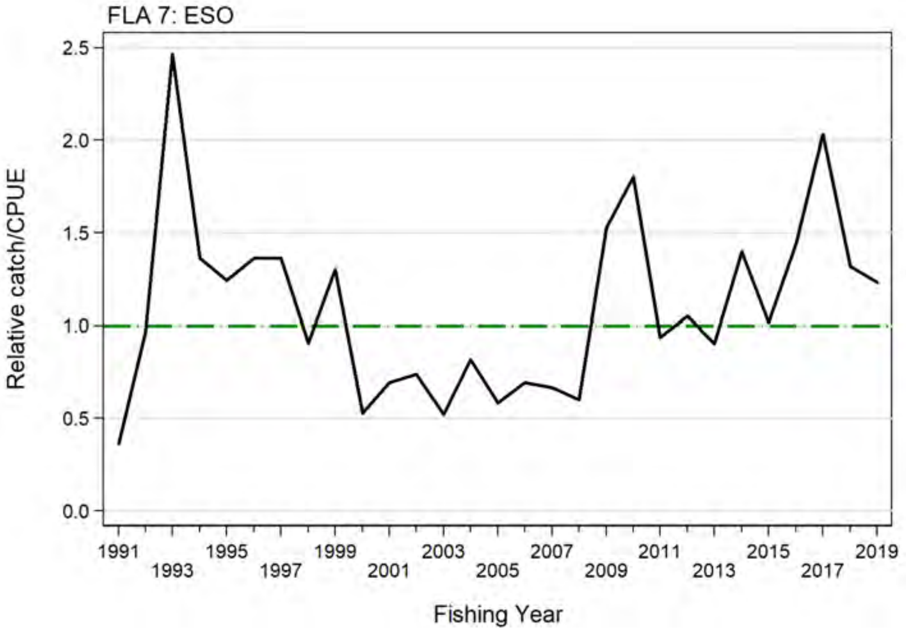
New Zealand sole are mostly taken off the west coast South Island portion of FLA 7, and there is very little catch taken in Tasman Bay/Golden Bay. The CPUE analysis presented in the table below is based on catch and effort data from the west coast (Statistical Areas 032, 033, 034, and 035).

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised lognormal bottom trawl CPUE for ESO in FLA 7, based on trips which landed FLA 7 but which did not use the FLA species code
Reference Points	Interim Target: B_{MSY} proxy based on mean standardised CPUE from 1990–91 to 2018–19 Soft Limit: 50% B_{MSY} proxy Hard Limit: 25% B_{MSY} proxy Overfishing threshold: F_{MSY} proxy based on mean relative exploitation rate for the period 1990–91 to 2018–19
Status in relation to Target	Unlikely (< 40%) to be at or above target
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Likely (< 10%) to be below
Status in relation to Overfishing	Likely (> 60%) that overfishing is occurring

Historical Stock Status Trajectory and Current Status



Standardised indices based on lognormal CPUE series for New Zealand sole (ESO), showing the agreed *BMSY* proxy (green dashed line: average 1990–91 to 2018–19 CPUE index) and the associated Soft (purple dashed line) and Hard (grey dashed line) Limits (Starr & Kendrick 2022b). Also shown is the ESO estimated catch by trips that landed FLA 7 but which did not use the FLA code. Fishing year designated by second year of the pair.



Relative fishing intensity for ESO in FLA 7, based on the ESO 'splitter' catch and the standardised lognormal ESO CPUE series. The horizontal dashed green line corresponds to the mean fishing intensity for the period 1991–2019.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE declined from a 2005–06 peak to a low in 2013–14, increased to 2016–17, and declined again to 0.77 in 2018–19.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has increased since 2010–11 to above the mean level.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Likely (> 60%) to remain below target for current catch
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) for current catch Hard Limit: Very Unlikely (< 10%) for current catch
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Likely (> 60%) for current catch

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches	
Assessment Dates	Latest assessment: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- uncertainty in stock structure assumptions	

Qualifying Comments
The lack of historic species-specific reporting for FLA stocks limits the ability to assess the long-term trends in these stocks; there is an expectation that the adoption of Electronic Reporting of catch will improve the reporting of species-specific estimated flatfish catch.

Fishery Interactions
The fishery is mainly confined to the inshore domestic trawl fleet except for a small incidental bycatch of soles, brill, and turbot by offshore trawlers. The main non-FLA target species landing flatfish as bycatch in FLA 7 are red cod, barracouta, gurnard, and tarakihi. The bycatch of FLA 7 in other QMS species has averaged 18% of the total 1989–90 to 2018–19 FLA 7 catch.

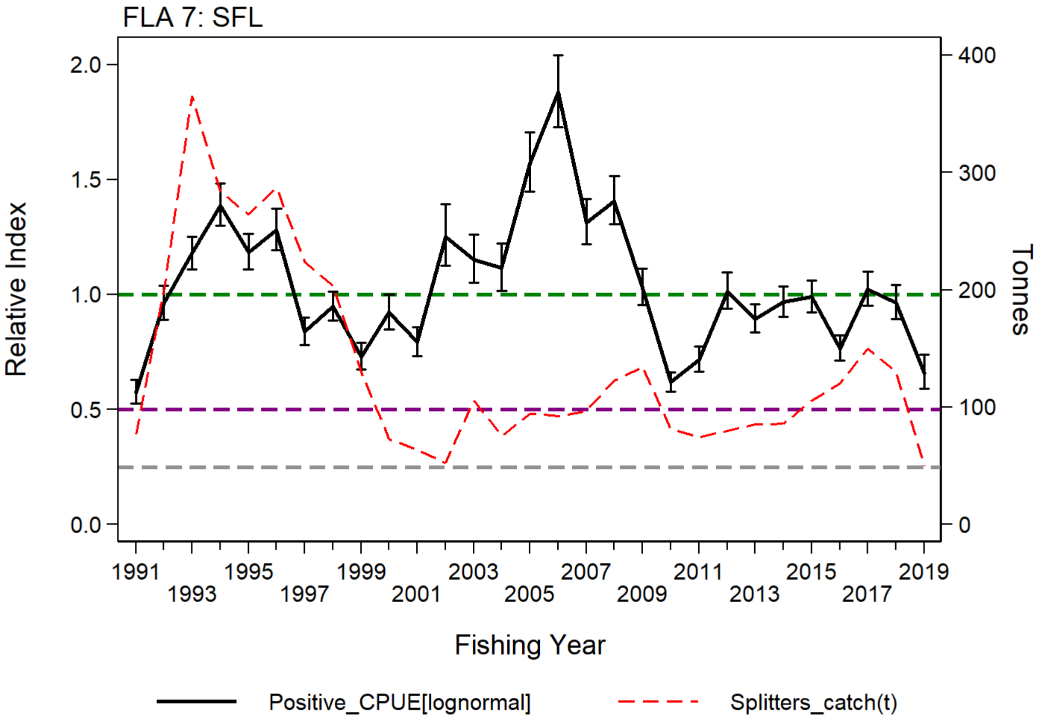
- **FLA 7: Sand Flounder (SFL)**

Stock Structure Assumptions

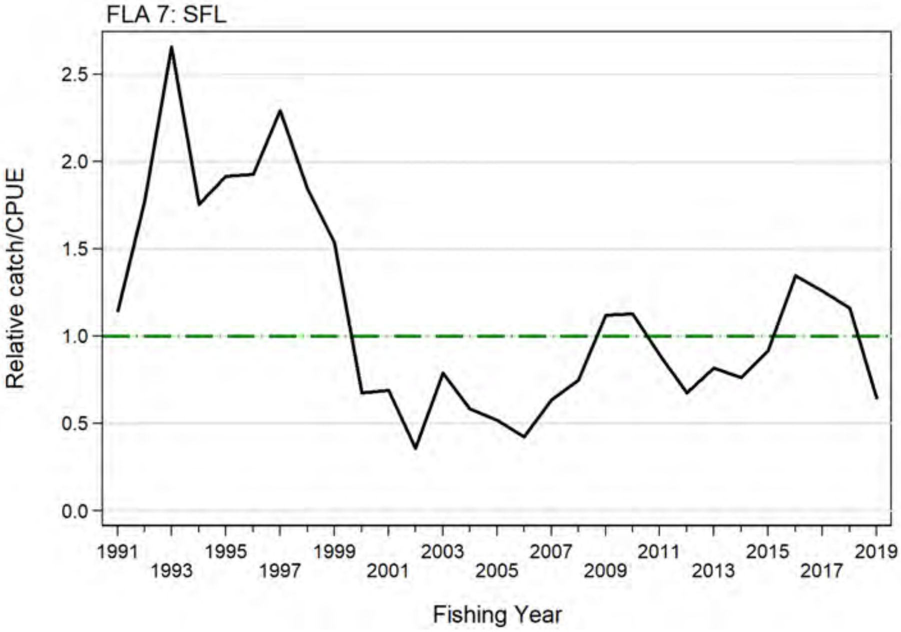
Sand flounder in FLA 7 is mostly taken in Tasman Bay/Golden Bay, with a small component of the catch coming from eastern Cook Strait. There is very little SFL catch from the west coast of the South Island. The analysis presented in the table below is based on catch and effort data from Tasman Bay/Golden Bay (Statistical Area 038).

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised lognormal bottom trawl CPUE for SFL in FLA 7, based on trips which landed FLA 7 but which did not use the FLA species code
Reference Points	Interim Target: B_{MSY} proxy based on mean standardised CPUE from 1990–91 to 2018–19 Soft Limit: 50% B_{MSY} proxy Hard Limit: 25% B_{MSY} proxy Overfishing threshold: F_{MSY} proxy based on mean relative exploitation rate for the period 1990–91 to 2018–19
Status in relation to Target	About as Likely as Not (40–60%) to be at or above target
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	About as Likely as Not (40–60%) that overfishing is occurring

Historical Stock Status Trajectory and Current Status



Standardised indices based on lognormal CPUE series for Sand flounder (SFL), showing the agreed B_{MSY} proxy (green dashed line: average 1990–91 to 2018–19 CPUE index) and the associated Soft (purple dashed line) and Hard (grey dashed line) Limits (Starr & Kendrick 2022b). Also shown is the SFL estimated catch by trips that landed FLA 7 but which did not use the FLA code. Fishing year designated by second year of the pair.



Relative fishing intensity for SFL in FLA 7, based on the SFL 'splitter' catch and the standardised lognormal SFL CPUE series. The horizontal dashed green line corresponds to the mean fishing intensity for the period 1991–2019.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has fluctuated without trend near the long-term average from 2010–11.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity dropped to relatively low levels in the late 2000s, and has since climbed back to the level of the F_{MSY} proxy.
Other Abundance Indices	Relative abundance from the WCSI trawl survey has fluctuated without trend since 1992.
Trends in Other Relevant Indicators	-

or Variables	
Projections and Prognosis	
Stock Projections or Prognosis	About as Likely as Not (40–60%) to remain near target for current catch
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) for current catch Hard Limit: Very Unlikely (< 10%) for current catch
Probability of Current Catch or TACC causing Overfishing to continue or to commence	About as Likely as Not (40–60%) to remain near overfishing threshold for current catch

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches	
Assessment Dates	Latest assessment: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- uncertainty in stock structure assumptions	

Qualifying Comments
The lack of historic species-specific reporting for FLA stocks limits the ability to assess the long-term trends in these stocks; there is an expectation that the adoption of Electronic Reporting of catch will improve the reporting of species-specific estimated flatfish catch.

Fishery Interactions
The fishery is mainly confined to the inshore domestic trawl fleet fishing in Tasman Bay/Golden Bay, which primarily targets gurnard and snapper, in addition to flatfish. Other species are incidental.

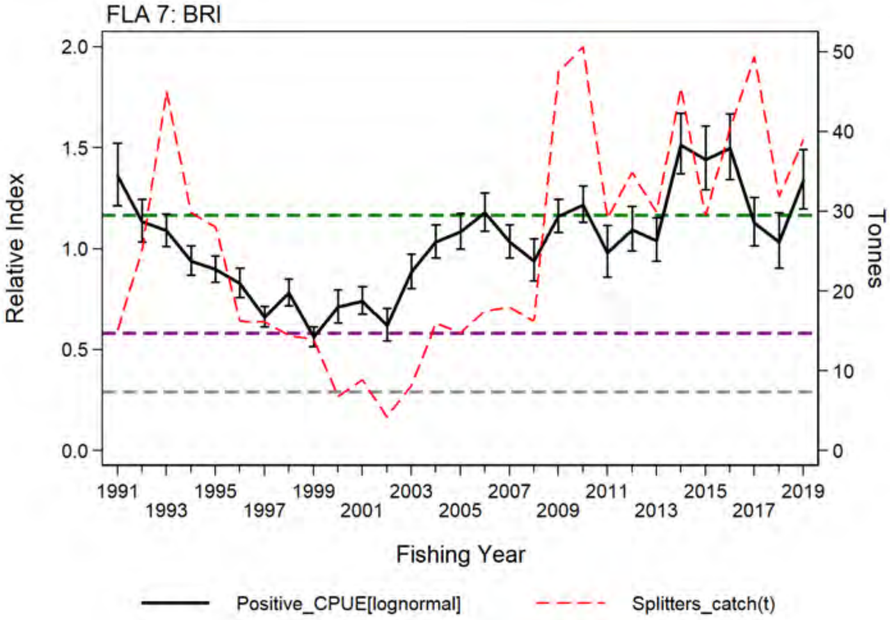
- **FLA 7: Brill (BRI)**

Stock Structure Assumptions

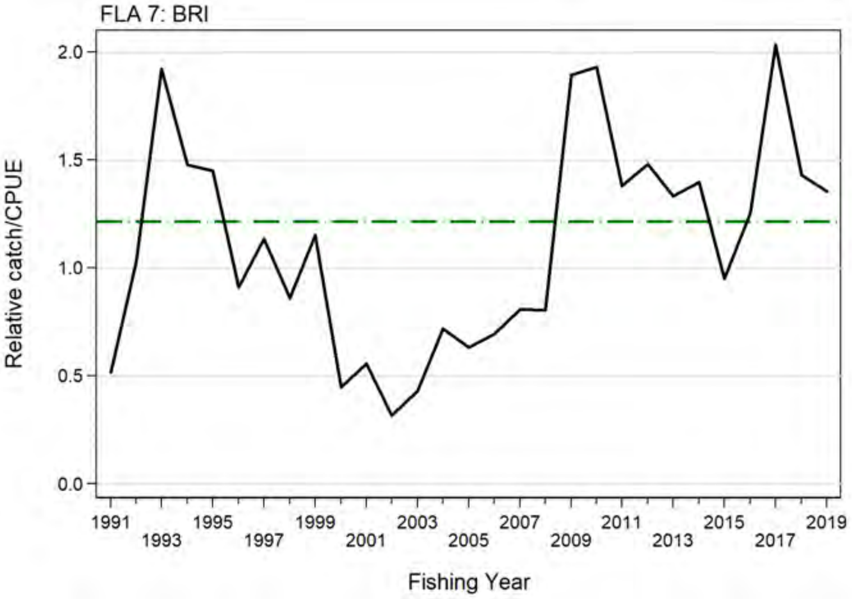
Brill are mostly taken off the west coast South Island portion of FLA 7, where they appear to comprise a continuous population, and there is very little catch taken in Tasman Bay/Golden Bay. The CPUE analysis presented in the table below is based on catch and effort off the west coast (Statistical Areas 032, 033, 034, and 035).

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised lognormal bottom trawl CPUE for BRI in FLA 7, based on trips which landed FLA 7 but which did not use the FLA species code
Reference Points	Interim Target: B_{MSY} proxy based on mean standardised CPUE from 2004–05 to 2018–19 Soft Limit: 50% B_{MSY} proxy Hard Limit: 25% B_{MSY} proxy Overfishing threshold: F_{MSY} proxy based on mean relative exploitation rate for the period 1990–91 to 2018–19
Status in relation to Target	About as Likely as Not (40–60%) to be at or above target
Status in relation to Limits	Soft Limit: Very Unlikely (< 10%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	About as Likely as Not (40–60%) that overfishing is occurring

Historical Stock Status Trajectory and Current Status



Standardised indices based on lognormal CPUE series for Brill (BRI), showing the agreed B_{MSY} proxy (green dashed line: average 2004–05 to 2018–19 CPUE index) and the associated Soft (purple dashed line) and Hard (grey dashed line) Limits (Starr & Kendrick 2022b). Also shown is the BRI estimated catch by trips that landed FLA 7 but which did not use the FLA code. Fishing year designated by second year of the pair.



Relative fishing intensity for BRI in FLA 7, based on the BRI 'splitter' catch and the standardised lognormal BRI CPUE series. The horizontal dashed green line corresponds to the mean fishing intensity for the period 2005–2019.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has been relatively constant at a high level since 2004–05 with a three-year excursion to 1.5 x the long-term average from 2014–15 to 2016–17.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has fluctuated, mostly above the F_{MSY} proxy since 2004–05, and was near the F_{MSY} proxy in 2018–19.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	About as Likely as Not (40–60%) to remain near target for current catch

Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) for current catch Hard Limit: Very Unlikely (< 10%) for current catch
Probability of Current Catch or TACC causing Overfishing to continue or to commence	About as Likely as Not (40–60%) to remain near overfishing threshold for current catch

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches	
Assessment Dates	Latest assessment: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- uncertainty in stock structure assumptions	

Qualifying Comments
The lack of historic species-specific reporting for FLA stocks limits the ability to assess the long-term trends in these stocks; there is an expectation that the adoption of Electronic Reporting of catch will improve the reporting of species-specific estimated flatfish catch.

Fishery Interactions
The fishery is mainly confined to the inshore domestic trawl fleet except for a small incidental bycatch of soles, brill, and turbot by offshore trawlers. The main non-FLA target species landing flatfish as bycatch in FLA 7 are red cod, barracouta, gurnard, and tarakihi. The bycatch of FLA 7 in other QMS species has averaged 18% of the total 1989–90 to 2018–19 FLA 7 catch.

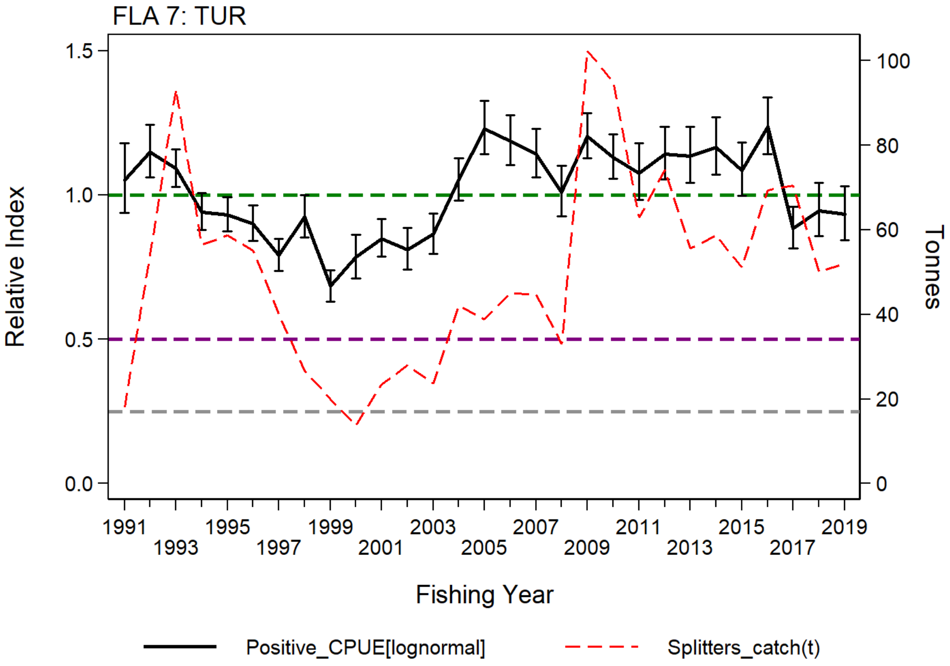
- **FLA 7: Turbot (TUR)**

Stock Structure Assumptions

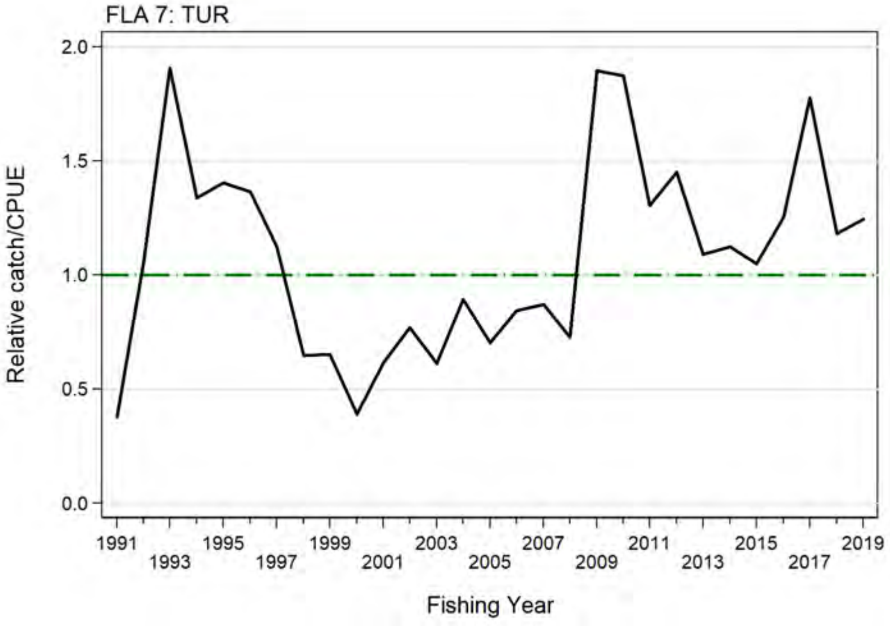
Turbot are mostly taken off the west coast South Island portion of FLA 7, where they appear to comprise a continuous population, and there is very little catch taken in Tasman Bay/Golden Bay. The CPUE analysis presented in the table below is based on catch and effort off the west coast (Statistical Areas 032, 033, 034, and 035).

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised lognormal bottom trawl CPUE for TUR in FLA 7, based on trips which landed FLA 7 but which did not use the FLA species code
Reference Points	Interim Target: B_{MSY} proxy based on mean standardised CPUE from 1990–91 to 2018–19 Soft Limit: 50% B_{MSY} proxy Hard Limit: 25% B_{MSY} proxy Overfishing threshold: F_{MSY} proxy based on mean relative exploitation rate for the period 1990–91 to 2018–19
Status in relation to Target	About as Likely as Not (40–60%) to be at or above target
Status in relation to Limits	Soft Limit: Very Unlikely (< 10%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	About as Likely as Not (40–60%) that overfishing is occurring

Historical Stock Status Trajectory and Current Status



Standardised indices based on lognormal CPUE series for Turbot (TUR), showing the agreed B_{MSY} proxy (green dashed line: average 1990–91 to 2018–19 CPUE index) and the associated Soft (purple dashed line) and Hard (grey dashed line) Limits (Starr & Kendrick 2022b). Also shown is the TUR estimated catch by trips that landed FLA 7 but which did not use the FLA code. Fishing year designated by second year of the pair.



Relative fishing intensity for TUR in FLA 7, based on the TUR 'splitter' catch and the standardised lognormal TUR CPUE series. The horizontal dashed green line corresponds to the mean fishing intensity of-r the period 1991–2019.

Fishery and Stock Trends

Recent Trend in Biomass or Proxy	CPUE has been relatively stable in this fishery, with a long period above the long-term average from 2004–05 to 2015–16; CPUE has dropped to below the long-term average after 2016–17.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has fluctuated, above the F_{MSY} proxy since 2007–08 and was just above the Fmsy proxy in 2018–19.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	About as Likely as Not (40–60%) to remain near target for current catch
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) for current catch Hard Limit: Very Unlikely (< 10%) for current catch
Probability of Current Catch or TACC causing Overfishing to continue or to commence	About as Likely as Not (40–60%) to remain near overfishing threshold for current catch

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches	
Assessment Dates	Latest assessment: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- uncertainty in stock structure assumptions	

Qualifying Comments
The lack of historic species-specific reporting for FLA stocks limits the ability to assess the long-term trends in these stocks; there is an expectation that the adoption of Electronic Reporting of catch will improve the reporting of species-specific estimated flatfish catch.

Fishery Interactions
The fishery is mainly confined to the inshore domestic trawl fleet except for a small incidental bycatch of soles, brill, and turbot by offshore trawlers. The main non-FLA target species landing flatfish as bycatch in FLA 7 are red cod, barracouta, gurnard, and tarakihi. The bycatch of FLA 7 in other QMS species has averaged 18% of the total 1989–90 to 2018–19 FLA 7 catch.

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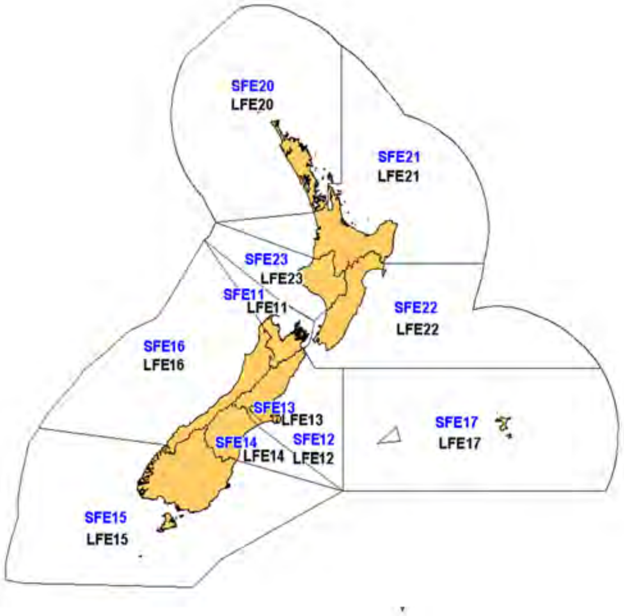
FRESHWATER EELS (SFE, LFE, ANG)

(Anguilla australis, Anguilla dieffenbachii, Anguilla reinhardtii)



1. FISHERY SUMMARY

1.1 Commercial fisheries

The freshwater eel fishery is distributed throughout accessible freshwaters (lakes, rivers, streams, farm ponds, tarns) and some estuarine and coastal waters of New Zealand, including the Chatham Islands. The contemporary commercial fishery dates from the mid-1960s when markets were established in Europe and Asia.

The New Zealand eel fishery is based on the two temperate species of freshwater eels occurring in New Zealand, the shortfin eel *Anguilla australis* and the longfin eel *A. dieffenbachii*. A third species of freshwater eel, the Australasian longfin (*A. reinhardtii*), identified in 1996, has been confirmed from North Island landings. The proportion of this species in landings is unknown but is thought to be small. Virtually all eels (98%) are caught with fyke nets. Eel catches are greatly influenced by water temperature, flood events (increased catches), and drought conditions (reduced catches). Catches decline in winter months (May to September), particularly in the South Island where fishing ceases.

The South Island eel fishery was introduced into the Quota Management System (QMS) on 1 October 2000 with shortfin and longfin species combined into six fish stocks (codes ANG 11 to ANG 16). The Chatham Island fishery was introduced into the QMS on 1 October 2003 with two fish stocks (shortfins and longfins separated into SFE 17 and LFE 17, respectively). The North Island eel fishery was introduced into the QMS on 1 October 2004 with eight fish stocks (four longfin stocks LFE 20–23 and four shortfin stocks SFE 20–23). On 1 October 2017 the former South Island ANG QMAs were split into corresponding longfin (LFE 11–16) and shortfin (SFE 11–16) QMAs, each with its own TACC. The Australasian longfin eel is combined as part of the shortfin eel stocks in the Chatham Islands and North Island, because this species has productivity characteristics closer to shortfins than longfins, and because the catch is not sufficient to justify its own separate stocks. The occasional catch of Australasian longfins is mainly confined to the upper North Island.

The fishing year for all stocks extends from 1 October to 30 September except for ANG 13 (Te Waihora/Lake Ellesmere) which has a fishing year from 1 February to 31 January (since 2002). Currently, there exist minimum and maximum commercial size limits for both longfins and shortfins (220 g and 4 kg, respectively) throughout New Zealand. North Island quota owners agreed in August

2012 to use 31 mm escapement tubes (equivalent to South Island regulation). The minimum legal diameter for escape tubes on the North Island was increased to 31 mm in October 2013. Quota owners from both islands formally agreed in 1995–96 not to land migratory female longfin eels. In the South Island the eel industry agreed to voluntary incremental increases in the diameter of escape tubes in fyke nets which increased from 25 mm to 26 mm in 1990–91, to 27 mm in 1993–94, to 28.5 mm in 1994–95, and finally to 31 mm in 1997–98, which effectively increases the minimum size limit of both main species to about 300 g. Since about 2006 there has been a voluntary code of practice to return all longfin eels caught in Te Waihora; catches of these longfins and all eels of legal size (220 g – 4 kg) were required to be recorded on Eel Catch Effort Returns (ECERs), and recorded under 'Destination X' on the Eel Catch Landing Returns (ECLRs). The introduction of the Electronic Reporting System (ERS) for the commercial eel fishery in late 2019 (replacing the ECER and ECLR) requires estimated weight of legal-size eels that are caught and released to be recorded on the Catch Record, and on the Disposal Report under disposal code 'X'.

In early 2005 the Mohaka, Motu, and much of the Whanganui river catchments were closed to commercial fishing and there are a number of smaller areas elsewhere that have been reserved as customary fisheries (see section 1.3). In addition, all Public Conservation lands managed by the Department of Conservation require at a minimum a concession to be commercially fished and most are closed to commercial fishing. In the Waikato-Tainui rohe (region), fisheries bylaws were introduced in March 2014 to limit the minimum harvest size to 300 g for SFE and 400 g for LFE. Amongst other things, these bylaws also introduced an upper limit of 2 kg for both species (to prevent the taking of longfin females that are in a migratory state) and added seasonal closures in some reaches.

Commercial catch data are available from 1965 and originate from different sources. Catch data prior to 1988 are for calendar years, whereas those from 1988 onwards are for fishing years (Table 1, Figure 1). Licensed Fish Receiver Returns (LFRRs), Quota Management Reports (QMRs), and Monthly Harvest Returns (MHRs) provide the most accurate data on landings over the period 1988–89 to 2020–21 for the whole of New Zealand.

Table 1: Eel catch data (t) for calendar years 1965 to 1988 and fishing years 1988–89 to present based on MAF Fisheries Statistics Unit (FSU) and Licensed Fish Receiver Returns (LFRR), Quota Management Reports (QMR), and Monthly Harvest Returns (MHR)*.

Year	Landings	Year	Landings	Year	Landings	Year	Landings
1965	30	1980	1 395	1994–95	1 438	2009–10	560
1966	50	1981	1 043	1995–96	1 429	2010–11	626
1967	140	1982	872	1996–97	1 342	2011–12	755
1968	320	1983	1 206	1997–98	1 210	2012–13	717
1969	450	1984	1 401	1998–99	1 219	2013–14	678
1970	880	1985	1 505	1999–00	1 133	2014–15	547
1971	1 450	1986	1 166	2000–01	1 071	2015–16	455
1972	2 077	1987	1 114	2001–02	978	2016–17	511
1973	1 310	1988	1 281	2002–03	808	2017–18	505
1974	860	1988–89	1 315	2003–04	729	2018–19	422
1975	1 185	1989–90	1 356	2004–05	708	2019–20	326
1976	1 501	1990–91	1 590	2005–06	771	2020–21	311
1977	906	1991–92	1 585	2006–07	718		
1978	1 583	1992–93	1 466	2007–08	660		
1979	1 640	1993–94	1 255	2008–09	518		

* MAF data, 1965–1982; FSU, 1983 to 1989–90; CELR, 1990–91 to 1999–2000; ECLR 2000–01 to 2003–04; MHR 2004–05–present.

There was a rapid increase in commercial catches during the late 1960s, with catches rising to a peak of 2077 t in 1972. Landings were relatively stable from 1983 to 2000, a period when access to the fishery was restricted, although overall catch limits were not in place. In 2000–01 landings dropped to 1070 t, and these reduced further during 2001–02 to 2004–05 as eel stocks were progressively introduced into the Quota Management System (QMS). Landings on the North Island were further constrained by the reduction in TACCs for both species introduced on 1 October 2007. Eel landings have remained below the TACCs as a result of reduced international market demand and deliberate decisions not to use ACE by some iwi, and from 2011–12 to 2019–20 have fluctuated around a declining trend from 755 t to 326 t. For the period 1991–92 to 2019–20, the North Island provided on average 60% of the total New Zealand eel catch, although 2019–20 provides the lowest percentage (Table 2).

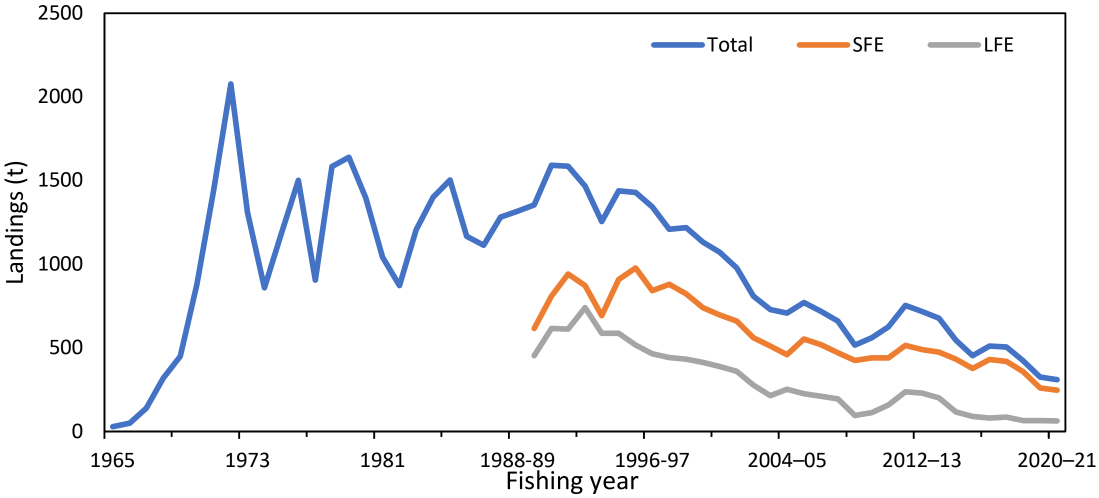


Figure 1: Total eel landings from 1965 to present, as well as separate shortfin and longfin landings from 1989–90 to present. Prior to 1988–89, the data points represent estimates for the period prior to the introduction of Eel Catch Landing Return (ECLR) forms and were generated by prorating the unidentified eel catch by the LFE:SFE ratio (see below).

Table 2: North Island and South Island eel catch (t) compiled from data from individual processors 1991–92 to 1999–00 and LFRR/QMR/MHR 2000–01 to present. Numbers in parentheses represent the percentage contribution from the North Island fishery.

Fishing year	North Island	South Island	Total individual processors	LFRR/QMR/MHR Total NZ (excluding Chatham Islands)
1991–92	989	631	1 621 (61%)	_
1992–93	865	597	1 462 (59%)	_
1993–94	744	589	1 334 (56%)	_
1994–95	1 004	510	1 515 (66%)	_
1995–96	962	459	1 481 (65%)	_
1996–97	830	418	1 249 (66%)	_
1997–98	795	358	1 153 (69%)	_
1998–99	804	381	1 185 (68%)	_
1999–00	723	396	1 119 (65%)	_
2000–01	768	303	_	1 071 (72%)
2001–02	644	319	_	962 (67%)
2002–03	507	296	_	803 (63%)
2003–04	454	282	_	737 (62%)
2004–05	426	285	_	712 (60%)
2005–06	497	285	_	781 (64%)
2006–07	440	278	_	718 (61%)
2007–08	372	288	_	660 (56%)
2008–09	303	215	_	517 (59%)
2009–10	318	242	_	560 (57%)
2010–11	330	296	_	626 (53%)
2011–12	418	337	_	755 (55%)
2012–13	364	353	–	717 (51%)
2013–14	367	311	–	678 (54%)
2014–15	306	241	–	547 (56%)
2015–16	254	201	–	455 (56%)
2016–17	297	214	–	511 (58%)
2017–18	296	209	–	505 (59%)
2018–19	269	155	–	424 (63%)
2019–20	156	170	–	326 (48%)
2020–21	179	132	–	311 (58%)

In 2016, South Island eel stocks (ANG 11–16) were separated into individual shortfin (SFE 11–16) and longfin (LFE 11–16) stocks. The new stocks utilise the same geographical areas as the pre-existing stocks (ANG 11–16) but were separated to allow species-specific management of the individual eel species. After the stocks were separated new catch limits and allowances were set. For the SFE stocks the new TACs were based on the highest historical catch, apart from SFE 13, which received a 10% increase because the CPUE index was well above the target. For LFE stocks, the TAC was reduced to a point that effectively eliminated commercial targeting (a TAC close to zero) for four of the six stocks (LFE 11, 12, 13, and 14). For the remaining two LFE stocks (LFE 15 and 16), TACs allow continued commercial utilisation, but at significantly reduced levels. The separated stocks and their associated catch limits and allowances came into force on 1 October 2016 for SFE/LFE 11, 12, 14, 15, and 16, and 1 Feb 2017 for SFE/LFE 2013.

Table 3: Total New Zealand eel landings (t) by species and fishing year. Numbers in parentheses represent the longfin proportion of total landings.

Fishing year	Shortfin (SFE)	Longfin (LFE)	Total landings
1989–90	617	453	1 069 (42%)
1990–91	808	616	1 424 (43%)
1991–92	941	612	1 553 (39%)
1992–93	872	741	1 613 (46%)
1993–94	692	588	1 279 (46%)
1994–95	909	588	1 497 (39%)
1995–96	977	518	1 495 (35%)
1996–97	841	465	1 307 (36%)
1997–98	881	442	1 323 (33%)
1998–99	824	434	1 258 (34%)
1999–00	741	413	1 154 (36%)
2000–01	698	388	1 086 (36%)
2001–02	660	360	1 020 (35%)
2002–03	560	279	839 (33%)
2003–04	510	216	726 (30%)
2004–05	460	254	713 (36%)
2005–06	553	226	774 (29%)
2006–07	520	210	730 (29%)
2007–08	470	196	666 (29%)
2008–09	424	95	519 (18%)
2009–10	441	114	555 (20%)
2010–11	440	159	599 (26%)
2011–12	515	237	752 (32%)
2012–13	491	230	721 (32%)
2013–14	475	201	676 (30%)
2014–15	434	116	550 (21%)
2015–16	378	89	467 (19%)
2016–17	431	81	511 (16%)
2017–18	418	87	505 (17%)
2018–19	357	66	424 (16%)
2019–20	261	65	326 (20%)
2020–21	247	64	311 (21%)

Prior to the 2000–01 fishing year, three species codes were used to record species landed, SFE (shortfin), LFE (longfin), and EEU (eels unidentified). A high proportion of eels (46% in 1990–91) were identified as EEU between the fishing years 1989–90 and 1998–99. Prorating the EEU catch by the ratio of LFE : SFE by fishing year provides a history of landings by species (Table 3), although it should be noted that prorated catches prior to 1999–2000 are influenced by the high proportion of EEU from some eel statistical areas (e.g., Waikato) and therefore may not provide an accurate species breakdown. The introduction of the new Eel Catch Landing Return (ECLR) form in 2001–02 improved the species composition information, because the EEU code was not included. There was a gradual decline in the proportion of longfin eels in landings, from over 40% in 1989–90 to about 30% in 2007–08, followed by a marked drop to 18% in 2008–09 (Table 3). The proportion of longfins in the catch then gradually increased and was about 30% of the total in 2013–14, before once again declining to 16% in 2016–17, then increasing to 20% by 2019–20. Several factors have contributed to the pattern in the proportion of longfin eels, including: declining abundance in the early part of the series; reduced quotas; the closure of some catchments to commercial fishing; and declining/fluctuating market demand.

Table 4: TACCs and commercial landings (t) for South Island eel stocks (based on ECLR data).

Fishing	ANG11		ANG12		ANG13		ANG14		ANG15		ANG16		Total
year	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	landings
Shortfin Eel (SFE)													
2000–01	40	4.5	43	4.4	122	102.2	35	6.1	118	19.4	63	9.8	146.6
2001–02	40	18.9	43	5.7	122	63.6*	35	10.1	118	20.2	63	20.2	83.8
2002–03	40	19.2	43	5.9	122	95.4	35	9.9	118	11.7	63	4.5	146.7
2003–04	40	8.7	43	4.8	122	118.2	35	7.5	118	13.0	63	9.4	161.8
2004–05	40	2.7	43	1.4	122	121.3	35	5.7	118	1.5	63	9.6	156.0
2005–06	40	9.0	43	4.3	122	119.9	35	7.4	118	12.0	63	11.2	164.0
2006–07	40	10.9	43	6.3	122	121.5	35	4.4	118	15.4	63	16.5	175.2
2007–08	40	8.5	43	1.2	122	119.7	35	5.8	118	21.2	63	11.5	167.9
2008–09	40	4.7	43	< 1	122	123.0	35	1.8	118	16.6	63	19.7	166.0
2009–10	40	3.8	43	5.8	122	97.3	35	3.9	118	29.1	63	30.3	170.2
2010–11	40	10.0	43	6.9	122	89.3	35	3.7	118	19.4	63	19.9	149.2
2011–12	40	8.8	43	10.8	122	113.3	35	7.3	118	21.4	63	13.1	174.8
2012–13	40	7.6	43	19.9	122	125.0	35	2.6	118	16.7	63	22.8	194.6
2013–14	40	3.4	43	16.5	122	119.3	35	2.5	118	11.7	63	16.8	170.2
2014–15	40	2.8	43	13.6	122	112.1	35	1.3	118	14.4	63	11.8	156.0
2015–16	40	< 1.0	43	0	122	109.9	35	< 1.0	118	22.7	63	10.2	144.4
New FMA	**SFE11**		**SFE 12**		**SFE 13**		**SFE 14**		**SFE 15**		**SFE 16**		**Total**
2016–17	19	0	20	0.2	134.1	132.8	10	0	29	20.7	30	12.97	166.7
2017–18	19	6.2	20	2.7	134.1	130.3	10	1.0	29	15.1	30	5.9	161.2
2018–19	19	4.1	20	4.2	134.1	81.6	10	0.2	29	12.3	30	8.5	110.9
2019–20	19	0	20	< 0.1	134.1	96.0	10	0.3	29	18.9	30	9.5	124.8
2020–21	19	0	20	2.2	134.1	65.9	10	2.1	29	11.3	30	3.9	85.5
Longfin Eel (LFE)													
2000–01	40	10.6	43	22.6	122	2.1	35	12.6	118	63.6	63	28.4	140.1
2001–02	40	16.4	43	15.6	122	1.0*	35	6.0	118	80.5	63	30.2	150.1
2002–03	40	10.6	43	10.1	122	1.4	35	10.0	118	73.0	63	27.2	132.6
2003–04	40	2.8	43	2.7	122	< 1.0	35	10.2	118	64.7	63	21.2	102.9
2004–05	40	2.8	43	3.4	122	< 1.0	35	2.3	118	79.6	63	34.4	123.7
2005–06	40	6.0	43	9.8	122	< 1.0	35	6.4	118	61.1	63	21.1	105.5
2006–07	40	4.4	43	1.7	122	<1.0	35	7.0	118	65.0	63	32.8	112.1
2007–08	40	11.9	43	6.5	122	< 1.0	35	7.4	118	73.0	63	23.1	122.9
2008–09	40	1.4	43	< 1.0	122	0	35	2.3	118	33.7	63	13.2	51.0
2009–10	40	8.0	43	< 1.0	122	< 1.0	35	3.2	118	40.0	63	15.3	68.0
2010–11	40	13.1	43	6.1	122	< 1.0	35	6.7	118	73.9	63	14.1	114.9
2011–12	40	11.2	43	11.0	122	2.0	35	18.4	118	85.4	63	27.6	155.7
2012–13	40	15.6	43	7.6	122	< 1.0	35	22.3	118	88.6	63	30.4	164.5
2013–14	40	14.0	43	6.1	122	< 1.0	35	10.7	118	77.9	63	29.3	138.5
2014–15	40	2.5	43	3.7	122	0	35	2.1	118	56.3	63	15.3	79.9
2015–16	40	< 1.0	43	0	122	0	35	4.5	118	43.0	63	10.5	59.0
New FMA	**LFE11**		**LFE 12**		**LFE 13**		**LFE 14**		**LFE 15**		**LFE 16**		**Total**
2016–17	1	0	1	< 1.0	1	0	1	0	52	33.4	25	14.1	47.5
2017–18	1	0	1	0.3	1	0.5	1	0.5	52	36.2	25	10.1	47.6
2018–19	1	0	1	0.2	1	0	1	0	52	34.2	25	9.5	43.9
2019–20	1	0	1	0.2	1	0	1	0	52	36.9	25	7.9	45.0
2020–21	1	0	1	0.4	1	0	1	0.2	52	38.2	25	7.3	46.2

*For the transition from a 1 October to 1 February fishing year, an interim TACC of 78 t was set for the period 1 October 2001 to 31 January 2002. From January 2002 the Te Waihora (Lake Ellesmere) fishing year was 1 February to 31 January. Fishing year for all other areas is 1 October to 30 September.

The species proportion of the landings varies by geographical area. From analyses of landings to eel processing factories and estimated catch from ECLRs, longfins are the dominant species in most areas of the South Island, except for a few discrete locations such as lakes Te Waihora (Ellesmere) and Brunner, and the Waipori Lakes, where shortfins dominate landings. Shortfins are dominant in North Island landings. The shortfin eel catches mostly comprise pre-migratory female feeding eels, with the exception of Te Waihora (Lake Ellesmere), where significant quantities of seaward migrating male shortfin eels (under 220 g) are taken during February to March.

Table 5: TACCs and commercial landings (t) for Chatham Island (SFE 17) and North Island shortfin stocks from 2003–04 to present (based on ECLR data).

Fishing	SFE 17		SFE 20		SFE 21		SFE 22		SFE 23		Total
year	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	landings
2003–04	10	0.7	–	–	–	–	–	–	–	–	0.7
2004–05	10	1.3	149	78.4	163	123.0	108	80.5	37	15.0	298.1
2005–06	10	2.7	149	93.3	163	144.3	108	106.9	37	31.5	378.6
2006–07	10	0.0	149	107.8	163	113.5	108	91.3	37	30.2	342.8
2007–08	10	0.0	86	76.0	134	125.3	94	82.5	23	15.8	299.5
2008–09	10	0.0	86	66.8	134	110.0	94	70.9	23	10.3	258.0
2009–10	10	0.0	86	60.2	134	124.1	94	68.5	23	17.5	270.3
2010–11	10	0.0	86	85.5	134	133.9	94	58.8	23	16.1	294.3
2011–12	10	0.0	86	85.6	134	140.9	94	95.7	23	18.8	341.0
2012–13	10	0.0	86	78.8	134	124.3	94	82.0	23	14.7	299.8
2013–14	10	0.0	86	71.6	134	139.2	94	82.1	23	14.5	307.4
2014–15	10	0.0	86	63.8	134	122.8	94	73.3	23	13.7	273.6
2015–16	10	0.0	86	53.8	134	119.1	94	49.2	23	10.4	232.5
2016–17	10	0.0	86	46.2	134	123.4	94	81.3	23	13.0	263.9
2017–18	10	0.0	86	59.6	134	120.3	94	67.1	23	10.0	257.1
2018–19	10	0.0	86	61.3	134	108.5	94	68.3	23	8.3	246.4
2019–20	10	0.0	86	34.0	134	55.3	94	41.7	23	4.9	135.93
2020–21	10	0.0	86	45.4	134	69.7	94	38.1	23	8.0	161.1

Table 6: TACCs and commercial landings (t) for Chatham Island (LFE 17) and North Island longfin stocks from 2003–04 to present (based on ECLR data).

Fishing	LFE 17		LFE 20		LFE 21		LFE 22		LFE 23		Total
Year	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	landings
2003–04	1	< 1	–	–	–	–	–	–	–	–	0.2
2004–05	1	< 1	47	27.4	64	53.5	41	23.9	41	24.5	129.3
2005–06	1	< 1	47	23.7	64	41.2	41	31.6	41	24.2	120.8
2006–07	1	0	47	27.2	64	29.8	41	25.9	41	14.5	97.4
2007–08	1	0	19	17.5	32	31.0	21	17.7	9	6.5	72.8
2008–09	1	0	19	11.5	32	22.7	21	7.7	9	2.5	44.4
2009–10	1	< 1	19	9.6	32	21.6	21	10.6	9	5.8	47.6
2010–11	1	< 1	19	10.2	32	13.7	21	5.7	9	6.2	35.8
2011–12	1	< 1	19	19.9	32	32.0	21	18.6	9	6.7	77.3
2012–13	1	< 1	19	18.3	32	25.1	21	15.1	9	5.6	64.1
2013–14	1	0	19	14.7	32	25.9	21	14.7	9	4.4	59.7
2014–15	1	0	19	10.1	32	9.9	21	12.0	9	3.3	35.3
2015–16	1	< 1	19	6.5	32	9.4	21	4.1	9	1.5	21.5
2016–17	1	0	19	8.0	32	13.9	21	7.4	9	3.9	33.2
2017–18	1	0	19	13.1	32	12.2	21	9.5	9	4.5	39.3
2018–19	1	0	14	5.8	23	11.8	13	4.8	5	0.3	22.3
2019–20	1	0	14	5.9	23	10.8	13	3.1	5	0.3	20.0
2020–21	1	0	14	4.8	23	8.9	13	3.9	5	0.6	18.2

The Total Allowable Commercial Catch (TACC) and reported commercial landings by species for the South Island eel stocks are shown in Table 4 from 2000–01 (when eels were first introduced into the QMS) to 2018–19. The annual landings are based on data recorded on ECLR forms, because the MHR forms report QMA catches for the two species combined.

The TACCs and commercial landings for the Chatham Island and North Island shortfin and longfin eel stocks are shown in Tables 5 and 6. The Chatham Island and North Island fisheries were first introduced into the QMS in 2003–04 and 2004–05, respectively. Note that from 1 October 2007 the TACCs were markedly reduced for all North Island shortfin and longfin stocks.

1.2 Recreational fisheries

In October 1994, a recreational individual daily bag limit of six eels was introduced throughout New Zealand. There is no quantitative information on the recreational harvest of freshwater eels. The recreational fishery for eels includes any eels taken by people fishing under the amateur fishing regulations and includes any harvest by Māori not taken under customary provisions. The extent of the recreational fishery is not known although the harvest by Māori might be significant.

1.3 Customary non-commercial fisheries

Eels are an important customary food source for Māori. Māori developed effective methods of harvesting and hold a good understanding of the habits and life history of eels. Fishing methods included ahuriri (eel weirs), hīnaki (eel pots), and other methods of capture. Māori exercised conservation and management methods, which included seeding areas with juvenile eels and imposing restrictions on harvest times and methods. The customary fishery declined after the 1900s but in most areas tangata whenua retain strong traditional ties to eels and their management and harvest.

In the South Island, Lake Forsyth (Waiwera) and its tributaries have been set aside exclusively for Ngai Tahu. Other areas, such as the lower Pelorus River, Horomaka Kohanga (Te Waihora), Wainono Lagoon and its catchment, the Waihao catchment, the Rangitata Lagoon, and the Ahuriri Arm of Lake Benmore, have been set aside as non-commercial areas for customary fisheries. Mātaitai reserves covering freshwater have been established in the South Island on the Mataura River, Okarito Lagoon, Waihao River (including Wainono Lagoon and parts of Waituna Stream and Hook River), Lake Forsyth, Waikawa River, Waikouaiti River, Opihi River, Washdyke Lagoon, Kahutara River, Oaro River and the Conway River. Commercial fishing is generally prohibited in mātaitai reserves. In the North Island, commercial fishing has been prohibited from the Taharoa lakes, Whakaki Lagoon, Lake Poukawa, and the Pencarrow lakes (Kohangapiripiri and Kohangatera) and associated catchments.

Customary non-commercial fishers desire eels of a greater size, i.e., over 750 mm and 1 kg. Currently, there appears to be a substantially lower number of larger eels in the main stems of some major river catchments throughout New Zealand, which may limit customary fishing. Consequently the availability of eels for customary non-commercial purposes has declined over recent decades in many areas. There is no overall assessment of the extent of the current or past customary non-commercial take. For the introduction of the South Island eel fishery into the QMS, an allowance was made for customary non-commercial harvest. It was set at 20% of the TAC for each QMA, equating to 107 t (Table 7). For the introduction of the North Island fishery into the QMS, the customary non-commercial allowance was set at 74 t for shortfins and 46 t for longfins (Tables 8 and 9). For the Chatham Islands, the customary non-commercial allowance was 3 t for shortfin and 1 t for longfin eels (Tables 8 and 9).

Table 7: TACs, TACCs, and customary non-commercial and recreational allowances (t) for South Island eel stocks. Note that an allowance for other sources of fishing-related mortality has not been set. [Continued on next page]

	LFE 11 Nelson/ Marlborough	LFE 12 North Canterbury	LFE 13 Te Waihora Lake Ellesmere	LFE 14 South Canterbury	LFE 15 Otago/ Southland	LFE 16 West Coast
2016 TAC	3	3	3	3	66.54	32.41
TACC	1	1	1	1	52.00	25.00
Customary Non-Commercial Allowance	1	1	1	1	13.27	6.41
Recreational Allowance	1	1	1	1	1.27	1.00

Table 7 [continued]

	SFE 11	SFE 12	SFE 13	SFE 14	SFE 15	SFE 16
2016 TAC	24.87	26.1	171.94	13.57	37.42	38.69
TACC	19.0	20.0	134.12	10.00	29.00	30.00
Customary Non-Commercial Allowance	4.87	5.1	34.38	2.57	7.42	7.69
Recreational Allowance	1.0	1.0	3.44	1.00	1.00	1.00

Eels may be harvested for customary non-commercial purposes only under regulations made under section 186 of the Fisheries Act 1996. The majority of the South Island customary harvest comes from QMAs ANG 12 (North Canterbury) and ANG 13 (Te Waihora/Lake Ellesmere).

Table 8: TACs and customary non-commercial, recreational, and other fishing-related mortality allowances (t) for the Chatham Island and North Island shortfin stocks.

	SFE 17	SFE 20	SFE 21	SFE 22	SFE 23
TAC	15	148	181	121	36
Customary Non-Commercial Allowance	3	30	24	14	6
Recreational Allowance	1	28	19	11	5
Other fishing-related mortality	1	4	4	2	2

Table 9: TACs and customary non-commercial, recreational, and other mortality allowances (t) for the Chatham Island and North Island longfin eel fisheries.

	LFE 17	LFE 20	LFE 21	LFE 22	LFE 23
TAC	3	34	51	26	30
Customary Non-Commercial Allowance	1	10	16	6	14
Recreational Allowance	1	8	10	5	9
Other fishing-related mortality	0	2	2	2	2

1.4 Illegal catch

No reliable estimates of illegal catch are available. There is some evidence of fishers exceeding the amateur bag limit, and some historical incidences of commercial fishers operating outside the reporting regime, but overall the extent of any current illegal take is not considered to be significant.

1.5 Other sources of mortality

Although there is no information on the level of fishing-related mortality associated with the eel fishery (i.e., how many eels die while in the nets), it is not considered to be significant given that the fishing methods used are passive and catch eels in a live state.

Eels are subject to significant sources of mortality from non-fishing activities, although this has not been quantified. Direct mortality occurs through the mechanical clearance of drainage channels, and damage by hydro-electric turbines and flood control pumping (Beentjes et al 2005). Survival of eels through hydroelectric turbines is affected by eel length, turbine type, and turbine rotation speed. The mortality of larger eels (specifically longfin females) is estimated to be 100%. Given the large number of eels in hydro lakes, this source of mortality could be significant and reduce spawner escapement from New Zealand. Mitigation activities such as trap and transfer of downstream migrants, installation of downstream bypasses, and spillway opening during runs are expected to have reduced this impact at those sites where such measures have been implemented. In addition to these direct sources of mortality, eel populations are likely to have been significantly reduced since European settlement from the 1840s by wetland drainage (wetland areas have been reduced by up to 90% in some areas), and ongoing habitat modification brought about by irrigation, channelisation of rivers and streams, and the reduction in littoral habitat. Ongoing drain maintenance activities by mechanical means to remove weeds may cause direct mortality to eels through physical damage or by stranding and subsequent desiccation.

2. BIOLOGY

Species and general life history

There are 16 species of freshwater eel worldwide, with the majority of species occurring in the Indo-Pacific region. New Zealand freshwater eels are regarded as temperate species, similar to the Northern

Hemisphere temperate species, the European eel *A. anguilla*, the North American eel *A. rostrata,* and the Japanese eel *A. japonica*. Freshwater eels have a life history unique among fishes that inhabit New Zealand waters. All *Anguilla* species are facultative catadromous, living predominantly in freshwater, and undertaking a spawning migration to an oceanic spawning ground. They spawn once and then die (i.e., are semelparous). The major part of the life cycle is spent in freshwater or estuarine/coastal habitat. Spawning of New Zealand species is presumed to take place in the southwest Pacific. Progeny undertake a long oceanic migration to freshwater where they grow to maturity before migrating to the oceanic spawning grounds. The average larval life is 6 months for shortfins and 8 months for longfins.

The longfin eel is endemic to New Zealand and is thought to spawn east of Tonga. The shortfin eel is also found in South Australia, Tasmania, and New Caledonia; spawning is thought to occur northeast of Samoa. Larvae (leptocephali) are transported to New Zealand largely passively on oceanic surface currents, and the metamorphosed juveniles (glass eels) enter freshwater from August to November. The subsequent upstream migration of elvers (pigmented juvenile eels) in summer distributes eels throughout the freshwater habitat. The two species occur in abundance throughout New Zealand and have overlapping habitat preferences with shortfins predominant in lowland lakes and slow moving, soft bottom rivers and streams, whereas longfins prefer fast flowing stony rivers and are dominant in high country lakes.

Growth

Age and growth of New Zealand freshwater eels was reviewed by Horn (1996). Growth in freshwater is highly variable and dependent on food availability, water temperature, and eel density. Eels, particularly longfins, are generally long lived. Maximum recorded age is 60 years for shortfins and 106 years for longfins. Ageing has been validated (e.g., Chisnall & Kalish 1993). Growth rates determined from the commercial catch sampling programme (1995–97) indicate that in both the North Island and South Island, growth rates are highly variable within and between catchments. Shortfins often grow considerably faster than longfins from the same location, although in the North Island longfins grow faster than shortfins in some areas (e.g., parts of the Waikato catchment). South Island shortfins take, on average, 12.8 years (range 8.1–24.4 years) to reach 220 grams (minimum legal size) compared with 17.5 years (range 12.2–28.7 years) for longfins, whereas in the North Island the equivalent times are 5.8 years (range 3–14.1 years) and 8.7 years (range 4.6–14.9 years) respectively. Australasian longfin growth is generally greater than that of New Zealand longfins, and closer to that of shortfins.

Growth rates (in length) are usually linear. Sexing immature eels is difficult, but from length-at-age data for migratory eels, there appears to be little difference in growth rate between the sexes. Sex determination in eels appears to be influenced by environmental factors and by eel density, with female eels being more dominant at lower densities. Age at migration may vary considerably between areas depending on growth rate. Males of both species mature and migrate at a smaller size than females. Migration appears to be dependent on attaining a certain length/weight combination and condition. The range in recorded age and length at migration for shortfin males is 5–22 years and 40–48 cm, and for females 9–41 years and 64–80 cm. For longfin eels the range in recorded age and length at migration is 11–34 years and 48–74 cm for males, and 27–61 years and 75–158 cm for females. However, because of the variable growth rates, eels of both sexes and species may migrate at younger or older ages.

Recruitment

The most sensitive measure of recruitment is monitoring of glass eels, the stage of arrival from the sea. In the Northern Hemisphere where glass eel fisheries exist, catch records provide a long-term time series that is used to monitor eel recruitment. In the absence of such fisheries in New Zealand, MPI took the unique opportunity that exists to monitor the relative abundance of elvers arriving at large in-stream barriers, where established elver trap and transfer programmes operate. Provided that the data are collected in a consistent manner every year, these data can be used to provide an index of eel recruitment into New Zealand’s freshwaters.

Although New Zealand has a small dataset of elver catch data compared with Asian, European, and North American recruitment records, including the 2020–21 season, there are now up to 26 years of reliable and accurate elver catch information for some sites (Crow et al 2020). These records show that the magnitude of the elver catch varies markedly between sites and that there are large variations in catches between seasons at all the sites (Table 10a). Although the majority of this variability is likely to be caused by natural oceanic and climatic influences, some is due to changes in fishing effort, technological advances, and recording procedures. These changes in fishing effort and capture efficiency through time have meant that a number of existing records needed to be excluded from recruitment trend analyses.

Because of the variability between sites and years, elver catch records were normalised following the method of Durif et al (2008), and a 'normal'catch index was calculated for each species, season, and location. The normalised catch index (Xij) is calculated as follows:

$$X_{i,j} = (x_{i,j} - \mu_j)/\sigma_j$$

Where:

$x_{i,j}$ = elver catch for a season
μ_j = mean elver catch at a site for all seasons
σ_j = standard deviation of elver catch at a site for all seasons.

Variation in the distance of dam sites from the sea and possibly differences in migration rates and growth rate between rivers has resulted in some variability in the size (age) structure of elvers captured at the monitored sites. Consequently the median ages of elvers at key sites were determined from examination of otoliths extracted from elvers randomly captured throughout the 2013–14 to 2017–18 seasons (Table 10b). The median ages were then used to adjust the normalised catch index by the median elver age so that it reflected the relative recruitment of glass eels (0 yrs old) into each catchment (Recruitment Index hereafter).

Elver catches in New Zealand were highly variable within sites between seasons (years), which makes assessing trends difficult. A good example of this variability can be seen at Matahina. where catch differed by a magnitude of up to 54-fold over three seasons (Table 10a). At present, there is no estimate of variability associated with the total elver catch estimate, but this is presently being developed and will be available in the next elver recruitment report. Error estimates will aid in future interpretations of trends in Catch Indices.

Assessment of Catch Index trends within each site showed one increasing but variable trend in longfin catch (Piripaua Dam), two increasing but variable trends in shortfin catch (Karapiro and Piripaua Dam), one decreasing but variable trend in shortfin catch (Patea), and no decreasing trends were observed for longfins (Figures 2 & 3). All these trends were subtle and were generally overshadowed by the catch variability between season. Moreover, the absence of any estimate of error for annual estimates makes interpretation of trends extremely difficult. The strongest trend was the increasing shortfin catches observed at Karapiro because this is the longest time series available. Interestingly, Matahina has a time series that covers a similar time period to Karapiro, but there were no trends evident for either species. The Piripaua Dam is the only site where Catch Indices may be increasing for both species. This increase is mainly associated with high catches seen after the 2011–12 season, with catches before this period being consistently low. The declining trend in shortfin catches for the Patea Dam is weak and, since the lowest catch ever recorded in 2011–12, the catches have been consistently increasing.

Combined Recruitment Indices among all sites and all seasons suggest that shortfin and longfin recruitment is variable within, and between sites, but has remained stable with a large degree of interannual variability (Figure 3 and Figure 4). Stable longfin elver catches are consistent with the findings by Crow et al (2016) who suggested longfin catch rates in the data stored in the New Zealand Freshwater Fish Database were stable. Crow et al (2016) also suggested shortfin catch rates were increasing; this is not reflected in the stable but variable trend seen for shortfin elver catches.

Spawning

Because eels are harvested before spawning, the escapement of sufficient numbers of eels to maintain a spawning population is essential to maintain recruitment. For shortfin eels the wider geographic distribution for this species (Australia, New Zealand, southwest Pacific) means that spawning escapement occurs from a range of locations throughout its range. In contrast, the more limited distribution of longfin eels (New Zealand and offshore islands) means that the spawning escapement must occur from New Zealand freshwaters and offshore islands.

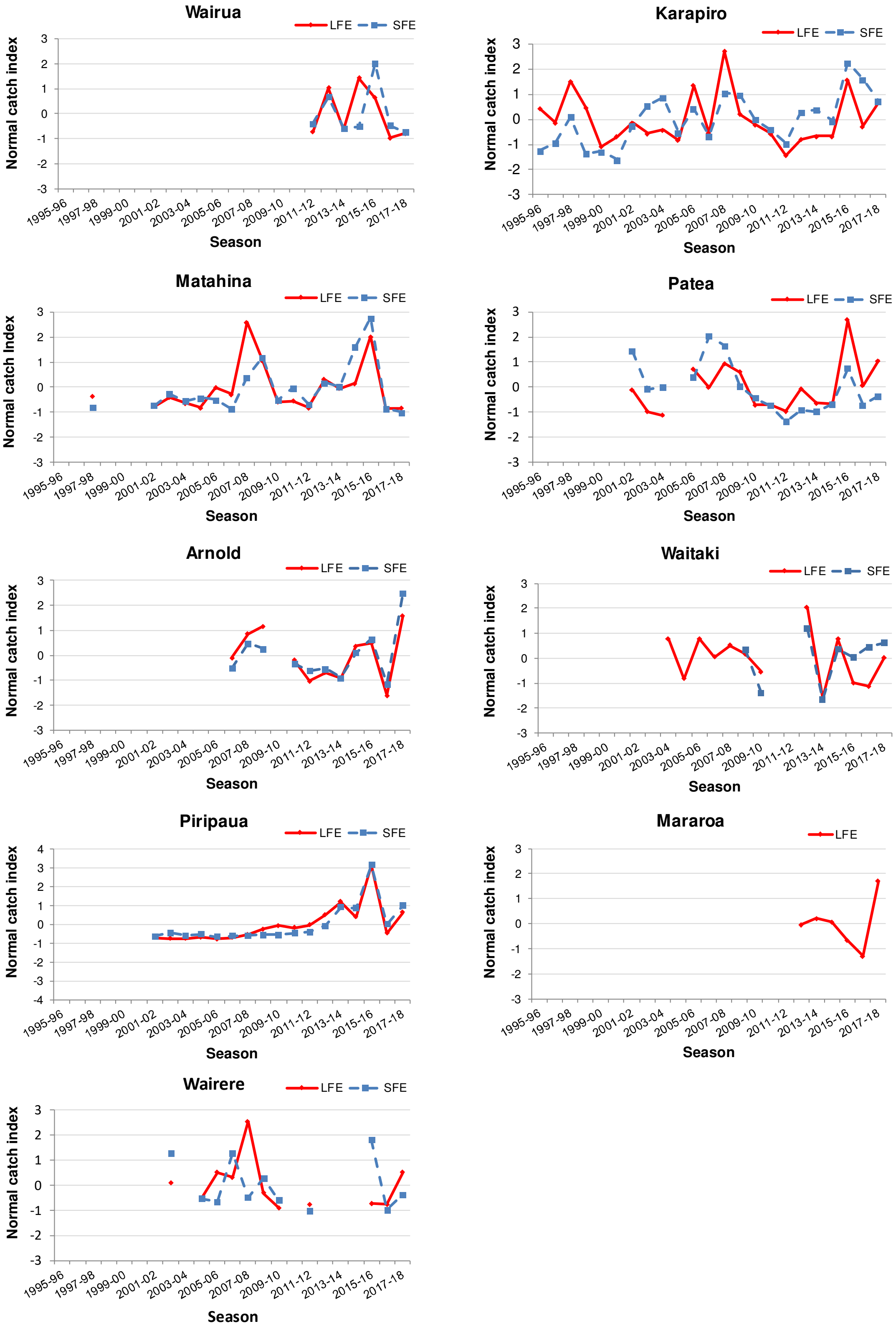


Figure 2: Normal catch index for longfin (LFE) and shortfin (SFE) elvers at monitored sites from 1995–96 to 2017–18. (Notes: incomplete records for season have been omitted; 0 = mean index for entire monitoring period for each site; few shortfins recorded at Mararoa Weir). Mararoa has inconsistent fishing effort so the trend shown may reflect increased trapping efficiency rather than increased recruitment.

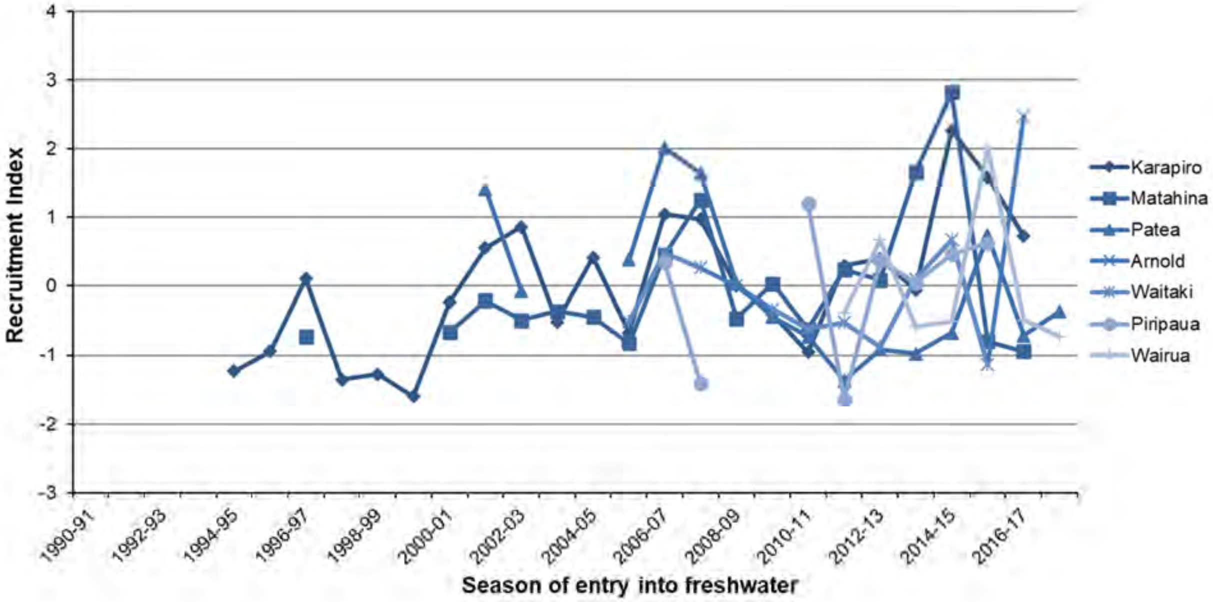


Figure 3: Recruitment Indices (i.e., Normalised Catch Indices offset by median age) by season for shortfin elvers. Plots are for all primary sites as well as Piripaua. A value of 0 indicates the mean catch for each site.

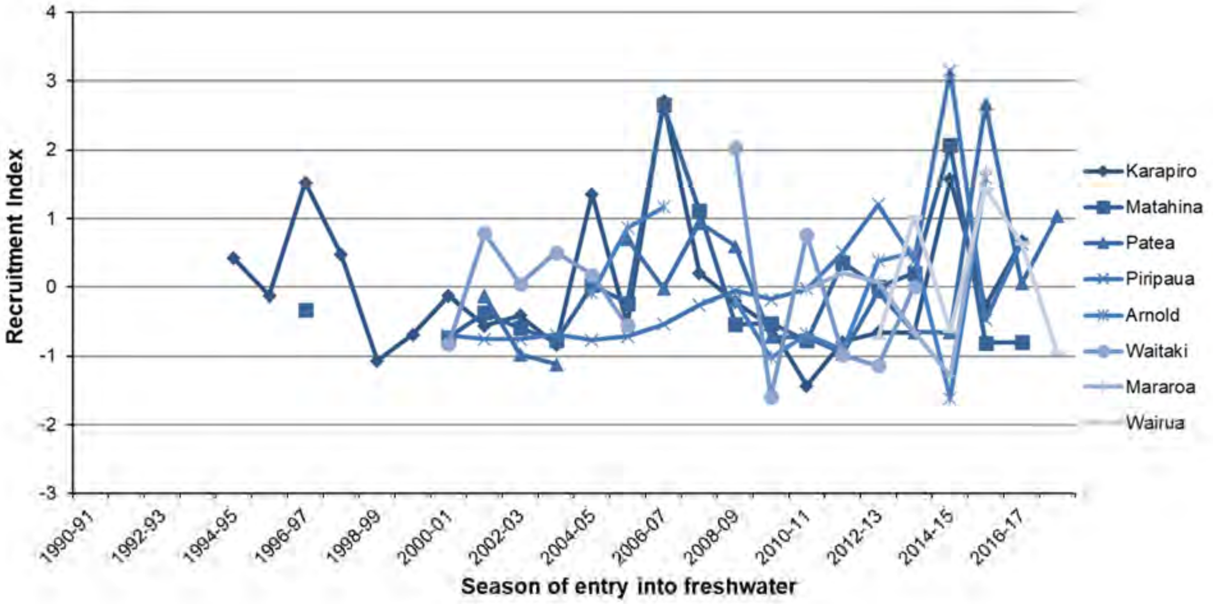


Figure 4: Recruitment Indices (i.e., Normalised Catch Indices offset by median age) for longfin elvers. A value of 0 indicates the mean catch for each site.

Table 10a: Estimated numbers (1000s) of all elvers and, in parentheses, longfins only; trapped at key elver trap and transfer monitoring sites by season (Dec–Apr) 1992–93 to 2017–18. Shaded cells indicate seasons when the records are considered unsuitable for trend analysis (monitoring disruption, flood damage, etc.). N/A = no species composition (from Martin et al 2016 and NIWA unpublished records.) Estimated total number (in 1000s) of shortfin and longfin elvers (in parentheses) captured at the primary (*) and secondary sites from the 1992–93 to 2017–18 recruitment seasons (Dec-Apr). Unreliable annual records for individual sites are shaded (NA=no species composition) (from Crow et al 2020).

					Site					
Season	Wairua*	Karapiro*	Matahina*	Wairere	Patea*	Piripaua	Arnold*	Waitaki*	Roxburgh	Mararoa
1992–93		92	> 32							
		(31)	(> 2)							
1993–94		518	> 215							
		(176)	(NA)							
1994–95		282	> 39							
		(96)	(NA)							
1995–96		1 155	> 144							
		(333)	(NA)							
1996–97		1 220	14			2.1			0.3	
		(246)	(4)			(1)				
1997–98		2 040	615			7.3			11	
		(510)	(136)			(NA)				
1998–99		1 097	1 002			3.1			7.4	43
		(341)	(NA)			(0.4)				(43)
1999–00		892	2 001	166	461	2.6				90
		(94)	(NA)	(NA)	(NA)	(<0.1)				(90)
2000–01		782	2 054	191	495	6				28
		(155)	(NA)	(NA)	(NA)	(0.2)				(28)
2001–02		1 596	619	130	754	4.1			1	NA
		(246)	(27)	(NA)	(48)	(0.4)				
2002–03		1 942	1 484	289	380	10.2		< 0.1	0.1	36
		(176)	(124)	(22)	(8)	(0.2)		(< 0.1)		(36)
2003–04		2 131	945	330	391	4.9		4.6	1.4	98
		(200)	(64)	(NA)	(1)	(0.2)		(4.6)		(98)
2004–05		1 333	1 117	155	450	8.1	27	1.5		64
		(132)	(15)	(13)	(NA)	(0.5)	(7)	(1.5)		(64)
2005–06		2 178	1 193	163	562	2.8	14	4.7		46
		(483)	(228)	(28)	(87)	(0.1)	(8)	(4.7)		(46)
2006–07		1 296	485	294	896	4.2	107	3.3		118
		(179)	(159)	(25)	(53)	(0.3)	(52)	(3.3)		(118)
2007–08		2 728	3 378	204	857	5.7	186	4.1		133
		(701)	(928)	(57)	(98)	(1.1	(78)	(4.1)		(133)
2008–09		2 288	4 307	216	480	9.5	183	4.7		81
		(298)	(517)	(16)	(82)	(2.2)	(87)	(3.5)		(81)
2009–10		1 708	1 002	146	309	10.3	20	2.4		71
		(232)	(78)	(7)	(20)	(2.9)	(5)	(2.1)		(71)
2010–11		1 434	1 841	227	247	11.8	114	2.9		198
		(175)	(84)	(NA)	(20)	(2.5)	(49)	(2.4)		(198)
2011–12	3 178	1 003	641	119	72	15.6	76	7	NA	266
	(11)	(36)	(15)	(0.5)	(6.8)	(3.1)	(26)	(5.8)	(NA)	(266)
2012–13	5 488	1 771	2 421	182	74	33	90	8.9	14	128
	(98)	(139)	(317)	(NA)	(16)	(5.2)	(36)	(7.1)	(14)	(128)
2013–14	2 780	1 843	2 068	193.1	193.2	68.7	65.3	0.2	0.8	150.4
	(16.2)	(160)	(220)	(NA)	(23.5)	(7.9)	(29.4)	(0.1)	(0.8)	(150.4)
2014–15	3 010	1 604	4 736	241.9	260.6	61.2	152.5	6.0	1.3	135.6
	(118)	(160)	(275)	(NA)	(23.1)	(4.7)	(65)	(4.6)	(1.3)	(135.5)
2015–16	8 279	3 191	7 184	315	735	160.4	186	2.4	1.4	88
	(79)	(517)	(771)	(10)	(180)	(15.6)	(69)	(1.3)	(1.4)	(86)
2016–17	2 947	2 534	376	123	286	28.8	32	2.3	Nil	41.0
	(0)	(221)	(6)	(10)	(56)	(1.3)	(10)	(1.0)		(41)
2017–18	2 446	2 229	133	183	411	69.9	311	4.6	8.7	268
	(8)	(373)	(8)	(28)	(103)	(5.7)	(98)	(3.2)	(8.7)	(248)

Table 10b: Median ages of elvers used to calculate the Recruitment Index.

Site	Species	Median age (years)
Wairua	shortfin	0+
	longfin	0+
Karāpiro	shortfin	1
	longfin	1
Matahina	shortfin	1
	longfin	1
Patea	shortfin	0+
	longfin	0+
Piripaua	shortfin	1
	longfin	2
Arnold	shortfin	1
	longfin	2
Waitaki	shortfin	2
	longfin	4
Mararoa	longfin	2

3. STOCKS AND AREAS

The lifecycle of each species has not been completely resolved but evidence supports the proposition of a single (panmictic) stock for each species. Biochemical evidence suggests that shortfins found in both New Zealand and Australia form a single biological stock. Longfins are endemic to New Zealand and are assumed to be a single biological stock.

Within a catchment, post-elver eels generally undergo limited movement until their seaward spawning migration. Therefore once glass eels have entered a catchment, each catchment effectively contains a separate population of each eel species. The quota management areas mostly reflect a combination of these catchment areas.

Shortfin and longfin eels have different biological characteristics in terms of diet, growth, maximum size, age of maturity, reproductive capacity, and behavioural ecology. These differences affect the productivity of each species, and the level of yield that may be sustainable on a longer term basis, as well as their interactions with other species. In order that catch levels for each species are sustainable in the longer term, and the level of removals does not adversely affect the productivity of each species, it is appropriate that the level of removals of each species is effectively managed.

4. STOCK ASSESSMENT

There is no formal stock assessment available for freshwater eels. Fu et al (2012) developed a length-structured longfin population model that generated New Zealand-wide estimates of the pre-exploitation female spawning stock biomass (approximately 1700 t) as well as the pre-exploitation biomass of legal-sized eels (16 000 t in all fished areas and 6000 t in protected areas). By contrast, the model estimated current female spawning stock biomass to be approximately 55% of pre-exploitation levels, whereas the current biomass of legal-size eels ranged from 20% to 90% of the pre-exploitation level for the fished areas. However, the Working Group did not accept the assessment and noted that further analyses were necessary to investigate the models underlying assumptions; given that the results were strongly driven by estimates of longfin commercial catches from individual eel statistical areas as well as GIS-based estimates of recruitment.

4.1 Size/age composition of commercial catch

Catch sampling programmes sampled commercial eel landings throughout New Zealand over three consecutive years between 1995–96 and 1997–98, and then in 1999–2000 and 2003–04 (Beentjes 2005, Speed et al 2001). Sampling provided information on the length and age structure, and sex composition of the commercially caught eel populations throughout the country, and indicated a high degree of variability within and among catchments.

Monitoring commercial eel fisheries programme

The commercial eel monitoring programme collects processor recorded catch data for each species by size-grade (market determined; two to three grades) and catch location (eel statistical sub-area; catchment based), from virtually all commercial landings throughout New Zealand. This programme began in 2003–04 in the North Island and 2010–11 in the South Island (Beentjes 2013, 2016, 2019) with fifteen years of North Island data and eight years of South Island data collected by the end of 2017–18. This programme is ongoing with collection of data from 2018–19 to 2020–21 in progress.

North Island (2003–04 to 2017–18). The North Island commercial eel catch is highly aggregated with nearly one-third of the shortfin catch caught from just 3 of the 65 subareas (AA4, Dargaville; AD12, Lake Waikare and Port Waikato; and AC1, Hauraki Plains west). Similarly, one third of North Island longfin was caught from just four subareas (AA4, Dargaville; AD10, Waipa River; AD12, Lake Waikare, Port Waikato; and AL1, Lake Wairarapa). North Island shortfin annual catch over 15 years (2003–04 to 2017–18) showed no consistent trend in annual catch weight or in the distribution of these catches in the three size grades. The longfin fishery is more prone to market demand fluctuations than shortfin because it is a less desirable species of eel. Longfin landed catches over the same period fluctuated more than shortfin and are characterised by particularly low catches in 2008–09 to 2010–11 and since 2014–15, with an overall trend of declining catch. Factors that may have influenced annual longfin catches, overall and within size ranges, include the 58% TACC reductions for North Island longfin stocks for the 2007–08 fishing year, fluctuating market demands, annual rainfall, and, more recently and most importantly, a progressive decline in the availability of ACE to fishers. The number of subareas for which shortfin and longfin catch was landed has been declining, indicating a contraction in the spatial distribution of fishing effort over time. Despite this the catch of both species in the key subareas over the 15 years shows no apparent trends.

South Island (2010–11 to 2017–18). South Island commercial eel catch is highly aggregated especially shortfin where nearly three-quarters of the catch originates from just two of the 58 subareas (Te Waihora, AS1 and AS2; and Lake Brunner, AX4). Longfin in the South Island is less aggregated than shortfin, but half of the catch originated from just seven subareas (AW11, Mataura River coast; AW9, Oreti River coast; AW3, Oreti River inland down to Bog Burn; AV10, Clutha River coast; AP2,Wairau River; AU5,Waitaki River; and AX3, Grey River Arnold River). There is no consistent trend in annual shortfin landed catch over the eight-year time series (2010–11 to 2017–18), although the proportions of large eels has declined. There is a trend of declining longfin landed catch over the same period, and in the largest weight grade. The lower longfin landed catch in recent years can be attributed to lower port price for large longfin, and primarily the split into separate shortfin and longfin stocks in 2016–17. The longfin landed catch is also well below the current TACC introduced in 2016–17, as a result of fisher retirements, shelved quota, and ACE imbalances resulting from the nominal 1 t TACCs set in LFE 11 to LFE 14 essentially closing these areas to target longfin fishing. Catch of longfin has been stable in the key subareas, but more variable for the subareas with smaller catches. The pattern of South Island shortfin landed catch by subarea is generally similar over the eight years, except that AS1 and AS2 catches tend to display opposite trends because fishers can catch their quota from either.

4.2 Catch-per-unit-effort analyses

Each species of eel is considered to be a New Zealand wide stock, with common species-specific spawning grounds within the Fiji Basin. However, once recruited to a river system, eels do not move between catchments, so eels within each catchment may be regarded as separate sub-populations for management purposes. Maintaining sub-populations within each QMA at or above (sub-area proxies) B_{MSY}, will ensure that the entire (national) stock of each species is maintained at that level. To develop subarea proxies, standardised catch-per-unit-effort (CPUE) analyses have been conducted for the commercial shortfin and longfin eel fisheries by Eel Statistical Area (ESA; Table 11 and Figure 5) from

1990–91 to 2017–18 for all North Island ESAs and from 1990–91 to 2018–19 for all South Island ESAs (Tables 12ab–13ab and Figures 4–7). These CPUE series monitor the relative abundance of each eel species within the area fished commercially within each ESA.

North Island CPUE

The North Island CPUE analyses undertaken using data up to 2014–15 included, for the first time, a binomial analyses on the valid zero catches, as well as the routine GLM analyses of positive catch. In addition, reconstructed target species was included as an explanatory variable, as were water quality variables. The variable 'catcher_ID' was not included because it has only been recorded since 2001–02 on the new ECER forms (Beentjes & McKenzie 2017); however, the data were linked by permit holder and client name (see below). Target species was recorded on CELR forms, but not on ECER forms. Target species was reconstructed for all records from recorded CELR target species and species proportions using a simple optimisation to evaluate the best proportion to use (Cohen's kappa coefficient). Target species was reconstructed for all records, including those from CELR data. In some cases, target species was defined on the basis of a minimum catch composition of 80%. Higher values tended to assign too many records to the category 'either', when kappa was above 80%. Target species often explained the most variance in the positive catch GLM, especially for longfin for which the trends in CPUE changed more than shortfin compared with previous analyses when target was not offered to the model. Target species could not be offered to the binomial model because, by definition, a target of longfin or shortfin cannot result in zero catch in the models and consequently the May 2017 plenary rejected the binomial model.

Prior to the introduction of North Island eel stocks into the QMS in 2004–05, some fishers had fished for existing permit holders during the permit moratorium and following introduction of eels into the QMS began fishing under their own permit numbers (Beentjes & Dunn 2010). If these fishers had fished for someone else pre-QMS and if they were the only fisher that had landed catch under a pre-QMS *Client_name*, and that client did not land catch pre- and post-QMS, they were linked in the analyses. There were 16 linkages made.

The transition between CELR and ECER in 2001–02 is unlikely to have biased trends in relative abundance (CPUE) because there was no change in the estimation of catches or recording of effort data, with both forms providing estimated catch of shortfin and longfin eels, the number of nets set per night, and the statistical area where eels were caught.

The most recent CPUE analyses using data up to 2017–18 used the same methods described above but no binomial analyses were carried out (Beentjes 2020). In general, CPUE for North Island shortfin, with the exception of Northland (ESA AA) where CPUE steadily increased throughout the time series, either initially declined or there were no trends, followed by strong increases, beginning from around 2002 (Table 12a, Figure 6) (Beentjes 2020). For longfin there were generally fewer data than for shortfin for most areas and indices were often more variable, associated with wider confidence intervals, or could not be estimated for all years (Table 12b, Figure 7). In general, longfin CPUE indices declined over the first 10 years of the time series, and then either remained stable or slightly increased (Table 12b, Figure 7).

Several factors may have resulted in conservative estimates of North Island longfin eel CPUE, especially after 2005–06:

1. The unrecorded return of small and medium sized longfin eels to the water. This became more prevalent after the substantial reduction in North Island longfin quotas in 2007–08, because many fishers did not have ACE to cover all of their catch (larger longfins are more valuable than small and medium specimens). Industry were previously unaware that eels of legal size (220 g to 4 kg) that are released are supposed to be recorded on ECLRs under the Destination 'X ' code which was only available as a legitimate code on ECLRs from 2007–08. Further, at the Eel Working Group Meeting in April 2017 it was established that some fishers were incorrectly recording only their retained legal-size eels on the ECERs and thus the estimated catch used in CPUE analyses was possibly biased downward as was the CPUE. North Island Destination 'X' catch was only 3% of the landed eel catch in 2014–15. Destination 'X' was first used in 2008 for shortfin and in 2009 for longfin and its use has generally increased each year peaking in 2017 when 12.7 t of longfin

and 4.3 t of shortfin were released and recorded under Destination 'X' accounting for 13% and 2% of the species estimated catch, respectively (Beentjes 2020). Investigations into catch recorded on ECERs and ECLRs in 2019 indicate that, Destination 'X' is now being used by most fishers as intended (Beentjes 2020). In 2007–08, a maximum size of 4 kg was introduced for longfins. Longfins over 4 kg could be legally landed before this date. There was no legal requirement to record the catch of eels over 4 kg on ECLRs. The introduction of electronic catch and position reporting for the eel fishery in 2019 requires fishers to record the numbers and weight of all longfin eels over 4 kg released, as well as other information such as finer-scale catch location details. This will provide estimates of the quantities of longfins (over 4 kg) that are caught and released, but not included in the estimated catch used for CPUE analyses.

2. Avoidance of longfin habitat post 2006–07 in some statistical areas because there is currently insufficient available ACE to allow targeting of longfin eels. The QMA most affected is LFE 23 (current TACC is 9 t) where, since 2007–08, up to half the ACE has not been made available for lease. Of the available longfin ACE, almost all is leased to a fisher operating in the Taranaki statistical area (AJ) of this QMA, leaving very little for the Whanganui-Rangitikei statistical area. The fisher in the latter statistical area consequently targets shortfin eels in farm dams, dune lakes, and the lower reaches of some rivers; thereby avoiding high longfin eel catch rates in the Rangitikei River. Shelving of ACE has continued through to 2017–18 for all QMAs, but is most marked in SFE 23 and LFE 23 (Beentjes 2019).

3. Voluntary uptake of larger escape tubes (31 mm) from 2010–11 (regulated in 2012–13) may have resulted in a stepped drop in CPUE. This is expected to result in a stepped increase in CPUE in future analyses, when excluded eels begin recruiting to the fishery.

Figure 5: New Zealand Eel Statistical Areas (ESAs).

Table 11: New Zealand Eel Statistical Areas (ESAs). Areas were given a numeric designation prior to Oct. 2001, at which point letter codes were assigned.

ESA	Letter code	Numeric code
Northland	AA	1
Auckland	AB	2
Hauraki	AC	3
Waikato	AD	4
Bay of Plenty	AE	5
Poverty Bay	AF	6
Hawke Bay	AG	7
Rangitikei-Whanganui	AH	8
Taranaki	AJ	9
Manawatu	AK	10
Wairarapa	AL	11
Wellington	AM	12
Nelson	AN	13
Marlborough	AP	14
South Marlborough	AQ	14
Westland	AX	15
North Canterbury	AR	16
South Canterbury	AT	17
Waitaki	AU	18
Otago	AV	19
Southland	AW	20
Te Waihora (outside-migration area)	AS1	21
Te Waihora migration area	AS2	21
Chatham Islands	AZ	22
Stewart Island	AY	23

Table 12a: North Island CPUE indices for shortfin eels by Eel Statistical Area (ESA). Fishing years are referred to by the second year (e.g., 1990–91 is referred to as 1991). – insufficient data. See Table 11 for ESA area names; data from Beentjes (2020).

	Shortfin (North Island ESAs)										
Year	AA	AB	AC	AD	AE	AF	AG	AH	AJ	AK	AL
1991	0.71	1.20	1.09	0.83	1.01	–	1.12	1.1	1.66	1.86	–
1992	0.65	0.82	0.95	0.85	0.73	–	1.15	0.99	2.70	3.79	–
1993	0.67	0.76	1.06	0.97	0.65	0.92	1.1	0.92	1.00	2.11	0.67
1994	0.61	0.93	0.96	1.07	0.71	0.63	1.16	1.04	0.69	0.71	1.03
1995	0.81	0.98	1.07	1.09	0.86	0.93	1.25	0.97	1.35	0.63	1.12
1996	0.86	1.04	1.03	1.16	0.92	1.17	0.92	1.24	1.23	0.53	1.06
1997	0.83	0.77	0.80	1.03	0.73	0.71	0.72	0.90	1.09	0.86	0.77
1998	0.91	0.97	0.73	1.02	0.48	–	0.64	0.82	0.96	0.70	0.85
1999	1.06	1.16	0.68	0.90	0.72	–	0.84	0.84	1.02	0.90	0.75
2000	1.03	0.86	0.82	0.78	0.45	0.95	0.75	0.77	0.93	0.47	0.74
2001	1.05	0.84	0.79	0.78	0.60	1.29	0.83	0.83	0.77	0.57	0.77
2002	0.97	0.72	1.07	0.81	0.42	0.82	0.49	0.65	0.8	0.74	0.58
2003	0.96	0.72	0.92	0.74	0.60	0.46	0.52	0.78	0.72	0.47	0.49
2004	1.01	0.84	1.07	0.90	0.69	1.37	0.73	0.21	0.87	1.25	–
2005	0.97	0.88	0.93	0.93	1.04	0.73	0.78	0.67	0.74	1.02	1.10
2006	1.02	0.92	1.00	1.01	1.08	1.54	0.94	1.06	0.97	1.06	1.08
2007	1.12	0.99	0.85	1.00	1.13	1.19	0.74	1.07	0.71	1.23	1.20
2008	1.12	1.21	0.89	1.04	1.37	–	0.90	1.16	0.91	1.36	1.30
2009	1.05	0.99	0.91	1.11	1.53	2.64	1.03	1.42	–	0.95	0.99
2010	1.18	1.05	0.93	1.16	1.47	–	1.08	1.13	1.33	1.11	1.48
2011	1.15	1.10	1.23	1.18	1.60	–	0.99	1.40	0.91	0.94	1.38
2012	1.15	1.06	1.33	1.00	2.12	–	1.09	1.64	0.88	0.87	1.45
2013	1.19	1.10	1.28	0.98	1.78	–	1.44	1.39	1.43	0.98	0.94
2014	1.12	1.12	1.32	0.98	1.28	–	1.73	1.12	0.74	1.03	1.23
2015	1.24	1.16	1.10	1.01	1.55	–	1.39	1.10	0.96	1.27	1.15
2016	1.18	1.38	1.08	1.16	–	–	1.74	1.88	–	1.24	0.96
2017	1.45	1.50	1.29	1.41	2.58	–	1.95	1.30	–	1.56	1.78
2018	1.62	1.45	1.28	1.41	2.61	–	1.74	1.37	–	1.17	1.24

Table 12b: North Island CPUE indices for longfin eels by Eel Statistical Area (ESA). Fishing years are referred to by the second year (e.g., 1990–91 is referred to as 1991). – insufficient data. See Table 11 for ESA area names; data from Beentjes (2020).

	Longfin (North Island ESAs)										
Year	**AA**	**AB**	**AC**	**AD**	**AE**	**AF**	**AG**	**AH**	**AJ**	**AK**	**AL**
1991	1.15	0.68	1.73	1.09	1.78	–	1.23	1.73	1.50	–	0.87
1992	1.00	1.21	1.80	1.19	1.24	–	1.34	1.88	1.75	–	–
1993	1.07	1.07	1.55	0.96	1.03	0.74	1.30	1.38	1.23	2.49	1.34
1994	1.02	1.04	1.13	1.15	1.05	1.10	1.23	1.66	1.07	1.84	0.85
1995	0.98	1.19	1.33	1.24	0.99	0.74	0.99	1.37	1.30	1.14	1.08
1996	1.07	0.90	1.47	1.06	0.74	0.69	1.03	1.36	1.24	1.26	0.92
1997	0.86	0.91	1.19	0.97	0.67	–	0.62	1.43	1.10	–	0.73
1998	1.06	1.23	0.94	0.87	0.76	–	0.79	0.90	1.06	0.52	0.83
1999	1.16	1.26	1.02	0.82	1.31	–	1.02	0.86	0.97	–	0.73
2000	1.09	1.07	1.02	0.85	0.59	0.92	1.11	1.03	0.94	0.86	0.69
2001	1.19	1.22	0.80	0.92	1.32	1.16	0.86	0.73	0.82	1.01	0.72
2002	1.05	0.89	0.82	0.83	0.81	1.10	0.64	0.68	0.82	0.45	0.66
2003	0.97	0.89	0.87	0.86	0.86	–	0.82	0.61	0.70	0.44	0.66
2004	1.02	0.95	0.84	0.95	1.06	–	0.70	0.47	0.77	1.18	1.08
2005	0.96	1.26	1.18	0.94	0.82	1.11	0.95	0.72	0.85	1.03	0.86
2006	0.99	0.82	0.91	0.91	1.10	–	0.88	0.82	0.83	0.86	1.15
2007	0.99	1.02	0.83	0.97	0.94	1.83	0.86	0.75	0.90	1.22	1.16
2008	0.97	1.02	0.84	0.95	1.02	–	0.78	–	0.97	0.99	1.06
2009	0.72	0.82	0.81	0.99	1.35	–	–	–	–	0.97	0.81
2010	0.82	0.89	0.77	1.06	0.84	–	–	–	0.89	1.14	1.13
2011	0.84	0.81	0.84	1.04	1.33	–	–	–	1.05	1.23	1.54
2012	0.83	1.02	1.01	1.10	1.23	–	1.02	–	1.11	1.09	1.38
2013	0.97	1.00	0.94	1.06	1.36	–	1.20	–	1.02	1.01	1.07
2014	0.80	0.97	0.93	0.95	0.69	–	1.52	–	0.88	0.89	1.14
2015	0.92	0.93	0.54	1.00	–	–	1.23	–	0.79	0.93	1.00
2016	0.92	0.82	0.92	0.98	–	–	1.58	–	–	1.18	1.08
2017	1.51	1.17	0.87	1.27	–	–	1.18	–	0.88	0.87	1.71
2018	1.39	1.33	1.10	1.27	–	–	0.88	–	1.17	1.08	1.87

South Island CPUE

The Eel Working Group in 2012 (EELWG-2012-05) made the decision to split South Island CPUE analyses into pre- and post-QMS time series with post-QMS CPUE analyses only required for areas with sufficient data and fishers (ESAs: Westland AX, Otago AV, Southland AW, Te Waihora AS1 outside migration area). This was done because many fishers fishing under existing permits pre-QMS obtained their own quota and entered the fishery as ‘new’ entrants when the QMS was introduced. Fishing coefficients for existing permit holders were therefore likely to have changed considerably after the QMS was introduced. It is not possible to separate catches in the pre-QMS data into individual fisher catch and effort, as was done in the North Island analysis, because the CELR forms used up to 2001–02 included only a field for permit holder, with no way of identifying individual operators. This problem was solved in 2001–02 with the introduction of the new ECER form by adding a field which identified the fisher (i.e., ‘catcher’) filling out the form.

This problem was less severe in the North Island because North Island eels were introduced to the QMS after the new ECER forms had been developed, making it possible to link catcher and permit holders before and after the introduction to the QMS. The two most recent South Island CPUE analyses, up to 2012–13, and up to 2018–19, included predictor variables: target species, water quality data (e.g., nitrogen, phosphates, clarity, temperature), and catcher (Beentjes & Dunn 2015, Beentjes in press). Catcher was only available for the post-QMS analyses. The first year in the post-QMS standardised CPUE time series is 2001–02 when catcher was first recorded on the new ECERs.

Shortfin

CPUE for South Island shortfin showed four distinct patterns in the data rich areas: a steady decline pre-QMS followed by a steady increase post-QMS (Southland); a steady decline pre-QMS followed by a stable period post-QMS with no trend (Otago); a steady increase pre- and post-QMS (Westland); a steep increase, followed by a stable period and then a steep decline (Te Waihora, AS1) (Table 13a, b, Figure 8).

Longfin

CPUE for South Island longfin showed two distinct patterns in the data rich areas: a steady decline pre-QMS followed by a stable period post-QMS with no clear trend (Otago and Southland); and a steady increase pre- and post-QMS (Westland) (Table 13a, b, Figure 8).

Table 13a: South Island CPUE indices for shortfin eels by Eel Statistical Area (ESA). Separate indices are presented for pre-QMS (1991–2000) and post-QMS (2001–2019). Fishing years are referred to by the second year (e.g., 1990–91 is referred to as 1991). – insufficient data. See Table 11 for ESA area names; data from Beentjes (in press).

QMS		Shortfin (South Island ESAs)								
status	Year	AN	AP_AQ	AR	AT	AU	AV	AW	AX	AS1
Pre-QMS	1991	–	2.36	1.15	1.84	1.65	1.51	1.30	0.95	–
	1992	–	1.95	1.14	0.99	1.63	1.20	1.03	0.61	–
	1993	1.42	1.61	0.90	0.84	0.74	1.05	0.99	1.07	–
	1994	–	1.34	1.00	1.00	1.08	1.03	1.33	0.96	–
	1995	1.68	1.15	0.84	0.79	0.76	0.92	1.01	1.00	–
	1996	1.03	0.66	0.98	1.02	1.21	0.87	0.88	0.79	–
	1997	0.32	0.55	0.98	0.89	0.80	0.90	0.79	0.74	–
	1998	0.82	0.39	0.99	1.10	1.09	0.84	0.89	1.27	–
	1999	1.52	0.72	1.08	0.70	0.60	0.83	0.90	1.55	–
	2000	1.02	0.86	0.98	1.20	0.96	1.02	1.01	1.48	–
Post-QMS	2001	–	–	–	–	–	–	–	–	–
	2002	–	–	–	–	–	0.82	0.67	0.76	0.31
	2003	–	–	–	–	–	0.94	0.64	0.66	0.37
	2004	–	–	–	–	–	0.79	0.84	0.81	0.50
	2005	–	–	–	–	–	0.98	0.91	0.93	0.60
	2006	–	–	–	–	–	0.96	1.06	0.82	0.75
	2007	–	–	–	–	–	1.16	0.97	0.93	1.02
	2008	–	–	–	–	–	0.77	1.28	0.82	1.20
	2009	–	–	–	–	–	1.19	0.90	1.41	1.32
	2010	–	–	–	–	–	1.33	1.21	1.09	1.07
	2011	–	–	–	–	–	1.24	1.41	1.09	2.08
	2012	–	–	–	–	–	0.97	0.96	1.09	2.19
	2013	–	–	–	–	–	0.74	1.02	1.06	2.04
	2014	–	–	–	–	–	0.68	1.05	0.98	2.39
	2015	–	–	–	–	–	0.76	1.14	1.10	1.50
	2016	–	–	–	–	–	1.27	1.06	1.08	0.86
	2017	–	–	–	–	–	0.89	1.02	1.18	0.79
	2018	–	–	–	–	–	1.56	0.99	0.99	0.93
	2019	–	–	–	–	–	1.51	1.21	1.59	1.08

Table 13b: South Island CPUE indices for longfin eels by Eel Statistical Area (ESA). Separate indices are presented for pre–QMS (1991–2000) and post QMS (2001–2019). Fishing years are referred to by the second year (e.g., 1990–91 is referred to as 1991). - insufficient data; –, no analysis. See Table 11 for ESA area names; data from Beentjes (in press).

							Longfin (South Island ESAs)		
QMS status	Year	AN	AP_AQ	AR	AT	AU	AV	AW	AX
Pre-QMS	1991	2.10	1.77	1.16	1.89	1.25	1.35	1.46	1.08
	1992	1.17	1.29	0.97	0.74	1.25	1.20	1.13	0.95
	1993	0.80	1.25	0.89	0.78	0.84	1.14	1.13	0.76
	1994	0.90	1.40	0.96	1.05	0.91	1.27	1.22	0.89
	1995	0.78	1.12	0.71	0.88	0.64	0.93	0.99	1.10
	1996	0.80	1.13	1.28	0.78	1.06	0.80	1.00	1.00
	1997	0.70	0.64	1.12	0.96	0.95	0.86	0.92	0.94
	1998	0.79	0.75	0.84	0.99	0.96	0.87	0.79	0.97
	1999	1.15	0.82	0.99	0.85	1.29	0.85	0.68	1.10
	2000	1.42	0.50	1.23	1.59	1.04	0.91	0.91	1.30
	2001	–	–	–	–	–	–	–	–
Post-QMS	2002	–	–	–	–	–	0.91	1.02	0.77
	2003	–	–	–	–	–	0.91	1.10	0.77
	2004	–	–	–	–	–	0.89	0.86	0.91
	2005	–	–	–	–	–	1.10	1.12	0.91
	2006	–	–	–	–	–	0.92	1.08	0.92
	2007	–	–	–	–	–	1.02	0.83	0.96
	2008	–	–	–	–	–	0.97	0.94	0.92
	2009	–	–	–	–	–	1.14	0.93	1.01
	2010	–	–	–	–	–	0.87	0.84	1.26
	2011	–	–	–	–	–	1.31	1.24	1.18
	2012	–	–	–	–	–	0.91	1.07	0.95
	2013	–	–	–	–	–	0.96	1.11	1.06
	2014	–	–	–	–	–	0.83	1.04	0.92
	2015	–	–	–	–	–	0.70	0.99	0.95
	2016	–	–	–	–	–	1.46	0.94	1.13
	2017	–	–	–	–	–	1.21	0.89	1.39
	2018	–	–	–	–	–	1.20	0.97	1.04
	2019	–	–	–	–	–	0.95	1.15	1.18

Te Waihora

CPUE analyses for Te Waihora were only carried out for AS1 feeder shortfin (the lake, outside the migration area) from 2000–01, coinciding with the introduction of the reporting codes (AS1 and AS2), to 2012–13. The two most recent analyses included new predictor variables: lake level, status of lake opening (i.e., open or closed), and catcher (Beentjes & Dunn 2015, Beentjes in press). The standardised CPUE time series begins in 2001–02, when the new ECER form was introduced and catcher was first recorded. CPUE of feeder shortfin eels in Te Waihora increased more than seven fold in nine years from 2001–02 to 2010–11 and then was reasonably stable until 2013–14 before steeply declining over the next two years then levelling out (Figure 9).

It is very likely that the fishery has initially experienced a progressive improvement in yield-per-recruit (YPR) as the minimum legal size was incrementally increased by 10 g per year from 140 g in 1993–94 to 220 g in 2001–02. This was then followed by a decline in YPR over the last five years. Analyses of the commercial shortfin eel size composition harvested from the lake in the 1990s compared with that over the last nine years demonstrates that the average size of commercially caught eels substantially increased over time before decreasing again, supporting the concept of a fluctuating yield-per-recruit (Figure 10; Beentjes & Dunn 2014, Beentjes in press). CPUE appears to have been highest when mean size was larger and vice versa. Further, shortfin eels are reported to be in poor condition in recent years and bully numbers are low, both signs of a reduction in lake productivity.

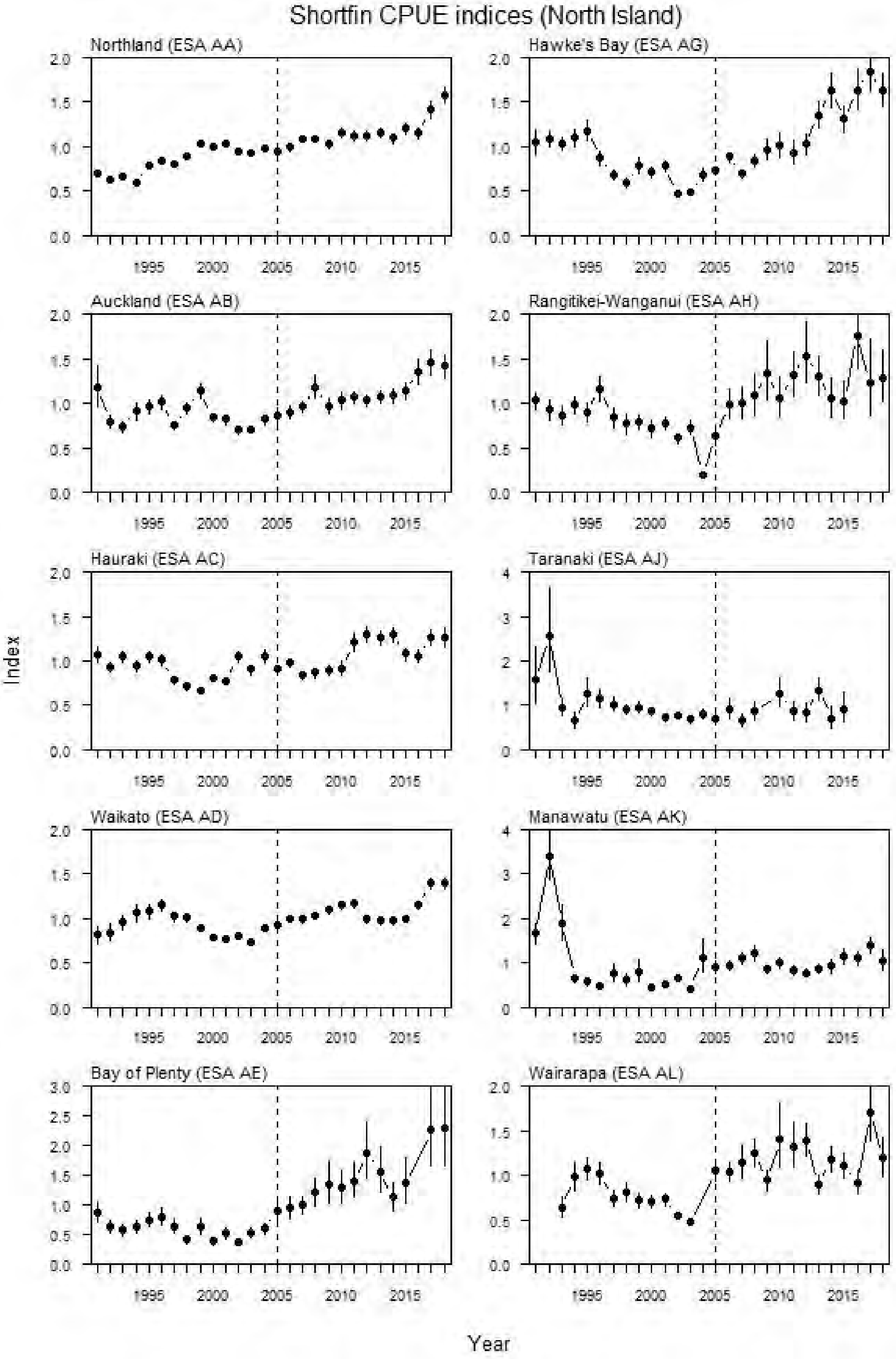


Figure 6: Trends in North Island shortfin CPUE indices for all North Island ESAs from 1990–91 to 2017–18, except Poverty Bay (AF) and Wellington (AM) where there were insufficient data. Vertical dotted line indicates the introduction to the QMS in 2004–05 (from Beentjes 2020).

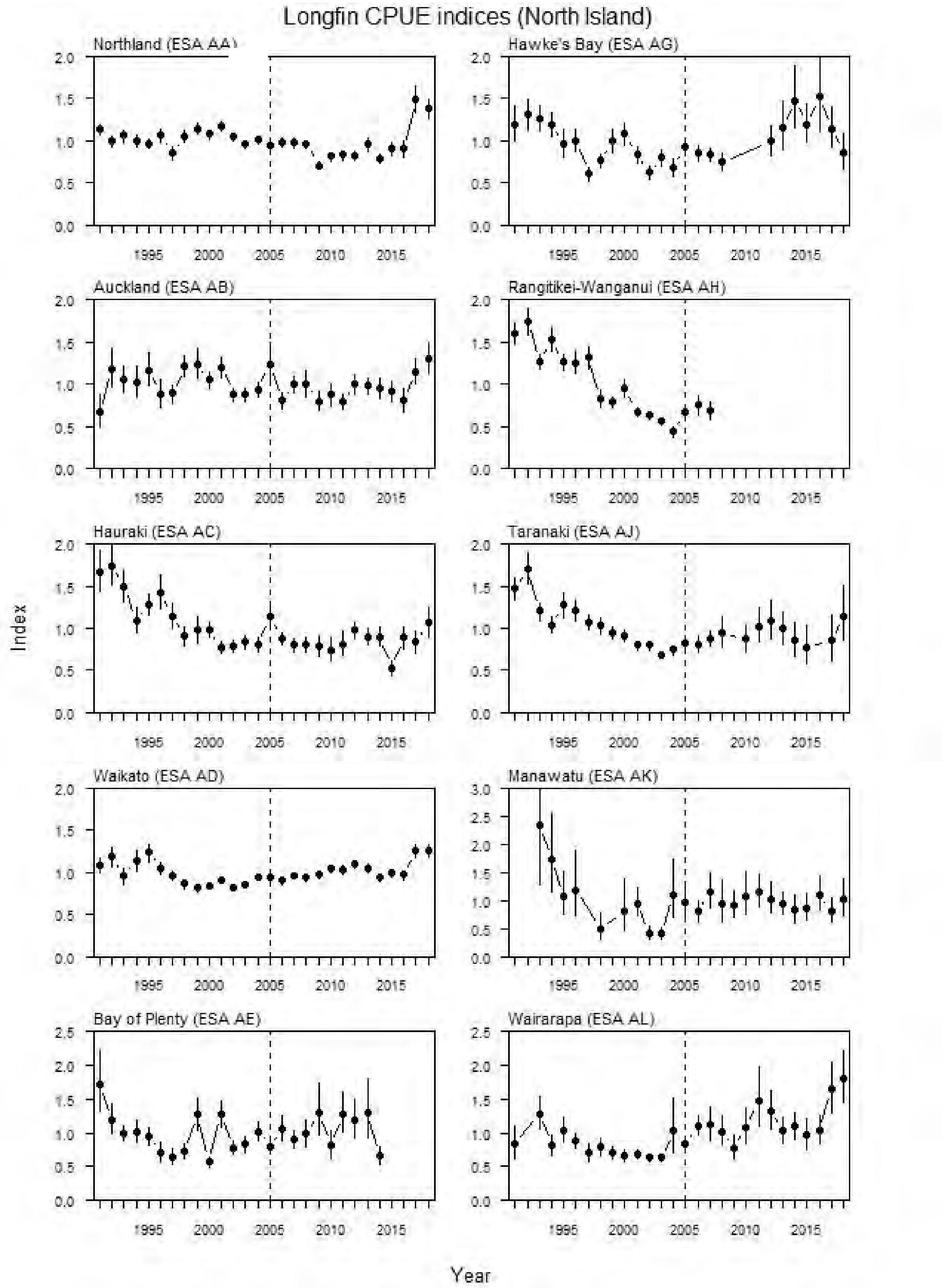


Figure 7: Trends in North Island longfin CPUE indices for all North Island ESAs from 1990–91 to 2018–19, except Poverty Bay (AF) and Wellington (AM) where there were insufficient data. Vertical dotted line indicates the introduction to the QMS in 2004–05 (from Beentjes 2020).

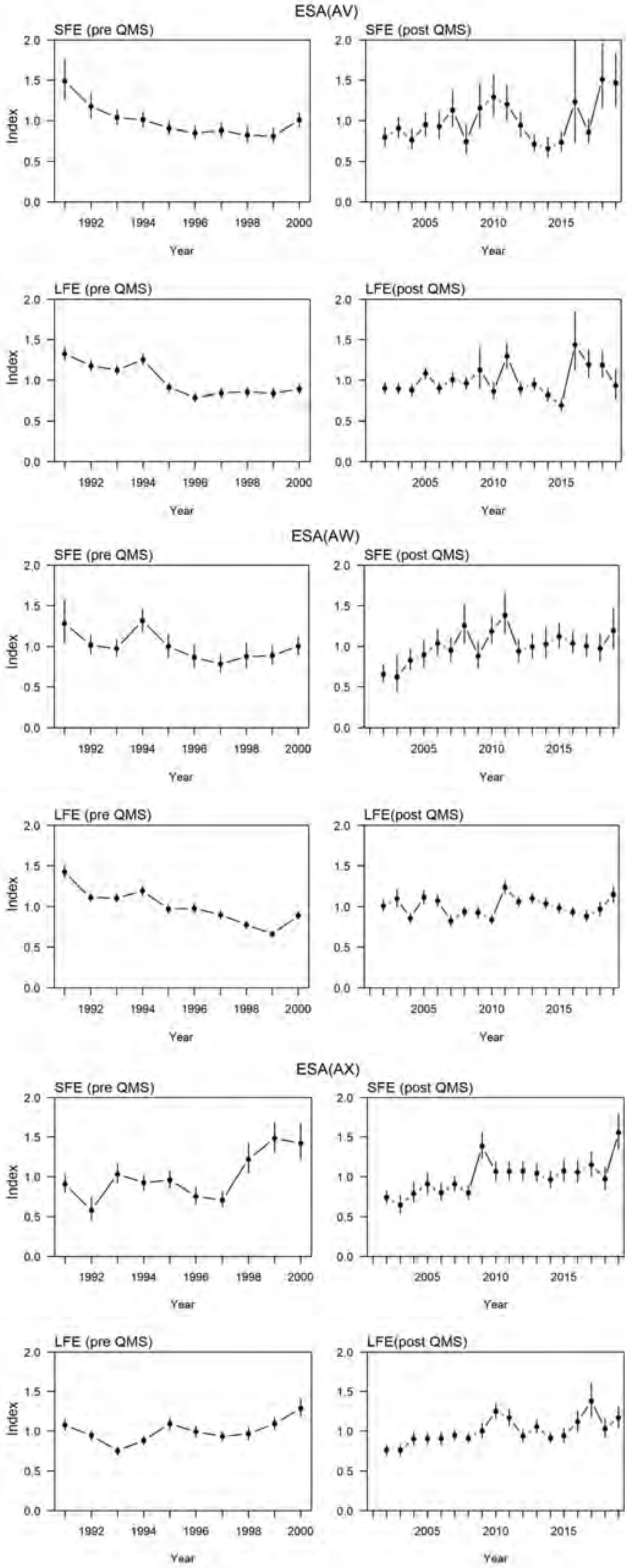


Figure 8: Trends in South Island shortfin and longfin CPUE indices for key ESAs: Otago (AV), Southland (AW), and Westland (AX). Separate indices are presented for pre-QMS (1991–2000) and post-QMS (2002–2019) (from Beentjes in press).

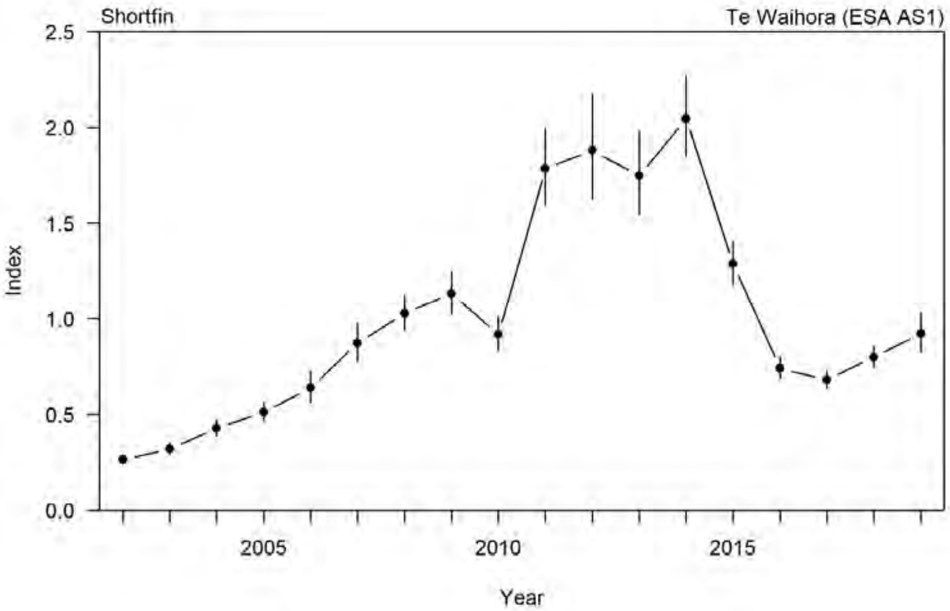


Figure 9: Te Waihora shortfin CPUE indices for AS1 (outside migration area) from 2001–02 to 2012–19 (from Beentjes in press).

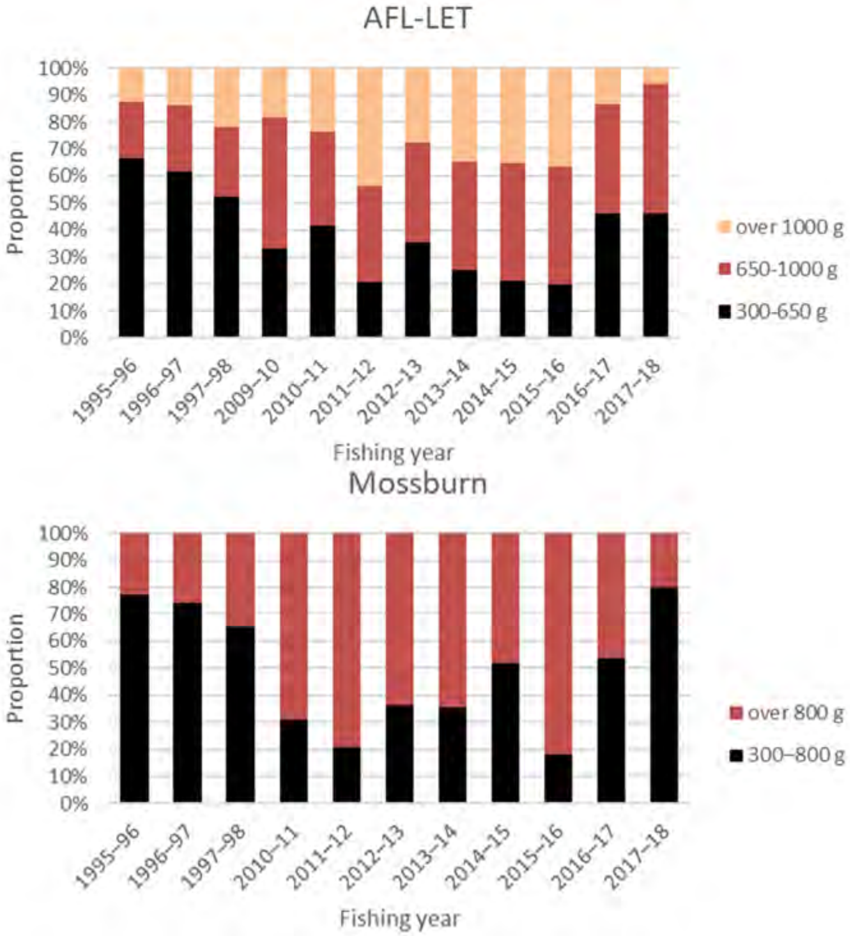


Figure 10: Size grade proportions of shortfin eels harvested from Te Waihora AS1 (lake) from eel processors AFL-Levin Eel Trading Ltd in 2009–10 to 2017–18, and Mossburn Enterprises Ltd in 2010–11 and 2017–18. The equivalent size grades have been estimated from the length of eels taken during commercial catch sampling of the commercial catch from Te Waihora in 1995–96 to 1997–98 (Beentjes & Dunn 2014, Beentjes in press).

4.3 Biomass estimates

Estimates of current and reference biomass for any eel fish stock are not available. Recent estimates of approximately 12 000 t have been made for longfin eels (Graynoth et al 2008, Graynoth & Booker 2009), but these are based on limited data on density, growth, and sex composition of longfin eel populations in various habitat types, including lakes and medium to large rivers.

4.4 Yield estimates and projections

In the absence of accurate current biomass estimates, this could not be estimated. Biological parameters relevant to the stock assessment are given in Table 14.

Table 14: Estimates of biological parameters.

Fishstock	**Estimate**	**Source**
1. Natural mortality (M)		
Unexploited shortfins (Lake Pounui)	$M = 0.038$	Jellyman (unpub. Data)
Unexploited longfins (Lake Pounui)	$M = 0.036$	Jellyman (unpub. Data)
Unexploited longfins (Lake Rotoiti)	$M = 0.02$	Jellyman (1995)
2. Weight (g) of shortfin and longfin eels at 500 mm total length		
	Mean weight	Range
Shortfins Lake Pounui	263	210–305
Shortfins Waihora	250	210–303
Longfins Lake Pounui	307	250–380

4.5 Other factors

Yield-per-recruit

Yield-per-recruit (YPR) models have been run on Te Waihora (Lake Ellesmere) and Lake Pounui data to test the impact of increases in size limit. Results indicated that an increase in minimum size should result in a small gain in YPR for shortfins in Te Waihora and longfins in Lake Pounui, but a decrease for shortfins in Lake Pounui.

A practical demonstration of the benefits of an increase in size limit has been reported from the Waikato area, where a voluntary increase in minimum size from 150 to 220 g in 1987 resulted in decreased CPUE for up to 18 months, but an increase thereafter.

Spawning escapement

A key component to ensuring the sustainability of eels is to maintain spawner escapement. As a sustainability measure, the Mohaka, Motu, and much of the Whanganui river catchments were closed to commercial fishing in early 2005 to aid spawning escapement. The importance of adequate spawner escapement for eels is evident from the three northern hemisphere (*A. anguilla, A. rostrata*, and *A. japonica*) species, which are all extensively fished at all stages of their estuarine/freshwater life and are subject to a variety of anthropogenic impacts similar to the situation in New Zealand. There has been a substantial decline in recruitment for all three northern hemisphere species since the mid-1970s with less than 1% of juvenile resources estimated to be remaining for major populations in 2003 (Québec Declaration of Concern 2003). More recently, Dekker & Casselman (2014) concluded that "the recent recruitment increase of some [northern hemisphere] stocks, and the relative stability of others, indicate that after many decades of continued decline depleted eel stocks around the world have the potential to recover".

Longfin habitat

It was estimated, based on GIS modelling in the early 2000s (Graynoth et al 2008), that 5% of longfin eel habitat throughout New Zealand is in water closed to fishing where there is protected egress to the sea to ensure spawning escapement. A further 10% of longfin habitat was estimated to be in areas closed to fishing in upstream areas but where the spawning migration could be subject to exploitation in downstream areas (migratory eels are not normally taken by commercial fishers). An additional 17% of longfin habitat was in small streams that are rarely or not commercially fished. Therefore, about 30% of longfin habitat in the North Island and 34% in the South Island was either in a reserve or in rarely/non-fished areas (Graynoth et al 2008). However, the estimate of the proportion of longfin habitat in streams rarely or not commercially fished was based on poor assumptions and was consequently vastly underestimated.

In 2015, commercial longfin eel fishing effort throughout New Zealand was mapped using GIS methods, providing the first detailed and high resolution representation of where and how often fishers set their nets in New Zealand rivers, lakes, and harbours (Beentjes et al 2016). The data used in the study came from face to face interviews with 53 commercial longfin fishers from throughout New Zealand and covered the five year period from 2009–10 to 2013–14. From these data, estimates were made of the proportion of longfin habitat that is currently fished (Beentjes et al 2016). The total current longfin habitat in rivers was derived from ‘probability of longfin capture’ models. About one quarter (27.2%) of the New Zealand longfin river and lake habitat, currently accessible to longfin eels, was commercially fished (32.5% in the South Island and 22.5% in the North Island) (Table 15). The proportion of virgin/original longfin habitat affected by anthropogenic activity (impeded access by dams and other structures, habitat degradation, and commercial fishing) is estimated at 42% (= Max. impacted abundance) (Table 15). Forty percent of the current habitat available to longfin eels in New Zealand is estimated to be within DOC Public Conservation Land, and just over half of this is in natural lakes (Beentjes et al 2016). Generally, DOC will not issue concessions for commercial eel fishing in Public Conservation Land, except for shortfin eels in Lake Brunner.

Table 15: Estimates of total current longfin habitat fished, virgin habitat fished, and maximum impacted abundance from all rivers and lakes by QMA, eel statistical area, and overall for South Island, North Island, and New Zealand. Current lake habitat includes that from natural lakes over 0.9 km^2, and rivers where longfin eels have unimpeded access to, and egress to the sea. Maximum impacted abundance is the proportion of virgin habitat affected by anthropogenic activities including loss to dams, impeded access, commercial fishing, and habitat loss. Max, maximum. QMA, Quota Management Area (from Beentjes et al 2016).

			Percent (%)		
Island	**QMA**	**Eel Statistical Area**	**Current habitat fished**	**Virgin habitat fished**	**Max. impacted abundance**
North Island	LFE 20	AA	36.1	34.7	40.2
North Island	LFE 20	AB	34.9	33.8	38.2
North Island	LFE 21	AC	50.0	47.6	55.0
North Island	LFE 21	AD	43.2	34.4	55.7
North Island	LFE 21	AE	17.4	16.2	23.9
North Island	LFE 21	AF	8.6	8.2	13.6
North Island	LFE 22	AG	17.3	16.0	24.7
North Island	LFE 23	AH	24.8	23.6	29.9
North Island	LFE 23	AJ	17.0	15.9	23.6
North Island	LFE 22	AK	36.0	34.5	40.6
North Island	LFE 22	AL	4.2	4.1	5.0
North Island	LFE 22	AM	2.4	2.2	7.4
South Island	ANG 11	AN	11.5	11.1	15.5
South Island	ANG 11	AP	42.1	40.1	47.1
South Island	ANG 12	AQ	7.9	7.6	12.4
South Island	ANG 12	AR	58.1	55.9	61.7
South Island	ANG 13	AS	0.0	0.0	0.4
South Island	ANG 14	AT	38.6	37.3	42.1
South Island	ANG 14	AU	52.2	12.4	85.9
South Island	ANG 15	AV	46.2	12.5	82.8
South Island	ANG 15	AW	32.2	24.2	40.7
South Island	ANG 16	AX	30.2	29.0	34.0
North Island	All	All	22.5	20.9	29.0
South Island	All	All	32.5	21.8	52.6
New Zealand	All	All	27.2	21.4	42.1

Sex ratio

The shortfin fishery is based on the exploitation of immature female eels, because most shortfin male eels migrate before reaching the minimum size of 220 g. The exception to this is Te Waihora where migratory male shortfin eels are also harvested. The longfin fishery is based on immature male and female eels.

A study on the Aparima River in Southland in 2001–02 found that female longfins were rare in the catchment. Only five of 738 eels sexed were females (McCleave & Jellyman 2004). This is in contrast to a predominance of larger female longfins in southern rivers established by earlier research in the 1940s and 1950s, prior to commercial fishing. The sex ratio in other southern catchments, determined from analysis of commercial landings, also show a predominance of males. In contrast, some other catchments (Waitaki River, some northern South Island rivers) showed approximately equal sex ratios. The predominance of males in the size range below the minimum legal size of 220 g cannot be attributed directly to the effects of fishing. Because the sexual differentiation of eels can be influenced by environmental factors, it is possible that changing environmental factors are responsible for the greater proportion of male eels in these southern rivers (Davey & Jellyman 2005).

Enhancement

The transfer of elvers and juvenile eels has been established as a viable method of enhancing eel populations and increasing productivity in areas where recruitment has been limited. Elver transfer operations are conducted in summer months when elvers reach river obstacles (e.g., the Karapiro Dam on the Waikato River; see Table 10a) on their upriver migration. Nationally some 10 million elvers are now regularly caught and transferred upstream of dams each year.

To mitigate the impact of hydro turbines on migrating eels, a catch and release programme for large longfin females has been conducted from Lake Aniwhenua with release below the Matahina Dam since 1995. An extensive capture and release programme has also been conducted from Lake Manapouri to below the Mararoa Weir on the Waiau River, Southland by Meridian Energy since 1998. Limited numbers of longfin migrants are also transferred to below the Waitaki Dam by local Runanga. Adult eel bypasses have been installed at the Wairere Falls and Mokauiti power stations in the Mokau River catchment since 2002, and controlled spillway openings have been undertaken at Patea Dam during rain events in autumn (when eels are predicted to migrate downstream) since the late 1990s. Additional eel protection infrastructure is currently being installed at Patea Dam and ongoing studies, including downstream bypass trials are in progress at Karapiro Dam (Waikato), Lake Whakamarino (Waikaremoana Power Scheme), and Wairua (Titoki) Power Station. So far, the effectiveness of none of these varied mitigation activities has been fully assessed.

Several projects have been undertaken to evaluate the enhancement of depleted customary fisheries through the transfer of juvenile eels. In 1997, over 2000 juvenile shortfin eels (100–200 g) were caught from Te Waihora (Lake Ellesmere), tagged and transferred to Cooper's Lagoon a few kilometres away (Jellyman & Beentjes 1998, Beentjes & Jellyman 2002). Only ten tagged eels, all females, were recovered in 2001. It is likely that a large number of eels migrated to sea as males following the transfer. Another project in 1998 transferred 7600 (21% tagged) mostly shortfin eels weighing less than 220 g from Lake Waahi in the Waikato catchment to the Taharoa Lakes near Kawhia (Chisnall 2000). No tagged eels were recovered when the lakes were surveyed in 2001. It is considered that a large number of shortfin eels migrated from the lake as males following the transfer. The conclusion from these two transfers is that transplanted shortfin eels need to be females, requiring that eels larger than 220 g and above the maximum size of migration for shortfin males need to be selected for transfer.

In 1998 approximately 10 000 juvenile longfin eels were caught in the lower Clutha River and transferred to Lake Hawea, of which 2010 (about 20%) were tagged (Beentjes 1998). In 2001, of 216 recaptured eels, 42 (19.4%) had tags (i.e., very little tag loss) (Beentjes & Jellyman 2003). The transferred eels showed accelerated growth and the mean annual growth in length was almost double that of eels from the original transfer site and all recaptures were females. A further sample of Lake Hawea in 2008 showed that of 399 longfin eel recaptures, 79 had tags (19.2%), indicating continued good tag retention (Beentjes & Jellyman 2011). Growth rate from the 2008 tag-recaptures was significantly greater than at release, but less than in 2001, and all recaptures were females.

Trends in the commercial catches from areas upstream of hydro dams on the Waikato, Rangitaiki, and Patea rivers indicate that elver trap and transfer operations have improved or at least maintained the eel populations upstream of barriers (Beentjes & Dunn 2010). Comparison of historical eel survey results have confirmed these observations (e.g., Beentjes et al 1997, Boubée & Hudson 2009, Crow & Jellyman 2010).

5. FUTURE RESEARCH CONSIDERATIONS

- Examine further the 'target species' reconstruction based on CELR data by, for example, running sensitivities to determine the effect of different assumptions.
- For the Te Waihora shortfin CPUE, explore the possibility of developing an index of the ratio between the AS1 and AS2 catch as a potential explanatory variable.
- Investigate the utility of using more stringent criteria for choosing core permits.
- Examine trends over time for individual fishers; i.e., consider deriving fisher-based indices as an alternative way of standardising.
- Determine whether ancillary data exist to refine or verify the derived targets.
- Determine the proportion of fishers using destination code 'X' to report the catches of legal-size fish that are released.
- Identify the fishers who haven't been using destination 'X 'correctly and fix this to the extent possible. Identify whether the issue is specific to certain areas. For some fishers it may be necessary to add the destination code 'X' estimates from the ECLR forms to the catch estimates from the ECER forms to obtain a more accurate estimate of catch per day for the CPUE analyses.
- Investigate ways of compensating for the lack of recording of eels over 4 kg since 2007–08 (especially since this should be rectified once new forms are developed).
- For areas with few fishers or records, the Eel Working Group should consider merging statistical areas and analysing data at the QMA level. Alternatively the working group needs to consider ways to develop statements about stock status for areas with few fisheries or low effort.
- Investigate the possibility of augmenting the current data with information from customary fisheries.
- Calculate a weighted CPUE by QMA, with the weighting based on the amount of suitable habitat in each area.

6. STATUS OF THE STOCKS

There are no Level 1 Full Quantitative Stock Assessments on which to base specific recommendations on eel catch levels. Nevertheless, recruitment data, commercial CPUE indices, information on spawner escapement, and information on the proportion of longfin habitat fished allow for Level 2 Partial Quantitative Stock Assessments of longfin and shortfin eels.

Stock Structure Assumptions

Longfin and shortfin eels are considered to be New Zealand wide stocks, with common species-specific spawning grounds within the Fiji Basin. However, once recruited to a river system, eels do not move between catchments, so eels within each catchment may be regarded as separate sub-populations for management purposes. Maintaining sub-populations within each QMA at or above (sub-area proxies for) B_{MSY}, will ensure that the entire (national) stock of each species is maintained at that level. North Island QMAs have from two to four ESAs, and South Island QMAs all have two, except Westland (LFE 16 and SFE 16) which has one. ESAs also contain multiple catchments or sub-populations from which eels are harvested.

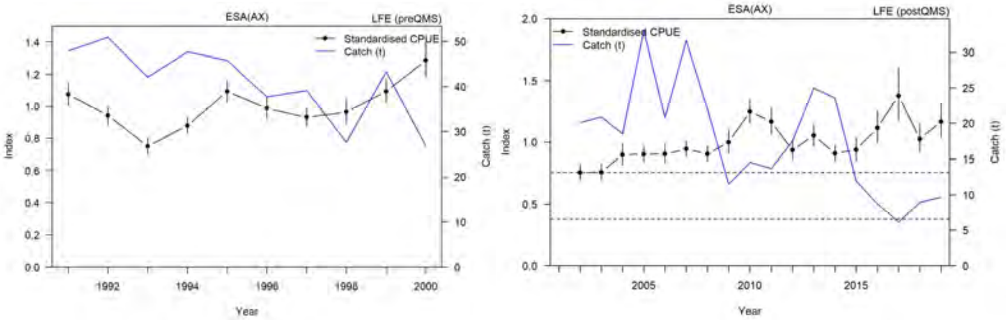
Status of South Island Eels

Level 2 Partial Quantitative Stock Assessments are conducted by statistical area and species and are only possible where accepted indices of abundance are available; i.e., Westland, Otago, Southland, and Te Waihora. Standardised CPUE provides information on the abundance of commercially harvested eels (300–4000 g) in areas that are fished commercially. Aproximately 67% of currently available longfin habitat in the South Island is either in reserves or in areas rarely or never fished by commercial fishers.

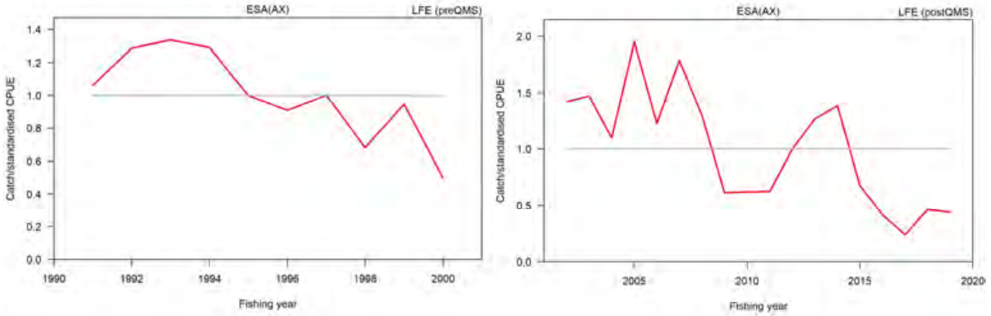
- **Westland (AX) longfin**

Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Standardised CPUE
Reference Points	Target: B_{MSY} assumed, but not estimated Interim Soft Limit: Mean CPUE from 2001–02 to 2002–03 Hard Limit: 50% of Soft Limit Overfishing threshold: F_{MSY} assumed, but not estimated
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Comparison of standardised CPUE for longfin eels in Westland (AX) from 1990–91 to 1999–2000 (pre-QMS) and 2001–02 to 2018–19 (post-QMS) (from Beentjes in press). Also shown is the total estimated core fisher longfin catch in AX from from ECERs. The two CPUE series have been scaled to the mean for each time series. Horizontal lines post-QMS represent the soft and hard limits. 2000 = 1999–2000 fishing year. Error bars are 95% confidence intervals.



Annual relative exploitation rate for longfin eels in the Westland (AX) pre- and post-QMS. 2000 = 1999–2000 fishing year.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Pre-QMS CPUE declined from 1990–91 to 1992–93, and then increased steadily to 1999–2000. Post-QMS CPUE increased steadily from 2001–02 to 2018–19.
Recent Trend in Fishing intensity or Proxy	Relative exploitation rate declined steeply throughout the pre-QMS time series and declined substantially post-QMS.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) if catch remains at current levels Hard Limit: Unlikely (< 40%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unlikely (< 40%) if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series (pre-QMS)	

Qualifying Comments

Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as culling (primarily 1930s to 1950s) and habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The basis for the biological reference points is tenuous and should be revised whenever new relevant information becomes available.

The proportion of current longfin habitat in Westland (Statistical Area AX, ANG 11) fished commercially during the period 2009–10 and 2013–14 is estimated at 30% (Table 15). The proportion of virgin habitat impacted by hydro dams, commercial fishing, and other anthropogenic activity was estimated to be 34%.

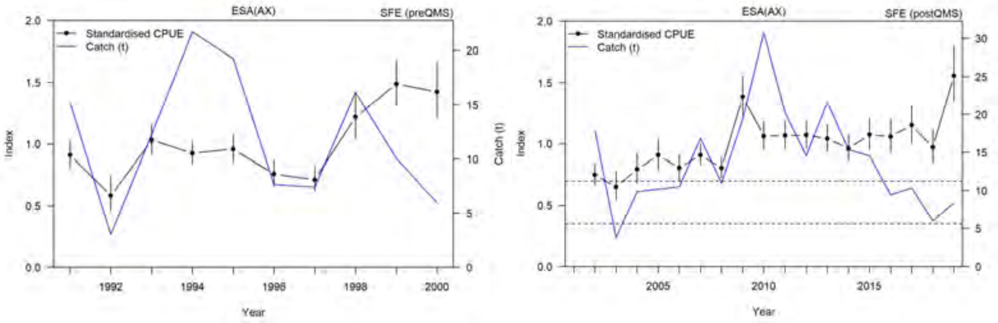
Fishery Interactions

Bycatch of other species in the commercial eel fishery is low and may include brown trout, galaxiids, yellow-eyed mullet, and kōura in order of amount caught. Bycatch species are usually returned alive.

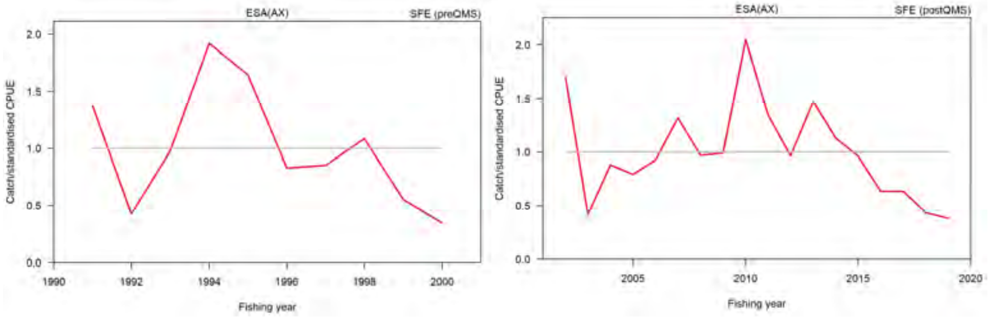
- **Westland (AX) shortfin**

Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Standardised CPUE
Reference Points	Target: B_{MSY} assumed, but not estimated Interim Soft Limit: Mean CPUE from 2001–02 to 2002–03 Hard Limit: 50% of Soft Limit Overfishing threshold: F_{MSY} assumed, but not estimated
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Comparison of standardised CPUE for shortfin eels in Westland (AX) from 1990–91 to 1999–2000 (pre-QMS) and 2001–02 to 2018–19 (post-QMS) (from Beentjes in press). Also shown is the total estimated core fisher shortfin catch in AX from ECERs. The two CPUE series have been scaled to the mean of each time series. Horizontal dashed lines post-QMS represent the soft and hard limits. 2000 = 1999–2000 fishing year. Error bars are 95% confidence intervals.



Annual relative exploitation rate for shortfin eels in the Westland (AX) pre- and post-QMS. 2000 = 1999–2000 fishing year.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Pre-QMS CPUE fluctuated without trend from 1990–91 to 1996–97 and then increased sharply to 1999–2000. Post-QMS CPUE increased steadily from 2001–02 to 2018–19.
Recent Trend in Fishing intensity or Proxy	Relative exploitation rate has shown large inter-annual fluctuations, with an increasing trend from 2003 to 2010, followed by a strongly declining trend.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) if catch remains at current levels Hard Limit: Very Unlikely (< 10%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unlikely (< 40%) if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series (pre-QMS)	

Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as culling (primarily 1930s to 1950s) and habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The basis for the biological reference points is tenuous and should be revised whenever new relevant information becomes available.

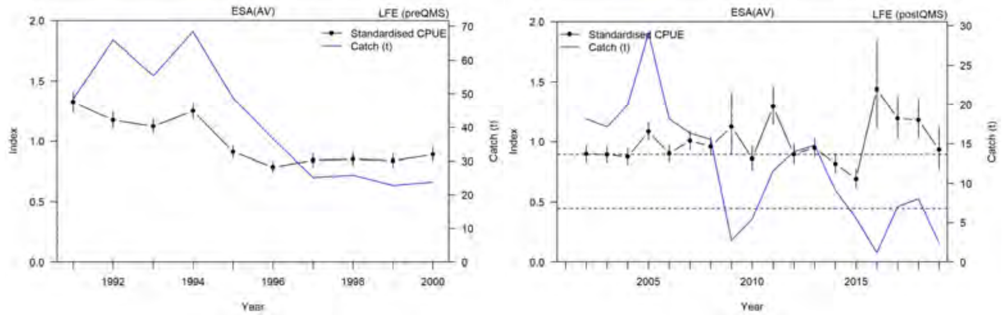
Fishery Interactions
Bycatch of other species in the commercial eel fishery is low and may include brown trout, galaxiids, yellow-eyed mullet, and kōura in order of amount caught. Bycatch species are usually returned alive.

- **Otago (AV) longfin**

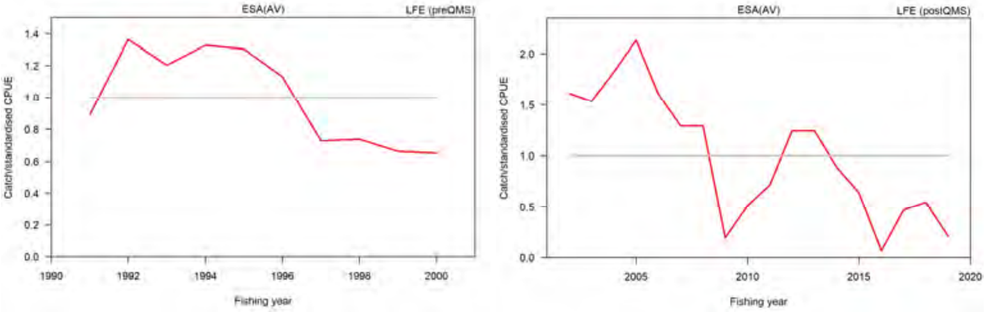
Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Standardised CPUE
Reference Points	Target: B_{MSY} assumed, but not estimated Interim Soft Limit: Mean CPUE from 2001–02 to 2002–03 Hard Limit: 50% of Soft Limit Overfishing threshold: F_{MSY} assumed, but not estimated
Status in relation to Target	Unknown

Status in relation to Limits	Soft Limit: About as Likely as Not (40–60%) to be below. Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Comparison of standardised CPUE for longfin eels in Otago (AV) from 1990–91 to 1999–2000 (pre-QMS) and 2001–02 to 2018–19 (post-QMS) (from Beentjes in press). Also shown is the total estimated core fisher longfin catch in AV from ECERs. The two CPUE series have been scaled to the mean of each time series. Horizontal lines post-QMS represent the soft and hard limits 2000 = 1999–2000 fishing year. Error bars are 95% confidence intervals.



Annual relative exploitation rate for longfin eels in the Otago (AV) pre- and post-QMS. 2000 = 1999–2000 fishing year.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Pre-QMS CPUE declined steadily from 1990–91 to 1995–96 and was stable to 1999–2000. Post-QMS CPUE is variable with no clear long-term trend.
Recent Trend in Fishing intensity or Proxy	Relative exploitation rate was variable but overall declined markedly from 2002 to 2019.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data began in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term if catch remains at current levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: About as Likely as Not (40–60%) if catch remains at current levels Hard Limit: Unlikely (< 40%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown if catch remains at current levels Unknown if catch were to increase to the level of the TACC

Assessment Methodology		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series (pre-QMS)	

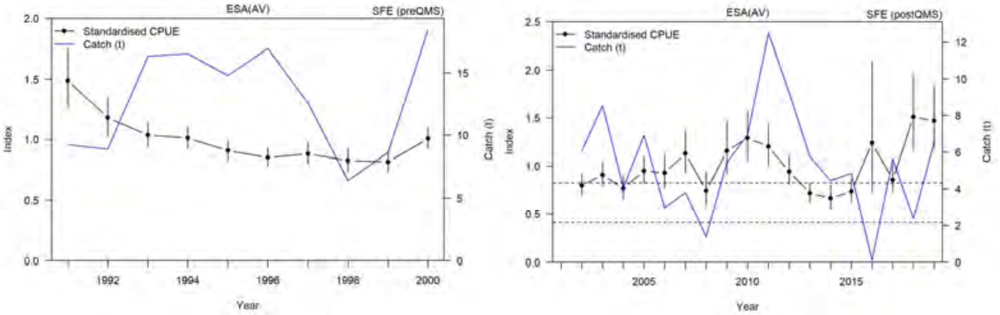
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as culling (primarily 1930s to 1950s) and habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The basis for the biological reference points is tenuous and should be revised whenever new relevant information becomes available. The proportion of current longfin habitat in Otago (Statistical Area AV) fished commercially during the period 2009–10 and 2013–14 is estimated at 46% (Table 15). The proportion of virgin habitat impacted by hydro dams, commercial fishing, and other anthropogenic activity was estimated to be 82.8%.

Fishery Interactions
Bycatch of other species in the commercial eel fishery is low and may include brown trout, galaxiids, yellow-eyed mullet, and kōura in order of amount caught. Bycatch species are usually returned alive.

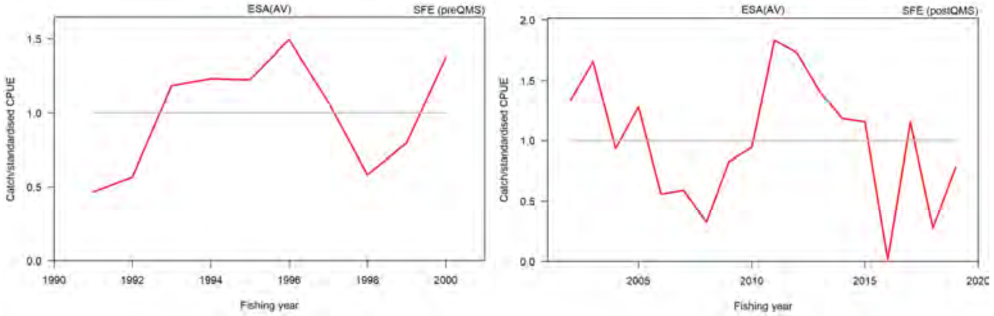
- **Otago (AV) shortfin**

Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Standardised CPUE
Reference Points	Target: B_{MSY} assumed, but not estimated Interim Soft Limit: Mean CPUE from 2001–02 to 2003–04 Hard Limit: 50% of Soft Limit Overfishing threshold: F_{MSY} assumed, but not estimated
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Comparison of standardised CPUE for shortfin eels in Otago (AV) from 1990–91 to 1999–2000 (pre-QMS) and 2001–02 to 2018–19 (post-QMS) (from Beentjes in press). Also shown is the total estimated shortfin core fisher catch in AV from ECERs. The two CPUE series have been scaled to the mean of each time series. Horizontal lines post-QMS represent the soft and hard limits 2000 = 1999–2000 fishing year. Error bars are 95% confidence intervals.



Annual relative exploitation rate for shortfin eels in the Otago (AV) pre- and post-QMS. 2000 = 1999–2000 fishing year.

Fishery and Stock Trends

Recent Trend in Biomass or Proxy	Pre-QMS CPUE declined steadily from 1990–91 to 1998–99 and then increased slightly to 1999–2000. Post-QMS CPUE fluctuated without trend until 2015, after which it has increased.
Recent Trend in Fishing intensity or Proxy	Relative exploitation rate has fluctuated without trend since 2002 but has largely been below the long-term mean since 2015.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis

Stock Projections or Prognosis	As both catch and exploitation rate show large inter-annual variation, it is not clear whether the population will continue to increase.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) if catch remains at current levels Hard Limit: Unlikely (< 40%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown if catch remains at current levels Likely (> 40%) if catch were to increase to the level of the TACC

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series (pre-QMS)	

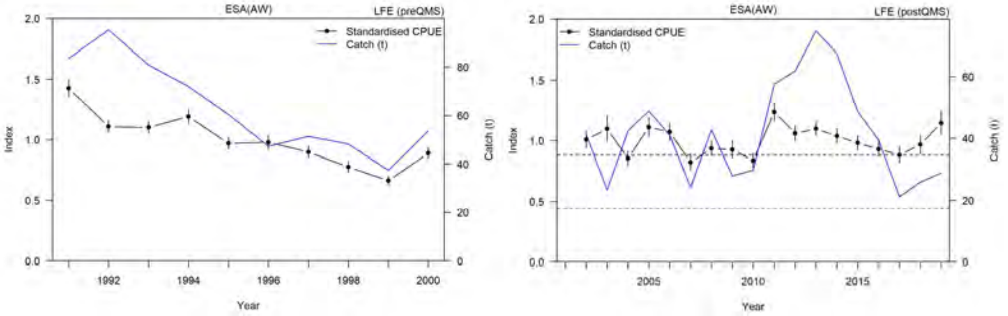
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as culling (primarily 1930s to 1950s) and habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

Fishery Interactions
Bycatch of other species in the commercial eel fishery is low and may include brown trout, black flounder, kōura, yellow-eyed mullet, galaxiids, yellowbelly flounder, and bullies in order of amount caught. Bycatch species are usually returned alive.

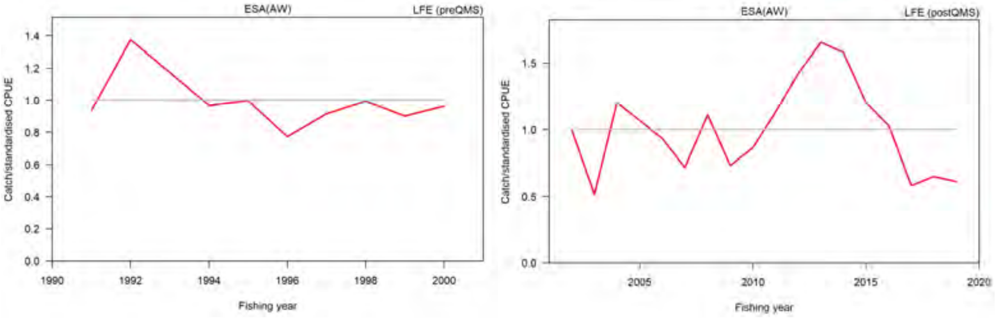
- **Southland (AW) longfin**

Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Standardised CPUE
Reference Points	Target: B_{MSY} assumed, but not estimated Interim Soft Limit: Mean CPUE from 2006–07 to 2009–10 Hard Limit: 50% of Soft Limit Overfishing threshold: F_{MSY} assumed, but not estimated
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Comparison of standardised CPUE for longfin eels in Southland (AW) from 1990–91 to 1999–2000 (pre-QMS) and 2001–02 to 2018–19 (post-QMS) (from Beentjes in press). Also shown is the total estimated core fisher longfin catch in AW from ECERs. The two CPUE series have been scaled to the mean of each time series. Horizontal lines post-QMS represent the soft and hard limits. 2000 = 1999–2000 fishing year. Error bars are 95% confidence intervals.



Annual relative exploitation rate for longfin eels in the Southland (AW) pre- and post-QMS. 2000 = 1999–2000 fishing year.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Pre-QMS CPUE declined steadily from 1990–91 to 1998–98 and increased to 1999–2000. Post-QMS CPUE is variable with no long-term trend.
Recent Trend in Fishing intensity or Proxy	Relative exploitation rate has fluctuated without trend since 2002.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline under recent levels of catch and exploitation rate
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) if catch remains at current levels Hard Limit: Unlikely (< 40%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series (pre-QMS)	

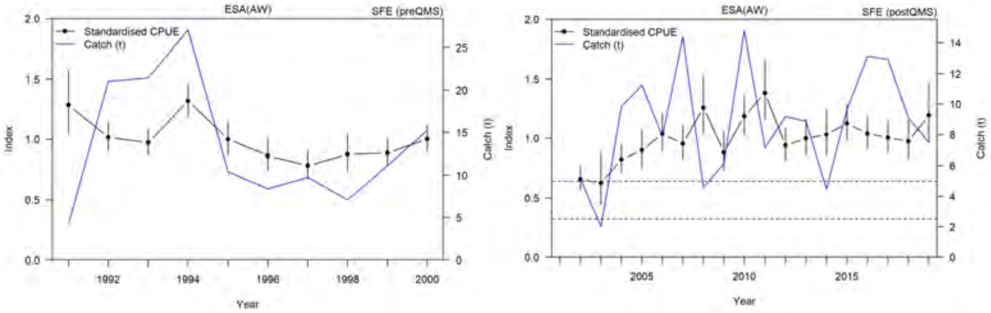
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as culling (primarily 1930s to 1950s) and habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The basis for the biological reference points is tenuous and should be revised whenever new relevant information becomes available. The proportion of current longfin habitat in Southland (Statistical Area AW) fished commercially during the period 2009–10 and 2013–14 is estimated at 32% (Table 15). The proportion of virgin habitat impacted by hydro dams, commercial fishing and other anthropogenic activity was estimated to be 41%.

Fishery Interactions
Bycatch of other species in the commercial eel fishery is low and may include brown trout, giant bullies, kōura, galaxiids, and common bullies in order of amount caught. Bycatch species are usually returned alive.

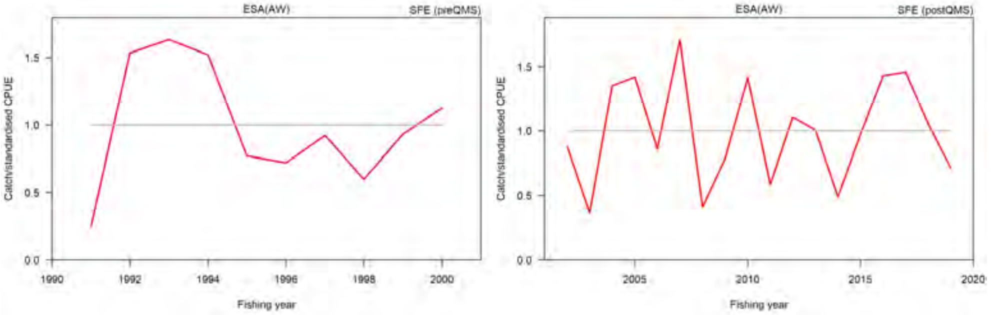
- **Southland (AW) shortfin**

Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Standardised CPUE
Reference Points	Target: B_{MSY} assumed, but not estimated Interim Soft Limit: Mean CPUE from 2001–02 to 2002–03 Hard Limit: 50% of Soft Limit Overfishing threshold: F_{MSY} assumed, but not estimated
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Comparison of standardised CPUE for shortfin eels in Southland (AW) from 1990–91 to 1999–2000 (pre-QMS) and 2001–02 to 2018–19 (post-QMS) (from Beentjes in press). Also shown is the total estimated core fisher shortfin catch in AW from ECERs. The two CPUE series have been scaled to the mean of each time series. Horizontal lines post-QMS represent the soft and hard limits. 2000 = 1999–2000 fishing year. Error bars are 95% confidence intervals.



Annual relative exploitation rate for shortfin eels in the Southland (AW) pre- and post-QMS. 2000 = 1999–2000 fishing year.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Pre-QMS CPUE declined slowly from 1990–91 to 1996–97 and then gradually increased to 1999–2000. Post-QMS CPUE fluctuated but increased substantially from 2001–02 to 2018–19.
Recent Trend in Fishing intensity or Proxy	Relative exploitation rate has fluctuated without trend since 2002.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Likely to remain stable in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) if the catch remains at current levels Hard Limit: Very Unlikely (< 10%) if the catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown if catch remains at current levels

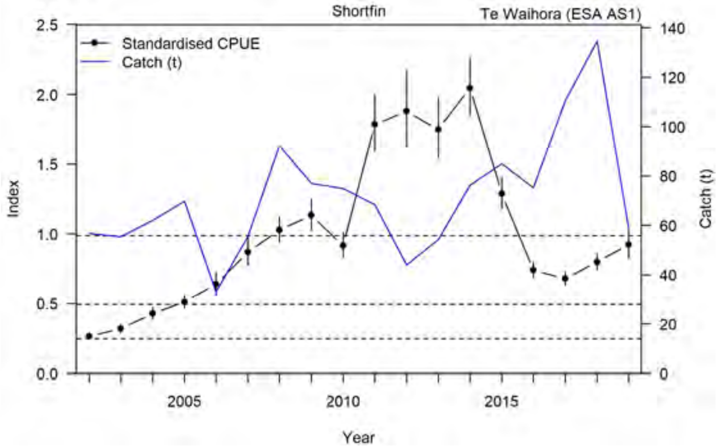
Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series (pre-QMS)	

Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as culling (primarily 1930s to 1950s) and habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The basis for the biological reference points is tenuous and should be revised whenever new relevant information becomes available.

Fishery Interactions
Bycatch of other species in the commercial eel fishery is low and may include brown trout, giant bullies, kōura, galaxiids, and common bullies in order of amount caught. Bycatch species are usually returned alive.

- **Te Waihora (AS1) shortfin**

Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Standardised CPUE of feeder eels in AS1
Reference Points	Interim Target: B_{MSY}-compatible proxy based on mean CPUE for the period: 2006–07 to 2009–10. Soft Limit: 50% of target Hard Limit: 50% of soft limit Overfishing threshold: F_{MSY}
Status in relation to Target	About as Likely as Not (40–60%) to be at or above B_{MSY}
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Overfishing is About as Likely as Not (40–60%) to be occurring

Historical Stock Status Trajectory and Current Status
 **Comparison of standardised CPUE for shortfin eels in Te Waihora (AS1) from 2001–02 to 2018–19 (post-QMS) (from Beentjes in press). Also shown is the total estimated core fisher shortfin catch in AS1 from ECERs. The CPUE series have been scaled to the mean of each time series. Horizontal lines represent the target, and soft and hard limits. 2002 = 2001–2002 fishing year. Error bars are 95% confidence intervals.**  **Annual relative exploitation rate for shortfin eels in the Te Waihora (AS1) post-QMS. 2002 = 2001–02 fishing year. Horizontal dashed line represents the overfishing threshold which is the mean relative exploitation rate for the target reference period.**

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE of feeder shortfin eels in Te Waihora (AS1) increased 7-fold from 2001–02 to 2010–11, before levelling off between 2011 and 2014, followed by a steep decline to below the target in 2016. CPUE increased gradually after 2016 to about the target in 2019.
Recent Trend in Fishing intensity or Proxy	Relative exploitation rate declined substantially (9-fold) from 2002 to 2012, then increased 7-fold before another steep decline after 2019.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment. Increasing mean size since the mid-1990s suggests reduced exploitation rates. Mean size appears to have declined since the peak CPUE in 2011 to 2014.

Projections and Prognosis	
Stock Projections or Prognosis	About as Likely as not (40–60%) to remain at or above the target in the medium term under current catch levels Likely (> 60%) to decline if the catch of feeder eels increased to the level of the TACC
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) if catch remains at current levels Hard Limit: Very Unlikely (< 10%) if catch remains at current levels Likely (> 60%) to decline below the soft limit if catch were to increase to the level of the TACC, especially if all the catch is taken from AS1
Probability of Current Catch or TACC causing Overfishing to continue or to commence	About as Likely as Not (40–60%) if catch remains at current levels Very Likely (> 90%) if catch was to increase to the level of the TACC and if all of the catch was taken from AS1. AS2 catch (migrating shortfin males) has declined in the last few years and was zero in 2019.

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Exclusion of zero catches • Changes in MLS and retention in early parts of the series (pre-QMS)	

Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The shortfin eel catch from Te Waihora comprises small migrant males from AS2 and feeder females from AS1. The index of abundance is based on the catch rates of feeder eels. The basis for the biological reference points is tenuous and should be revised whenever new relevant information becomes available. Commercial fishers in Te Waihora have varied the size of escape tubes since 2015 to avoid smaller eels when there was no market for them.

Fishery Interactions
Bycatch of other species in the commercial eel fishery may include: bullies, black flounder, yellowbelly flounder, sand flounder, and goldfish in order of the amount caught. The flatfish

species are usually released alive or retained if caught under quota. Longfin eels are not abundant and are usually voluntarily released alive. All other bycatch is released alive.

Status of North Island Eels

Level 2 Partial Quantitative Stock Assessments are conducted by statistical area and species where accepted indices of abundance are available. Standardised CPUE provides information on the abundance of commercially harvested eels (300–4000 g) in areas that are fished commercially.

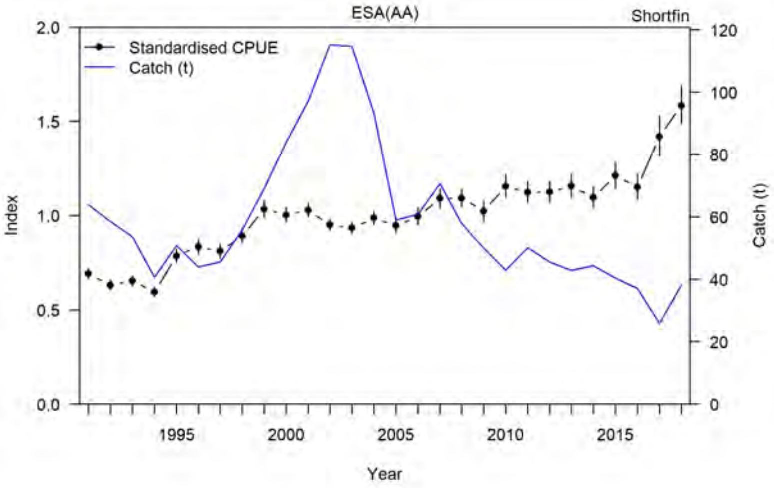
Aproximately 73% of current longfin habitat in the North Island is either in reserves or in areas rarely or never fished by commercial fishers. Statements regarding the status of longfin eels in relation to reference points are made separately for the entire ESA and for the area commercially fished within it. There is no information available on the proportion of shortfin habitat in each ESA that is fished commercially.

QMA SFE 20 and LFE 20 (includes ESAs AA and AB)

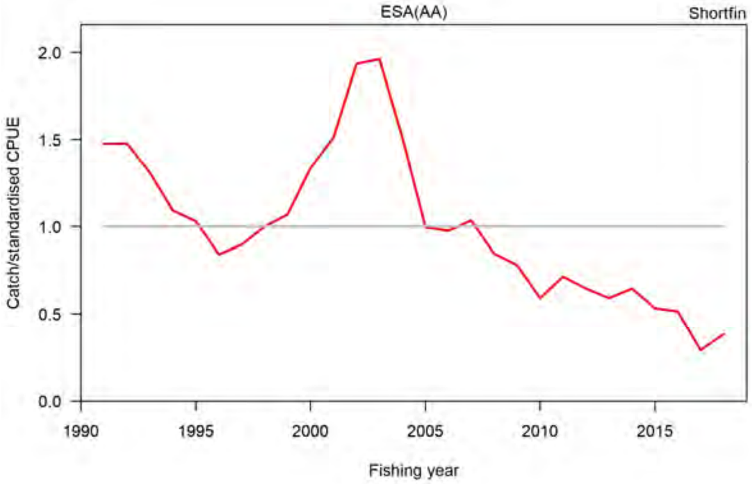
- **Northland (AA) shortfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	Target: B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for shortfin eels in Northland (AA) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher shortfin catch in AA from ECERs. Error bars are 95% confidence intervals. Before 2001, 37% of the catch was recorded as EEU (unidentified) and these catches are omitted. 2000 = 1999–2000 fishing year.



Annual relative exploitation rate for shortfin eels in the Northland (AA). Because some catch of shortfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2001.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Increasing trend in CPUE since early 1990s, with steep increase in the last two years
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has declined steeply since 2003 and in 2018 was well below the series mean
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches	

	- Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 - Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained

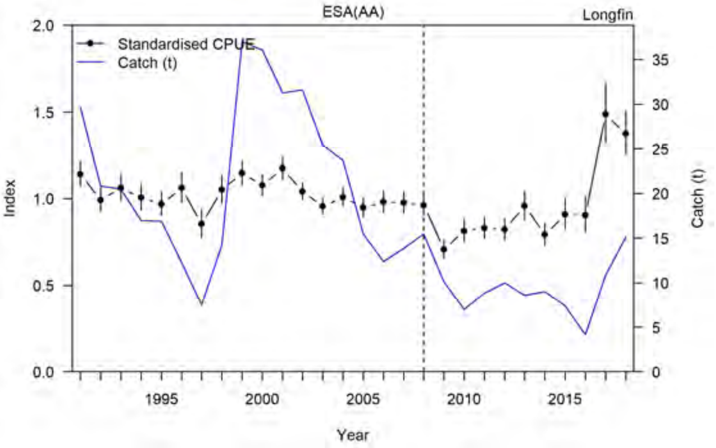
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

Fishery Interactions
Bycatch of other species in the commercial Northland eel fishery includes mainly catfish, with lesser quantities of kōura, goldfish, and perch. Most bycatch species are usually returned alive.

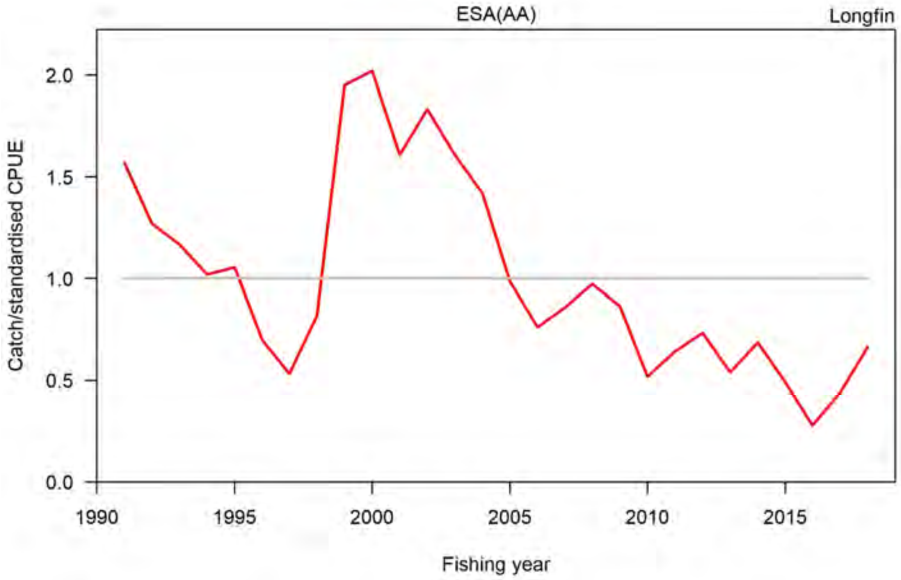
- **Northland (AA) longfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	For ESA, Interim Target is 40% B_0 For commercially fished area, Target is B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 For ESA, Overfishing threshold is F_{MSY} For commercially fished area, Overfishing threshold is F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	For total ESA: Likely (> 60%) to be at or above For fished area: Unknown
Status in relation to Limits	For ESA, Soft Limit: Very Unlikely (< 10%) to be below For ESA, Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	For ESA: Unlikely (< 40%) to be overfishing For fished area: Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for longfin eels in Northland (AA) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher longfin catch in AA from ECERs. Error bars are 95% confidence intervals. Vertical dashed line indicates when the 4 kg maximum size was introduced in 2007–08 after which longfin eels 4 kg and over are not recorded on ECERs. Before 2001, 37% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for longfin eels in the Northland (AA). Because some catch of longfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2001.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Very slight downward trend in CPUE over the time series, with large increase in last two years.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has declined steeply since 2002 and in 2018 was well below the series mean.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For ESA, Soft Limit: Very Unlikely (< 10%) if catch remains at current levels For ESA, Hard Limit: Very Unlikely (< 10%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For ESA, Unlikely (< 40%) if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	

Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers (for some ESAs) • Uncertainty in the method used to derive target species • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-sized eel caught, not just those retained • Unrecorded release of > 4kg eels since 2007–08

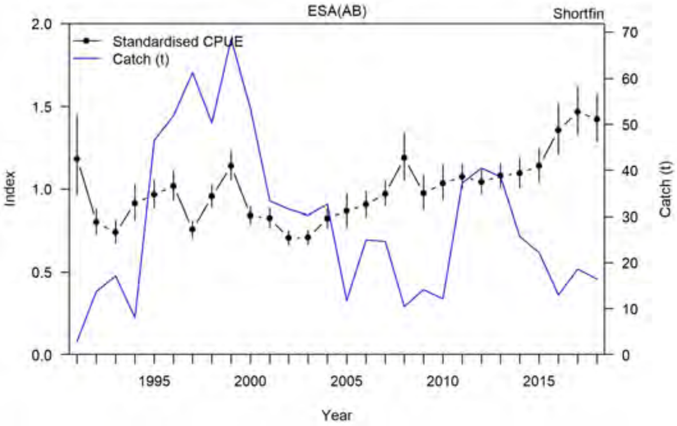
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The proportion of current longfin habitat in Northland (Statistical Area AA) fished commercially during the period 2009–10 and 2013–14 is estimated at 36% (Table 15). The proportion of virgin habitat impacted by hydro dams, commercial fishing, and other anthropogenic activity was estimated to be 40%.

Fishery Interactions
Bycatch of other species in the commercial Northland eel fishery includes mainly catfish, with lesser quantities of kōura, goldfish and perch. Most bycatch species are usually returned alive.

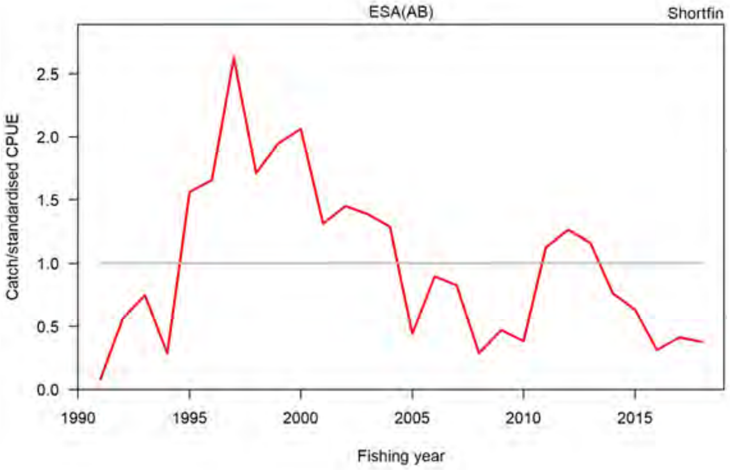
- **Auckland (AB) shortfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	Target: B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for shortfin eels in Auckland (AB) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher shortfin catch in AB from ECERs. Error bars are 95% confidence intervals. Before 2000, 26% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for shortfin eels in the Auckland (AB). Because some catch of shortfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2000.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	No trend in CPUE until 2003, after which it increases consistently and steeply in the last three years.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate declined from 2012 and in 2018 was below the series mean.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained	

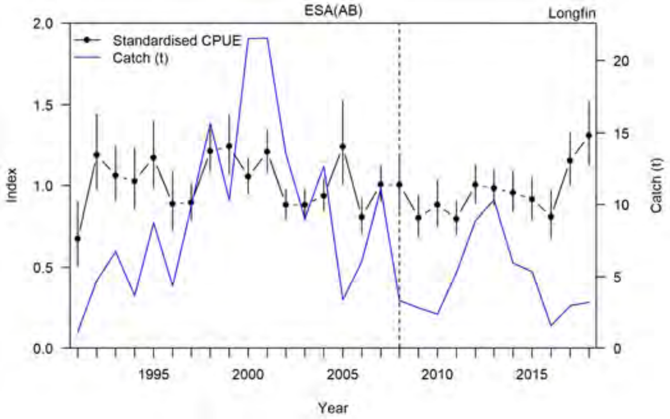
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

Fishery Interactions
Bycatch of other species in the commercial Auckland eel fishery includes mainly catfish, with lesser quantities of koi carp, goldfish, kōura, grey mullet, and yellowbelly flounder. Most bycatch species are usually returned alive.

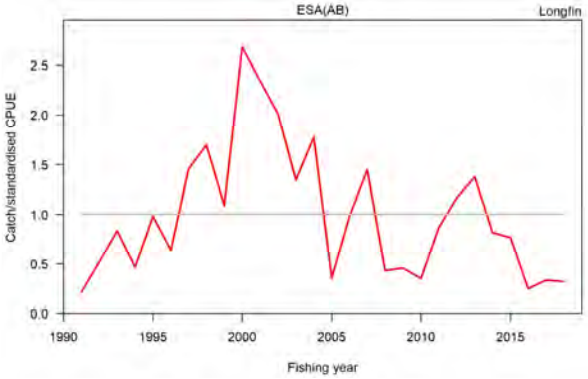
- **Auckland (AB) longfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	For ESA, Interim Target is 40% B_0 For commercially fished area, Target is B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 For ESA, Overfishing threshold is F_{MSY} For commercially fished area, Overfishing threshold is F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	For total ESA: Likely (> 60%) to be at or above For fished area: Unknown
Status in relation to Limits	For ESA, Soft Limit: Very Unlikely (< 10%) to be below For ESA, Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	For ESA: Unlikely (< 40%) to be overfishing For fished area: Unknown

Historical Stock Status Trajectory and Current Status



Comparison of standardised CPUE for longfin eels in Auckland (AB) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher longfin catch in AB from ECERs. Vertical dashed line indicates when the 4 kg maximum size was introduced in 2007–08 after which longfin eels 4 kg and over are not recorded on ECERs. Error bars are 95% confidence intervals. Before 2000, 26% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for longfin eels in the Auckland (AB). Because some catch of longfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have beenhigher than shown before 2000.

Fishery and Stock Trends

Recent Trend in Biomass or Proxy	A slight decline in CPUE to 2016, with a steep increase in the last two years.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has declined since 2013 and in 2018 was below the series mean.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis

Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For ESA, Soft Limit: Very Unlikely (< 10%) if catch remains at current levels For ESA, Hard Limit: Very Unlikely (< 10%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For ESA, Unlikely (< 40%) if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only providndex of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained • Unrecorded release of > 4kg eels since 2007–08	

Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The proportion of current longfin habitat in Auckland (Statistical Area AB) fished commercially during the period 2009–10 and 2013–14 is estimated at 35% (Table 15). The proportion of virgin habitat impacted by hydro dams, commercial fishing, and other anthropogenic activity was estimated to be 38%.

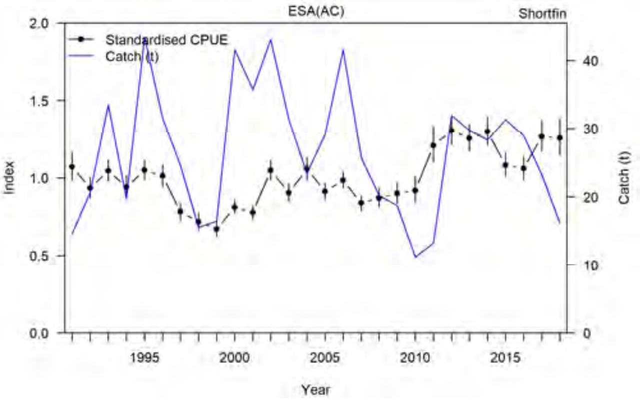
Fishery Interactions
Bycatch of other species in the commercial Auckland eel fishery includes mainly catfish, with lesser quantities of koi carp, goldfish, kōura, grey mullet, and yellowbelly flounder. Most bycatch species are usually returned alive.

QMA SFE 21 and LFE 21 (includes ESAs AC, AD, AE and AF)

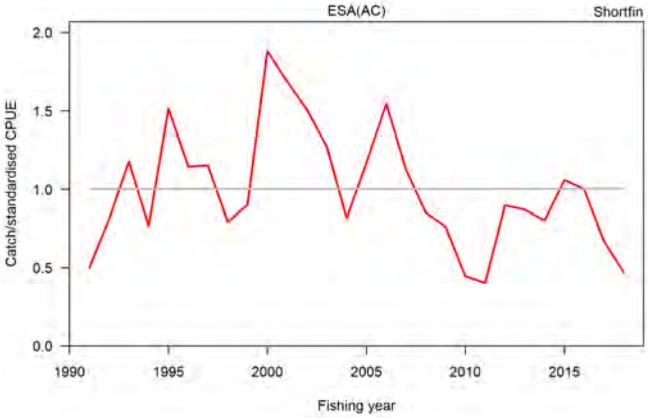
- **Hauraki (AC) shortfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	Target: B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for shortfin eels in Hauraki (AC) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher shortfin catch in AC from ECERs. Error bars are 95% confidence intervals. Before 2002, 16% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for shortfin eels in the Hauraki (AC). Because some catch of shortfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2002.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	No trend in CPUE until 2010, after which it has increased
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has declined since 2006, and in 2018 was below the series mean.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained	

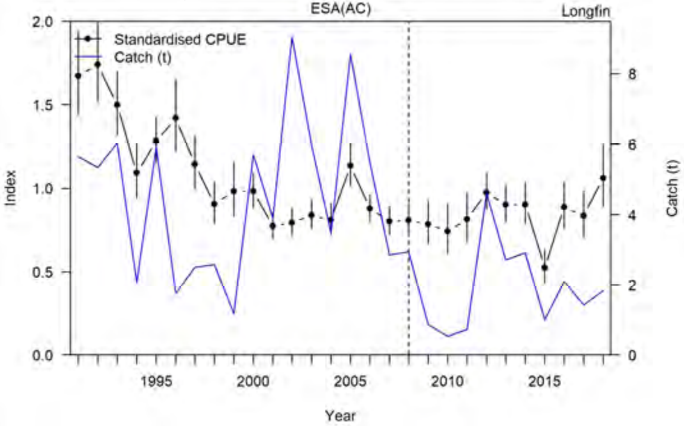
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

Fishery Interactions
Bycatch of other species in the commercial Hauraki eel fishery includes mainly catfish, with lesser quantities of brown trout, goldfish, koi carp, and kōkopu. Most bycatch species are usually returned alive.

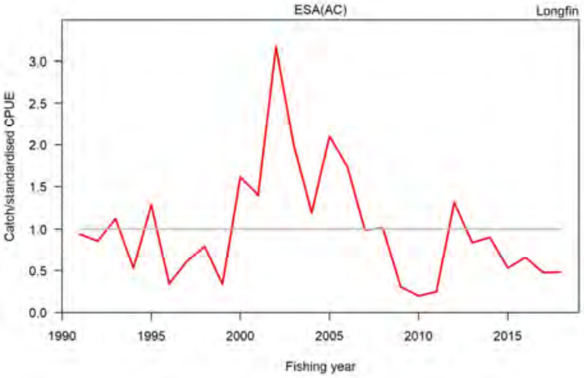
- **Hauraki (AC) longfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	For ESA, Interim Target is 40% B_0 For commercially fished area, Target is B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 For ESA, Overfishing threshold is F_{MSY} For commercially fished area, Overfishing threshold is F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	For total ESA: Likely (> 60%) to be at or above For fished area: Unknown
Status in relation to Limits	For ESA, Soft Limit: Very Unlikely (< 10%) to be below For ESA, Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	For ESA: Unlikely (< 40%) to be overfishing For fished area: Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for longfin eels in Hauraki (AC) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher longfin catch in AC from ECERs. Vertical dashed line indicates when the 4 kg maximum size was introduced in 2007–08 after which longfin eels 4 kg and over are not recorded on ECERs. Error bars are 95% confidence intervals. Before 2002, 16% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for longfin eels in the Hauraki (AC). Because some catch of longfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2002.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Steep decline in CPUE to 2000–01, and then without trend/stable to 2017–18
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has declined steeply since 2012 and in 2018 was well below the average for the series.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.
Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For ESA, Soft Limit: Very Unlikely (< 10%) if catch remains at current levels For ESA, Hard Limit: Very Unlikely (< 10%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For ESA, Unlikely (< 40%) if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained • Unrecorded release of > 4kg eels since 2007–08	

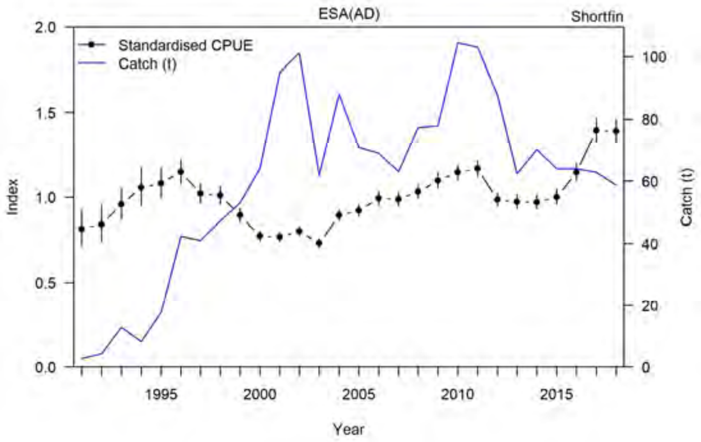
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The proportion of current longfin habitat in Hauraki (Statistical Area AC) fished commercially during the period 2009–10 and 2013–14 is estimated at 50% (Table 15). The proportion of virgin habitat impacted by hydro dams, commercial fishing, and other anthropogenic activity was estimated to be 55%.

Fishery Interactions
Bycatch of other species in the commercial Hauraki eel fishery includes mainly catfish, with lesser quantities of koi carp, goldfish, kōura, grey mullet, and yellowbelly flounder. Most bycatch species are usually returned alive.

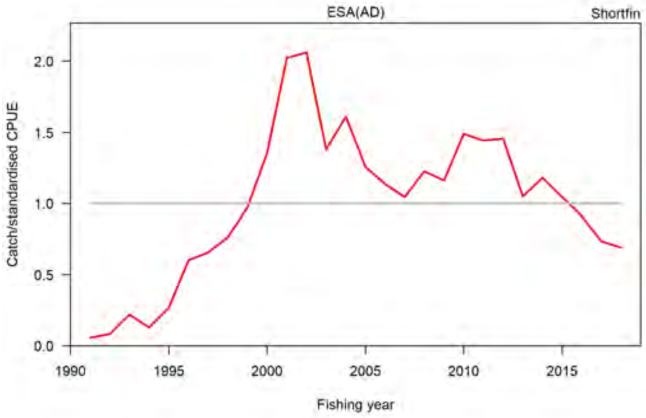
- **Waikato (AD) shortfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	Target: B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for shortfin eels in Waikato (AD) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher shortfin catch in AD from ECERs. Error bars are 95% confidence intervals. Before 2002, 71% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for shortfin eels in the Waikato (AD). Because considerable catch of shortfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been much higher than shown before 2002.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	No long-term trend in CPUE until 2003, after which it increased, most steeply in the last three years.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has declined since 2009 and in 2018 was below the series mean.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained	

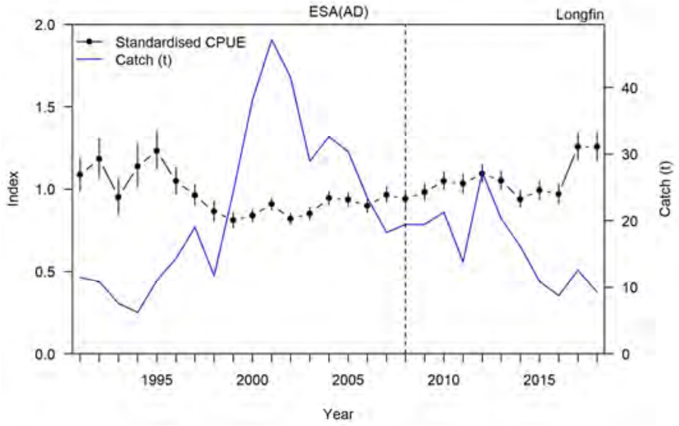
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

Fishery Interactions
Bycatch of other species in the commercial Waikato eel fishery includes large quantities of catfish and koi carp, as well as goldfish, rudd, kōura, brown trout, perch, and kōkopu. Most bycatch species are usually returned alive.

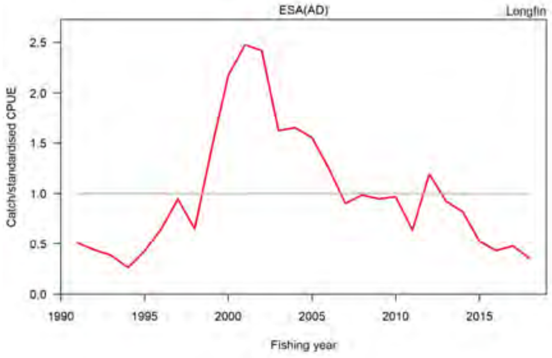
- **Waikato (AD) longfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	For ESA, Interim Target is 40% B_0 For commercially fished area, Target is B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 For ESA, Overfishing threshold is F_{MSY} For commercially fished area, Overfishing threshold is F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	For total ESA: Likely (> 60%) to be at or above For fished area: Unknown
Status in relation to Limits	For ESA, Soft Limit: Very Unlikely (< 10%) to be below For ESA, Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	For ESA: Unlikely (< 40%) to be overfishing For fished area: Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for longfin eels in Waikato (AD) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher longfin catch in AD from ECERs. Vertical dashed line indicates when the 4 kg maximum size was introduced in 2007–08 after which longfin eels 4 kg and over are not recorded on ECERs. Error bars are 95% confidence intervals. Before 2002, 71% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for longfin eels in the Waikato (AD). Because considerable catch of longfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been much higher than shown before 2002.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	A moderate decline in CPUE to 1998, and then a gradual increase, steepest in the last two years to around the level of the former peak.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has declined steeply since 2002 and in 2018 was well below the series mean.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For ESA, Soft Limit: Very Unlikely (< 10%) if catch remains at current levels For ESA, Hard Limit: Very Unlikely (< 10%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For ESA, Unlikely (< 40%) if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained • Unrecorded release of > 4kg eels since 2007–08	

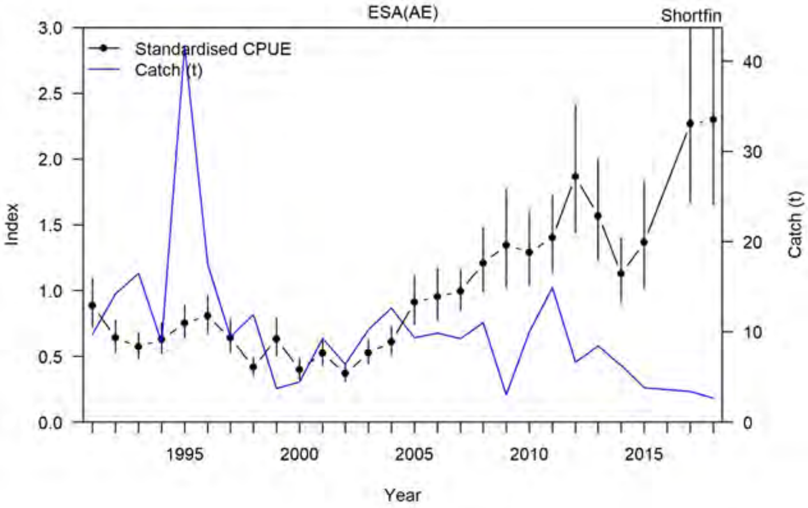
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The proportion of current longfin habitat in Waikato (Statistical Area AD) fished commercially during the period 2009–10 and 2013–14 is estimated at 43% (Table 15). The proportion of virgin habitat impacted by hydro dams, commercial fishing and other anthropogenic activity was estimated to be 56%.

Fishery Interactions
Bycatch of other species in the commercial Waikato eel fishery includes large quantities of catfish and koi carp, as well as goldfish, rudd, kōura, brown trout, perch, and kōkopu. Most bycatch species are usually returned alive.

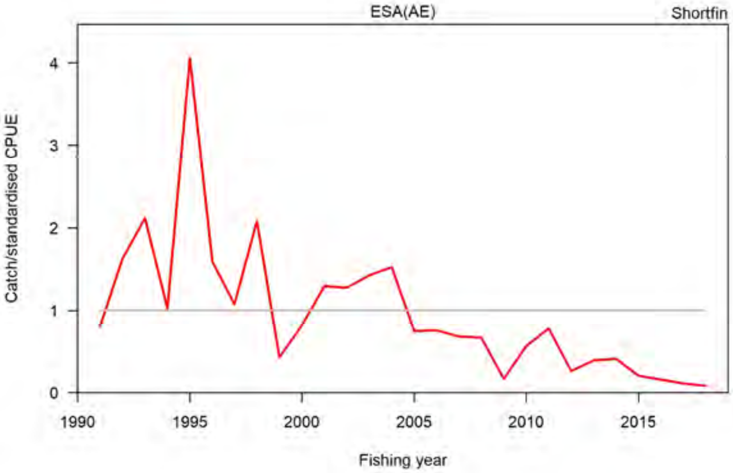
- **Bay of Plenty (AE) shortfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	Target: B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for shortfin eels in Bay of Plenty (AE) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher shortfin catch in AE from ECERs. Error bars are 95% confidence intervals. Before 2000, 13% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for shortfin eels in the Bay of Plenty (AE). Because some catch of shortfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2000.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	No trend in CPUE until 2002, after which it increases steeply to a peak in 2018.
Recent Trend in Fishing intensity or Proxy	Relative exploitation rate has declined since 2002, and in 2018 was well below the series mean.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels

Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained	

Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

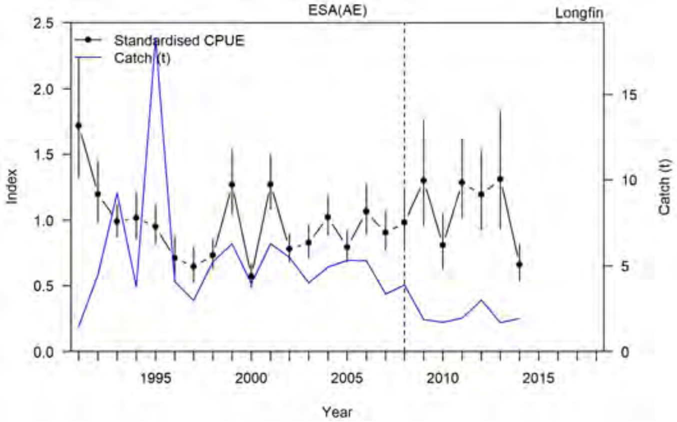
Fishery Interactions
Bycatch of other species in the commercial Bay of Plenty eel fishery includes very small quantities of goldfish and bullies. Most bycatch species are usually returned alive.

- **Bay of Plenty (AE) longfin**

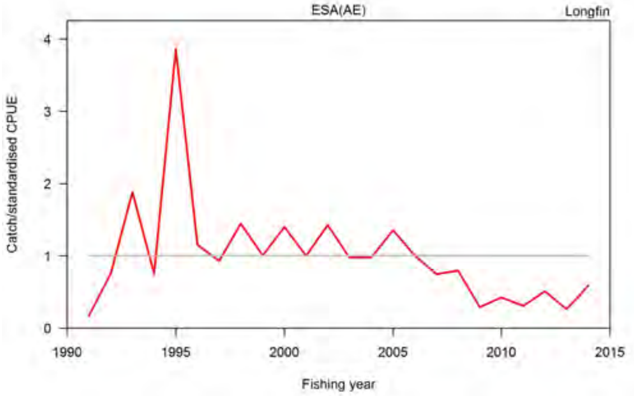
Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	For ESA, Interim Target is 40% B_0 For commercially fished area, Target is B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 For ESA, Overfishing threshold is F_{MSY} For commercially fished area, Overfishing threshold is F_{MSY} proxy based on relative exploitation rate; not determined

Status in relation to Target	For total ESA: Likely (> 60%) to be at or above For fished area: Unknown
Status in relation to Limits	For ESA, Soft Limit: Very Unlikely (< 10%) to be below For ESA, Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	For ESA: Unlikely (< 40%) to be overfishing For fished area: Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for longfin eels in Bay of Plenty (AE) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher longfin catch in AE from ECERs. Vertical dashed line indicates when the 4 kg maximum size was introduced in 2007–08 after which longfin eels 4 kg and over are not recorded on ECERs. Error bars are 95% confidence intervals. Before 2000, 13% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for longfin eels in the Bay of Plenty (AE). Because some catch of longfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2000.

Fishery and Stock Trends

Recent Trend in Biomass or Proxy	A steep decline in CPUE to 2000, and then variable with no clear trend. Insufficient data to produce indices after 2013–14.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has declined since 2005, and since 2007 has been below the series mean. Insufficient data to produce exploitation rate after 2013–14.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For ESA, Soft Limit: Very Unlikely (< 10%) if catch remains at current levels For ESA, Hard Limit: Very Unlikely (< 10%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For ESA, Unlikely (< 40%) if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained • Unrecorded release of > 4kg eels since 2007–08	

Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The proportion of current longfin habitat in Bay of Plenty (Statistical Area AE) fished commercially during the period 2009–10 and 2013–14 is estimated at 17% (Table 15). The proportion of virgin habitat impacted by hydro dams, commercial fishing, and other anthropogenic activity was estimated to be 24%.

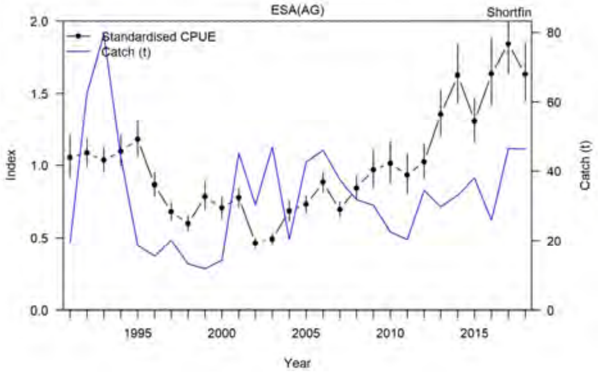
Fishery Interactions
Bycatch of other species in the commercial Bay of Plenty eel fishery includes very small quantities of goldfish and bullies. Most bycatch species are usually returned alive.

QMA SFE 22 and LFE 22 (includes ESAs AG, AK, AL and AM)

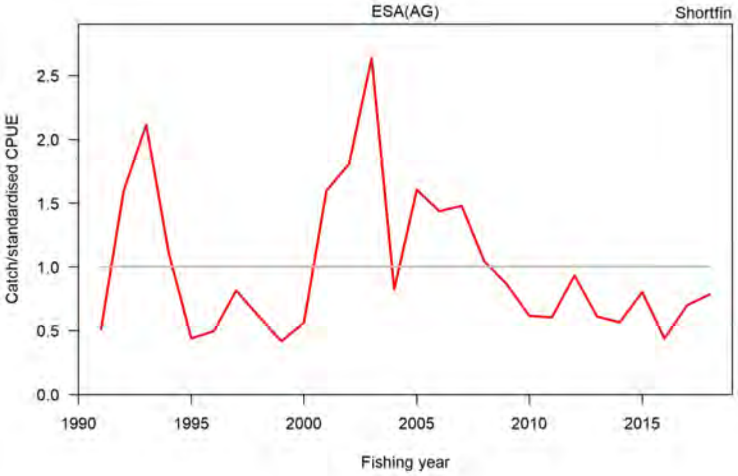
- **Hawkes Bay (AG) shortfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	Target: B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for shortfin eels in Hawkes Bay (AG) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher shortfin catch in AG from ECERs. Error bars are 95% confidence intervals. Before 2001, 5% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for shortfin eels in the Hawkes Bay (AG). Because some catch of shortfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2001.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE declined until 2002, followed by a steep increase to well above the previous peak in 1995.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has declined since 2007, and from 2009 has been below the series mean.

Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained	

Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

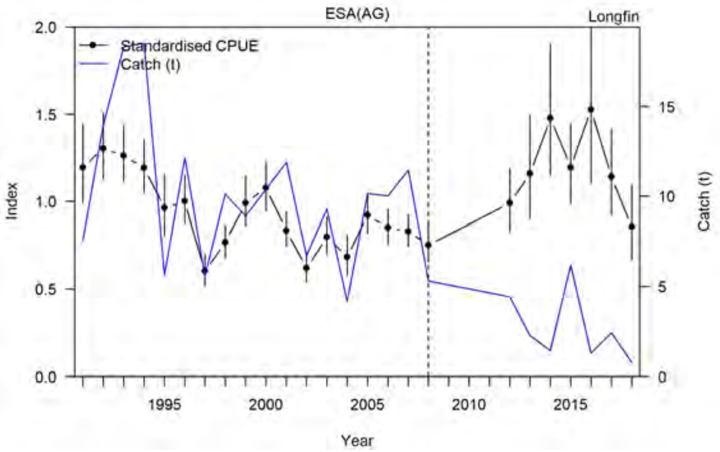
Fishery Interactions
Bycatch of other species in the commercial Hawkes Bay eel fishery includes mostly goldfish and small quantities of brown trout. Most bycatch species are usually returned alive.

- **Hawkes Bay (AG) longfin**

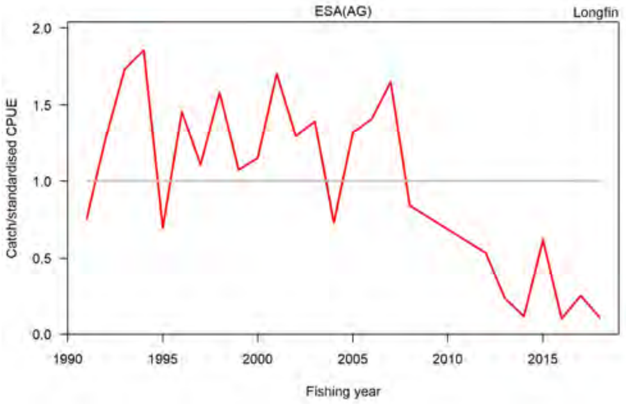
Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	For ESA, Interim Target is 40% B_0

	For commercially fished area, Target is B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 For ESA, Overfishing threshold is F_{MSY} For commercially fished area, Overfishing threshold is F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	For total ESA: Likely (> 60%) to be at or above For fished area: Unknown
Status in relation to Limits	For ESA, Soft Limit: Very Unlikely (< 10%) to be below For ESA, Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	For ESA: Unlikely (< 40%) to be overfishing For fished area: Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for longfin eels in Hawkes Bay (AG) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher longfin catch in AG from ECERs. Vertical dashed line indicates when the 4 kg maximum size was introduced in 2007–08 after which longfin eels 4 kg and over are not recorded on ECERs. Error bars are 95% confidence intervals. Before 2001, 5% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for longfin eels in the Hawke's Bay (AG). Because some catch of longfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2001.

Fishery and Stock Trends

Recent Trend in Biomass or Proxy	CPUE declined until 1997, was stable until 2008 and then increased until 2015–16, declining steeply in the last two years.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has declined steeply since 2007, and in 2018 was well below the series mean.

Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For ESA, Soft Limit: Very Unlikely (< 10%) if catch remains at current levels For ESA, Hard Limit: Very Unlikely (< 10%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For ESA, Unlikely (< 40%) if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained • Unrecorded release of > 4kg eels since 2007–08	

Qualifying Comments

Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

The proportion of current longfin habitat in Hawkes Bay (Statistical Area AG) fished commercially during the period 2009–10 and 2013–14 is estimated at 17% (Table 15). The proportion of virgin habitat impacted by hydro dams, commercial fishing, and other anthropogenic activity was estimated to be 25%.

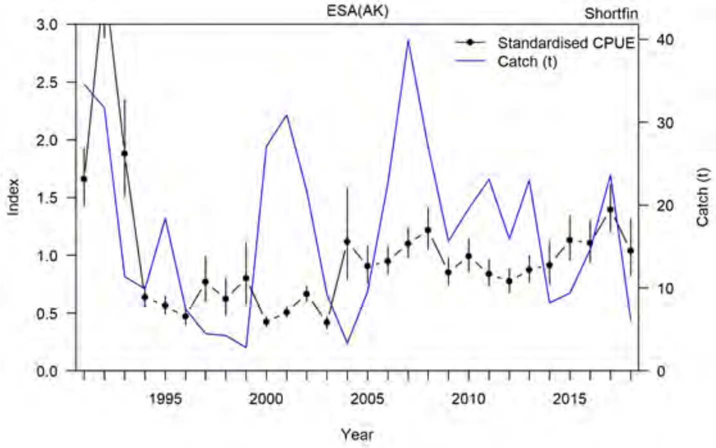
Fishery Interactions

Bycatch of other species in the commercial Hawkes Bay eel fishery includes mostly goldfish and small quantities of brown trout. Most bycatch species are usually returned alive.

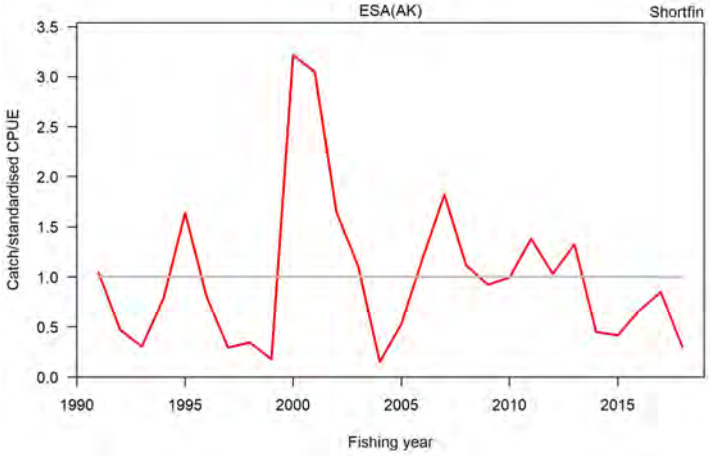
- **Manawatu (AK) shortfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	Target: B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for shortfin eels in Manawatu (AK) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher shortfin catch in AK from ECERs. Error bars are 95% confidence intervals. Before 2001, 56% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for shortfin eels in the Manawatu (AK). Because some catch of shortfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2001.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE dropped markedly from 1992 to 1994, was stable until an increase in 2004, and has since fluctuated without a long-term trend.

Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has declined since 2013, and in 2018 was below the series mean.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained	

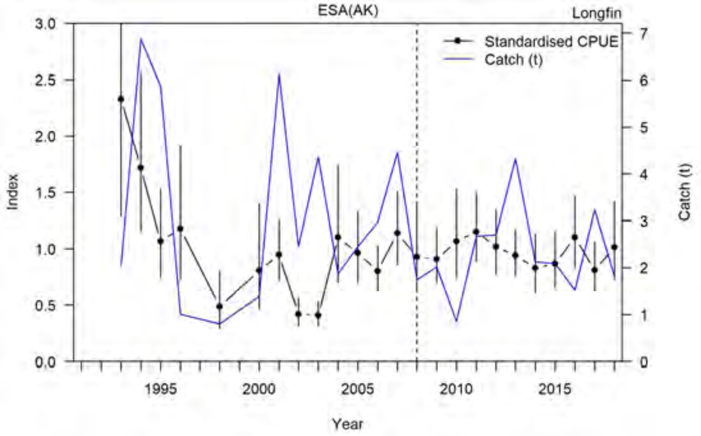
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

Fishery Interactions
Bycatch in the commercial Manawatu eel fishery include small quantities of koi carp, black flounder, yellowbelly flounder, and perch. Most bycatch species are usually returned alive.

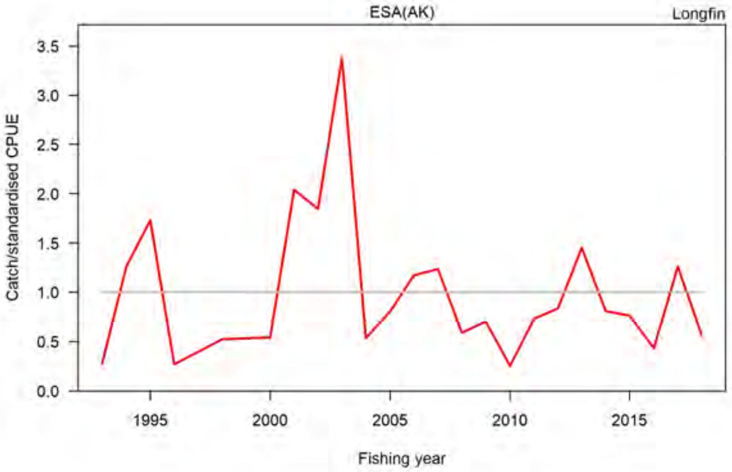
- **Manawatu (AK) longfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	For ESA, Interim Target is 40% B_0 For commercially fished area, Target is B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 For ESA, Overfishing threshold is F_{MSY} For commercially fished area, Overfishing threshold is F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	For total ESA: Likely (> 60%) to be at or above For fished area: Unknown
Status in relation to Limits	For ESA, Soft Limit: Very Unlikely (< 10%) to be below For ESA, Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	For ESA: Unlikely (< 40%) to be overfishing For fished area: Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for longfin eels in Manawatu (AK) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher longfin catch in AK from ECERs. Vertical dashed line indicates when the 4 kg maximum size was introduced in 2007–08 after which longfin eels 4 kg and over are not recorded on ECERs. Error bars are 95% confidence intervals. Before 2001, 56% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for longfin eels in the Manawatu (AK). Because some catch of longfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2001.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE declined steeply until 2003, increased in 2004, and has fluctuated without trend since then.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate has fluctuated around the series mean since 2003 and in 2018 was below the series mean.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For ESA, Soft Limit: Very Unlikely (< 10%) if catch remains at current levels For ESA, Hard Limit: Very Unlikely (< 10%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For ESA, Unlikely (< 40%) if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained • Unrecorded release of > 4kg eels since 2007–08	

Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The proportion of current longfin habitat in Manawatu (Statistical Area AK) fished commercially during the period 2009–10 and 2013–14 is estimated at 36% (Table 15). The proportion of virgin

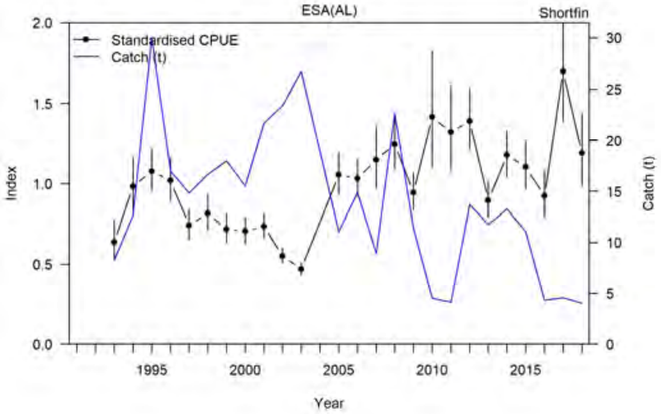
habitat impacted by hydro dams, commercial fishing, and other anthropogenic activity was estimated to be 41%.

Fishery Interactions
Bycatch in the commercial Manawatu eel fishery include small quantities of koi carp, black flounder, yellowbelly flounder, and perch. Most bycatch species are usually returned alive.

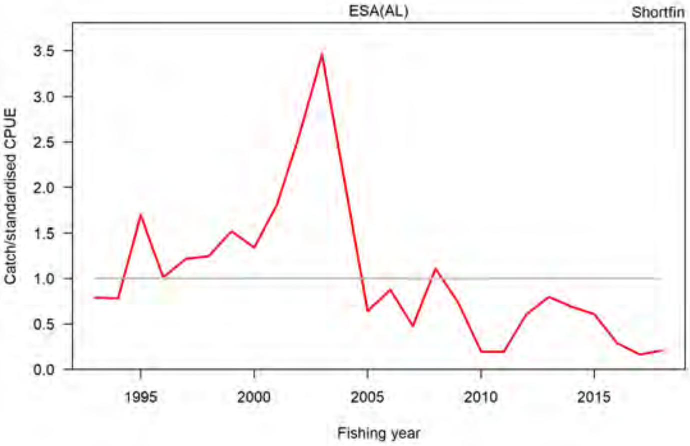
- **Wairarapa (AL) shortfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	Target: B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for shortfin eels in Wairarapa (AL) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher shortfin catch in AL from ECERs. Error bars are 95% confidence intervals. Before 1999, 33% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for shortfin eels in the Wairarapa (AL). Because some catch of shortfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 1999.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE declined from 1995 to 2003, increased in 2005, and has fluctuated without trend since then.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate declined steeply after 2003, and has been below the series mean since 2005.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained	

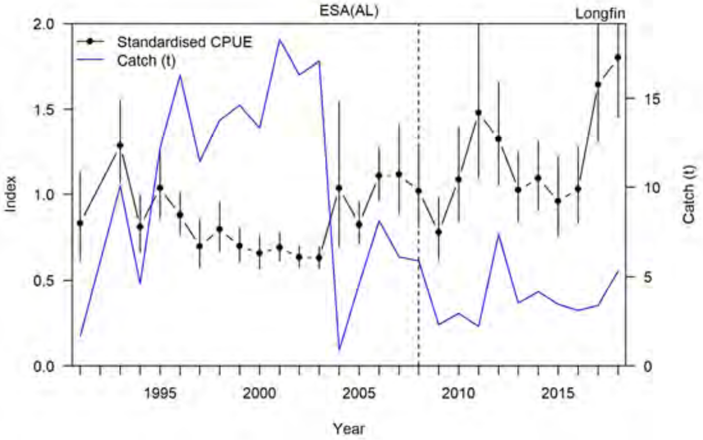
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

Fishery Interactions
Bycatch in the commercial Wairarapa eel fishery include mostly rudd and perch, with smaller quantities of flatfish and goldfish. Most bycatch species are usually returned alive.

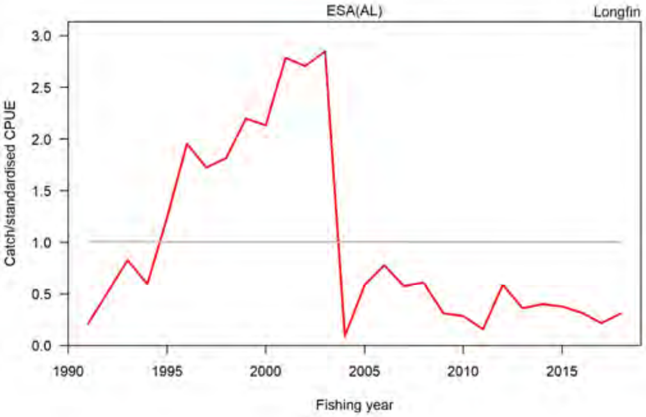
- **Wairarapa (AL) longfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	For ESA, Interim Target is 40% B_0 For commercially fished area, Target is B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 For ESA, Overfishing threshold is F_{MSY} For commercially fished area, Overfishing threshold is F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	For total ESA: Likely (> 60%) to be at or above For fished area: Unknown
Status in relation to Limits	For ESA, Soft Limit: Very Unlikely (< 10%) to be below For ESA, Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	For ESA: Unlikely (< 40%) to be overfishing For fished area: Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for longfin eels in Wairarapa (AL) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher longfin catch in AL from ECERs. Vertical dashed line indicates when the 4 kg maximum size was introduced in 2007–08 after which longfin eels 4 kg and over are not recorded on ECERs. Error bars are 95% confidence intervals. Before 1999, 33% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for longfin eels in the Wairarapa (AL). Because some catch of longfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 1999.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE declined until 2003, increased in 2004, and fluctuated without trend until the last two years when CPUE increased steeply
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate declined steeply after 2003, and has been below the series mean since 2005.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For ESA, Soft Limit: Very Unlikely (< 10%) if catch remains at current levels For ESA, Hard Limit: Very Unlikely (< 10%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For ESA, Unlikely (< 40%) if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained • Unrecorded release of > 4kg eels since 2007–08	

Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The proportion of current longfin habitat in Wairarapa (Statistical Area AL) fished commercially during the period 2009–10 and 2013–14 is estimated at 4% (Table 15) (Beentjes et al 2016). The

proportion of virgin habitat impacted by hydro dams, commercial fishing, and other anthropogenic activity was estimated to be 5%.

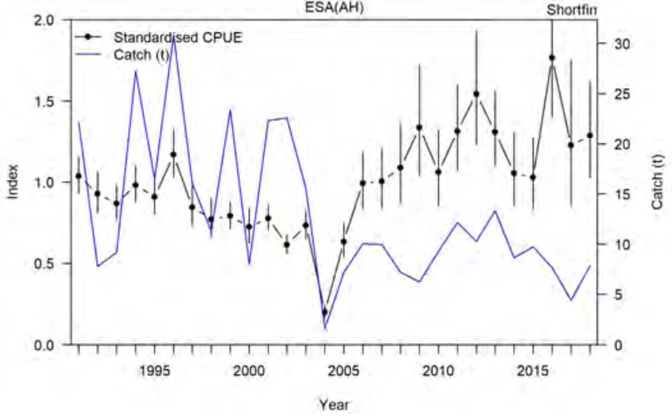
Fishery Interactions
There has been no recorded bycatch in the commercial Wairarapa eel fishery since 2000–01. Most bycatch species are usually returned alive.

QMA SFE 23 and LFE 23 (includes ESAs AH, AJ)

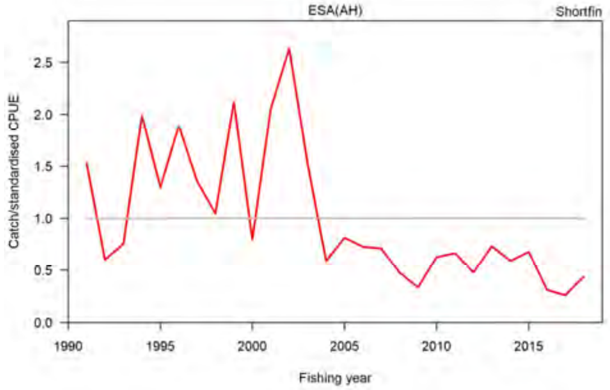
- **Rangitikei-Whanganui (AH) shortfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	Target: B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for shortfin eels in Rangitikei-Whanganui (AH) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher shortfin catch in AH from ECERs. Error bars are 95% confidence intervals. Before 2001, 7% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for shortfin eels in the Rangitikei-Whanganui (AH). Because some catch of shortfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2001.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE declined gradually until 2005, and then increased to well above the former peak.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate declined steeply after 2003, and has been below the series mean since 2004.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained	

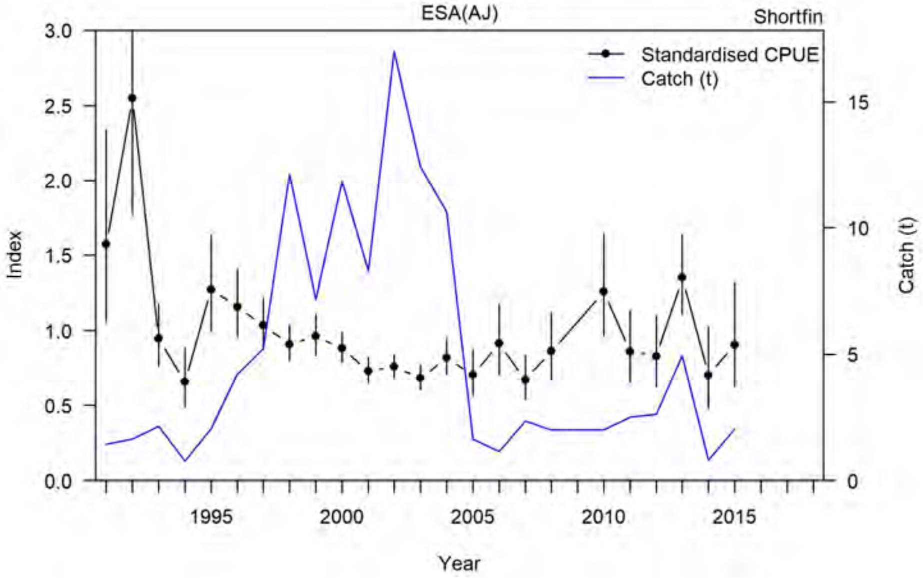
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

Fishery Interactions
The only recorded bycatch in the commercial Rangitikei-Whanganui eel fishery since 2000–01 has been brown trout. Most bycatch species are usually returned alive.

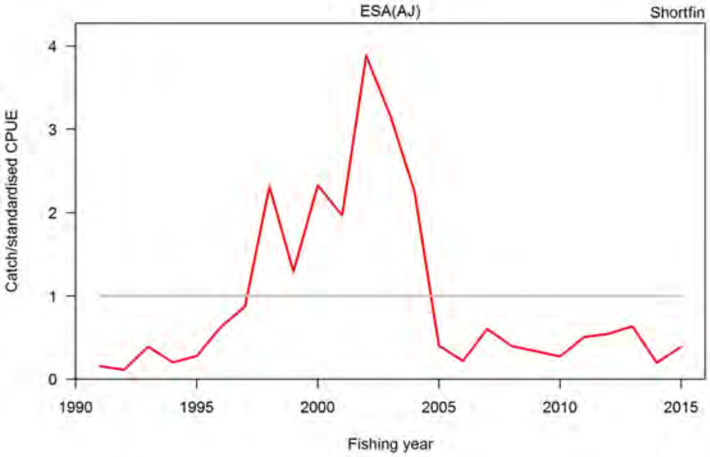
- **Taranaki (AJ) shortfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	Target: B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for shortfin eels in Taranaki (AJ) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher shortfin catch in AJ from ECERs. Error bars are 95% confidence intervals. Before 2001, 16% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for shortfin eels in the Taranaki (AJ). Because some catch of shortfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2001.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE declined to 2003, and then fluctuated without trend. There were insufficient data to generate indices after 2014–15.
Recent Trend in Fishing intensity or Proxy	Relative exploitation rate declined steeply after 2002, and has been below the series mean since 2005. There were insufficient data to generate relative exploitation rates after 2014–15.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of shortfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained	

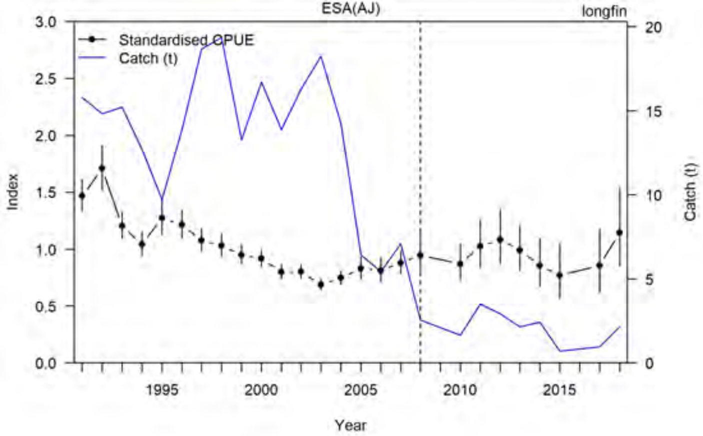
Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series.

Fishery Interactions
There has been no recorded bycatch in the commercial Taranaki eel fishery since 2000–01. Most bycatch species are usually returned alive.

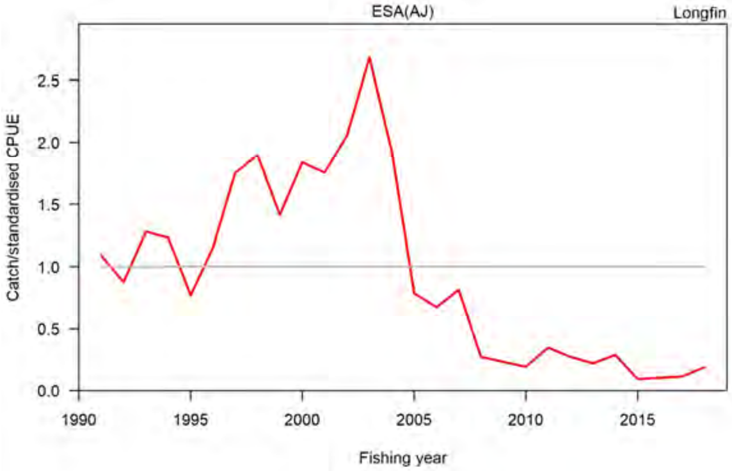
- **Taranaki (AJ) longfin**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE on positive catch
Reference Points	For ESA, Interim Target is 40% B_0 For commercially fished area, Target is B_{MSY} proxy based on CPUE; not determined Default Soft Limit: 20% B_0 Default Hard Limit: 10% B_0 For ESA, Overfishing threshold is F_{MSY} For commercially fished area, Overfishing threshold is F_{MSY} proxy based on relative exploitation rate; not determined
Status in relation to Target	For total ESA: Likely (> 60%) to be at or above For fished area: Unknown
Status in relation to Limits	For ESA, Soft Limit: Very Unlikely (< 10%) to be below For ESA, Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	For ESA: Unlikely (< 40%) to be overfishing For fished area: Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE for longfin eels in Taranaki (AJ) from 1990–91 to 2017–18 (from Beentjes 2020). Also shown is the total estimated core fisher longfin catch in AJ from ECERs. Vertical dashed line indicates when the 4 kg maximum size was introduced in 2007–08 after which longfin eels 4 kg and over are not recorded on ECERs. Error bars are 95% confidence intervals. Before 2001, 16% of the catch was recorded as EEU (unidentified) and these catches are omitted.



Annual relative exploitation rate for longfin eels in the Taranaki (AJ). Because some catch of longfin was reported as EEU (unidentified) and has not been allocated to species, the exploitation rate is likely to have been higher than shown before 2001.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Moderate decline in CPUE until 2003, then fluctuating without trend.
Recent Trend in Fishing intensity or Proxy	The relative exploitation rate declined steeply after 2003, and in 2018 was well below the series mean.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches of longfin elvers at primary monitoring sites have fluctuated without trend since the series of reliable data begins in 1995–96, suggesting no overall trend in recruitment.

Projections and Prognosis	
Stock Projections or Prognosis	Unlikely (< 40%) to decline in the medium term under current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For ESA, Soft Limit: Very Unlikely (< 10%) if catch remains at current levels For ESA, Hard Limit: Very Unlikely (< 10%) if catch remains at current levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For ESA, Unlikely (< 40%) if catch remains at current levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on positive catches from commercial fyke net	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Standardised CPUE only provides an index of abundance for eels in areas fished by commercial fishers. Other potential issues with the CPUE indices include: • Low numbers of fishers • Uncertainty in target species after 2000 • Exclusion of zero catches • Changes in MLS and retention in early parts of the series and increased escape tube size from 25 mm to 31 mm in 2012–13 • Failure of some fishers to record on ECE returns all legal-size eels caught, not just those retained • Unrecorded release of > 4kg eels since 2007–08	

Qualifying Comments
Because the commercial eel fishery has had a long history (beginning in the late 1960s), and indices of abundance are only available from the early 1990s, it is difficult to infer stock status from recent abundance trends, and these should therefore be interpreted with caution. Other sources of mortality, such as habitat alteration (historical and current), have also reduced abundance prior to the CPUE series. The proportion of current longfin habitat in Taranaki (Statistical Area AJ) fished commercially during the period 2009–10 and 2013–14 is estimated at 17% (Table 15). The proportion of virgin habitat impacted by hydro dams, commercial fishing, and other anthropogenic activity was estimated to be 24%.

Fishery Interactions
There has been no recorded bycatch in the commercial Taranaki eel fishery since 2000–01. Most bycatch species are usually returned alive.

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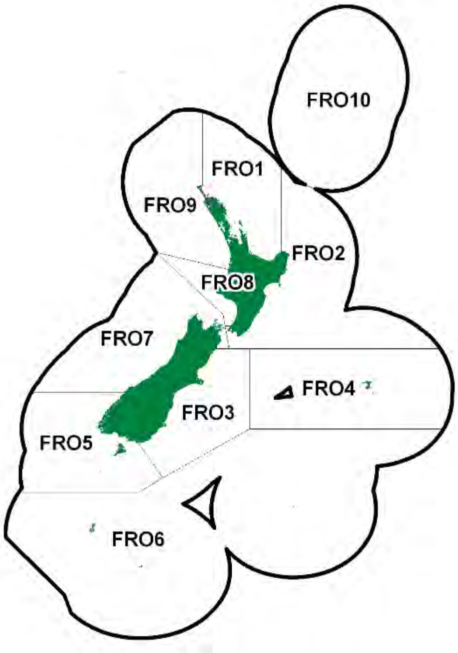
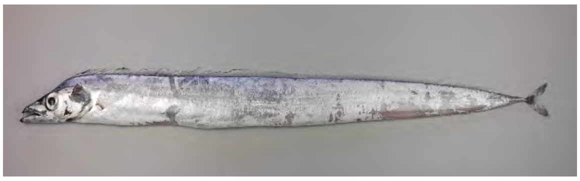
FROSTFISH (FRO)

(*Lepidopus caudatus)*
Para, Taharangi, Hikau





1. FISHERY SUMMARY

1.1 Commercial fisheries

Frostfish are predominantly taken as bycatch from target trawl fisheries on jack mackerel and hoki and to a lesser extent, arrow squid, barracouta and gemfish. These fisheries are predominantly targeted by larger vessels owned or chartered by New Zealand fishing companies. Target fishing for frostfish is reported from the west coast of both the South Island and North Island and at Puysegur Bank, with the best catches taken from the west coast of the South Island.

Frostfish catches are mainly reported to the west of New Zealand primarily in QMA 7 on the west coast of the South Island and to a lesser extent QMA 8 and 9 in the north and south Taranaki Bight. The highest annual catches are associated with hoki fishing during winter (since 1986–87) and jack mackerel fishing during late spring and early summer. The proportion of catch coming from these two main fisheries has varied over time. Sources of error in the catch figures include unreported catch and discarded catch. Compliance investigations have shown that damaged and small hoki were recorded as frostfish by some vessels.

Since the mid-2000s, most frostfish landings have come from the trawl fishery targeting jack mackerel (JMA) in the North and South Taranaki Bights and off the west coast of the South Island (Statistical Areas 035 to 041; FRO 7, 8, 9). In 2009–10, over 80% of the national frostfish landings came from this fishery. Since 1999–2000, the fishery has been dominated by seven vessels which use midwater trawling exclusively. Catches of frostfish have become more concentrated on two distinct periods, October to January and June to July, and in the north and south Taranaki Bight (Statistical Areas 037, 040, 041) rather than the west coast of the South Island (Statistical Areas 034, 035, 036).

No catch data from deepwater vessels for frostfish are available prior to the introduction of the EEZ in 1978 (Table 1). Frostfish were introduced into the QMS from 1 October 1998.The total reported landings and TACCs for each QMA are given in Table 2 and 3, while Figure 1 shows the historical landings and TACC values for the main FRO stocks. An allowance of 2 t was made for non-commercial catch in each of FRO 1, 2, 7 and 9. TACCs were increased from 1 October 2006 in FRO 2 to 110 t, in FRO 3 to 176 t and in FRO 4 to 28 t. In these stocks landings were above the TACC for a number of years and the TACCs were increased to the average of the previous seven years plus an additional 10% (Table 3). Landings have since been well below the TACCs for FRO 2, FRO 3, and FRO 4, with the exception of FRO 4 in 2014–15, when the 28 t TACC was exceeded by just under 150% and in 2018–19, when the landings were over 250%. Landings frequently exceeded the TACCs for FRO 8 until 2016–17, but has declined slightly since. In FRO 9, landings follow a similar pattern to FRO 8 until 2018–19 and 2019-20 when the TACC was exceeded. In 2020-21 there was a redistribution of TACCs of two groups of stocks: FRO 3 (from 176 to 80 t) and 4 (from 28 to 124 t); and FRO 7 (from 2623 to 2110 t), 8 (from 649 to 900 t), and 9 (from 138 to 400 t). The rationale was that the original QMAs for frostfish were based on FMAs and not aligned with the distribution of the biological stocks.

Table 1: Reported landings (t) of frostfish by fishing year and area, by foreign licensed and joint venture vessels, 1978–79 to 1983–83. The EEZ areas (see figure 2 of Baird & McKoy 1988) correspond approximately to the QMAs as indicated. Fishing years are from 1 April to 31 March. The 1983–83 is a 6 month transitional period from 1 April to 30 September. No data are available for the 1980–81 fishing year.

EEZ area	B	C(M)	C(-)	D	E	F	G	H	Total
QMA	1 & 2	3	3	4	6	5	7	8 & 9	
1978–79	5	1	6	0	1	0	1 283	226	1 522
1979–80	13	0	1	23	1	1	26	151	216
1980–81	-	-	-	-	-	-	-	-	-
1981–82	0	5	2	19	1	4	55	464	550
1982–83	0	1	0	9	3	1	56	1 545	1 615
1983–83	0	1	1	1	1	1	22	123	150

Table 2: Reported landings (t) for the main QMAs from 1931 to 1982 [Continued on next page].

Year	FRO 1	FRO 2	FRO 3	FRO 4	FRO 5	Year	FRO 1	FRO 2	FRO 3	FRO 4	FRO5
1931–32	0	0	0	0	0	1957	0	0	0	0	0
1932–33	0	0	0	0	0	1958	0	0	0	0	0
1933–34	0	0	0	0	0	1959	0	0	0	0	0
1934–35	0	0	0	0	0	1960	0	0	0	0	0
1935–36	0	0	0	0	0	1961	0	0	0	0	0
1936–37	0	0	0	0	0	1962	0	0	0	0	0
1937–38	0	0	0	0	0	1963	0	0	0	0	0
1938–39	0	0	0	0	0	1964	0	0	0	0	0
1939–40	0	0	0	0	0	1965	0	0	0	0	0
1940–41	0	0	0	0	0	1966	0	5	0	0	0
1941–42	0	1	0	0	0	1967	0	0	0	0	0
1942–43	0	0	0	0	0	1968	0	0	0	0	0
1943–44	0	0	0	0	0	1969	0	0	0	0	0
1944	0	0	0	0	0	1970	0	0	0	0	0
1945	0	0	0	0	0	1971	0	0	0	0	0
1946	0	0	0	0	0	1972	0	0	0	0	0
1947	3	0	0	0	0	1973	0	0	0	0	0
1948	0	0	0	0	0	1974	0	0	0	0	0
1949	0	0	0	0	0	1975	0	0	0	0	0
1950	0	0	0	0	0	1976	0	0	0	0	0
1951	0	0	0	0	0	1977	0	0	0	0	0
1952	0	0	0	0	0	1978	1	4	2	0	0
1953	0	0	0	0	0	1979	1	14	4	19	1
1954	0	0	0	0	0	1980	0	0	2	20	7
1955	0	0	0	0	0	1981	0	0	6	25	3
1956	0	0	0	0	0	1982	4	0	0	8	13

Year	FRO 6	FRO 7	FRO 8	FRO 9	Year	FRO 6	FRO 7	FRO 8	FRO 9
1931–32	0	0	0	0	1957	0	0	0	0
1932–33	0	0	0	0	1958	0	0	0	0
1933–34	0	0	0	0	1959	0	0	0	0
1934–35	0	0	0	0	1960	0	0	0	0
1935–36	0	0	0	0	1961	0	0	0	0
1936–37	0	0	0	0	1962	0	0	0	0
1937–38	0	0	0	0	1963	0	0	0	0
1938–39	0	0	0	0	1964	0	0	0	0
1939–40	0	0	0	0	1965	0	0	0	0
1940–41	0	0	0	0	1966	0	0	0	0
1941–42	0	0	0	0	1967	0	0	0	0
1942–43	0	0	0	0	1968	0	0	0	0
1943–44	0	0	0	0	1969	0	0	1	0
1944	0	0	0	0	1970	0	0	1	0
1945	0	0	0	0	1971	0	0	0	0
1946	0	0	0	0	1972	0	0	0	0
1947	0	0	0	1	1973	0	0	0	0
1948	0	0	0	0	1974	0	0	0	0
1949	0	0	0	0	1975	0	0	0	0
1950	0	0	0	0	1976	0	0	0	0

Table 2 [Continued]

Year	FRO 6	FRO 7	FRO 8	FRO 9	Year	FRO 6	FRO 7	FRO 8	FRO 9
1951	0	0	0	0	1977	0	0	0	0
1952	0	0	0	0	1978	0	782	30	16
1953	0	0	0	0	1979	1	614	93	88
1954	0	0	0	0	1980	1	41	54	10
1955	0	0	0	0	1981	0	327	226	209
1956	0	0	0	0	1982	0	132	385	546

Notes:

The 1931–1943 years are April–March but from 1944 onwards are calendar years, Data up to 1985 are from fishing returns: Data from 1986 to 1990 are from Quota Management Reports, Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings.

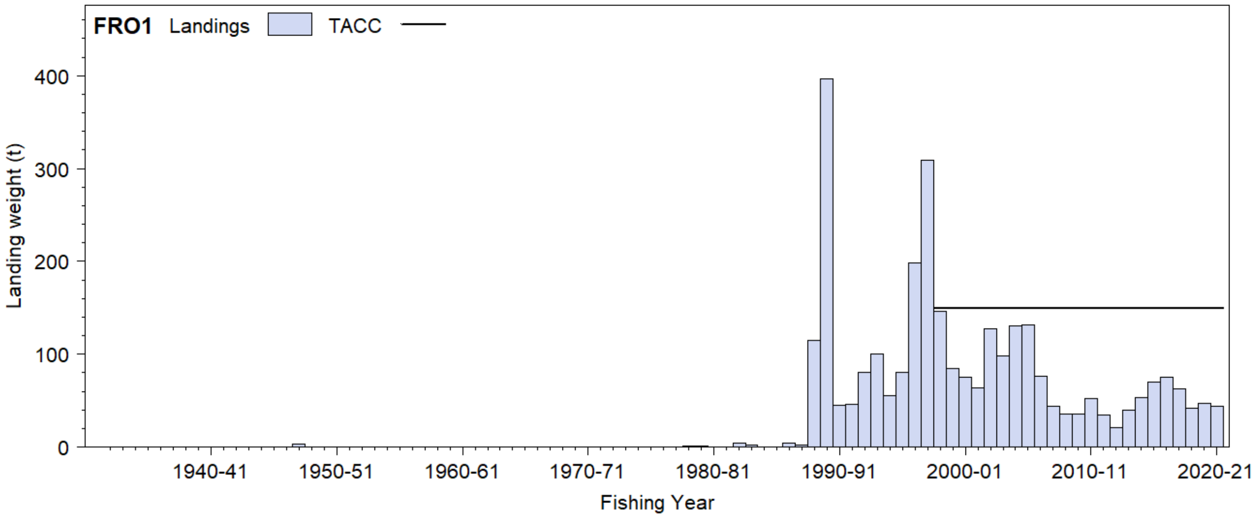
Table 3: Reported landings (t) of frostfish by QMA and fishing year, 1983–84 to present. The data in this table has been updated from that published in the 1998 Plenary Report by using the data up to 1996–97 in table 26 on p. 244 of the "Review of Sustainability Measures and Other Management Controls for the 1998–99 Fishing Year - Final Advice Paper" dated 6 August 1998. Data since 1997–98 based on catch and effort returns (where area was not reported catch was pro-rated across all QMAs). There are no landings reported from QMA 10. [Continued on next page].

Fishstock	FRO 1		FRO 2		FRO 3		FRO 4		FRO 5	
FMA	1		2		3		4		5	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84	2	-	0	-	0	-	10	-	28	-
1984–85	0	-	0	-	2	-	1	-	100	-
1985–86	0	-	0	-	9	-	2	-	258	-
1986–87	4	-	4	-	5	-	6	-	71	-
1987–88	2	-	0	-	3	-	1	-	20	-
1988–89	115	-	0	-	1	-	0	-	15	-
1989–90	397	-	0	-	58	-	0	-	146	-
1990–91	45	-	24	-	224	-	0	-	496	-
1991–92	46	-	3	-	143	-	0	-	337	-
1992–93	80	-	9	-	51	-	0	-	0	-
1993–94	100	-	19	-	168	-	0	-	0	-
1994–95	55	-	14	-	120	-	0	-	87	-
1665–96	80	-	40	-	72	-	29	-	0	-
1996–97	198	-	6	-	12	-	4	-	8	-
1997–98	309	-	273	-	35	-	< 1	-	9	-
1998–99	146	149	134	20	39	128	< 1	5	19	135
1999–00	84	149	161	20	97	128	< 1	5	57	135
2000–01	76	149	194	20	107	128	48	5	33	135
2001–02	64	149	67	20	176	128	81	5	59	135
2002–03	127	149	66	20	268	128	15	5	63	135
2003–04	98	149	52	20	19	128	7	5	14	135
2004–05	130	149	38	20	427	128	15	5	20	135
2005–06	132	149	40	20	45	128	31	5	17	135
2006–07	76	149	31	110	21	176	13	28	16	135
2007–08	44	149	30	110	31	176	7	28	5	135
2008–09	36	149	24	110	6	176	10	28	2	135
2009–10	36	149	24	110	15	176	3	28	4	135
2010–11	52	149	41	110	< 1	176	4	28	14	135
2011–12	34	149	15	110	8	176	14	28	3	135
2012–13	21	149	18	110	32	176	2	28	4	135
2013–14	40	149	34	110	63	176	15	28	11	135
2014–15	54	149	41	110	13	176	69	28	14	135
2015–16	70	149	46	110	10	176	13	28	8	135
2016–17	75	149	52	110	9	176	9	28	27	135
2017–18	62	149	51	110	12	176	16	28	44	135
2018–19	42	149	34	110	12	176	100	28	4	135
2019–20	47	149	16	110	7	176	16	28	5	135
2020–21	43	149	13	110	19	80	12	124	75	135

Fishstock	FRO 6		FRO 7		FRO 8		FRO 9			
FMA	6		7		8		9		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84	7	-	432	-	539	-	457	-	1 475	-
1984–85	0	-	214	-	455	-	129	-	901	-
1985–86	0	-	344	-	574	-	226	-	1 415	-
1986–87	4	-	1 089	-	898	-	190	-	2 272	-
1987–88	0	-	3 466	-	875	-	22	-	4 391	-
1988–89	3	-	1 950	-	413	-	455	-	2 952	-
1989–90	29	-	1 370	-	132	-	0	-	2 132	-
1990–91	67	-	3 029	-	539	-	0	-	4 424	-
1991–92	7	-	2 295	-	750	-	1	-	3 582	-
1992–93	0	-	1 360	-	1 165	-	0	-	2 665	-
1993–94	0	-	1 998	-	696	-	12	-	2 993	-
1994–95	0	-	3 069	-	388	-	7	-	3 740	-
1995–96	0	-	1 536	-	22	-	9	-	1 788	-
1996–97	0	-	2 881	-	126	-	93	-	3 328	-
1997–98	0	-	2 590	-	143	-	205	-	3 564	-
1998–99	0	11	2 461	2 623	156	649	33	138	2 969	3 858

Table 3 [Continued]

Fishstock	FRO 6		FRO 7		FRO 8		FRO 9			
FMA	6		7		8		9		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1999–00	< 1	11	917	2 623	28	649	48	138	1 392	3 858
2000–01	< 1	11	1 620	2 623	303	649	43	138	2 424	3 858
2001–02	< 1	11	2 303	2 623	138	649	25	138	2 913	3 858
2002–03	< 1	11	1 025	2 623	621	649	67	138	2 252	3 858
2003–04	< 1	11	959	2 623	293	649	367	138	1 809	3 858
2004–05	< 1	11	934	2 623	770	649	327	138	2 661	3 858
2005–06	< 1	11	888	2 623	787	649	181	138	2 119	3 858
2006–07	< 1	11	951	2 623	722	649	142	138	1 972	4 019
2007–08	< 1	11	906	2 623	678	649	136	138	1 837	4 019
2008–09	< 1	11	576	2 623	605	649	110	138	1 369	4 019
2009–10	< 1	11	382	2 623	686	649	238	138	1 389	4 019
2010–11	< 1	11	248	2 623	578	649	167	138	1 106	4 019
2011–12	< 1	11	500	2 623	893	649	198	138	1 665	4 019
2012–13	< 1	11	570	2 623	890	649	278	138	1 814	4 019
2013–14	< 1	11	880	2 623	814	649	261	138	2 120	4 019
2014–15	< 1	11	1 027	2 623	732	649	373	138	2 322	4 019
2015–16	< 1	11	1 063	2 623	692	649	310	138	2 212	4 019
2016–17	< 1	11	1 164	2 623	553	649	96	138	1 986	4 019
2017–18	< 1	11	2 062	2 623	380	649	65	138	2 693	4 019
2018–19	< 1	11	1 999	2 623	507	649	171	138	2 869	4 019
2019–20	< 1	11	931	2 623	434	649	247	138	1 702	4 019
2020–21	< 1	11	923	2 110	430	900	122	400	1 638	4 019



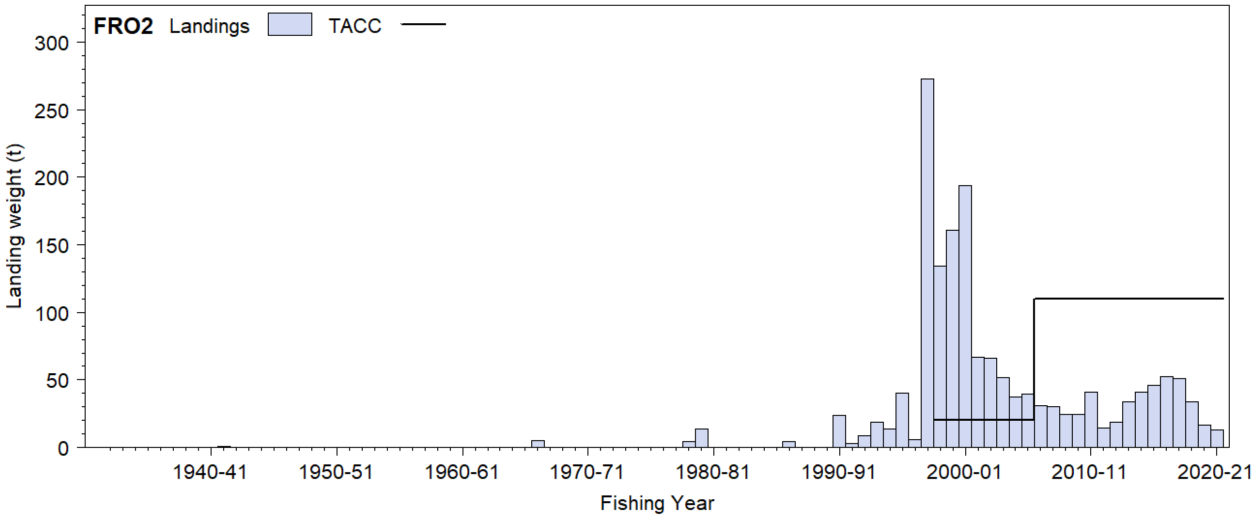
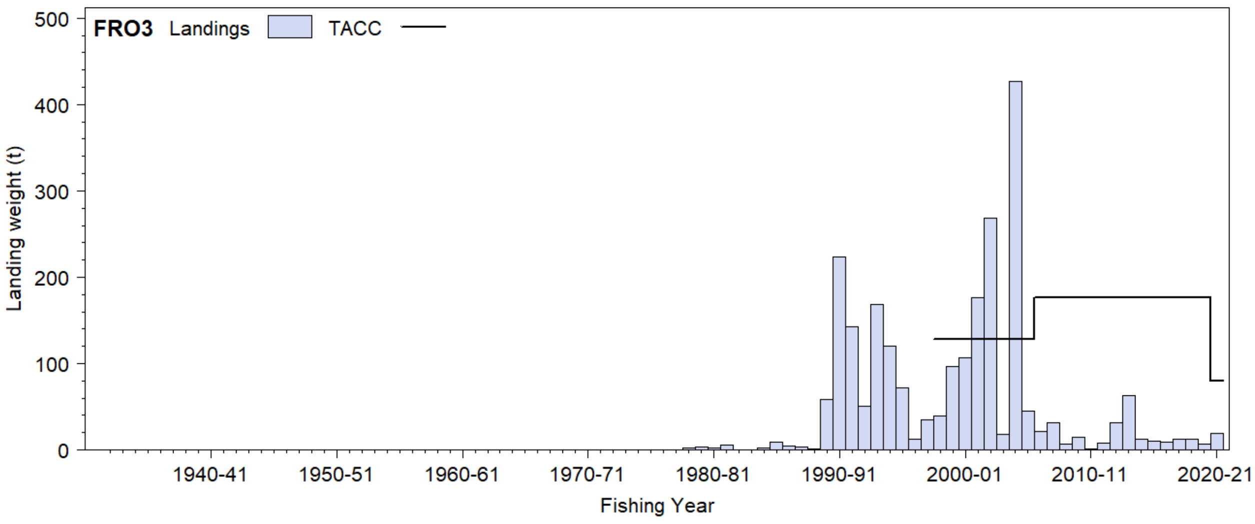
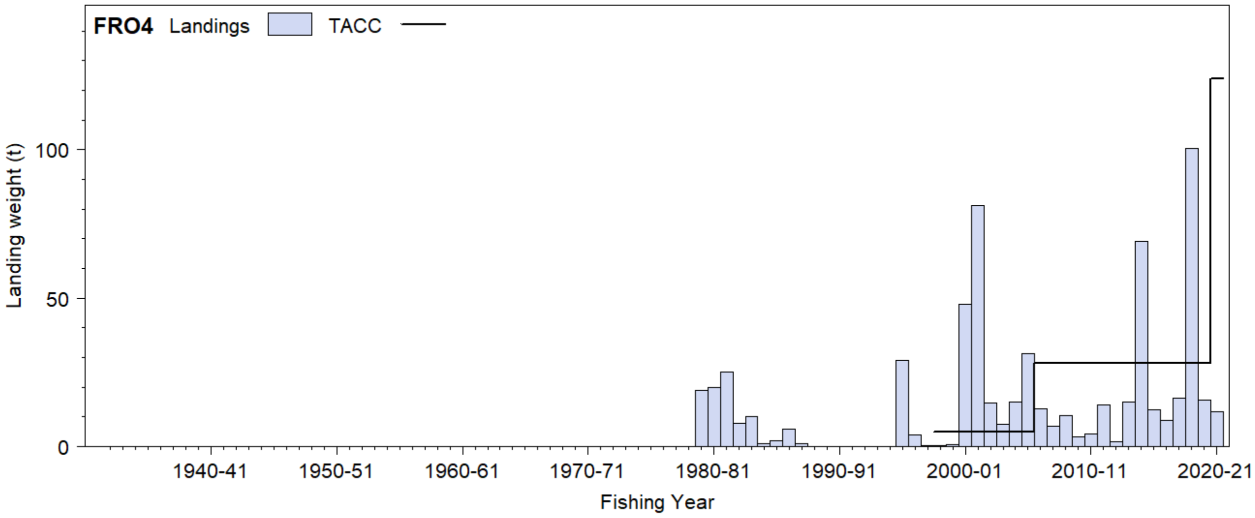


Figure 1: Reported commercial landings and TACC for the eight main FRO stocks. From top: FRO 1 (Auckland East) and FRO 2 (Central East). [Continued on next page]





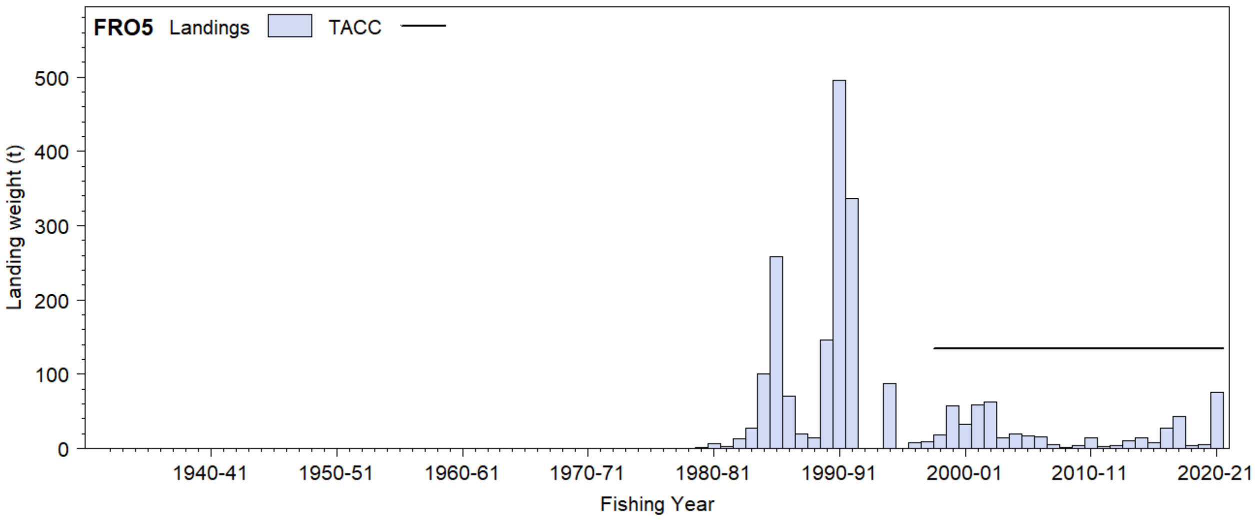


Figure 1 [Continued]: Reported commercial landings and TACC for the eight main FRO stocks. From top: FRO 3 (South East Coast), FRO 4 (South East Chatham Rise) and FRO 5 (Southland). [Continued on next page]

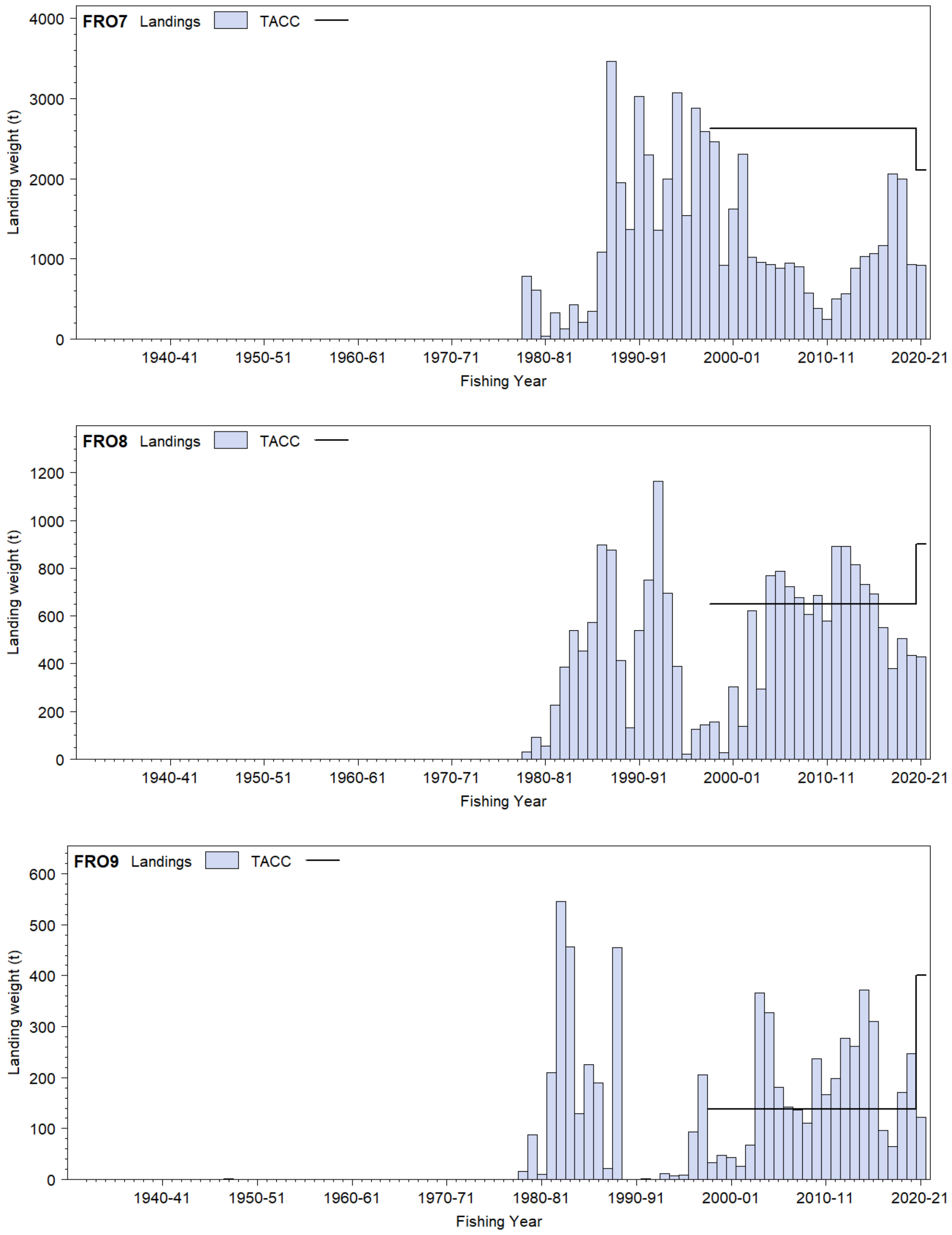


Figure 1 [Continued]: Reported commercial landings and TACC for the eight main FRO stocks. From top: FRO 7 (Challenger), FRO 8 (Central West) and FRO 9 (Auckland West). Note that these figures do not show data prior to entry into the QMS.

1.2 Recreational fisheries

Frostfish are occasionally taken by recreational fishers. Small numbers have been reported from recreational diary surveys, mainly in QMA 1, and rarely in QMA 2 and 9.

1.3 Customary non-commercial fisheries

No quantitative information is available on the current level of customary non-commercial take. Maori have collected beach cast frostfish in the past (Graham 1956).

1.4 Illegal catch

No information is available.

1.5 Other sources of mortality

No information is available on other sources of mortality.

2. BIOLOGY

Frostfish are widely distributed throughout the continental shelf and upper slopes of all oceans, except the North Pacific, and have a benthopelagic lifestyle. In New Zealand, frostfish are found from about 34°S to 49°S, but are most common between 36°S and 44°S. They occur mainly in depths of 50–600 m with the largest catches made at around 200 m bottom depth. Preferred bottom temperatures range between 10 and 16°C. There is one species of *Lepidopus* recorded from New Zealand waters. However, scabbardfishes (*Benthodesmus* species) and the false frostfish (*Paradiplospinosus gracilis*) may be confused with small *Lepidopus caudatus*.

Frostfish reach a maximum length of 165 cm (fork length) around New Zealand, although the same species may reach 205 cm and 8 kg weight in the eastern North Atlantic (Nakamura & Parin 1993). In the northwestern Mediterranean males reach sexual maturity at 97 cm and a maximum length of 176 cm, whilst females reach sexual maturity at 111 cm and a maximum length of 196 cm (Demestre et al 1993).

The adults probably congregate in the late spring months, and spawn during the summer and autumn over the mid to outer shelf. Fertilisation has been calculated to take place between noon and sunset at depths greater than 50 m where the surface waters have a temperature of 17.5 to 22.0°C (Robertson 1980).

A 2013 study developed ageing methods and estimated growth rates for frostfish from the west coast of New Zealand (Horn 2013). This study confirmed that frostfish are fast growing and relatively short lived. Most fish reach 100 cm FL (fork length) by the end of their third year and the maximum estimated age for both sexes was 10.6 years. The von Bertalanffy parameters estimated for both sexes combined were: L_∞=137 cm, k=0.505 yr^{-1}, t_0=0.07 yr. The estimated growth curves were similar, for the first four years, to those estimated for northern hemisphere frostfish, although the asymptotic length is lower. Horn (2013) estimated the instantaneous rate of natural mortality to be 0.6 yr^{-1} based on 1% of the population reaching 7–8 years of age.

A length-weight relationship for New Zealand frostfish is available from the *Kaharoa* trawl surveys (Horn 2013).

Frostfish migrate into mid-water at night and feed on crustaceans, small fish and squid (Nakamura & Parin 1993). Euphausiids and *Pasiphaea* spp. (both crustaceans) are the most common prey of frostfish in the northwest Mediterranean (Demestre et al 1993). In Tasmanian waters, the diet of frostfish consists mainly of myctophids and euphausiids (Blaber & Bulman 1987).

Frostfish are distributed widely in temperate seas but are most commonly reported in the north-eastern Atlantic (including the Mediterranean), in the southern Atlantic off Namibia and South Africa, and in the south-west Pacific around Australia and New Zealand (Nakamura & Parin 1993, Froese & Pauly 2012). Morphometric studies have shown differences in dorsal-fin pigmentation and meristic characteristics between north-eastern Atlantic and southern Atlantic populations (Mikhailin 1977). Genome sequencing of frostfish showed strong genetic differentiation between the northern and southern hemisphere populations and suggests that there are two distinct biological species (Ward et al 2008).

Robertson (1980) examined the seasonality and location of frostfish spawning based on the occurrence of planktonic eggs. He concluded that spawning probably occurs around all of New Zealand except for the south-east coast and adults probably congregate in the late spring months, and spawn during the summer and autumn over the mid to outer shelf. Fertilisation was calculated to take place between noon and sunset at depths greater than 50 m where the surface waters have a temperature of 17.5 to 22.0°C. Analysis of data on female gonad stages from the scientific observer programme (see Section 6.1) suggests that for the west coast of both the North and South Islands frostfish have a protracted spawning period starting in mid-winter with a peak from summer to early autumn.

Biological parameters relevant to the stock assessment are shown in Table 4.

Table 4: Estimates of biological parameters for frostfish.

Fishstock						**Estimate**	**Source**
1. Natural mortality (*M*)							
All stocks	$M = 0.6\ y^{-1}$ considered best estimate for all areas for both sexes						Horn (2013)
2. Weight = a (length)^b (Weight in g, length in cm fork length)							
			a	b			
WCSI trawl surveys			0.000407	3.155			Horn (2013)
3. von Bertalanffy growth parameters							
	Male			Female			
	L_∞	k	t_0	L_∞	k	t_0	
WCSI	129.2	0.56	0.08	143.5	0.457	-0.04	Horn (2013

3. STOCKS AND AREAS

Spawning areas identified from eggs taken in plankton tows include the outer shelf from the Bay of Islands to south of East Cape, and an area off Fiordland (Robertson 1980). No eggs were recorded from the south-east coast of the South Island and no spawning has been recorded on the Chatham Rise. Spawning is also known to take place on the west coast of the South Island in March.

Juvenile frostfish (less than 30 cm) have been reported from trawl surveys in the Bay of Plenty, the Hauraki Gulf, off Northland, the west coast of the North Island and the west coast of the South Island.

The occurrence of spawning in three areas at similar times of year and the distribution of frostfish from catches suggest that there may be at least three separate stocks. A fourth stock is also possible based on known distribution of juveniles and adults and analogies with other species which often have a separate Chatham Rise stock. Bagley et al (1998) proposed the following Fishstock areas for management of frostfish: FRO 1: (FMA 1 and 2); FRO 3: (FMA 3 and 4); FRO 5: (FMA 5 and 6) and FRO 7: (FMA 7, 8, and 9). There have been no reported landings from QMA 10. TACs were set for each QMA (1–9) in 1998 and each FMA is managed separately.

4. STOCK ASSESSMENT

There are no stock assessments available for any stocks of frostfish and therefore estimates of biomass and yields are not available.

4.1 Estimates of fishery parameters and abundance

No estimates of fishery parameters are available for frostfish.

Biomass indices on frostfish are available from trawl surveys carried out by different vessels (Table 5). Few surveys cover the central west coast of New Zealand where the commercial catch records highest landings. The catchability of frostfish is not known but, because they are known to occur frequently well off the bottom, catchability is expected to be low and variable between surveys.

Table 5: Doorspread biomass indices (t) and CVs (%) of frostfish from random stratified trawl surveys 1981–2013.

Vessel	Trip Code	Depth Range (m)	Biomass index (t)	CV (%)	Date
QMA 1					
Bay of Plenty					
Kaharoa	KAH9004	10–150	246	87	February/March 1990
Kaharoa	KAH9202	10–150	92	48	February 1992
Kaharoa	KAH9601	10–250	328	49	February 1996
Kaharoa	KAH9902		193	34	February 1999
QMA 2					
Kaharoa	KAH9304	20–400	573	38	March/April 1993
Kaharoa	KAH9402	20–400	1 079	40	February/March 1994
Kaharoa	KAH9502	20–400	493	22	February/March 1995
Kaharoa	KAH9602	20–400	693	17	February/March 1996
QMA 7 & 8					
Tomi Maru		30–300	2 173	22	December 1980 - January 1981
Shinkai Maru	SHI8102	20–300	6 638	12	October/November 1981
Cordella	COR9001	25–300	2 189	20	February/March 1990
QMA 7 (WCSI)					
Kaharoa	KAH9006	20–400	121	27	March/April 1990
Kaharoa	KAH9204	20–400	24	29	March/April 1992
Kaharoa	KAH9404	20–400	53	37	March/April 1994
Kaharoa	KAH9504	20–400	89	31	March/April 1995
Kaharoa	KAH9701	20–400	259	32	March/April 1997
Kaharoa	KAH0004	20–400	316	16	March/April 2000
Kaharoa	KAH0304	20–400	494	22	March/April 2003
Kaharoa	KAH0504	20–400	423	45	March/April 2005
Kaharoa	KAH0704	20–400	529	38	March/April 2007
Kaharoa	KAH0904	20–400	835	34	March/April 2009
Kaharoa	KAH1104	20–400	251	28	March/April 2011
Kaharoa	KAH1305	20–400	424	24	March/April 2013
WCSI south of 41° 30’					
James Cook	JCO8311	25–450	183	34	September/October 1983
James Cook	JCO8415	25–450	181	25	August/September 1985

4.2 Biomass estimates

No biomass estimates are available for frostfish.

4.3 Yield estimates and projections

MCY cannot be determined as only a small percentage (less than 2%) of the reported catch in recent years is from target fishing. Annual catches are likely to vary according to effort targeting other species in areas of frostfish abundance. It is therefore not possible to choose a catch history which represents a period of stable and unrestricted effort in order to estimate yields. Other problems include under-reporting of frostfish catches and restrictions on targeting frostfish in QMAs 3, 4, 5, and 6.

There are no reliable data on current biomass; *CAY* was therefore not estimated.

4.4 Other factors

None available.

5. STATUS OF THE STOCKS

Estimates of current and reference biomass are not available. The stock structure is uncertain; the fishery is variable and almost entirely a bycatch of other target fisheries. No age data or estimates of abundance are available.

It is therefore not possible to estimate yields. It is not known if recent catches are sustainable or whether they are at levels that will allow the stock to move towards a size that will support the maximum sustainable yield.

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GARFISH (GAR)

(*Hyporhamphus ihi*)
Takeke

1. FISHERY SUMMARY

Garfish was introduced into the QMS from 1 October 2002 with allowances, TACCs and TACs as shown in Table 1. These have not changed.

Table 1: Recreational and Customary non-commercial allowances, TACCs and TACs (t) of garfish by Fishstock.

Fishstock	Recreational Allowance	Customary Non-Commercial Allowance	TACC	TAC
GAR 1	20	10	25	55
GAR 2	8	4	5	17
GAR 3	2	1	5	8
GAR 4	1	1	2	4
GAR 7	10	5	8	23
GAR 8	8	4	5	17
GAR 10	0	0	0	0

1.1 Commercial fisheries

Garfish landings were first recorded in 1933, and a minor fishery must have existed before this (Table 2). Moderate quantities of garfish can be readily caught by experienced fishers, it is a desirable food fish, and informal sales at beaches or from wharves are likely to have been made from the late 1800s onwards. Reported landings to 1990 almost certainly understate the actual “commercial” catch.

Table 2: Reported total New Zealand landings (t) of garfish from 1931 to 1990.

Year	Landings	Year	Landings	Year	Landings	Year	Landings	Year	Landing	Year	Landing
1931	–	1941	1	1951	4	1961	3	1971	11	1981	7
1932	–	1942	1	1952	7	1962	4	1972	4	1982	11
1933	1	1943	1	1953	6	1963	4	1973	10	1983	12
1934	–	1944	2	1954	8	1964	2	1974	6	1984	13
1935	–	1945	9	1955	9	1965	2	1975	2	1975	8
1936	–	1946	3	1956	7	1966	3	1976	5	1986	14
1937	–	1947	2	1957	2	1967	4	1977	5	1987	36
1938	–	1948	1	1958	2	1968	3	1978	15	1988	20
1939	4	1949	6	1959	4	1969	5	1979	12	1989	15
1940	6	1950	2	1960	6	1970	13	1980	12	1990	24

Source: Annual Reports on Fisheries (Marine Department/Ministry of Agriculture & Fisheries) to 1974, and subsequent MAF data.

By 1990 reported landings were in the range 20–40 t, and the total catches may have reached 50 t. Reported catches and landings through the 1990s were of a similar order of magnitude, before catches declined to lower levels during the 2000–01 to 2011–12 fishing seasons. Since 2012 landings have increased to levels last seen in the 1990s (Table 3).

Table 3: Reported catches or landings (t) of garfish by Fishstock from 1990–91 to present*. Prior to 2001–02 the catches or landings (t) of garfish were reported by FMA.

Fishstock	GAR 1		GAR 2		GAR 3		GAR 4	
FMA (s)	1		2		3,5&6		4	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1990–91†	31	-	< 1	-	2	-	-	-
1991–92†	22	-	< 1	-	1	-	-	-
1992–93†	14	-	< 1	-	1	-	-	-
1993–94†	23	-	0	-	2	-	-	-
1994–95†	17	-	< 1	-	< 1	-	-	-
1995–96†	15	-	< 1	-	1	-	-	-
1996–97†	15	-	< 1	-	1	-	-	-
1997–98†	21	-	< 1	-	< 1	-	-	-
1998–99†	19	-	< 1	-	< 1	-	-	-
1999–00†	17	-	< 1	-	< 1	-	-	-
2000–01†	11	-	0	-	< 1	-	-	-
2001–02†	8	25	0	5	< 1	5	0	2
2002–03†	6	25	0	5	< 1	5	0	2
2003–04†	11	25	0	5	0	5	0	2
2004–05†	13	25	< 1	5	0	5	0	2
2005–06†	7	25	< 1	5	1	5	0	2
2006–07†	10	25	0	5	0	5	0	2
2007–08†	8	25	0	5	0	5	< 1	2
2008–09†	10	25	0	5	0	5	0	2
2009–10†	9	25	0	5	0	5	0	2
2010–11†	11	25	0	5	< 1	5	0	2
2011–12†	8	25	0	5	0	5	0	2
2012–13	12	25	< 1	5	< 1	5	0	2
2013–14	15	25	0	5	0	5	0	2
2014–15	16	25	0	5	0	5	0	2
2015–16	25	25	0	5	0	5	0	2
2016–17	26	25	0	5	0	5	0	2
2017–18	22	25	0	5	0	5	0	2
2018–19	16	25	0	5	< 1	5	0	2
2019–20	23	25	0	5	0	5	0	2
2020–21	14	25	0	5	0	5	0	2

Fishstock	GAR 7		GAR 8		GAR 10			
FMA (s)	7		8&9		10			Total
	Landings	TACC	Landings	TACC	Landings	TACC	Landings#	TACC
1990–91†	4	-	1	-	0	-	38	
1991–92†	6	-	0	-	0	-	29	-
1992–93†	2	-	2	-	0	-	18	-
1993–94†	2	-	0	-	0	-	26	-
1994–95†	2	-	0	-	0	-	19	-
1995–96†	3	-	< 1	-	0	-	19	-
1996–97†	5	-	< 1	-	0	-	20	-
1997–98†	4	-	1	-	0	-	27	-
1998–99†	6	-	1	-	0	-	26	-
1999–00†	4	-	< 1	-	0	-	21	-
2000–01†	2	-	0	-	0	-	13	-
2001–02†	3	8	0	5	0	0	11	50
2002–03†	< 1	8	0	5	0	0	6	50
2003–04†	1	8	< 1	5	0	0	12	50
2004–05†	0	8	< 1	5	0	0	13	50
2005–06†	0	8	0	5	0	0	9	50
2006–07†	< 1	8	< 1	5	0	0	10	50
2007–08†	< 1	8	0	5	0	0	8	50
2008–09†	1	8	0	5	0	0	11	50
2009–10†	3	8	0	5	0	0	12	50
2010–11†	1	8	0	5	0	0	13	50
2011–12†	< 1	8	< 1	5	0	0	9	50
2012–13	0	8	0	5	0	0	12	50
2013–14	0	8	0	5	0	0	15	50
2014–15	< 1	8	0	5	0	0	16	50
2015–16	< 1	8	0	5	0	0	25	50
2016–17	0	8	0	5	0	0	26	50
2017–18	0	8	0	5	0	0	22	50
2018–19	0	8	0	5	0	0	16	50
2019–20	0	8	0	5	0	0	23	50
2020–21	0	8	0	5	0	0	14	50

* Listed as landings but are the higher of catch or landing values. There were relatively small differences between the two series.

† CELR data.

\# Note totals may not match figures in the tables due to rounding errors.

Largest catches and landings (8–31 t) were made in FMA 1, mostly in Statistical Area 003 (southern east Northland) and 009 (central Bay of Plenty). Small (2–6 t) quantities were taken in FMA 7, almost entirely in area 017 (Marlborough Sounds). Only minor and intermittent catches and landings were made elsewhere. The most consistent catches were taken by beach seine, with some catches by lampara net. Most of the catch is reported as targeted.

In the early 1990s about 50 vessels reported a catch or landing in a year; by the late 1990s this had declined to 20–30. Most vessels reported garfish in only a few years. Annual reported landings have fluctuated between 9 and 26 tonnes since 2010–11.

1.2 Recreational fisheries

Some garfish is taken, probably incidentally, using rod and line but most is taken in a small and specific fishery using beach seines from the shore in northern FMAs. The total annual harvest is estimated to be 20–30 000 fish (Wynne-Jones et al 2019).

1.3 Customary non-commercial fisheries

Quantitative information on the current level of customary non-commercial catch is not available.

1.4 Illegal catch

Estimates of illegal catch are not available, but this is probably insignificant or nil.

1.5 Other sources of mortality

There may be some accidental catches of garfish in small-mesh nets (purse seines, lampara nets, and beach seines) used in the fisheries for pilchard and yellow-eyed mullet.

2. BIOLOGY

Only one species of garfish or piper is common in New Zealand waters, *Hyporhamphus ihi*. It is endemic, but very similar species occur in Australia. A larger garfish, *Euleptorhamphus viridis*, is occasionally recorded in northern New Zealand. The common garfish is not closely related to the ocean piper or saury, *Scomberexox saurus*. Garfish occur around most of New Zealand, and are present at the Chatham Islands. They are most abundant in sheltered gulfs, bays, and large estuaries, particularly near seagrass beds in shallow water, and over shallow reefs. The pale green, almost transparent colouring, and localised schooling behaviour of garfish makes them difficult to see and their abundance difficult to estimate.

Spawning occurs during spring and summer probably in suitable shallow bays; the eggs sink to the seafloor and adhere to vegetation. Larvae are seldom taken in coastal plankton surveys. Patterns of age and growth are not known in New Zealand, but likely to be similar to Australia, where the larger of two closely related species (southern garfish, *H. melanochir*) matures at 25 cm (2–3 years) and reaches 52 cm (10 years). The New Zealand garfish matures at 22 cm, and with a maximum size of 40 cm may have a lower maximum age. Average size is 20–30 cm.

Garfish feed on zooplankton. They form single-species schools, but occur in close proximity with other small pelagic fishes in shallow coastal waters, particularly yellow-eyed mullet.

There have been no biological studies that are directly relevant to the recognition of separate stocks, or to yield estimates. Consequently, no estimates of biological parameters are available.

3. STOCKS AND AREAS

There is no information on whether separate biological stocks occur in New Zealand. Given their preferred habitat of shallow sheltered waters, and the mode of reproduction in which the eggs are attached to the seafloor rather than free-floating, it is probable that localised populations occur, and possible that these may differ in some biological parameters (e.g., growth and recruitment). Consequently, these populations may be susceptible to local depletion.

Garfish are sometimes taken as a non-target catch in the pilchard fishery, but this catch is likely to be very small. Although the target fisheries for these two species are quite separate, it is convenient for their Fishstocks to have the same boundaries.

4. STOCK ASSESSMENT

There have been no previous stock assessments of garfish.

4.1 Estimates of fishery parameters and abundance

No fishery parameters are available.

4.2 Biomass estimates

No estimates of biomass (B_0, B_{MSY}, or $B_{current}$) are available.

4.3 Yield estimates and projections

MCY cannot be determined.

Current biomass cannot be estimated, so *CAY* cannot be determined.

4.4 Other yield estimates and stock assessment results

No information is available.

4.5 Other factors

The extent of natural variability in the size of garfish populations is not known, but from their very shallow inshore distribution, and demersal rather than pelagic eggs, it is suspected that they are less variable than other small pelagic species. However, these features also suggest localised populations, susceptible to local depletion.

There is anecdotal information that garfish are very abundant in some localities. It is not known whether this represents similar abundance over a larger region, or a tendency for a few schools to become concentrated in these localities. Apparent abundance, and initial catches, may be misleading in terms of sustainable yields.

The maximum age of 10 years proposed for a similar Australian garfish implies that productivity might not be as high as would be expected from a small pelagic species.

There is no reliable information on catches from the recreational fishery for garfish, or even their size relative to that of the commercial fishery.

5. STATUS OF THE STOCKS

No estimates of current biomass are available. A fishery has existed for several decades, but it is not known how heavily this has exploited the stock. It is not possible to determine if recent catch levels will allow the stock(s) to move towards a size that would support the *MSY*.

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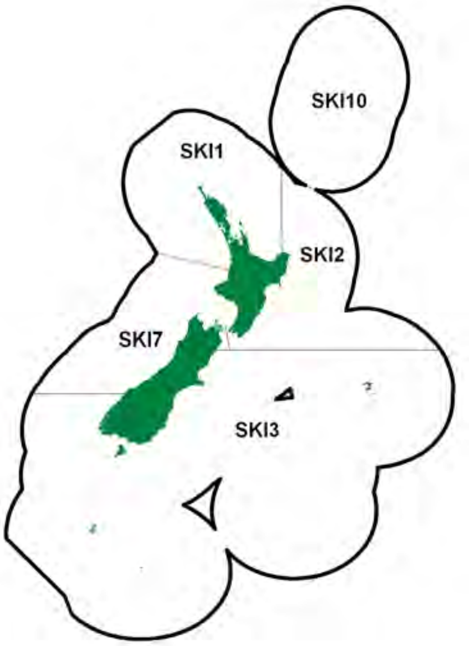
GEMFISH (SKI)

(*Rexea* spp.)
Maka-taharaki, Maka-tikati, Tiikati



1. FISHERY SUMMARY

Gemfish were introduced into the QMS on 1 October 1986. Current allowances, TACCs, and TACs are given in Table 1.

Table 1: Recreational and customary non-commercial allowances (t), TACCs (t), and TACs (t) by Fishstock, as at 1 October 2020.

Fishstock	Recreational Allowance	Customary non-commercial Allowance	Other sources of fishing related mortality	TACC	TAC
SKI 1	27	3	25	252	307
SKI 2	5	3	0	240	248
SKI 3	0	1	6	599	606
SKI 7	0	1	6	599	606
SKI 10	–	–	–	10	–

1.1 Commercial fisheries

Gemfish are caught in coastal waters around mainland New Zealand down to about 550 m. Historical estimated and recent reported gemfish landings and TACCs are shown in Tables 2–4, and Figure 1 shows the historical and recent landings and TACC values for the main gemfish stocks. Annual catches increased significantly in the early 1980s and peaked at about 8250 t in 1985–86 (Table 2). In the late 1980s, annual catches generally ranged from about 4200 t to 4800 t per annum (Table 4). Annual catches declined substantially after 1989–90 and total landings were less than 1200 t from 1998–99 to 2016–17 before an increase to over 2000 t in subsequent years (Table 4). TACCs were reduced in SKI 3 and SKI 7 for the 1996–97 fishing year and were progressively reduced in SKI 1 and SKI 2 from 1997–98. Annual catches remained below the TACCs until 2016–17 in SKI 1 and SKI 7. Catches were substantially in excess of the TACCs for SKI 3 and SKI 7 in 2017–18 and 2018–19, and in 2020–21 after the TACC was increased in both these areas from 1 October 2019. The 2019–20 SKI 7 landings matched the 2018–19 landings at 938 t, 399 t greater than the increased TACC of 599 t whereas the 2019–20 SKI 3 landings did not reach the increased TACC. In SKI 1 the landings of 394 t in 2019–20 were 88% higher than the TACC of 210 t and the lower landings for 2020–21 were 13% over the increased SKI 1 TACC of 252 t introduced from 1 October 2020. In SKI 2, landings from 2017–18 to 2020–21 exceeded the TACC by 15–53%.

Most of the recorded catch is taken by bottom trawl (BT), with midwater (MW) trawl catches increasing in recent years in SKI 3 and particularly in SKI 7. There was also some midwater trawl catch in SKI 2 in the mid-1990s. Target gemfish fisheries developed off the eastern and northern coasts of the North Island. From 1993 to 2000, there was a major shift in effort from east of North Cape to the west, and over 50% of the SKI 1 catch was taken from FMA 9 in some years. However, the distribution of fishing changed substantially after 2001 when the SKI 1 and SKI 2 quotas were reduced. The northwest coast fishery virtually disappeared, as did the fishery off East Northland. Although landings were historically concentrated in the months of May and June, they are now spread throughout the year. Most SKI 1 and SKI 2 landings are now bycatch in a range of trawl fisheries, including tarakihi, barracouta, scampi, and hoki, although targeting of gemfish does occur. Gemfish catches off the west coast of the South Island (SKI 7) are primarily a bycatch of the winter hoki target fishery whereas the majority of the gemfish catch in SKI 3 occurs while fishing for squid on the Stewart-Snares shelf. There is some bycatch of gemfish in the inshore mixed target species trawl fisheries that operate off both the east and the west coasts of the South Island.

Table 2: Reported gemfish catch (t) from 1978–79 to 1987–88. Source - MAF and FSU data.

Fishing	New Zealand		Foreign Licensed			
year	Domestic	Chartered	Japan	Korea	USSR	Total
1978–79*	352	53	1 509	1 079	0	2 993
1979–80*	423	1 174	1 036	78	60	2 771
1980–81*	1 050	N/A	N/A	N/A	N/A	> 1 050
1981–82*	1 223	1 845	391	16	0	3 475
1982–83*	822	1 368	274	567	0	3 031
1983–83†	1 617	1 799	57	37	0	3 510
1983–84‡	1 982	3 532	819	305	0	6 638
1984–85‡	1 360	2 993	470	223	0	5 046
1985–86‡	1 696	4 056	2 059	442	0	8 253
1986–87‡	1 603	2 277	269	76	0	4 225 §
1987–88‡	1 016	2 331	90	35	0	3 472 §

* 1 April–31 March.
‡ 1 October–30 September.
† 1 April–30 September.
§ These totals do not match those in Table 3 due to under-reporting to the FSU.
N/A Unknown.

Table 3: Reported landings (t) for the main QMAs from 1931 to 1982.

Year	SKI 1	SKI 2	SKI 3	SKI 7
1931–32	0	0	0	0
1932–33	0	0	0	0
1933–34	0	42	0	66
1934–35	0	70	0	105
1935–36	0	39	0	59
1936–37	0	37	13	57
1937–38	0	86	19	130
1938–39	0	50	47	66
1939–40	0	48	47	72
1940–41	0	58	72	87
1941–42	1	63	50	96
1942–43	0	47	22	71
1943–44	0	15	15	23
1944	0	14	15	23
1945	6	19	13	30
1946	5	20	30	33
1947	0	23	74	32
1948	1	28	51	44
1949	4	19	48	28
1950	15	32	59	30
1951	5	29	35	27
1952	1	21	45	22
1953	1	13	42	10
1954	2	31	12	38
1955	0	25	22	23
1956	0	31	27	35
1957	2	12	21	10
1958	5	34	19	28
1959	2	40	58	38
1960	3	61	65	39
1961	6	42	14	19
1962	5	58	49	27
1963	19	72	19	38
1964	17	48	20	29
1965	19	96	11	28
1966	12	102	15	26
1967	32	173	14	46
1968	18	183	15	33
1969	60	308	11	22
1970	50	281	22	28
1971	52	315	24	59
1972	85	261	15	37
1973	56	237	46	102
1974	21	150	14	89
1975	2	96	172	37
1976	11	108	8	36
1977	22	118	4	74
1978	36	235	411	1 069
1979	82	235	2 104	628
1980	278	287	1 899	924
1981	236	350	1 369	1 669
1982	546	219	971	676

Notes:

1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data include both foreign and domestic landings.

Table 4: Reported landings (t) of gemfish by Fishstock from 1983–84 to present and TACCs from 1986–87.

Fishstock	SKI 1		SKI 2		SKI 3		SKI 7		SKI 10		
FMA (s)	1 & 9		2		3, 4, 5, & 6		7 & 8		10	Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	TACC	Landings	TACC
1983–84*	588	–	632	–	3 481	–	1 741	–	† –	6 442 §	–
1984–85*	388	–	381	–	2 533	–	1 491	–	† –	4 793 §	–
1985–86*	716	–	381	–	5 446	–	1 468	–	† –	8 011 §	–
1986–87	773	550	896	860	2 045	2 840	1 069	1 490	†10	4 783	5 750
1987–88	696	632	1 095	954	1 664	2 852	1 073	1 543	†10	4 528	5 991
1988–89	1 023	1 139	1 011	1 179	1 126	2 922	1 083	1 577	†10	4 243	6 827
1989–90	1 230	1 152	1 043	1 188	1 164	3 259	932	1 609	†10	4 369	7 218
1990–91	1 058	1 152	949	1 188	616	3 339	325	1 653	†10	2 948	7 342
1991–92	1 017	1 152	1 208	1 197	287	3 339	584	1 653	†10	3 096	7 350
1992–93	1 292	1 152	1 020	1 230	371	3 345	469	1 663	†10	3 152	7 401
1993–94	1 156	1 152	1 058	1 300	75	3 345	321	1 663	†10	2 616	7 470
1994–95	1 032	1 152	905	1 300	160	3 355	103	1 663	†10	2 169	7 480
1995–96	801	1 152	789	1 300	49	3 355	81	1 663	†10	1 720	7 480
1996–97	965	1 152	978	1 300	58	1 500	238	900	†10	2 240	4 862
1997–98	627	752	671	849	27	300	44	300	†10	1 369	2 211
1998–99	413	460	336	520	17	300	59	300	†10	825	1 590
1999–00	409	460	506	520	62	300	107	300	†10	1 083	1 590
2000–01	335	460	330	520	47	300	87	300	†10	799	1 590
2001–02	201	210	268	240	72	300	123	300	†10	664	1 060
2002–03	206	210	313	240	115	300	268	300	†10	902	1 060
2003–04	221	210	301	240	78	300	542	300	†10	1 142	1 060
2004–05	234	210	259	240	72	300	635	300	†10	1 199	1 060
2005–06	230	210	182	240	27	300	248	300	†10	687	1 060
2006–07	215	210	317	240	26	300	209	300	†10	767	1 060
2007–08	216	210	249	240	18	300	179	300	†10	662	1 060
2008–09	191	210	191	240	11	300	213	300	†10	606	1 060
2009–10	247	210	176	240	20	300	144	300	†10	587	1 060
2010–11	226	210	300	240	33	300	301	300	†10	860	1 060
2012–13	182	210	140	240	23	300	234	300	†10	580	1 060
2013–14	198	210	268	240	39	300	268	300	†10	764	1 060
2014–15	83	210	168	240	21	300	231	300	†10	503	1 060
2015–16	188	210	224	240	80	300	186	300	†10	677	1 060
2016–17	244	210	236	240	248	300	431	300	†10	1 159	1 060
2017–18	277	210	286	240	466	300	583	300	†10	1 612	1 060
2018–19	354	210	328	240	577	300	937	300	†10	2 196	1 060
2019–20	394	210	275	240	514	599	938	599	†10	2 120	1 658
2020–21	284	252	368	240	1 063	599	1 012	599	†10	2 728	1 700

* FSU data. † No recorded landings.

§ The totals do not match those in Table 2 because some fish were not reported by area (FSU data prior to 1986–87).

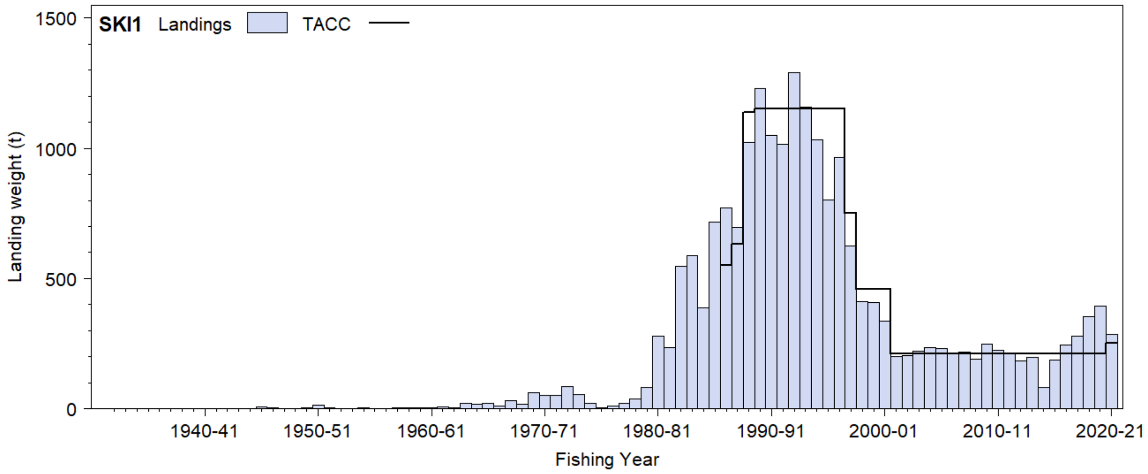


Figure 1: Reported commercial landings and TACC for the four main SKI stocks. SKI 1 (Auckland East). [Continued on next page]

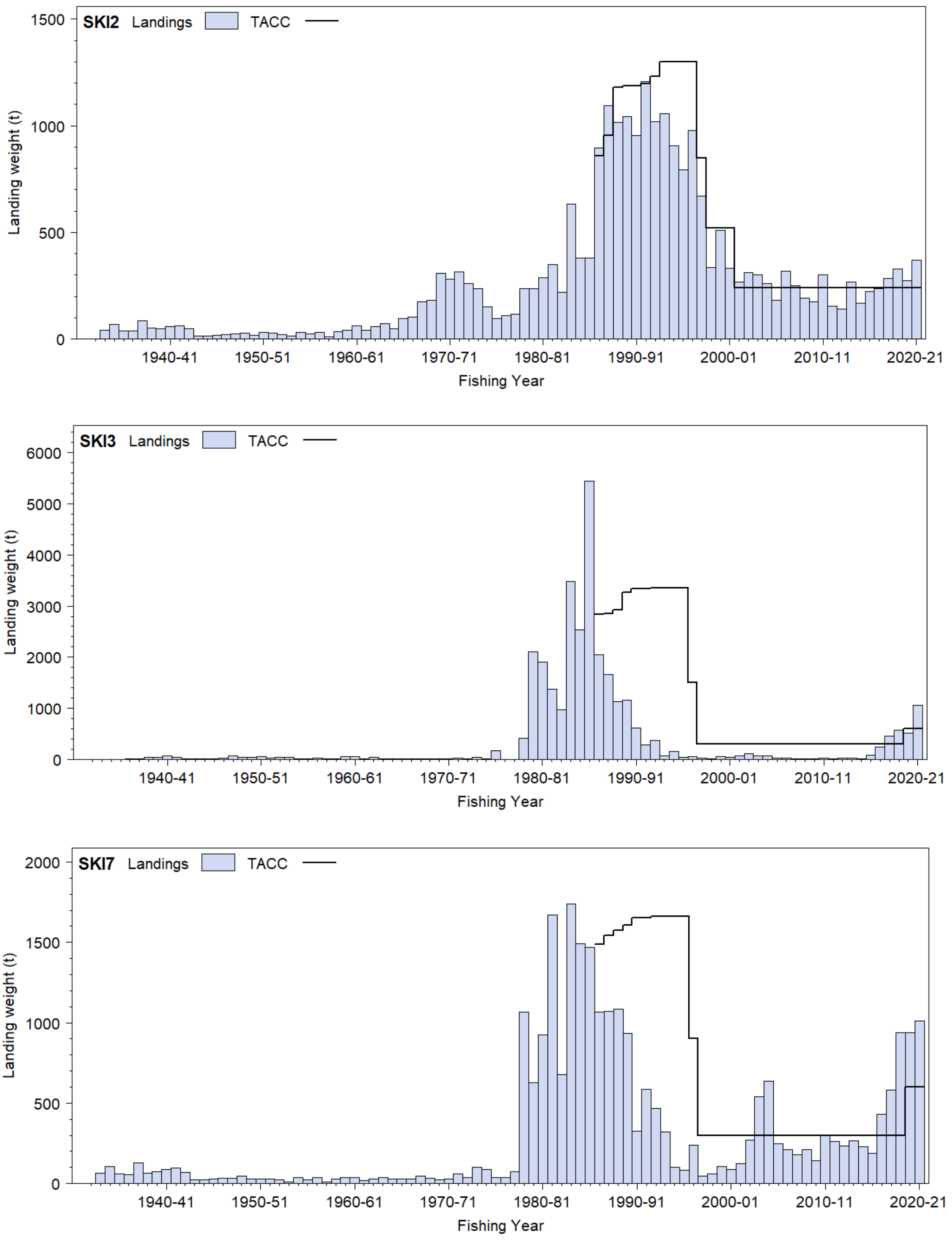


Figure 1: [Continued] Reported commercial landings and TACC for the four main SKI stocks. SKI 2 (Central East), SKI 3 (South East Coast), and SKI 7 (Challenger).

1.2 Recreational fisheries

Little or no recreational catch was reported in marine recreational fishing telephone/diary surveys between 1992 and 2001, but the harvest estimates provided by these surveys are no longer considered reliable. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a national panel survey was conducted for the first time throughout the 2011–12 fishing year (Wynne-Jones et al 2014). The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year.

The panel members were contacted regularly about their fishing activities and harvest information in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 5. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 5: Recreational harvest estimates for gemfish stocks (Wynne-Jones et al 2014, 2019). Mean fish weights were not available from boat ramp surveys so catches cannot be converted to weight.

Stock	Year	Method	Number of fish	Total weight (t)	CV
SKI 1	2011–12	Panel survey	2 752	–	0.39
	2017–18	Panel survey	7 140	–	0.33
SKI 2	2011–12	Panel survey	0	–	–
	2017–18	Panel survey	1 299	–	0.53
SKI 3	2011–12	Panel survey	0	–	–
	2017–18	Panel survey	0	–	–
SKI 7	2011–12	Panel survey	137	–	1.03
	2017–18	Panel survey	27	–	1.01

1.3 Customary non-commercial fisheries

Quantitative information on the current level of customary non-commercial take is not available and is assumed to be negligible.

1.4 Illegal catch

No data on the scale of misreporting are available but misreporting is assumed to be negligible.

1.5 Other sources of mortality

There may have been some gemfish discarded prior to the introduction of the EEZ, but this is likely to have been minimal since the early 1980s because gemfish is a medium value species.

2. BIOLOGY

Silver gemfish (*Rexea solandri*) occur on the continental shelf and slope, from about 50–550 m depth. They are known to undertake spawning migrations and the pre-spawning runs have formed the basis of winter target fisheries, but exact times and locations of spawning are not well known. Spawning probably takes place about July near North Cape and late August/September off the west coast of the South Island.

Ageing of southern gemfish indicates that fish attain about 30 cm at the end of the first year, 45 cm at the end of the second year, 53 cm at the end of the third year, and 63 cm at the end of the fourth year. Both sexes display similar growth rates until age 5, but subsequently females grow larger. The maximum ages recorded for gemfish (from 1989 to 1994) are 17 years for both sexes. In the northern fishery (SKI 1, SKI 2), males and females appear to recruit into the fishery from age 3 but are probably not fully recruited until about age 5 (SKI 2) or age 7 or 8 (spawning fishery in SKI 1). In the southern fishery, gemfish start to recruit at age 2 into spawning and non-spawning fisheries, but age at full recruitment is difficult to determine because of large variation in year class strength.

Recruitment variability in SKI 3 and SKI 7 (during the 1980s and early 1990s) has been correlated with wind and sea surface temperature patterns during the spawning season (Renwick et al 1998). Patterns of recruitment for 2000–2015 in SKI 3 and SKI 7 do not appear to be consistent with the previous correlation with SST (Langley 2020). No significant correlations were found between SKI 1 and SKI 2 recruitment indices and a range of climate variables (Hurst et al 1999).

Biological parameters relevant to stock assessment are given in Table 6.

Table 6: Estimates of biological parameters for gemfish.

Fishstock		**Source**
1. Natural mortality (*M*)		
All stocks	$M = 0.25\ y^{-1}$ considered best estimate for all areas for both sexes	Horn & Hurst (1999)

2. Weight = *a* (length)^b (Weight in g, length in cm fork length)

	Male		Female		
	a	*b*	*a*	*b*	
SKI 1	0.0034	3.22	0.0008	3.55	Langley et al (1993)
SKI 3	0.0012	3.41	0.0095	3.47	Hurst & Bagley (1998)

3. von Bertalanffy growth parameters

	Male			Female			
	L_∞	*k*	t_0	L_∞	*k*	t_0	
East Northland	90.7	0.204	-0.49	122.7	0.114	-1.1	Langley et al (1993)
East Northland	88.4	0.235	-0.54	108.5	0.167	-0.71	Horn & Hurst (1999)
Wairarapa	90.8	0.287	0.00	103.4	0.231	-0.1	Horn & Hurst (1999)
West Northland	86.3	0.295	-0.11	103.4	0.209	-0.37	Horn & Hurst (1999)
North combined	87.4	0.266	-0.35	105	0.194	-0.55	Horn & Hurst (1999)
Southland	88.5	0.242	-0.66	104.2	0.178	-0.88	Horn & Hurst (1999)

3. STOCKS AND AREAS

When introduced to the QMS in 1986, the gemfish stock was defined as comprising only silver gemfish, *Rexea solandri*. In 1996, the species definition was amended to *Rexea* spp. (section 319 of the Fisheries Act 1996) and separate research codes were established for *Rexea solandri* (RSO), *Rexea prometheoides* (REP), and *Rexea antefurcata* (LFG). The statutory reporting code remained SKI, but with the meaning amended to *Rexea* spp. (Fisheries (Reporting) Amendment Regulations 2005, clause 10(3)). A small number of landings and estimated catches have been reported using all three of the species-specific codes, but all observer and research records in Fisheries New Zealand databases are recorded as *Rexea solandri*. Unless otherwise noted, all references to gemfish in this chapter are considered to be to *Rexea solandri*.

In previous assessments, analysis of seasonal trends in gemfish fisheries indicated that there may be at least two stocks:

1. A southern/west coast stock (SKI 3 & 7) caught on Pukaki Rise and the Stewart-Snares shelf in spring, summer, and autumn, which appears to migrate to the west coast of the South Island to spawn and is caught there mainly in August–September. Spawning is thought to occur in late August/early September (Hurst 1988, Horn & Hurst 1999).
2. A northern/east coast stock (SKI 1E & SKI 2) caught mainly off the North Island east coast in spring and summer, which then migrates in May–June to spawn north of the North Island and is intercepted in the Bay of Plenty and East Northland. Seasonal trends in commercial catch and length frequency data from SKI 1E (FMA 1) are consistent with pre- and post-spawning migrations through the area; similar data from SKI 2 are inconclusive but indicate lower catches during the peak spawning months, although this could be partly due to target fishing on other species, particularly orange roughy, at this time.

The relationship of the pre-spawning fishery in SKI 1W (FMA 9) to the pre-spawning fishery in SKI 1E was investigated by Horn & Hurst (1999). They presented age frequency distributions from commercial catches for SKI 1E, SKI 1W, and SKI 2 and from research sampling for SKI 3. Age distributions for the two SKI 1 spawning fisheries appeared to be similar, with year classes in 1980, 1982, 1984, 1986, and 1991 strong relative to other year classes. The SKI 2 distribution also exhibited the same pattern, although the relative dominance of the 1991 year class was greater, as might be expected from an area in which pre-recruit fish occur. The age distribution from SKI 3 gemfish showed that the 1982, 1984, 1985, and 1989 year classes were strong. There were no significant differences in the von Bertalanffy growth parameters calculated for northern and southern gemfish (Horn & Hurst 1999).

Recent biochemical analyses of Australasian gemfish suggested that there may be a very low level of mixing between eastern Australian and New Zealand gemfish, but not high enough to treat them as a single stock (Colgan & Paxton 1997). There was also a suggestion of a difference between north-eastern and southern New Zealand gemfish.

Two alternative hypotheses have been proposed: that both SKI 1 and SKI 2 are one stock, or that SKI 1W is separate from SKI 1E and SKI 2. The Middle Depths Working Group concluded that based on the close similarity in declines in CPUE indices and in age distributions from commercial catches that the northern gemfish should be assessed using SKI 1 and 2 combined.

4. STOCK ASSESSMENT

The most recent fully quantitative stock assessment for SKI 1 and SKI 2 was conducted in 2008 (Fu et al unpublished). Subsequent trends in stock abundance are assessed using standardised CPUE indices, updated in 2021.

In 2008, the northern gemfish stock was assessed using the hypothesis of one stock (SKI 1 and SKI 2). The alternative hypothesis, that SKI 1W is separate from SKI 1E and SKI 2 was not modelled, because results from previous assessments were similar to those from SKI 1 and SKI 2 combined. Estimates of virgin biomass (B_0) and mature biomass in 2006 and 2007 are presented below.

A stock assessment of the southern stock (SKI 3 & 7) was conducted in 1997 using the MIAEL procedure (Hurst & Bagley 1998). This analysis was considered highly uncertain by the Middle Depths Working Group, which only accepted the minimum and maximum ranges for B_0, stock status, and yields. Langley (2020) incorporated CPUE indices derived from the west coast South Island (WCSI) hoki fishery, length composition data from the main commercial fisheries (from observers), and trawl surveys of the west coast of the South Island by *Kaharoa* and *Tangaroa* into a preliminary stock assessment model for the southern stock. However, the Deepwater Working Group (DWWG) concluded that this preliminary stock assessment model was not sufficiently reliable to estimate current stock status. Starr et al (in press) conducted an extensive analysis of all available catch and effort data for SKI 3 and SKI 7, reporting ten CPUE series covering three SKI 3 and SKI 7 fisheries which were based on four distinct data sets (event-based CPUE, daily CPUE, and daily processed catch, using the statutory catch, effort, and landings data, and observed catch CPUE using data from fisheries observers).

4.1 Auckland (SKI 1) and Central East (SKI 2)

4.1.1 Combined landings and TACCs for SKI 1 and SKI 2

Figure 2 shows the landings and TACCs for SKI 1 and SKI 2 combined.

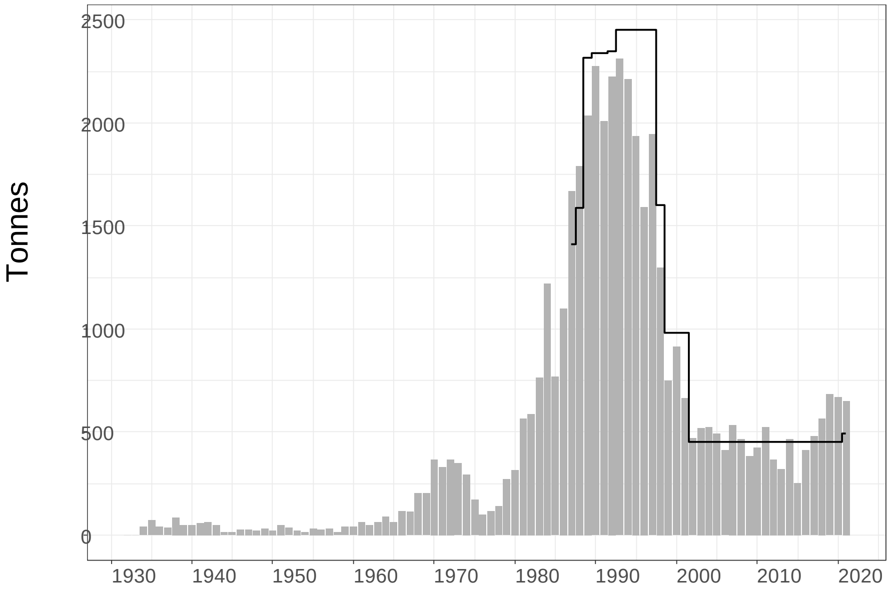


Figure 2: Combined landings (bars) and TACC (line) for SKI 1 and SKI 2.

4.1.2 Age composition of commercial catches

Commercial catch-at-age data included in the models were: SKI 1E for 1989–1994, 1997–1999, 2002, and 2006; SKI 1W for 1996–1999 and 2002; and SKI 2 for 1996–2005 and 2007. Age data for SKI 1E and SKI 1W were combined for the stock assessment model. Catch-at-age was subsequently reported for the 2010 SKI 1 target trawl fishery (Langley et al 2012).

4.1.3 Estimates of abundance used in the 2008 assessment

Standardised CPUE indices for SKI 1 and SKI 2 were calculated for three fishery sub-groups in 2007: (1) target catch only, (2) all gemfish catch, and (3) all gemfish catch on TCEPR forms. The indices for TCEPR all gemfish catch (SKI 1 for 1990–2006, SKI 2 for 1994–2006) were used in the assessment. The indices for SKI 1 from SKI 1E and SKI 1W combined and for SKI 2 included both midwater and bottom trawl methods. Both time series showed steep declines to the early 2000s, followed by marked increases.

4.1.4 Assessment model

The 2008 stock assessment model for SKI 1 and SKI 2 (Fu et al unpublished) updated the 2007 assessment (Fu et al 2008) and included two fishery types, based on spawning activity. The first was the home ground fishery, SKI 2, where all age classes occur and where fishing is mainly in the non-spawning season. The second was on the spawning migration fishery, SKI 1, where only mature age classes occur and where fishing was in the winter months. The stock assessment was implemented as a Bayesian single stock model using the general-purpose stock assessment program CASAL v2.20 (Bull et al 2008).

The assessment model partitioned the stock into two areas (spawning (SKI 1E and 1W) and home ground (SKI 2)), two sexes and age groups 1–20, with no plus group. There were four time steps in the model (Table 7). In the first time step, the 1 year olds recruit to the population, which is then subjected to fishing mortality in SKI 2. In the second time step, fish migrate into SKI 1, and again are subjected to fishing mortality. In time step 3, fish ages are incremented, and spawning occurs. Fish migrate back to SKI 2 in the final time step.

Table 7: Annual cycle of the stock model for gemfish, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

				Observations	
Step	**Period**	**Processes**	M[1]	**Description**	%M[2]
1	Oct–Apr	Fishing (SKI 2)	0.58	CPUE (SKI 2)	50
		Recruitment		Proportions at age (SKI 2)	50
2	May–Jun	Migration to SKI 1	0.17	CPUE (SKI 1)	50
		Fishing (SKI 1)		Proportions at age (SKI 1)	50
3	Jul	Spawning	0.08		
		Increment age			
4	Aug–Sep	Migration to SKI 2	0.17		

1. M is the proportion of natural mortality that was assumed to have occurred in that time step.
2. %M is the percentage of the natural mortality within each time step that was assumed to have taken place at the time each observation was made.

4.1.5 Results

Estimates of biomass were obtained using the biological parameters and model input described by Fu et al (2008). Three model runs were considered, because there were concerns that the most recent SKI 2 catch-at-age samples could be biased due to changes in the fishery. Model run ‘$2006_{YCS2000}$’ used data up to 2006 and estimated year class strengths (YCSs) from 1978 to 2000; run ‘$2006_{YCS2001}$’ used the same data but estimated the year class strengths from 1978 to 2001; run ‘$2007_{YCS2003}$’ incorporated data up to 2007, with year class strengths estimated from 1978 to 2003. Table 8 describes the three model runs.

Table 8: Model run labels and descriptions for the base case and sensitivity model runs.

Model run	Description
$2006_{YCS2000}$	Fitting to catch-at-age up to 2006, and CPUE indices based on TCEPR to 2001, and estimating YCSs 1978–2000 using an average natural mortality of 0.25 y^{-1} and separate age-based logistic fishing selectivities for SKI 2 fisheries before and after 2001.
$2006_{YCS2001}$	$2006_{YCS2000}$, but estimated YCS from 1978–2001.
$2007_{YCS2003}$	$2006_{YCS2000}$, but included 2007 SKI 1 and 2 catch and 2007 SKI 2 catch-at-age, and estimated YCSs 1978–2003.

For each model run, MPD fits were obtained and qualitatively evaluated. MPD estimates of biomass trajectories are shown in Figure 3. MCMC estimates of the posterior median and 95% percentile credible intervals for current and virgin biomass are reported in Table 9, and for year class strengths are shown in Figure 4.

Year class strengths were poorly estimated before 1990 when the only data available to determine year class strength were from older fish (see Figure 4). The estimates suggest a period of generally higher than average recruitment during the 1980s, followed by a period of generally lower than average recruitment (1992–2000). For run $2006_{YCS2001}$, the 2001 year class strength was estimated to be weak. For run $2007_{YCS2003}$, recruitment appeared to have improved in 2002 and 2003, but was still below average, and the estimate of 2003 year class strength was very uncertain.

The stock declined markedly during the early 1980s, followed by a small period of recovery due to recruitment of strong year classes in the late 1980s. After 1992, the stock declined to its lowest level due to increasing exploitation rates combined with a long period of low recruitment beginning in the early 1990s (see Figure 3). For model runs including data up to 2006, the estimated posterior median of B_{2006} was at about 32% of B_0 when the 2001 year class strength was fixed at 1, or 26% of B_0 when this year class was being estimated. More pessimistic estimates of biomass were obtained when 2007 catch-at-age data were included, which suggest that the posterior median of B_{2007} was at about 22% of B_0 (see Table 9).

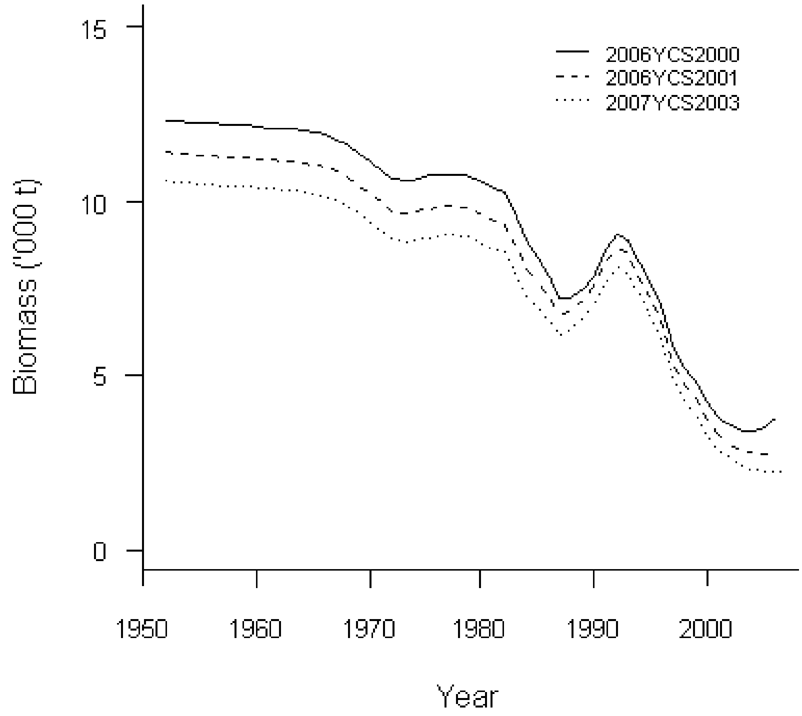


Figure 3: MPD biomass trajectories for the northern stock (SKI 1 & 2) from northern stock (SKI 1 & 2) from three model runs: $2006_{YCS2000}$, $2006_{YCS2001}$, and $2007_{YCS2003}$.

Table 9: Bayesian median and 95% credible intervals of B_0, $B_{current}$, and $B_{current}$ as a percentage of B_0 for the northern stock (SKI 1 & 2) from three model runs. $B_{current}$ refers to B_{2006} for run $2006_{YCS2000}$ and $2006_{YCS2001}$, and B_{2007} for run $2007_{YCS2003}$.

Model run	B_0	$B_{current}$	$B_{current}$ (% B_0)
$2006_{YCS2000}$	12 672 (11 398–14 709)	4 007 (2 759–5 766)	32 (24–40)
$2006_{YCS2001}$	11 691 (10 636–13 283)	3 008 (2 024–4 593)	26 (19–35)
$2007_{YCS2003}$	10 900 (9 853–12 403)	2 443 (1 448–3 924)	22 (15–32)

The effect of using a lower and higher value of natural mortality was investigated for run $2007_{YCS2003}$: with the average M set at 0.20, the current biomass is about 16% B_0; with an average M set at 0.30, the current biomass is about 28% B_0. Estimates of other model parameters were relatively insensitive to the assumed value of natural mortality.

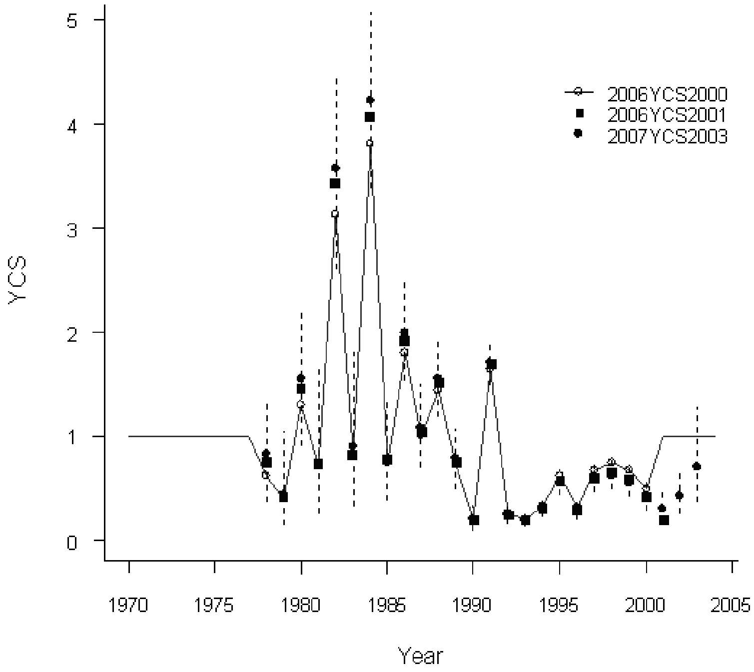


Figure 4: Bayesian median of year class strength for the three model runs $2006_{YCS2000}$, $2006_{YCS2001}$, and $2007_{YCS2003}$. Dashed lines are the 95% credible intervals for run $2007_{YCS2003}$.

4.1.6 Yield estimates

MCY and *CAY* were determined using stochastic sample-based simulations. One simulation run was done for each sample from the posterior, ultimately producing an estimate of yield that has been averaged over all samples (Bull et al 2008). Each run extended over 150 years with recruitment randomly sampled, but with the first 100 of those years discarded to allow the population to stabilise. Yield calculation was based on the procedures of Francis (1992), where yields were maximised subject to the constraint that spawning stock biomass should not fall below 20% of B_0 more than 10% of the time (Table 10).

Table 10: Yield estimates (*MCY* and *CAY*) and associated parameters for the for the northern stock (SKI 1 & 2) from three model runs where simulations were based on recruits resampled from the entire period in which year class strengths were estimated.

Model run	B_{MCY} (t)	B_{MCY} (% B_0)	*MCY* (t)	B_{MAY} (t)	B_{MAY} (% B_0)	*MAY* (t)	*CAY* (t)
$2006_{YCS2000}$	6 698	53	995	4 117	32	1 404	1 305
$2006_{YCS2001}$	6 304	54	865	3 934	34	1 270	925
$2007_{YCS2003}$	5 928	48	816	3 676	34	1 194	755

4.1.7 2022 SKI 1 and SKI 2 CPUE update

The SKI 2 CPUE series was previously updated in 2014 with data up to the end of 2012–13 (Starr & Kendrick 2016). The 2014 SKI 2 CPUE series differed from the series used in the 2008 assessment in a number of ways: a) only bottom trawl was used; b) data from all form types were amalgamated into a day of fishing by a vessel, selecting the modal target species and modal statistical area when there were multiple values within a day; c) target species (including SKI) was included in the analysis as an explanatory variable. These analyses appeared to be robust, with only small differences in the models that excluded or included SKI as a target category. The Working Group concluded that future CPUE analyses should include data from the Bay of Plenty.

In 2020, the 2014 CPUE indices were initially updated using the same approaches and with the addition of data from the Bay of Plenty. The updated series showed large increases in 2017–18 and 2018–19 that were primarily driven by data from the tarakihi target fishery. The tarakihi target fishery generally operates in shallower depths than the gemfish target fishery. Examination of length-frequency data from observers and market sampling suggested that the tarakihi fishery took a mix of sub-adult and adult gemfish, and that adult gemfish were taken when targeting gemfish. As a result, separate CPUE indices were developed for the TAR and SKI target fisheries, with both including data from SKI 2 and the east and west coast fisheries in SKI 1 on the basis that SKI 1 and SKI 2 are assessed as a single biological stock. This was supported by implied residual plots, which showed consistent trends across all statistical areas for each series.

For the TAR target fisheries, a trip-resolution index was developed, which addressed the fact that gemfish may not be well estimated in event-level data from the tarakihi fishery. The 2020 plenary accepted the BT-TAR positive catches trip-based index as an index of abundance for mixed sub-adult and adult gemfish in SKI 1 and SKI 2. The BT-TAR trip-based index was updated in 2021 (and accepted by the Plenary), using a combined binomial-lognormal model, and further updated in 2022 with data to the end of the 2020–21 fishing year. This series showed a steep decline from 1990 to 1999, a stable period to 2016, and then a rapid increase to 2020 which dropped somewhat in 2021 (Figure 5). A tarakihi target event-resolution index from 2007–08 showed a similar trend for the common years (Figure 5).

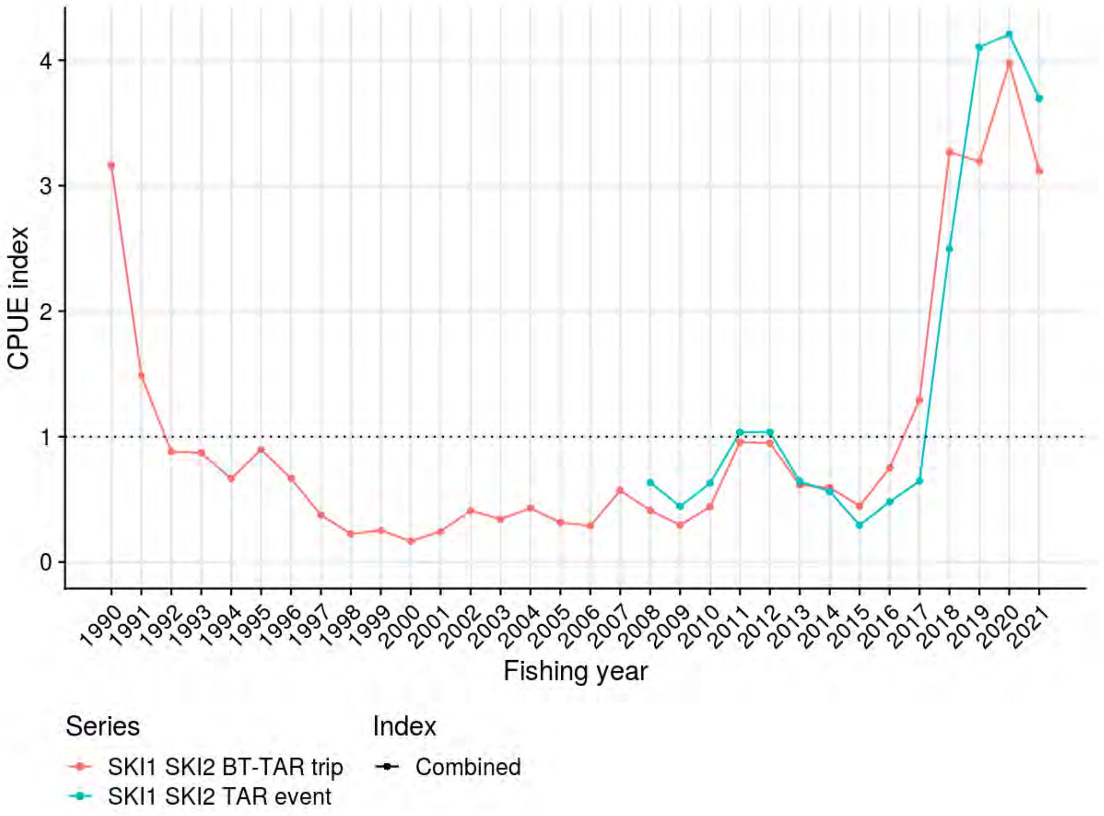


Figure 5: The SKI 1 and SKI 2 CPUE series using trip-resolution data from the tarakihi-target bottom trawl fishery, scaled to a geometric mean of one, and the tarakihi-target bottom trawl event-resolution index from 2007–08.

For the SKI target fisheries, event-based data were available from the mid-1990s in SKI 1. However, the 2020 Fisheries Assessment Plenary concluded that the BT-SKI indices could not be accepted as indexing abundance of SKI 1 and SKI 2 due to sparse data, large changes in distribution of fishing effort, and considerably reduced targeting. To address concerns with the SKI target index, a new event-resolution index was developed in 2021 using data from HOK and SKI target tows by bottom trawl and midwater trawl fished within 10 m of the bottom. The index was limited to the Bay of Plenty and SKI 2 where there was a continuous fishery operating. Market sampling data indicated that gemfish and hoki target trips caught adult gemfish with a similar size composition, and the event-resolution HOK-SKI target index from the east coast fisheries was therefore accepted as an index of abundance of adult gemfish by the 2021 Fisheries Assessment Plenary. This index was also updated in 2022, with data to the end of the 2020–21 fishing year.

The HOK-SKI target series began in 1994, declined to a low point in the early 2000s, then increased until around 2008 where it remained stable until increasing rapidly from 2017 to 2021, with the recent increase in abundance following on from the increase seen previously for mixed sub-adult/adult fish in the BT-TAR index (Figure 6). A sensitivity without standardising for target species showed a similar increase, and further sensitivities in 2022 confirmed that the trends were robust to changes in the composition of the fleet.

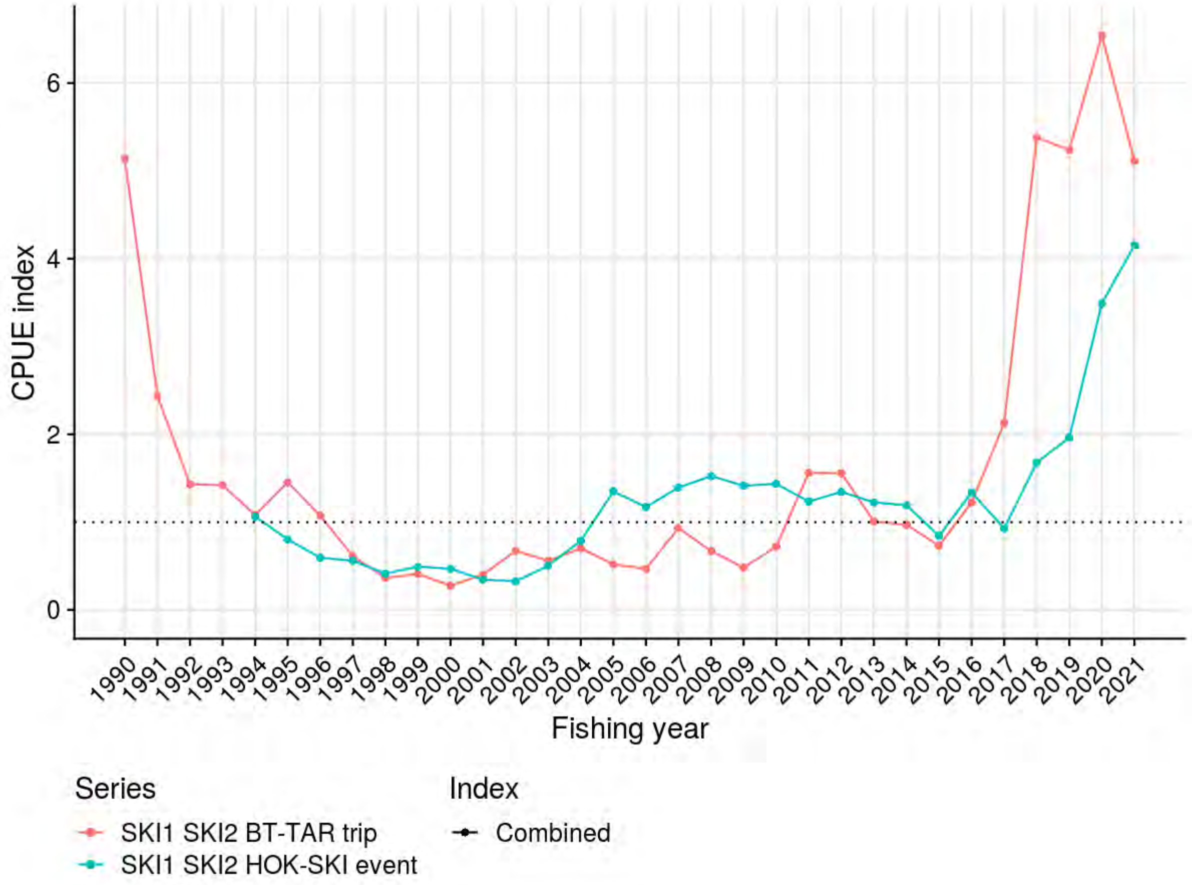


Figure 6: The SKI 1 and SKI 2 CPUE series for mixed sub-adult/adult gemfish (trip-resolution index from the tarakihi-target bottom trawl fishery) (SKI1 SKI2 BT-TAR trip), and adult gemfish (event-resolution index from HOK and SKI target trawl events in the Bay of Plenty and SKI 2) (SKI1 SKI2 HOK-SKI event).

Establishing B_{MSY} compatible reference points

In 2021, the Working Group adopted geometric mean CPUE from the HOK and SKI event-resolution model for the period 2004 to 2017 as the soft limit reference point for SKI 1 and 2. The results of the 2008 assessment were used as guidance, in particular the conclusion that stock status in 2007 was in the range 20–30% B_0. The Working Group adopted the default Harvest Strategy Standard definitions for the target and hard limit of twice and half the soft limit, respectively. The Working Group noted that the resulting assessment of stock status in the mid-1990s and early 2000s was poorer than indicated by the 2008 assessment results, and that the 2008 assessment had not provided a good fit to the increase in CPUE in the mid-2000s. However, adopting the period 2004 to 2017 as the soft limit was considered the best option to provide reference points that reflected the assessed status in 2008.

4.2 South-East/Southland (SKI 3) and Challenger/Central (West) (SKI 7)

4.2.1 Trawl survey biomass indices

The relative abundance of gemfish in the Southland area (SKI 3) was monitored by trawl surveys conducted by *Shinkai Maru* (early 1980s) and *Tangaroa* (early 1990s) (Table 11). Since the early 1990s, a regular series of inshore trawl surveys of the west coast South Island (SKI 7) has been conducted by *Kaharoa* during April–May. Although gemfish is not considered to be a target species for the survey, the survey appears to monitor the relative abundance of juvenile gemfish in the survey area. The more recent series of trawl surveys of the west coast South Island by *Tangaroa* overlaps the main distribution of gemfish and may occur during the early part of the spawning period. The survey appears to monitor the adult and juvenile components of the gemfish stock in the WCSI.

Table 11: Biomass indices (t) and coefficients of variation (CV) from trawl surveys (assuming area availability, vertical availability, and vulnerability = 1).

Fishhstock	Area	Vessel	Trip code	Date	Biomass	% CV
SKI 3	Southland	*Shinkai Maru*	SHI8102	Feb 1981	3 900	17
			SHI8201	Mar–Apr 1982	3 100	31
			SHI8303	Apr 1983	5 500	33
SKI 3	Southland	*Tangaroa*	TAN9301	Feb–Mar 1993	1 066	17
			TAN9402	Feb–Mar 1994	406	18
			TAN9502	Feb–Mar 1995	539	25
			TAN9604	Feb–Mar 1996	529	23
SKI 7	WCSI	*Kaharoa*	KAH9204	Mar–Apr 1992	130	19
			KAH9404	Mar–Apr 1994	68	29
			KAH9504	Mar–Apr 1995	21	55
			KAH9701	Mar–Apr 1997	704	83
			KAH0004	Mar–Apr 2000	120	30
			KAH0304	Mar–Apr 2003	137	23
			KAH0503	Mar–Apr 2005	474	49
			KAH0704	Mar–Apr 2007	101	19
			KAH0904	Mar–Apr 2009	143	29
			KAH1104	Mar–Apr 2011	101	34
			KAH1305	Mar–Apr 2013	113	28
			KAH1503	Mar–Apr 2015	186	17
			KAH1703	Mar–Apr 2017	545	28
			KAH1902	Mar–Apr 2019	559	22
SKI 7	WCSI	*Tangaroa*	TAN1210	Jul–Aug 2012	14	32
			TAN1308	Aug 2013	11	43
			TAN1609	Aug 2016	127	23
			TAN1807	Jul–Aug 2018	702	33

Footnote: The *Tangaroa* WCSI survey in 2000 was not used because the survey in that year did not extend inshore of 300 m depth.

4.2.2 Exploratory population modelling

Langley (2020) developed CPUE analyses based on data derived from the bycatch of gemfish from the WCSI hoki fishery. Two analyses were put forward, one a negative binomial series based on all catch and effort data from the target HOK trawls conducted by the WCSI trawl (BT and MW) fishery during July–September from 1989–90 to 2017–18. The other, using a delta-lognormal procedure, was a pared down data set limited to New Zealand domestic vessel effort in a 250–600 m depth range within the northern area of the hoki fishery during late August–September. The Deepwater Working Group considered these indices to be qualitatively reflecting a recent increase in biomass but were unlikely to be directly proportional to abundance. Nevertheless, these CPUE series were used in a preliminary age-structured stock assessment model to test the implications of the apparent increase in southern gemfish abundance (Langley 2020).

This preliminary age structured population model was configured to integrate the various data sets available from SKI 7 and was extended to include the entire southern gemfish stock (SKI 3 and SKI 7). The data sets included trawl survey biomass estimates and age composition data available from the *Tangaroa* Southland surveys (4 surveys 1993–1996) and biomass estimates from three earlier *Shinkai Maru* trawl surveys (1981–1983). Total annual catches were available from SKI 3 and SKI 7 for 1975 to 2017–18. Additional observer sampled length composition data were also available from the gemfish sampled from the Southland squid fishery (SKI 3) (14 years of observations).

The model was implemented in Stock Synthesis and configured as follows.

- Model period 1975–2018 (2018 = 2017–18 fishing year).
- Initial conditions equilibrium, unexploited in 1975 with the first year of catch in 1975.
- Population structure: two sexes, 15 age classes (1–15+), 1 cm length bins (10–110 cm).
- Biological parameters (natural mortality, growth, maturity, length-weight) as documented in Table 6.
- Single model region, i.e., spatial structure of fisheries not explicitly modelled.
- Beverton-Holt spawner-recruitment relationship (steepness *h* 0.85). Recruitment deviates 1975–2016, with models using sigmaR from 1.0 to 2.0.
- Abundance indices: four sets of trawl survey indices and SKI 7 CPUE indices *(all data or partial data* indices, with CV 0.30).
- Annual catches from two fisheries (SKI 3 and SKI 7) with allowance for under reporting pre- and post-QMS.
- Length-based selectivity functions. Logistic selectivities estimated for two commercial fisheries. Southland trawl surveys were assumed to have the equivalent selectivity to the SKI 3 fishery selectivity. Double normal selectivities estimated for *Kaharoa* and *Tangaroa* WCSI trawl surveys.

In general, the model provided a reasonable fit to most of the data sets. However, the fit to the *all data CPUE* indices was poor because the short period of high CPUE indices in 2003–04 and 2004–05 appeared to be inconsistent with the annual catches and fishery length composition data from the following years (given the biological parameters of the species). The model yielded a much better fit to the *partial data CPUE* indices throughout the time series (1997–2018).

The model estimated a period of relatively high recruitment in the late 1970s-early 1980s, minimal recruitment during the late 1980s to 1990s and intermittent recruitment during the 2000s. The model estimated exceptionally high recruitment estimates in 2014 and 2015 to fit the recent large increases in the CPUE indices and WCSI trawl survey biomass indices and the higher recent catches. The magnitude of these recent recruitment estimates was not consistent with that for the recruitment estimates for the entire preceding period. Further, the magnitudes of the recent recruitment estimates were inconsistent with the individual year classes evident in the length compositions from the 2018 WCSI fishery and *Tangaroa* trawl survey. It was only possible to appreciably improve the fit to the recent length compositions by excluding the last few years of CPUE indices and trawl survey biomass estimates and by reducing the catches in the terminal year.

The Deepwater Working Group considered that the model was not sufficiently reliable to provide estimates of current biomass and stock status. Nonetheless, the DWWG considered that there was sufficient information available from the trawl surveys and commercial fisheries data to conclude that there has been a considerable increase in stock abundance in recent years due to strong cohorts from the 2014, 2015, and 2016 year classes.

4.2.3 2021 SKI 3 & 7 CPUE analysis

Starr et al (in press) conducted detailed analyses of all available catch and effort data for SKI 3 and SKI 7, extending the preliminary CPUE analyses conducted by Langley (2020). They identified the following three southern gemfish fisheries:

- SKI 7 target HOK: a target HOK fishery operating in the winter (May–September) off the west coast of the South Island (Statistical Areas 034 and 035) based on bottom trawl (BT) gear or midwater gear fished within 10 m of the bottom (MB);
- SKI 3 Stewart-Snares shelf: a mixed target (SQU, BAR, HOK, SWA, SKI, LIN) fishery operating year round on the Stewart-Snares shelf and Pukaki Rise (Statistical Areas 025–030 and 504) based on bottom trawl (BT) gear or midwater gear fished within 10 m of the bottom (MB);
- SKI 3 East coast: a mixed target (SQU, BAR, HOK, RCO, TAR) fishery operating year round off the east coast South Island (Statistical Areas 020 and 022) based on bottom trawl (BT) gear or midwater gear fished within 10 m of the bottom (MB);

For each of these fisheries, they considered four data sets:

- event: tow-by-tow event-based data, based on TCEPR, TCER, and ERS-trawl forms, with estimated catches scaled to landings and constrained to report only the top five species caught in each tow (to conform to the requirements of the TCEPR form);
- daily processing: based on processing data from large factory trawlers, where the processed catch for the day was assumed to have been caught on that day; effort was the sum of the hours fished on that day, depth was the mean depth fished, and the modal statistical area and target species for the day was used;
- observer: tow-by-tow observer data; there was no concern about missing SKI in each tow with the assumption that the observer would find gemfish if it was present in the tow;
- daily rollup: the catch for the day was summed, along with the hours fished; the modal statistical area and target species for the day was used and the catch was constrained to be the top five species caught for the day; this 'roll-up' was meant to emulate the CELR form requirements and was intended to include inshore vessels into the analysis; all MW catch and effort were included because depth is not a valid CELR field.

Although the event and daily rollup data sets will have considerable data overlap, the catch data in the daily processing data set should be relatively independent from the event data set and the observer data set. This latter data set is based on many of the same events, but the data are recorded independently from the statutory catch and effort logs.

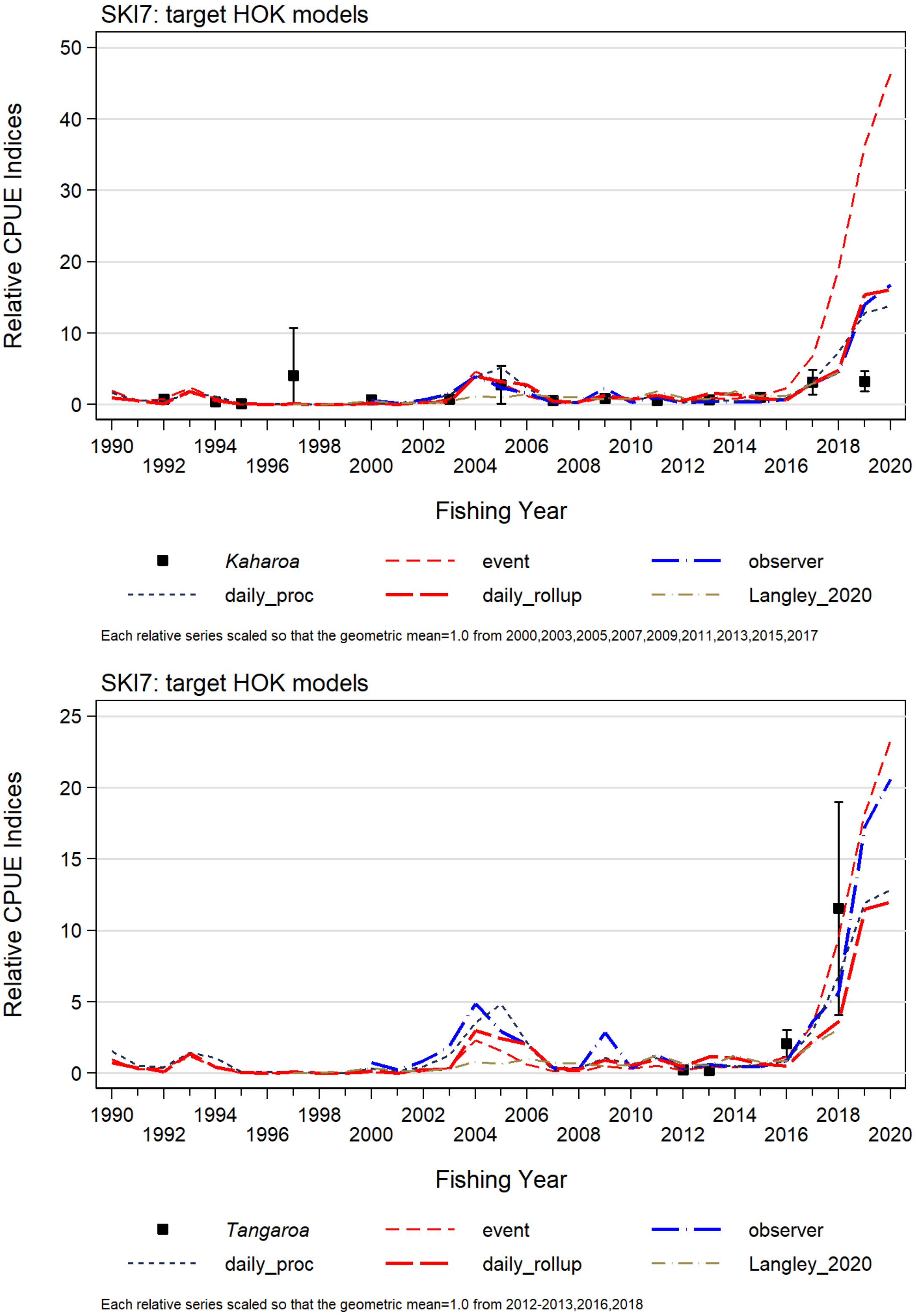
CPUE series were developed for the following ten fishery/data-set combinations, showing the years covered, the core vessel selection criteria, and the depth range used:

	Data set			
Fishery	Event	Daily processing	Observer	Daily roll-up
SKI 7 target HOK	1990–2020 5 year/1 trip 250–600 m	1990–2020 4 year/1 trip 250–600 m	2000–2020 5 year/1 trip 250–600 m	1990–2020 4 year/1 trip
SKI 3 Stewart/Snares shelf	1990–2020 5 year/1 trip 50–600 m	1990–2020 3 year/1 trip 50–600 m	2000–2020 5 year/1 trip 50–600 m	1990–2020 3 year/1 trip
SKI 3 East coast	1996–2020 3 year/1 trip 50–600 m	2001–2020 2 year/1 trip 50–600 m	insufficient data	insufficient data

A standardised lognormal GLM was fitted to the positive gemfish catches from each series and a binomial GLM was fitted to the presence/absence of gemfish observations in the same data set. Explanatory variables appropriate to the data set were offered to each model, including vessel, depth, duration of fishing, season-day, start latitude, start longitude, hour of day, speed, headline height, method of capture, and statistical area. However, most models only accepted a few of these variables, primarily the vessel key and the season-day variable. The binomial and lognormal models were then combined into a single series using the multiplicative delta-lognormal procedure.

The Deepwater Working Group accepted that all ten series indicated a considerable increase in apparent relative biomass compared with the low levels of gemfish observed during the period 1989–90 to the mid-2010s, assuming these series were indexing biomass. This was true for all three evaluated fisheries: SKI 7 target HOK (Figure 7), the SKI 3 Stewart-Snares shelf (Figure 8, top panel), and the SKI 3 Banks (East coast, Figure 8, bottom panel). The DWWG also noted that the correspondence between the SKI 7 target HOK series with the *Kaharoa* survey was poor (Figure 7, top panel), but this was acceptable because this survey primarily indexes gemfish recruitment. The DWWG also noted that the gemfish index from the 2018 *Tangaroa* survey showed an increase that was consistent with several of the SKI 7 target HOK series (Figure 7, bottom panel). This observation corroborates the SKI 7 CPUE series, despite the short series for this survey, given the assumption that this survey is more likely to be indexing recruited gemfish.

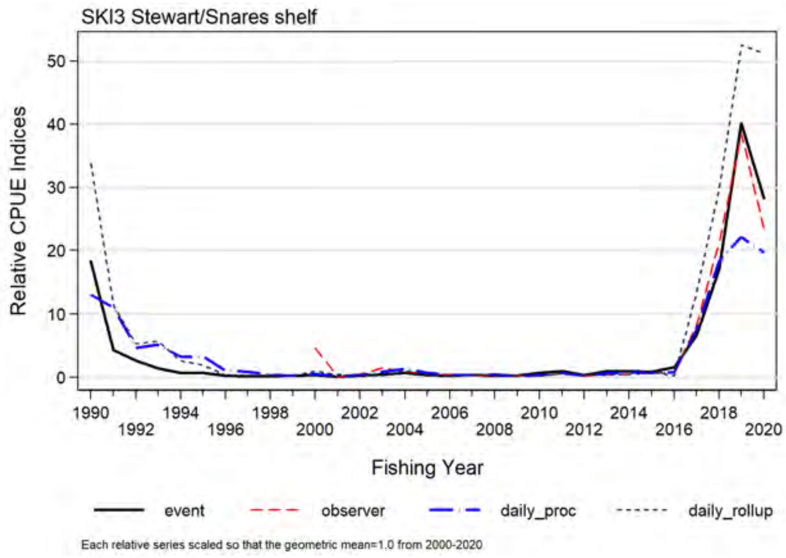
The DWWG preferred the daily processing series because these series were not affected by the limitations of the species reporting requirements of the TCEPR forms and were longer than the observer CPUE series. All three daily processing series are presented with error bars in Figure 9. The DWWG also accepted the SKI 7 target HOK daily processing series as the primary abundance indicator for southern gemfish because it operates during the spawning period in the primary location where this stock is presumed to spawn. The SKI 3 Stewart-Snares shelf series was viewed as a corroborative series which operates in the feeding and migratory region for this stock.



Each relative series scaled so that the geometric mean=1.0 from 2000,2003,2005,2007,2009,2011,2013,2015,2017

Each relative series scaled so that the geometric mean=1.0 from 2012-2013,2016,2018

Figure 7: Comparison of the four SKI 7 HOK target combined delta-lognormal CPUE models and the Langley (2020) *partial data* CPUE model with the *Kaharoa* survey indices (top panel) and the *Tangaroa* survey indices (bottom panel), showing approximate 95% confidence intervals for the survey indices.



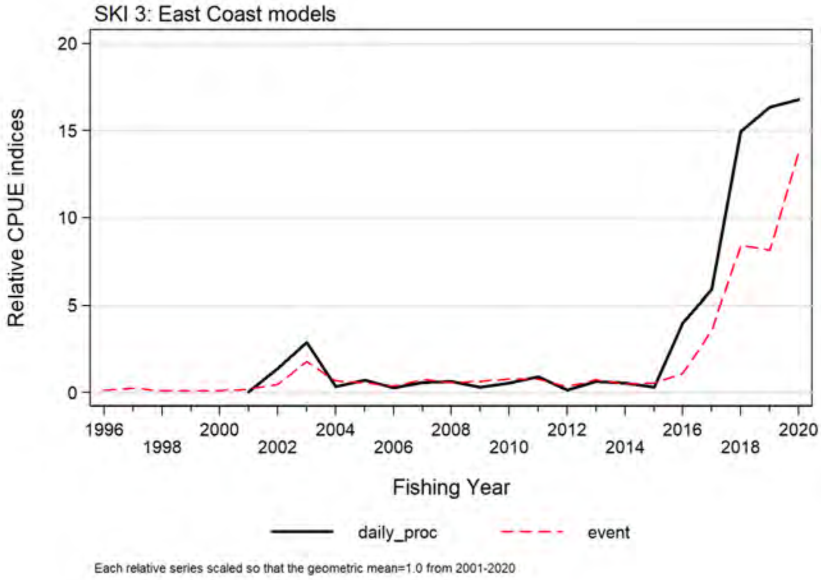


Figure 8: Comparison of the four SKI 3 Stewart-Snares shelf combined delta-lognormal CPUE models (top panel) and the two East coast CPUE series (bottom panel).

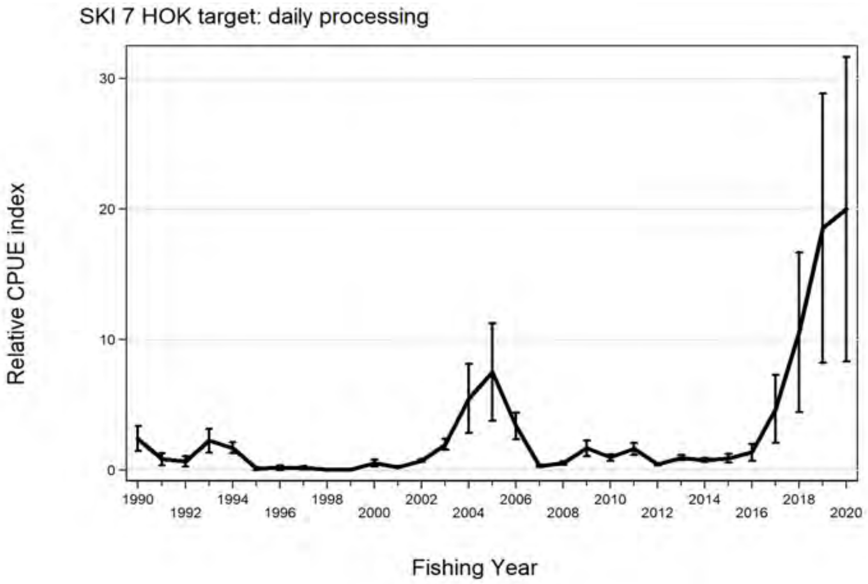
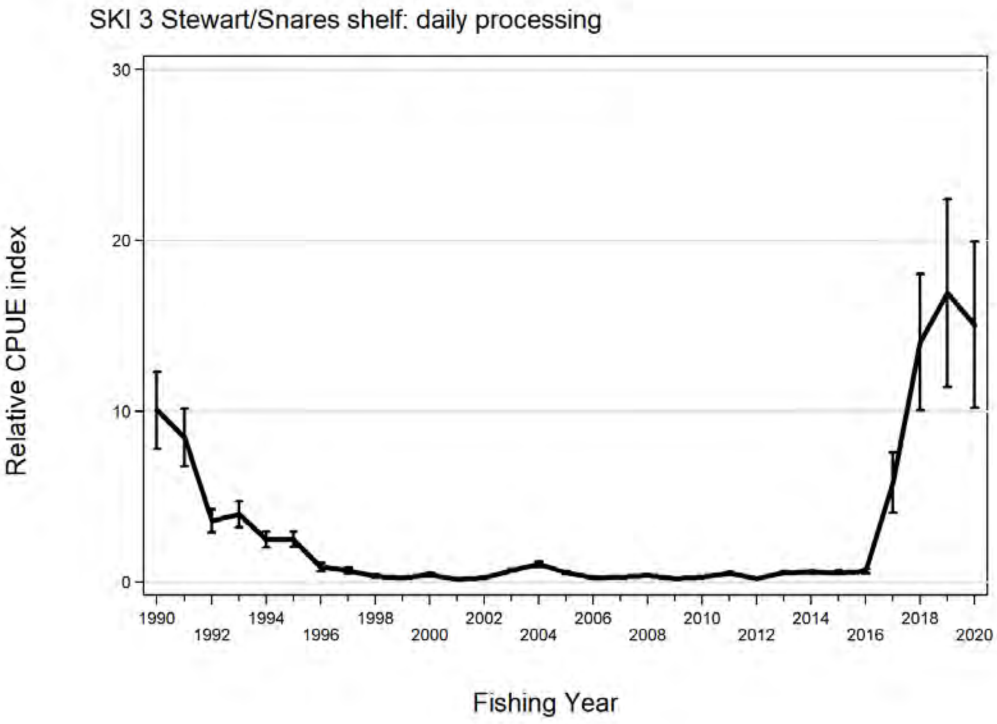


Figure 9: Daily processing combined delta-lognormal CPUE indices for the SKI 7 HOK target fishery, SKI 3 Stewart-Snares shelf fishery, and SKI 3 East coast southern gemfish, showing approximate 95% confidence intervals. [Continued on next page]



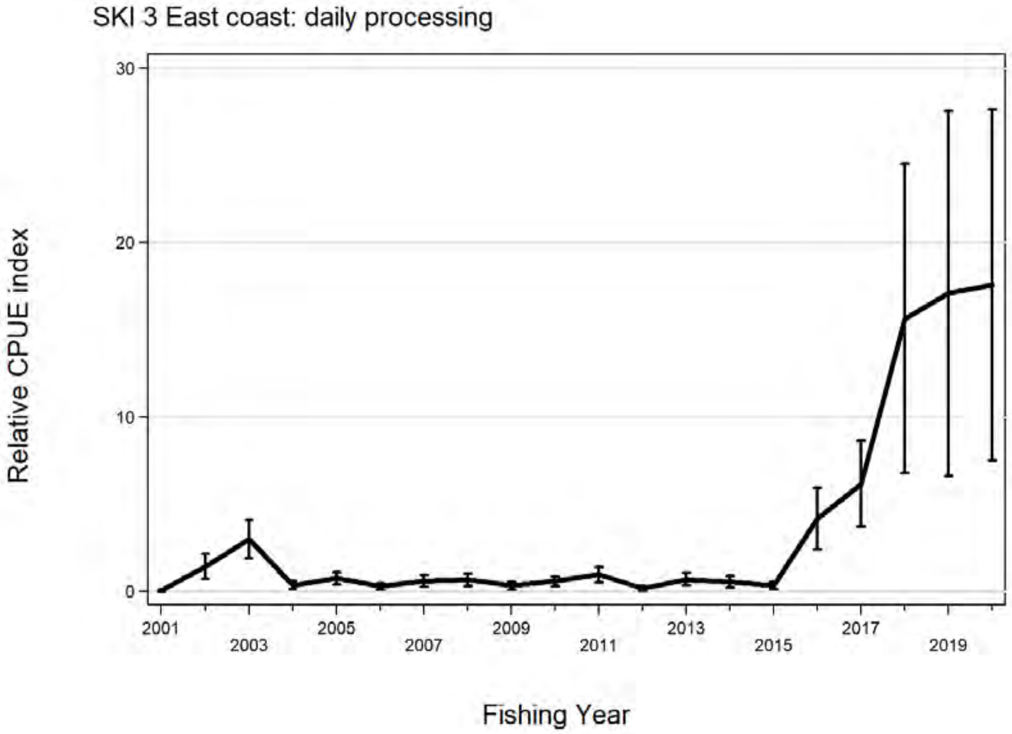


Figure 9: [Continued] Daily processing combined delta-lognormal CPUE indices for the SKI 7 HOK target fishery, SKI 3 Stewart-Snares shelf fishery (middle panel), and SKI 3 East coast southern gemfish (bottom panel), showing approximate 95% confidence intervals.

4.2.5 SKI 3 and SKI 7 observer length frequency data (2021)

Starr et al (in press) also summarised the available observer length frequency data for SKI 3 and SKI 7. These summaries show clear progressions of length modes in all observer regions where southern gemfish occur for both bottom trawl (Figure 10) and midwater trawl (Figure 11). These progressions are most evident in the Challenger (west coast South Island) observer region where there is much better observer coverage. Both capture methods in the Challenger region show a broadening of the length frequency distributions in 2019 and particularly in 2020 with fish smaller than 30 cm seen, which probably indicates that additional new recruitment has been entering these fisheries.

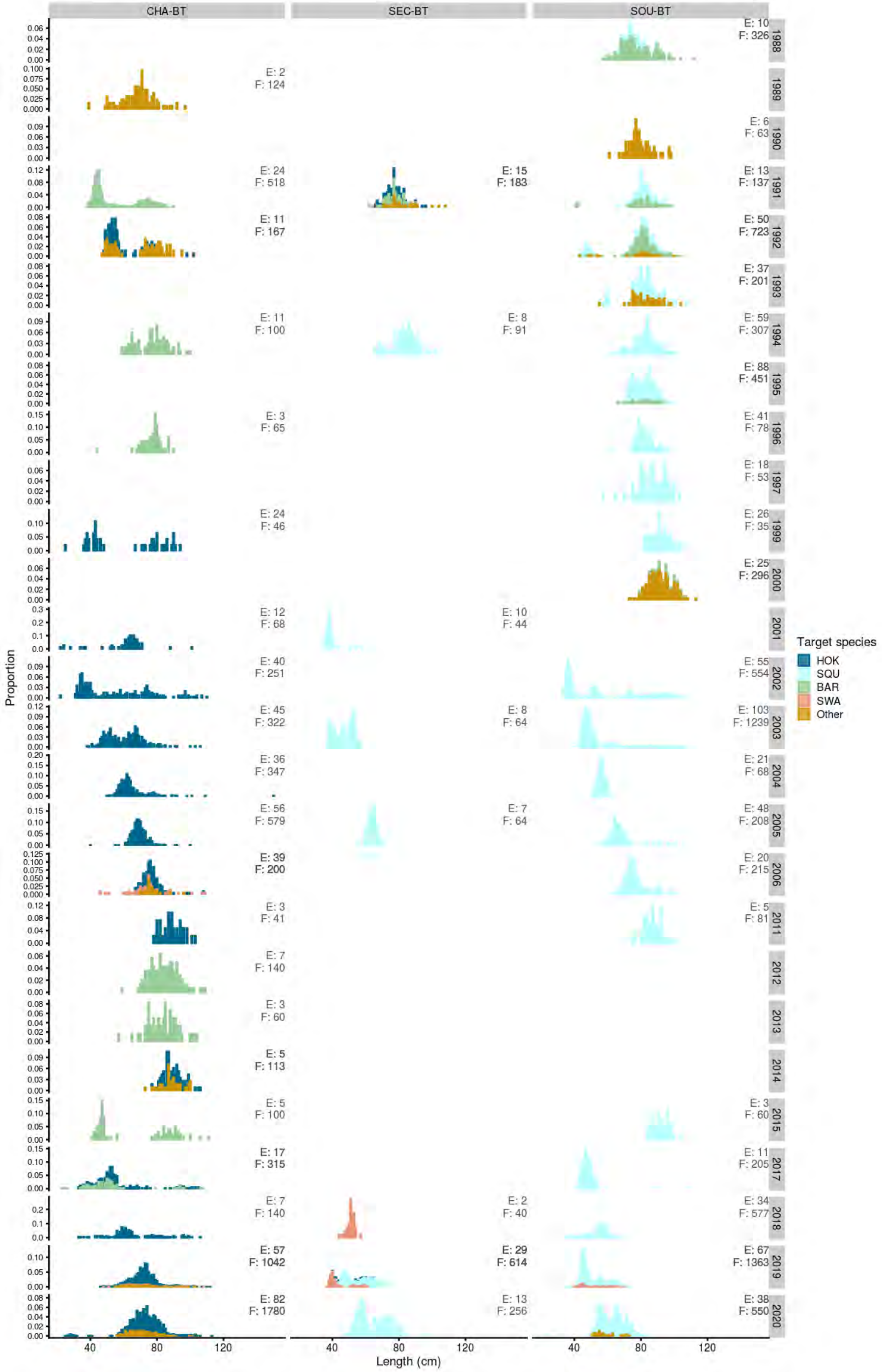


Figure 10: Unweighted aggregate observer length-frequency distributions for gemfish caught in the bottom trawl fishery, by observer region (CHA: Challenger; SEC: Chatham Rise/East coast; SOU: Southland), year, and target species (E: Events sampled; F: number of measured fish).

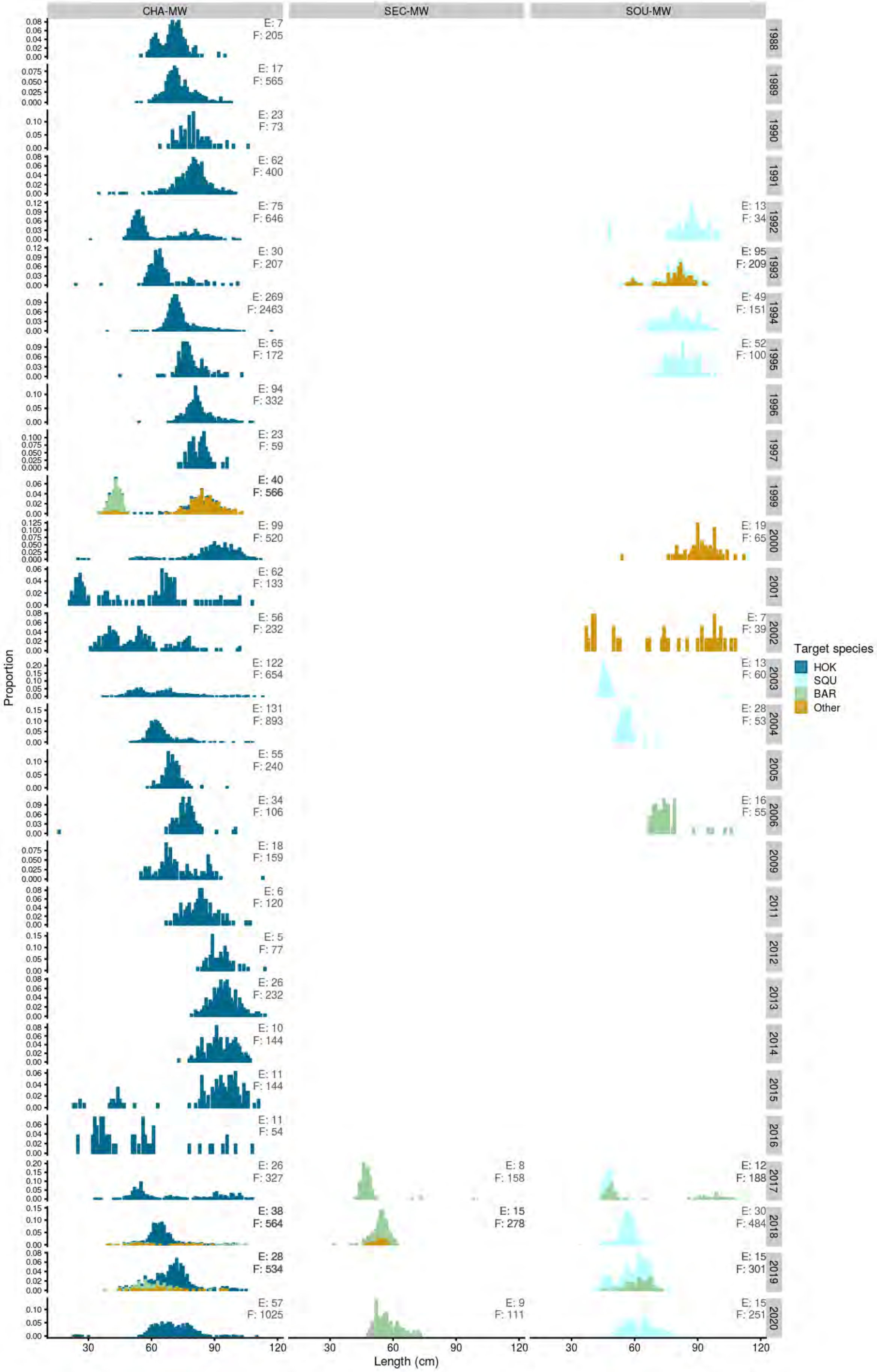


Figure 11: Unweighted aggregate observer length-frequency distributions for gemfish caught in the midwater trawl fishery, by observer region (CHA: Challenger; SEC: Chatham Rise/East coast; SOU: Southland), year, and target species (E: Events sampled; F: number of measured fish).

4.3 Future research considerations

All stocks

- Evaluate potential environmental influences on SKI distribution and recruitment. It is recognised that there is considerably more information available from the SKI 3 and 7 stocks and that these data provide the best opportunity to progress such an analysis and provide inferences about the dynamics of the SKI 1 and 2 stock.
- Assess records of *Rexea* spp. other than *Rexea solandri* in New Zealand waters.

SKI 1 and SKI 2:

- Evaluate the utility of conducting a fully quantitative stock assessment, including sampling to provide series of the length and age composition of catches made by the SKI 1 and SKI 2 gemfish target fisheries (this should include reading otoliths collected in SKI 1 in 2012 and 2014).
- Better sampling is needed to estimate biological parameters of gemfish in SKI 1 and 2.

SKI 3 and SKI 7:

- The southern gemfish stock merits an age-based full quantitative stock assessment, given the strong CPUE response observed in ten analyses across three defined fisheries, as well as the corroborative increase in the 2018 WCSI *Tangaroa* survey biomass estimate and the modal length frequency progression observed in the observer samples from three fisheries and two capture methods.
- Because the abundance increase is likely driven by more than one recruitment event, this stock assessment must be informed with age data. There have been variable collections of gemfish otoliths by observers from three defined fisheries (Challenger (CHA), Chatham Rise/East coast (SEC), Southland (SOU)) as well the possible collection of otoliths from the WCSI *Tangaroa* survey series. For an age-based stock assessment to be conducted, these historical otoliths need to be catalogued, sourced, and aged.
- A WCSI *Tangaroa* survey is scheduled for winter 2021. It is vital to arrange for the collection of sufficient otoliths to construct a gemfish age-length key so that the age composition of the gemfish biomass can be estimated. This collection will be an important component to any future southern gemfish stock assessment, regardless of when it is undertaken.
- Reanalyse the data collected during the *Kaharoa* WCSI inshore trawl survey series to develop weight- and number-based juvenile abundance indices for RSO.
- Determine whether the *new_FSU* database has data that can be used to extend the CPUE series backwards.

5. STATUS OF THE STOCKS

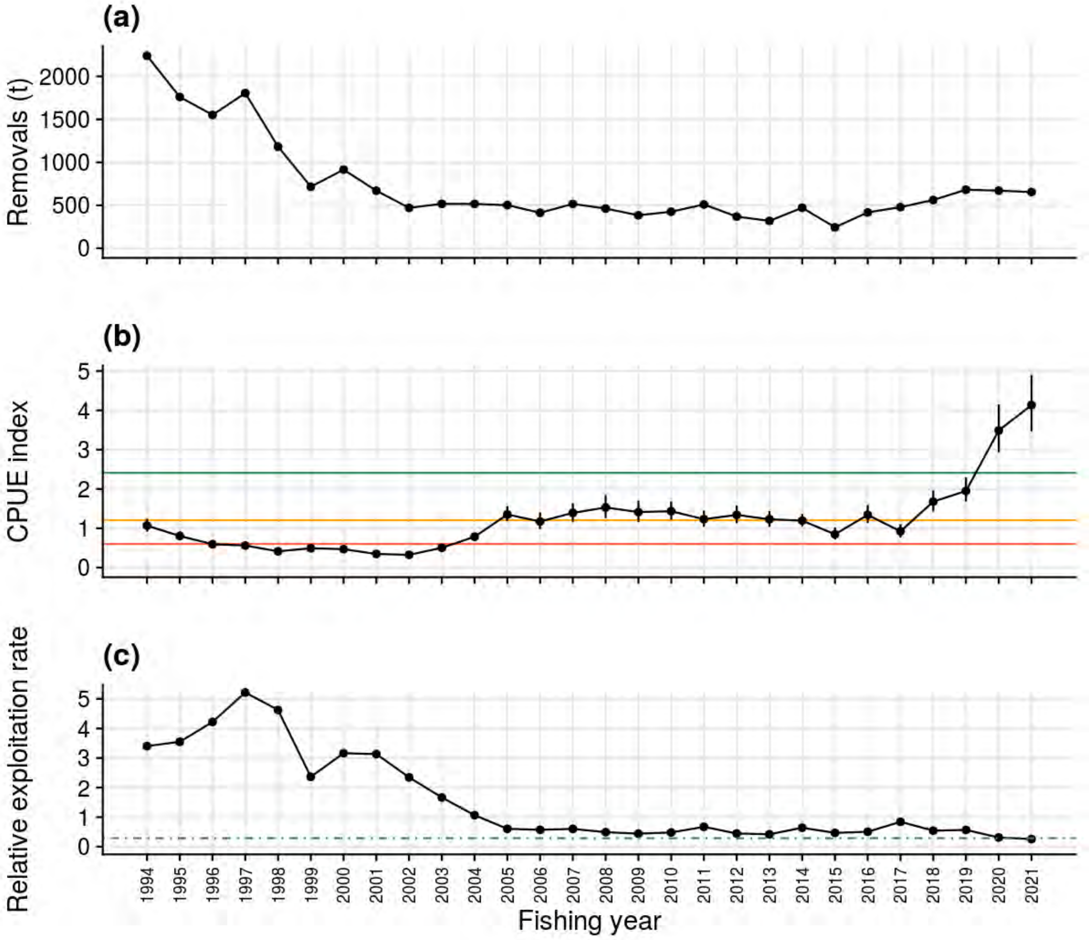
Stock Structure Assumptions

Gemfish are assessed as two biological stocks, based on spawning migration and timing and the location of spawning grounds. These stocks are managed and assessed separately and are assumed to be non-mixing. The SKI 1&2 stock is found off the east and west coasts of the North Island, with adults migrating north to spawn north of the North Island during May–June. The SKI 3&7 stock occurs in the south of New Zealand and migrates to the west coast South Island to spawn in August–September.

SKI 1&2

Stock Status	
Year of Most Recent Assessment	2022
Assessment Runs Presented	Event resolution CPUE index from hoki and gemfish target trawl in the Bay of Plenty and SKI 2
Reference Points	Management Target: 40% B_0, interpreted as twice the geometric mean CPUE for the period 2004–2017 Soft Limit: geometric mean CPUE in the period 2004–2017 Hard Limit: 50% of the soft limit Overfishing threshold: Half the relative exploitation rate in 2004–2017
Status in relation to Target	Likely (> 60%) to be at or above the target in 2021
Status in relation to Limits	Soft Limit: Very Unlikely (< 10%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Overfishing is About As Likely As Not (40–60%) to be occurring

Historical Stock Status Trajectory and Current Status



(a) Annual removals for SKI 1 and SKI 2; (b) the standardised catch per unit effort (CPUE) index, relative to the agreed reference points, for SKI 1 and SKI 2 from trawling targeting hoki and gemfish; (c) annual relative exploitation rate (catch/CPUE) for gemfish in SKI 1 and SKI 2. The green, orange, and red solid lines in (b) represent the interim target, soft limit and hard limit respectively. The green dashed line in (c) represents the overfishing threshold.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Adult relative abundance doubled between 2019 and 2020 and increased further in 2021.
Recent Trend in Fishing Mortality or Proxy	Relative exploitation rate was relatively stable and slightly above the threshold from 2005 to 2019, dropping in 2020 and 2021 as abundance increased.
Other Abundance Indices	Relative abundance of pre-recruits (TAR index) increased six-fold between 2016–17 and 2017–18, preceding the large increase in the adult index. The pre-recruit index remained high to 2020 but dropped in 2021.
Trends in Other Relevant Indicators or Variables	An event-resolution index using tarakihi target trawls from 2008 shows the same trend for sub-adult/adult fish abundance as the BT-TAR trip-resolution index.

Projections and Prognosis	
Stock Projections or Prognosis	The increase in the subadult/adult tarakihi target CPUE index indicates that the spawning stock should remain high in the short term (next 2–3 years).
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For current (1 October 2021) TACC and catch levels: Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	About As Likely As Not (40–60%) for current catch and TACC

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	CPUE analysis	
Assessment Dates	Latest assessment: 2022	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Fisheries New Zealand catch and effort data for tarakihi bottom trawl and gemfish/hoki target trawl	1 – High quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments

The HOK-SKI target index was restricted to the Bay of Plenty and FMA 2 due to reduced fisheries off East Northland and the West Coast and therefore may not be indexing the whole stock.

The size composition of gemfish in the FMA2 and BoP HOK-SKI target fishery includes smaller fish than were present in the SKI target fishery off east Northland.

Perceptions of stock status in the early 2000s based on the CPUE reference point are poorer than was indicated by the 2008 stock assessment.

Fishery Interactions

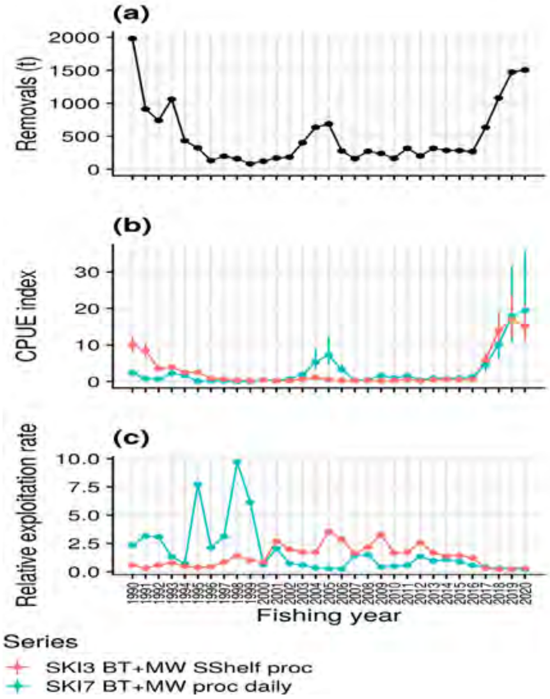
Gemfish are common bycatch in the hoki, tarakihi, rubyfish, and scampi target fisheries and are also taken in gemfish target fishing. Bycatch of gemfish target fishing is variable but includes hoki and tarakihi.

- **SKI 3 & 7**

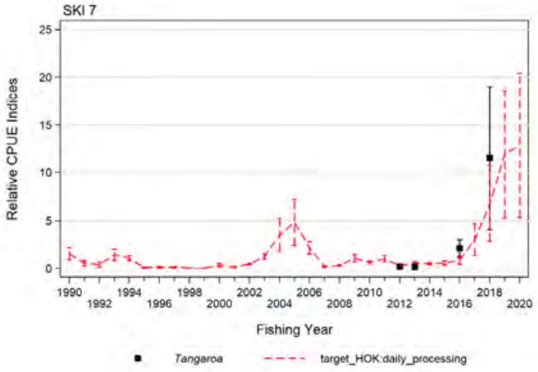
Updated CPUE analyses were conducted for SKI 3 & 7 in 2021.

Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Standardised CPUE indices (SKI 7 target HOK daily process CPUE and SKI 3 Stewart-Snares shelf daily process CPUE), and *Tangaroa* WCSI trawl surveys (2012–2018).
Reference Points	Target: 40% SB_0 Soft Limit: 20% SB_0 Hard Limit: 10% SB_0 Overfishing threshold: $F_{SB40\%}$
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unlikely (< 40%) to be below
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



(a) annual removals for SKI 3 and SKI 7; (b) the standardised catch per unit effort (CPUE) indices for SKI 3 and SKI 7 from daily processing records; (c) annual relative exploitation rate (catch/CPUE) for gemfish in SKI 3 and SKI 7 implied by the two CPUE indices.



Daily processing combined delta-lognormal CPUE indices showing approximate 95% confidence intervals for the SKI 7 HOK target fishery and *Tangaroa* WCSI trawl survey.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has increased by about ten-fold from 2015 following improved recruitment.
Recent Trend in Fishing Intensity or Proxy	Catches have increased with increased biomass over the last few years. Fishing intensity has decreased since about 2015.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	The length compositions from the recent East and West Coast South Island *Kaharoa* trawl surveys revealed three consecutive year classes that have started to recruit to the commercial fishery. Recent length frequencies from the commercial fishery indicate one or two additional year classes have begun recruiting to the fishery in 2019 and 2020.

Projections and Prognosis	
Stock Projections or Prognosis	Given recent recruitments, stock size is likely to increase over the short term (1–3 years).
Probability of Current Catch or TACC causing biomass to remain below or to decline below Limits	<u>Current Catch or TACC</u> Soft Limit: Unknown Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing overfishing to continue or to commence	TACC: Unknown Current catch: Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE indices, trawl survey biomass indices	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment of quality rank	1 – High Quality	
Main data inputs (rank)	- Commercial catch history	1 – High Quality
	- CPUE indices	1 – High Quality
	- *Tangaroa* trawl survey abundance estimates	1 – High Quality
	- Recent commercial length frequency	1 – High Quality
Data not used (rank)	*Kaharoa* trawl surveys	2 – Medium or Mixed Quality: recruitment index only
	CPUE series based on event or daily roll-up	2 – Medium or Mixed Quality: affected by limitations of species reporting requirements
	CPUE series based on observer data	2 – Medium or Mixed Quality: shorter series with patchy coverage
	CPUE series for Banks area	2 – Medium or Mixed Quality: not adult population
Changes to Model Structure and Assumptions	- The 2021 CPUE analyses were extended to include the catch of gemfish in a mixed target fishery on the Stewart-Snares shelf.	

	- The Plenary accepted the CPUE series defined by the daily processing data for the SKI 7 HOK target fishery and the SKI 3 mixed species target Stewart-Snares shelf fishery.
Major Sources of Uncertainty	- Reliability of CPUE (potentially biased low) in late 1990s when catches were very low. - Although the CPUE indices and trawl survey biomass indices indicate that stock abundance has increased considerably in recent years, the indices do not provide an estimate of the size of current stock biomass relative to historical (unfished) levels (SSB_0). - The scale of the increase in biomass relative to the lowest observed levels, based on the recent CPUE indices, is poorly determined. - Although it is thought that gemfish reside on the Stewart-Snares shelf and migrate to the west coast of the South Island to spawn, it is not known if there are other spawning areas. There are recruiting gemfish off the west and east coasts of the South Island, and the relationship of the latter populations to the main population of southern gemfish is not known. - The magnitude of the recent increase in stock biomass is dependent on the strength of the recent year classes which are poorly determined.

Qualifying Comments
- The *Kaharoa* WCSI trawl survey monitors the juvenile component of the stock. The survey does not fully monitor the adult component of the stock due to the timing and limited depth range of the survey. - The time series of WCSI *Tangaroa* trawl surveys is short. - Standardised CPUE indices from the WCSI hoki fishery are likely to be influenced by changes in the operation of the hoki fishery.

Fishery Interactions
Gemfish is predominantly caught as a bycatch of the WCSI hoki fishery (SKI 7) and the Southland squid trawl fishery (SKI 3). There is also a catch of gemfish taken by the WCSI inshore trawl fishery (SKI 7). The associated species in these fisheries are the same as for the relevant target fisheries (e.g., squid and hoki).

6. FOR FURTHER INFORMATION

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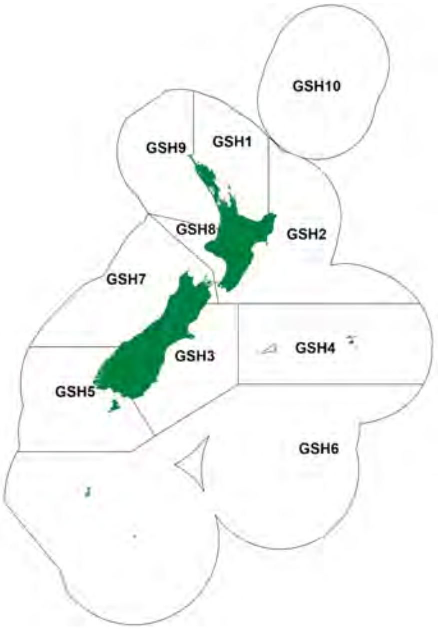
DARK GHOST SHARK (GSH)

(*Hydrolagus novaezealandiae*)



1. FISHERY SUMMARY

1.1 Commercial fisheries

Two species (dark and pale ghost sharks) make up effectively all commercial ghost shark landings. Dark ghost shark (*Hydrolagus novaezealandiae*) was introduced into the QMS from the beginning of the 1998–99 fishing year for the 10 FMAs shown above.

Both ghost shark species are taken almost exclusively as a bycatch of other target trawl fisheries. In the 1990s, about 43% of ghost sharks were landed as a bycatch of the hoki fishery, with fisheries for silver warehou, arrow squid and barracouta combining to land a further 36%. The two ghost shark species were seldom differentiated on catch landing returns prior to the start of the 1998–99 fishing year. Estimated landings of both species by foreign licensed and joint venture vessels over the period 1 April 1978 to 30 September 1983 are presented in Table 1. Landings by domestic (inshore) vessels would have been negligible during this time period. The unknown quantities of ghost sharks that were discarded and not recorded will have resulted in an under-reported total, particularly before both species were included in the QMS.

In the early to mid-1980s about half of the reported ghost shark landings were from FMA 3. Virtually all the additional catch was spread over FMAs 4–7. In 1988–89, landings from west coast South Island (FMA 7) began to increase, almost certainly associated with the development of the hoki fishery. In 1990–91, significant landing increases were apparent on the Chatham Rise, off southeast South Island and on the Campbell Plateau. The development of fisheries for non-spawning hoki were probably responsible for these increases.

Estimated landings of dark ghost shark by QMA are shown in Tables 2 and 3, while the historical landings and TACC for the main GSH stocks are depicted in Figure 1. Landings from 1983–84 to 1994–95 were derived by splitting all reported ghost shark landings into depth and area bins, and allocating to species based on distribution data derived from trawl surveys (*see* section 2). Landings from 1995–96 to 1998–99 were estimated assuming dark ghost shark made up 70% of the total ghost shark catch in FMAs 5 and 6, and 75% in all other FMAs. However this approach assumes that the proportion that each species contributes to the whole is consistent from year to year and does not change in response to various sources of mortality, fishing-induced or otherwise. As such, the data covered by this period of time should be treated with caution. Catches from the 1999–00 fishing year are more reliable, when pale ghost shark had also been included in the QMS, bringing both under the system.

Table 1: Reported landings (t) of both ghost shark species by fishing year and EEZ area, taken by foreign licensed and joint venture vessels. An approximation of these areas with respect to current QMA boundaries is used to assign catches to QMAs. No data are available for the 1980–81 fishing year.

Year	EEZ Area												
	B	C(M)	C(1)	D	E(B)	E(P)	E(C)	E(A)	F(E)	F(W)	G	H	Total
QMA	1&2	3	4	6	5	7	8						
1978–79*	1	37	99	26	3	16	11	88	90	8	68	17	465
1979–80*	1	55	54	426	10	4	28	138	183	7	1	5	912
1980–81*													-
1981–82*	0	84	28	117	0	2	6	29	71	9	4	0	350
1982–83*	0	108	35	84	0	2	17	98	99	29	1	1	474
1983–83#	0	84	41	73	0	0	17	5	16	17	0	0	253

* 1 April to 31 March # 1 April to 30 Sept.

Table 2: Reported landings (t) for the main QMAs from 1931 to 1982.

Year	GSH 1	GSH 2	GSH 3	GSH 4	GSH 5	GSH 6	GSH 7	GSH 8
1931–32	0	0	0	0	0	0	0	0
1932–33	0	0	0	0	0	0	0	0
1933–34	0	0	0	0	0	0	0	0
1934–35	0	0	0	0	0	0	0	0
1935–36	0	0	0	0	0	0	0	0
1936–37	0	0	0	0	0	0	0	0
1937–38	0	0	0	0	0	0	0	0
1938–39	0	0	0	0	0	0	0	0
1939–40	0	0	0	0	0	0	0	0
1940–41	0	0	0	0	0	0	0	0
1941–42	0	0	0	0	0	0	0	0
1942–43	0	0	0	0	0	0	0	0
1943–44	0	0	0	0	0	0	0	0
1944	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0
1948	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0
1951	0	0	0	0	0	0	0	0
1952	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0
1957	0	0	0	0	0	0	0	0
1958	0	0	0	0	0	0	0	0
1959	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0
1972	0	0	103	0	11	0	0	0
1973	0	0	0	0	0	0	0	0
1974	0	0	7	0	1	0	0	0
1975	0	0	8	0	1	0	0	0
1976	0	0	19	0	2	0	0	1
1977	0	0	2	0	0	0	0	0
1978	0	0	54	0	100	30	15	2
1979	0	2	486	383	178	131	268	2
1980	0	0	150	230	92	144	144	28
1981	0	0	233	243	111	35	17	17
1982	0	0	320	97	223	29	11	7

Notes:
The 1931–1943 years are April–March but from 1944 onwards are calendar years. Data up to 1985 are from fishing returns: Data from 1986 to 1990 are from Quota Management Reports. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings. Data were aggregated to FMA using methods and assumptions described by Francis & Paul (2013).

Table 3: Estimated landings (t) of dark ghost shark by Fishstock from 1982–83 to present, based on reported landings of both ghost shark species combined, and actual TACCs set from 1998–99. * - FSU data. [Continued on next page]

Fishstock		GSH 1		GSH 2		GSH 3		GSH 4		GSH 5
FMA (s)		1		2		3		4		5
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1982–83*	1	-	< 1	-	151	-	65	-	35	-
1983–84*	0	-	< 1	-	185	-	65	-	42	-
1984–85*	< 1	-	4	-	136	-	95	-	50	-
1985–86*	< 1	-	1	-	276	-	60	-	30	-
1986–87	3	-	13	-	472	-	97	-	34	-
1987–88	4	-	< 1	-	539	-	53	-	49	-
1988–89	9	-	27	-	460	-	21	-	67	-
1989–90	1	-	14	-	383	-	29	-	78	-
1990–91	1	-	40	-	665	-	271	-	70	-
1991–92	4	-	7	-	444	-	179	-	81	-
1992–93	8	-	5	-	399	-	151	-	76	-
1993–94	7	-	7	-	569	-	144	-	51	-
1994–95	3	-	2	-	737	-	187	-	63	-
1995–96	13	-	37	-	678	-	253	-	71	-
1996–97	17	-	66	-	817	-	402	-	94	-
1997–98	17	-	17	-	767	-	262	-	70	-
1998–99	18	15	60	37	950	1 187	318	373	64	109
1999–00	15	15	51	37	938	1 187	173	373	71	109
2000–01	15	10	50	33	1 111	1 185	179	370	85	109
2001–02	22	10	52	33	1 068	1 185	241	370	76	109
2002–03	17	10	58	33	1 371	1 185	265	370	93	109
2003–04	21	10	84	33	894	1 185	157	370	45	109
2004–05	14	10	74	33	880	1 185	282	370	80	109
2005–06	20	10	57	33	583	1 185	318	370	61	109
2006–07	20	22	60	66	654	1 185	396	370	115	109
2007–08	19	22	100	66	484	1 185	562	370	67	109
2008–09	14	22	71	66	490	1 185	251	370	61	109
2009–10	13	22	64	66	520	1 185	233	370	108	109
2010–11	17	22	95	66	640	1 185	311	370	73	109
2011–12	11	22	57	66	497	1 185	482	370	72	109
2012–13	12	22	51	66	420	1 185	210	370	111	109
2013–14	15	22	83	89	667	1 185	201	370	53	109
2014–15	16	22	44	89	406	1 185	217	370	42	109
2015–16	21	22	38	89	547	1 185	217	370	56	109
2016–17	21	22	47	89	493	1 185	223	370	83	109
2017–18	21	22	53	89	584	1 185	198	370	63	109
2018–19	28	22	40	89	528	1 185	166	370	51	109
2019–20	26	22	44	89	349	1 185	147	370	55	109
2020–21	28	22	61	89	419	1 185	191	370	54	109

Fishstock		GSH 6		GSH 7		GSH 8		GSH 9		
FMA (s)		6		7		8		9		Total
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1982–83*	19	-	10	-	< 1	-	0	-	282	-
1983–84*	56	-	38	-	< 1	-	0	-	387	-
1984–85*	61	-	63	-	< 1	-	0	-	409	-
1985–86*	41	-	31	-	3	-	0	-	442	-
1986–87	36	-	71	-	4	-	0	-	729	-
1987–88	6	-	68	-	1	-	0	-	720	-
1988–89	6	-	133	-	2	-	0	-	725	-
1989–90	9	-	180	-	27	-	0	-	722	-
1990–91	94	-	217	-	3	-	0	-	1 361	-
1991–92	80	-	124	-	3	-	1	-	923	-
1992–93	68	-	221	-	11	-	0	-	938	-
1993–94	53	-	513	-	14	-	0	-	1 357	-
1994–95	61	-	703	-	3	-	0	-	1 778	-
1995–96	68	-	548	-	8	-	3	-	1 679	-
1996–97	135	-	926	-	9	-	11	-	2 477	-
1997–98	136	-	170	-	3	-	12	-	1 454	-
1998–99	110	95	409	1 121	7	12	22	14	1 958	2 963
1999–00	117	95	466	1 121	19	12	25	14	1 875	2 963
2000–01	76	95	475	1 121	22	12	31	8	2 043	2 943
2001–02	94	95	463	1 121	22	12	25	8	2 063	2 943
2002–03	99	95	593	1 121	15	12	20	8	2 531	2 943
2003–04	72	95	652	1 121	27	12	12	8	1 964	2 943
2004–05	53	95	694	1 121	31	12	10	8	2 118	2 943
2005–06	31	95	625	1 121	22	12	8	8	1 725	2 943
2006–07	43	95	696	1 121	16	22	6	22	2 006	3 012
2007–08	36	95	601	1 121	29	22	13	22	1 911	3 012
2008–09	49	95	991	1 121	24	22	16	22	1 967	3 012
2009–10	19	95	1 037	1 121	29	22	6	22	2 028	3 012
2010–11	38	95	1 129	1 121	33	22	6	22	2 341	3 012
2011–12	37	95	1 041	1 121	37	22	6	22	2 240	3 012
2012–13	70	95	767	1 121	32	22	10	22	1 683	3 012
2013–14	72	95	691	1 121	27	34	9	22	1 817	3 047
2014–15	72	95	458	1 121	20	34	7	22	1 283	3 047
2015–16	64	95	400	1 121	19	34	6	22	1 368	3 047
2016–17	59	95	423	1 121	19	34	14	22	1 382	3 047
2017–18	71	95	329	1 121	18	34	25	22	1 363	3 047

Table 3 [continued]

Fishstock		GSH 6		GSH 7		GSH 8		GSH 9		
FMA (s)		6		7		8		9		Total
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
2018–19	68	95	485	1 121	20	34	19	22	1 406	3 047
2019–20	35	95	333	1 121	28	34	24	22	1 039	3 047
2020–21	49	95	345	1 121	16	34	14	22	1 177	3 047

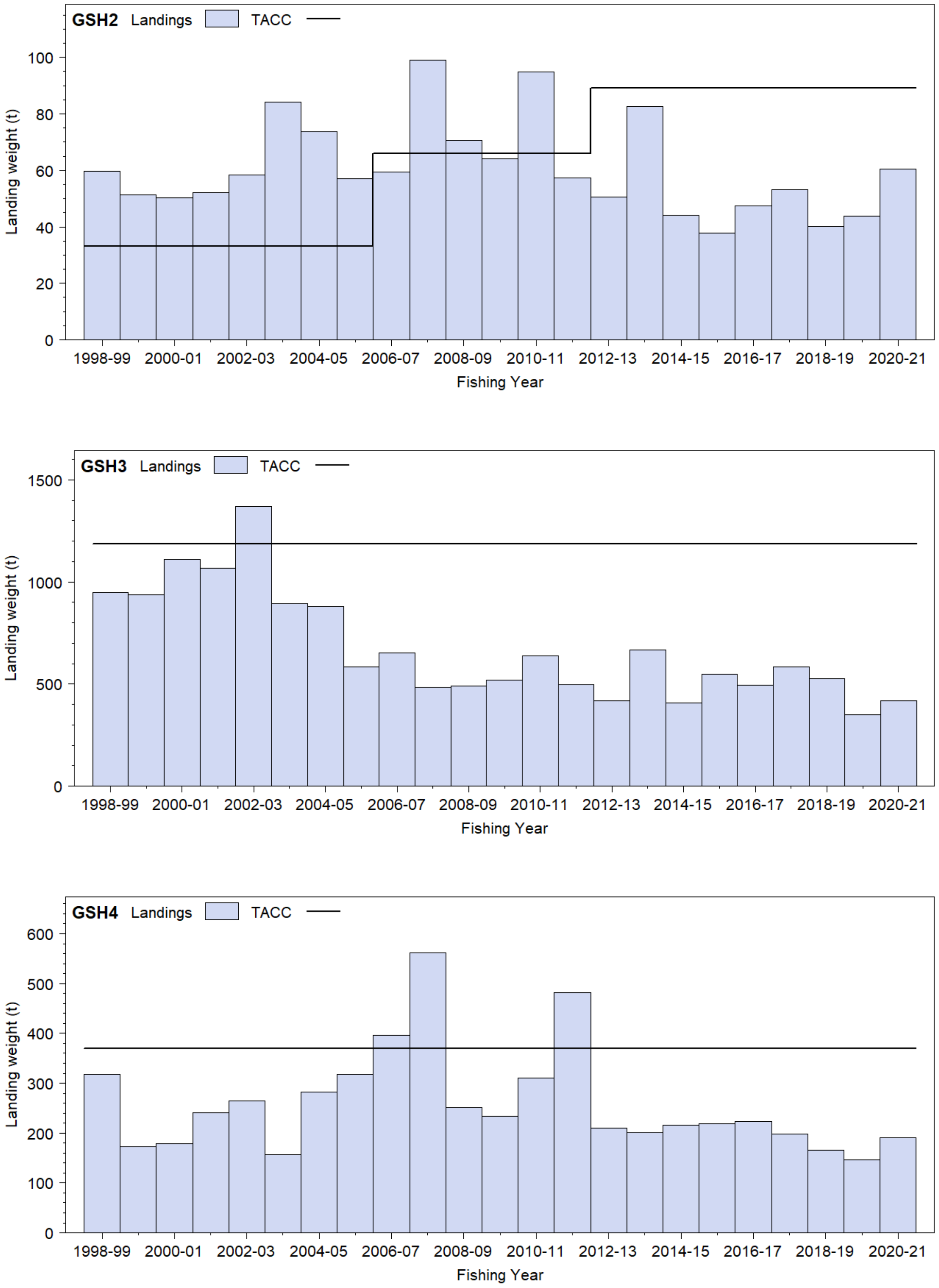


Figure 1: Reported commercial landings and TACC for GSH stocks. From top GSH 2 (Central East), GSH 3 (South East Coast), GSH 4 (South East Chatham Rise). [Continued on next page]

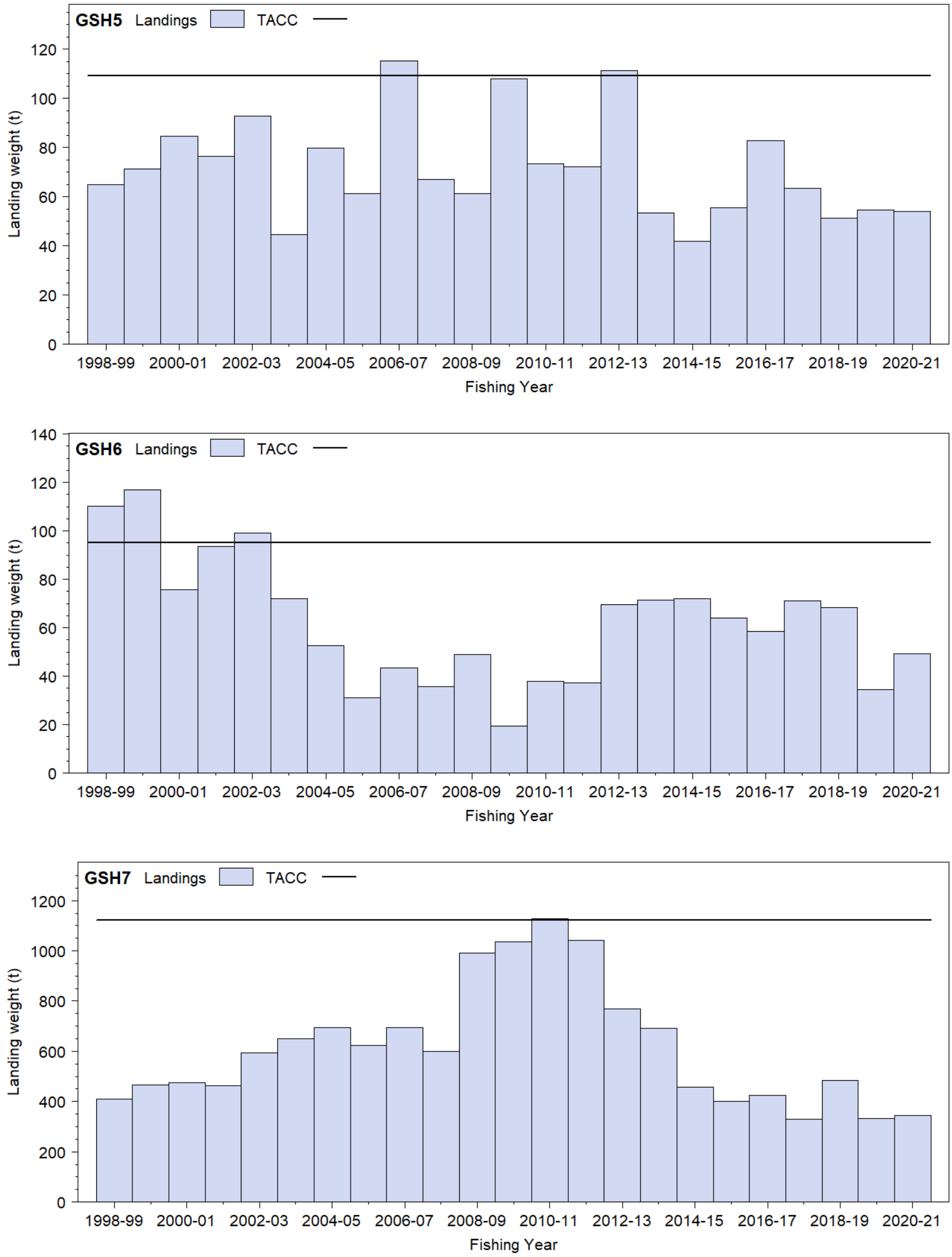


Figure 1 [Continued]: Reported commercial landings and TACC for GSH stocks. From top GSH 5 (Southland), GSH 6 (Sub-Antarctic), and GSH 7 (West Coast South Island).

The TACs currently applied to dark ghost shark were initially intended to apply to a combined fishery for both species, and were based on the average catch of both species over various periods (see the "Review of Sustainability Measures and Other Management Controls for the 1998–99 Fishing Year - Final Advice Paper" dated 6 August 1998). No allowance for non-commercial interests was included in the final allocation because recreational and customary non-commercial catches are likely to be very small due to the depth distribution of this species.

TACCs were increased from 1 October 2006 in GSH 1 to 22 t, in GSH 2 to 66 t, in GSH 8 to 22 t and in GSH 9 to 22 t. In these stocks landings had been above the TACC for a number of years and the

TACCs were increased to the average of the previous 7 years plus an additional 10%. In GSH 2 and 8 landings continued to consistently exceed the TACCs after 2006. Consequently the TACCs were further increased to 89 t in GSH 2 and 34 t in GSH 8 in 2013. Landings have remained below the TACCs for all GSH stocks since 2013.

1.2 Recreational fisheries

Current catches of dark ghost sharks by recreational fishers are believed to be negligible in all areas.

1.3 Customary non-commercial fisheries

Quantitative information on the current level of customary non-commercial catch is not available but is likely to be negligible

1.4 Illegal catch

Quantitative information on the level of illegal catch is not available. In 1998–99 (when dark ghost shark were in the QMS, but pale ghost shark were not), a quantity of dark ghost shark were reported as pale ghost shark.

1.5 Other sources of mortality

Ghost sharks have been dumped and not reported in the past by commercial fishers in QMAs 1 and 2. Similar behaviour is believed to occur in all other QMAs. The extent of the unreported dumping is unknown in all areas.

2. BIOLOGY

Dark ghost shark (*Hydrolagus novaezelandiae*) occur through much of the New Zealand EEZ in depths from 30 to 850 m, but they are sparse north of 40° S and have not been recorded from the Bounty Platform. They are most abundant in waters 150–500 m deep on the west coast of the South Island and the Chatham Rise, and in depths of 150–700 m on the Stewart-Snares shelf and Southland/sub-Antarctic. Smaller sharks (under 40 cm chimaera length) are more abundant in waters shallower than 200 m, particularly in the Canterbury Bight.

Trawl surveys show that dark and pale ghost shark exhibit niche differentiation, with water depth being the most influential factor, although there is some overlap of habitat. On the Chatham Rise, the main overlap range appears quite compact (from about 340 to 540 m). In the Southland/sub-Antarctic region, the overlap range is wider (about 350 to 770 m). Stomach contents indicate that both species are predominantly benthic feeders.

No published information is available on the age or growth rate of any *Hydrolagus* species, or even any species in the family Chimaeridae. A research report by Francis & Ó Maolagáin (2001) found that eye lens diameter showed potential as an ageing technique but further work was needed. They calculated Von Bertalanffy parameters (Table 4) from trawl survey caught fish and found that growth rates were similar and moderately rapid for males and females with both sexes reaching 50 cm in 5–9 years. They caution the use of these parameters, however, as ageing of dark ghost sharks has not been validated. Length-frequency histograms indicate that females grow to a larger size than males. Without population age structures or confident estimates of longevity, it is not possible to estimate natural or total mortalities.

On the Chatham Rise, the estimated size at 50% sexual maturity for dark ghost sharks is 52–53 cm for males and 62–63 cm for females. As for most other elasmobranchs, ghost shark fecundity is likely to be low.

Length-weight parameters are shown in Table 5.

Table 4: Von Bertalanffy growth parameters for dark ghost shark. Source: Francis & Ó Maolagáin (2001).

		Von Bertalanffy growth parameters		
Region	**Sex**	**L_∞**	**K**	**t_0**
East coast South Island	Female	135.3	0.052	–0.94
	Male	89.0	0.091	–0.61
West coast South Island	Female	123.0	0.065	–1.15
	Male	123.4	0.044	–1.43
Stewart–Snares Shelf	Female	122.1	0.087	–1.01
	Male	108.0	0.073	–1.34
Chatham Rise	Female	97.0	0.090	–1.17
	Male	-	-	-

Table 5: Length-weight parameters for dark ghost shark.

1. Weight = a (length)^b (Weight in g, length in cm chimaera length)

FMA	Estimate		
	a	**b**	**Source**
Chatham Rise	0.002986	3.170546	O'Driscoll et al (2011)
Sub-Antarctic	0.001653	3.3256	Bagley et al (2013)

3. STOCKS AND AREAS

The only information which may indicate a stock boundary is an apparent difference in maximum size of dark ghost sharks, with both males and females from the Chatham Rise attaining a maximum size 3–4 cm greater than those in Southland/sub-Antarctic waters.

Horn (1997) proposed that ghost sharks be managed as three Fishstocks, i.e., east coast New Zealand (FMAs 1–4), Stewart-Snares shelf and Campbell Plateau (FMAs 5 and 6), and west coast New Zealand (FMAs 7, 8, and 9). Areas of narrow continental shelf separate these FMA groupings, so they could well provide barriers to stock mixing for pale ghost shark which have a preference for deeper water. This would be less influential for dark ghost shark, however, which are found much shallower. Pale ghost shark were given the QMAs recommended by Horn when introduced into the QMS, but dark ghost shark were already based on the generic FMAs.

4. STOCK ASSESSMENT

No assessment of any stocks of dark ghost shark has been completed. Therefore, no estimates of yield are available.

4.1 Estimates of fishery parameters and abundance

Estimates of fishery parameters are not available for dark ghost sharks. Several time series of relative biomass estimates are available from fishery independent trawl surveys (Table 6), but wide fluctuations between years suggest the need for caution in using these as indicators of relative abundance. The Chatham Rise time series may provide a reasonable index of abundance for GSH 4, but not GSH 3 as the survey does not fish shallower than 200 m where dark ghost shark are abundant. Much of GSH 3 is covered by the winter east coast South Island trawl survey however, which is optimised for dark ghost shark among other species.

4.2 Biomass estimates

Biomass estimates from various trawl surveys are given in Table 6. Of those, ongoing estimates are available from random stratified bottom trawl surveys from the east coast South Island, Chatham Rise, sub-Antarctic, and west coast South Island trawl surveys.

Table 6: Biomass indices (t) and coefficients of variation (CV). Estimates for the Chatham Rise and sub-Antarctic summer surveys on *Tangaroa* are for core strata only (200–800 and 300–800 m respectively). Estimates for the ECSI winter surveys are for the core strata only (30–400 m) [Continued on next page]

FMA	Area	Vessel	Trip code	Date	Biomass	% CV
3 & 4	Chatham Rise	*Tangaroa*	TAN9106	Jan-Feb 1992	6 700	11.1
			TAN9212	Jan-Feb 1993	5 950	9.2
			TAN9401	Jan-94	10 360	15.3
			TAN9501	Jan-95	3 490	11.2
			TAN9601	Jan-96	6 170	12.4
			TAN9701	Jan-97	6 240	11.7
			TAN9801	Jan-98	6 720	14.1
			TAN9901	Jan-99	12 125	23.4
			TAN0001	Jan-00	9 154	25.2
			TAN0101	Jan-01	10 356	12
			TAN0201	Jan-02	9 997	11.1
			TAN0301	Jan-03	10 341	9.1
			TAN0401	Jan-04	10 471	15
			TAN0501	Jan-05	11 885	16.3
			TAN0601	Jan-06	11 502	12
			TAN0701	Jan-07	7 852	11
			TAN0801	Jan-08	9 391	10.9
			TAN0901	Jan-09	8 445	13.7
			TAN1001	Jan-10	11 596	16.8
			TAN1101	Jan-11	6 588	17
			TAN1201	Jan-12	13 162	20.6
			TAN1301	Jan-13	11 723	11.6
			TAN1401	Jan-14	9 050	18
			TAN1601	Jan-16	11 925	12
5 & 6	Southland Sub-Antarctic	*Tangaroa* (summer)	TAN9105	Nov-Dec 1991	1 030	25.4
			TAN9211	Nov-Dec 1992	710	43.2
			TAN9310	Nov-Dec 1993	1 060	33.6
			TAN0012	Nov-Dec 2000	1 459	89.6
			TAN0118	Nov-Dec 2001	1 391	35.7
			TAN0219	Nov-Dec 2002	175	37.7
			TAN0317	Nov-Dec 2003	382	48.9
			TAN0414	Nov-Dec 2004	843	41.7
			TAN0515	Nov-Dec 2005	517	40
			TAN0617	Nov-Dec 2006	354	32
			TAN0714	Nov-Dec 2007	659	37
			TAN0813	Nov-Dec 2008	1128	32
			TAN0911	Nov-Dec 2009	433	43
			TAN1117	Nov-Dec 2011	3 709	75
			TAN1215	Nov-Dec 2012	1 794	68.3
		Tangaroa (autumn)	TAN9204	Mar-Apr 1992	3 740	48.6
			TAN9304	Apr-May 1993	750	44.7
			TAN9605	Mar-Apr 1996	3 080	47.6
			TAN9805	Apr-May 1998	2 490	44
5	Stewart-Snares#	*Tangaroa*	TAN9301	Feb-Mar 1993	120	44
			TAN9402	Feb-Mar 1994	490	43
			TAN9502	Feb-Mar 1995	790	71
			TAN9604	Feb-Mar 1996	1 870	63
2	East coast North Island	*Kaharoa*	KAH9304	Mar-Apr 1993	450	61.5
			KAH9402	Feb-Mar 1994	40	41.3
			KAH9502	Feb-Mar 1995	10	48.6
			KAH9602	Feb-Mar 1996	80	33.5
3	ECSI winter surveys	*Kaharoa*	KAH9105	May-91	962	42
			KAH9205	May-92	934	44
			KAH9306	May-93	2 911	42
			KAH9406	May-94	2 702	25
			KAH9606	May-96	3 176	23
			KAH0705	May-07	4 483	25
			KAH0806	May-June-08	3 763	20
			KAH0905	May-Jun-09	4 330	24
			KAH1207	Apr-Jun-13	10 704	29
			KAH1402	Apr-Jun-14	13 137	26
			KAH1605	Apr-Jun-16	15 271	26
			KAH1803	Apr-Jun-18	6 485	23
			KAH2104	Apr-Jun-21	12 004	27

Table 6: [continued]

FMA	Area	Vessel	Trip code	Date	Biomass	% CV
3	ECSI summer surveys	*Kaharoa*	KAH9618	Dec ’96 - Jan ’97	3 066	18
			KAH9704	Dec ’97 - Jan ’98	5 870	33
			KAH9809	Dec ’98 - Jan ’99	7 416	27
			KAH9917	Dec ’99 - Jan ’00	2 512	19
			KAH0014	Dec ’00 - Jan ’01	2 950	18
7	West coast South Island	*Kaharoa*	KAH9204	Mar-Apr 1992	380	20
			KAH9404	Mar-Apr 1994	720	14.3
			KAH9504	Mar-Apr 1995	770	23.7
			KAH9701	Mar-Apr 1997	1 590	21.2
			KAH0004	Mar-Apr 2000	2 260	9
			KAH0304	Mar-Apr 2003	540	15
			KAH0503	Mar-Apr 2005	830	22
			KAH0704	Mar-Apr 2007	2 215	21
			KAH0904	Mar-Apr 2009	900	17
			KAH1104	Mar-Apr 2011	2 363	23
			KAH1305	Mar-Apr 2013	981	23

East coast South Island winter trawl surveys

Total biomass in the east coast South Island winter surveys core strata (30–400 m) increased 16-fold between 1992 and 2016, before a 57% decline in 2018 and an 85% increase in 2021 (Table 6, Figure 2) (Beentjes et al. in prep). All surveys had a large component of pre-recruit biomass ranging from 30–61%. In 2021 the pre-recruit biomass was 36% of total biomass. The juvenile and adult biomass (based on length-at-50% maturity) of both sexes have generally increased proportionately over the time series and juvenile biomass comprised about half of the total biomass. In 2021 the juvenile biomass was 35% of total biomass.

Distribution over the ECSI winter trawl survey time series was similar and was confined to the continental slope and edge mainly in the Canterbury Bight. The size distributions in each of the eleven surveys from 1993–2016 were similar and generally bimodal (Beentjes et al in prep). The 2012, 2014 and 2016 length frequency distributions were distinct from previous years with relatively large numbers of adults or mature fish, commensurate with the large biomass increase. These larger fish still accounted for a large proportion of the total biomass in 2018 and 2021 although overall numbers are lower than in the 2016 peak biomass. The distributions differ from those of the Chatham Rise and Southland/Sub-Antarctic surveys (O'Driscoll & Bagley 2001, Livingston et al. 2002, Stevens et al. 2015, Bagley et al. 2017) in that ECSI has a large component of juvenile fish, suggesting that this area may be an important nursery ground for dark ghost shark.

Chatham Rise winter trawl surveys

The Chatham Rise trawl survey time series is not optimised for dark ghost shark and there has been some year-to-year variation between surveys, particularly for the first ten years (Figure 3). This time series may provide a reasonable index of abundance for that part of the eastern fishery (see Section 5) covered by GSH 4. However the survey extends into GSH 3 where commercial catches of dark ghost shark are significant but shallower than the survey’s starting depth of 200 m.

Sub-Antarctic winter trawl surveys

Biomass indices from the sub-Antarctic trawl survey time series are significantly lower than those for the east coast South Island and Chatham Rise surveys. Indices have fluctuated somewhat (Figure 4). The large spike seen in 2011 is due to randomly allocated stations within stratum 6 (300–600 m) being located at the shallower, northern end of the stratum where dark ghost shark are more likely to be encountered. The starting depth of 300 m may mean that this survey is unlikely to be a reliable index of abundance.

West coast South Island winter trawl surveys

Biomass estimates from the west coast South Island inshore trawl survey are lower than those from the east coast South Island and Chatham Rise surveys. Estimates fluctuate considerably and are unlikely to reflect real changes in abundance (Figure 5).

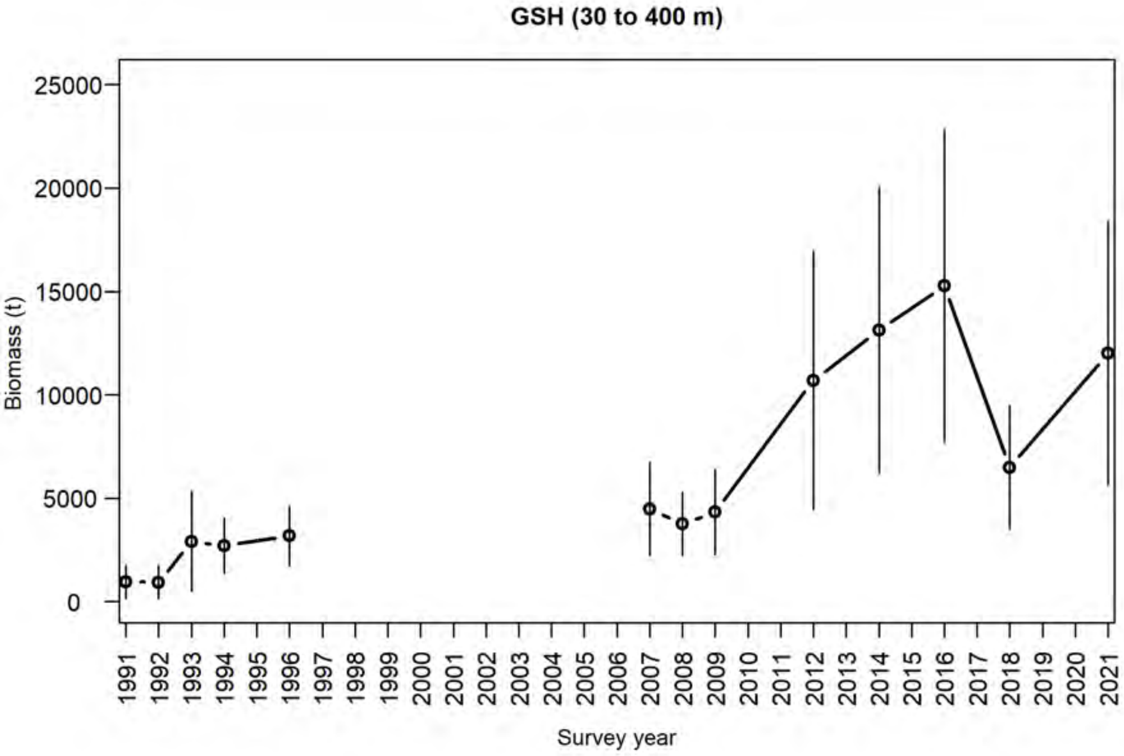


Figure 2: Biomass for dark ghost shark from the east coast South Island winter trawl surveys in core strata (30–400 m). Error bars are ±2 standard errors.

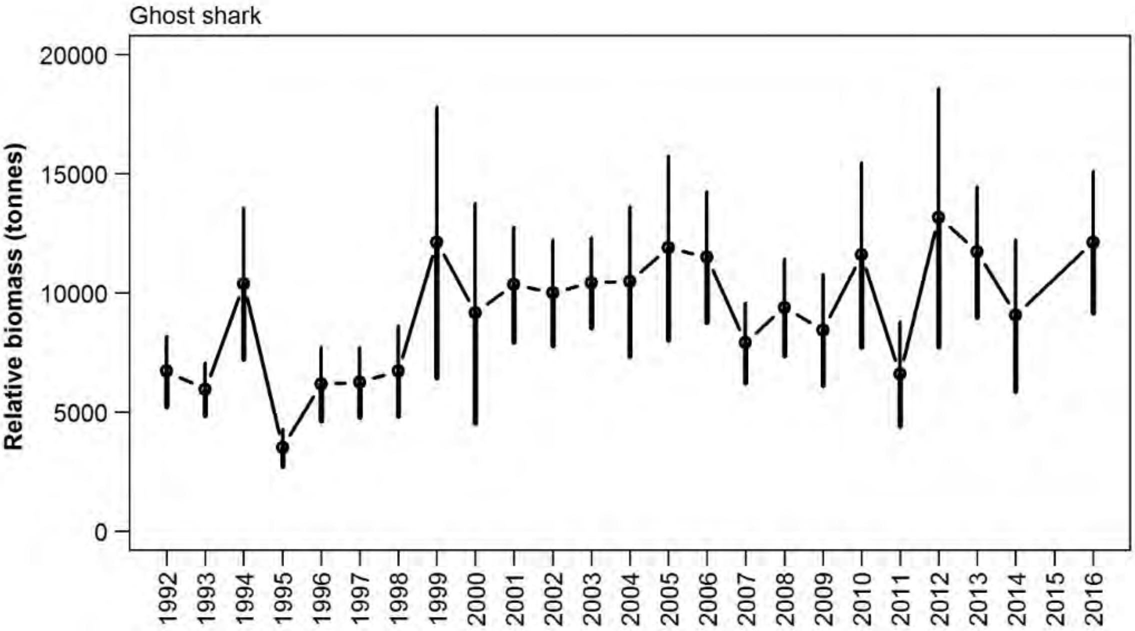


Figure 3: Biomass for dark ghost shark from the Chatham Rise trawl survey. Error bars are ± 2 standard errors.

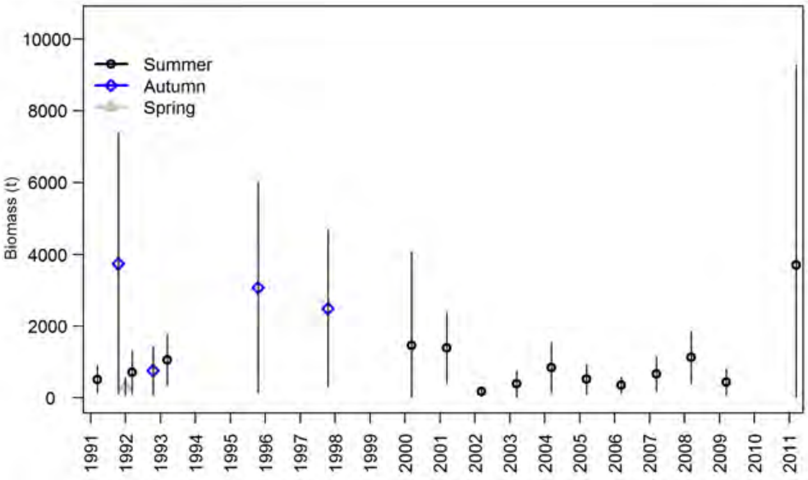


Figure 4: Biomass trends ±95% CI (estimated from survey CVs assuming a lognormal distribution) from the Sub-Antarctic trawl survey.

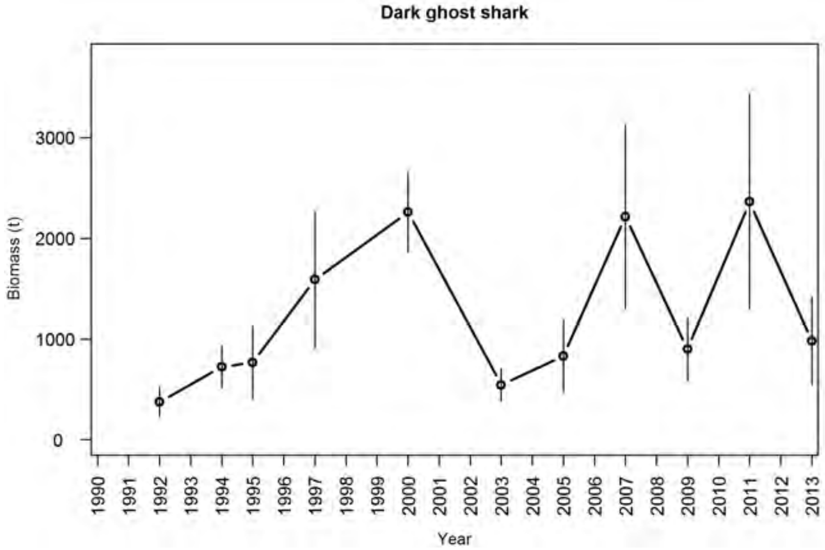


Figure 5: Biomass trends ±95% CI (estimated from survey CVs assuming a lognormal distribution) from the West Coast South Island trawl survey.

4.3 Estimation of Maximum Constant Yield (*MCY*)

As there are no available estimates of biomass or harvest rates, the only possible method of calculating maximum constant yield is $MCY = cY_{AV}$ (Method 4). However, it was decided that no estimates of *MCY* would be presented because:

i. M (and hence, the natural variability factor c) is unknown;

ii. the level of discarding is unknown and may have been considerable; and

iii. no sufficiently long period of catches was available where there were no systematic changes in catch or effort (noting that the period of catches from which Y_{AV} is derived should be at least half the exploited life span of the fish).

4.4 Estimation of Current Annual Yield (*CAY*)

In the absence of estimates of current biomass, *CAY* has not been estimated.

4.5 Other yield estimates and stock assessment results

No other yield estimates are available.

4.6 Other factors

Elasmobranchs are believed to have a strong stock-recruit relationship; the number of young born is related directly to the number of adult females. Ghost shark fecundity is unknown, but is probably low. Assuming a strong stock-recruit relationship, Francis & Francis (1992) showed that the estimates of

MCY obtained using the equations in current use in New Zealand stock assessments were overly optimistic for rig, and it is likely that they are also unsuitable for ghost sharks.

A data informed qualitative risk assessment was completed on all chondrichthyans (sharks, skates, rays and chimaeras) at the New Zealand scale in 2014 (Ford et al 2015). Dark ghost shark was ranked seventh highest in terms of risk of the eleven QMS chondrichthyan species. Data were described as existing but poor for the purposes of the assessment and consensus over this risk score was achieved by the expert panel. This risk assessment does not replace a stock assessment for this species but may influence research priorities across species.

5. STATUS OF THE STOCKS

Stock Structure Assumptions

Based on differences in length frequency distributions between the sub-Antarctic and Chatham Rise trawl surveys, and the location of commercial catches, there are most likely two main stocks of dark ghost shark.

1. The eastern fishery; extending from the upper east coast of the South Island and out east across the Chatham Rise.
2. The southern fishery; extending from the lower east coast of the South Island, south around the Stewart/Snares Shelf, Campbell Plateau, and Puysegur trench.

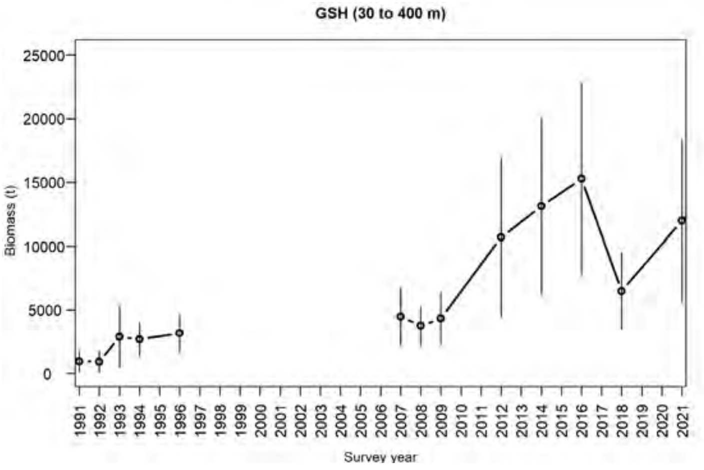
Further work needs to be done to investigate what if any relationship there is between dark ghost shark caught on the west coast of the South Island, around both coasts of the North Island, and the eastern and southern stocks.

- **Chatham Rise and ECSI**

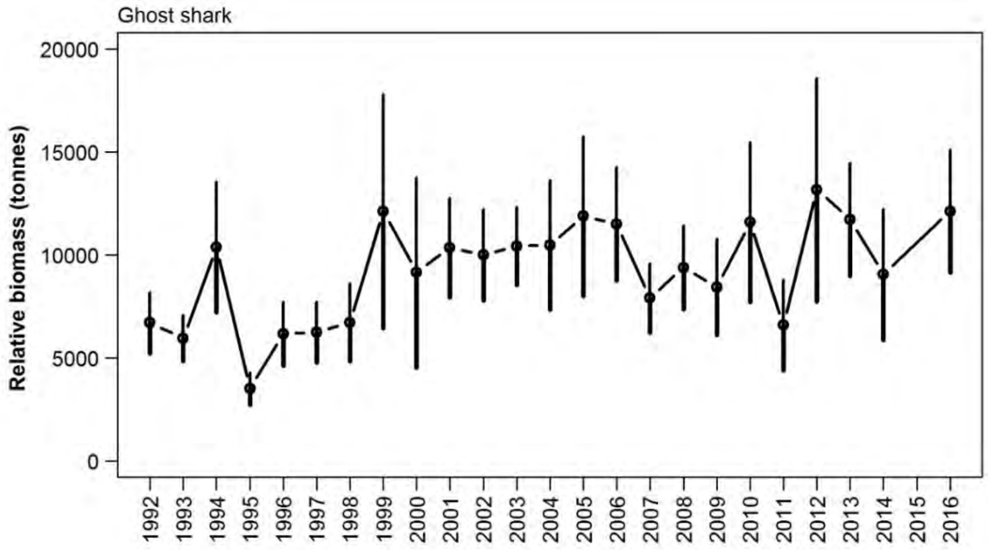
Stock Status	
Year of Most Recent Assessment	2016
Assessment Runs Presented	-
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Not defined
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status

ECSI core strata



Biomass trajectory for dark ghost shark from the ECSI trawl survey. Error bars are ± 2 standard errors.



Biomass for dark ghost shark from the Chatham Rise trawl survey. Error bars are ± 2 standard errors.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass indices from the east coast South Island inshore trawl survey time series have been steadily increasing since 2009 but decline substantially in 2018, before increasing again in 2021. Biomass indices from the Chatham Rise have fluctuated somewhat over the time series. Estimates from the last ten years have been more stable.
Recent Trend in Fishing Intensity or Proxy	Landings have been stable for the last five years from GSH 3, and relatively stable from GSH 4, apart from a small spike in the 2007–08 fishing year.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown, but there is no evidence of a systematic decline in biomass indices from either the east coast of the South Island or the Chatham Rise.

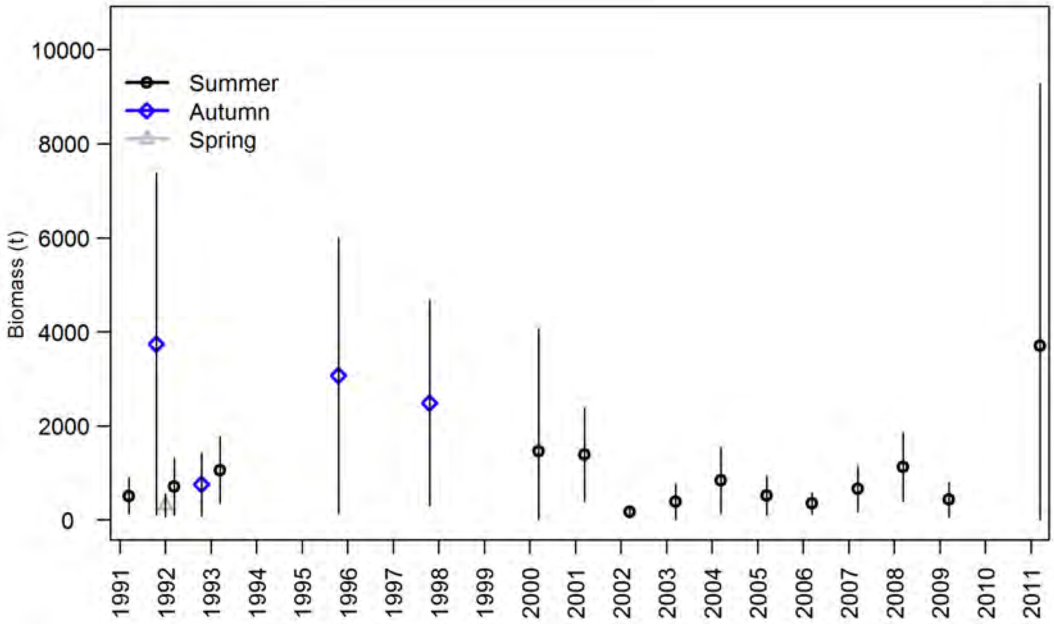
Qualifying Comments
-

Fishery Interactions
Dark ghost shark in the eastern fishery is caught exclusively as bycatch in other target fisheries with the two most important ones being hoki followed by arrow squid. For both target fisheries, incidental interactions and associated mortalities are noted for New Zealand fur seals and seabirds, and low productivity species taken in the fisheries include basking sharks and deepsea skates.

- **Southern stock**

Stock Status	
Year of Most Recent Assessment	2011
Assessment Runs Presented	-
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Not defined
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Biomass trends ±95% CI (estimated from survey CVs assuming a lognormal distribution) from the Sub-Antarctic trawl survey.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass indices from the summer sub-Antarctic trawl survey time series have been relatively flat for the last few years apart from a large spike in 2011 due to a number of randomly allocated stations occurring at the shallower end of the depth range for dark ghost shark.
Recent Trend in Fishing Intensity or Proxy	Unknown. Landings have fluctuated somewhat from GSH 5 in recent years, and have been relatively stable from GSH 6.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown, but there is no evidence of a systematic decline in biomass indices from the sub-Antarctic survey.

Qualifying Comments
-

Fishery Interactions
Dark ghost shark in the southern fishery is caught exclusively as bycatch in other target fisheries with the two most important ones being arrow squid followed by hoki. For both target fisheries, incidental interactions and associated mortalities have been recorded for New Zealand fur seals and seabirds, and low productivity species taken in the fisheries include basking sharks and deepsea skates. Interactions with other species are currently being characterised.

6. FOR FURTHER INFORMATION

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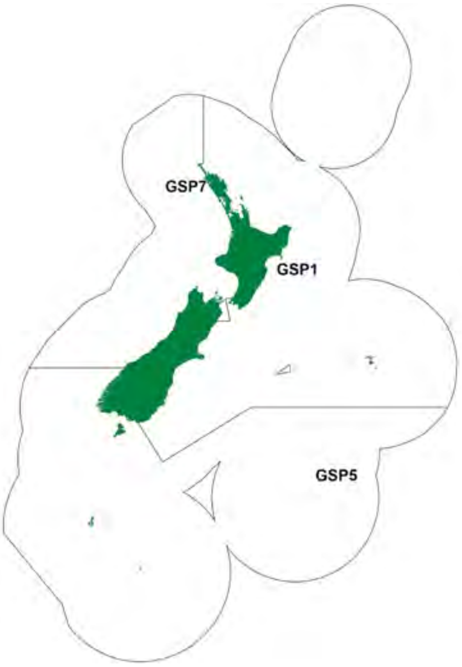
PALE GHOST SHARK (GSP)

(*Hydrolagus bemisi*)



1. FISHERY SUMMARY

1.1 Commercial fisheries

Two species (dark and pale ghost sharks) make up virtually all the commercial ghost shark landings. Pale ghost shark (*Hydrolagus bemisi*) was introduced into the QMS from the beginning of the 1999–00 fishing year as three Fishstocks: GSP 1 (FMAs 1 to 4, and 10), GSP 5 (FMAs 5 and 6) and GSP 7 (FMAs 7, 8 and 9).

Both ghost shark species are taken almost exclusively as a bycatch of other target trawl fisheries. In the 1990s, about 43% of ghost sharks were landed as a bycatch of the hoki fishery, with fisheries for silver warehou, arrow squid and barracouta combining to land a further 36%. The two ghost shark species were seldom differentiated on catch landing returns prior to the start of the 1998–99 fishing year. Estimated landings of both species by foreign licensed and joint venture vessels over the period 1 April 1978 to 30 September 1983 are presented in Table 1. Landings by domestic (inshore) vessels would have been negligible during this time period. The unknown quantities of ghost sharks that were discarded and not recorded are likely to have resulted in under-reported total catches over the full period for which data are available.

Table 1: Reported landings (t) of both ghost shark species by fishing year and EEZ area, taken by foreign licensed and joint venture vessels. An approximation of these areas with respect to current FMA boundaries is used to assign catches to QMAs. No data are available for the 1980–81 fishing year.

Year		EEZ Area												
		B	C(M)	C(1)	D	E(B)	E(P)	E(C)	E(A)	F(E)	F(W)	G	H	Total
	FMA	1&2	3		4	6				5		7	8	
1978–79*		1	37	99	26	3	16	11	88	90	8	68	17	465
1979–80*		1	55	54	426	10	4	28	138	183	7	1	5	912
1980–81*														-
1981–82*		0	84	28	117	0	2	6	29	71	9	4	0	350
1982–83*		0	108	35	84	0	2	17	98	99	29	1	1	474
1983–83#		0	84	41	73	0	0	17	5	16	17	0	0	253

* 1 April to 31 March. # 1 April to 30 Sept

In the early to mid 1980s, about half of the reported ghost shark landings were from FMA 3. Virtually all the additional catch was spread over FMAs 4–7. In 1988–89, landings from west coast South Island (FMA 7) began to increase, almost certainly associated with the development of the hoki fishery. In

1990–91, significant increases in landings were apparent on the Chatham Rise, off southeast South Island, and on the Campbell Plateau. The development of fisheries for non-spawning hoki was probably responsible for these increases.

Estimated landings of pale ghost shark by QMA are shown in Table 2. Landings from 1983–84 to 1994–95 were derived by splitting all reported ghost shark landings into depth and area bins, and allocating to species based on distribution data derived from trawl surveys (Section 2). Landings from 1995–96 to 1998–99 were estimated assuming that pale ghost shark made up 30% of the total ghost shark catch in FMAs 5 and 6, and 25% in all other FMAs.

Table 2: Estimated landings (t) of pale ghost shark by Fisheries Management Area for fishing years 1982–83 to 1998–99 based on the reported landings of both species combined. The estimated landings up to 1994–95 are based on data in the 1997 Plenary Report. Landings from 1995–96 to 1998–99 were estimated assuming pale ghost shark made up 30% of the total ghost shark catch in FMAs 5 and 6, and 25% in all other FMAs.

										FMA	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
1982–83	1	1	74	35	21	13	2	1	0	0	148
1983–84	0	1	63	24	11	15	7	1	0	0	122
1984–85	1	1	60	49	16	19	12	0	0	0	158
1985–86	1	1	96	23	10	14	7	1	0	0	153
1986–87	1	2	110	27	11	12	13	1	0	0	177
1987–88	1	1	138	21	13	2	15	1	0	0	192
1988–89	2	7	124	9	19	2	34	1	0	0	198
1989–90	1	3	86	8	41	5	33	5	0	0	182
1990–91	1	7	148	63	61	82	39	1	0	0	402
1991–92	1	2	218	95	64	54	35	2	1	0	472
1992–93	2	1	227	99	77	55	53	7	0	0	521
1993–94	1	2	173	42	36	32	99	4	0	0	389
1994–95	1	1	246	62	27	26	234	1	0	0	598
1995–96	4	12	226	84	30	29	183	3	1	0	572
1996–97	6	22	272	134	40	58	309	3	3	0	847
1997–98	6	6	256	87	30	58	57	1	4	0	505
1998–99	6	20	315	107	27	47	136	2	7	0	667

Table 3: Estimated landings (t) of pale ghost shark by Fishstock for 1999–2000 to present and actual TACCs set from 1999–2000 (QMR data).

Fishstock	**GSP 1**			**GSP 5**		**GSP 7**		
FMA (s)	**1,2,3,4,10**			**5,6**		**7,8,9**		**Total**
	Landings	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**
1999–00	577	509	216	118	35	176	828	803
2000–01	1 142	509	454	118	16	176	1 613	803
2001–02	1 033	509	545	118	71	176	1 649	803
2002–03	1 277	509	602	118	16	176	1 895	803
2003–04	1 009	509	529	118	15	176	1 553	803
2004–05	635	1 150	247	454	5	176	887	1 780
2005–06	565	1 150	134	454	9	176	708	1 780
2006–07	553	1 150	226	454	15	176	794	1 780
2007–08	473	1 150	329	454	16	176	818	1 780
2008–09	486	1 150	294	454	15	176	795	1 780
2009–10	534	1 150	206	454	11	176	751	1 780
2010–11	395	1 150	203	454	13	176	611	1 780
2011–12	447	1 150	201	454	10	176	659	1 780
2012–13	510	1 150	163	454	25	176	697	1 780
2013–14	409	1 150	286	454	33	176	727	1 780
2014–15	476	1 150	243	454	38	176	759	1 780
2015–16	493	1 150	171	454	26	176	690	1 780
2016–17	577	1 150	324	454	25	176	926	1 780
2017–18	525	1 150	469	454	35	176	1 029	1 780
2018–19	515	1 150	305	454	21	176	841	1 780
2019–20	468	1 150	193	454	19	176	681	1 780
2020–21	530	1 150	226	454	33	176	789	1 780

From 1 Oct 1999 TACCs were set for pale ghost shark fishstocks as follows: GSP 1 509 t, GSP 5 118 t and GSP 7 176 t. The TAC in each case was set equal to the TACC. Estimated and reported landings for this period are shown in Table 3, while Figure 1 shows the historical landings and TACC values for the main GSP stocks. The fisheries in GSP 1 and GSP 5 exceeded the TACC by large amounts, possibly

as a result of better reporting of catches. From 1 October 2004 the TACCs for GSP 1 and GSP 5 were increased to 1150 t and 454 t respectively, the level of catch being reported from the fisheries. Catches have since declined to well below the TACC levels in GSP 1 and GSP 7. Landings of pale ghost sharks in GSP 5 exceeded the TACC for the first time since the 2004 introduction of the higher TACC in 2017-18.

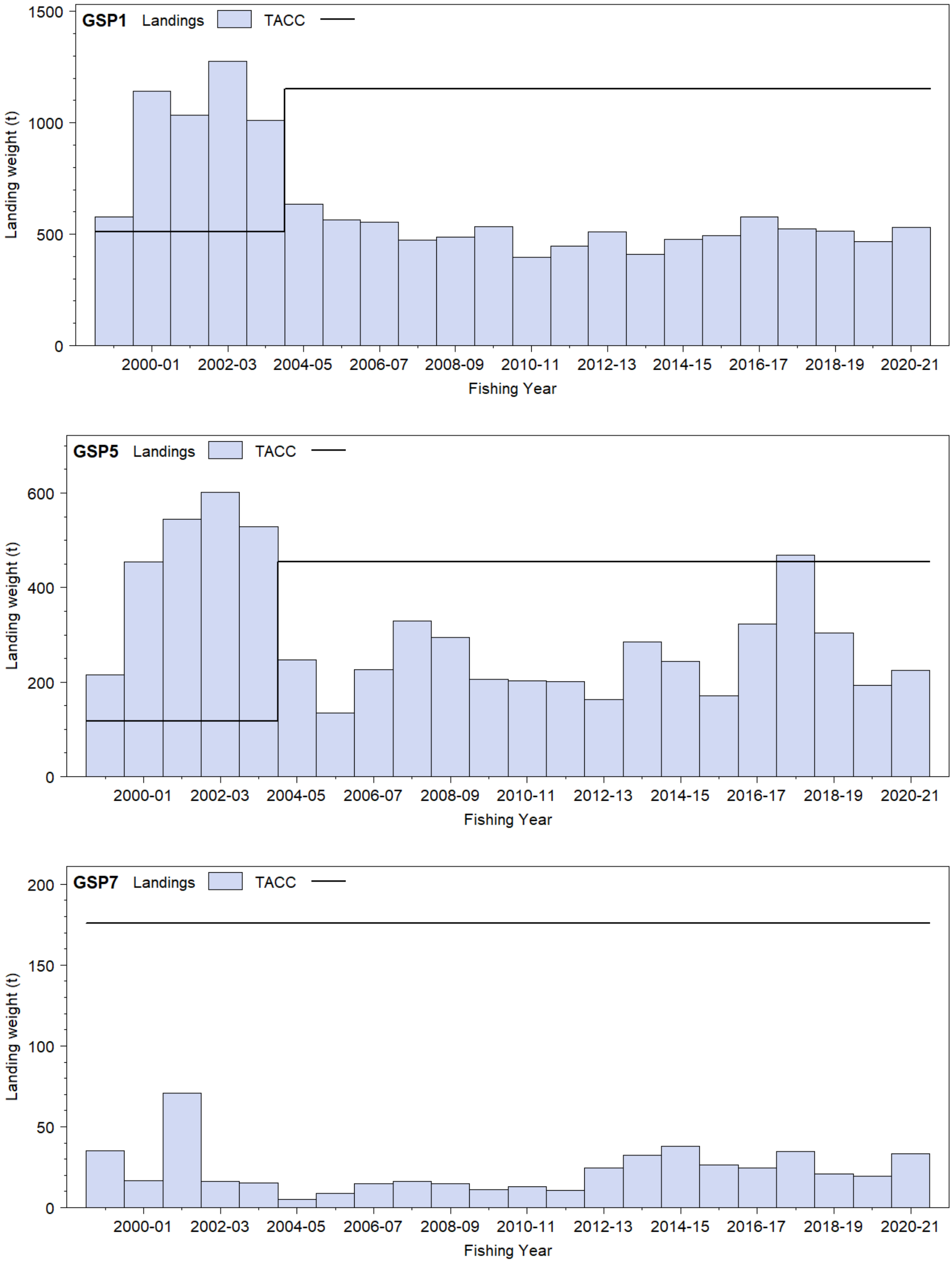


Figure 1: Reported commercial landings and TACC for the three main GSP stocks. From top: GSP 1 (Auckland East), GSP 5 (Southland) and GSP 7 (Challenger). Note that these figures do not show data prior to entry into the QMS.

In GSP 1, catches are mainly taken on the Chatham Rise while in GSP 5 catches are mainly taken in the Sub-Antarctic area; both as bycatch of the hoki trawl fisheries. Estimated catches appear to have been under-reported both before and after the introduction to the QMS. The original TACCs were based on estimated catches, but these are likely to have been much lower than the actual catches. Estimated catches on TCEPR forms since 1999–2000 have been only 25–30% of the QMR totals.

1.2 Recreational fisheries

Current catches of ghost sharks by recreational fishers are believed to be negligible in all areas.

1.3 Customary non-commercial fisheries

Quantitative information on the current level of customary non-commercial take is not available.

1.4 Illegal catch

Quantitative information on the level of illegal catch is not available. In 1998–99 (when dark ghost shark were in the QMS, but pale ghost shark were not), a quantity of dark ghost shark were reported as pale ghost shark.

1.5 Other sources of mortality

Ghost sharks have been dumped and not reported in the past by commercial fishers in FMAs 1 and 2. Similar behaviour is believed to occur in all other FMAs. The extent of the unreported dumping is unknown in all areas.

2. BIOLOGY

Pale ghost shark occur throughout the EEZ and have been recorded in depths ranging from 270 to 1200 m. They are most abundant in depths of 400–1000 m on the Chatham Rise and Southland/Sub-Antarctic, but are uncommon north of 40° S and appear to inhabit a narrower depth range in that region (600–950 m).

Trawl surveys show that dark and pale ghost shark exhibit niche differentiation, with water depth being the most influential factor, although there is some overlap of habitat. On the Chatham Rise, the main overlap range appears quite compact (from about 340 to 540 m). In the Southland/Sub-Antarctic region, the overlap range is wider (about 350 to 770 m). Stomach contents indicate that both species are predominantly benthic feeders.

No published information is available on the age or growth rate of any *Hydrolagus* species, or even any species in the family Chimaeridae. Length-frequency histograms indicate that females grow to a larger size (and presumably have a faster growth rate) than males. Hard parts of pale ghost shark have not yet been examined to check the existence of any banding pattern that may represent annual growth zones. Without population age structures or confident estimates of longevity it is not possible to estimate natural or total mortalities. A recent study has shown that eye lens measurements and spine band counts are potentially useful ageing techniques for dark ghost sharks (Francis & Ó Maolagáin 2001). However, these techniques have yet to be validated.

On the Chatham Rise, the estimated size at 50% sexual maturity for pale ghost sharks is 59–60 cm for males and 69–70 cm for females. As for most other elasmobranchs, their fecundity is likely to be low.

Biological parameters relevant to the stock assessment are shown in Table 4.

Table 4: Estimates of biological parameters for pale ghost shark, from Horn (1997).

FMA	Estimate	
1. Weight = a (length)^b (Weight in g, length in cm chimaera length)		
Pale ghost shark	a	b
3 & 4	0.00512	3.037
5 & 6	0.00946	2.883

3. STOCKS AND AREAS

Horn (1997) proposed that ghost sharks be managed as three Fishstocks, i.e., east coast New Zealand (FMAs 1–4), Stewart-Snares shelf and Campbell Plateau (FMAs 5 and 6), and west coast New Zealand (FMAs 7, 8, and 9). Areas of narrow continental shelf separate these FMA groupings, so they could well provide barriers to stock mixing, particularly for the pale ghost shark. The deep water separating the Bounty Platform from the Campbell Plateau may also provide a barrier to mixing, and these areas may hold separate stocks.

4. STOCK ASSESSMENT

No assessment of any stocks of ghost shark has been completed. Therefore, no estimates of yield are available.

4.1 Estimates of fishery parameters and abundance

Table 5: Biomass indices (t) and coefficients of variation (CV)

					Pale ghost shark	
GSP	**Area**	**Vessel**	**Trip code**	**Date**	**Biomass**	**% CV**
1	Chatham Rise	*Tangaroa*	TAN9106	Jan–Feb 1992	6 060	5.7
			TAN9212	Jan–Feb 1993	3 570	7
			TAN9401	Jan-94	5 900	8.6
			TAN9501	Jan-95	2 750	8.4
			TAN9601	Jan-96	7 900	10
			TAN9701	Jan-97	2 870	12.2
			TAN9801	Jan-98	4 052	9.3
			TAN9901	Jan-99	5 272	9.7
			TAN0001	Jan-00	4 892	7.6
			TAN0101	Jan-01	7 094	9
			TAN0201	Jan-02	4 896	10
			TAN0301	Jan-03	4 653	12.1
			TAN0401	Jan-04	3 627	8.6
			TAN0501	Jan-05	4 061	9.2
			TAN0601	Jan-06	3 237	11
			TAN0701	Jan-07	4 766	9.0
			TAN0801	Jan-08	3 235	6.1
			TAN0901	Jan-09	3 995	7.6
			TAN1001	Jan-10	3 216	11.7
			TAN1101	Jan-11	2 550	14.2
			TAN1201	Jan-12	4 327	8.5
			TAN1301	Jan-13	4 270	18.0
5	Southland Sub-Antarctic	*Tangaroa*	TAN9105	Nov–Dec 1991	11 210	6.1
			TAN9211	Nov–Dec 1992	4 750	7.2
			TAN9310	Nov–Dec 1993	11 670	9.4
			TAN0012	Nov–Dec 2000	17 823	12.4
			TAN0118	Nov–Dec 2001	11 219	8.8
			TAN0219	Nov–Dec 2002	9 297	9.3
			TAN0317	Nov–Dec 2003	10 360	8.7
			TAN0414	Nov–Dec 2004	8 549	10.3
			TAN0515	Nov–Dec 2005	9 416	10
			TAN0617	Nov–Dec 2006	12 619	10
			TAN0714	Nov–Dec 2007	13 107	11
			TAN0813	Nov–Dec 2008	10 098	13
			TAN0911	Nov–Dec 2009	13 553	9
			TAN1117	Nov–Dec 2011	11 677	9.6
			TAN1215	Nov–Dec 2012	16 181	12.6
5	Southland Sub-Antarctic	*Tangaroa*	TAN9204	Mar–Apr 1992	10 530	6.1
			TAN9304	Apr–May 1993	14 640	9.5
			TAN9605	Mar–Apr 1996	16 380	9.9
			TAN9805	Apr–May 1998	15 758	10

Estimates of fishery parameters are not available for ghost sharks. Several time series of relative biomass estimates are available from trawl surveys (Table 5). In 2004, the Plenary agreed that the trawl survey series for both GSP 1 and GSP 5 indicated that previous catch levels had made little impact on the biomass of pale ghost shark, however, the actual level of catch is not known. The recorded catch history for this species is likely to underestimate actual catches. The trawl series fluctuates over time and decreases in 2010 and 2011 on the Chatham Rise. In the Sub-Antarctic the trawl biomass indices have increased since 2005.

4.2 Biomass estimates

No biomass estimates are available for ghost shark.

4.3 Yield estimates and projections

As no estimate of biomass or harvest rate are available, the only possible method of calculating maximum constant yield is $MCY = cY_{AV}$ (Method 4).

However, it was decided that no estimates of *MCY* would be presented because:

i. M (and hence, the natural variability factor c) is unknown;

ii. the level of discarding is unknown and may have been considerable; and

iii. no sufficiently long period of catches was available where there were no systematic changes in catch or effort (noting that the period of catches from which Y_{AV} is derived should be at least half the exploited life span of the fish).

In the absence of estimates of current biomass, *CAY* has not been estimated.

4.4 Other factors

Elasmobranchs are believed to have a strong stock-recruit relationship; the number of young born is related directly to the number of adult females. Ghost shark fecundity is unknown, but is probably low. Assuming a strong stock-recruit relationship, Francis & Francis (1992) showed that the estimates of *MCY* obtained using the equations in current use in New Zealand stock assessments were overly optimistic for rig, and it is likely that they are also unsuitable for ghost sharks.

A data informed qualitative risk assessment was completed on all chondrichthyans (sharks, skates, rays and chimaeras) at the New Zealand scale in 2014 (Ford et al 2015). Pale ghost shark was ranked ninth highest in terms of risk of the eleven QMS chondrichthyan species. Data were described as existing but poor for the purposes of the assessment and no consensus over this risk score was achieved by the expert panel. This risk assessment does not replace a stock assessment for this species but may influence research priorities across species.

5. STATUS OF THE STOCKS

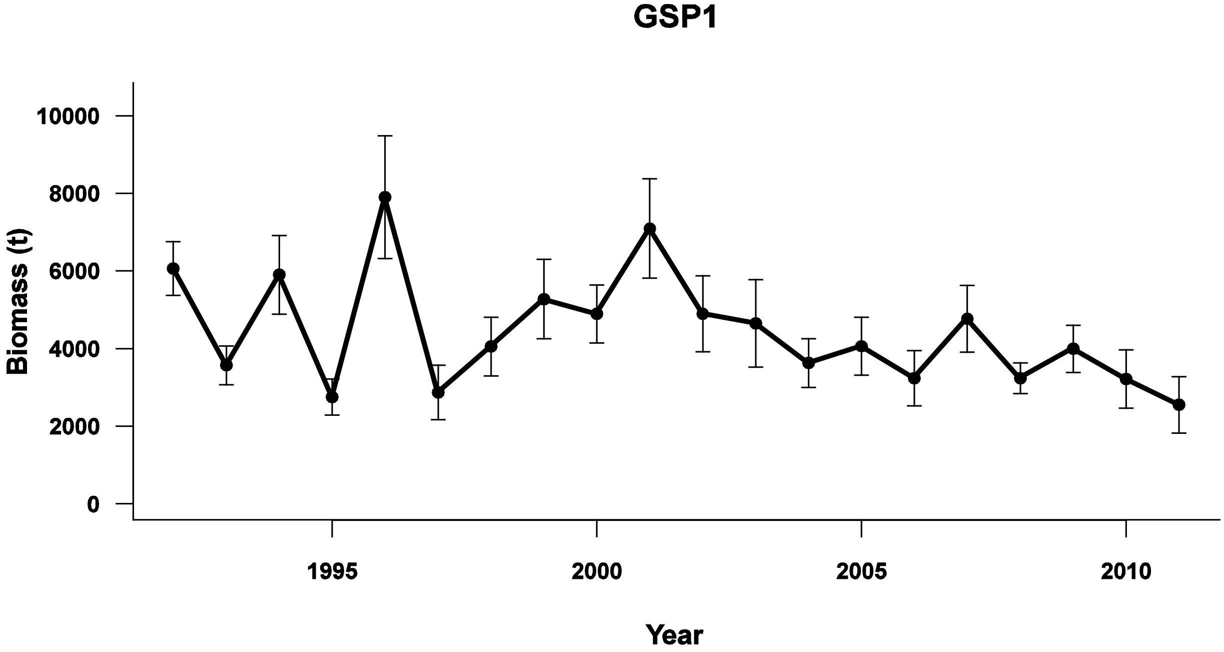
No estimates of current and reference biomass are available for pale ghost shark.

- **GSP 1**

Stock Status	
Year of Most Recent Assessment	2011
Assessment Runs Presented	
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold:-
Status in relation to Target	Unknown

Status in relation to Limits	Unlikely (< 40%) to be below soft limit Very Unlikely (< 10%) to be below hard limit
Status in relation to Overfishing	-

Historical Stock Status Trajectory and Current Status



Doorspread biomass estimates of pale ghost shark (error bars are ± two standard deviations) from the Chatham Rise, from *Tangaroa* surveys from 1992 to 2011.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass estimates from trawl surveys on the Chatham Rise have fluctuated over the time series showing a decreasing trend since 2001. Precision is generally good in this time series (< 10%). The Working Group considered this index to be suitable to monitor major trends in this stock.
Recent Trend in Fishing Mortality or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches have been well below the TACC since 2004–05.

Projections and Prognosis	
Stock Projections or Prognosis	-
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) at recent catch levels; unknown at the TACC Hard Limit: Very Unlikely (< 10%) at recent catch levels; unknown at the TACC
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment	
Assessment Method	Evaluation of trawl survey indices on the Chatham Rise	
Assessment Dates	Latest assessment: 2011	Next assessment: Unknown
Overall assessment quality rank		
Main data inputs (rank)	- Research time series of abundance indices (trawl surveys)	

Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	The core strata in the trawl survey do not cover the full depth distribution of pale ghost shark.	

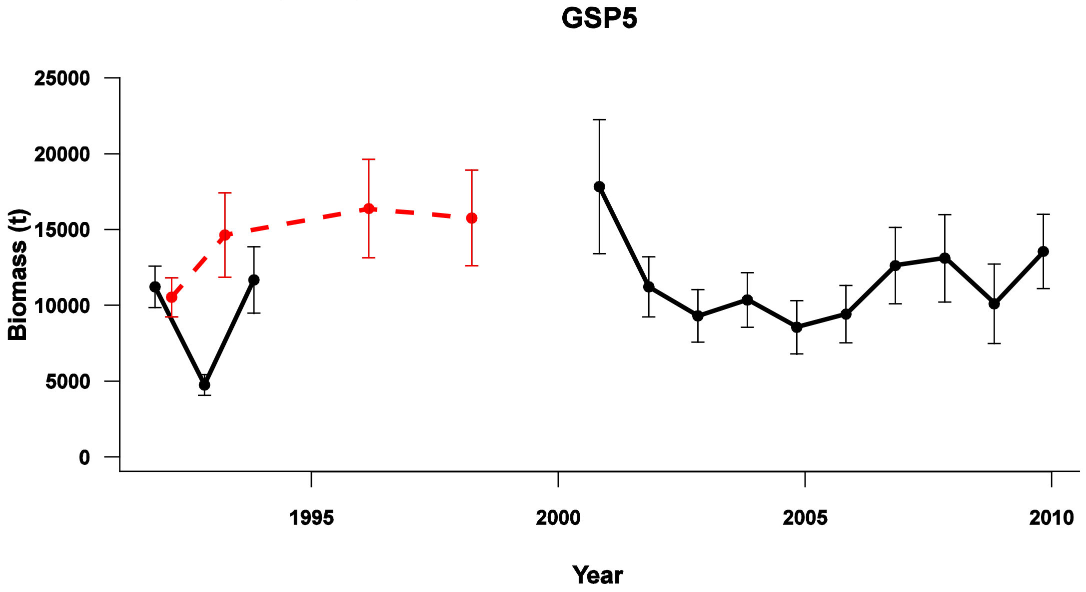
Qualifying Comments
The catch history for this species is likely to underestimate actual catches.

Fishery Interactions
The pale ghost shark in GSP 1 is mainly taken as bycatch of the hoki fishery. Interactions with other species are currently being characterised.

- **GSP 5**

Stock Status	
Year of Most Recent Assessment	2011
Assessment Runs Presented	-
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold:-
Status in relation to Target	Unknown
Status in relation to Limits	Unlikely (< 40%) to be below soft limit Very Unlikely (< 10%) to be below hard limit
Status in relation to Overfishing	-

Historical Stock Status Trajectory and Current Status



Doorspread biomass estimates of pale ghost shark (error bars are ± two standard deviations) from the Sub-Antarctic, from *Tangaroa* summer surveys from 1991 to 1993, and 2000 to 2009 (solid line) and autumn surveys from 1992 to 1998 (dashed line).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass estimates from trawl surveys on the Sub-Antarctic have increased in recent years. Precision is generally good in this time series (about 10%). The Working Group considered this index to be suitable to monitor major trends in this stock.
Recent Trend in Fishing Mortality or Proxy	Unknown

Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Catches have been well below the TACC since 2004–05.

Projections and Prognosis	
Stock Projections or Prognosis	Stock size is Unlikely (< 40%) to change much at current catch levels in FMA 5&6.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) at recent catch levels; unknown at the TACC Hard Limit: Very Unlikely (< 10%) at recent catch levels; unknown at the TACC
Probability of Current Catch or TACC causing overfishing to continue or to commence	-

Assessment Methodology		
Assessment Type	Level 2 - Quantitative stock assessment	
Assessment Method	Evaluation of trawl survey indices on the Chatham Rise	
Assessment Dates	Latest assessment: 2011	Next assessment: Unknown
Overall assessment quality rank	-	
Main data inputs	- Research time series of abundance indices (trawl surveys)	
Data not used (rank)		
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
The early catch history for this species is likely to underestimate actual catches.

Fishery Interactions
The pale ghost shark in GSP 5 is mainly taken as bycatch of the hoki fishery. Interactions with other species are currently being characterised.

- **GSP 7**

There are no accepted stock monitoring indices available for GSP 7.

6. FOR FURTHER INFORMATION

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Stevens, D; Livingston, M; Bagley, N (2001) Trawl survey of hoki and middle depth species on the Chatham Rise, January 2001 (TAN0101). Final Research Report for Ministry of Fisheries Research Project HOK2000/02, Objectives 1 and 2. 13 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

GIANT SPIDER CRAB (GSC)

(*Jacquinotia edwardsii*)

1. FISHERY SUMMARY

1.1 Commercial fisheries

The giant spider crab (*Jacquinotia edwardsii*) was introduced into the Quota Management System on 1 April 2004 with a combined TAC of 451 t and TACC of 419 t. As of April 2021, the total TAC and TACC increased to 555 t and 513 t respectively. There are no allowances for customary or recreational take, and there is an allowance for other sources of mortality of 42 t. The fishing year is from 1 April to 31 March and commercial catches are measured in greenweight.

Table 1: TACCs and reported landings (t) of giant spider crab by Fishstock from 1990–91 to present. The fishing year is from 1 April to 31 March [Continued on next page].

	GSC 1		GSC 3		GSC 5		GSC 6A	
Fishing year	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1990–91	< 1	–	0	–	0	–	0	–
1991–92	0	–	0	–	0	–	0	–
1992–93	0	–	0	–	0	–	0	–
1993–94	< 1	–	0	–	0	–	0	–
1994–95	0	–	0	–	0	–	0	–
1995–96	0	–	0	–	0	–	0	–
1996–97	< 1	–	0	–	< 1	–	0	–
1997–98	0	–	0	–	< 1	–	0	–
1998–99	< 1	–	0	–	0	–	0	–
1999–00	0	–	< 1	–	0	–	0	–
2000–01	0	–	< 1	–	0	–	0	–
2001–02	0	–	< 1	–	1	–	0	–
2002–03	0	–	< 1	–	< 1	–	0	–
2003–04	0	–	< 1	–	2	–	0	–
2004–05	0	1	< 1	14	5	19	24	148
2005–06	0	1	< 1	14	8	19	63	148
2006–07	0	1	< 1	14	5	19	23	148
2007–08	0	1	< 1	14	11	19	16	148
2008–09	< 1	1	13	14	10	19	13	148
2009–10	< 1	1	12	14	25	19	44	148
2010–11	0	1	1	14	19	19	23	148
2011–12	0	1	2	14	14	19	83	148
2012–13	< 1	1	<1	14	54	19	80	148
2013–14	0	1	2	14	72	19	52	148
2014–15	0	1	14	14	80	19	128	148
2015–16	0	1	2	14	39	19	37	148
2016–17	0	1	6	14	48	19	132	148
2017–18	0	1	8	14	91	19	140	148
2018–19	< 1	1	6	14	66	19	89	148
2019–20	< 1	1	11	14	86	19	167	148
2020–21	< 1	1	6	14	52	19	169	148
2021–22	< 1	1	8	19	70	86	108	170

Table 1 [Continued]: TACCs and reported landings (t) of giant spider crab by Fishstock from 1990–91 to present. The fishing year is from 1 April to 31 March.

	GSC 6B		GSC 10		Total	
Fishing year	Landings	TACC	Landings	TACC	Landings	TACC
1990–91	0	–	0	–	< 1	–
1991–92	0	–	0	–	0	–
1992–93	0	–	0	–	0	–
1993–94	0	–	0	–	1	–
1994–95	0	–	0	–	0	–
1995–96	0	–	0	–	< 1	–
1996–97	0	–	0	–	< 1	–
1997–98	0	–	0	–	< 1	–
1998–99	0	–	0	–	0	–
1999–00	0	–	0	–	2	–
2000–01	0	–	0	–	< 1	–
2001–02	0	–	0	–	8	–
2002–03	0	–	0	–	4	–
2003–04	0	–	0	0	27	419
2004–05	2	237	0	0	35	419
2005–06	1	237	0	0	72	419
2006–07	< 1	237	0	0	30	419
2007–08	2	237	0	0	29	419
2008–09	< 1	237	0	0	36	419
2009–10	3	237	0	0	84	419
2010–11	< 1	237	0	0	43	419
2011–12	< 1	237	0	0	99	419
2012–13	5	237	0	0	140	419
2013–14	< 1	237	0	0	127	419
2014–15	2	237	0	0	224	419
2015–16	2	237	0	0	80	419
2016–17	< 1	237	0	0	186	419
2017–18	4.2	237	0	0	243	419
2018–19	< 1	237	0	0	162	419
2019–20	< 1	237	0	0	264	419
2020–21	< 1	237	0	0	227	419
2021–22	< 1	237	0	0	186	513

Although profitable deepwater crab fisheries exist in other countries, targeted giant spider crab fisheries have not become established in New Zealand despite multiple attempts to do so since the 1960s. In recent years, all commercially caught giant spider crab have been taken as non-target catch (bycatch of up to 10 t per fishing event), principally by large trawl vessels targeting squid. Up until 2001–02, reported commercial catches of this crab were generally low (Table 1). Since then, total reported landings have risen from about 8 t to a peak of 264 t in 2019–20 but have declined since (Table 1).

There was exploratory fishing for this crab in the late 1960s and early 1970s in the Auckland Islands and Pukaki Rise areas. Following that, catches remained low (maximum 1 tonne) until the 1999–2000 fishing year when catches started to increase. Figure 1 shows the historical landings and TACC for the two main GSC stocks.

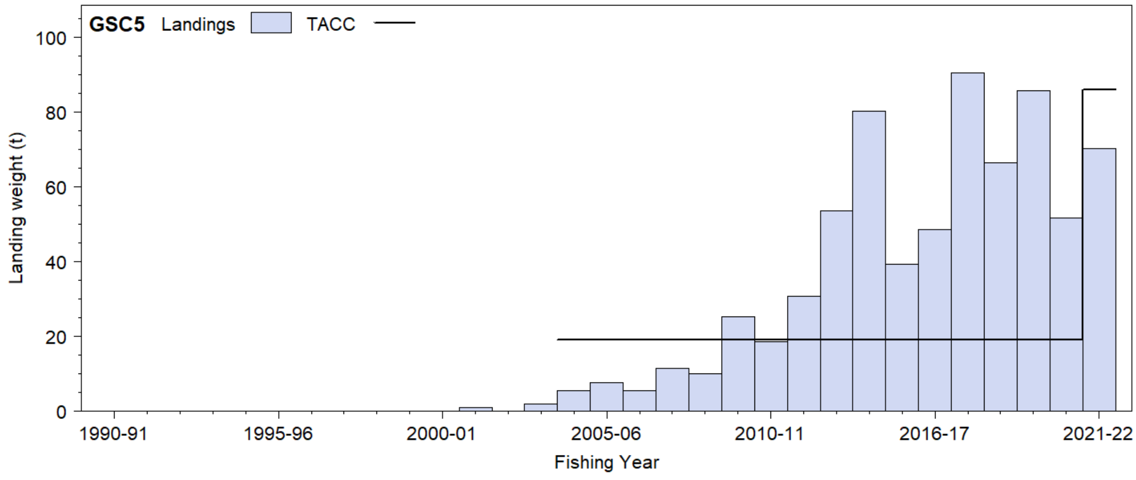

Figure 1: Reported commercial landing and TACC for GSC 5 (Southland). The fishing year is from 1 April to 31 March [Continued on next page].

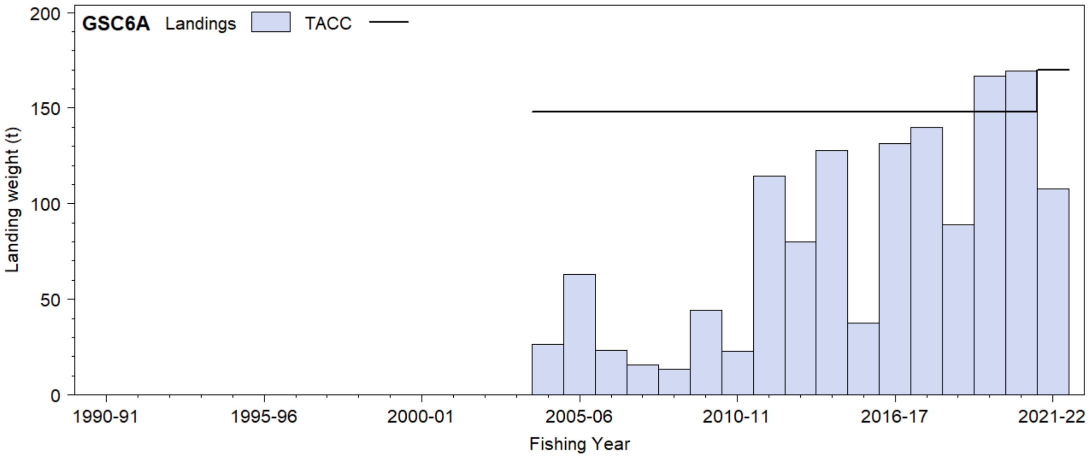

Figure 1 [Continued]: Reported commercial landing and TACC for GSC 6A (Southern Islands). The fishing year is from 1 April to 31 March.

1.2 Recreational fisheries

There are no known records of recreational use of this crab.

1.3 Customary non-commercial fisheries

There are no known records of customary use of this crab.

1.4 Illegal catch

There is no known illegal catch of this crab.

1.5 Other sources of mortality

There is no quantitative information on other sources of mortality.

2. BIOLOGY

Jacquinotia is found from the intertidal to over 500 m in the southeast and south of New Zealand from near Mernoo Gap to Campbell Island. It appears to attain highest densities southeast of the Snares, on the Pukaki Rise, and around the Auckland Islands. Ryff & Voller (1976) recorded *Jacquinotia* in highest quantities on the Pukaki Rise and at the Auckland Islands, with decreasing quantities at the Campbell Islands, Bounty Islands, Stewart Island, Stewart-Snares shelf, Puysegur Bank, and off Otago Heads, an observation consistent with earlier resource surveys (Ritchie 1970, 1973; Webb 1972). At the Auckland Islands they appear to be most abundant between 20 m and 40 m, but on the Pukaki Rise between 140 m and 160 m.

This spider crab, also sometimes known as the southern spider crab or the Auckland Islands crab, is a large, conspicuous brachyuran with a brick red carapace and bright red to yellowish-white chelae. The male grows much larger than the female, to at least 20 cm across the back and, together with its up to 40 cm long clawed legs, can give a total spread approaching 1 m. The males at least seem to be migratory. There have been reports of ‘mounding’ behaviour associated with moulting and mating (Bennett 1964, Ritchie 1970) in which large numbers of crabs form clumps, particularly in spring and autumn. This is consistent with trawl vessels occasionally reporting catches of several tonnes of crabs in a single tow.

Large males have been observed feeding on ribbed mussels (*Aulacomya maoriana*) and they probably also feed on other shellfish, both bivalves (*Mytilus*, *Mactra*) and gastropods (*Haliotis*, *Maurea*, *Struthiolaria*). In contrast, females are detritus feeders on sandy substrates, and juveniles seem to feed on drift algae. These differences mean that, although both males and females may enter pots, only males have been observed feeding on fish bait.

Sexes are separate and in both there appears to be a terminal moult. Males reach maturity at 110 mm carapace length (CL) and females at 100 mm CL. It appears that, at least near land masses, large males migrate between shallow and deep water seasonally. Pairs form in shallow water (less than 10 m) or just out of the water in September–November, when females are in late berry. Egg extrusion probably takes place in September to February and larval release in September to November. A female of 101 mm CL carries about 37 500 eggs; a female of 126 mm CL about 71 200 eggs. Only one batch of eggs is produced each year and the interval between hatching of one lot of eggs and extrusion of the next batch is very short. In summer, females and pre-puberty males occur mainly in shallow water whereas large males are found deeper.

Larval duration, survival, behaviour, and settlement are poorly known. There are two zoeal stages but the megalopa is unknown. Zoea probably occur in the plankton during September to November. Juveniles have been found in large numbers close inshore at the Auckland Islands, where shoreline rock meets the deeper mud and sand flats. Seaweed present here was apparently both food and shelter for the young crabs.

There is little or no information available on age, growth, and natural mortality. Moulting appears to take place between November and March. Males reach 220 mm CL; females 144 mm. According to Ritchie (1970), M for mature females is 13–25% and may be slightly higher for mature males.

3. STOCKS AND AREAS

For management purposes stock boundaries are based on FMAs, however, there is currently no biological or fishery information which could be used to identify stock boundaries. The GSC6A and 6B fishstocks were intentionally aligned with those for the sub-Antarctic scampi stocks.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

There are no estimates of fishery parameters or abundance for any giant spider crab fishstock.

4.2 Biomass estimates

There are no biomass estimates for any giant spider crab fishstock.

4.3 Yield estimates and projections

There are no estimates of *MCY* for any giant spider crab fishstock.

There are no estimates of *CAY* for any giant spider crab fishstock.

5. STATUS OF THE STOCKS

There are no estimates of reference or current biomass for any giant spider crab fishstock.

6. FOR FURTHER INFORMATION

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GREEN-LIPPED MUSSEL (GLM)

(Perna canaliculus)
Kuku, Kutai

1. FISHERY SUMMARY

Green-lipped mussels were introduced into the Quota Management System on 1 October 2004. The fishing year is from 1 October to 31 September. A breakdown of the Total Allowable Catch (TAC) for each Quota Management Area (QMA) is listed in Table 1.

Table 1: Current Total Allowable Catch (TAC, t), customary and recreational allowances (t), and Total Allowable Commercial Catches (TACC, t) for green-lipped mussel.

Fishstock	TAC	Customary allowance	Recreational allowance	TACC
GLM 1	415	243	162	10
GLM 2	35	15	10	10
GLM 3	155	87	58	10
GLM 7A	1 548	29	19	1 500
GLM 7B	23	8	5	10
GLM 8	43	26	17	0
GLM 9	233	59	39	135
GLM 10	0	0	0	0
Total	2 452	467	310	1 675

1.1 Commercial fisheries

Commercial harvesting of green-lipped mussels began with handpicking of inter-tidal beds in the late nineteenth century and expanded in 1927 with the development of a dredge fishery for sub-tidal mussels in the Hauraki Gulf. Following a brief decline in catch rates from 1935–45, landings increased steadily to peak in 1961 at more than 2000 t. Overexploitation of the Hauraki Gulf beds caused the fishery to close in 1966. A second dredge fishery developed in Tasman Bay and Kenepuru Sound in 1962; however, under an open access regime this fishery also declined within five years.

Between 2004 and 2007 reported landings were dominated by GLM 7A; since 2007 GLM 9 landings have been dominant. Total landings have been low and declining compared to the total TACC in GLM 1 and GLM 7A, but landings exceeded the GLM 9 TACC in 2009–10, 2014–15, 2015–16, and 2016–17. Recent estimated landings of green-lipped mussels are shown in Table 2, while Figure 1 shows the historical landings and TACC for the three main GLM stocks.

Table 2: Reported landings (t) of Green-lipped mussel and actual TACCs (t) from 2004–05 to the present.

Fishstock	GLM 1		GLM 2		GLM 3		GLM 7A	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
2004–05	6.2	10	0	10	0.2	10	410.9	1 500
2005–06	12.5	10	0.2	10	0.2	10	229.0	1 500
2006–07	7.8	10	0	10	0	10	84.3	1 500
2007–08	3.5	10	0	10	< 0.1	10	7.4	1 500
2008–09	6.7	10	0	10	< 0.1	10	0.1	1 500
2009–10	4.4	10	0	10	< 0.1	10	< 1	1 500
2010–11	1.0	10	0	10	0	10	1.4	1 500
2011–12	0.5	10	0	10	0	10	0.1	1 500
2012–13	0.6	10	0	10	0	10	0	1 500
2013–14	0.1	10	0	10	0	10	8.3	1 500
2014–15	< 0.1	10	0	10	0	10	8.3	1 500
2015–16	0.1	10	0	10	0	10	0	1 500
2016–17	0.2	10	0	10	0	10	0	1 500
2017–18	< 0.1	10	0	10	0	10	0	1 500
2018–19	0	10	0	10	0.7	10	0	1 500
2019–20	0	10	0	10	0	10	0	1 500
2020–21	0	10	0	10	0	10	0	1 500

	GLM 9		Total	
Fishing year	Landings	TACC	Landings	TACC
2004–05	121.3	180	539	1 720
2005–06	93.0	180	335	1 720
2006–07	136.9	180	229	1 720
2007–08	141.7	180	153	1 720
2008–09	67.9	180	75	1 720
2009–10	183.3	180	187	1 720
2010–11	78.1	180	80	1 720
2011–12	162.0	180	163	1 720
2012–13	129.0	180	130	1 720
2013–14	159.9	180	167	1 720
2014–15	207.0	180	215	1 720
2015–16	203.4	180	203	1 720
2016–17	208.9	180	209	1 720
2017–18	151.9	180	152	1 720
2018–19	139.3	135	140	1 675
2019–20	94	135	94	1 675
2020–21	111	135	111	1 675

Spat collecting is the other commercial venture with green-lipped mussels. Until green-lipped mussels were introduced into the QMS a permit was required to harvest spat attached to beach cast seaweed.

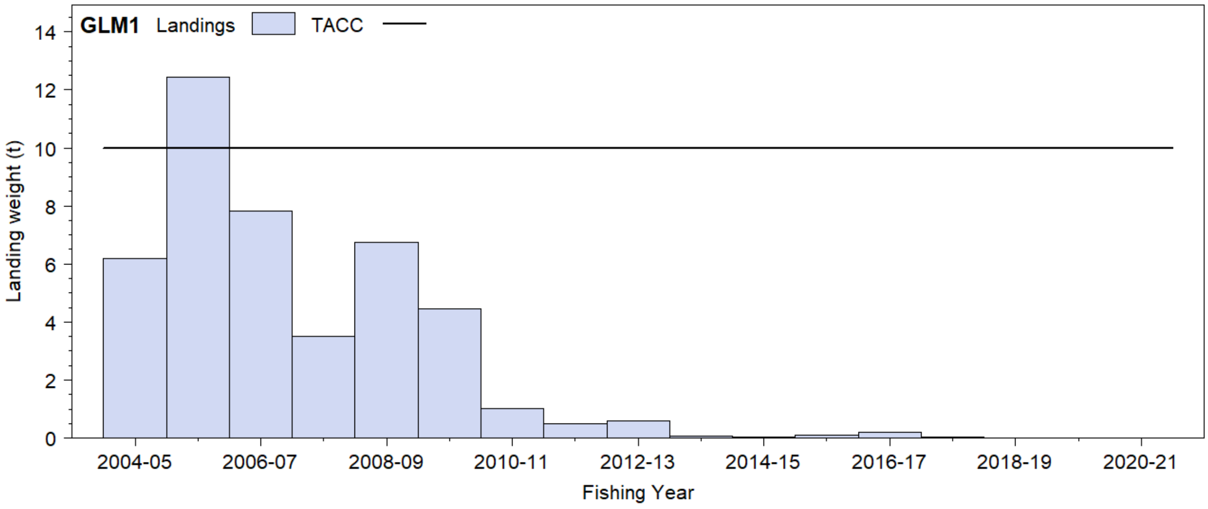
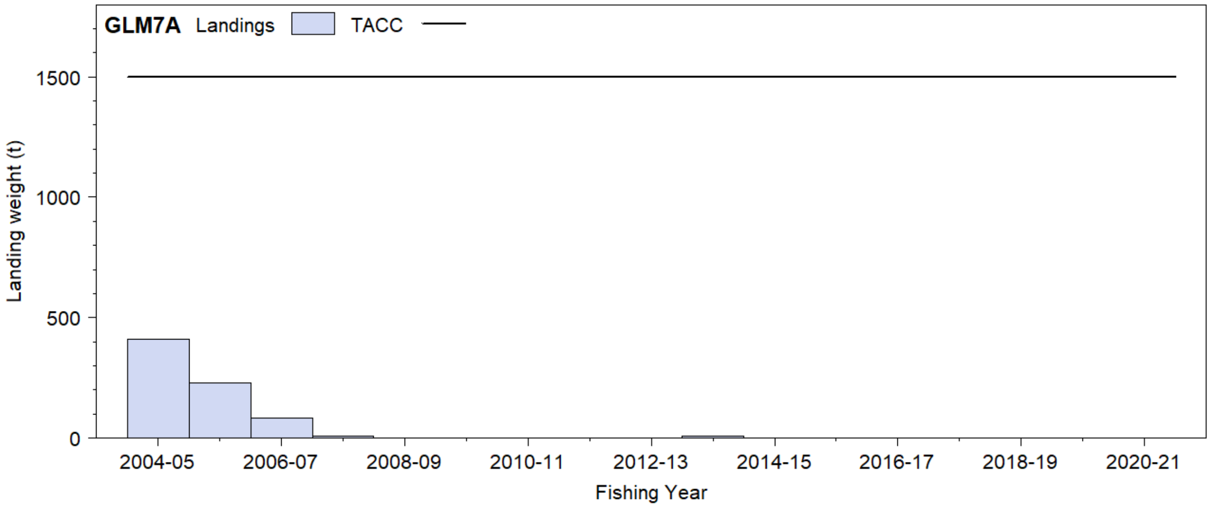


Figure 1:Reported commercial landings and TACC for GLM 1 (Auckland East). Note that these figures do not show data prior to entry into the QMS [Continued on next page].



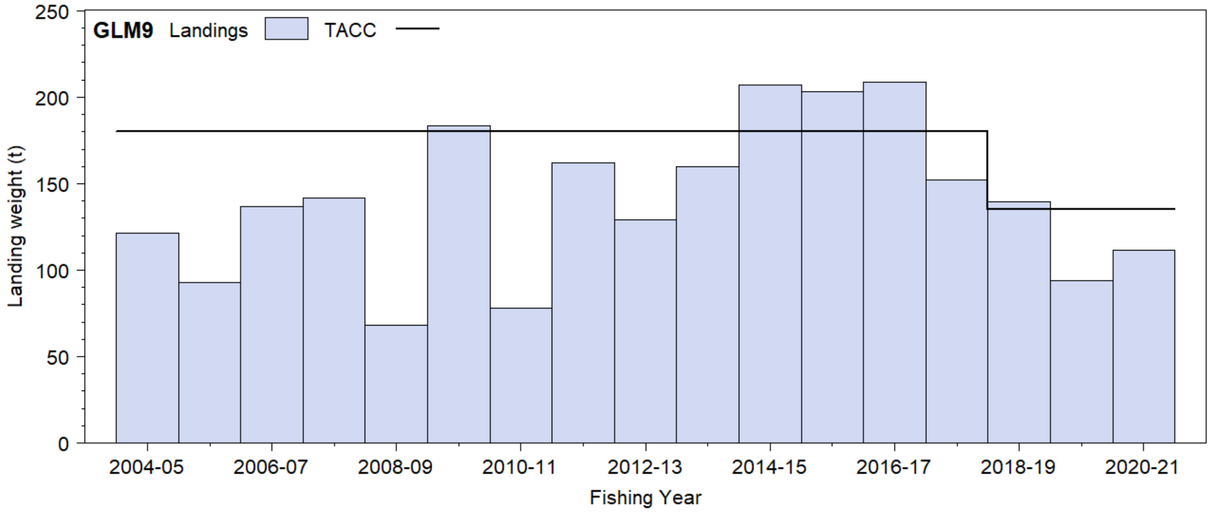


Figure 1 [Continued]: Reported commercial landings and TACC GLM 7A (Nelson Marlborough), and GLM 9 (Auckland West). Note that these figures do not show data prior to entry into the QMS.

1.2 Recreational fisheries

Recreational harvest estimates for green-lipped mussels have been obtained from the 1996, 2000 and 2001 national telephone diary surveys of recreational fishers (Table 3). Estimates of green-lipped mussels from the 1996 survey are only available for FMA 1. No weights were available from the surveys to estimate recreational harvest by tonnage. The Recreational Technical Working Group has reviewed the harvest estimates from the national telephone diary surveys and considered that the estimates from the 1996 survey are unreliable because the survey contained a methodological error. The estimated number of green-lipped mussels from the 2000 and 2001 surveys is also considered to be unreliable. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year (Wynne-Jones et al. 2014). The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The panel survey was repeated in 2017–18 (Wynne-Jones et al. 2019).

1.3 Customary non-commercial fisheries

Green-lipped mussels are very important to customary fishing. This species was used extensively by Māori, appearing in middens throughout the country. The species continues to be important to Māori and, anecdotally, a number of customary fishers have noted its importance as a resource in a number of areas. Green-lipped mussels form an important fishery for customary non-commercial, but the total annual catch is not known.

Table 3: Harvest estimates of mussels (000s of individuals of *P. canaliculus* combined) from the 1996, 2000 and 2001 national recreational surveys, by FMA (Bradford 1998, Boyd et al. 2004) and the national panel surveys in 2011–12 and 2017–18 (Wynne-Jones et al. 2014, Wynne-Jones et al. 2019).

Area	Number (thousands)	CV
1996 (telephone-diary)		
GLM 1	818	
GLM 2		
GLM 3		
GLM 5		
GLM 7		
GLM 8		
GLM 9		
2000 (telephone diary)		
GLM 1	1 308	
GLM 2	8	
GLM 3	402	
GLM 5	1	
GLM 7	3	
GLM 8	242	
GLM 9	25	
2002 (telephone diary)		
GLM 1	949	
GLM 2	22	
GLM 3	187	
GLM 5	36	
GLM 7	363	
GLM 8	-	
GLM 9	148	
2011–12 (national panel survey)		
GLM 1	576	
GLM 2	56	
GLM 3	73	
GLM 5	8	
GLM 7	78	
GLM 8	39	
GLM 9	154	
GLM total	983	
2017–18 (national panel survey)		
GLM 1	147	0.29
GLM 2	54	0.44
GLM 3	44	0.41
GLM 5	23	0.49
GLM 7	55	0.42
GLM 8	3	0.72
GLM 9	17	0.46
GLM total	342	

Māori customary fishers utilise the provisions under both the recreational fishing regulations and the various customary regulations. Many tangata whenua harvest green-lipped mussels under their recreational allowance and these are not included in records of customary catch. Customary reporting requirements vary around the country. Customary fishing authorisations issued in the South Island and Stewart Island would be under the Fisheries (South Island Customary Fishing) Regulations 1999. Many rohe moana / areas of the coastline in the North Island and Chatham Islands are gazetted under the Fisheries (Kaimoana Customary Fishing) Regulations 1998 which require reporting on authorisations. In the areas not gazetted, customary fishing permits would be issued would be under the Fisheries (Amateur Fishing) Regulations 2013, where there is no requirement to report catch.

The information on Māori customary harvest under the provisions made for customary fishing can be limited (Table 4). These numbers are likely to be an underestimate of customary harvest as only the catch approved and harvested in kilograms and numbers are reported in the table.

While little information is available, the green-lipped mussels remain an important element of customary fishing throughout many parts of New Zealand and efforts are being made collaboratively with iwi to manage populations in localised areas, e.g., Ōhiwa Harbour Implementation Forum.

Table 4: Fisheries New Zealand records of customary harvest of green-lipped mussels (approved and reported as weight (kg) and in numbers), since 2005-06. – no data.

		Weight (kg)		Numbers	
Stock	Fishing year	Approved	Harvested	Approved	Harvested
GLM 1	2009–10	280	25	1 000	700
	2010–11	470	120	725	545
	2011–12	80	30	75	50
	2014–15	530	500	350	300
	2015–16	445	440	–	–
	2016–17	340	80	160	45
	2017–18	–	–	300	200
GLM 2	2013–14	–	–	350	350
GLM 3	2005–06	–	–	225	75
	2006–07	–	–	1 410	694
	2007–08	–	–	4 569	4 284
	2008–09	–	–	9 820	7 920
	2009–10	–	–	2 890	2 175
	2010–11	–	–	1 900	1 900
	2011–12	–	–	1 905	1 725
	2012–13	–	–	4 115	3 300
	2013–14	–	–	300	100
	2014–15	–	–	–	–
	2015–16	–	–	9 430	7 934
	2016–17	–	–	3 150	1 224
	2017–18	–	–	600	308
	2018–19	–	–	400	203
	2019–20	–	–	12 295	8 677
	2020–21	–	–	550	200
GLM 7B	2006–07	200	200	–	–
	2007–08	–	–	200	200
	2016–17	–	–	650	650

1.4 Illegal catch

Current levels of illegal harvest are not known.

1.5 Other sources of mortality

There is no quantitative information.

2. BIOLOGY

The green-lipped mussel is a filter-feeding mollusc. While distributed throughout New Zealand, it is most common in central and northern parts where it frequently forms dense beds of up to 100 m^2. This species is absent from the Chatham Islands and other offshore islands. It is typically a bivalve of the lower shore and open coast and is found from the mid-littoral to depths of over 50 m. The species can grow to over 240 mm in shell length (anterior-posterior axis).

The green-lipped mussel is a dioecious (uni-sexual) broadcast spawner. Gonadal development takes place at temperatures above 11°C and is also related to food availability, environmental conditions, and stock origin. Most spawning occurs in late spring to early autumn, but larvae can be present all year. Sexual maturity has been observed in some populations to begin from 27 mm shell length, with most individuals sexually mature by 40 mm shell length. Sexual maturity is reached in the first year, and females can produce up to 100 million eggs per season. Fertilisation is largely dependent on the proximity of adults.

Settlement processes associated with marine farms have been well studied, but less is known about natural settlement. The planktonic stage (pediveligers) of the green-lipped mussel is ready to settle at 220–350 µm in length, after a three to five week larval phase. The larvae swim only vertically but they can be transported large distances by currents and tides. Settlement is most intense from late winter to early summer, but is highly variable spatially and temporally. In the wild, larvae settle over a wide range of depths, preferring fine filamentous substrata including hydroids, bryozoans, and filamentous and turfing algae. Settlement is completed with the attachment of byssus threads and subsequent metamorphosis.

Primary settlement onto beds of adult mussels is uncommon, but can take place on surrounding algae and on the byssi of adults. Secondary settlement, after a form of byssopelagic migration or mucous drifting, is thought to be the means by which most juveniles recruit into mussel beds. The spat detaches from the substrate by severing the byssus threads and the secreted mucous strand, this enables it to swim or drift to new areas for attachment. Juvenile mussels may move numerous times like this before settling on adult mussel beds. This drifting ability is lost once spat reach about 6 mm in shell length.

There is little information on age, growth and natural mortality, particularly for wild populations, however recent evidence suggests that stock origin can have a significant effect on their growth indicating a large genetic component. Green-lipped mussels in suspended culture typically grow from 10 to 75 mm shell length in six months, to 111–115 mm in one year, and to 195 mm in three and a half years. Growth is typically faster in cultured situations compared with natural beds, which are often overcrowded, are on exposed coasts, and are not constantly submerged so feeding is discontinuous. At Piha and West Tamaki Head, green-lipped mussel growth is variable, with individuals reaching 20–70 mm shell length in their first year.

3. STOCKS AND AREAS

Green-lipped mussels are distributed in seven of the ten FMAs (1–3, 5 and 7–9) but are most common in the central and northern parts of New Zealand.

There is little information on stock structure, recruitment patterns, or other biological characteristics. There appears to be strong genetic structuring of the New Zealand green-lipped mussel population, with a northern and southern group being differentiated by frequency shifts in common haplotypes, and the occurrence of a unique haplotype in the South Island west coast population. The southern-northern population split occurs south of Cook Strait.

4. STOCK ASSESSMENT

There are no stock assessments or biomass estimates for green-lipped mussels.

5. STATUS OF THE STOCKS

It is not known whether green-lipped mussel stocks are at, above, or below a level that can produce *MSY* as no estimates of reference or current biomass are available for any green-lipped mussel fishstock at a management area level. However, some localised information is available. Green-lipped mussel populations have been intermittently surveyed in Ōhiwa Harbour since 2006. What this monitoring has shown is a reduction in the historical distribution of green-lipped mussels within the harbour along with a > 99% reduction in abundance in the decade since 2006 across all size-classes due to sediment deposition.

6. FOR FURTHER INFORMATION

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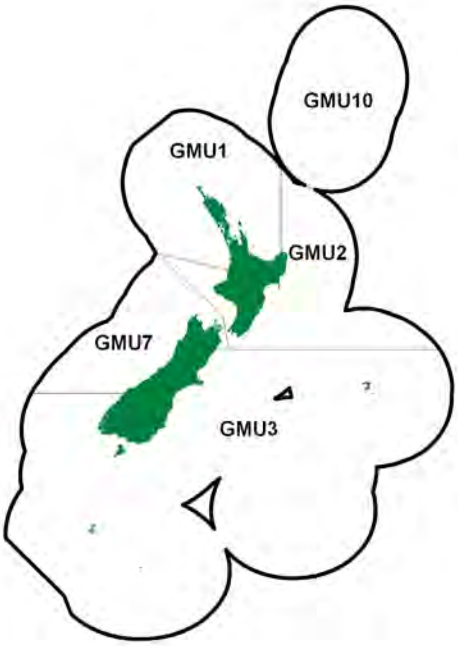
GREY MULLET (GMU)

(*Mugil cephalus*)
Kanae, Hopuhopu



1. FISHERY SUMMARY

1.1 Commercial fisheries

Commercial fishing for grey mullet occurs predominantly in GMU 1, where annual landings increased from approximately 128 t in 1931 to a maximum of 1142 t in 1983–84 (Table 1; 2). Marked changes in fishing effort occurred during this period through the development of more efficient fishing techniques and an increase in the market demand for this species. Before the introduction of the QMS, total domestic catches declined from the maximum (1160 t) in 1983–84 to 901 t in 1985–86. The TACC was consistently under caught after GMU 1 was introduced into the QMS (Figure 1). The Minister of Fisheries therefore reduced the TACC for GMU 1 to 925 t, beginning in 1998–99. The reduction in TACC had little effect on the annual catches, and it has only ever been reached in GMU 1 in 2004–05 and 2013–14 (Table 2).

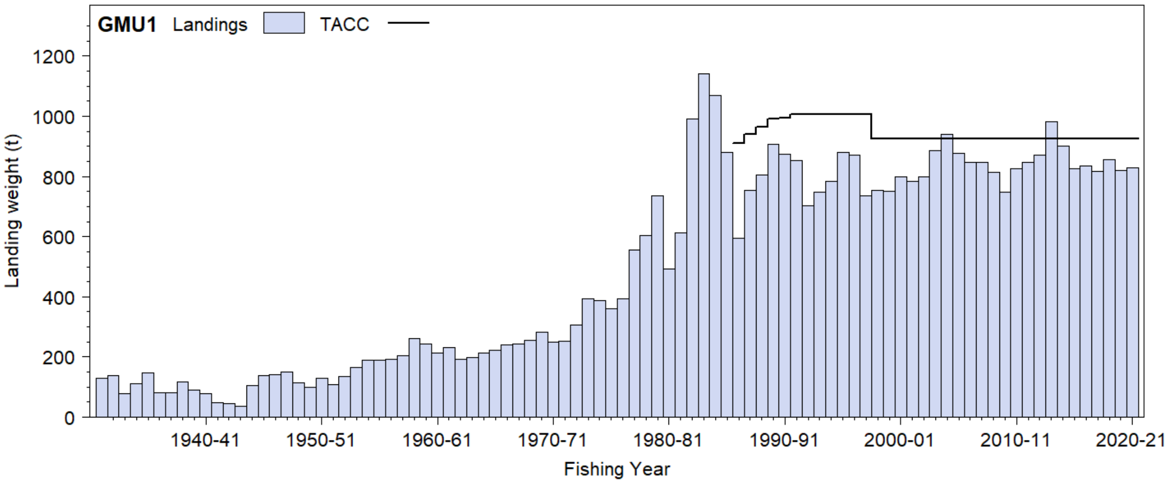


Figure 1: Reported commercial landings and TACC for the main GMU stock; GMU 1 (Auckland).

Table 1: Reported landings (t) for the main QMAs from 1931 to 1990.

Year	GMU 1	GMU 2	GMU 3	GMU 7	Year	GMU 1	GMU 2	GMU 3	GMU7
1931–32	128	0	0	0	1957	204	1	0	0
1932–33	138	0	0	0	1958	262	0	0	0
1933–34	78	0	0	0	1959	244	0	0	0
1934–35	111	0	0	0	1960	213	0	0	0
1935–36	147	0	0	0	1961	230	0	0	0
1936–37	80	0	0	0	1962	191	0	0	0
1937–38	82	0	0	0	1963	199	0	0	0
1938–39	117	1	0	1	1964	214	0	0	0
1939–40	91	0	0	0	1965	222	2	3	0
1940–41	77	0	0	0	1966	240	0	0	0
1941–42	48	2	0	0	1967	243	0	0	0
1942–43	44	2	0	0	1968	256	0	0	0
1943–44	35	0	0	0	1969	283	1	1	0
1944	104	0	0	0	1970	248	1	0	0
1945	138	0	0	0	1971	253	1	0	0
1946	141	0	0	0	1972	305	0	1	0
1947	151	0	0	0	1973	393	1	4	2
1948	114	0	0	0	1974	386	0	0	0
1949	100	0	0	0	1975	360	0	0	0
1950	129	0	0	0	1976	394	0	0	0
1951	108	0	0	0	1977	557	0	0	0
1952	136	0	0	0	1978	604	0	0	0
1953	166	0	0	0	1979	735	0	0	0
1954	190	0	0	0	1980	494	0	0	0
1955	188	0	0	0	1981	612	0	0	0
1956	193	0	0	0	1982	990	0	8	2

Notes:

1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: Data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings.

Table 2: Reported landings (t) of grey mullet by Fishstock from 1983–84 to present and actual TACCs (t) for 1986–87 to present. QMS data from 1986-present. There have been no report landings for GMU 10. *FSU data. [Continued on next page]

Fishstock	GMU 1		GMU 2		GMU 3		GMU 7		GMU 10		
QMA (s)	1 & 9		2 & 8		3, 4, 5 & 6		7		10		Total
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	TACC	Landings	TACC
1983–84*	1 142	-	6	-	5	-	7	-	-	1 160	-
1984–85*	1 069	-	5	-	0	-	15	-	-	1 089	-
1985–86*	881	-	10	-	0	-	10	-	-	901	-
1986–87	595	910	3	20	< 1	30	0	20	10	598	990
1987–88	751	941	3	20	0	30	0	20	10	754	1 021
1988–89	792	963	3	20	0	30	0	20	10	795	1 043
1989–90	907	990	2	20	0	30	4	20	10	913	1 070
1990–91	875	994	2	20	1	30	< 1	20	10	879	1 073
1991–92	848	1 006	1	20	2	30	1	20	10	852	1 086
1992–93	711	1 006	< 1	20	< 1	30	0	20	10	712	1 086
1993–94	743	1 006	< 1	20	< 1	30	0	20	10	706	1 086
1994–95	776	1 006	0	20	< 1	30	10	20	10	787	1 086
1995–96	866	1 006	0	20	< 1	30	< 1	20	10	866	1 086
1996–97	870	1 006	< 1	20	1	30	< 1	20	10	872	1 086
1997–98	730	1 006	< 1	20	< 1	30	< 1	20	10	730	1 086
1998–99	750	925	< 1	20	< 1	30	< 1	20	10	750	1 005
1999–00	749	925	< 1	20	0	30	< 1	20	10	750	1 005
2000–01	797	925	1	20	0	30	< 1	20	10	798	1 005
2001–02	782	926	2	20	< 1	30	< 1	20	10	784	1 005
2002–03	797	926	1	20	< 1	30	0	20	10	798	1 005
2003–04	886	926	< 1	20	0	30	< 1	20	10	796	1 005
2004–05	941	926	< 1	20	0	30	0	20	10	941	1 005
2005–06	878	926	< 1	20	< 1	30	0	20	10	878	1 005
2006–07	847	926	1	20	0	30	< 1	20	10	845	1 005
2007–08	848	926	1	20	< 1	30	< 1	20	10	849	1 005
2008–09	814	926	1	20	0	30	0	20	10	815	1 005
2009–10	746	926	< 1	20	0	30	0	20	10	746	1 005
2010–11	825	926	< 1	20	< 1	30	< 1	20	10	826	1 006
2011–12	848	926	< 1	20	< 1	30	< 1	20	10	848	1 006
2012–13	871	926	< 1	20	< 1	30	< 1	20	10	871	1 006
2013–14	981	926	< 1	20	0	30	0	20	10	981	1 006
2014–15	900	926	< 1	20	0	30	< 1	20	10	901	1 006
2015–16	827	926	< 1	20	0	30	0	20	10	827	1 006
2016–17	835	926	< 1	20	0	30	0	20	10	836	1 006
2017–18	817	926	0	20	0	30	3	20	10	820	1 006
2018–19	857	926	< 1	20	< 1	30	0	20	10	857	1 006

Table 2 [continued]

Fishstock		GMU 1		GMU 2		GMU 3		GMU 7	GMU 10		
QMA (s)		1 & 9		2 & 8		3, 4, 5 & 6		7	10		Total
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	TACC	Landings	TACC
2019–20	821	926	< 1	20	0	30	< 1	20	10	821	1 006
2020–21	829	926	< 1	20	0	30	< 1	20	10	829	1 006

1.2 Recreational fisheries

Grey mullet is a popular recreational species particularly in the Auckland FMA. Information is available on the relative levels of commercial and amateur catch of this species in the Manukau Harbour and the lower Waikato River based on limited tagging work undertaken in 1987. Of the number of tags returned 38% were from amateur fishers, suggesting that recreational use of the resource was relatively high.

Telephone-diary surveys is 1993–94 (Teirney et al 1997), 1996 (Bradford 1998), and 2000 (Boyd et al 2004) were used to estimate the annual recreational catch from GMU 1 as 150, 106, and 100 t, respectively (Table 3). The Minister of Fisheries provided an allowance for customary harvest of 100 t beginning in 1998–99.

The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year (Wynne-Jones et al 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 3. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 3: Estimated number of grey mullet harvested by recreational fishers by Fishstock and survey year (Wynne-Jones et al 2014, 2019 for panel surveys), and the estimated Fishstock harvest (using mean weights from Hartill & Davey 2015 and Davey et al 2019).

Survey	Fishstock	Number	CV	Harvest range (t)	Harvest estimate (t)
1994 telephone-diary	GMU 1	170 000	0.19	90–210	150
1996 telephone-diary	GMU 1	110 000	0.25	80–130	106
2000 telephone-diary	GMU 1	110 000	0.33	68–136	102
2011–12 panel survey	GMU 1	29 622	0.41	-	27.3
2011–12 panel survey	GMU 2	1 531	0.53	-	2.8
2011–12 panel survey	GMU 3	5 252	0.93	-	4.8
2011–12 panel survey	GMU 7	191	0.73	-	0.2
2017–18 panel survey	GMU 1	38 088	0.62	-	29.9
2017–18 panel survey	GMU 2	2 400	0.63	-	1.9
2017–18 panel survey	GMU 3	25	1.00	-	<0.1
2017–18 panel survey	GMU 7	25 453	0.35	-	20.0

1.3 Customary non-commercial fisheries

No quantitative information is available on the current level of customary non-commercial take. The Minister of Fisheries provided an allowance for customary harvest of 100 t per annum beginning in 1998–99.

1.4 Illegal catch

Estimates of illegal catch are unknown but anecdotal evidence suggests 10–20% under-reporting is plausible. In the latest stock assessment, an annual under-reporting of 20% was assumed for the period before 1986 and 10% thereafter.

1.5 Other sources of mortality

No quantitative estimates are available regarding the impact of other sources of mortality on grey mullet stocks. Grey mullet principally occur in sheltered harbours and estuarine ecosystems. Some of these habitats are known to have suffered environmental degradation.

2. BIOLOGY

Grey mullet has a worldwide distribution, occurring commonly along coasts, in estuaries, and in lower river systems between latitudes of 42° N and 42° S. Overseas and New Zealand tagging studies indicate that movement patterns of adult grey mullet are complex. Some schools remain in one locality, while others appear to be on the move almost continuously. Recorded movements of tagged grey mullet of 160 km within a few weeks of release are not uncommon.

Females grow faster than males and attain a larger size. Both sexes mature at 3 years of age at an average size of 33 cm fork length (FL) for males and 35 cm FL for females. Maximum ages appear to be 12 to 14 years, with ages 4–8 making up the bulk of the commercial fishery.

Natural mortality was estimated from the equation $M = \log_e 100/\text{maximum age}$, where maximum age is the age to which 1% of the population survives in an unexploited stock. Using 15 years for the maximum age results in an estimate of $M = 0.33$. (Note: the maximum age of 15 years was obtained from an exploited population, so M is likely to be less than 0.33).

Grey mullet commonly occur in schools, which generally become larger and more prevalent in the spawning season. Spawning in northern New Zealand occurs during November to February. Females are highly fecund and may release up to 1 million eggs in a spawning event. It is likely that grey mullet spawn at sea, because running-ripe females have only been caught off coastal beaches or in offshore waters, and eggs and larvae are a component of the offshore coastal plankton at certain times of the year. Small post-larval grey mullet occur seasonally in estuaries, which serve as nursery grounds for juveniles.

Adult grey mullet typically feed on diatom algae and small invertebrates which are gulped along with surface scum or with detrital ooze and sifted by fine teeth and gill-rakers.

Biological parameters relevant to stock assessment are shown in Table 4.

Table 4: Estimates of biological parameters of grey mullet.

Fishstock							**Estimate**	**Source**
1. Natural mortality (M)								
GMU 1							0.33	NIWA (unpubl. data)
2. Weight = $a(\text{length})^b$ (Weight in g, length in cm fork length).								
	Both Sexes							
	a		b					
GMU 1	0.04236		2.826					Breen & McKenzie (unpublished)
3. Von Bertalanffy growth parameters								
	Females			Males				
	L_∞	k	t_0	L_∞	k	t_0		
GMU 1	40.1	0.587	1.3469	37.0	0.619	1.3257		Breen & McKenzie (unpublished)

3. STOCKS AND AREAS

There is little biological data to determine the level of sub stock separation within GMU 1. Results from a small scale tagging program in the Manukau Harbour and the Lower Waikato River indicated that there is fish movement between these two localities and also north along the west coast but the net level of movement cannot be ascertained. There is evidence in the CPUE data that GMU 1 may be comprised of six populations with low to moderate mixing between them (McKenzie 1997).

GMU 1 has been divided into two sub-stocks (east coast and west coast) for the purposes of fisheries stock assessment. The boundary between the two sub-stocks is assumed to be due north from North Cape.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

Standardised CPUE analyses were undertaken for the six largest catching areas in GMU 1. The analysis was based on setnet catch and effort data for the years 1990–91 to 2005–06 (McKenzie & Vaughan 2008), and updated to 2010–11 (Kendrick & Bentley 2012). However, internal and anecdotal evidence suggest that method is being misreported in these fisheries and that standardized CPUE is unlikely to reflect relative abundance for GMU. CPUE was therefore rejected as an index of relative abundance for all sub-areas within GMU 1.

4.2 Biomass estimates

West coast GMU 1

A stock assessment was undertaken for the west GMU 1 substock using a stochastic dynamic age-structured observation-error time series model (Breen & McKenzie 1998), but this did not prove to be robust and the results were rejected by the Working Group.

4.3 Yield estimates and projections

There is insufficient information with which to revise the yield estimates of either the West or East coast GMU 1 substocks. The *MCY* estimate derived in 1986 using the equation $MCY = cY_{AV}$ (Method 4) remains the accepted yield estimate for GMU 1.

Annual landings of grey mullet in the Auckland QMA for the period 1974–84 showed an increasing trend to a maximum in 1984. There were some fluctuations throughout this period. A general increase in fishing effort occurred during this time. Fishing effort between 1983–84 and 1985–86 appeared relatively constant, and catches during these years were averaged to estimate Y_{AV}. The constant '*c*' was set at 0.8. This is not consistent with the maximum observed age of 14 years, which equates with an estimate of $M = 0.33$ and $c = 0.7$. However, it is believed that they live to older ages in unexploited populations. Therefore, the accuracy of *MCY* derived for grey mullet is uncertain. The estimate of *MCY* for GMU 1 is shown in Table 5. *MCY* cannot be estimated for the other fish stocks.

Table 5: Estimate of *MCY* (t) rounded to the nearest 5 t.

Fishstock	QMA	Y_{AV}	*MCY*
GMU 1	Auckland 1 & 9	1 030	825

The level of risk to the stock by harvesting the population at the estimated *MCY* level cannot be determined. No estimates of current biomass, fishing mortality, or other information are available which would permit the estimation of *CAY*.

4.5 Other Factors

The minimum legal mesh size for use in the grey mullet fishery is 89 mm. However, fishers typically use mesh larger than 89 mm when fishing for grey mullet (Fisheries New Zealand data). There are no data available to compare the selectivity characteristics of different mesh sizes. It is possible that a significant fraction of the grey mullet stock comprising larger older fish is poorly selected by the fishery. If this is true then the von Bertalanffy parameter estimates, which are based on random samples from the 1997–98 setnet landings, are likely to be biased: L_∞ will be biased low, K biased high.

Grey mullet have been exploited by customary, commercial, and recreational fishers for over a hundred years. They are found predominantly in harbours and these environments have undergone considerable change over this period due to a range of anthropogenic sources. The impact of these changes on potential carrying capacity and productivity are not understood and this potentially has impacts on the yields of GMU.

Characterisation shows an overall trend away from set netting towards ring netting, and, within the nominal setnet method, a trend towards shorter nets; a trend that is not seen in flatfish setnet fisheries in the same areas. This suggests there have been systematic changes in fishing strategy that are not captured by the CELR form. Anecdotal information from interviews of net fishers suggests that fishers use the various net method codes interchangeably, and that the methods describe differences in strategy rather than in gear, from passive fishing to spotting and encircling schools of fish. While the passive form of set netting is an appropriate sampling tool, any contamination by ring net or similarly 'directed' fishing could mask trends in the abundance of the underlying population.

The Working Group agreed that given the misreporting issues and its consequences, that standardized CPUE is unlikely to reflect relative abundance for GMU.

5. STATUS OF THE STOCKS

Given the misreporting of method and its consequences, standardized CPUE is unlikely to reflect relative abundance for GMU. CPUE was therefore rejected as an index of relative abundance for all sub-areas within GMU 1.

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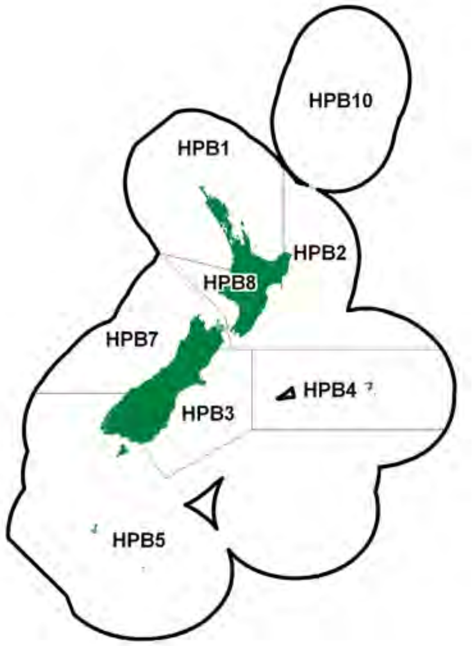
GROPER (HPB)

(*Polyprion oxygeneios*, *Polyprion americanus*)
Hāpuku, Moeone



1. FISHERY SUMMARY

1.1 Commercial fisheries

Both groper species, *Polyprion oxygeneios* (hāpuku) and *P. americanus* (bass), occur in shelf and slope waters of the New Zealand mainland and offshore islands, from the Kermadecs to the Auckland Islands. The groper fishery takes both species, but in different proportions by region, depth, fishing method and season, and these have changed over time. Reported landings generally do not distinguish between species, and published data combine them. In earlier years, bluenose (*Hyperoglyphe antarctica*) landings were sometimes also combined with groper. In this document, groper is used as collective term for hāpuku and bass. Historical estimated and recent reported groper landings and TACCs are shown in Tables 1, 2 and 3, while Figure 1 shows the historical and recent landings and TACC values for the main groper stocks.

Table 1: Reported total New Zealand landings (t) of groper from 1948 to 1983.

Year	Landings	Year	Landings	Year	Landings	Year	Landings
1948	1 665	1957	1 368	1966	1 222	1975	1 422
1949	1 969	1958	1 532	1967	1 314	1976	1 512
1950	1 709	1959	1 310	1968	1 073	1977	1 942
1951	1 396	1960	1 223	1969	1 122	1978	1 488
1952	1 430	1961	1 203	1970	1 499	1979	2 078
1953	1 403	1962	1 173	1971	1 346	1980	2 435
1954	1 364	1963	1 194	1972	1 120	1981	2 379
1955	1 305	1964	1 370	1973	1 312	1982	2 218
1956	1 399	1965	1 249	1974	1 393	1983	2 511

Reported foreign catches are included from 1974.
Source: Fisheries data.

The main fishery comprises a number of domestic fishers working small to medium sized vessels - longliners, setnetters and trawlers, at a variety of depths (according to method) out to 500 m (Paul 2002a). Over 90% of early (to 1950) total groper catches were taken by longline. Trawl catches rose from 5–10% during this period to 20–30% by the late 1970s. A setnet fishery developed in the late 1970s and early 1980s, mainly at Kaikoura, taking 14% in 1983 and then subsequently declining. From 1950 to the mid-1980s, line-fishing took 70–80% of the catch. After the introduction of the QMS in 1986, the proportion of the catch taken by lines appeared to drop.

The Cook Strait region has always supported the main groper fishery, followed by the Canterbury Bight; both show the same slow decline from 1949 to 1986 (equivalent regional data from subsequent years are not available). Northland, Bay of Plenty and Hawke Bay fisheries developed at different rates during the 1960s and 1970s. In most other areas, the groper fishery has been small and/or variable.

The first recorded landings of about 1 500 t in 1936 were typical of the range of catches (1000–2000 t) from then until 1978. After a decrease during the war when effort was restricted, landings in the total fishery slowly declined from almost 2000 t in 1949 to about 1300 t in the mid-1970s. They then increased sharply to 2700 t in 1983–84 (Tables 1 and 2). Figure 1 shows the historical landings and TACC values for the main HPB stocks.

Table 2: Reported landings (t) for the main QMAs from 1931 to 1982.

Year	HPB 1	HPB 2	HPB 3	HPB 4	HPB 5	HPB 7	HPB 8
1931–32	231	0	207	2	130	13	13
1932–33	201	276	242	0	91	98	53
1933–34	198	330	173	25	99	127	53
1934–35	204	304	212	57	115	106	56
1935–36	179	201	146	70	33	109	33
1936–37	129	445	115	12	29	156	50
1937–38	119	523	315	15	29	148	52
1938–39	90	621	479	8	75	156	50
1939–40	118	502	409	12	59	155	43
1940–41	120	444	286	9	54	142	41
1941–42	80	450	302	10	46	150	44
1942–43	69	287	315	9	44	115	35
1943–44	59	316	271	8	42	112	42
1944	55	332	286	9	60	188	117
1945	106	311	271	3	65	173	128
1946	154	326	409	7	83	229	190
1947	98	401	563	5	142	250	175
1948	111	450	526	11	140	275	151
1949	174	498	547	7	142	364	236
1950	141	423	555	9	116	281	184
1951	104	353	381	19	102	267	171
1952	112	368	373	35	100	281	162
1953	105	349	431	33	96	252	137
1954	156	355	397	32	77	235	112
1955	142	351	419	26	82	197	88
1956	106	404	439	32	114	227	77
1957	133	380	419	23	92	246	76
1958	115	473	458	30	96	250	109
1959	147	406	350	54	68	198	87
1960	122	394	331	48	100	150	77
1961	135	369	348	50	82	139	80
1962	163	355	298	40	101	142	75
1963	197	315	321	56	75	159	71
1964	224	397	365	41	76	193	74
1965	212	368	325	68	48	176	52
1966	213	415	315	4	49	163	62
1967	229	448	275	0	49	228	85
1968	139	357	264	0	67	176	70
1969	197	454	220	0	30	138	84
1970	259	670	239	2	54	175	97
1971	191	562	289	4	41	181	78
1972	401	370	188	0	29	99	33
1973	419	481	215	0	30	136	32
1974	356	457	208	2	43	140	72
1975	227	315	213	18	55	379	62
1976	183	220	350	107	101	445	37
1977	277	301	265	87	47	575	113
1978	348	470	194	10	59	280	67
1979	620	487	355	147	113	276	71
1980	956	376	414	40	199	315	105
1981	693	373	457	59	218	381	166
1982	957	336	402	26	133	256	46

Notes:

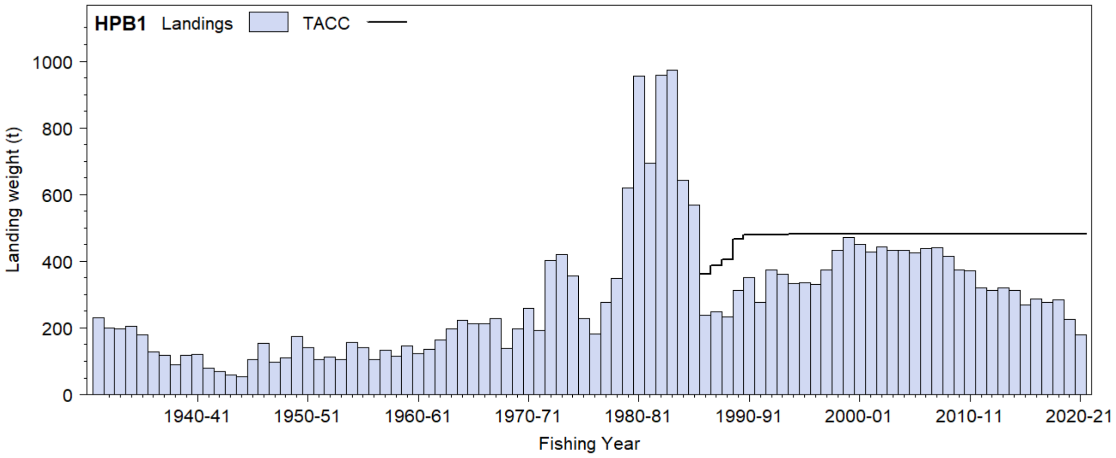
1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: Data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings.

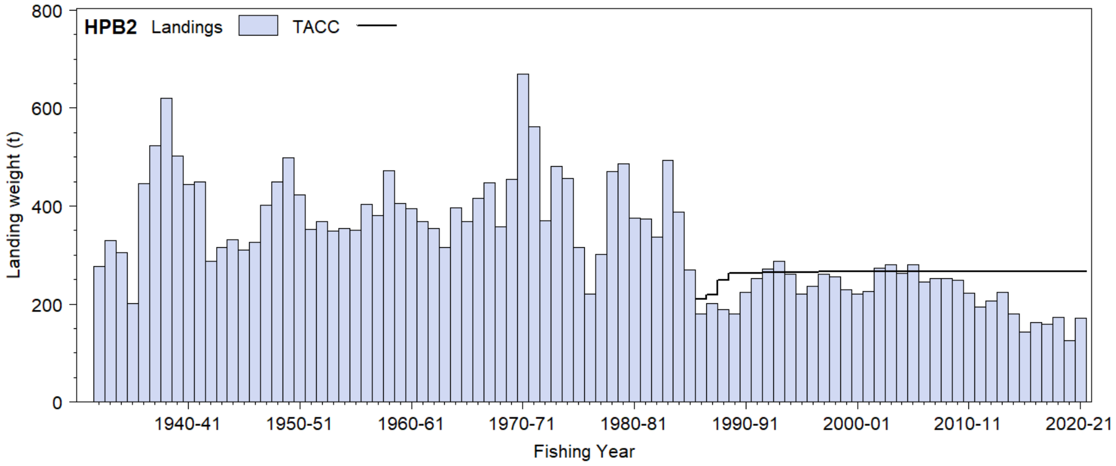
Table 3: Reported landings (t) of groper by Fishstock from 1983–84 to present and actual TACCs (t) from 1986–87 to present. QMS data from 1986–present. * FSU data, includes exploratory permit catches.

Fishstock	HPB 1		HPB 2		HPB 3		HPB 4		HPB 5		HPB 7		HPB 8		HPB 10		Total	
FMA (s)	1 & 9		2		3		4		5 & 6		7		8		10			
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	974	-	493	-	505	-	55	-	395	-	174	-	46	-	0	-	2 698	-
1984–85*	642	-	388	-	418	-	52	-	228	-	207	-	33	-	0	-	2 039	-
1985–86*	569	-	270	-	391	-	53	-	126	-	199	-	25	-	0	-	1 697	-
1986–87	238	360	179	210	260	270	42	300	131	410	149	210	35	60	0	10	1 036	1 830
1987–88	248	388	202	219	268	286	43	315	91	414	158	215	66	76	0	10	1 076	1 923
1988–89	231	405	187	248	259	294	49	315	70	425	132	226	39	78	1	10	968	2 001
1989–90	310	465	179	263	283	318	40	322	127	430	119	229	43	80	0	10	1 098	2 117
1990–91	350	480	225	263	311	326	77	323	120	436	128	235	48	80	23#	10	1 282	2 153
1991–92	277	480	252	263	298	326	58	323	112	446	175	235	50	80	83#	10	1 319	2 163
1992–93	375	480	273	264	299	327	68	323	128	446	186	236	62	80	22#	10	1 405	2 165
1993–94	363	480	287	264	306	330	90	323	147	446	193	236	69	80	0	10	1 455	2 167
1994–95	334	481	259	264	274	335	149	323	161	451	192	236	68	80	0	10	1 437	2 179
1995–96	335	481	214	264	321	335	173	323	144	451	214	236	78	80	0	10	1 479	2 179
1996–97	331	481	234	264	301	335	131	323	149	451	186	236	71	80	15	10	1 418	2 179
1997–98	375	481	260	266	329	335	88	323	91	451	147	236	60	80	33#	10	1 406	2 181
1998–99	433	481	256	266	348	335	121	323	97	451	218	236	78	80	3#	10	1 562	2 181
1999–00	471	481	229	266	385	335	66	323	169	451	165	236	65	80	0#	10	1 561	2 181
2000–01	450	481	220	266	381	335	45	323	188	451	171	236	64	80	0#	10	1 519	2 181
2001–02	427	481	226	266	343	335	82	323	169	451	204	236	62	80	< 1	10	1 514	2 181
2002–03	442	481	273	266	350	335	79	323	212	451	233	236	72	80	0	10	1 661	2 181
2003–04	433	481	281	266	335	335	87	323	166	451	239	236	66	80	0	10	1 607	2 181
2004–05	433	481	263	266	371	335	147	323	208	451	240	236	80	80	0	10	1 742	2 181
2005–06	425	481	280	266	406	335	185	323	167	451	207	236	56	80	0	10	1 728	2 181
2006–07	483	481	245	266	394	335	222	323	157	451	206	236	66	80	0	10	1 773	2 181
2007–08	439	481	253	266	341	335	241	323	138	451	195	236	44	80	0	10	1 651	2 181
2008–09	415	481	253	266	391	335	138	323	153	451	207	236	71	80	0	10	1 628	2 181
2009–10	374	481	249	266	358	335	213	323	152	451	221	236	66	80	0	10	1 633	2 181
2010–11	371	481	222	266	322	335	231	323	128	451	191	236	80	80	0	10	1 543	2 181
2011–12	312	481	193	266	336	335	265	323	158	451	173	236	61	80	0	10	1 187	2 181
2012–13	314	481	206	266	337	335	156	323	140	451	209	236	75	80	0	10	1 436	2 181
2013–14	319	481	224	266	301	335	169	323	143	451	182	236	63	80	0	10	1 401	2 181
2014–15	314	481	180	266	280	335	156	323	126	451	132	236	67	80	0	10	1 254	2 181
2015–16	270	481	143	266	315	335	144	323	143	451	148	236	73	80	0	10	1 236	2 181
2016–17	287	481	162	266	342	335	152	323	156	451	141	236	69	80	0	10	1 309	2 181
2017–18	276	481	159	266	344	335	142	323	158	451	110	236	61	80	0	10	1 250	2 181
2018–19	283	481	173	266	347	335	137	323	167	451	105	236	47	80	0	10	1 260	2 182
2019–20	226	481	126	266	299	335	181	323	161	451	79	236	33	80	0	10	1 105	2 182
2020–21	180	481	170	266	284	335	197	323	195	451	78	236	43	80	0	10	1 147	2 182

Landings and TACCs for all Fishstocks are given in Table 3. Total landings of groper were relatively stable throughout the mid-1990s, remaining below 1500 t until 1998–99. From 1999–2000 onwards, landings have generally ranged between 1200 t and 1700 t. Although the TACC in HPB 3 has been exceeded in some years, landings have generally remained within the quotas for individual Fishstocks and have never exceeded the total TACC.

For the 1991–92 fishing year the conversion factor for headed and gutted groper was increased from 1.40 to 1.45, for fish landed in this state (about 75% of the total), which resulted in a reduction in removals from the stock of 3.5% for the same nominal quota.





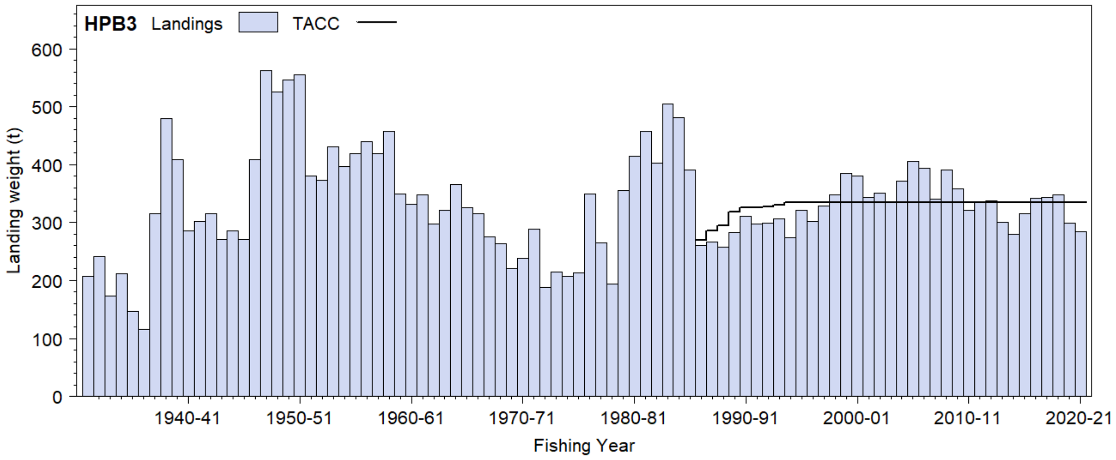


Figure 1: Total reported landings and TACC for the seven main HPB stocks. From top to bottom: HPB 1 (Auckland), HPB 2 (Central East) and HPB 3 (South East Coast) [Continued on the next page].

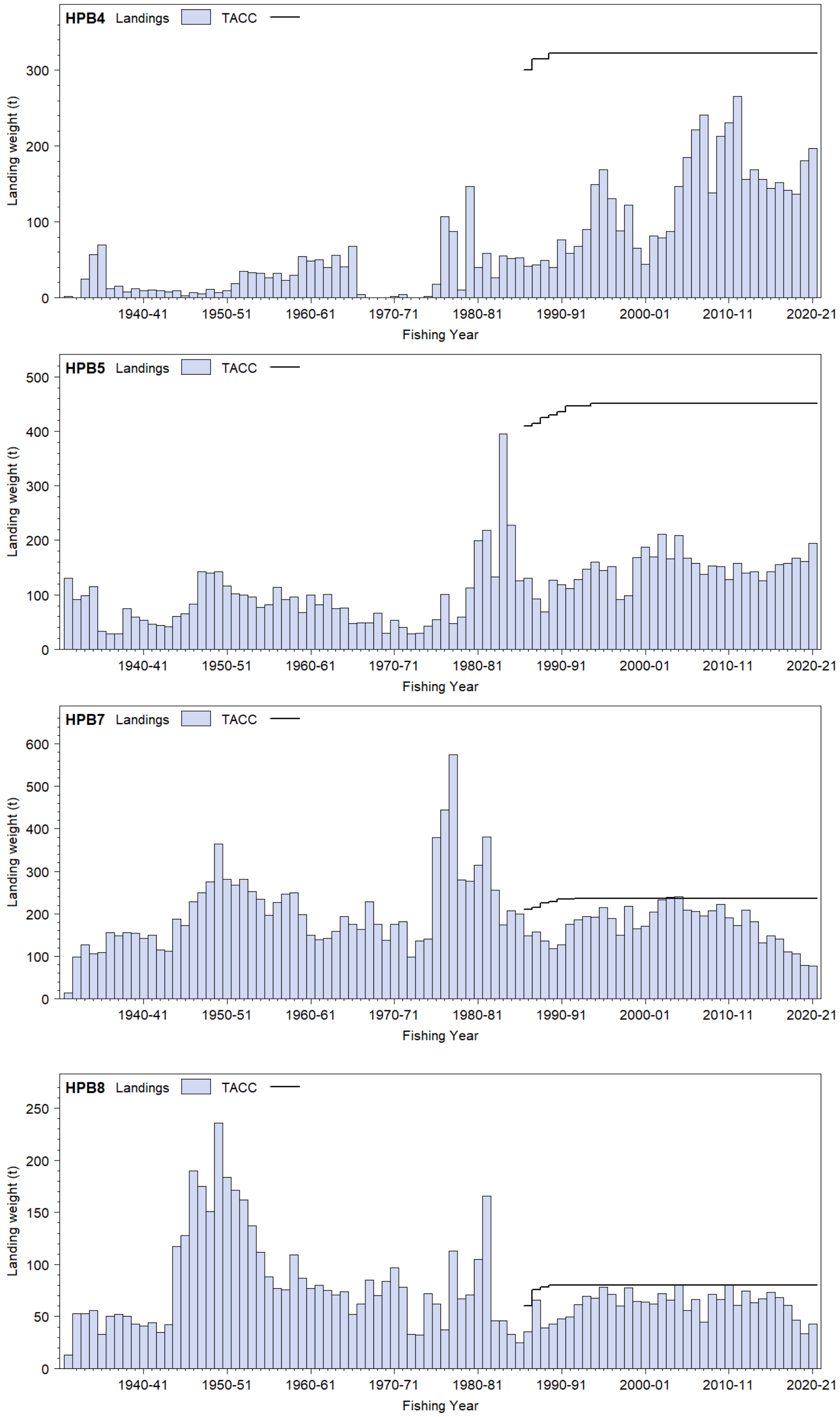


Figure 1 [Continued]: Total reported landings and TACC for the seven main HPB stocks. From top to bottom: HPB 4 (Chatham Rise), HPB 5 (Southland, Sub-Antarctic), HPB 7 (Challenger), and HPB 8 (Central).

1.2 Recreational fisheries

Groper are taken by handline and setline, and to a lesser extent by setnets. Recreational catch estimates from surveys undertaken in the 1990s are given in Tables 4–6.

Table 4: Estimated number of groper harvested by recreational fishers by Fishstock and survey, the corresponding estimated survey harvest and the estimated Fishstock harvest. Surveys were carried out in different years in the MAF Fisheries regions: South in 1991–92, Central in 1992–93 and North in 1993–94 (Teirney et al 1997).

		Total		
Fishstock	**Survey**	**Number**	**CV (%)**	**Survey harvest (t)**
HPB 1	North	22 000	17	190–220
HPB 2	North	1 000	-	5–10
HPB 2	Central	10 000	37	45–85
HPB 3	Central	3 000	-	10–30
HPB 3	South	4 000	40	10–30
HPB 5	Central	7 000	36	20–40
HPB 5	South	2 000	-	5–15
HPB 7	Central	12 000	40	45–115
HPB 8	Central	1 000	-	5−10

Table 5: Results of a national diary survey of recreational fishers in 1996, indicating estimated number of groper harvested by recreational fishers by Fishstock and the corresponding harvest tonnage. The mean weights used to convert numbers to catch weight are considered the best available estimates. Estimated harvest is also presented as a range to reflect the uncertainty in the estimates (from Bradford 1998).

Fishstock	**Number caught**	**CV (%)**	**Harvest range (t)**	**Point Estimate (t)**
HPB 1	11 000	17	40–60	49
HPB 2	23 000	22	75–125	100
HPB 3	4 000	-	-	-
HPB 5	2 000	-	-	-
HPB 7	9 000	-	-	-
HPB 8	< 500	-	-	-

Table 6: Results of the 1999–2000 national diary survey of recreational fishers (Dec 1999–Nov 2000). Estimated number of groper harvested by recreational fishers by Fishstock, and the corresponding harvest tonnage. Estimated harvest is presented as a range to reflect the uncertainty in the estimates (Boyd & Reilly 2002).

Fishstock	**Number caught**	**CV (%)**	**Harvest range (t)**	**Point estimate (t)**
HPB 1	60 000	39	209–476	342
HPB 2	56 000	33	307–608	457
HPB 3	52 000	50	97–293	195
HPB 5	6 000	70	14–80	47
HPB 7	17 000	37	79–172	125
HPB 8	2 000	67	6–32	19

The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year (Wynne-Jones et al 2019). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 7. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 7: Recreational harvest estimates for groper stocks (Wynne-Jones et al 2014, 2019). Mean fish weights were obtained from boat ramp surveys (Hartill & Davey 2015, Davey et al 2019).

Stock	Year	Method	Number of fish	Total weight (t)	CV
HPB 1	2011–12	Panel survey	14 264	83.5	0.37
HPB 2	2011–12	Panel survey	10 179	59.6	0.28
HPB 3	2011–12	Panel survey	6 383	37.4	0.31
HPB 5	2011–12	Panel survey	138	0.8	1.00
HPB 7	2011–12	Panel survey	2 163	12.7	0.41
HPB 8	2011–12	Panel survey	4 376	25.6	0.54
HPB 1	2017–18	Panel survey	12 250	73.1	0.21
HPB 2	2017–18	Panel survey	9 175	54.7	0.29
HPB 3	2017–18	Panel survey	8 474	50.5	0.36
HPB 5	2017–18	Panel survey	1 389	8.3	0.42
HPB 7	2017–18	Panel survey	5 937	35.4	0.35
HPB 8	2017–18	Panel survey	1 047	6.2	0.49

1.3 Customary non-commercial fisheries

Groper (hāpuku and bass) were certainly taken by early Maori, and would have been available in greater numbers at shallower depths than is the case at present. Traditional groper grounds are known in several regions. Quantitative information on the current level of customary non-commercial catch is not available.

1.4 Illegal catch

Quantitative information on the level of illegal catch is not available.

1.5 Other sources of mortality

None are apparent.

2. BIOLOGY

Both hāpuku and bass are widely distributed around New Zealand, generally over rough ground from the central shelf (about 100 m) to the shelf edge and down the upper slope. Their lower limits are ill-defined, but hāpuku extends to at least 300 m and bass to 500 m.

Hāpuku mature sexually between 10 and 13 years old and may live in excess of 60 years (Francis et al 1999). Cook Strait hāpuku mature over a wide size range, with the size at 50% maturity at 80–85 cm total length (TL) and 85–90 cm TL for males and females respectively (Paul 2002d). Spawning occurs during winter, anecdotally earlier in the north of New Zealand than in the south, but running ripe fish are seldom caught and spawning grounds are unknown. The smallest juveniles are virtually unknown, but are mottled, pelagic and epi-pelagic, perhaps schooling in association with drifting weed.

The size range of commercially caught hāpuku is 50–140 cm TL, with a broad mode between 70 and 100 cm TL. Bass are slightly larger at 60–150 cm TL, with a mode at 80–110 cm TL, but much bulkier and heavier at equivalent lengths.

There appear to be some regional differences in the size structure of populations. Trawl-caught hāpuku on the Stewart-Snares Shelf are mainly 50–80 cm, modal length 60 cm, and therefore juveniles. Trawl-caught hāpuku on the Chatham Rise are slightly larger, 50–100 cm, modal length 70 cm, with those on the shelf around the islands having their main mode at 60–75 cm; most of these fish are also juveniles. These offshore regions may be important nurseries.

Both groper species are assumed to be long-lived. Natural mortality in the past was assumed to be 0.2, however, a study of a South American (Juan Fernandez) population suggested that it may be lower (0.13–0.16) (Pavez & Oyarzun 1985). Furthermore, preliminary unvalidated ageing in New Zealand has indicated that maximum age may be greater than 40 years, and that *M* may be 0.1 or less (Francis et al 1999). This value of *M* will be retained until clearer information becomes available from ageing. Parker et al (2011) compared regional differences in the catch composition from observer collected data. This report noted that the proportion of age 10+ fish in the catch in the Kermadec and Northeastern regions (FMA 2) was greater than that of Southland.

Migration patterns are also little known, but are probably related to spawning. Tagging of mostly immature fish in Cook Strait has shown a high level of site fidelity, but about 5% of these fish have moved up to 160 km north and south. Other information is largely anecdotal and speculative. It is known that good fishing grounds, particularly pinnacles and reefs or ledges, can be quickly fished out and take some time to recover, suggesting a high level of residency (except, perhaps, for during the spawning season). On the other hand, trawlers sometimes catch groper on the flat and clear seafloor, and it is not known whether this represents their normal habitat, whether they are simply dispersing by travelling from one rough ground to another, or whether they are on a purposeful spawning migration.

Hāpuku and bass prey on a wide variety of fish and invertebrates, including red cod, tarakihi, blue cod, hoki and squid. In Cook Strait, they are preyed upon by sperm whales, although probably neither heavily nor selectively. Biological parameters relevant to stock assessment are shown in Table 8.

Table 8: Estimates of biological parameters of groper.

Fishstock	Estimate		Source
1. Natural mortality (*M*)			
All	$M = 0.1$		Francis et al (1999)
2. Weight = a (length)^b (Weight in g, length in cm fork length)			
	Both sexes combined		
BAS 1	a = 0.2734	b = 2.382	Johnston (1993)
HAP 1	a = 0.0142	b = 3.003	Johnston (1993)
HAP 2	a = 0.0242	b = 2.867	Johnston (1993)
HAP 7, 8	a = 0.0142	b = 2.998	Johnston (1983)

(HAP = hāpuku, BAS = bass groper)

3. STOCKS AND AREAS

Tagging studies reveal considerable mixing of hāpuku between Otago, South Canterbury and Cook Strait. Fishstock boundaries in Cook Strait separate Cook Strait hāpuku into three separate "stocks" (HPB 2, HPB 7, and HPB 8), none of which include Otago-Canterbury fish (HPB 3). Current Fishstock boundaries appear inappropriate for the management of Cook Strait and South Island hāpuku. Current stock boundaries are based on QMAs and do not reflect biological stocks. Existing data cannot describe the stock structure of New Zealand groper (Paul 2002b). Electrophoretic studies suggest that separate stocks of hāpuku could occur. However, the genetic heterogeneity of Cook Strait hāpuku, seasonal movements of hāpuku through this area, moderately long-distance movements of some tagged hāpuku, the presence of both species on open ground and the eventual recovery of heavily exploited reefs, suggest that either each stock is moderately mobile or that there is essentially only one stock (of each species) with some small geographic or temporal genetic differences.

4. STOCK ASSESSMENT

Yield estimates for HPB 4 and HPB 5 have been removed because the previous method used is now considered obsolete. The yield estimates for the other Fishstocks have been revised based on a revision of the estimate of *M*.

4.1 Estimates of fishery parameters and abundance

Estimates of fishery parameters and abundance are not available. Paul (2002c) found that CPUE indices could not be developed for hāpuku and bass either separately or in combination.

4.2 Biomass estimates

Estimates of current and reference biomass are not available. Data for hāpuku from the East Coast South Island trawl surveys have moderate CVs (average over all years = 28.17; range 19–35) and although the survey does not extend to the entire habitat range, the survey may be monitoring settled juveniles (Figure 2).

4.3 Yield estimates and projections

Current biomass cannot be estimated, so *CAY* cannot be determined.

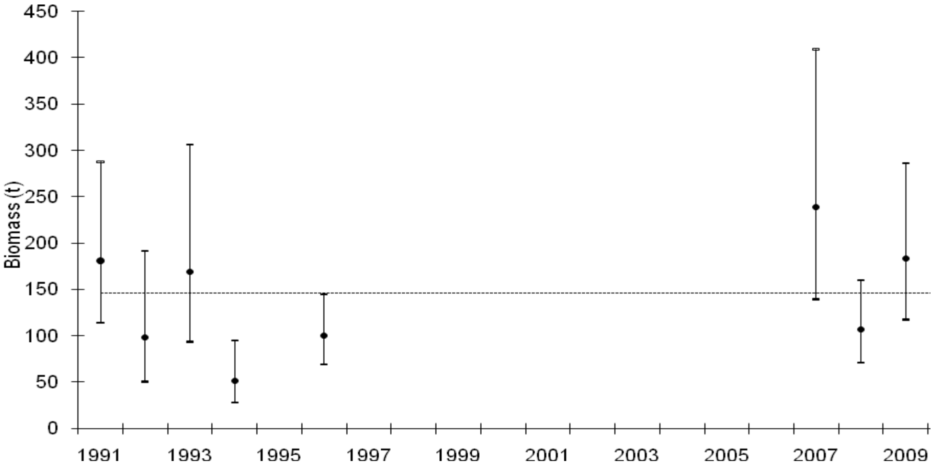


Figure 2: Biomass estimates ±95% CI (estimated from survey CVs assuming a lognormal distribution) and the time series mean (dotted line) from the East Coast South Island trawl survey.

4.4 Other factors

Although no distinct stocks of either groper species have been identified, results from trawl surveys suggest that there are reasonably large but dispersed populations over the Stewart-Snares Shelf and the Chatham Rise. The relationship between these "offshore" and the more traditionally fished "inshore" populations is not known due to the lack of information on groper movements. Little is known of the species composition and population structure of groper on the rough bottom shelf and ridges extending northwards from New Zealand.

The relative quantity of groper taken as target and non-target catch has not been investigated, but is likely to have varied both spatially and temporally. Groper have been taken by the foreign licensed, chartered and New Zealand-owned trawlers working offshore grounds; although being regarded as a small bycatch they were not accurately reported before 1986. The *MCY* may therefore be under-estimated.

There are three regions where the groper catch has been substantially lower than the TACC.

HPB 1 - Three features of the fishery appear to explain the under-catch of the TACC. (i) A considerable part of the fishing effort which had generated the high catches in the early 1980s left the fishery. (ii) The allocated quota is widely distributed in small units among fishers who appear to use only a modest proportion of it to cover bycatch. (iii) The fishers who hold larger amounts of quota generally also use only a proportion of it to land high-quality fish (in contrast to the earlier bulk landings of lower-quality fish).

HPB 4 and 5 - The original yield estimates made before the introduction of the QMS and the original TAC were based on trawl surveys, not catch histories. The TACCs for these Fishstocks can only be economically targeted around the Chatham Islands in HPB 4, and a few localities in HPB 5. Elsewhere, it is used to cover a small bycatch from trawlers. A moderate quantity of quota is held, unused, by companies which would require it should they resume target fishing for ling and associated species.

5. STATUS OF THE STOCKS

No estimates of current biomass are available. An estimate of B_{AV} is available for HPB 5.

It is not known if current catches or the TACCs are sustainable or at levels that will allow the stocks to move towards a size that will support the maximum sustainable yield.

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HAKE (HAK)

(Merluccius australis)

Tiikati, kehe

1. FISHERY SUMMARY

1.1 Commercial fisheries

Hake was introduced into the Quota Management System on 1 October 1986. Hake are widely distributed throughout the middle depths of the New Zealand EEZ, mostly south of 40° S. Adults are mainly distributed from 250 to 800 m, but some have been found as deep as 1200 m, whereas juveniles (0+) are found in inshore regions shallower than 250 m. Hake are taken mainly by large trawlers, often as bycatch in hoki target fisheries, although hake target fisheries do exist.

The largest fishery has been off the west coast of the South Island (WCSI, HAK 7) with the highest catch (17 000 t) recorded in 1977 (Table 1, catches not allocated to Fishstock), immediately before the establishment of the EEZ. The WCSI hake fishery has generally consisted of bycatch in the much larger hoki fishery, but it has undergone several changes over time (Dunn et al in prep). These include changes to the TACCs of both hake and hoki, and changes in fishing practices such as gear used, tow duration, and strategies to limit hake bycatch. In some years there has been a hake target fishery in September after the peak of the hoki fishery is over; more than 2000 t of hake were taken in this target fishery during September 1993 (Ballara 2018). High bycatch levels of hake early in the fishing season have also occurred in some years (Ballara 2018). From 1 October 2005 the TACC for HAK 7 was increased to 7700 t (Table 2) within an overall TAC of 7777 t. The TACC was reduced to 5064 t in 2017–18 and then again to 2272 t in 2019–20 (out of a total TACC for the EEZ of 7783 t) in response to changes in estimated stock status.

On the Chatham Rise and in the Sub-Antarctic, hake have been caught mainly as bycatch by trawlers targeting hoki (Ballara 2018). However, significant targeting for hake has occurred in both areas, particularly in Statistical Area 404 (HAK 4), and around the Norwegian Hole between the Stewart-Snares shelf and the Auckland Islands Shelf in the Sub-Antarctic. Increases in TACCs from 2610 t to 3500 t in HAK 1 and from 1000 t to 3500 t in HAK 4 from 1991–92 allowed the fleet to increase their reported landings of hake from these fish stocks. TACCs were further increased to 3632 t in 1994–95 and to 3701 t in HAK 1 in 2001–02 and have remained at that level since. Reported catches rose over several years to the level of the new TACCs in both HAK 1 and HAK 4. In HAK 1, annual catches remained relatively steady (generally between 3000 t and 4000 t) up to 2004–05 but were generally less than 3000 t from 2005–06 until 2009–10, and generally less than 2000 t since. The reduction in catch of hake in the Sub-Antarctic has coincided with a reduction in targeting of hake and reduced spatial extent of the hoki fishery in the Sub-Antarctic from about 2004–05.

From 2004–05, the TACC for HAK 4 was reduced from 3500 t to 1800 t. Landings from HAK 4 have declined from over 3000 t in 1998–99 to between about 130–300 t since 2009–10. An unusually large aggregation of possibly mature or maturing hake was fished on the western Chatham Rise, west of the Mernoo Bank (HAK 1) in October 2004. Over a four-week period, about 2000 t of hake were caught from that area. In previous years, catches from this area have typically been between 100 t and 800 t. These unusually high catches on the western Chatham Rise resulted in the TACC for HAK 1 being over-caught during the 2004–05 fishing year (4795 t against a TACC of 3701 t) and a substantial increase in the landings (more than 3700 t) associated with the Chatham Rise. Fishing on aggregated schools in the same area also occurred during October–November 2008 and 2010 (Ballara 2015).

Reported catches from 1975 to 1987–88 are shown in Table 1. Reported landings for each Fishstock since 1983–84 and TACCs since 1986–87 are shown in Table 2. Figure 1 shows the historical landings and TACC values for the main hake stocks.

Table 1: Reported hake catches (t) from 1975 to 1987–88. Data from 1975 to 1983 from MAF; data from 1983–84 to 1985–86 from FSU; data from 1986–87 to 1987–88 from QMS.

	New Zealand			Foreign licensed				
Fishing year	**Domestic**	**Chartered**	**Total**	**Japan**	**Korea**	**USSR**	**Total**	**Total**
1975 [1]	0	0	0	382	0	0	382	382
1976 [1]	0	0	0	5 474	0	300	5 774	5 774
1977 [1]	0	0	0	12 482	5 784	1 200	19 466	19 466
1978–79 [2]	0	3	3	398	308	585	1 291	1 294
1979–80 [2]	0	5 283	5 283	293	0	134	427	5 710
1980–81 [2]				No data available				
1981–82 [2]	0	3 513	3 513	268	9	44	321	3 834
1982–83 [2]	38	2 107	2 145	203	53	0	255	2 400
1983 [3]	2	1 006	1 008	382	67	2	451	1 459
1983–84 [4]	196	1 212	1 408	522	76	5	603	2 011
1984–85 [4]	265	1 318	1 583	400	35	16	451	2 034
1985–86 [4]	241	2 104	2 345	465	52	13	530	2 875
1986–87 [4]	229	3 666	3 895	234	1	1	236	4 131
1987–88 [4]	122	4 334	4 456	231	1	1	233	4 689

[1] Calendar year.
[2] April 1 to March 31.
[3] April 1 to September 30.
[4] October 1 to September 30.

Table 2: Reported landings (t) of hake by Fishstock from 1983–84 to present and actual TACCs (t) for 1986–87 to present. FSU data from 1984–1986; QMS data from 1986 to the present. [Continued on next page]

Fish stock	HAK 1		HAK 4		HAK 7		HAK 10			
FMA(s)	1, 2, 3, 5, 6, 8 & 9		4		7		10		Total	
	Landings	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**
1983–84 [1]	886	–	180	–	945	–	0	–	2 011	–
1984–85 [1]	670	–	399	–	965	–	0	–	2 034	–
1985–86 [1]	1 047	–	133	–	1 695	–	0	–	2 875	–
1986–87	1 022	2 500	200	1 000	2 909	3 000	0	10	4 131	6 510
1987–88	1 381	2 500	288	1 000	3 019	3 000	0	10	4 689	6 510
1988–89	1 487	2 513	554	1 000	6 835	3 004	0	10	8 876	6 527
1989–90	2 115	2 610	763	1 000	4 903	3 310	0	10	7 781	6 930
1990–91	2 603	2 610	743	1 000	6 148	3 310	0	10	9 494	6 930
1991–92	3 156	3 500	2 013	3 500	3 027	6 770	0	10	8 196	13 780
1992–93	3 525	3 501	2 546	3 500	7 154	6 835	0	10	13 225	13 846
1993–94	1 803	3 501	2 587	3 500	2 974	6 835	0	10	7 364	13 847
1994–95	2 572	3 632	3 369	3 500	8 841	6 855	0	10	14 782	13 997
1995–96	3 956	3 632	3 466	3 500	8 678	6 855	0	10	16 100	13 997
1996–97	3 534	3 632	3 524	3 500	6 118	6 855	0	10	13 176	13 997
1997–98	3 810	3 632	3 524	3 500	7 416	6 855	0	10	14 749	13 997
1998–99	3 845	3 632	3 324	3 500	8 165	6 855	0	10	15 334	13 997
1999–00	3 899	3 632	2 803	3 500	6 898	6 855	0	10	13 599	13 997
2000–01	3 429	3 632	2 784	3 500	7 698	6 855	0	10	14 111	13 997
2001–02	2 870	3 701	1 424	3 500	7 519	6 855	0	10	11 813	14 066
2002–03	3 336	3 701	811	3 500	7 433	6 855	0	10	11 580	14 066
2003–04	3 466	3 701	2 275	3 500	7 945	6 855	0	10	13 686	14 066
2004–05	4 795	3 701	1 264	1 800	7 317	6 855	0	10	13 377	12 366
2005–06	2 742	3 701	305	1 800	6 905	7 700	0	10	9 952	13 211
2006–07	2 025	3 701	899	1 800	7 668	7 700	0	10	10 592	13 211
2007–08	2 445	3 701	865	1 800	2 620	7 700	0	10	5 930	13 211
2008–09	3 415	3 701	856	1 800	5 954	7 700	0	10	10 226	13 211
2009–10	2 156	3 701	208	1 800	2 352	7 700	0	10	4 716	13 211
2010–11	1 904	3 701	179	1 800	3 754	7 700	0	10	5 837	13 211
2011–12	1 948	3 701	161	1 800	4 459	7 700	0	10	6 568	13 211
2012–13	2 079	3 701	177	1 800	5 434	7 700	0	10	7 690	13 211
2013–14	1 883	3 701	168	1 800	3 642	7 700	0	10	5 693	13 211

Table 2 [Continued]:

Fish stock FMA(s)	HAK 1 1, 2, 3, 5, 6, 8 & 9		HAK 4 4		HAK 7 7		HAK 10 10		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
2014–15	1 725	3 701	304	1 800	6 219	7 700	0	10	8 248	13 211
2015–16	1 584	3 701	274	1 800	2 864	7 700	0	10	4 722	13 211
2016–17	1 175	3 701	268	1 800	4 701	7 700	0	10	6 144	13 211
2017–18	1 350	3 701	267	1 800	3 086	5 064	0	10	4 702	10 575
2018–19	896	3 701	183	1 800	1 563	5 064	0	10	2 642	10 575
2019–20	1 062	3 701	137	1 800	2 063	2 272	0	10	3 262	7 783
2020–21	1 503	3 701	207	1 800	1 368	2 272	0	10	3 077	7 783

[1] FSU data

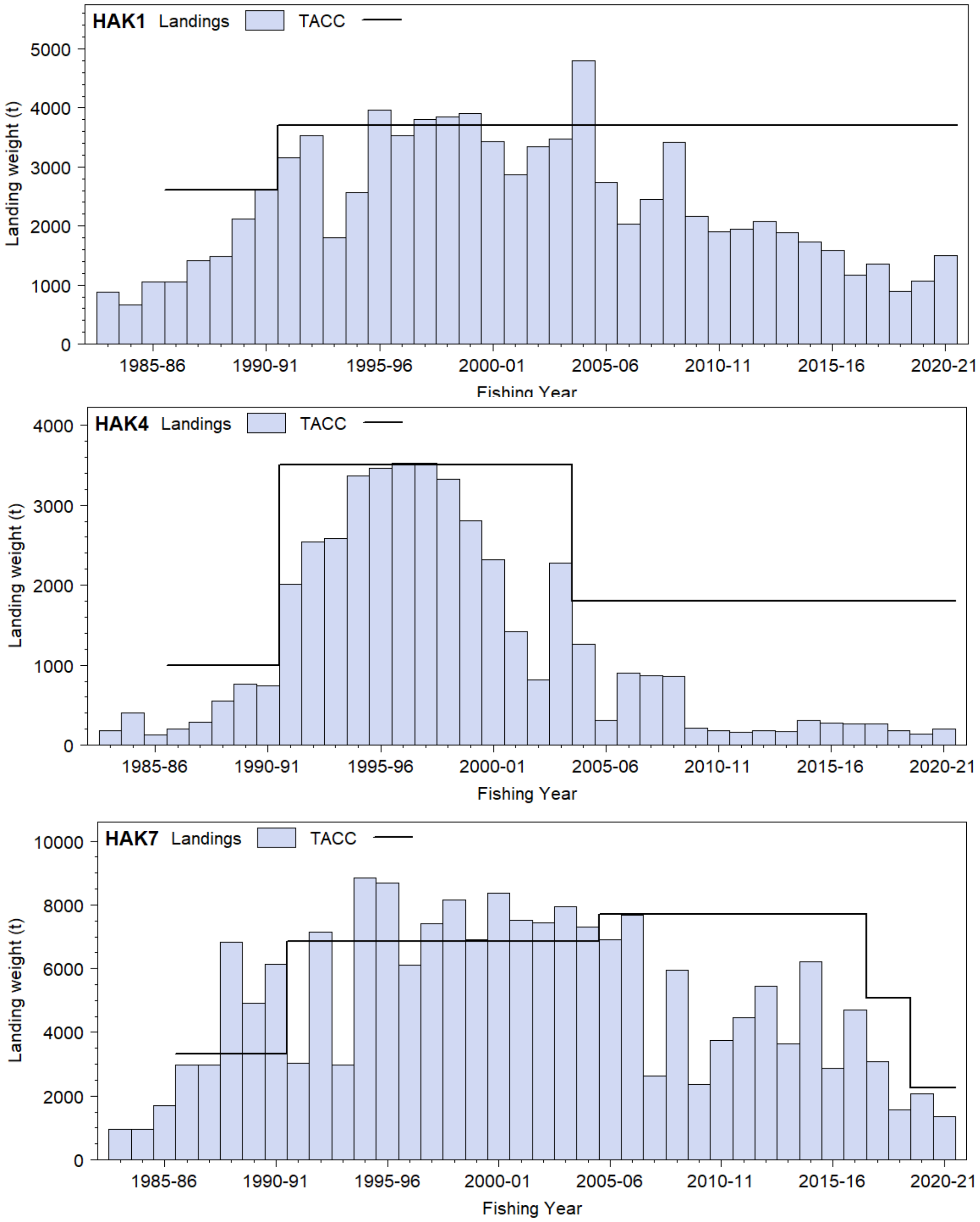


Figure 1: Reported commercial landings and TACC for the three main HAK stocks. From top: HAK 1 (Sub-Antarctic and part of Chatham Rise), HAK 4 (eastern Chatham Rise), and HAK 7 (Challenger).

1.2 Recreational fisheries

The recreational fishery for hake is negligible.

1.3 Customary non-commercial fisheries

The amount of hake caught by Māori is not known but is likely to be negligible.

1.4 Illegal catch

In late 2001, a small number of fishers admitted misreporting of hake catches between areas, pleading guilty to charges of making false or misleading entries in their catch returns. As a result, the reported catches of hake in each area were reviewed in 2002 and suspect records identified. Dunn (2003) provided revised estimates of the total landings by stock, estimating that the level of hake over-reporting on the Chatham Rise (and hence under-reporting off the West Coast South Island) was between 16 and 23% (700–1000 t annually) of landings between 1994–95 and 2000–01, mainly in June, July, and September. Probable levels of area misreporting prior to 1994–95 and between the West Coast South Island and Sub-Antarctic were estimated as small (Dunn 2003). There is no evidence of similar area misreporting since 2001–02 (Ballara 2018).

In earlier years, before the introduction of higher TACCs in 1991–92, there is some evidence to suggest that catches of hake were not always fully reported. Comparison of catches from vessels carrying observers with those not carrying observers, particularly in HAK 7 from 1988–89 to 1990–91, suggested that actual catches were probably considerably higher than reported catches. For these years, the ratio of hake to hoki in the catch of vessels carrying observers was significantly higher than in the catch of vessels not carrying observers (Colman & Vignaux 1992). The actual hake catch in HAK 7 for these years was estimated by multiplying the total hoki catch (which was assumed to be correctly reported by vessels both with and without observers) by the ratio of hake to hoki in the catch of vessels carrying observers. Reported and estimated catches for 1988–89 were respectively 6835 t and 8696 t; for 1989–90, 4903 t reported and 8741 t estimated; and for 1990–91, 6189 t reported and 8246 t estimated. More recently, the level of such misreporting has not been estimated and is not known. No such corrections have been applied to either the HAK 1 or HAK 4 fishery.

For the purposes of stock assessment, the Chatham Rise stock was considered to include the whole of the Chatham Rise (including the western end currently forming part of the HAK 1 management area). Therefore, catches from this area were subtracted from the Sub-Antarctic stock and added to the Chatham Rise stock. The revised landings for 1974–75 to present are given in Table 3.

The fisheries in the Sub-Antarctic and on the Chatham Rise largely take place in September and October and catch histories used in the assessment models adjust the fishing year to reflect this (see Tables 7 and 13).

1.5 Other sources of mortality

There is likely to be some mortality associated with escapement from trawl nets, mostly from small fish that can escape through the trawl mesh. The mortality of hake associated with escapement is not known. In the Sub-Antarctic, the catch and effort records for hake suggest that small hake are uncommon in areas where the hoki/hake/ling fishery occurs with only very low proportions of small hake recorded by observers. Hence the level of mortality of hake associated with escapement is likely to be low over the history of the fishery and is assumed to be negligible.

Table 3: Revised landings for Sub-Antarctic and Chatham Rise stocks and the West Coast South Island for 1975 to present fishing years. Note, these relate to biological fish stocks, not QMA Fishstocks.

Fishing year	West Coast S.I.	Sub-Antarctic	Chatham Rise
1974–75	71	120	191
1975–76	5 005	281	488
1976–77	17 806	372	1 288
1977–78	498	762	34
1978–79	4 737	364	609
1979–80	3 600	350	750
1980–81	2 565	272	997
1981–82	1 625	179	596
1982–83	745	448	302
1983–84	945	722	344
1984–85	965	525	544
1985–86	1 918	818	362
1986–87	3 755	713	509
1987–88	3 009	1 095	574
1988–89	8 696	1 827	804
1989–90[1]	8 741	2 366	950
1990–91[1]	8 246	2 749	931
1991–92	3 010	3 265	2 418
1992–93	7 059	1 452	2 798
1993–94	2 971	1 844	2 934
1994–95	9 535	2 888	3 271
1995–96	9 082	2 273	3 959
1996–97	6 838	2 599	3 890
1997–98	7 674	2 789	4 074
1998–99	8 742	2 789	3 589
1999–00	7 031	3 011	3 174
2000–01	8 346	2 787	2 962
2001–02	7 498	2 510	1 770
2002–03	7 404	2 741	1 401
2003–04	7 939	3 251	2 465
2004–05	7 298	2 530	3 518
2005–06	6 892	2 555	489
2006–07	7 660	1 812	1 081
2007–08	2 583	2 204	1 096
2008–09	5 912	2 427	1 825
2009–10	2 282	1 958	391
2010–11	3 462	1 288	951
2011–12	4 299	1 893	194
2012–13	5 171	1 883	344
2013–14	3 387	1 832	187
2014–15	5 966	1 639	348
2015–16	2 733	1 504	355
2016–17	4 701	1 037	406
2017–18	3 085	1 205	412
2018–19	1 562	636	443
2019–20	2 063	930	318
2020–21	1 367	1 355	355

[1] West Coast South Island revised estimates for 1989–90 and 1990–91 were from Colman & Vignaux (1992) who corrected for under-reporting in 1989–90 and 1990–91, and not Dunn (2003) who ignored such under-reporting.

[2] Estimates from 2019 to 2021 were from Dunn et al (2021a) using a minor redefinition of statistical area for the Sub-Antarctic.

2. BIOLOGY

The New Zealand hake reach a maximum age of at least 25 years. Males, which rarely exceed 100 cm total length (TL), do not grow as large as females, which can grow to 120 cm TL or more. Horn (1997) validated the use of otoliths to age hake and estimated von Bertalanffy growth curves. Growth parameters were updated for all stocks by Horn (2008) using both the von Bertalanffy and Schnute growth models, with the Schnute model found to better fit the data. More recently, growth parameters for the Sub-Antarctic (Dunn et al 2021a) and the WCSI (Dunn et al in prep) using a Bayesian von Bertalanffy growth model provided a better fit than the previous Schnute model.

Chatham Rise hake reach 50% maturity at about 5.5 years for males and 7 years for females, Sub-Antarctic hake at about 6 years for males and 6.5 years for females, and WCSI hake at about 4.5 years for males and 5 years for females (Horn & Francis 2010, Horn 2013a).

Estimates of natural mortality (M) and the associated methodology are given by Dunn et al (2000); M is estimated as 0.18 y^{-1} for females and 0.20 y^{-1} for males. Colman et al (1991) previously estimated M as 0.20 y^{-1} for females and 0.22 y^{-1} for males from the maximum age (i.e., the maximum ages at which 1% of the population survives in an unexploited stock were estimated at 23 years for females and 21 years for males). Recent assessment models for all hake stocks have either assumed a constant M (0.19 yr^{-1} for both sexes) and estimated a constant M, or have estimated age-dependent ogives for M (because true M is likely to vary with age).

Data collected by observers on commercial trawlers and data from trawl surveys suggest that there are at least three main spawning areas for hake (Colman 1998). The best known area is off the west coast of the South Island, where the season can extend from June to October, usually with a peak in September. Spawning also occurs to the west of the Chatham Islands during a prolonged period from at least September to January. Spawning on the Campbell Plateau, primarily to the north-east of the Auckland Islands Shelf, occurs from September to February with a peak in September–October. Spawning fish have been recorded occasionally on the Puysegur Bank, with a seasonality that appears similar to that on the Campbell Plateau (Colman 1998).

An aggregation of medium size hake fished on the western Chatham Rise in October 2004 may have comprised either spawning or pre-spawning fish. Fishing on aggregated schools in the same area also occurred during October–November 2008 and 2010. Also, the trawl survey took high catches of young, mature fish in this area in January 2009. It is possible that young, mature hake spawn on the western Chatham Rise and slowly move east, towards the main spawning area, as they age.

Juvenile hake have been taken in coastal waters on both sides of the South Island and on the Campbell Plateau. They reach a length of about 15–20 cm TL at one year old, and about 35 cm TL at 2 years (Colman 1998).

Dunn et al (2010) found that the diet of hake on the Chatham Rise was dominated by teleost fishes, in particular Macrouridae. Macrouridae accounted for 44% of the prey weight and consisted of at least six species, of which javelinfish, *Lepidorhynchus denticulatus*, was most frequently identified. Hoki were less frequent prey but being relatively large accounted for 37% of prey by weight. Squid were found in 7% of the stomachs and accounted for 5% of the prey by weight. Crustacean prey was predominantly natant decapods, with pasiphaeid prawns, occurring in 19% of the stomachs.

The biological parameters relevant to the stock assessments are given in Table 4.

Table 4: Estimates of biological parameters.

Parameter						**Estimate**	**Source**
1. Natural mortality							
	Males	$M = 0.20$					(Dunn et al 2000)
	Females	$M = 0.18$					(Dunn et al 2000)
	Both sexes	$M = 0.19$					(Horn & Francis 2010)
2. Weight = $a(\text{length})^b$ (Weight in t, length in cm)							
Sub-Antarctic	Males	$a = 2.34 \times 10^{-9}$	$b = 3.258$				(Dunn et al 2021a)
	Females	$a = 1.86 \times 10^{-9}$	$b = 3.310$				(Dunn et al 2021a)
	Both sexes	$a = 1.50 \times 10^{-9}$	$b = 3.262$				(Dunn et al 2021a)
Chatham Rise	Males	$a = 2.56 \times 10^{-9}$	$b = 3.228$				(Horn 2013a)
	Females	$a = 1.88 \times 10^{-9}$	$b = 3.305$				(Horn 2013a)
	Both sexes	$a = 2.00 \times 10^{-9}$	$b = 3.288$				(Horn 2013a)
WCSI	Males	$a = 3.34 \times 10^{-9}$	$b = 3.175$				(Dunn et al in prep)
	Females	$a = 3.48 \times 10^{-9}$	$b = 3.177$				(Dunn et al in prep)
	Both sexes	$a = 3.02 \times 10^{-9}$	$b = 3.204$				(Dunn et al in prep)
3. von Bertalanffy growth parameters							
Sub-Antarctic	Males	$k = 0.260$	$t_0 = -0.71$	$L_\infty = 89.3$		cv = 0.07	(Dunn et al 2021a)
	Females	$k = 0.160$	$t_0 = -1.33$	$L_\infty = 115.5$		cv = 0.08	(Dunn et al 2021a)
Chatham Rise	Males	$k = 0.330$	$t_0 = 0.09$	$L_\infty = 85.3$			(Horn 2008)
	Females	$k = 0.229$	$t_0 = 0.01$	$L_\infty = 106.5$			(Horn 2008)
WCSI	Males	$k = 0.329$	$t_0 = -0.43$	$L_\infty = 83.1$		cv = 0.07	(Dunn et al in prep)
	Females	$k = 0.192$	$t_0 = -0.98$	$L_\infty = 107.0$		cv = 0.10	(Dunn et al in prep)
4. Schnute growth parameters ($\tau_1 = 1$ and $\tau_2 = 20$ for all stocks)							
Chatham Rise	Males	$y_1 = 24.6$	$y_2 = 90.1$	$a = 0.184$	$b = 1.742$		(Horn 2008)
	Females	$y_1 = 24.4$	$y_2 = 114.5$	$a = 0.098$	$b = 1.764$		(Horn 2008)
	Both sexes	$y_1 = 24.5$	$y_2 = 104.8$	$a = 0.131$	$b = 1.700$		(Horn & Francis 2010)

5. Maturity ogives (proportion mature at age) (Horn 2013a)

	Age	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
SubAnt	Males	0.01	0.04	0.11	0.30	0.59	0.83	0.94	0.98	0.99	1.00	1.00	1.00
	Females	0.01	0.03	0.08	0.19	0.38	0.62	0.81	0.92	0.97	0.99	1.00	1.00
	Both	0.01	0.03	0.09	0.24	0.49	0.73	0.88	0.95	0.98	0.99	1.00	1.00
Chatham	Males	0.02	0.07	0.20	0.44	0.72	0.89	0.96	0.99	1.00	1.00	1.00	1.00
	Females	0.01	0.02	0.06	0.14	0.28	0.50	0.72	0.86	0.94	0.98	0.99	1.00
	Both	0.02	0.05	0.13	0.29	0.50	0.70	0.84	0.93	0.97	0.99	0.99	1.00
WCSI	Males	0.01	0.05	0.27	0.73	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00
	Females	0.02	0.07	0.25	0.57	0.84	0.96	0.99	1.00	1.00	1.00	1.00	1.00
	Both	0.01	0.06	0.26	0.65	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00

3. STOCKS AND AREAS

There are three main hake spawning areas: off the west coast of the South Island, on the Chatham Rise, and on the Campbell Plateau. Juvenile hake are found in all three areas. There are differences in size frequencies of hake between the west coast and other areas, and differences in growth parameters between all three areas (Horn 1997). There is good evidence, therefore, to suggest that at least three separate stocks exist in the EEZ.

Analysis of morphometric data (Colman unpublished data) shows little difference between hake from the Chatham Rise and hake from off the east coast of the North Island but shows highly significant differences between these fish and those from the Sub-Antarctic, Puysegur, and off the west coast. No studies have been done on morphometric differences of hake across the Chatham Rise. The Puysegur fish are most similar to those from off the west coast South Island, although, depending on which variables are used, they cannot always be distinguished from the Sub-Antarctic hake. Hence, the stock affinity of hake from this area is uncertain.

Present management divides the fishery into three Fishstocks: (a) the Challenger FMA (HAK 7), (b) the Chatham Rise FMA (HAK 4), and (c) the remainder of the EEZ comprising the Auckland, Central, Southeast (Coast), Southland, and Sub-Antarctic FMAs (HAK 1). An administrative Fishstock (with no recorded landings) exists for the Kermadec FMA (HAK 10).

4. STOCK ASSESSMENT

The stock assessments reported here were completed in 2022 for the west coast South Island stock (Dunn et al in prep), 2021 for the Sub-Antarctic stock (Dunn et al 2021b) and in 2020 for the Chatham Rise stock (Holmes 2021). In stock assessment modelling, the Chatham Rise stock was considered to include the whole of the Chatham Rise (including the western end currently forming part of the HAK 1 management area). The Sub-Antarctic stock was considered to comprise the Southland and Sub-Antarctic management areas. Although fisheries management areas around the North Island are also included in HAK 1, few hake are caught in these areas.

4.1 HAK 1 (Sub-Antarctic stock)

The 2021 stock assessment (Dunn et al 2021b) was carried out with data up to the end of the 2020 calendar year, implemented as a Bayesian model using the general-purpose stock assessment program CASAL v2.30 (Bull et al 2012). The assessment used research time series of abundance indices (trawl surveys of the Sub-Antarctic from 1991 to 2020), catch-at-age from the trawl surveys and the commercial fishery since 1990–91, and estimates of biological parameters. A trawl fishery CPUE series was used in a sensitivity run.

4.1.1 Model structure

The model had a single area and was an age-structured two-sex model partitioned into age groups 1–30 with the last age group considered a plus group. Maturity-at-age was assumed using estimates made outside the model. The annual cycle assumed is given in Table 5.

The model was initialised assuming an equilibrium age structure at an unfished equilibrium biomass (B_0), i.e., with constant recruitment set equal to the mean of the recruitments over the period 1974–2016. The selectivity for the fishery was assumed to be logistic, and the selectivities were domed (double normal) for each of the November–December and April–May trawl survey series (Table 6). Selectivities were assumed constant across all years in the fishery and the surveys, and hence there was no allowance for possible annual changes in selectivity. Growth was assumed to be constant and fixed using a von Bertalanffy growth model. Natural mortality was estimated as a constant over all age classes and years. Year class strengths for the period 1974–2016 were estimated, and otherwise assumed to be 1.0.

Model parameters were estimated using Bayesian estimation implemented using the CASAL software (Bull et al 2012). Initial models were estimated to MAP, and, for final model runs, the full posterior distribution was sampled using Markov chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm.

Table 5: Annual cycle of the stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

					Observations	
Step	**Period**	**Processes**	***M****	**Age†**	**Description**	**%*Z*‡**
1	August-Mar	Ageing	0.58	0.2	Commercial catch-at-age	0.5
		Recruitment			Trawl catch-at-age	0.5
		Summer trawl fishery (~78%)			Trawl survey (November)	0.5
		Maturation and spawning			CPUE (sensitivity)	0.5
2	Apr-July	Winter trawl fishery (~22%)	0.42	0.5	Trawl survey (April)	0.0

* *M* is the proportion of natural mortality that was assumed to have occurred in that time step.
† Age is the age fraction, used for determining length-at-age, that was assumed to occur in that time step.
‡ %*Z* is the percentage of the total mortality in the step that was assumed to have taken place at the time each observation was made.

Table 6: Summary of the relative abundance series applied in the models.

Data series	Model years
Trawl survey biomass (*Tangaroa*, November)	1992–94, 2001–10, 2012–13, 2015, 2017, 2019, 2021
Trawl survey proportion-at-age (*Tangaroa*, November)	1992–94, 2001–10, 2012–13, 2015, 2019, 2021
Trawl survey biomass (*Tangaroa*, April)	1992–93, 1996, 1998
Trawl survey proportion-at-age (*Tangaroa*, April)	1992–93, 1996, 1998
CPUE	1991–2020
Commercial trawl proportion-at-age	1990, 1992–1994, 1996, 1998–2020

4.1.2 Fixed biological parameters and observations

There were five main data sources: the catch history; research trawl survey biomass indices for November–December 1992–2021 (November series) and for April–May 1992–98 (April series), with the September 1992 biomass index used as a sensitivity only; catch-at-age estimates from the research surveys; catch-at-age estimates from the commercial fishery 1990–2020; and a commercial CPUE biomass index from daily processed data of trawls targeting hoki, hake, or ling from 1991–2020 (sensitivity run only).

Catch history

To align with the season of the fishery more closely (specifically between 1990 and 1998), the model year was set as September to August, rather than the fishing year (October to September). The catch history was modified accordingly (Table 7). The catch history includes the revised estimates of catch reported by Dunn (2003). The catch for the most recent year (2021) is not yet known and is assumed to be equal to the mean of the most recent 5 years (1066 t).

The effect of possible incidental mortality associated with escapement from trawl nets and potential unreported catch from before the introduction of the QMS was evaluated in a sensitivity model. Discards from the hoki/hake/ling target fishery were likely to be very low (< 0.5%, Anderson et al 2019). Incidental mortality of small fish associated with escapement was also assumed to be low because the hake fishery occurs in areas away from locations where small hake are found. Unreported catch prior to the introduction of the QMS is not known but assumed to be low due to the high commercial value of hake at that time. A sensitivity model assumed 5% additional fishery mortality for years before the introduction of the QMS (1986) and 2% thereafter (labelled the reference+ model).

Biological parameters

All biological parameters other than natural mortality rate *M* were estimated outside the model. Estimated and assumed values for biological parameters used in the assessments are given in Table 4.

Growth was assumed to be von Bertalanffy and constant over time (Table 4). *M* was constant over ages and time and estimated with an informed prior (Table 8). A Beverton-Holt stock recruitment relationship was used with an assumed steepness *h* of 0.8. Year class strengths were estimated for the period 1974–2016, following the Haist parameterisation, with a lognormal prior with CV of 1.1. All other estimated parameters assumed non-informative priors, either uniform log (CPUE *q* where used) or uniform. Ageing error was assumed (with CV = 0.08). All mature fish were assumed to spawn every year.

Table 7: Commercial catch history (t) for the Sub-Antarctic stock. Note that totals by model year from 1990 differ from those for fishing year (see Table 3) because the September catch has been shifted from the fishing year into the following model year. *Model year landings for 2021 assume catch to be the same as mean for the previous 5 years.

Model year	Total	Model year	Total	Model year	Total	Model year	Total
1975	120	1987	713	1999	2 871	2011	1 319
1976	281	1988	1 095	2000	3 100	2012	1 902
1977	372	1989	1 237	2001	2 816	2013	1 878
1978	762	1990	718	2002	2 444	2014	1 840
1979	364	1991	2 318	2003	2 780	2015	1 608
1980	350	1992	2 806	2004	3 228	2016	1 470
1981	272	1993	3 919	2005	2 591	2017	1 042
1982	179	1994	1 620	2006	2 538	2018	1 175
1983	448	1995	1 982	2007	1 706	2019	662
1984	722	1996	2 789	2008	2 330	2020	983
1985	525	1997	1 919	2009	2 445	2021	1 066*
1986	818	1998	2 944	2010	1 927		

Table 8: The assumed priors for key distributions (when estimated) for the Sub-Antarctic stock assessment. The parameters are mean (in natural space) and CV for lognormal.

Parameter description	Distribution	Parameters		Bounds	
B_0	Uniform-log	–	–	5 000	350 000
Year class strengths	Lognormal (μ, cv)	1.0	1.1	0.01	100
Trawl survey q*	Lognormal (μ, cv)	0.16	0.79	0.01	0.40
CPUE q	Uniform-log	–	–	1e-8	1e-3
Selectivities	Uniform	–	–	1	25–200†
M	Normal (μ, sd)	0.19	0.05	0.05	0.40

* The trawl survey q values were estimated independently, but all had the same priors.

† A range of maximum values was used for the upper bound, depending on the parameter.

Research trawl surveys

The biomass estimates from the research trawl surveys are given in Table 9.

Table 9: Research survey indices (and associated CVs) for the Sub-Antarctic stock.

Fishing Year	Vessel	November series†		April series‡		September series‡	
		Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
1989*	*Amaltal Explorer*	2 660	0.21				
1992	*Tangaroa*	5 686	0.43	5 028	0.15	3 760	0.15
1993	*Tangaroa*	1 944	0.12	3 221	0.14		
1994	*Tangaroa*	2 567	0.12				
1996	*Tangaroa*			2 026	0.12		
1998	*Tangaroa*			2 554	0.18		
2001	*Tangaroa*	2 657	0.16				
2002	*Tangaroa*	2 170	0.20				
2003	*Tangaroa*	1 777	0.16				
2004	*Tangaroa*	1 672	0.23				
2005	*Tangaroa*	1 694	0.21				
2006	*Tangaroa*	1 459	0.17				
2007	*Tangaroa*	1 530	0.17				
2008	*Tangaroa*	2 470	0.15				
2009	*Tangaroa*	2 162	0.17				
2010	*Tangaroa*	1 442	0.20				
2012	*Tangaroa*	1 885	0.24				
2013	*Tangaroa*	2 428	0.23				
2015	*Tangaroa*	1 477	0.25				
2017§	*Tangaroa*	1 373	0.34				
2019	*Tangaroa*	1 675	0.25				
2021	*Tangaroa*	1 572	0.20				

* Not used in the reported assessment.

† Series based on indices from 300–800 m core strata, including the 800–1000 m strata in Puysegur, but excluding Bounty Plateau.

‡ Series based on the biomass indices from 300–800 m core strata, excluding the 800–1000 m strata in Puysegur and the Bounty Plateau.

§ Due to bad weather, the core survey strata were unable to be completed in 2017; biomass estimates were scaled-up using factors based on the proportion of hake biomass in those strata in previous surveys from 2000 to 2014. This introduced additional uncertainty into the 2017 biomass estimate (O'Driscoll et al 2018).

The priors for survey qs were estimated by assuming that q was the product of areal availability, vertical availability, and vulnerability. A simple simulation was conducted that estimated a distribution of possible values for the relativity constant by assuming that each of these factors was uniformly distributed. A prior was then determined by assuming that the resulting sampled distribution was lognormally distributed. Values assumed for the parameters were: areal availability (0.50–1.00), vertical availability (0.50–1.00), and vulnerability (0.01–0.50). The resulting (approximate lognormal) distribution had mean 0.16 and CV 0.79, with bounds assumed to be (0.01–0.40) (Table 8). Note that the values of survey relativity constants are dependent on the selectivity parameters, and the absolute catchability can be determined by the product of the selectivity by age and sex, and the relativity constant q. All trawl qs were estimated as free (not nuisance) parameters.

Biomass indices were fitted with lognormal likelihoods with assumed CVs set equal to the sampling CV. The CVs (for observations fitted with lognormal likelihoods) are assumed to have allowed for sampling error only. Additional variance, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance for all observations in all model runs. For the biomass indices, no additional process error was added to the trawl survey indices, but a process error CV of 0.20 was added to the CPUE indices (where used).

Catch-at-age

Catch-at-age observations were available for each trawl survey of the Sub-Antarctic and for the commercial fisheries from observer data. A plus group for all the catch-at-age data was set at 21 with the lowest age set at 3. Catch-at-age distributions were fitted assuming multinomial errors, with an effective sample size set following Francis (2011) (Table 10).

Table 10: Catch-at-age data for the Sub-Antarctic stock, giving the multinomial effective sample sizes assumed for each sample in the stock assessment model. The effective sample size is proportional to the weight given to the data in the model fit.

	Research surveys		
Fishing year	November	April	Commercial catch-at-age
1990	13		13
1991			
1992	14	17	34
1993	20	17	27
1994	25		9
1995			
1996		13	10
1997			
1998		14	16
1999			31
2000			49
2001	40		28
2002	31		41
2003	36		19
2004	36		36
2005	21		12
2006	27		41
2007	27		12
2008	33		32
2009	40		35
2010	40		61
2011			48
2012	34		83
2013	41		52
2014			47
2015	15		36
2016			31
2017			31
2018			38
2019	14		48
2020			27
2021	18		

4.1.3 Model estimation

In the reference model, the main parameters estimated were: pre-exploitation (unfished, equilibrium) biomass (B_0), trawl survey selectivities, fishery selectivity, natural mortality rate, and year class strengths (YCS) from 1974 to 2016.

A wide range of sensitivity models to the reference model were run. Sensitivity models reported here were run to investigate the effect of fixing M at a low (M=0.15 y^{-1}) or high (M=0.23 y^{-1}) value, the sensitivity of the model to the inclusion of the CPUE index; and sensitivity to the inclusion of incidental mortality and unreported catch before the introduction of the QMS.

The fits to the biomass indices were acceptable (Figure 2). Fits to the commercial catch-at-age were generally good (Figure 3), as were the fits to the research survey catch-at-age (Figure 4).

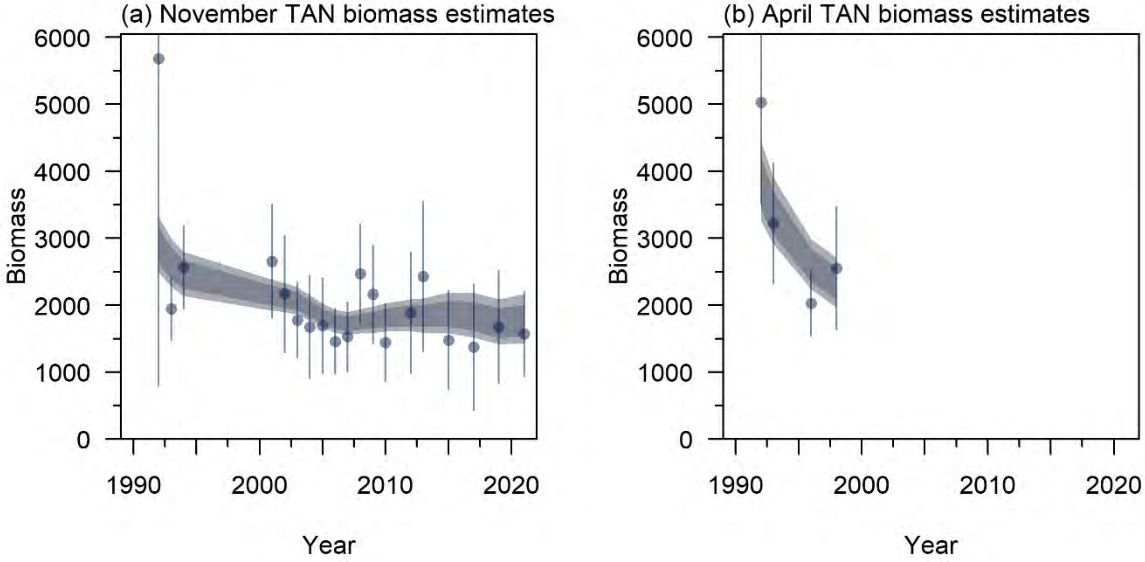


Figure 2: MCMC observed (points) and expected values for the reference model for the Sub-Antarctic stock to the (a) November and (b) April research trawl biomass indices. Dark shaded areas represent the 80% CIs, and light shaded areas the 95% CIs.

Estimated selectivities for the surveys were not strongly domed (even though they were estimated using double normal parameterisation). Hake were fully selected by the November survey at age 4–5, by the April survey at age 12, and by the fishery at about age 9.

Year class strength estimates suggested that the Sub-Antarctic stock was characterised by a group of above average year class strengths in the late 1970s, a very strong year class in 1980, followed by a period of average to less than average recruitment through to 2016 (Figure 5).

The absolute catchability of the Sub-Antarctic trawl surveys was estimated to be extremely low (Figure 6). Although catchability was expected to be higher, hake are believed to be relatively more abundant over rough ground (that is likely to be avoided during a trawl survey), and it is known that hake tend to school off the bottom, particularly during their spring-summer spawning season, hence reducing their availability to the bottom trawl.

Biomass estimates for the stock appeared well above the target (40% B_0), with estimated current biomass from the base model at about 62% B_0 (95% CIs 50–75% B_0) (Figure 7, Table 11). Annual exploitation rates (catch over vulnerable biomass) were low in all years because of the high estimated stock size relative to the level of catches.

A wide range of sensitivity runs was conducted, and these produced similar estimates of stock size and status. The 2021 assessment model structure was different to the previous (2018) model in (a) correcting the time series of survey biomass estimates used and (b) modifying the annual cycle to more accurately align the observations with their timing in the model. The biomass estimates from the reference model and the 2018 model were similar, albeit the current estimates were more optimistic due to the correction in the time series of biomass estimates used. The sensitivity run using the commercial fishery CPUE index did not allow the observer catch-at-age to be better fitted and was considered to be less plausible than the model fitted to the trawl survey series only. The CPUE model did not converge at MCMC but gave comparable estimates to the reference model. In addition to what is shown in Figure 5, the Deepwater Working Group noted there may be additional uncertainty in the strength of the early age classes, and the resulting trajectory of the assessment. Sensitivity models carried out suggested that the model conclusions were robust to choices of the early strength of year classes. The inclusion of estimates of incidental mortality and pre-QMS unreported catch resulted in a very similar status, and similar estimates of current biomass.

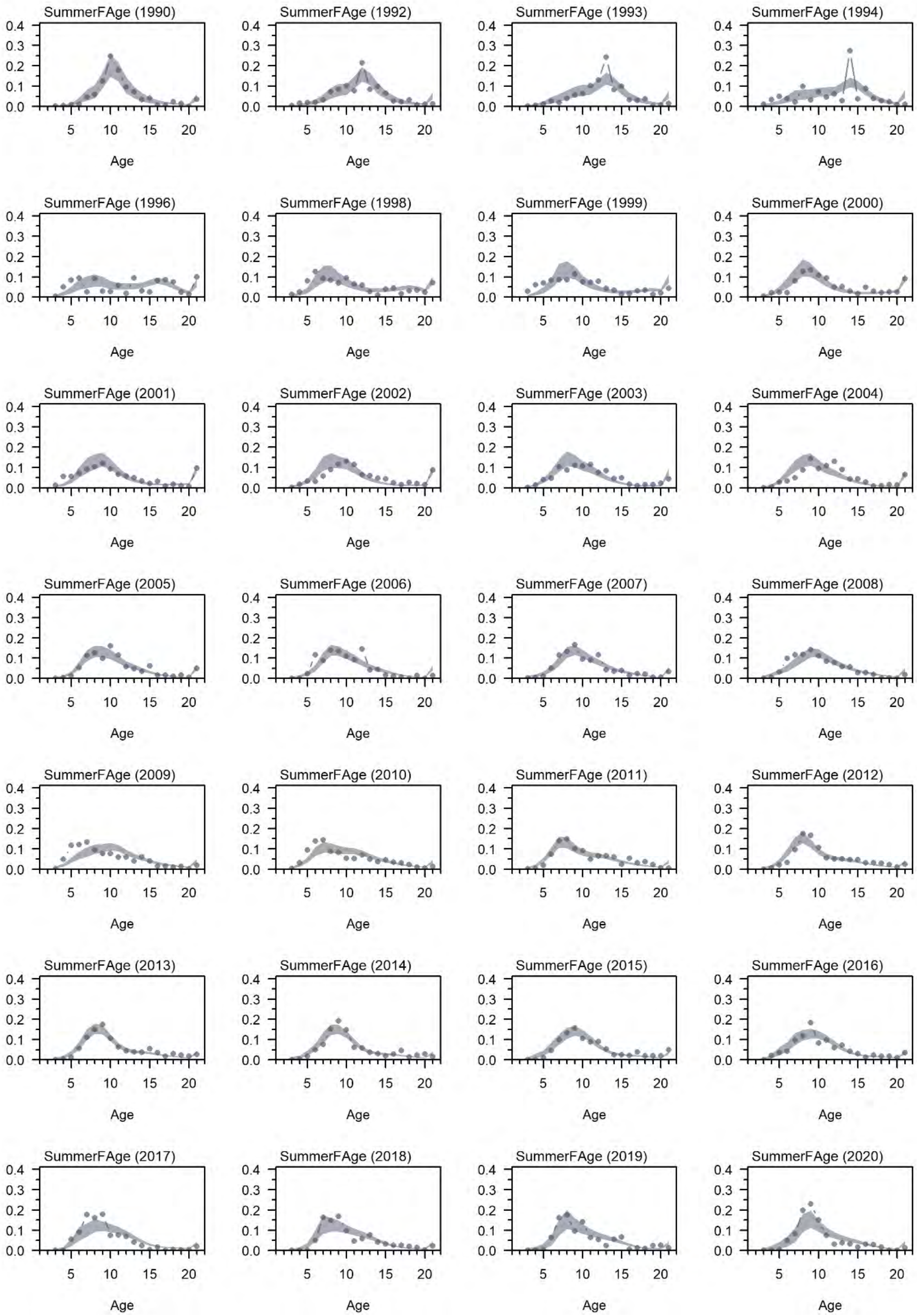


Figure 3: MCMC observed (points) and expected values for reference model for the commercial fishery catch-at-age data.

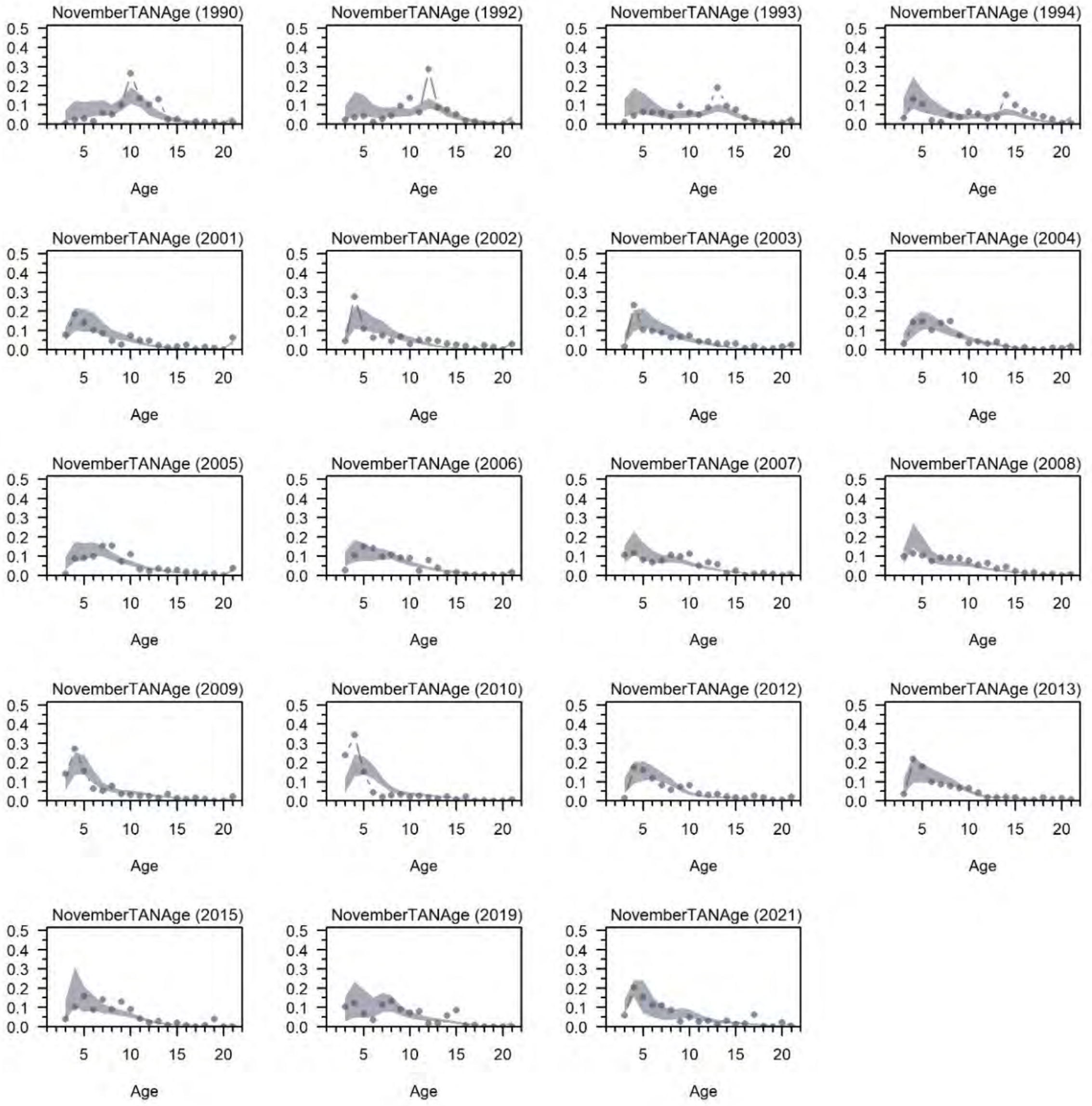


Figure 4: MCMC observed (points) and expected values for reference model for the November research survey catch-at-age data.

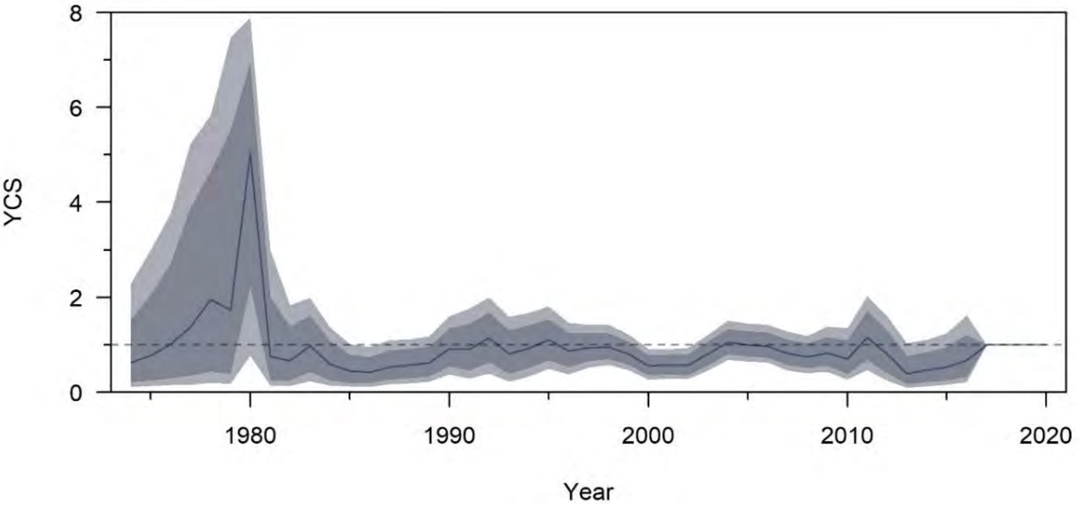


Figure 5: Estimated posterior distributions of year class strengths for the reference case for the Sub-Antarctic stock. The dashed horizontal line indicates a year class strength of one. Dark shaded areas represent the 80% CIs, and light shaded areas the 95% CIs.

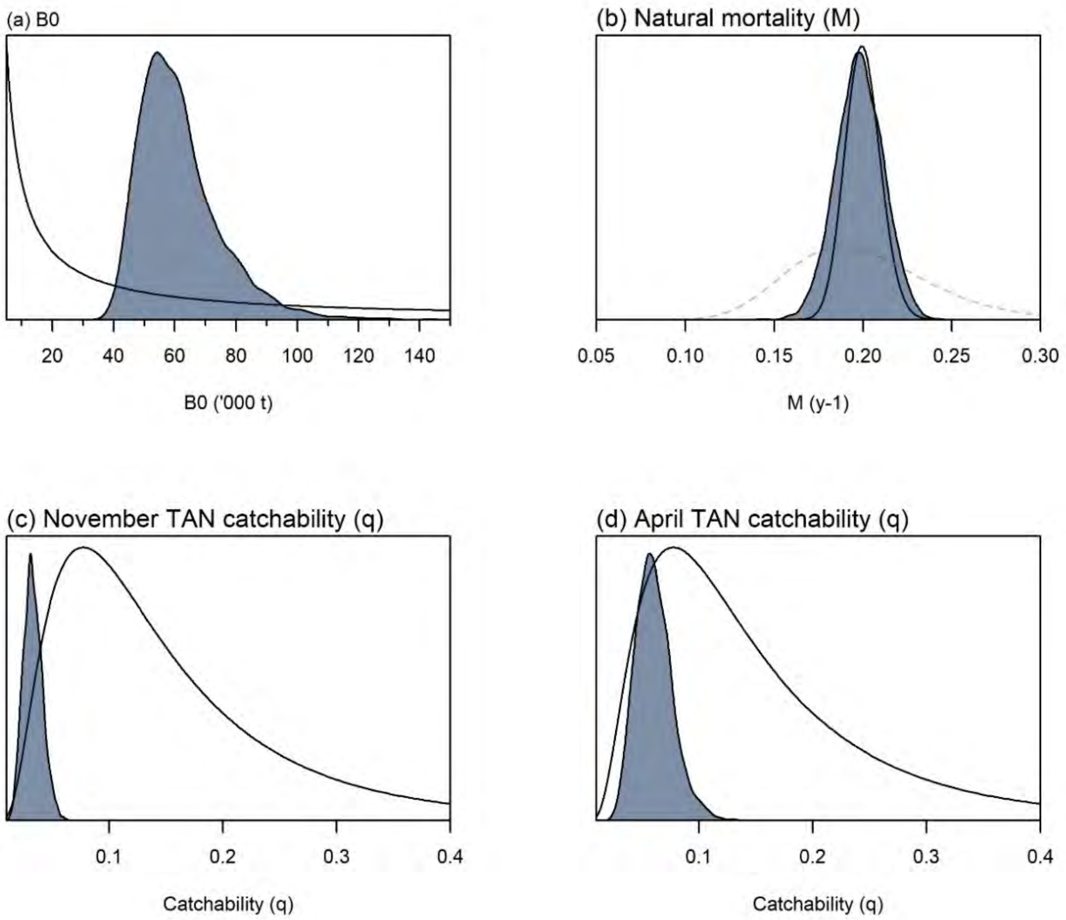


Figure 6: Reference model estimated prior (lines) and posterior distributions (shaded region) of (a) B_0, (b) natural mortality, (c) catchability for the November research surveys, and (d) catchability for the April research surveys.

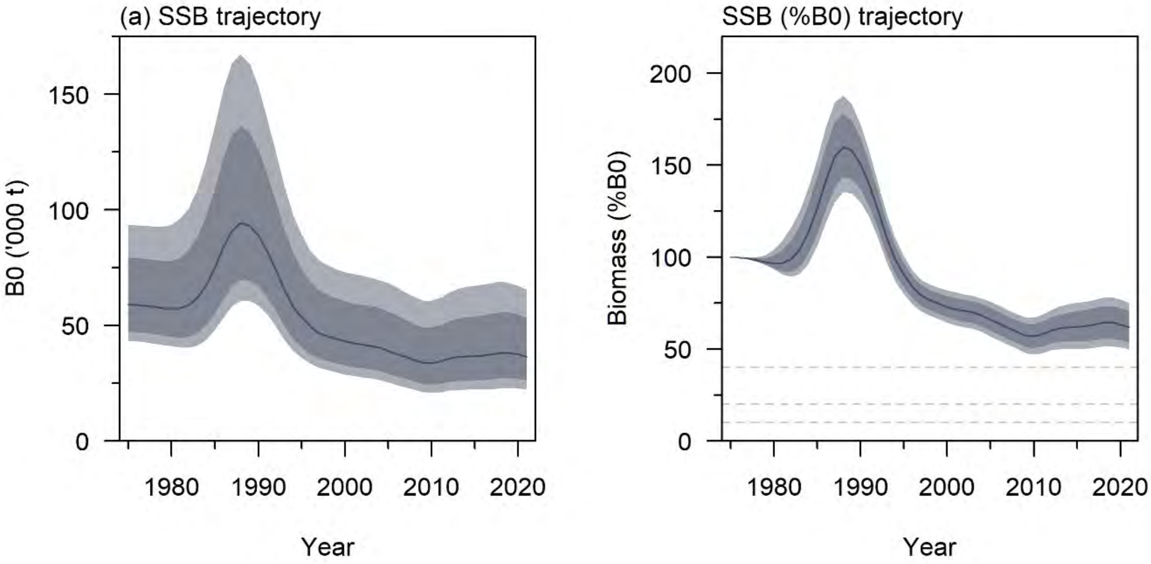


Figure 7: Reference model MCMC trajectories for absolute spawning stock biomass and spawning stock biomass as a percentage of B_0. Dark shaded areas represent the 80% CIs, and light shaded areas the 95% CIs. The management target (40% B_0, upper dotted horizontal line), soft limit (20% B_0, middle dotted horizontal line), and hard limit (10% B_0, lower dotted horizontal line) are shown on the right-hand panel.

Table 11: MCMC median (95% credible intervals) of B_0, B_{2021}, B_{2021} as a percent of B_0, and the probability of B_{2021} being above the target (40% B_0), for the reference model and sensitivity runs.

Model run	B_0	B_{2021}	B_{2021} (% B_0)	P(B_{2021} > 0.4 B_0)
Reference model	59 000 (43 220–93 600)	36 490 (22 250–65 510)	62 (50–75)	1.00
Fixed M=0.15 y^{-1}	40 440 (36 050–46 170)	20 990 (14 970–28 760)	52 (41–64)	0.98
Fixed M=0.23 y^{-1}	75 130 (55 310–110 190)	51 700 (33 480–85 480)	68 (55–84)	1.00

Projections

Five-year biomass projections were made for the Base model run assuming future annual catch in the Sub-Antarctic to be an average of the catch from the last five years (1066 t), or the TACC (3701 t). For each projection scenario, future recruitment variability was sampled from actual estimates between 1974 and 2016 (all YCS) or from the most recent ten years (2007–2016, most recent YCS).

At the current catch (1066 t), *SSB* is predicted to remain stable over the next five years (Table 12). At a catch of the TACC (3701 t), *SSB* is predicted to decrease. At the current catch, the estimated probability of *SSB* falling below the soft or hard limits is zero. At the TACC, the probability of the *SSB* dropping below the soft limit is about 1% or less using both all YCS or just more recent YCS.

Table 12: HAK 1 Bayesian median (t) and 95% credible intervals (t, in parentheses) of projected B_{2026}, B_{2026} as a percentage of B_0, and B_{2026}/B_{2021} (%) for the reference model.

Model run	Catch (t)	B_{2026}	B_{2026} (% B_0)	B_{2026}/B_{2021} (%)	p(B_{2026} > 0.4 B_0)	p(B_{2026} < 0.2 B_0)	p(B_{2026} < 0.1 B_0)
Reference model	1 066	34 410 (19 950–64 740)	58 (42–78)	94 (76–117)	0.99	0.00	0.00
with recent YCS	3 701	26 240 (11 620–56 700)	44 (25–66)	72 (47–96)	0.66	0.01	0.00
Reference model	1 066	38 070 (21 960–78 930)	63 (46–111)	102 (80–176)	1.00	0.00	0.00
with all YCS	3 701	29 950 (13 590–71 460)	49 (30–97)	80 (54–155)	0.82	0.00	0.00

4.2 Chatham Rise stock (HAK 4 and HAK 1 north of Otago peninsula)

The 2020 stock assessment was carried out up to the end of 2020 using data up to the end of the 2018–19 fishing year and an assumed catch of 436 t for the 2019–20 year (Holmes 2021). The assessment used research time series of abundance indices (trawl surveys of the Chatham Rise from 1992 to 2020), catch-at-age from the trawl survey series and the commercial fishery since 1990–91, a CPUE series from the eastern trawl fishery, and estimates of biological parameters.

To align with the seasons of the fishery more closely, the model year was set as September to August, rather than the fishing year (October to September). The catch history was modified accordingly (Table 13). The catch history includes the revised estimates of catch reported by Dunn (2003).

4.2.1 Model structure

The base case model partitioned the Chatham Rise stock population into unsexed age groups 1–30 with the last age group considered a plus group. No CPUE was included and a constant *M* was used. The models were initialised assuming an equilibrium age structure at an unfished equilibrium biomass (B_0), i.e., with constant recruitment set equal to the mean of the recruitments over the period 1975–2017. Commercial fishing was split into two fisheries, east and west (split at latitude 178.1° E). Double-normal selectivity-at-age ogives were used for the west commercial fishing selectivity and a survey selectivity for the Chatham Rise January trawl survey series. In a change to the previous assessment base case, a logistic selectivity-at-age ogive was used for the east commercial fishing selectivity. Selectivities were assumed constant across all years in both fisheries and the survey, and hence there was no allowance for possible annual changes in selectivity. The age at full selectivity for the trawl survey series was strongly encouraged to be in the range 8±2 years. This range was determined by visual examination of the at-age plots and was implemented because unconstrained selectivity resulted in age at full selectivity being older than most of the fish caught in the survey series.

4.2.2 Fixed biological parameters and observations

Estimates and assumed values for biological parameters used in the assessments are given in Table 4. Variability in the Schnute age-length relationship was assumed to be lognormal with a constant CV of 0.1.

Catch-at-age observations were available for each survey on the Chatham Rise and from observer data for commercial trawl fisheries on the eastern and western Chatham Rise in some years. The catch histories assumed in all model runs (Table 13) include the revised estimates of catch reported by Dunn (2003). Resource survey abundance indices are given in Table 14.

4.2.3 Model estimation

Model parameters were derived using Bayesian estimation implemented using the general-purpose stock assessment program CASAL v2.30 (Bull et al 2012). For final runs, the full posterior distribution was sampled using Markov chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm.

The error distributions assumed were multinomial for the proportions-at-age and lognormal for all other data. Biomass indices had assumed CVs set equal to the sampling CV, with additional process error of 0.15 retained from the previous assessment (process error estimated from an MPD run was very similar). A process error CV of 0.20 for the CPUE series estimated following Francis (2011) was also retained from the previous assessment. The multinomial observation error effective sample sizes for the at-age data were adjusted using the reweighting procedure of Francis (2011). Ageing error was assumed to occur for the observed proportions-at-age data, by assuming a discrete normally distributed error with a CV of 0.08.

Table 13: Commercial catch history (t) by fishery (West and East) and total, for the Chatham Rise stock. Note that from 1990 totals by model year differ from those for fishing year (see Table 3) because the September catch has been shifted from the fishing year into the following model year.

Model year	West	East	Total	Model year	West	East	Total
1975	80	111	191	1998	1 424	1 124	2 547
1976	152	336	488	1999	1 169	3 339	4 509
1977	74	1 214	1 288	2000	1 155	2 130	3 285
1978	28	6	34	2001	1 208	1 700	2 908
1979	103	506	609	2002	454	1 058	1 512
1980	481	269	750	2003	497	718	1 215
1981	914	83	997	2004	687	1 983	2 671
1982	393	203	596	2005	2 585	1 434	4 019
1983	154	148	302	2006	184	255	440
1984	224	120	344	2007	270	683	953
1985	232	312	544	2008	259	901	1 159
1986	282	80	362	2009	1 084	838	1 922
1987	387	122	509	2010	275	134	409
1988	385	189	574	2011	777	165	942
1989	386	418	804	2012	108	101	209
1990	309	689	998	2013	249	117	366
1991	409	503	912	2014	109	96	205
1992	718	1 087	1 805	2015	139	83	222
1993	656	1 996	2 652	2016	249	209	458
1994	368	2 912	3 280	2017	302	124	426
1995	597	2 903	3 500	2018	228	173	401
1996	1 353	2 483	3 836	2019	364	93	457
1997	1 475	1 820	3 295	2020*	286	150	436

* 2020 values are means of the 2016–2019 values for each area.

Year class strengths were assumed known (and equal to one) for years before 1975 and after 2017, where inadequate or no catch-at-age data were available. Otherwise, year class strengths were estimated under the assumption that the estimates from the model should average one.

MCMCs were estimated using a burn-in length of 3×10^6 iterations, with every 5000th sample taken from a minimum of the next 5×10^6 iterations (i.e., a final sample of at least length 1000 was taken from the Bayesian posterior).

Table 14: Research survey indices (and associated CVs) for the Chatham Rise stock.

Year	Vessel	Biomass (t)	CV
1989*	*Amaltal Explorer*	3 576	0.19
1992	*Tangaroa*	4 180	0.15
1993	*Tangaroa*	2 950	0.17
1994	*Tangaroa*	3 353	0.10
1995	*Tangaroa*	3 303	0.23
1996	*Tangaroa*	2 457	0.13
1997	*Tangaroa*	2 811	0.17
1998	*Tangaroa*	2 873	0.18
1999	*Tangaroa*	2 302	0.12
2000	*Tangaroa*	2 090	0.09
2001	*Tangaroa*	1 589	0.13
2002	*Tangaroa*	1 567	0.15
2003	*Tangaroa*	890	0.16
2004	*Tangaroa*	1 547	0.17
2005	*Tangaroa*	1 049	0.18
2006	*Tangaroa*	1 384	0.19
2007	*Tangaroa*	1 820	0.12
2008	*Tangaroa*	1 257	0.13
2009	*Tangaroa*	2 419	0.21
2010	*Tangaroa*	1 700	0.25
2011	*Tangaroa*	1 099	0.15
2012	*Tangaroa*	1 292	0.15
2013	*Tangaroa*	1 877	0.15
2014	*Tangaroa*	1 377	0.15
2016	*Tangaroa*	1 299	0.19
2018	*Tangaroa*	1 660	0.34
2020	*Tangaroa*	1 037	0.20

* Not used in the reported assessment.

4.2.4 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 15. The priors for B_0 and year class strengths were intended to be relatively uninformed and had wide bounds. Priors for the trawl fishery selectivity parameters were assumed to be uniform. Priors for the trawl survey selectivity parameters were assumed to have a normal-by-stdev distribution, with a very tight distribution set for age at full selectivity, but an essentially uniform distribution for parameters *aL* and *aR*. The prior for the survey *q* was informative and was estimated using a simple simulation as described in section 4.1.2 above.

Penalty functions were used a) to constrain the model so that any combination of parameters that resulted in a stock size that was so low that the historical catch could not have been taken was strongly penalised, b) to ensure that all estimated year class strengths averaged 1, and c) to smooth the year class strengths estimated over the period 1975 to 1983.

Table 15: The assumed priors for key distributions (when estimated) for the Chatham Rise stock assessment. The parameters are mean (in natural space) and CV for lognormal and normal priors, and mean (in natural space) and standard deviation for normal-by-stdev priors.

Parameter description	Distribution	Parameters		Bounds	
B_0	Uniform-log	–	–	10 000	250 000
Year class strengths	Lognormal	1.0	1.1	0.01	100
Selectivity (fishery)	Uniform	–	–	1	25–200
Selectivity (survey, *a1*)	Normal-by-stdev	8	1	1	25
Selectivity (survey, *aL*, *aR*)	Normal-by-stdev	10	500	1	25–200
M	Normal	0.19	0.2	0.1	0.35

4.2.5 Model estimates

Estimates of biomass were produced for an agreed base case run (research survey abundance series, constant *M,* logistic selectivity for the eastern fishery) using the biological parameters and model input parameters described in section 4.1.2. Sensitivity models were run to investigate the effects of estimating:

- ‘High M’: A higher fixed constant *M* (*M* raised from 0.19 to 0.23) (MPD only).
- ‘Low M’: A lower fixed constant *M* (*M* lowered from 0.19 to 0.15) (MPD only).

- 'All double normal': Selectivities for the survey and both fisheries were modelled as double normal.
- 'CPUE': the eastern CPUE series was included. The CPUE analysis for Chatham Rise hake investigated three CPUE series. The first used catch and effort data from the whole Chatham Rise. Two more were based on the catch and effort of the western and eastern fisheries data, respectively. During the characterisation work for the stock, it was concluded the Eastern CPUE demonstrated least conflict in abundance signal with the survey series.

Stock status from these four models was not markedly different to the base case. For all runs, MPD fits were obtained and qualitatively evaluated. MCMC runs were performed of the base case and all double normal and CPUE models. Base case MCMC estimates of the median posterior and 95% percentile credible intervals are reported for virgin, current, and projected biomass.

Estimated MCMC marginal posterior distributions from the base case model are shown for year class strengths (Figure 8) and biomass (Figure 9). The year class strength estimates suggested that the Chatham Rise stock was characterised by a group of relatively strong relative year class strengths in the late 1970s to early 1980s and again in the early 1990s, followed by a period of relatively poor recruitment since then (except for 2002 and 2011). Consequently, biomass increased slightly during the late 1980s, then declined to about 2006. The growth of the strong 2002 year class resulted in an upturn in biomass from about 2007, followed by a further upturn from 2016 as the 2011 year class began to recruit. Current stock biomass was estimated at about 55% of B_0 (see Figure 9 and Table 16). Annual exploitation rates (catch over vulnerable biomass) were low (less than 0.1) up to 1993 and since 2006, but moderate (although probably less than 0.25) in the intervening period (Figure 10).

The resource survey and fishery selectivity ogives all had relatively wide bounds after age at peak selectivity. The survey ogive was essentially logistic (even though fitted as double normal) and had hake fully selected by the research gear from about age 9. Recall that age at full selectivity for the trawl survey was strongly influenced by tight priors. Fishing selectivities indicated that hake were fully selected in the western fisheries by about age 7 years. For the eastern fishery, fitting the selectivity as logistic (as in the base case) resulted in wide bounds up to and beyond age of full selectivity which was not until age 14 or 15; this is logical given that the eastern fishery concentrates more on the spawning (i.e., older) biomass. If fitted as double normal the eastern fishery ogive was again essentially logistic.

Base case projections

Five-year biomass projections were made assuming future catches on the Chatham Rise were much higher (and assumed equal to the HAK 4 TACC of 1800 t) or the mean annual catch over the last six years (362 t). For the projections, estimated future recruitment variability was sampled in two ways: the first from actual estimates between 1975 and 2017, a period including the full range of recruitment successes; the second from actual estimates between 2008 and 2017 only. Restricting sampling to the more recent year class strengths was in response to estimated YCS indicating a declining long-term trend in YCS decadal means.

Base case model projections assuming a future annual catch of 1800 t suggest that biomass will decline between 2021 and 2025 (Table 17). The rate of decline depends on whether recruitments are some combination of those from all estimated years or whether they remain at the level of the last decade. In either recruitment scenario there is little risk (i.e., < 1%) that the stock will fall below 20% B_0 in the next five years under this catch scenario. Note that 1800 t is higher than recent annual landings from the stock (they have averaged about 362 t in the last six years), but lower than what could be taken (if all the HAK 4 TACC plus some HAK 1 catch from the western Chatham Rise was taken). Under the assumption there has been no long-term decline in recruitment, future catches of 362 t per year will allow further stock rebuilding. If it is assumed recruitment will remain at the level of the last decade, future catches of 362 t per year are predicted to see *SSB* essentially unchanged over the next 5 years.

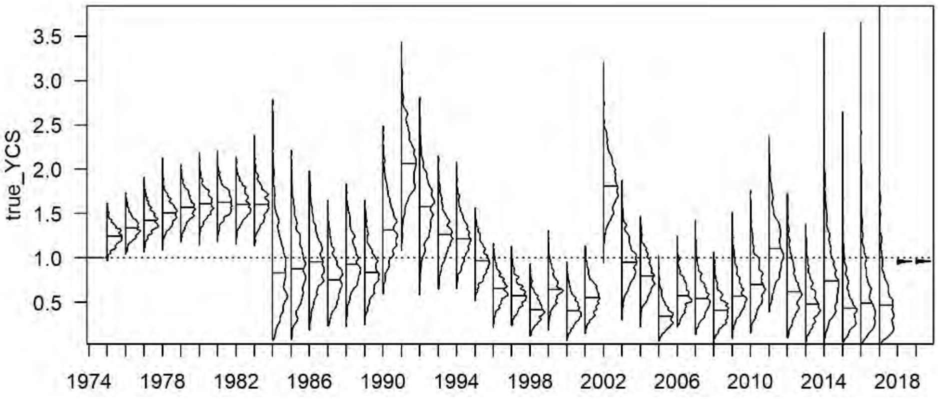


Figure 8: Estimated posterior distributions of year class strengths for the Chatham Rise base case. The dashed horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

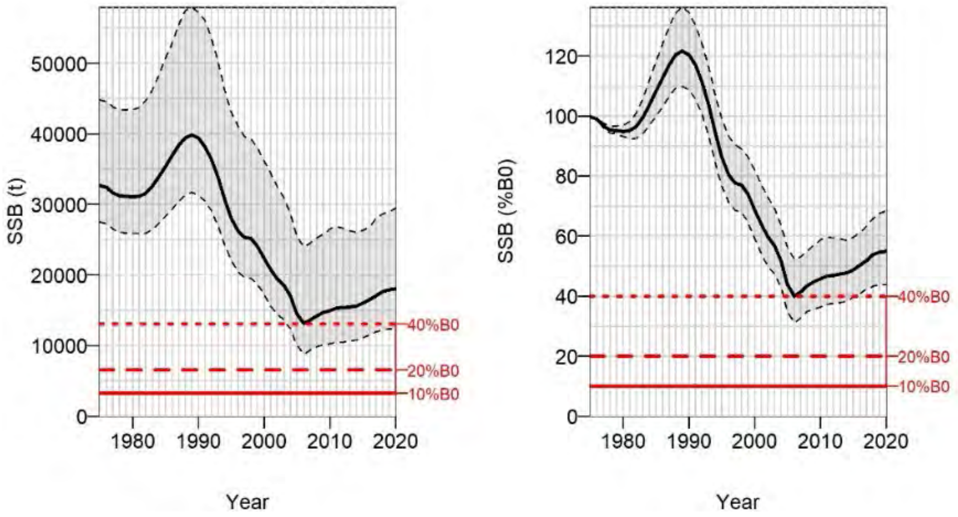


Figure 9: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for the Chatham Rise base case model for absolute biomass and stock status (biomass as a percentage of B_0).

Table 16: Bayesian median and 95% credible intervals of B_0, B_{2020} and B_{2020} as a percentage of B_0 for the Chatham Rise model runs.

Model run	B_0	B_{2020}	B_{2020} (%B_0)	P(B_{2020} > 0.4 B_0)
Base case	32 838 (28 280–42 721)	18 150 (13 204–27 258)	55.1 (45.7–65.9)	0.99
Double normal	32 859 (27 998–43 444)	18 237 (13 175–27 659)	55.4 (45.4–66.8)	0.996
CPUE	34 367 (29 504–44 113)	20 035 (15 096–28 979)	58.0 (49.6–68.1)	1.0

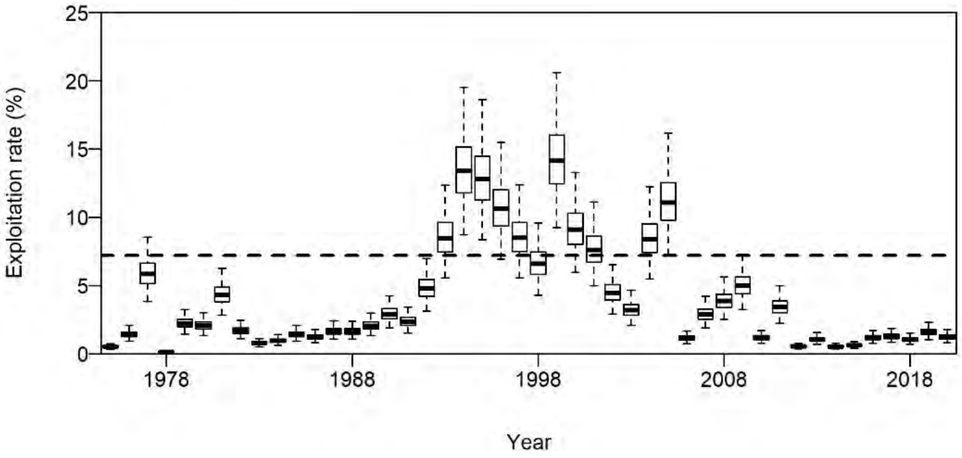


Figure 10: Exploitation rates (catch over vulnerable biomass) for the Chatham Rise stock base case model. Overall exploitation rate uses a catch weighted average of the component fishery exploitations.

Table 17: Chatham Rise base model: Bayesian median and 95% credible intervals of projected biomass, probability (%) of being above target (40% B_0) and below soft limit (20% B_0) or hard limit (10% B_0) in each year to 2025.

Recruitment	Future catch (t)	Year	B	B (% B_0)	p($B > 0.4\,B_0$)	p($B < 0.2\,B_0$)	p($B < 0.1\,B_0$)
All YCS	1 800	2021	17 600 (11 700–29 200)	53.5 (42.0–68.4)	0.992	0	0
		2022	16 400 (10 700–28 100)	50.2 (37.6–66.8)	0.937	0	0
		2023	15 700 (9 800–27 800)	47.6 (34.1–65.6)	0.844	0	0
		2024	15 100 (8 900–27 700)	45.9 (31.2–66.1)	0.762	0	0
		2025	15 000 (8 400–27 500)	45.0 (29.1–66.8)	0.717	0.001	0
All YCS	362	2021	18 100 (12 300–29 800)	55.1 (43.9–69.6)	0.997	0	0
		2022	18 100 (12 300–29 800)	55.2 (43.4–71.2)	0.995	0	0
		2023	18 300 (12 600–30 500)	55.7 (43.2–73.0)	0.992	0	0
		2024	18 800 (12 600–31 500)	57.0 (43.4–76.0)	0.993	0	0
		2025	19 600 (13 000–32 400)	59.3 (44.1–79.8)	0.997	0	0
Recent YCS	1 800	2021	17 500 (11 700–29 100)	53.3 (41.8–68.2)	0.991	0	0
		2022	16 200 (10 400–27 900)	49.7 (36.7–66.4)	0.918	0	0
		2023	15 100 (9 200–27 800)	45.9 (32.1–66.2)	0.769	0	0
		2024	13 900 (8 000–27 400)	42.5 (27.7–65.9)	0.607	0.001	0
		2025	13 000 (6 900–27 000)	39.5 (23.0–65.5)	0.484	0.007	0
Recent YCS	362	2021	18 100 (12 200–29 700)	54.9 (43.7–69.6)	0.996	0	0
		2022	17 900 (12 100–29 500)	54.8 (42.7–71.2)	0.994	0	0
		2023	17 800 (11 900–30 600)	54.3 (41.4–74.1)	0.987	0	0
		2024	17 800 (11 800–31 300)	54.1 (40.0–75.5)	0.975	0	0
		2025	17 800 (11 500–32 000)	53.9 (39.1–77.7)	0.969	0	0

4.3 HAK 7 (West Coast, South Island)

The stock assessment for HAK 7 was updated in 2022 by Dunn et al (in prep). While historical assessments used standardised Catch Per Unit Effort (CPUE) as an index of abundance (Dunn 1998), more recent assessments did not use CPUE because it was not considered to be a reliable index of abundance. Research survey data from the deepwater west coast South Island survey by the RV *Tangaroa* collected over the period 2000–2021 (Table 18) showed that the trends in abundance from CPUE and the survey had diverged to the point that they could not be reconciled within a single stock assessment model (Horn 2017). The 2022 assessment used only the survey indices.

The assessment modelled the fishery from 1974–75 to 2021–22, using catches (Table 19) and catch age composition data from the commercial trawl fishery and the *Tangaroa* research survey biomass indices and age composition data for the core strata (300–650 m) from 2000 to 2021 (Table 18).

4.3.1 Model structure

The model assumed two sexes (male and females) for ages 1–30, with the last age assumed to be a plus group. Natural mortality was assumed constant at M=0.19 per year. The model assumed two time steps: the first representing the period between October and April when recruitment occurred; and the second May to September, when the fishery and the survey took place. Selectivity ogives were assumed to follow logistic ogives for both the commercial fishery and the research survey. Models were explored using double-normal ogives for the commercial fishery and/or the survey, and the resulting estimated curves were almost logistic, with little difference to the model fits or results. Hake sexual maturation was set to occur according to an age-specific schedule by Horn (2013a). The relation between spawning stock biomass and recruitment was assumed to follow a Beverton-Holt relationship with assumed fixed steepness equal to 0.84. The model was initialised assuming an equilibrium age structure at an unfished equilibrium biomass (B_0) in 1975, i.e., with constant recruitment set equal to the mean of the recruitments over the period 1975 to 2015.

4.3.2 Fixed biological parameters and observations

Estimates and assumed values for biological parameters used in the assessments are given in Table 4.

Commercial fishery catch-at-age observations were available from observers from 1989–90 to 2020–21 (Figure 11) and were modelled as three separate fisheries based on the fishery stratification by Horn (2013b).

The research survey off the west coast of the South Island has been conducted since 2000. This survey initially covered an area from 300 m to 650 m depths north of Hokitika Canyon (‘core area’). From 2012, the survey was extended into both shallower and deeper water to cover the distribution of a number of species more adequately, including hake (covering an area referred to as ‘all areas’). The survey was initially extended to 200–800 m. An additional 800–1000 m deep stratum was added in 2016, to further investigate hake distributions and to better monitor shovelnose dogfish and ribaldo. However, the survey remains north of Hokitika Canyon and consequently does not monitor hake that occur in the canyon and south of the Hokitika Canyon.

Due to variable estimates in the numbers of hake of length less than about 67 cm in both the *Tangaroa* research survey and commercial length frequency data, ages for hake of less than 5 years were excluded from the commercial catch-at-age data, and the survey biomass and age data used in the model. Analyses showed that the amount of catch associated with these size classes was low, made up a negligible proportion of the total catch, and did not appear represent a consistent index of juvenile hake in either the *Tangaroa* research survey or the commercial catch data over time.

The representativeness of the *Tangaroa* research survey of the hake population on the WCSI is not well known. The survey may index a changing proportion of the population over time because it does not monitor areas either in or south of the Hokitika Canyon that are known to support hake in substantial numbers.

Because of concerns about changing fishing behaviour, including targeting and avoidance, advances in gear technology, and changes in fleet structure, the Working Group did not consider CPUE to be a reliable index of abundance.

Table 18: *Tangaroa* research survey indices of abundance (biomass in tonnes) and associated CVs (in parentheses) for the ‘core’ research survey (300-650 m).

Year	Core	Year	Core
2000	803 (0.13)	2016	221 (0.25)
2012	582 (0.13)	2018	229 (0.33)
2013	330 (0.17)	2021	507 (0.34)

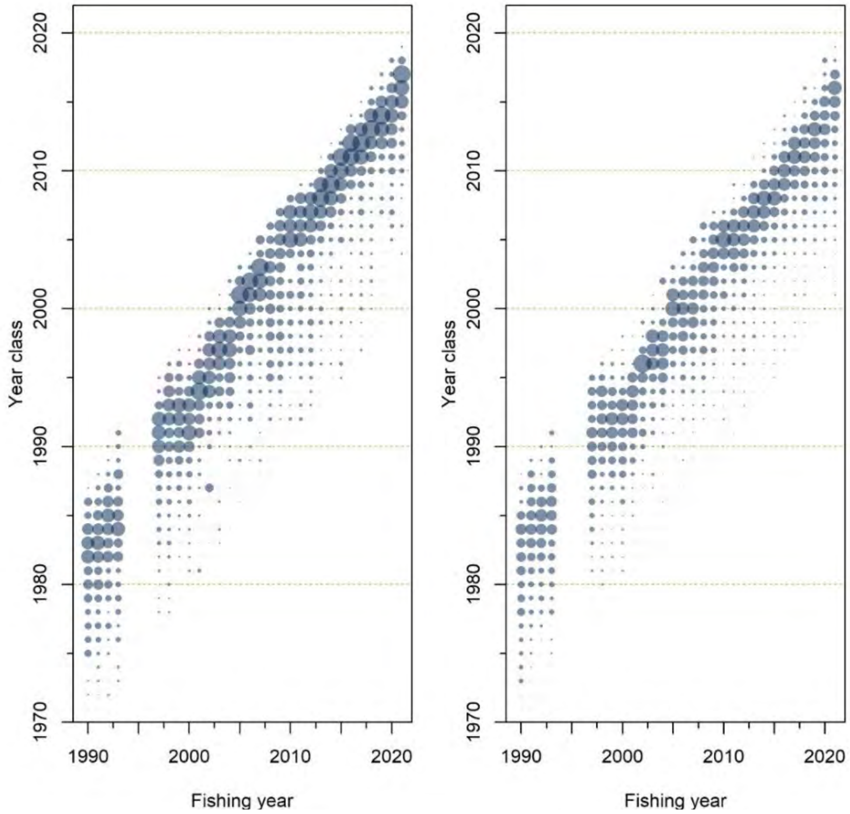


Figure 11: Proportion of hake estimated in the HAK 7 fishery by age-group (x-axis) and year class (y-axis) for data collected from 1990 to -2021.

Table 19: Revised landings (t) from fishing years 1975 to 2022 for the WCSI. Note, these relate to biological stocks, not QMAs.

Fishing year	West Coast S.I.	Fishing year	West Coast S.I.	Fishing year	West Coast S.I.
1974–75	71	1990–91	8 246	2006–07	7 696
1975–76	5 005	1991–92	3 026	2007–08	2 617
1976–77	17 806	1992–93	7 131	2008–09	5 952
1977–78	498	1993–94	2 974	2009–10	2 346
1978–79	4 737	1994–95	9 373	2010–11	3 586
1979–80	3 600	1995–96	9 937	2011–12	4 459
1980–81	2 565	1996–97	8 022	2012–13	5 434
1981–82	1 625	1997–98	7 882	2013–14	3 641
1982–83	745	1998–99	9 098	2014–15	6 219
1983–84	945	1999–00	7 446	2015–16	2 863
1984–85	965	2000–01	9 344	2016–17	4 701
1985–86	1 918	2001–02	7 519	2017–18	3 085
1986–87	3 755	2002–03	7 432	2018–19	1 562
1987–88	3 009	2003–04	7 943	2019–20	2 063
1988–89	8 696	2004–05	7 315	2020–21	1 367
1989–90[1]	8 741	2005–06	6 906	2021–22	2 272*

* Catch for 2021–22 was assumed to be equal to the TACC.

4.3.3 Model estimation

Model parameters were derived using Bayesian estimation, implemented by using the general-purpose stock assessment program CASAL v2.30 (Bull et al 2012). For final model runs, the full posterior distribution was sampled using Markov chain Monte Carlo (MCMC) methods.

The model was fitted to proportions-at-age using a multinomial likelihood, and to the survey abundance index using a lognormal likelihood. The multinomial observation error effective sample sizes for the at-age data were adjusted using the reweighting procedure of Francis (2011). No additional process error was assumed for the *Tangaroa* research survey as the Francis reweighting estimated no additional process error. Ageing error was assumed to occur for the observed proportions-at-age data, by assuming a normally distributed error with a CV of 0.08.

Year class strengths were assumed known (and equal to one) for years before 1974 and after 2015, when inadequate or no catch-at-age data were available. Otherwise, year class strengths were estimated under the assumption that the estimates from the model average to one.

4.3.4 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 20. The priors for B_0 and selectivities were relatively uninformed and had wide bounds. Priors for the year class strengths were assumed to be relatively uninformed with lognormal priors with mu = 1.0 and CV = 1.1. The prior for the survey q was informative and was estimated using the hake survey priors from other areas as a starting point (see section 4.1.2) because the survey series in both areas used the same vessel and fishing gear. However, the WCSI survey area in the 200–800 m depth range comprised 12 928 km^2; seabed area in that depth range in the entire HAK 7 biological stock area (excluding the Challenger Plateau) is estimated to be about 24 000 km^2. Because the biomass survey coverage only includes 54% of the known WCSI hake habitat, the mean of the Chatham Rise prior was modified accordingly (i.e., $0.16 \times 0.54 = 0.09$). Bounds were assumed to be wide and were 0.001–1.0.

A penalty function was used to constrain the model so that any combination of parameters that resulted in a stock size that was so low that the historical catch could not have been taken was strongly penalised.

Table 20: The assumed priors for key distributions (when estimated) for the WCSI stock assessment. The parameters are mean (in natural space) and CV for lognormal and normal priors.

Parameter description	Distribution	Parameters		Bounds	
B_0	Uniform-log	–	–	25 000	250 000
Year class strengths	Lognormal	1.0	1.1	0.01	100
Trawl survey q	Lognormal	0.09	0.79	0.01	1.00
Selectivities	Uniform	–	–	0	50

4.3.5 Model sensitivities

Three main model sensitivity models were developed: (i) assuming year classes before 1985 were fixed at one, (2) and a low *M* (0.15 y^{-1}), and (3) high *M* (0.23 y^{-1}) assumption.

Additional sensitivities (not shown) explored the exclusion of the 2000 survey index, the use of the RV *Kaharoa* WCSI inshore research survey biomass and length frequency data as an index of juvenile abundance, the choice of domed selectivities for the fishery and the RV *Tangaroa* survey, introducing a time split in the south shallow fishery after 2006, upweighting and downweighting the *Tangaroa* survey index, and assuming a lower steepness (h=0.7) for the stock. These sensitivities did not significantly change the initial or current status of the model nor estimates of future status under the projection assumptions.

The fixed 1984 YCS sensitivity was to explore the effect of fixing the early and uncertain, year classes in the model. This sensitivity suggested that the fixing of early year classes resulted in a higher stock status than the base case. The low *M* and high *M* sensitivities suggested similar initial biomass (B_0) but lower status for the low *M* sensitivity (31% B_0) and higher status for the high *M* sensitivity (45% B_0).

The remaining sensitivities also gave similar outcomes to the base case with status ranging between 30% B_0 when the *Kaharoa* biomass and length frequencies were included and 41% B_0 when the south shallow fishery was split into two time periods (up to 2006, and 2007 onwards).

Estimates of the status in 2019 (the time that the previous stock assessment was carried out) gave similar, but slightly higher estimates of status for 2019, with the base case giving a status in 2019 of 25% B_0 (95% CIs 18–36 % B_0) compared with an estimate of 17% from the 2019 assessment.

4.3.6 Model estimates

Results from the base case assessment model and the three main sensitivity models are presented here. For all models, MPD fits were obtained and qualitatively evaluated; MCMC estimates of the median posterior and 95% percentile credible intervals were determined for current and virgin biomass; and projected state calculated under assumptions of recent year classes (i.e., assuming future year class strengths were equal to the period 2006–2015) and all year class strengths (i.e., the period 1975–2015).

The base case stock assessment model estimated spawning stock biomass declined throughout the late 1970s (see Figure 15) when there were relatively high catch levels. The biomass then increased through the mid-1980s, after which it steadily declined to a low point in 2018–19 because of the higher levels of exploitation and below-average recruitment between 2000–01 and 2014–15 (Figure 12). The stock followed the general trend shown by the trawl survey index (Table 13).

The sensitivity models produced similar trends in the biomass trajectory and in the pattern of year class strength. The base case model estimated the status in 2018–19 to be 25.0% B_0 (95% CIs 18–35%) of initial biomass (B_0), and the current status (2022) to be 39 % B_0 (95% CIs 30–52%) (Table 21). Because of uncertainty in the early YCS, a sensitivity that fixed early YCS to 1984 at one was run. This showed that the assumptions of early YCS being forced to have a lower average had considerable impact on current status. This sensitivity gave a less credible estimate of current status and was much higher than the status estimated for the base case.

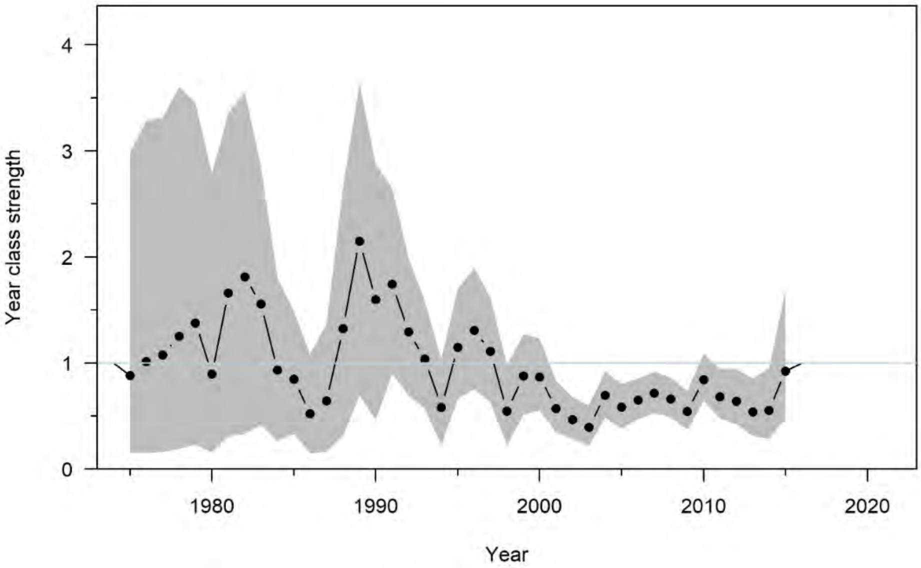


Figure 12: MCMC estimates of year class strengths for the base case model with median (line and individual points) and 95% credible interval (grey band).

Table 21: Bayesian median (95% credible intervals) (MCMC) of B_0 and SSB_{2022} (t), and SSB_{2022} as a percentage of B_0 for the WCSI models. The run with the 1984 fixed YCS was considered by the Plenary to not be credible.

Model run	B_0	SSB_{2022}	SSB_{2022} (% B_0)
Base case	78 870 (74 140–84 810)	30 350 (22 450–43 390)	38.6 (29.5–52.2)
Fixed 1984 YCS*	81 680 (74 440–92 170)	54 080 (35 390–80 350)	66.1 (47.5–87.4)
Low M	80 020 (76 550–84 670)	25 140 (18 080–36 640)	31.4 (23.3–43.5)
High M	85 650 (78 710–94 600)	38 580 (29 070–53 920)	45.1 (35.3–59.4)

* Deemed not to be a credible run.

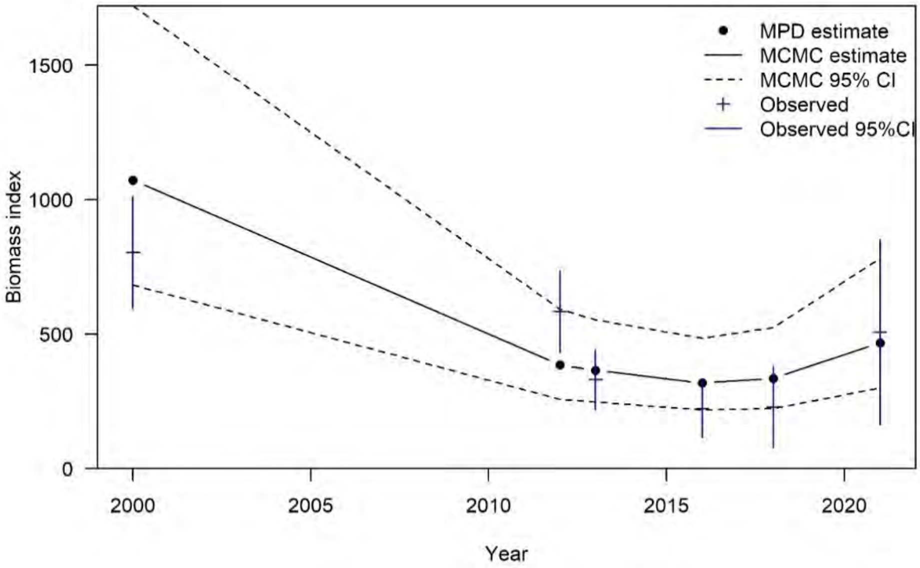


Figure 13: Fit of the base case model to the survey index of abundance from *Tangaroa* research survey for the core strata.

Base case MPD estimates indicated that hake were fully selected by about age 7, similar to the age of maturity and that the three fisheries had similar selectivity by age, but different selectivities by sex (Figure 14).

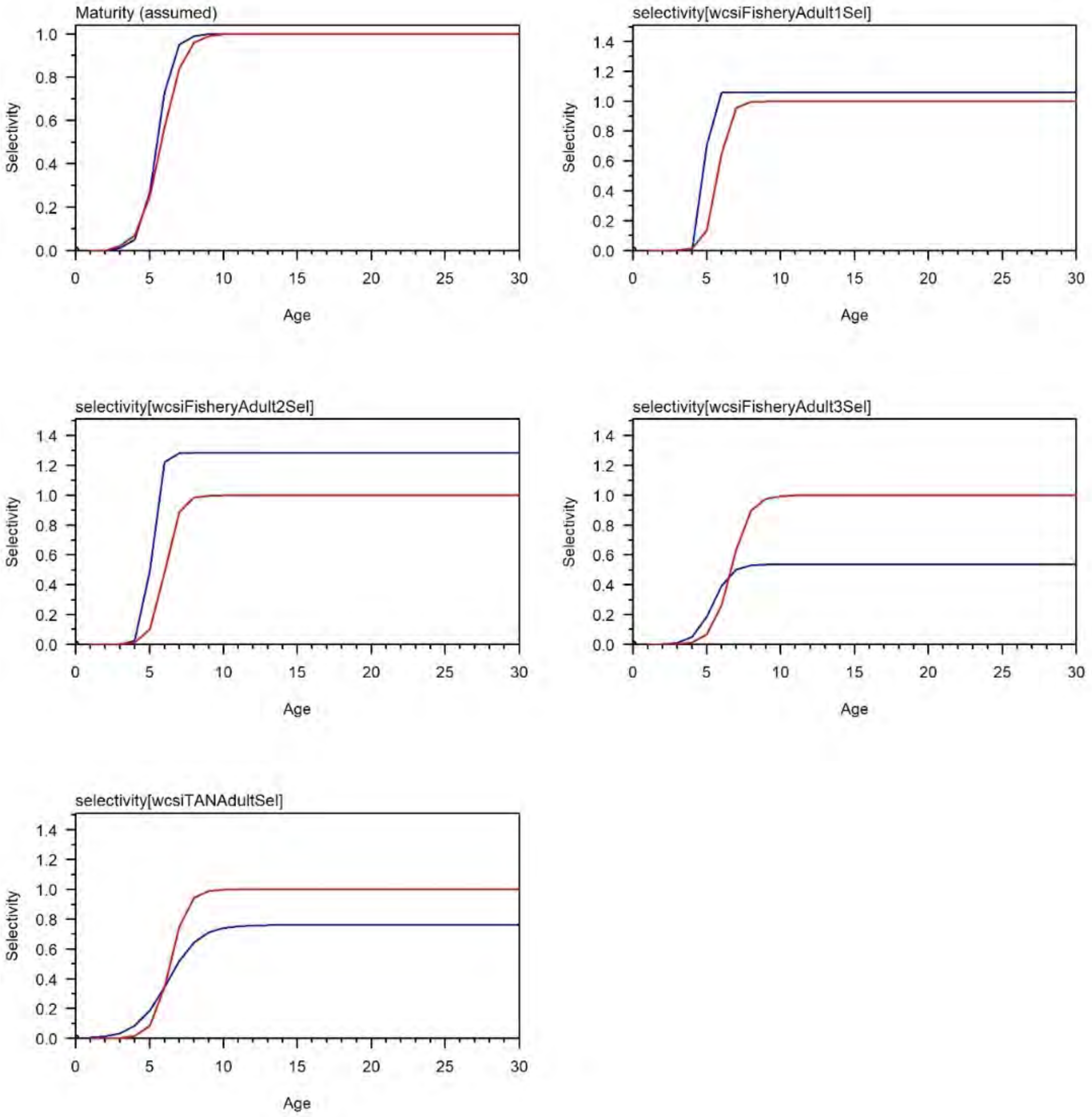


Figure 14: Assumed maturity ogive (top left) and the MPD estimated selectivities for the base case model for the three fisheries and the *Tangaroa* research survey.

4.3.8 Yield estimates and projections

The status of HAK 7 was projected for 5 years (2023–2027), assuming two scenarios for the future catch: (1) catches remaining at the average of 2019–2021 levels (1664 t), and (2) catches at the TACC limit (2272 t). For each projection scenario, future recruitment deviates were sampled from either all years (1974–2015) or for the most recent ten years (2006–2015). Note that the RV *Tangaroa* survey in 2018 and 2021 suggested that the 2016 year class may be near the long-term average but above the recent (2006–2015) average, but these observations were not used in the projections.

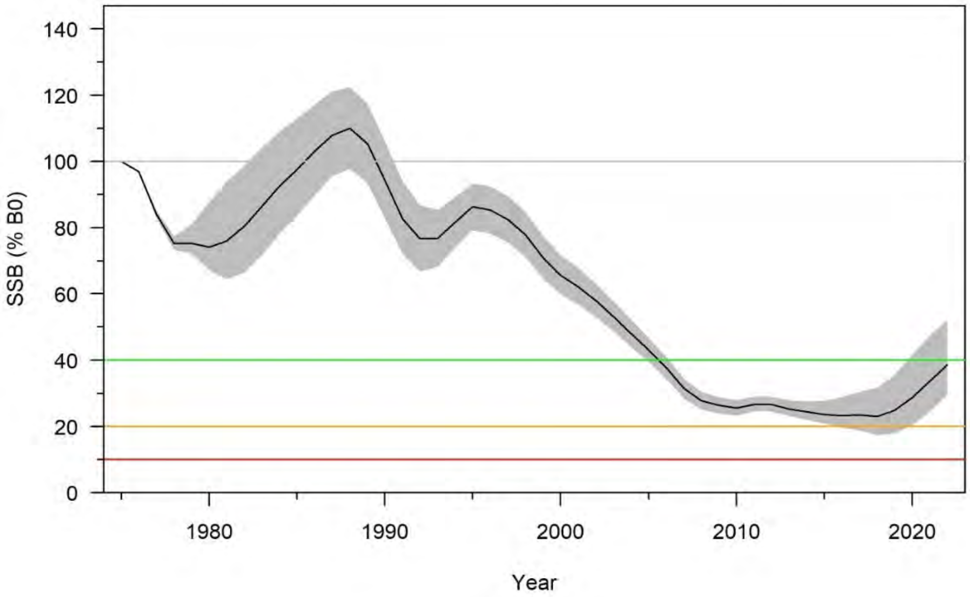


Figure 15: Estimated median spawning stock biomass trajectories for the WCSI stock base case (with 95% credible intervals shown as grey band) for biomass as a percentage of B_0. The red horizontal line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and the green line is the % B_0 target (40% B_0).

Projections with the base case model using the 2006–2015 recruitment series indicated that spawning biomass will continue to rebuild towards the target biomass for both the current catch (Figure 16) and if catches were at the TACC (Figure 17). If recruitments increased to earlier levels, the biomass is likely to exceed the target (Table 22, Figure 16, Figure 17). The projected stock status in relation to the limits and target are presented in Table 23.

Table 22: Bayesian median (t) and 95% credible intervals of projected B_{2027}, B_{2027} as a percentage of B_0, and B_{2027}/B_{2022} (%) for the base case under two future annual catch scenarios and two future recruitment scenarios.

Future catch (t)	Future YCS	B_{2022}	B_{2027}	B_{2027} (%B_0)	B_{2027}/B_{2022} (%)
Base case					
1664	2006–2015	25 820 (16 770–41 850)	31 650 (20 450–50 130)	40.2 (26.8–60.5)	122.4 (105.1–142.3)
2772		25 820 (16 770–41 850)	29 580 (18 350–48 060)	37.5 (24.0–58.0)	114.1 (97.3–133.7)
1664	1974–2015	30 150 (18 920–47 970)	45 520 (27 840–71 030)	57.7 (36.1–88.5)	148.1 (103.7–230.4)
2772		30 150 (18 920–47 970)	43 420 (25 740–68 920)	55.0 (33.4–85.8)	141.1 (98.1–222.8)

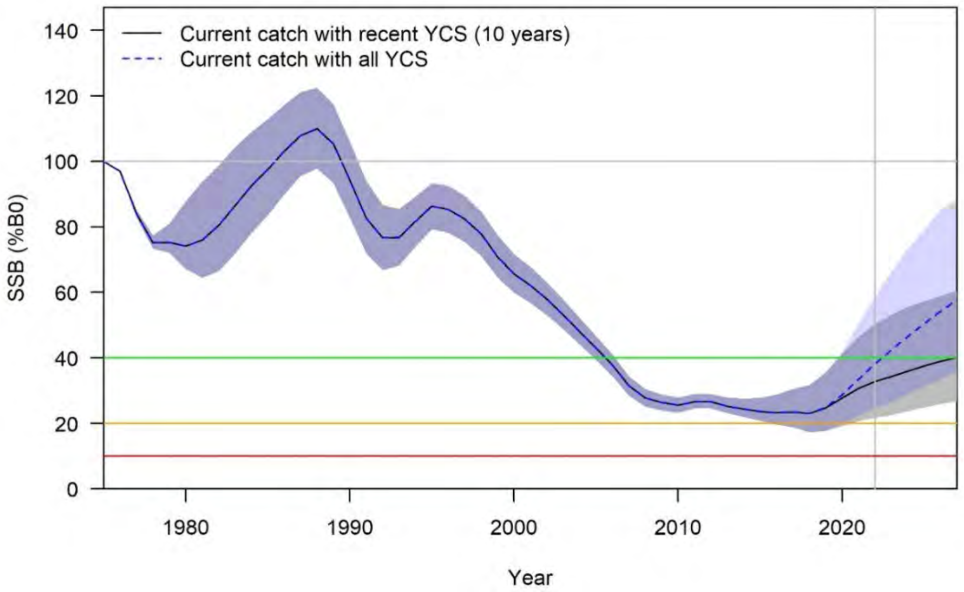


Figure 16: Spawning stock biomass (*SSB*) trajectories including projections from 2023 to 2027 for the base model, projected with catch of 1664 t, with YCS sampled from all years or most recent estimated 10 years (with 95% credible intervals shown as blue band for the long-term recruitments and grey band for the recent recruitments) for biomass as a percentage of B_0. The red horizontal line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and the green line is the % B_0 target (40% B_0).

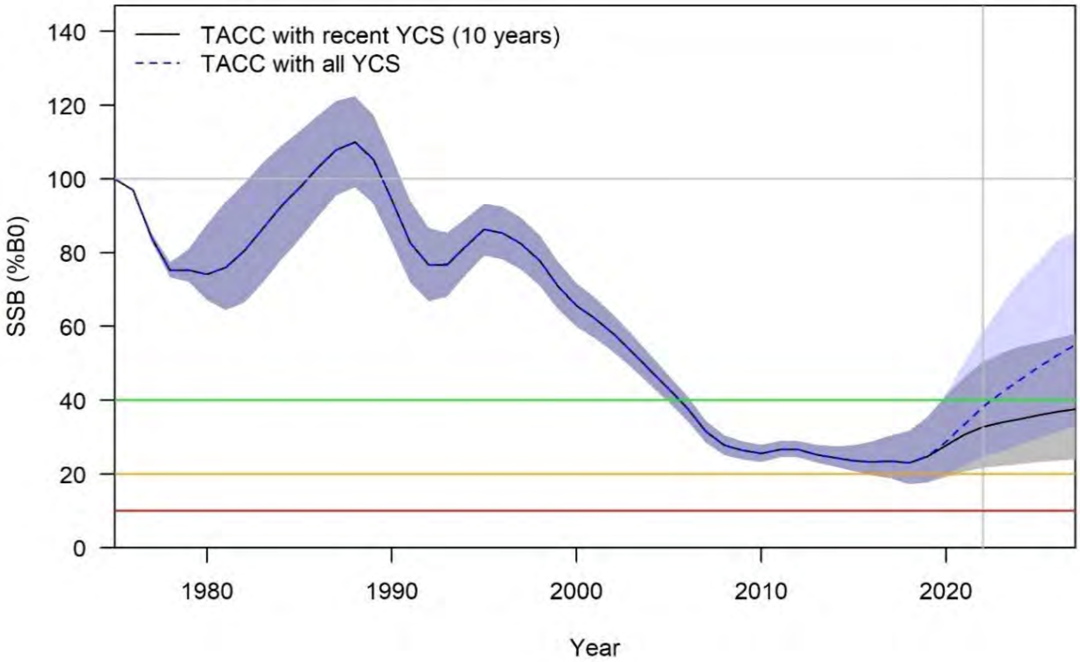


Figure 17: Spawning Stock Biomass (*SSB*) trajectories including projections from 2023 to 2027 for the base model, projected with catch equal to the TACC (2772 t), with YCS sampled from all years or most recent estimated 10 years (with 95% credible intervals shown as blue band for the long-term recruitment and grey band for the recent recruitments) for biomass as a percentage of SSB_0. The red horizontal line at 10% SSB_0 represents the hard limit, the orange line at 20% SSB_0 is the soft limit, and the green line is the % B_0 target (40% SSB_0).

Table 23: Probability of the stock being less than 10% and 20% SSB_0 and greater than 40% SSB_0 for the base case in 2027 with either current catch (1664 t) or TACC (2772 t).

Future catch (t)	Future YCS	P(> 40%)	P(< 20%)	P(< 10%)
Base case				
1664	2006–2015	0.51	0.00	0.00
2772		0.39	0.00	0.00
1664	1974–2015	0.93	0.00	0.00
2772		0.89	0.00	0.00

5. FUTURE RESEARCH CONSIDERATIONS

All HAK stocks

- Review historical ageing of hake to address the uncertainty seen in the1990s.

HAK 1

- Review the age and length data for Sub-Antarctic hake in HAK1 and verify the estimated proportions at age for the commercial data, specifically for periods up to 2000, before further assessments are conducted for this stock.
- Explore the spatial-temporal structure of Sub-Antarctic hake in HAK1 refine the best possible definitions of fisheries for this stock.
- Consider exclusion of the 2017 *Tangaroa* Sub-Antarctic trawl survey biomass estimate from future stock assessments of HAK 1, given that making adjustments to correct this estimate will introduce some undefinable uncertainty.

HAK 7

- Explore the linkage between HAK 7 and HAK 1, particularly the linkage to Puysegur.
- Consider novel options to address concerns regarding the WCSI trawl survey coverage in relation to the HAK 7 stock, particularly the region south of the survey area where much of the commercial fishery takes place. Increasing coverage using bottom trawls is not possible given the topography of this area. Tagging and acoustics have also been previously considered and could be revisited if the stock continues to increase.

- Determine the optimal frequency or periodicity of *RV Tangaroa* surveys to monitor biomass and detect recruitment patterns (e.g., two consecutive surveys every 5 years, or one survey every 3 years), considering both costs and potential benefits.
- Continue development of spatio-temporal analyses to understand the length, age and sex structure of the WCSI hake survey and commercial data using alternative spatial analyses (juveniles, sub-adults and adults) with consideration of seasonal spawning cycles and the timing of surveys.
- Investigate whether juveniles from *RV Tangaroa* (and possibly *RV Kaharoa*) surveys could provide an index of recruitment for the projections.
- Consider development of spatial age-length relationships and the value of additional age data. Further evaluate ageing “outliers”.
- Explore potential climate impacts on spatial and temporal population dynamics and recruitment to the stock.
- Continue spatio-temporal analyses of fisheries CPUE data with consideration of seasonal variability.

6. STATUS OF THE STOCKS

Stock Structure Assumptions
Hake are assessed as three independent biological stocks, based on the presence of three main spawning areas (eastern Chatham Rise, south of Stewart-Snares shelf, and WCSI), and some differences in biological parameters between these areas.

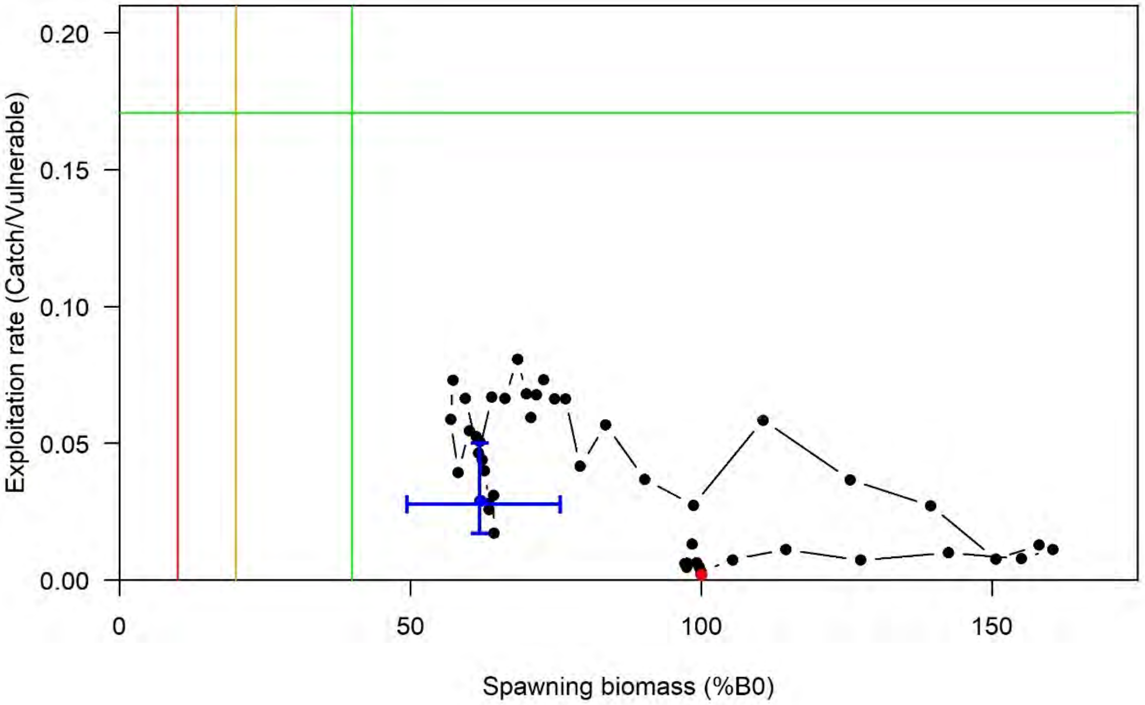
The HAK 1 Fishstock includes all the Sub-Antarctic biological stock, part of the Chatham Rise biological stock, and all hake around the North Island (which are more likely part of either the WCSI or Chatham Rise stocks). The Sub-Antarctic stock is defined as all of Fishstock HAK 1 south of the Otago Peninsula; the Chatham Rise stock is all of HAK 4 plus that part of HAK 1 north of the Otago Peninsula; the WCSI stock is HAK 7.

- **Sub-Antarctic Stock (HAK 1 South of Otago Peninsula)**

Stock Status	
Year of Most Recent Assessment	2021
Assessment Runs Presented	Reference case
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%}$
Status in relation to Target	B_{2021} was estimated at 62% B_0; Very Likely (> 90%) to be at or above the target
Status in relation to Limits	B_{2021} is Exceptionally Unlikely (< 1%) to be below both the Soft and Hard Limits
Status in relation to Overfishing	Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is estimated to have been stable since 2010.
Recent Trend in Fishing Mortality or Proxy	Exploitation rate is estimated to have been low throughout the duration of the fishery.
Other Abundance Indices	A CPUE series showed a similar (albeit slightly larger decline) in the biomass trend in the research surveys.
Trends in Other Relevant Indicators or Variables	Recent year classes (since 2008) have been below average.

Historical Stock Status Trajectory and Current Status



Trajectory over time of exploitation rate (*U*) and spawning biomass (%B_0), for the Sub-Antarctic stock reference model from the start of the assessment period in 1974 (represented by a red point), to 2021 (blue cross). The red vertical line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and green lines are the %B_0 target (40% B_0) and the corresponding exploitation rate (U_{40}= 0.17 calculated using CASAL CAY calculation). Biomass and exploitation rate estimates are medians from MCMC results.

Projections and Prognosis	
Stock Projections or Prognosis	The biomass of the Sub-Antarctic stock was expected to remain stable at recent average catch levels. At the TACC, the stock biomass is expected to slowly decline.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Exceptionally Unlikely (< 1%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Current catch: Extremely Unlikely (< 1%) TACC: Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl survey: summer, autumn) - Proportions-at-age data from the commercial fisheries and trawl surveys - Estimates of biological parameters	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	- Commercial CPUE (used in sensitivity run only)	2 – Medium Quality: potentially biased owing to changes in

		spatial extent and fishing practices
Changes to Model Structure and Assumptions	-Revisions to annual cycle -Removal of the September *Tangaroa* biomass index	
Major Sources of Uncertainty	- The summer trawl survey series estimates are variable and catchability may vary between surveys. The general lack of contrast in this series (the main relative abundance series) makes it difficult to accurately estimate past and current biomass. - The assumption of a single Sub-Antarctic stock (including the Puysegur Bank), independent of hake in all other areas, is the most parsimonious interpretation of available information. However, this assumption may not be correct. - Uncertainty about the size of recent year classes affects the reliability of stock projections. - Although the catch history used in the assessment has been corrected for some misreported catch (see Section 1.4), it is possible that additional misreporting exists. - There is concern that there may be spatial structure that is not adequately captured in the model	

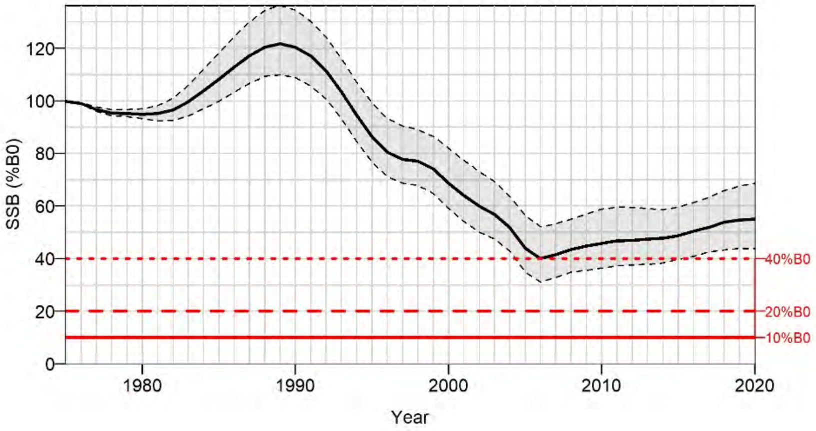
Qualifying Comments
-

Fishery Interactions
Hake are often taken as a bycatch in hoki target fisheries. Some target fisheries for hake do exist, with the main bycatch species being hoki, ling, silver warehou, and spiny dogfish. Hake are a key predator of hoki. Incidental interactions and associated mortality have been recorded for some protected species, including New Zealand fur seals and seabirds.

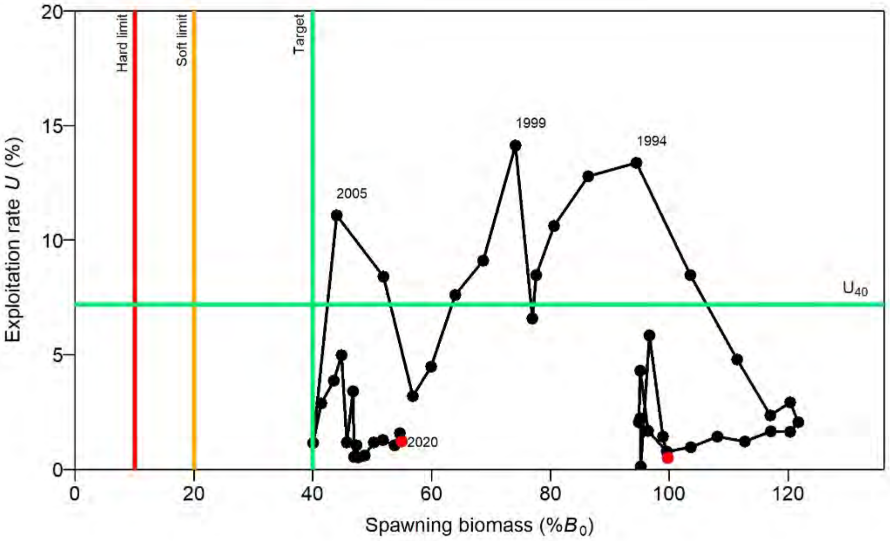
- **Chatham Rise Stock (HAK 4 plus HAK 1 north of Otago Peninsula)**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	An agreed base case, fitted primarily to a research survey abundance series
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%Bo}$
Status in relation to Target	B_{2020} was estimated to be about 55% B_0; Very Likely (> 90%) to be at or above target
Status in relation to Limits	B_{2020} is Exceptionally Unlikely (< 1%) to be below the Soft or Hard Limits
Status in relation to Overfishing	Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Historical Stock Status Trajectory and Current Status



Trajectory over time of spawning biomass (% *B0*, with 95% credible intervals shown as broken lines) for the Chatham Rise hake stock from the start of the assessment period in 1975 to 2020 (the final assessment year). The management target (40% *B0*, short dash horizontal line) and soft limit (20% *B0*, dashed horizontal line) and hard limit (solid line) are shown. Years on the x-axis indicate fishing year with "2005" representing the 2004–05 fishing year. Biomass estimates are based on MCMC results.



Trajectory over time of exploitation rate (*U*) and spawning biomass (% *B0*), for the HAK 4 stock base model from the start of the assessment period in 1975 (represented by a red point), to 2020 (red and labelled). The red vertical line at 10% *B0* represents the hard limit, the orange line at 20% *B0* is the soft limit, and green lines are the %*B0* target (40% *B0*) and the corresponding exploitation rate (*U40*). Biomass and exploitation rate estimates are medians from MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Median estimates of biomass fell to 40% B_0 in 2006, but biomass has been slowly increasing since 2007.
Recent Trend in Fishing Intensity or Proxy	Fishing pressure is estimated to have been low since 2006 (relative to estimated fishing pressure in most years from 1994 to 2005).
Other Abundance Indices	The CPUE index for the eastern Chatham Rise has been increasing since 2012.
Trends in Other Relevant Indicators or Variables	Recruitment (1996–2013, but excluding 2002 and 2011) is estimated to be lower than the long-term average for this stock.

Projections and Prognosis	
Stock Projections or Prognosis	Expectations for the biomass of the Chatham Rise stock over the next 5 years depends on whether recruitment is assumed able to increase to levels from throughout the time series or

	assumed to be restricted to levels seen recently. If the former, then catch levels equivalent to those from recent years (i.e., about 360 t annually) are expected to result in an increase in SSB, but if recruitments are restricted to the levels of recent years SSB is expected to remain more or less constant. If future catches increase to the level of the full HAK 4 TACC of 1800 t, biomass is expected to decline under both recruitment scenarios with the median estimate reaching 40% B_0 in 2025 under the more pessimistic recruitment assumption.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Assuming recent recruitment and current catch (362 t): Soft Limit: Exceptionally Unlikely (< 1%) Hard Limit: Exceptionally Unlikely (< 1%) Assuming recent recruitment and future catches at 1800 t (based on the HAK 4 TACC): Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Assuming recent recruitment and future catches at the level of the current catch: Very Unlikely (< 10%) Assuming recent recruitment and future catches at 1800 t (based on the HAK 4 TACC): About as Likely as Not (40–60%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl survey)	1 – High Quality
	- Proportions-at-age data from the commercial fisheries and trawl surveys	1 – High Quality
Data not used (rank)	- Commercial CPUE	2 – Medium or Mixed Quality: does not track stock biomass well, and was used in a sensitivity model
Changes to Model Structure and Assumptions	- Selectivity for the commercial fishery to the east of the Chatham Rise is modelled as logistic (double normal previously) - Catch history revised from 2009 onwards	
Major Sources of Uncertainty	- Catch at age information from the commercial catch has not been available since 2016 due to declining catches - Although the catch history used in the assessment has been corrected for some misreported catch (see Section 1.4), it is possible that additional misreporting exists	

Qualifying Comments
- In October 2004, large catches were taken in the western deep fishery (i.e., near the Mernoo Bank). This was repeated to a lesser extent in 2008 and 2010. There is no information indicating whether these aggregations fished on the western Chatham Rise were spawning; if they were then this might indicate that there is more than one stock on the Chatham Rise. However, the progressive increase in mean fish size from west to east is indicative of a single homogeneous stock on the Chatham Rise.

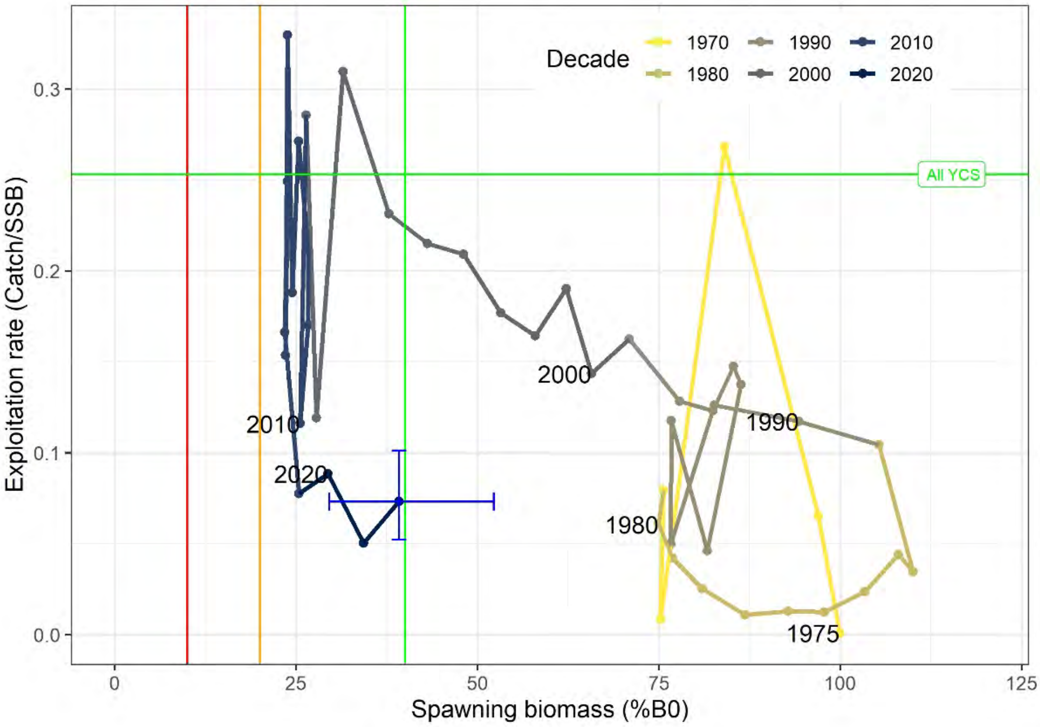
- A pronounced reduction in average recruitment over 40 years may indicate a decline in the productivity of this stock.

Fishery Interactions
Hake are often taken as a bycatch catch in hoki target fisheries. Some target fisheries for hake do exist, with the main bycatch species being hoki, ling, silver warehou and spiny dogfish. Hake are a key predator of hoki. Incidental interactions and associated mortality have been recorded for some protected species, notably New Zealand fur seals and seabirds.

- **West Coast South Island Stock (HAK 7)**

Stock Status	
Year of Most Recent Assessment	2022
Assessment Runs Presented	Base case
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%B_0}$
Status in relation to Target	B_{2022} was estimated to be 39% B_0; About as Likely as Not (40–60%) to be at or above the target
Status in relation to Limits	B_{2022} was Unlikely (< 40%) to be below the Soft Limit and Very Unlikely (< 10%) to be below the hard Limit
Status in relation to Overfishing	Overfishing in 2022 was Unlikely (< 40%) to be occurring

Historical Stock Status Trajectory and Current Status



Trajectory over time of exploitation rate (U) and spawning biomass (% B_0), for the HAK 7 base case model, from the start of the assessment period in 1975 (represented by a yellow point), to 2022. The red vertical line at 10% SSB_0 represents the hard limit, the orange line at 20% SSB_0 is the soft limit, and green lines are the %SSB_0 target (40% SSB_0) and the corresponding exploitation rate (U_{40} = 0.25 based on all YCS, calculated using CASAL CAY calculation. Biomass and exploitation rate estimates are medians from MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	- Biomass has increased substantially since 2019

Recent Trend in Fishing Intensity or Proxy	- The exploitation rate was estimated to have been low from 2019 to 2021.
Other Abundance Indices	
Trends in Other Relevant Indicators or Variables	- Recruitment from 2006–2014 was estimated to be lower than the long-term average. The 2021 survey found a high abundance of juveniles suggesting that recruitment in 2015 and 2016 is likely to be higher than in 2006–2014.

Projections and Prognosis	
Stock Projections or Prognosis	- The biomass of the WCSI stock is expected to increase under both recent recruitment and long-term recruitment, for both the current catch and the TACC
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	- Using recent average recruitment: Current catch: Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%) TACC: Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Using recent average recruitment: Current catch: Very Unlikely (< 10%) TACC: Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2022	2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- RV *Tangaroa* research trawl surveys (2000-2021 for core area) - Proportions-at-age data from the commercial fishery and research surveys - Estimates of fixed biological parameters	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	- RV *Kaharoa* WCSI inshore trawl survey - RV *Tangaroa* survey estimates from outside the core area - Commercial fishery CPUE	- Does not monitor the adult stock and may not monitor juvenile abundance - Time series not long enough - May not track stock biomass
Changes to Model Structure and Assumptions	- New model assumes three fleets-as-areas fisheries selectivities rather than two period based selectivities - Base case model updated to use the core strata survey series (and included the 2000 survey estimate) rather than all strata series	
Major sources of Uncertainty	- Uncertainty about the size of recent year classes affects current stock status and the reliability of stock projections	

	- The spatial and temporal representativeness of the RV *Tangaroa* research survey of the hake stock on the WCSI is not known - Although the catch history used in the assessment has been corrected for some misreported catch (see Section 1.4), it is possible that additional misreporting exists

Qualifying Comments
-

Fishery Interactions
- The main bycatch species of hoki-hake-ling-silver warehou-white warehou target fisheries are rattails, javelin fish, and spiny dogfish. Hake are a key predator of hoki. Incidental interactions and associated mortality have been recorded for protected species, including New Zealand fur seals and seabirds.

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HOKI (HOK)

(*Macruronus novaezelandiae*)
Hoki

1. FISHERY SUMMARY

1.1 Commercial fisheries

Historically, the main fishery for hoki operated from mid-July to late August off the west coast of the South Island (WCSI) where hoki aggregate to spawn. The spawning aggregations begin to concentrate in depths of 300–700 m around the Hokitika Canyon from late June, and further north off Westport later in the season. Fishing in these areas continues into September in some years. Starting in 1988, another major fishery developed in Cook Strait, where separate spawning aggregations of hoki occur. The spawning season in Cook Strait runs from late June to mid-September, peaking in July and August. Small catches of spawning hoki are taken from other spawning grounds off the east coast South Island (ECSI) and late in the season at Puysegur Bank.

Outside the spawning season, when hoki disperse to their feeding grounds, substantial fisheries have developed since the early 1990s on the Chatham Rise and in the Sub-Antarctic. These fisheries usually operate in depths of 300–800 m. The Chatham Rise fishery generally has similar catches over all months except in July-September, when catches are lower due to the fishery moving to the spawning grounds. In the Sub-Antarctic, catches have typically peaked in April-June. Out-of-season catches are also taken from Cook Strait and the east coast of the North Island, but these are small by comparison.

The hoki fishery was developed by Japanese and Soviet vessels in the early 1970s. Catches peaked at 100 000 t in 1977 but dropped to less than 20 000 t in 1978 when the EEZ was declared and quota limits were introduced (Table 1). From 1979 on, the hoki catch increased to about 50 000 t until an increase in the TACC from 1986 to 1990 saw the fishery expand to a maximum catch in 1987–88 of about 255 000 t (Table 2).

From 1986 to 1990, surimi vessels dominated the catches and took about 60% of the annual WCSI catch. However, after 1991, the surimi component of catches decreased and processing to head and gut, or to fillet product increased, as did “fresher” catch for shore processing. The hoki fishery now operates throughout the year, producing high quality fillet product from both spawning and non-spawning fisheries. No surimi has been produced from hoki since 2002. Since 1998, twin-trawl rigs have operated in some hoki fisheries, and trawls made of spectra twine (a high strength twine with reduced diameter resulting in reduced drag and improved fuel efficiencies) were introduced to some vessels in 2007–08.

Between 2012–13 and 2017, Precision Seafood Harvest (PSH) technology was tested in the hoki fishery. This included a prototype trawl system called a Modular Harvest System (MHS) that aimed to target specific species and fish size, as well as enabling fish to be landed in much better condition than traditional trawls. Approval to use MHS gear in the hoki, hake, and ling fisheries was granted in 2018. During the 2017–18 fishing year, seven vessels used the gear to target hoki and caught 9595 t (7% of the total hoki catch). The MHS catch increased to 17 127 t (14% of the total catch) in 2018–19 but has subsequently decreased due to a change in preference of product from fillet to block. In 2020–21, only 2453 t (2.4 % of the total catch) was taken with MHS.

Table 1: Reported trawl catches (t) by fleet from 1969 to 1987–88, 1969–1983 by calendar year, 1983–84 to 1987–88 by fishing year (Oct-Sept). Source - FSU data.

				New Zealand		
Year	**USSR**	**Japan**	**South Korea**	**Domestic**	**Chartered**	**Total**
1969	–	95	–	–	–	95
1970	–	414	–	–	–	414
1971	–	411	–	–	–	411
1972	7 300	1 636	–	–	–	8 936
1973	3 900	4 758	–	–	–	8 658
1974	13 700	2 160	–	125	–	15 985
1975	36 300	4 748	–	62	–	41 110
1976	41 800	24 830	–	142	–	66 772
1977	33 500	54 168	9 865	217	–	97 750
1978*	†2 028	1 296	4 580	678	–	8 581
1979	4 007	8 550	1 178	2 395	7 970	24 100
1980	2 516	6 554	–	2 658	16 042	27 770
1981	2 718	9 141	2	5 284	15 657	32 802
1982	2 251	7 591	–	6 982	15 192	32 018
1983	3 853	7 748	137	7 706	20 697	40 141
1983–84	4 520	7 897	93	9 229	28 668	50 407
1984–85	1 547	6 807	35	7 213	28 068	43 670
1985–86	4 056	6 413	499	8 280	80 375	99 623
1986–87	1 845	4 107	6	8 091	153 222	167 271
1987–88	2 412	4 159	10	7 078	216 680	230 339

* Catches for foreign licensed and New Zealand chartered vessels from 1978 to 1984 are based on estimated catches from vessel logbooks. Few data are available for the first 3 months of 1978 because these vessels did not begin completing these logbooks until 1 April 1978.

† Soviet hoki catches are taken from the estimated catch records and differ from official MAF statistics. Estimated catches are used because of the large amount of hoki converted to meal and not recorded as processed fish.

Annual catches ranged between 175 000 t and 215 000 t from 1988–89 to 1995–96, increasing to 246 000 t in 1996–97, and peaking at 269 000 t in 1997–98, when the TACC was over-caught by 19 000 t. Catches declined, tracking the TACC as it was reduced to address poor stock status, reaching a low of 89 000 t in 2008–09, then increasing again up to 161 500 t in 2014–15 following increases in the TACC as stock status improved (Table 2). The TACC was reduced to 150 000 t in 2015–16 and catches in the next four years were below this level (Table 2). The fishing industry voluntarily shelved 20 000 t of western ACE in 2018–19, leading to an effective lowering of the western catch limit in that year to 70 000 t. The TACC was further reduced to 115 000 t in 2019–20 when the annual catch was 107 700 t. In 2020–21, the TACC remained the same, but available ACE (allowing for shelving and carry-forward) was 52 984 t in the west and 60 899 t for the east, with an annual catch of 100 817 t. The TACC for 2021–22 was reduced to 110 000 t with agreed catch limits of 45 000 t for the western stock and 65 000 t for the eastern stock and there was also an agreement that in the 2021–22 fishing year, catches would be limited to 100 000 t (plus any carryover) with a catch split of 45 000 t from the western stock areas and 55 000 t for the eastern stock areas.

The pattern of fishing has changed markedly since 1988–89 when over 90% of the total catch was taken in the WCSI spawning fishery. This has been due to a combination of TACC changes and redistribution of fishing effort. The WCSI fishery accounted for about 35% of the total hoki catch in 2020–21 and was the second largest hoki fishery in New Zealand behind the Chatham Rise (CR) (Table 3). Cook Strait (CS) catches peaked at 67 000 t in 1995–96 but have been relatively stable in the range from 12 500 t to 21 500 t in the past 14 years. The Chatham Rise was the largest hoki fishery in 2020–21 and contributed about 38% of the total catch. Catches from the Sub-Antarctic (SA) peaked at over 30 000 t from 1999–2000 to 2001–02 but have been variable since, ranging between 6600 t and 19 900 t over the past 14 years (Table 3). Catches from other areas remained at relatively low levels (Table 3).

Table 2: Reported catch (t) from QMS, estimated catch (t), and TACC (t) for HOK 1 from 1986–87 to 2020–21. Reported catches are from the QMR and MHR systems. Estimated catches include TCEPR and CELR data (from 1989–90), LCER data (from 2003–04), NCELR data (from 2006–07), TCER, and LTCER data (from 2007–08), and ERS-trawl data (from 2017–18). Catches from 1986–87 to 1999–00 are rounded to the nearest 500 t.

Year	Reported catch	Estimated catch	TACC
1986–87	158 000	175 000	250 000
1987–88	216 000	255 000	250 000
1988–89	208 500	210 000	250 000
1989–90	210 000	210 000	251 884
1990–91	215 000	210 000	201 897
1991–92	215 000	215 000	201 897
1992–93	195 000	215 000	202 156
1993–94	191 000	195 000	202 156
1994–95	174 000	190 000	220 350
1995–96	210 000	168 000	240 000
1996–97	246 000	194 000	250 000
1997–98	269 000	230 000	250 000
1998–99	244 500	234 000	250 000
1999–00	242 000	237 000	250 000
2000–01	230 625	229 858	250 000
2001–02	200 054	195 492	200 000
2002–03	182 560	184 659	200 000
2003–04	133 764	135 784	180 000
2004–05	102 885	104 364	100 000
2005–06	101 984	104 385	100 000
2006–07	97 790	101 009	100 000
2007–08	87 815	89 318	90 000
2008–09	87 598	88 805	90 000
2009–10	105 105	107 209	110 000
2010–11	115 782	118 805	120 000
2011–12	126 184	130 108	130 000
2012–13	127 962	131575	130 000
2013–14	143 705	146 344	150 000
2014–15	156 471	161 528	160 000
2015–16	136 087	136 719	150 000
2016–17	138 555	141 567	150 000
2017–18	131 504	135 418	150 000
2018–19	116 700	122 459	150 000
2019–20	102 586	107 737	115 000
2020–21	97 513	100 819	115 000

Note: Discrepancies between QMS data and actual catches from 1986 to 1990 arose from incorrect surimi conversion factors. The estimated catch in those years has been corrected from conversion factors measured each year by Scientific Observers on the WCSI fishery. Since 1990 the new conversion factor of 5.8 has been used, and the total catch reported to the QMS is considered to be more representative of the true level of catch.

In 2018–19, 20 000 t of western ACE was voluntarily shelved by the fishing industry so the effective TACC was 130 000 t. In 2020–21, 20 000 t of western ACE was voluntarily shelved by the fishing industry so the effective TACC was 95 000 t.

Since the 2020–21 stock assessment, fisheries were defined, within which the exploitation patterns were more consistent, following the review work of Langley (2020). The main regions (WCSI, Chatham Rise, Sub-Antarctic, and Cook Strait) were split into fisheries, with estimation of length and age frequencies produced for each fishery. The WCSI region was split into three fisheries spatially: WC_north, WC_south, and WC_inside (Figure 1), where ‘inside’ relates to inside the 25 nm limit. The WCSI WC_north sub-fishery has been the largest WCSI fishery in most years, with most of the recent declines in catch occurring in this fishery. Fish size is smaller in the north, and substantially larger fish are caught inside the 25 nm line. The Sub-Antarctic region was structured spatially as SA_auck (Auckland Islands), SA_snares (the Stewart-Snares shelf), and SA_suba (the remaining SA area) (Figure 1) based on fish size. The SA_snares sub-fishery is the largest Sub-Antarctic fishery in most years. The smallest hoki are on the Stewart-Snares shelf, medium sized fish are around the Auckland Islands, and most of the catch in the rest of the Sub-Antarctic comprises large females. The Chatham Rise region was structured using depth, with effort depth greater than or equal to 475 m defined as CR_deep, and shallower than 475 m as CR_shallow, because larger fish are predominantly found in deeper water. The CR_deep sub-fishery makes up most of the Chatham Rise catch in each year. Puysegur was defined as its own spawning fishery for catches from June to September; catches from Puysegur outside these spawning months were included in the SA_snares fishery. Cook Strait and ECSI catches from spawning months (June-September) made up the CS fishery, and catches from these areas outside the spawning months were included in the CR fisheries. A table of catches by fishing year and fishery as defined for the 2020–21 stock assessment is presented under the Stock Assessment section of this report (see Table 20).

Table 3: Estimated total catch (t) (scaled to reported QMR or MHR) of hoki by area 1988–89 to 2020–21. Catches from 1988–89 to 1997–98 are rounded to the nearest 500 t and catches from 1998–99 to 2020–21 are rounded to the nearest t. Unrep. is catch with no location information.

Fishing		Spawning fisheries			Non-spawning fisheries			Total		
year	WCSI	Puysegur	Cook Strait	ECSI	Sub-Antarctic	Chatham and ECSI	ECNI	WCNI	Unrep.	Catch
1988-89	188 000	3 500	7 000	-	5 000	5 000	-	-	-	208 500
1989-90	165 000	8 000	14 000	-	10 000	13 000	-	-	-	210 000
1990-91	154 000	4 000	26 500	1 000	18 000	11 500	-	-	-	215 000
1991-92	105 000	5 000	25 000	500	34 000	45 500	-	-	-	215 000
1992-93	98 000	2 000	21 000	-	26 000	43 000	2 000	-	3 000	195 000
1993-94	113 000	2 000	37 000	-	12 000	24 000	2 000	-	1 000	191 000
1994-95	80 000	1 000	40 000	-	13 000	39 000	1 000	-	-	174 000
1995-96	73 000	3 000	67 000	1 000	12 000	49 000	3 000	-	2 000	210 000
1996-97	91 000	5 000	61 000	1 500	25 000	56 500	5 000	-	1 000	246 000
1997-98	107 000	2 000	53 000	1 000	24 000	75 000	4 000	-	3 000	269 000
1998-99	94 565	2 874	45 240	1 977	23 780	73 593	2 315	62	134	244 540
2099-00	102 723	2 880	43 192	2 351	33 772	56 014	1 387	98	4	242 421
2000-01	102 235	6 798	36 298	2 411	30 076	49 847	2 035	147	-	229 847
2001-02	92 720	5 322	23 976	2 971	30 175	39 151	1 147	39	-	195 501
2002-03	73 860	5 948	36 713	7 382	20 199	39 091	929	532	8	184 662
2003-04	45 112	1 158	41 034	2 140	11 635	33 650	880	126	-	135 735
2004-05	33 111	5 548	24 833	3 244	6 244	30 673	522	37	-	104 212
2005-06	38 989	1 437	21 803	665	6 732	34 058	686	8	-	104 378
2006-07	33 328	408	20 113	1 006	7 661	37 813	667	8	-	101 004
2007-08	20 931	308	18 470	2 323	8 708	37 920	640	17	-	89 317
2008-09	20 548	233	17 535	1 054	9 807	39 011	588	25	-	88 801
2009-10	36 349	272	17 880	669	12 275	39 138	618	7	-	107 208
2010-11	48 373	1 176	14 937	1 625	12 655	38 447	1 588	2	-	118 803
2011-12	54 532	1 308	15 859	2 531	15 743	39 246	858	31	-	130 108
2012-13	56 219	955	19 396	3 311	14 098	36 536	1 051	9	-	131 575
2013-14	69 400	778	18 400	2 750	19 927	33 752	1 326	9	-	146 342
2014-15	78 705	1 875	20 100	3 624	16 378	40 071	766	11	5	161 535
2015-16	68 877	1 056	18 378	4 126	6 639	36 714	888	20	-	136 698
2016-17	65 962	1 209	16 084	4 405	13 157	39 919	826	6	-	141 568
2017-18	55 533	1 133	21 473	3 569	15 431	37 134	1 141	4	-	135 418
2018-19	46 464	1 268	20 349	3 674	9 061	40 462	1 177	4	-	122 459
2019-20	43 927	349	16 909	4 722	8 039	32 939	844	6	-	107 735
2020-21	35 141	448	12 524	4 064	9 136	38 751	746	7	-	100 817

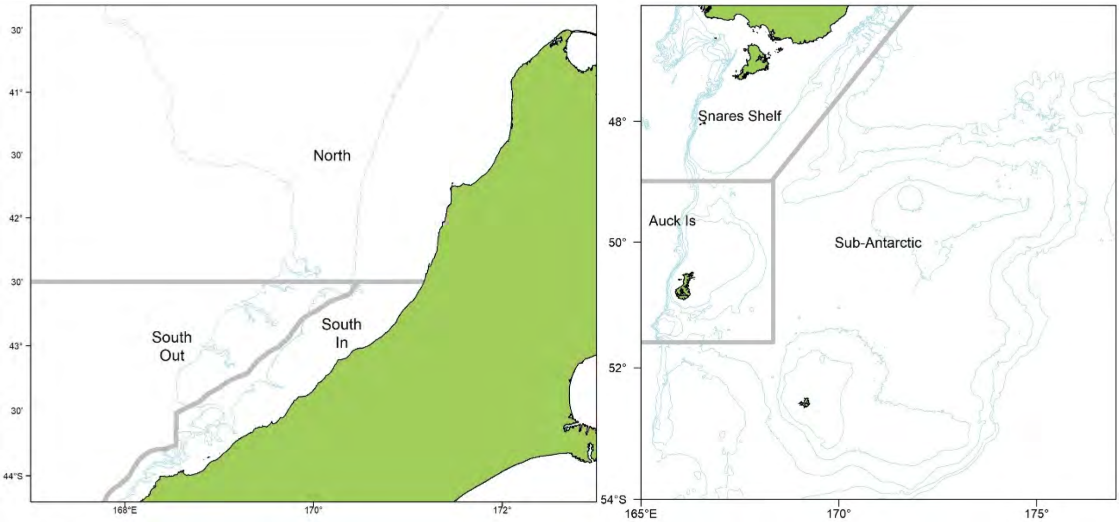


Figure 1: Spatial definitions for WC fisheries (left) and SA (Sub-Antarctic) fisheries (right) as defined for the 2020–21 stock assessment. North: WC_north; South Out: WC_south; South In: WC_inside; Stewart-Snares (Snares) shelf: SA_snares; Auck Is: SA_auck; Sub-Antarctic: SA_suba.

From 1999–2000 to 2001–02, there was a redistribution in catch from eastern stock areas (Chatham Rise, ECSI, east coast North Island (ECNI), and Cook Strait) to western stock areas (WCSI, Puysegur, and Sub-Antarctic) (Table 4). This was initially due to industry initiatives to reduce the catch of small fish in the area of the Mernoo Bank but, from 1 October 2001, was part of an informal agreement with the Minister responsible for fisheries that 65% of the catch should be taken from the western fisheries to reduce pressure on the eastern stock. This arrangement ended following the 2003 hoki assessment in 2002–03, which indicated that the eastern hoki stock was less depleted than the western stock and effort was shifted back into eastern areas, particularly Cook Strait. Since 2004–05 there have been a series of agreements, including limiting catch below the TACC and voluntary catch splits between western and eastern fishing grounds (Table 5). The split between eastern and western catches has been close to the agreed catches in most years. In 2020–21, eastern and western catches (including carry forward) were below catch limits for both eastern and western stock areas. Figure 2a shows the reported landings and TACC for HOK 1, and Figure 2b shows the eastern and western catch components of this stock since 1988–89.

Table 4: Proportions of total catch for different fisheries.

Fishing	Spawning fisheries		Non-spawning fisheries	
Year	West	East	West	East
1988–89	92%	3%	2%	3%
1989–90	82%	7%	5%	6%
1990–91	74%	13%	8%	5%
1991–92	51%	12%	16%	21%
1992–93	51%	11%	14%	24%
1993–94	60%	19%	7%	14%
1994–95	47%	23%	7%	23%
1995–96	36%	33%	6%	25%
1996–97	39%	26%	10%	25%
1997–98	41%	20%	9%	30%
1998–99	38%	20%	10%	32%
1999–00	43%	19%	14%	24%
2000–01	47%	15%	13%	24%
2001–02	50%	13%	15%	22%
2002–03	43%	23%	11%	23%
2003–04	34%	30%	9%	27%
2004–05	37%	25%	6%	32%
2005–06	39%	20%	6%	35%
2006–07	33%	19%	8%	40%
2007–08	24%	20%	10%	46%
2008–09	23%	18%	11%	48%
2009–10	34%	15%	11%	39%
2010–11	42%	11%	11%	36%
2011–12	43%	12%	12%	33%
2012–13	43%	14%	11%	32%
2013–14	48%	12%	14%	27%
2014–15	50%	12%	10%	28%
2015–16	51%	14%	5%	30%
2016–17	47%	12%	9%	31%
2017–18	42%	16%	11%	31%
2018–19	39%	20%	7%	34%
2019–20	41%	18%	8%	33%
2020–21	35%	17%	9%	39%

Table 5: Total available ACE (total catch available) including voluntary catch splits and industry shelving agreements by year. Values are in tonnes.

Year	TACC	Eastern catch limit	Western catch limit	Total available HOK 1 ACE	Industry shelving of ACE
2001–02	200 000	70 000	130 000	199 402	–
2002–03	200 000	70 000	130 000	203 943	–
2003–04	180 000	70 000	110 000	180 000	–
2004–05	100 000	60 000	40 000	100 000	–
2005–06	100 000	60 000	40 000	100 251	–
2006–07	100 000	60 000	40 000	100 493	–
2007–08	90 000	65 000	25 000	90 000	–
2008–09	90 000	65 000	25 000	90 682	–
2009–10	110 000	60 000	50 000	111 872	–
2010–11	120 000	60 000	60 000	124 666	–
2011–12	130 000	60 000	70 000	135 770	–
2012–13	130 000	60 000	70 000	135 650	–
2013–14	150 000	60 000	90 000	153 959	–
2014–15	160 000	60 000	100 000	167 572	–
2015–16	150 000	60 000	90 000	150 000	–
2016–17	150 000	60 000	90 000	161 205	–
2017–18	150 000	60 000	90 000	166 075	–
2018–19	150 000	60 000	90 000	164 730	20 000 (from West)
2019–20	115 000	60 000	55 000	115 000	–
2020–21	115 000	60 000	55 000	122 259	20 000 (split evenly East/West)
2021–22	110 000	65 000	45 000	110 000	10 000 (from East)

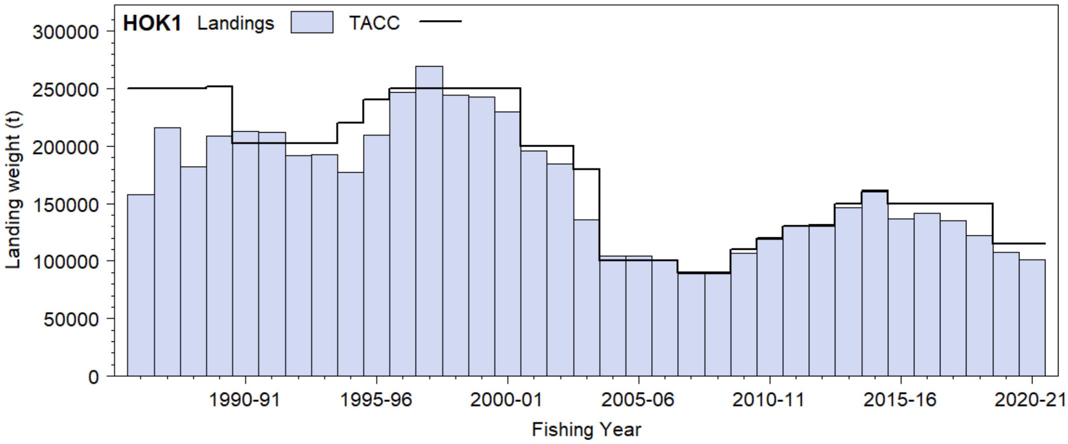


Figure 2a: Reported commercial landings and TACCs for HOK 1 since 1986–87. Note that this graph does not show data prior to entry into the QMS.

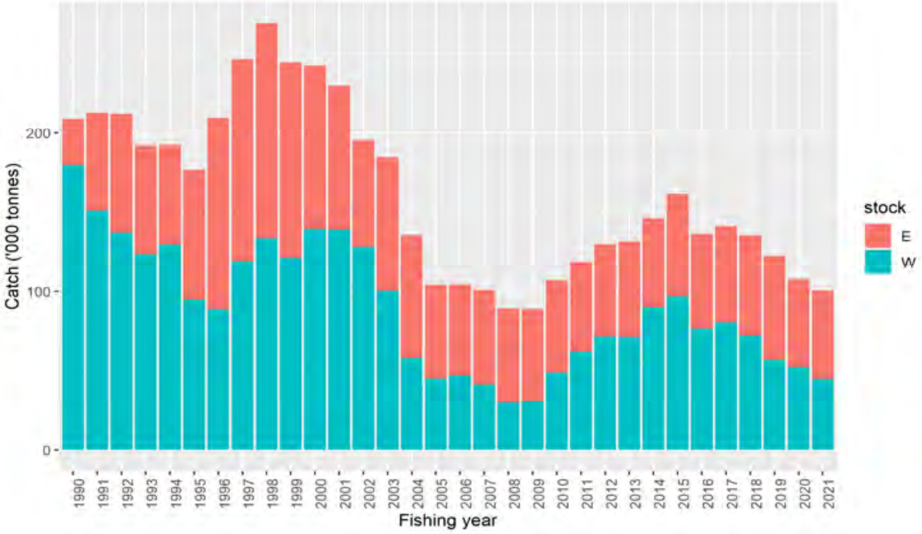


Figure 2b: The eastern and western components of the total HOK 1 landings since 1988–89. Note that these figures do not show data prior to entry into the QMS.

Total Allowable Commercial Catch (TACC) and area restrictions

In the 2020–21 fishing year, the TACC for HOK 1 was 115 000 t. This TACC applied to all areas of the EEZ (except the Kermadec FMA which had a TACC of 10 t). With the allowance for other mortality at 1500 t and 20 t allowances for customary and recreational catch, the 2020–21 TAC was 116 540 t, but available ACE (allowing for shelving and carry-forward) was 52 984 t in the west and 60 899 t for the east. From 1 October 2021 the TACC for HOK 1 decreased to 110 000 t, with a voluntary catch split arrangement of 65 000 t from eastern stock areas and 45 000 t from western stock areas. There was also an agreement that in the 2021–22 fishing year, catches would be limited to 100 000 t (plus any carryover) with a catch split of 45 000 t from the western stock areas and 55 000 t for the eastern stock areas (Table 5).

Vessels larger than 46 m in overall length may not fish inside the 12 nautical mile (nm) Territorial Sea, and there are other various vessel size restrictions around some parts of the coast. On the WCSI, a 25-nm line closes much of the hoki spawning area in the Hokitika Canyon, and most of the area south to the Cook Canyon, to vessels larger than 46 m overall length. In Cook Strait, the whole spawning area is closed to vessels over 46 m overall length. In November 2007 the Government closed 17 Benthic Protection Areas to bottom trawling and dredging, representing about 30% of the EEZ and including depths that are outside the depth range of hoki.

The fishing industry introduced a Code of Practice (COP) for hoki target trawling in 2001 with the aim to protect small fish (less than 60 cm). The main components of this COP were: 1) a restriction on fishing in waters shallower than 450 m; 2) a rule requiring vessels to ‘move on’ if there are more than 10% small hoki in the catch; and 3) seasonal and area closures in spawning fisheries. The COP was superseded by Operational Procedures for Hoki Fisheries, also introduced by the fishing industry from 1 October 2009. The Operational Procedures aim to manage and monitor fishing effort within four industry Hoki Management areas where there are thought to be high abundances of juvenile hoki (Narrows Basin of Cook Strait, Canterbury Banks, Mernoo Bank, and Puysegur). These areas are closed to trawlers over 28 m targeting hoki, with increased monitoring when targeting species other than hoki. There is also a general recommendation that vessels move from areas where catches of juvenile hoki (now defined as less than 55 cm total length) comprise more than 20% of the hoki catch by number.

From 2018–19 to 2020–21 there was agreement from industry to close certain fishing grounds to target fishing for hoki to allow spawning to occur undisturbed at peak times (Operational Procedures version 18). Seasonal spawning closures were:

- WCSI inside the 25-nm line: between 0000 h 18 July and 2400 h 24 July.
- WCSI outside the 25-nm closure, shallower than 800 m, between Kahurangi Point in the north and the boundary between FMAs 5 and 7 in the south: between 0000 h 25 July and 2400 h 31 July.
- Cook Strait: Entire fishery between 0000 h 1 August and 2400 h 7 August.
- Pegasus: between 0000 h 1 September and 2400 h 7 September.

2020–21 hoki fishery

The overall reported catch of 100 817 t was about 6900 t lower than the catch in 2019–20, and about 14 200 t lower than the TACC of 115 000 t (Table 3). Total available ACE was 122 259 t with 20 000 t shelved (Table 5) giving an agreed catch of 102 259 t. Relative to 2019–20, catches in 2020–21 decreased in most areas (WCSI, Cook Strait, ECSI, Sub-Antarctic, Puysegur, and ECNI) and increased on the Chatham Rise.

The WCSI catch decreased by 8700 t, to 35 141 t in 2021 (2020–21). Catches from inside the 25-nm line made up 28% of the total WCSI catch in 2021, a decrease in proportion from 2020, but still lower than the peak of 41% of the catch taken from inside-the-line in 2004. From 2011 to 2019, fishing off the WCSI began in May (with most pre-June catch from inside the 25-nm line) and continued into September; but in 2020 and 2021 very little catch was taken in May. Most (66%) of the WCSI catch in 2021 was taken by midwater trawl. Twin trawls accounted for about 27% of the bottom trawl catch and 7% of the WCSI catch overall. Unstandardised catch rates increased slightly from 2020, with a median catch rate in all midwater tows targeting hoki of 4.4 t per hour in 2021. The WCSI catch in 2021 was dominated by fish from 60 to 110 cm total length (TL) from the 2011 to 2018 year classes (ages 3–10). Previous comparisons showed fishing inside the 25-nm line catches a higher proportion of larger fish (greater than 70 cm) than fisheries outside the line. This was seen again in 2021; the observer and land-based sampling data from the WC_inside sub-fishery had very few fish less than 80 cm, but many fish smaller than 80 cm were caught in the WC_north and WC_south sub-fisheries. The WC_north fishery had the highest proportion of small fish, especially males, with 19% of hoki less than 65 cm. From 2000 to 2004, the sex ratio of the WCSI catch was highly skewed, with many more females caught than males. In 2005 to 2011, as the catch of younger fish increased, the sex ratio reversed with more males than females caught. The sex ratio of the WCSI catch in 2021 was 54% females in WC_inside, and 63–65% females in WC_north and WC_south. The mean length-at-age for hoki off the WCSI increased from the start of the fishery to the mid-2000s but has since decreased.

The Chatham Rise fishery caught 38 751 t in 2020–21, an increase of 5812 t from 2019–20, and overtaking the WCSI as the largest New Zealand hoki fishery. The Chatham Rise fishery now occurs all year around, with catches throughout the winter spawning period. Over 93% of the 2020–21 Chatham Rise catch was taken in bottom trawls. There was an increase in catch from twin trawls, with this method accounting for 43% of the bottom trawl catch in 2020–21. The median unstandardised catch rate in bottom trawls targeting hoki was 2.0 t per hour, which was higher than in 2019–20 (1.7 t per hour). There was a large decrease in the Chatham Rise catch taken using the Modular Harvest System (MHS) (treated as a separate method to bottom trawls) from 6280 t in 2019–20 to 1990 t in 2020–21. Less than 2% of the Chatham Rise catch was taken by midwater trawls. The length frequency distributions in the CR_shallow and CR_deep sub-fisheries for both male and female hoki had modes at 40–80 cm, corresponding to fish from the 2019, 2018, 2014, and 2015 year classes. The CR_shallow sub-fishery has proportionally more small fish by number, with about 49% of the CR_shallow catch less than 65 cm, compared with 38% of the CR_deep catch.

The catch from Cook Strait in 2021 (2020–21) was 12 524 t, a decrease of 4385 t from that in 2020. Peak catches were from mid-July to mid-September. Most catch (99%) is taken by midwater trawls. Unstandardised catch rates in Cook Strait continued to be high; the median catch rate in midwater tows targeting hoki increased from 18.8 t in 2020 to 20.6 t per hour in 2021. A broad size range of hoki was caught in 2021, with the main modes at ages 2–12 (2009 to 2019 year classes) for females, and ages 2–9 (2012 to 2019 year classes) for males. About 20% of the Cook Strait catch was of fish less than 65 cm. As for the WCSI, the mean length-at-age in the Cook Strait fishery increased until the mid-2000s and has subsequently declined, although there was an increase in mean length-at-age for most year classes from 2019–20 to 2020–21.

The catch from the Sub-Antarctic increased by 1097 t from 2019–20 to 9136 t in 2020–21. Over 99% of the catch was taken in bottom trawls, of which 29% was from twin trawls. There was no MHS catch. The median unstandardised catch rate in bottom trawls targeting hoki was lower than that on the Chatham Rise, at 1.2 t per hour in 2020–21. The 2020–21 SA_snares and SA_auck sub-fishery observed catches had a large peak of fish at about 75 cm, with most fish from the 2014 to 2016 year classes. The SA_suba sub-fishery had proportionally more old fish, with the modal age of 7 (2013 year class) for males and 9 (2011 year class) for females. About 36%, 35%, and 2% of the SA_snares, SA_auck, and SA_suba sub-fishery catch was of fish less than 65 cm, respectively.

Catches from ECSI and ECNI decreased to 4064 t and 746 t, respectively, and catches from Puysegur increased slightly to 448 t in 2020–21.

1.2 Recreational fisheries

Recreational fishing for hoki is negligible.

1.3 Customary non-commercial fisheries

The level of this fishery is believed to be negligible.

1.4 Illegal catch

No information is available about illegal catch, but it is believed to be negligible.

1.5 Other sources of fishing mortality

There are a number of potential sources of additional fishing mortality in the hoki fishery. In the years just prior to the introduction of the EEZ, when large catches were first reported, and following the increases of the TACC in the mid-1980s, it is likely that high catch rates from the west coast South Island spawning fishery resulted in burst bags, loss of catch, and some mortality. Although burst bags were recorded by some scientific observers, the extent of fish loss has not been estimated; however, the occurrence was at a sufficient level to result in the introduction of a code of practice to minimise losses in this way. Based on observer records from the period 2000–01 to 2006–07, Ballara et al (2010) and Anderson et al (2019) found that fish lost from the net during landing accounted for 0–14.5% of the non-retained catch each year in the hoki, hake, and ling fishery.

- The use of escape panels or windows part way along the net (developed to avoid burst bags) may also in itself result in some mortality of fish that pass through the window. It is believed that such devices are not currently used in the fishery.
- The development of the fishery on younger hoki (2 years and over) on the Chatham Rise from the mid-1990s, and the prevalence of small hoki in catches off the WCSI in some years, may have resulted in some unreported mortality of small fish.
- Overseas studies indicate that large proportions of small fish can escape through trawl meshes during commercial fishing and that the mortality of escapees can be high, particularly among species with deciduous scales (scales that shed easily) such as hoki. Selectivity experiments in the 1970s indicated that the 50% selection length for hoki for a 100-mm mesh cod-end is about 57–65 cm total length (Fisher 1978, as reported by Massey & Hore 1987). Research using a twin-rig trawler in June 2007 estimated that the 50% selection length was somewhat lower at 41.5 cm with a selection range (length range between 25% and 75% retention) of 14.3 cm (Haist et al 2007). Applying the estimated retention curve to scaled length frequency data for the Chatham Rise fishery suggested that between 47 t (in 1997–98) and 4287 t (in 1995–96) of hoki may have escaped commercial fishing gear each year. More recent research comparing the selectivity of 100 mm and MHS cod-ends in June 2017 suggested similar mean 50% selection lengths of about 48–49 cm for both gears, but with the MHS gear having a narrower selection range (11.7 cm compared with 14.8 cm for a 100-mm cod-end) (O'Driscoll & Millar 2017). Net-damaged adult hoki have been recorded in the WCSI fishery in some years indicating that there may be some survival of escapees. The extent of damage and resulting mortality of fish passing through the net is unknown.

These sources of additional fishing mortality are not incorporated in the current stock assessment.

2. BIOLOGY

Hoki are widely distributed throughout New Zealand waters from 34° S to 54° S, from depths of 10 m to over 900 m, with greatest abundance between 200 m and 600 m. Large adult hoki are generally found deeper than 400 m, whereas juveniles are more abundant in shallower water. In the January 2003 Chatham Rise trawl survey, exploratory tows with midwater gear over a hill complex east of the survey area found low density concentrations of hoki in midwater at 650 m over depths of 900 m or greater (Livingston et al 2004). The proportion of larger hoki outside the survey grounds is unknown. Commercial data also indicate that larger hoki have been targeted over other hill complexes outside the survey areas of both the Chatham Rise and Sub-Antarctic (Dunn & Livingston 2004) and have also been caught as bycatch by tuna fishers over very deep water (Bull & Livingston 2000).

The two main spawning grounds on the WCSI and in Cook Strait are considered to comprise fish from separate stocks, based on the geographical separation of these spawning grounds and a number of other factors (see Section 3 "Stocks and areas" below).

Hoki migrate to spawning grounds in Cook Strait, WCSI, Puysegur, and ECSI areas in the winter months. Throughout the rest of the year the adults are dispersed around the edge of the Stewart-Snares shelf, over large areas of the Sub-Antarctic and Chatham Rise, and to a lesser extent around the North Island. Juvenile fish (2–4 y) are found on the Chatham Rise throughout the year.

Hoki spawn from late June to mid-September, releasing multiple batches of eggs. In recent years, spawning has occurred in early June off the WCSI. They have moderately high fecundity with a female of 90 cm TL spawning over 1 million eggs in a season (Schofield & Livingston 1998). Not all hoki within the adult size range spawn in a given year. Winter surveys of both the Chatham Rise and Sub-Antarctic have found notable numbers of large hoki with no gonad development, at times when spawning is occurring in other areas. Histological studies of female hoki from the Sub-Antarctic in May 1992 and 1993 estimated that 67% of hoki aged 7 years and older on the Sub-Antarctic would spawn in winter 1992, and 82% in winter 1993 (Livingston et al 1997). A similar study repeated in April 1998 found that a much lower proportion (40%) of fish aged 7 and older was developing to spawn (Livingston & Bull 2000). Reanalysis of the 1998 data has shown that there is a correlation between stratum and oocyte development (Francis 2009). A method, developed to estimate proportion spawning from summer samples of post-spawner hoki in the Sub-Antarctic, indicated that approximately 85% of the hoki aged 4 years and older from 2003 and 2004 had spawned (Grimes & O'Driscoll 2006, Parker et al 2009).

The main spawning grounds are centred on the Hokitika Canyon off the WCSI and in Cook Strait Canyon. The planktonic eggs and larvae move inshore by advection or upwelling (Murdoch et al 1990, Murdoch 1992) and are widely dispersed north and south with the result that 0+ and 1-year-old fish can be found in most coastal areas off the South Island and parts of the North Island. The major nursery ground for juvenile hoki aged 2–4 years is along the Chatham Rise, in depths of 200 to 600 m. The older fish disperse to deeper water and are widely distributed in the Sub-Antarctic and on the Chatham Rise. Analyses of trawl survey (1991–2002) and commercial data suggest that a significant proportion of hoki move from the Chatham Rise to the Sub-Antarctic as they approach maturity, with most movement between ages 3 and 7 years (Bull & Livingston 2000, Livingston et al 2002). Based on a comparison of RV *Tangaroa* trawl survey data, on a proportional basis (assuming equal catchability between areas), 80% or more of hoki aged 1–2 years occur on the Chatham Rise. Between ages 3 and 7, this drops to 60–80%. By age 8, 35% or fewer fish are found on the Chatham Rise compared with 65% or more in the Sub-Antarctic. A study of the observed sex ratios of hoki in the two spawning and two non-spawning fisheries found that in all areas, the proportion of male hoki declines with age (Livingston et al 2000). There is little information at present to determine the season of movement, the exact route followed, or the length of time required, for fish to move from the Chatham Rise to the Sub-Antarctic. Bycatch of hoki from tuna vessels following tuna migrations from the Sub-Antarctic showed a northward shift in the incidence of hoki towards the WCSI in May-June (Bull & Livingston 2000). The capture of net-damaged fish on Pukaki Rise following the WCSI spawning season where there had been intense fishing effort in 1989 also provides circumstantial evidence that hoki migrate from the WCSI back to the Sub-Antarctic post-spawning (Jones 1993).

Growth is fairly rapid with juveniles reaching about 27–35 cm TL at the end of the first year. There is evidence for changing growth rates over time. In the past, hoki reached about 45, 55, and 60–65 cm TL at ages 2, 3, and 4, respectively, but in the mid-2000s length modes were centred at 50, 60, and 70 cm TL for ages 2, 3, and 4. Recently growth has slowed and is intermediate between these two levels. Although smaller spawning fish are taken on the spawning grounds, males appear to mature mainly from 60–65 cm TL after 3–5 years, whereas females mature at 65–70 cm TL. From the age of maturity, the growth of males and females differs. Males grow up to about 115 cm TL, whereas females grow to a maximum of 130 cm TL and up to 7 kg weight. Horn & Sullivan (1996) estimated growth parameters for the two stocks separately (Table 6). Fish from the eastern stock sampled in Cook Strait are smaller on average at all ages than fish from the WCSI. Maximum age is from 20 to 25 years, and the instantaneous rate of natural mortality in adults is about 0.25 to 0.30 per year.

Ageing error may cause problems in the estimation of year class strength. For example, the 1989 year class appeared as an important component in the catch-at-age data at older ages, yet this year class is believed to have been extremely weak in comparison with the preceding 1988 and 1987 year classes. An improved ageing protocol was developed to increase the consistency of hoki age estimation, and this has been applied to the survey data from 2000 onwards and to catch samples from 2001 (Francis 2001). Data from earlier samples, however, are still based on the original ageing methodology.

Estimates of biological parameters relevant to stock assessment are shown in Table 6.

Table 6: Estimates of fixed biological parameters.

Fishstock	**Estimate**		**Source**
1. Natural mortality (M)			
	Females	Males	
HOK 1	0.25	0.30	Sullivan & Coombs (1989)
2. Weight = a (length)^b (Weight in g, length in cm total length)			
	Both stocks		
	a	b	
HOK 1	0.00479	2.89	Francis (2003)

3. von Bertalanffy growth parameters	Females			Males			
	K	t_0	L_∞	K	t_0	L_∞	
HOK 1 (Western Stock)	0.213	-0.60	104.0	0.261	-0.50	92.6	Horn & Sullivan (1996)
HOK 1 (Eastern Stock)	0.161	-2.18	101.8	0.232	-1.23	89.5	Horn & Sullivan (1996)

3. STOCKS AND AREAS

Morphometric and ageing studies have found consistent differences between adult hoki taken from the two main dispersion areas (Chatham Rise and Sub-Antarctic), and from the two main spawning grounds in Cook Strait and WCSI (Livingston et al 1992, Livingston & Schofield 1996b, Horn & Sullivan 1996). These differences demonstrate that there are possibly two sub-populations of hoki. Whether or not they reflect genetic differences between the two sub-populations, or they are just the result of environmental differences between the Chatham Rise and Sub-Antarctic, is not known. No genetic differences have been detected with selectively neutral markers (Smith et al 1981, 1996), but a low exchange rate between stocks could reduce genetic differentiation. Results of an ongoing genetics study indicate that there appears to be little genetic differentiation between hoki within the New Zealand EEZ although differences were detected between New Zealand and Tasmanian hoki (Koot et al 2021).

Two pilot studies appeared to provide support for the hypothesis of spawning stock fidelity for the Cook Strait and WCSI spawning areas. Smith et al (2001) found significant differences in gill raker counts, and Hicks & Gilbert (2002) found significant differences in measurements of otolith rings, between samples of 3-year-old hoki from the 1997 year class caught off the WCSI and in Cook Strait. However, when additional year classes were sampled, differences were not always detected (Hicks et al 2003). If there are differences in the mean number of gill rakers and otolith measurements between stocks, due to high variation, large sample sizes would be needed to statistically detect these (Hicks et al 2003). Francis et al (2011) carried out a pilot study to determine whether analyses of stable isotopes and trace elements in otoliths could be useful in testing stock structure hypotheses and the question of natal fidelity. However, none of the six trace elements or two stable isotopes considered provided evidence of unambiguously differentiated stocks.

The DWWG has assessed the two spawning groups as separate stock units (Figure 3). The west coast of the North Island and South Island and the area south of New Zealand including Puysegur, Stewart-Snares shelf, and the Sub-Antarctic has been taken as one stock unit (the ‘western stock’). The area of the ECSI, Mernoo Bank, Chatham Rise, Cook Strait, and the ECNI up to North Cape has been taken as the other stock unit (the ‘eastern stock’). The two stocks are assumed to mix as juveniles on Chatham Rise.

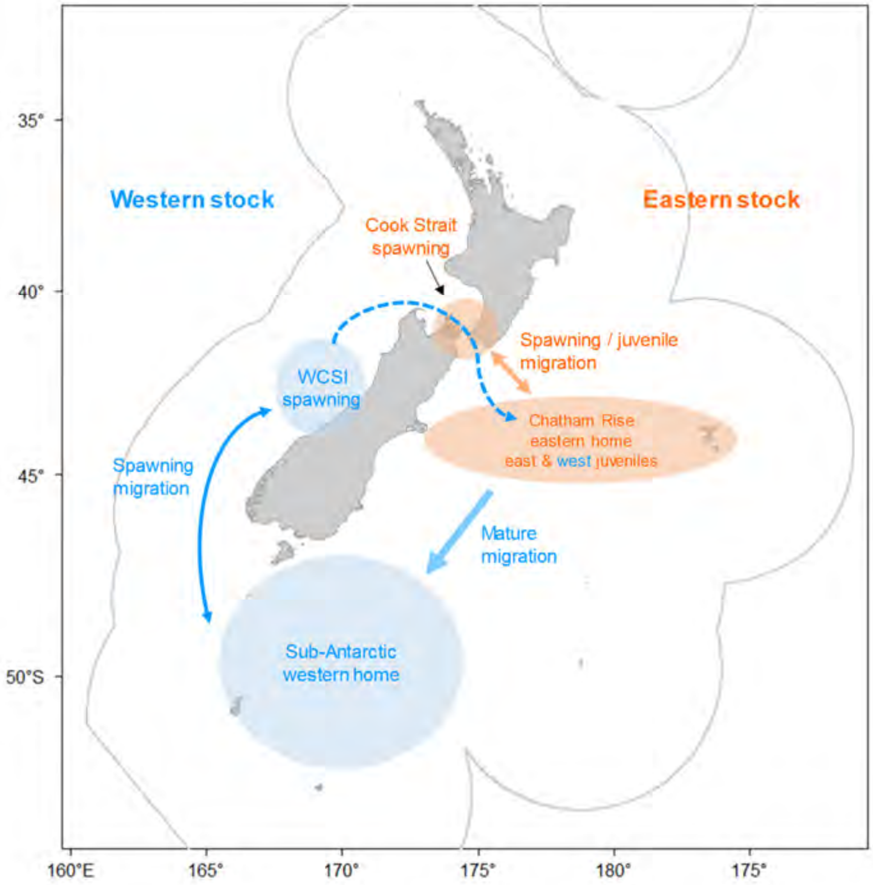


Figure 3: Hoki juvenile nurseries, spawning grounds, and assumed migration routes for the eastern and western stocks.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was developed and reviewed by the Aquatic Environment Working Group for the May 2012 Fisheries Assessment Plenary and has been updated annually with more recent data, where available, and minor corrections made to reflect the updates. This summary is from the perspective of the hoki fishery; a more comprehensive review from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021), online at https://www.mpi.govt.nz/dmsdocument/51472-Aquatic-Environment-and-Biodiversity-Annual-Review-AEBAR-2021-A-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment.

4.1 Role in the ecosystem

Hoki is the species with the highest biomass in the bottom fish community of the upper slope (200–800 m), particularly around the South Island (Francis et al 2002) and is considered to be a key biological component of the upper slope ecosystem. Understanding the predator-prey relationships between hoki and other species in the slope community is important, particularly because substantial changes in the biomass of hoki have taken place since the fishery began (Horn & Dunn 2010). Other metrics such as ecosystem indicators may also provide insight into fishery interactions with target and non-target fish populations (e.g., Tuck et al 2014). For example, changes in growth rate can be indicative of density-dependent compensatory mechanisms in response to changes in population density.

4.1.1 Trophic interactions

On the Chatham Rise, hoki is a benthopelagic and mesopelagic forager preying primarily on lantern fishes and other midwater fishes and natant decapods with little seasonal variation (Clark 1985a, b, Dunn et al 2009a, Connell et al 2010, Stevens et al 2011). Hoki show ontogenetic shifts in their feeding preferences. Larger hoki (over 80 cm) consume proportionately more fish and squid than smaller hoki (Dunn et al 2009a, Connell et al 2010). The diet of hoki overlaps with that of alfonsino, arrow squid, hake, javelinfish, Ray's bream, and shovelnose dogfish (Dunn et al 2009a). Hoki are prey to several piscivores, particularly hake but also stargazers, smooth skates, several deepwater shark species, and ling (Dunn et al 2009a). The proportion of hoki in the diet of hake averages 38% by weight and declined from 1992 to 2008, possibly because of a decline in the relative abundance of hoki on the Chatham Rise between 1991 and 2007 (Dunn & Horn 2010). There is little information about the size of hoki eaten by predators (i.e., specifically whether the hoki are large enough to have recruited to the fishery or not), but this could be an important factor in understanding the interaction with the fishery.

4.1.2 Ecosystem Indicators

Tuck et al (2009) used data from the Sub-Antarctic and Chatham Rise trawl survey series to derive fish-based ecosystem indicators using diversity, fish size, and trophic level. Species-based indicators appeared the most useful in identifying changes in the marine ecosystem correlated with fishing intensity; Pielou's evenness appears the most consistent, but the Shannon-Wiener index, species richness, and Hill's N1 and N2 also showed some promise (Tuck et al 2009). Trends in diversity in relation to fishing are not necessarily downward and depend on the nature of the community. Size-based indicators did not appear as useful for New Zealand trawl survey series as they have been overseas, and this may be related to the requirement to consider only measured species. In New Zealand, routine measurement of all fish species in trawl surveys was implemented in 2008 and this may increase the utility of size-based indicators in the future.

Between 1992 and 1999 the growth rates of all year classes of hoki increased by 10% in all four fishery areas, but it is unclear whether this was a result of reduced competition for food within and among cohorts or some other factor (Bull & Livingston 2000). The abundance of mesopelagic fish, a major prey item for hoki, has the potential to be an indicator of food availability. Recent research using acoustic backscatter data collected during trawl surveys has shown no clear temporal trend in mesopelagic fish biomass on the Chatham Rise between 2001 and 2009, but a decline in the Sub-Antarctic area from 2001 to 2007, followed by an increase in 2008 and 2009. The abundance of mesopelagic fish is consistently much higher on the Chatham Rise than in the Sub-Antarctic, with highest densities observed on the western Chatham Rise and lowest densities on the eastern Campbell Plateau (O'Driscoll et al 2011a). Spatial patterns in mesopelagic fish abundance closely matched the distribution of hoki. O'Driscoll et al (2011a) hypothesise that prey availability influences hoki distribution, but that hoki abundance is being driven by other factors such as recruitment variability and fishing. There was no evidence for a link between hoki condition and mesopelagic prey abundance and there were no obvious correlations between mesopelagic fish abundance and environmental indices.

4.2 Bycatch (fish and invertebrates)

Hoki, hake, and ling made up 84%, 2%, and 3%, respectively, of the observed catch in target hoki trawls Hoki, hake, ling, silver warehou, and white warehou are frequently caught together, and trawl fisheries targeting these species are, as of 2018, considered one combined trawl fishery. The total catch weight of the main bycatch species caught in this combined fishery was estimated from a model which used observer and fisher-reported data (Anderson et al 2019). Based on this model the total non-target fish and invertebrate catch in the combined hoki, hake, ling, silver warehou, and white warehou fishery fluctuated between 17 t and 49 000 t per year in the period between 1990–91 and 2016–17 (Anderson et al 2019). Between 1 October 2002 and 30 September 2017, the five target species combined accounted for 90.14% of the total estimated catch from all observed target trawls in this fishery (Table 8). Hoki was the main catch species (73%), followed by hake (6.7%), ling (5.2%), silver warehou (3.9%), and white warehou (1.3%). The main non-target species caught in the combined fishery off the west coast South Island, on Chatham Rise, and in the Sub-Antarctic are rattails, javelinfish, and spiny dogfish. In Cook Strait, the main non-target species caught is spiny dogfish. The hoki, hake, ling, silver warehou, and white warehou fishery is complex, and changes in fishing practice are likely to have contributed to variability between years (Ballara & O'Driscoll 2015b).
between 2013–14 and 2017–18 (Table 7).

Table 7: Percentage of total observed catch weight of species taken in hoki target trawls for the 2013–14 to 2017–18 fishing years. Only species with an observed annual catch of over 20 t for any of the five years are listed. Data were last updated in 2019 from the Centralised Observer Database (Anderson et al 2019).

Species	2013–14	2014–15	2015–16	2016–17	2017–18
Hoki	85.9	87.7	86.2	83.9	78.7
Ling	2.8	2.4	3.2	2.8	4.6
Hake	2.1	1.8	1.8	2.7	3.2
Javelinfish	1.3	1.4	1.8	2.2	2.9
Rattails	1.2	1.1	1.5	2.3	1.8
Spiny dogfish	1.1	0.8	0.7	1.2	1.3
Silver warehou	1.1	0.9	1	0.5	1.7
Black oreo	0.7	<0.1	0.1	0.4	0.1
Frostfish	0.5	0.6	0.7	0.3	0.6
White warehou	0.3	0.1	0.1	0.3	0.3
Pale ghost shark	0.3	0.2	0.2	0.3	0.4
Lookdown dory	0.2	0.2	0.2	0.2	0.2
Arrow squid	0.2	0.1	0.2	0.2	0.2
Gemfish	0.2	0.1	0.1	0.3	0.3
Ribaldo	0.2	0.1	0.1	0.1	0.2
Southern blue whiting	0.1	0.1	0.1	0.1	0.2
Sea perch	0.1	0.2	0.2	0.2	0.3
Baxter’s lantern dogfish	0.1	<0.1	0.1	0.1	0.1
Shovelnose dogfish	0.1	<0.1	0.2	0.1	0.2
Smooth skate	0.1	0.1	0.1	0.2	0.1
Stargazer	0.1	0.1	0.1	0.1	0.1
Ray’s bream	0.1	0.1	<0.1	<0.1	<0.1
Alfonsino	0.1	0.3	0.1	0.1	<0.1
Redbait	0.1	0.1	<0.1	0.1	0.1
Leafscale gulper shark	0.1	<0.1	0.1	<0.1	0.1
Long-nosed chimaera	0.1	<0.1	<0.1	<0.1	<0.1
Scabbardfish	0.1	<0.1	0.1	<0.1	0.1
Dark ghost shark	<0.1	0.1	0.1	0.1	0.1
Smooth oreo	<0.1	<0.1	<0.1	<0.1	<0.1
Conger eel	<0.1	<0.1	<0.1	<0.1	<0.1
Seal shark	<0.1	<0.1	<0.1	<0.1	<0.1
Silverside	<0.1	<0.1	<0.1	0.1	0.1
Warty squid	<0.1	<0.1	<0.1	<0.1	0.1
Banded bellowsfish	<0.1	<0.1	<0.1	<0.1	0.1
Barracouta	<0.1	0.3	<0.1	0.3	0.4
Swollenhead conger	<0.1	<0.1	<0.1	<0.1	<0.1
Deepsea flathead	<0.1	<0.1	<0.1	0.1	0.1
Silver roughy	<0.1	<0.1	<0.1	<0.1	<0.1
Silver dory	<0.1	<0.1	0.1	<0.1	<0.1
Northern spiny dogfish	<0.1	<0.1	<0.1	<0.1	<0.1
Cardinalfish	<0.1	<0.1	<0.1	<0.1	0.2
Jack mackerel	<0.1	0.1	0.1	0.1	0.2
Common warehou	<0.1	<0.1	<0.1	<0.1	0.2
Others	0.5	0.5	0.5	0.5	0.5

Table 8: Modelled annual bycatch estimates (t) for main bycatch species in the combined hoki, hake, ling, silver warehou, and white warehou trawl fishery from the 2012–13 to the 2016–17 fishing years, and percentage of total observed catch for the target trawl fishery from 1 Oct 2002 to 30 Sep 2017, in decreasing order (Anderson et al 2019). [Continued on next page]

	Model-based estimates of total catch					% of observed
Species	2012–13	2013–14	2014–15	2015–16	2016–17	2002–03 to 2016–
Combined target species (5 species)	148 525	160 402	178 661	149 150	156 636	90.14
Javelinfish	4 807	4 099	7 443	7 138	7 483	1.87
Rattails (excl. Javelinfish)	5 656	3 914	7 068	6 067	7 116	1.55
Spiny dogfish	1 957	3 841	3 596	2 114	3 764	1.41
Arrow squid	563	604	1 117	722	815	0.51
Barracuda	639	624	509	320	1 290	0.47
Morid cods	615	1 004	1 161	711	806	0.42
Pale ghostshark	747	1 084	1 151	1 298	923	0.32
Ribaldo	378	591	981	415	486	0.28
Sea perch	672	399	975	846	582	0.27
Dark ghostshark	418	477	581	842	560	0.24
Lookdown dory	551	555	833	681	664	0.23
Black oreo	673	1517	593	343	733	0.21
Southern blue whiting	28	232	175	135	143	0.17
Giant stargazer	283	314	619	371	327	0.16
Red cod	172	275	164	227	251	0.14
Shovelnose dogfish	274	338	211	346	217	0.13

Table 8 [continued]

Species	Model-based estimates of total catch 2012–	2013–	2014–15	2015–16	2016–	% of observed 2002–03 to
Gemfish	164	236	173	281	689	0.12
Jack mackerel	21	14	62	45	29	0.08
Alfonsino	25	50	118	33	75	0.03
Orange roughy	8	8	9	11	6	0.02
Slickheads	6	13	14	11	13	0.01

4.3 Incidental capture of protected species (mammals, seabirds, and protected fish)

For protected species, capture estimates presented here include all animals recovered to the deck (alive, injured, or dead) of fishing vessels but do not include any cryptic mortality (e.g., seabirds struck by a warp but not brought on board the vessel, Middleton & Abraham 2007).

4.3.1 Marine mammal captures

New Zealand fur seal captures

The New Zealand fur seal was classified in 2008 as 'Least Concern' by the International Union for Conservation of Nature (IUCN) and in 2010 as 'Not Threatened' under the New Zealand Threat Classification System (Baker et al 2019).

Vessels targeting hoki incidentally catch fur seals (Baird 2005c, Smith & Baird 2009, Thompson & Abraham 2010a, Baird 2011, Abraham et al 2016 & 2021, Abraham & Richard 2019). The lowest capture rates have occurred in the most recent years (Table 9). Observed captures have occurred mostly off the west coast South Island and in the Cook Strait. Estimated captures of New Zealand fur seals in the hoki fishery have accounted for 44% (749 out of 1691) of all fur seals estimated to have been caught by trawling in the EEZ between 2002–03 and 2017–18 for those fisheries modelled.

Table 9: Number of tows (commercial and observed) by fishing year, observed and estimated New Zealand fur seal captures and capture rate in hoki trawl fisheries, 2002–03 to 2019–20 (Abraham et al 2021). Estimates are available online at https://protectedspeciescaptures.nz/PSCv6/released/. Observed and estimated protected species captures in this table derive from the PSC database version PSCV6.

	Fishing effort			Obs. captures		Est. captures		Est. capture rate	
Fishing year	Tows	No. Obs	% obs	Captures	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	27 787	2 593	9.3	45	1.74	609	401–912	2.19	1.44–3.28
2003–04	22 522	2 345	10.4	56	2.39	522	343–784	2.32	1.52–3.48
2004–05	14 541	2 134	14.7	120	5.62	1 021	713–1 467	7.02	4.90–10.09
2005–06	11 588	1 775	15.3	62	3.49	535	350–811	4.61	3.02–7.00
2006–07	10 600	1 755	16.6	29	1.65	343	216–527	3.24	2.04–4.97
2007–08	8 783	1 877	21.4	58	3.09	347	235–505	3.95	2.67–5.75
2008–09	8 175	1 661	20.3	37	2.23	226	146–345	2.76	1.79–4.22
2009–10	9 965	2 066	20.7	30	1.45	191	129–276	1.92	1.29–2.77
2010–11	10 407	1 724	16.6	24	1.39	264	151–443	2.54	1.45–4.26
2011–12	11 333	2 694	23.8	34	1.26	221	143–332	1.95	1.26–2.93
2012–13	11 690	4 512	38.6	60	1.33	352	222–554	3.01	1.90–4.74
2013–14	12 948	3 977	30.7	32	0.80	141	95–206	1.09	0.73–1.59
2014–15	13 590	3 614	26.6	42	1.16	261	168–396	1.92	1.24–2.91
2015–16	12 639	3 474	27.5	42	1.21	220	146–324	1.74	1.16–2.56
2016–17	12 952	2 908	22.5	37	1.27	238	156–351	1.84	1.20–2.71
2017–18	13 793	4 767	34.6	41	0.86	190	128–283	1.38	0.93–2.05
2018–19	12 070	3 463	28.7	21	0.61				
2019–20	9 550	3 893	40.8	21	0.54				

New Zealand sea lion captures

The New Zealand (or Hooker's) sea lion was classified in 2008 as 'Vulnerable' by IUCN and in 2019 as 'Nationally Vulnerable' under the New Zealand Threat Classification System (Baker et al 2019) (having formerly been classed 'Nationally Critical' by Baker et al 2016). There are contrasting pup production trends at different breeding colonies. Pup production declined at the main colonies on the Auckland Islands from a peak in 1999 to a low in 2009 and appear to have stabilised thereafter. At Campbell Islands, pup production increased rapidly from low numbers in the early 1990s and appear to have plateaued since around 2010. Newly established breeding populations on Stewart Island and the New Zealand mainland appear to be rapidly increasing.

New Zealand sea lions are rarely captured by vessels trawling for hoki; since 2002–03 there have been three observed captures during fishing seasons with 9–41% of observer coverage (Abraham et al 2016), and all were near the Auckland Islands. The spatial overlap of the fisheries with the foraging distribution of sea lions is low, and observer coverage in these fisheries has been high. The spatial risk assessment model of Large et al (2019) estimated very low capture rates (median 0 per year) of sea lions, with high certainty (upper 95% CI = 1).

Common dolphin captures

Three common dolphins have been observed captured in the hoki trawl fishery since 2002–03 (https://protectedspeciescaptures.nz/PSCv6/released/).

4.3.2 Seabird captures

Vessels targeting hoki incidentally catch seabirds. Information on observed captures is summarised for 1998–99 to 2002–03 by Baird (2005a), for 2003–04 to 2005–06 by Baird & Smith (2007, 2008), for 1989–90 to 2008–09 by Abraham & Thompson (2011) and subsequently by Abraham et al (2016). For species that are sufficiently abundant (and captured sufficiently frequently in hoki fisheries) to enable capture rates to be estimated directly, capture rates are estimated using a hierarchical mixed-effects generalised linear model (GLM), fitted using Bayesian methods (Abraham et al 2016, Abraham & Richard 2017, 2018). Separately, a multi-species seabird risk assessment model applying the SEFRA (spatially explicit fisheries risk assessment) framework is used (Richard et al 2017, 2020) to estimate fisheries impacts across all commercial fisheries for all seabird species and relate the cumulative fisheries impact to an impact threshold that reflects the ability of the species to sustain impacts while still achieving a defined population recovery or stabilisation outcome.

Using the direct captures estimation approach, in the 2018–19 fishing year, there were 80 observed seabird captures in hoki trawl fisheries, and an estimated total of 278 (95% c.i. 224–341) captures (Table 10). In the 2019–20 fishing year, there were 113 observed seabird captures in hoki trawl fisheries, and an estimated total of 239 (95% c.i. 201–286) captures. Annual observed seabird capture rates have ranged between 1.3 and 4 per 100 tows in the hoki fishery over the time period 2002–03 to 2019–20, with little apparent trend. These figures represent summed totals across all seabird species and all methods of capture. To determine changes for particular species of interest or within particular subsets of the hoki fishery, more detailed analysis will be required.

Table 10: Number of tows by fishing year and observed seabird captures in hoki trawl fisheries, 2002–03 to 2019–20. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows. Estimates are based on methods described by Abraham & Richard (2020) and are available online at https://protectedspeciescaptures.nz/PSCv6/released/. Observed and estimated protected species captures in this table derive from the PSC database version PSCV6.

	Fishing effort			Obs. captures		Est. captures		Est. capture rate	
Fishing year	Tows	No. Obs	% obs	Captures	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	27 787	2 593	9.3	82	3.16	729	570–931	2.62	2.05–3.35
2003–04	22 522	2 345	10.4	32	1.36	451	343–585	2.00	1.52–2.6
2004–05	14 541	2 134	14.7	45	2.11	384	295–495	2.64	2.03–3.4
2005–06	11 588	1 775	15.3	54	3.04	348	256–465	3.00	2.21–4.01
2006–07	10 600	1 755	16.6	23	1.31	228	160–313	2.15	1.51–2.95
2007–08	8 783	1 877	21.4	28	1.49	190	135–258	2.16	1.54–2.94
2008–09	8 175	1 661	20.3	37	2.23	257	186–344	3.14	2.28–4.21
2009–10	9 965	2 066	20.7	53	2.57	269	204–345	2.70	2.05–3.46
2010–11	10 407	1 724	16.6	55	3.19	337	254–436	3.24	2.44–4.19
2011–12	11 333	2 694	23.8	58	2.15	271	211–343	2.39	1.86–3.03
2012–13	11 690	4 512	38.6	103	2.28	304	249–373	2.60	2.13–3.19
2013–14	12 948	3 977	30.7	159	4.00	418	349–502	3.23	2.7–3.88
2014–15	13 590	3 614	26.6	82	2.27	439	349–551	3.23	2.57–4.05
2015–16	12 639	3 474	27.5	49	1.41	257	201–321	2.04	1.59–2.54
2016–17	12 952	2 908	22.5	59	2.03	299	235–375	2.31	1.81–2.9
2017–18	13 793	4 767	34.6	142	2.98	338	285–400	2.45	2.07–2.9
2018–19	12 070	3 463	28.7	80	2.31	278	224–341	2.30	1.86–2.83
2019–20	9 550	3 893	40.8	113	2.90	239	201–286	2.50	2.1–2.99

Observed seabird captures in hoki fisheries since 2002–03 have been dominated by six species: Salvin's, southern Buller's, and New Zealand white-capped albatrosses make up 45%, 27%, and 22% of the albatrosses captured, respectively; and sooty shearwaters, white-chinned petrels, and cape petrels make up 58%, 23%, and 6% of other birds, respectively (Table 11). The highest proportions of captures have been observed off the east coast of the South Island (50%), on the Stewart-Snares shelf (20%), on the Chatham Rise (11%), and off the west coast of the South Island (9%). These numbers should be regarded as only a general guide on the distribution of captures because observer coverage is not uniform across areas and may not be representative. The spatial risk assessment is designed to correct for potential bias arising from spatially non-representative data.

The seabird risk assessment approach identifies ten at-risk seabird species for which the hoki fishery makes a contribution to the cumulative commercial fisheries risk score (see Table 11). The two species for which the hoki fisheries are responsible for the highest risk are southern Buller's albatross (hoki fishery mean risk score 0.14, i.e., 36% of the cumulative species risk score 0.39) and Salvin's albatross (hoki fishery mean risk score 0.12, i.e., 15% of the cumulative species risk score 0.78).

Table 11: Outputs of the Zealand seabird risk assessment for all at-risk seabirds. Risk ratios are shown for the hoki fishery in isolation and cumulatively for all commercial fisheries. The risk ratio is an estimate of annual fishery related deaths as a proportion of the Population Sustainability Threshold, PST (see Richard et al 2017, 2020). The DOC threat classifications are also shown (Robertson et al 2017 at http://www.doc.govt.nz/documents/science-and-technical/nztcs19entire.pdf).

		Risk ratio			
Species name	**PST(mean)**	**HOK***	**TOTAL**	**Risk category**	**DOC Threat Classification**
Southern Buller's albatross	1 360	0.144	0.37	High	At Risk: Naturally Uncommon
Salvin's albatross	3 460	0.120	0.65	High	Threatened: Nationally Critical
Westland petrel	351	0.068	0.54	High	At Risk: Naturally Uncommon
NZ white-capped albatross	10 800	0.042	0.29	Medium	At Risk: Declining
Northern Buller's albatross	1 640	0.033	0.26	Medium	At Risk: Naturally Uncommon
Northern giant petrel	337	0.030	0.15	Medium	At Risk: Naturally Uncommon
Chatham Island albatross	428	0.015	0.28	High	At Risk: Naturally Uncommon
Campbell black-browed albatross	2 000	0.010	0.06	Low	At Risk: Naturally Uncommon
Black petrel	447	0.009	1.23	Very high	Threatened: Nationally Vulnerable
Flesh-footed shearwater	1 450	0.008	0.49	High	Threatened: Nationally Vulnerable

*Risk ratio HOK comes from Richard et al (2017).

Mitigation methods such as streamer (tori) lines, Brady bird bafflers, warp deflectors, and offal management are used in the hoki trawl fishery. Warp mitigation was voluntarily introduced from about 2004 and made mandatory in April 2006 (Department of Internal Affairs 2006). The 2006 notice mandated that all trawlers over 28 m in length use a seabird scaring device while trawling (being "paired streamer lines", "bird baffler", or "warp deflector" as defined in the notice).

To understand changing fisheries risk over time as affected by changes in mitigation uptake, vessel behaviour, or gear configuration, it will be necessary to disaggregate the seabird risk assessment to examine trends for subsets of the fishery and species of interest. Of particular relevance, the seabird risk assessment includes estimates of cryptic mortality (i.e., deaths that are not counted among observable captures) whereas the captures estimation does not. In trawl fisheries, it is thought that for every observed seabird capture on a trawl warp, there may be several additional cryptic deaths (due to bird carcasses falling off the warps unobserved), but the true multiplier is uncertain. In contrast, seabird captures in the net have a much lower cryptic mortality multiplier, and some birds are released alive. For this reason, even a relatively constant total capture rate (as in Table 10) may conceal substantial changes in total deaths and population level risk at the species level, if the ratio of net captures to warp captures has changed in this period.

4.3.3 Protected fish species captures

Basking shark

The basking shark (*Cetorhinus maximus*) was classified as 'Endangered' by IUCN in 2013 and as 'Threatened – Nationally Vulnerable' in 2016, under the New Zealand Threat Classification System (Duffy et al 2018). Basking shark has been a protected species in New Zealand since 2010, under the Wildlife Act 1953 and is also listed in Appendix II of the CITES convention.

Basking sharks are caught occasionally in hoki trawls (Francis & Duffy 2002, Francis & Smith 2010, Ballara et al 2010). Standardised capture rates from observer data showed that the highest rates and catches occurred in 1989 off the WCSI and in 1987–92 off the ECSI. Smaller peaks in both areas were observed in the late 1990s and early 2000s, but captures have been few since then (Table 12). Most basking sharks have been captured in spring and summer and nearly all came from FMAs 3, 5, 6, and 7. It is not known whether the low numbers of captures in recent decades are a result of different operational methods used by the fleet, a change in regional availability of sharks, or a decline in basking shark abundance (Francis 2017). Of a range of fisheries and environmental factors considered, vessel nationality stood out as a key factor in high catches in the late 1980s and early 1990s (Francis & Sutton 2012). Research to improve the understanding of the interactions between basking sharks and fisheries was reported by Francis & Sutton (2012) and updated by Francis (2017).

Table 12: Total number of tows, number and percentage of observed tows, and number of observed basking shark captures from 1988–89 to 2019–20 in the hoki target trawl fishery, extracted from the Central Observer Database. Observed trawls used bottom trawl (BT) and midwater trawl (MW) fishing methods.

Fishing year	Tows	No. observed	% observed	No. captures	Fishing year	Tows	No. observed	% observed	No. captures
1988–89	8 341	2 213	26.5	10	2004–05	14 554	3 334	22.9	1
1989–90	15 656	2 246	14.3	0	2005–06	11 584	1 773	15.3	0
1990–91	21 859	2 495	11.4	4	2006–07	10 600	1 764	16.6	0
1991–92	21 873	2 246	10.3	2	2007–08	8 779	1 923	21.9	1
1992–93	22 583	2 311	10.2	0	2008–09	8 170	1 671	20.5	1
1993–94	21 704	2 959	13.6	3	2009–10	9 964	2 116	21.2	0
1994–95	26 141	1 550	5.9	2	2010–11	10 398	1 766	17.0	0
1995–96	31 886	2 148	6.7	2	2011–12	11 328	2 709	23.9	2
1996–97	37 263	1 241	3.3	2	2012–13	11 672	4 510	38.6	1
1997–98	38 406	3 159	8.2	14	2013–14	12 941	4 001	30.9	3
1998–99	32 324	3 560	11.0	7	2014–15	13 539	3 618	26.7	0
1999–00	33 070	4 844	14.6	3	2015–16	12 636	3 474	27.5	0
2000–01	32 073	5 716	17.8	4	2016–17	12 897	2 936	22.8	0
2001–02	27 234	6 333	23.3	1	2017–18	13 773	4 789	34.8	0
2002–03	27 792	4 470	16.1	5	2018–19	12 051	3 486	28.9	1
2003–04	22 535	3 594	15.9	2	2019–20	9 503	3 853	40.5	1

4.4 Benthic interactions

The spatial extent of seabed contact by trawl fishing gear in New Zealand's EEZ and Territorial Sea has been estimated and mapped in numerous studies for trawl fisheries targeting deepwater species (Baird et al 2011, Black et al 2013, Black & Tilney 2015, Black & Tilney 2017, Baird & Wood 2018, and Baird & Mules 2019, 2021a, 2021b), species in waters shallower than 250 m (Baird et al. 2015, Baird & Mules 2021a, 2021b), and all trawl fisheries combined (Baird & Mules 2021a, 2021b). The most recent assessment of the deepwater trawl footprint was for the period 1989–90 to 2018–19 (Baird & Mules 2021b).

The only target method of capture in the hoki fishery is trawling using either bottom (demersal) or midwater gear. Baird & Wood (2012) estimated that trawling for hoki accounted for 20–40% of all tows on or near the sea floor reported on TCEPR forms 1989–90 to 2005–06, and Black et al (2013) estimated that hoki trawling has accounted for 30% of all tows reported on TCEPR forms between 1989–90 and 2009–10. Between 2006–07 and 2010–11, 93% of hoki catch was reported on TCEPR forms. In the early years of the hoki fishery, vessels predominantly used midwater trawls because most of the catch was taken from spawning aggregations off the WCSI. Outside the spawning season, bottom trawling is used on the Chatham Rise and Sub-Antarctic fishing grounds (Table 13). Twin trawls were used to catch almost half of the TACC in some years. This gear is substantially wider than single trawl gear and catches more fish per tow than single trawl gear. The relationship between total catch and bottom impact of twin trawls has, however, not been analysed. As year-round fishing increased, vessels increased fishing effort on the Chatham Rise and in the Sub-Antarctic, and the bottom trawl effort increased to a peak between 1997–98 and 2003–04. Effort has declined substantially in all areas since 2005–06, largely as a result of TACC reductions but has increased again with increases in TACCs. Midwater trawling peaked in 1995–96 to 1996–97 in Cook Strait and on the Chatham Rise 1996–97 to 1997–98 but declined in all areas from 1997–98. Overall, midwater trawling has declined by about 90% since the peak in 1997 and bottom trawling by about 70% since the peak in 2000 (Table 13).

Table 13: Summary of number of hoki target trawl tows (TCEPR and ERS-trawl only) in the hoki fishery from fishing years (FY) 1989–90 to 2020–21. (MW, midwater trawl; BT, bottom trawl).

Fishery	WCSI/Puysegur		Cook Strait/ECSI		Sub-Antarctic		Chatham Rise/ECSI				
Season	Spawning		Spawning		Non-spawn		Non-spawn		All areas combined		%
Method	MW	BT	MW	BT	MW	BT	MW	BT	MW	BT	BT
FY											
1989–90	7 849	1 187	1 084	25	36	2 109	28	2 027	8 997	5 348	37
1990–91	7 351	1 678	2 226	26	81	3 927	953	3 492	10 611	9 123	46
1991–92	5 624	1 579	1 772	14	117	5 442	443	5 555	7 956	12 590	61
1992–93	5 488	1 861	1 564	18	442	4 915	1 054	5 266	8 548	12 060	59
1993–94	8 014	1 639	1 852	154	562	2 039	1 331	3 448	11 759	7 280	38
1994–95	7 223	1 501	2 019	258	419	2 329	2 174	6 260	11 835	10 348	47
1995–96	5 698	2 017	3 187	1 439	418	2 506	2 305	7 913	11 608	13 875	54
1996–97	7 428	1 894	3 672	1 350	332	3 423	2 314	9 305	13 746	15 972	54
1997–98	6 979	1 548	2 371	701	165	4 376	3 780	11 456	13 295	18 081	58
1998–99	5 476	2 118	1 992	580	420	3 659	2 428	11 445	10 316	17 802	63
1999–00	5 470	2 275	1 943	370	516	5 943	2 706	9 494	10 635	18 082	63
2000–01	6 229	2 577	1 969	175	667	5 448	912	9 862	9 777	18 062	65
2001–02	4 988	3 095	1 136	173	132	6 449	858	7 820	7 114	17 537	71
2002–03	4 615	2 977	2 117	282	96	4 407	496	9 278	7 324	16 944	70
2003–04	4 274	1 887	1 812	72	78	3 023	385	7 225	6 549	12 207	65
2004–05	2 534	1 308	1 457	111	68	1 428	340	4 996	4 399	7 843	64
2005–06	1 783	1 508	1 020	49	74	719	140	4 822	3 017	7 098	70
2006–07	1 147	752	919	82	25	1 194	57	4 769	2 148	6 797	76
2007–08	813	492	393	386	36	925	75	4 203	1 317	6 006	82
2008–09	689	354	747	148	38	927	11	3 914	1 485	5 343	78
2009–10	1 182	612	799	77	56	1 251	116	4 361	2 153	6 301	75
2010–11	1 581	913	544	63	62	1 245	52	4 075	2 239	6 296	74
2011–12	1 660	1 188	836	81	70	1 202	74	4 397	2 640	6 868	72
2012–13	1 826	1 019	1 022	98	6	1 373	169	4 175	3 023	6 665	69
2013–14	2 318	1 111	1 011	65	12	1 872	131	3 981	3 472	7 029	67
2014–15	2 716	1 244	953	53	89	1 620	209	4 319	3 967	7 236	65
2015–16	2 694	1 529	823	93	10	834	101	4 066	3 628	6 522	64
2016–17	2 366	1 907	729	100	24	1 278	99	4 193	3 218	7 478	70
2017–18	2 102	2 043	833	18	81	1 728	63	3 658	3 080	7 447	71
2018–19	2 978	965	1 327	108	12	830	63	2 705	4 380	4 608	51
2019–20	2 553	714	975	66	5	692	32	2 759	3 565	4 231	54
2020–21	1 764	655	734	94	2	927	75	3 514	2 575	5 190	67

Note: Spawning fisheries include WCSI (Jul–Sep), Cook Strait (Jul–Sep), Puysegur (Jul–Dec), ECSI (Jul–Sep). Non-spawning fisheries include ECSI (Aug–Jun), Chatham Rise (Aug–Jun), Sub-Antarctic (Aug–Jun). TCER, CELR, and North Island tows are excluded.

During 1989–90 to 2018–19, about 434 000 bottom-contacting hoki trawls were reported on TCEPRs, TCERs, and ERS (Baird & Mules 2021b). The total footprint generated from these tows was estimated at about 167 650 km^2. This footprint represented coverage of 4.1% of the seafloor of the combined EEZ and the Territorial Sea areas and 12% of the ‘fishable area’, that is, the seafloor area open to trawling, in depths of less than 1600 m. In the 2018–19 fishing year, almost 8700 hoki tows resulted in a trawl footprint of 24 392 km^2, equivalent to 0.6% of the EEZ and Territorial Sea and 1.8 % of the fishable area (Baird & Mules 2021b).

The overall trawl footprint for hoki (1989–90 to 2018–19) covered 20% of the seafloor in 200–400 m, 28% of 400–600 m seafloor, and 28% of the 600–800 m seafloor (Baird & Mules 2021b). The hoki footprint contacted 1.6%, 6.7%, and 2.7% of those depth ranges in 2018–19, respectively (Baird & Mules 2021b). The Benthic-optimised Marine Environment Classification (BOMEC, Leathwick et al 2012) classes with the highest proportion of area covered by the hoki footprint were classes G (Cook Strait), H (Chatham Rise), I (Chatham Rise slope and shelf edge of the east coast South Island), and L (Southern Plateau waters). In 2018–19, 3% of class G (6342 km^2), 4% of class H (138 551 km^2), 19.7% of class I, and 2.3% of class L were contacted by the hoki footprint (Baird & Mules 2021b).

Bottom trawling for hoki, like trawling for other species, is likely to have effects on benthic community structure and function (e.g., Rice 2006) and there may be consequences for benthic productivity (e.g., Jennings et al 2001, Hermsen et al 2003, Hiddink et al 2006, Reiss et al 2009). These are not considered in detail here but are discussed in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021).

4.5 Other factors

4.5.1 Spawning disruption

Fishing during spawning may disrupt spawning activity or success. Although there has been no research on the disruption of spawning hoki by fishing in New Zealand, the hoki quota owners voluntarily ceased fishing some defined spawning grounds for certain periods on the WCSI, Pegasus Canyon (ECSI), and Cook Strait as a precautionary measure from the 2004 to 2009 spawning seasons with the intention of assisting stock rebuilding. This closure was lifted in the 2010 spawning season because the biomass of the western stock was estimated to have rebuilt to within the management target range, but seasonal spawning closures were reintroduced from 2018–19 (see Section 1).

4.5.2 Habitat of particular significance to fisheries management

Habitats of particular significance to fisheries management have not been defined for hoki or any other New Zealand fish. Studies of potential relevance have identified areas of importance for spawning and juveniles (O'Driscoll et al 2003). Areas on Puysegur Bank, Canterbury Bight, Mernoo Bank, and Cook Strait have been subject to non-regulatory measures to reduce fishing mortality on juvenile hoki (Deepwater Group 2011).

5. RECRUITMENT, ENVIRONMENTAL VARIABILITY, AND CLIMATE CHANGE

This section was last updated in May 2021.

Recruitment dynamics are challenging to assess or predict because of the many underlying drivers that vary over time and space. Stock size, demographic and trait composition, condition and distribution of spawning fish, and the spatio-temporal dynamics of trophic and environmental interactions all influence recruitment processes. Annual variations in hoki recruitment have considerable impact on this fishery and a better understanding of the influence of environmental variables on recruitment patterns would be very useful for the future projection of stock size under different climate change scenarios and different environmental conditions.

New Zealand waters are becoming warmer and more acidic due to the emission of anthropogenic carbon dioxide (Law et al 2018a, Law et al 2018b) and, as in other parts of the world, some fish distributions will be or already are changing. The link between climate, oceanographic conditions, and hoki recruitment is still not well understood. Analyses by Francis et al (2006) do not support conclusions drawn by Bull & Livingston (2001) that model estimates of recruitment to the western stock are strongly correlated with the southern oscillation index (SOI). Francis et al (2006) noted that there is a correlation of -0.70 between the autumn SOI and annual estimates of recruitment (1+ and 2+ fish) from the Chatham Rise trawl survey but found this difficult to interpret because the survey is considered to be an index of the combined recruitment to both the eastern and western stocks. A more recent analysis supports some climate variable effect on hoki recruitment but remains equivocal about its strength or form (Dunn et al 2009b). Bradford-Grieve & Livingston (2011) collated and reviewed information on the ocean environment off the WCSI in relation to hoki and other spawning fisheries. The authors noted that understanding of the underlying mechanisms and causal links between the WCSI marine environment and hoki recruitment remain elusive.

New Zealand research trawl data indicate small hoki (< 30 cm TL) are absent at bottom temperatures above about 15 °C and occur most frequently at 13–14 °C, whereas adults prefer cooler bottom water temperatures of about 6–10 °C (Dunn et al in prep). Surface water temperature has no clear relationship to hoki occurrence. Gunn et al (1989) hypothesised that hoki spawning and migration off Tasmania was influenced by water temperature, with spawning starting once temperatures dropped to 13–14 °C.

Off Australia, colder water temperatures during winter have been thought to be conducive to higher year class strength (Pecl et al 2014).

A baseline report summarising trends in climatic and oceanographic conditions in New Zealand that are of potential relevance for fisheries and marine ecosystem resource management identified a reciprocal correlation between northern gemfish and hoki year class strength (Hurst et al 2012). An updated chapter on oceanic trends in the Aquatic Environment & Biodiversity Annual Review 2021 (Fisheries New Zealand 2021) examines a recent review of temperature trends in New Zealand waters by Sutton & Bowen (2019). It notes that the effects of recent warmer temperatures (e.g., the high surface temperatures off the WCSI during the 2016 and 2017 spawning seasons, marine heatwaves, and general warming of the Tasman Sea) on fish distribution, growth, or spawning success have yet to be determined.

The state of knowledge of climate change-associated predictions for components of New Zealand's marine environment that are most relevant to fisheries has been documented (Cummings et al 2021). Past and future projected changes in coastal and ocean properties, including temperature, salinity, stratification and water masses, circulation, oxygen, ocean productivity, detrital flux, ocean acidification, coastal erosion and sediment loading, and wind and waves are reviewed. Fish stock responses to climate change effects on these coastal and ocean properties are discussed, as well as their likely impact on the fisheries sector, where known.

A range of decision support tools in use overseas were evaluated with respect to their applicability for dissemination of the state of knowledge on climate change and fisheries. Three species, for which there was a relatively large amount of available information, were chosen for further analysis. These were pāua, snapper, and hoki (shellfish, inshore, and middle-depths/deepwater fisheries, respectively). An evaluation of the sensitivity and exposure of hoki to climate change-associated threats, based on currently available published literature and expert opinion, assessed hoki vulnerability as 'low' (Cummings et al 2021).

Recent work on the growth rate of fish exposed to temperature increases showed that the stochasticity of recruitment and density-dependence overrides the background influence of global warming (Neubauer et al in press). It was concluded that extreme or catastrophic events such as marine heatwaves may have a greater influence on recruitment and biomass than the incremental changes of background warming (Neubauer et al in press).

Another recent study of hoki growth found that fishing and environmental factors initially promote individual fish growth but may then heighten the sensitivity of stocks to environmental change (Morrongiello et al 2021). Regional-scale wind and temperature affected growth of tarakihi and snapper, whereas deepwater hoki and ling growth was sensitive to the Interdecadal Pacific Oscillation (Morrongiello et al 2021).

No substantive changes in hoki spatial occurrence have been reported to date. Models predicting the spatial distribution of hoki at the end of the 21st Century, in response to changes in average water temperature and productivity predicted by the New Zealand Earth Systems Model, suggested some reduction in hoki occurrence on the Chatham Rise, but the overall change in hoki distribution was expected to be negligible in the short to medium term (Dunn et al in prep.).

Brooks (2020) used ecological niche modelling (Maxent) to predict current and future hoki distribution around New Zealand. The models were trained on catch data from the Fisheries New Zealand research trawl database and remote-sensed environmental data. Under more severe climate change scenarios, hoki habitat was predicted to contract to the south Chatham Rise and sub-tropical convergence zone around southern New Zealand and be lost from the west coast South Island. The main predictors of these changes were sea surface temperature and salinity.

The effects of climate change on the temperature of surface waters are reasonably well determined in New Zealand because the data are derived from satellite records (Ministry for the Environment & Stats NZ 2019, Law et al 2018b). However, deriving temperature from hoki fisheries depths 200–800 m below the sea surface is hampered by a lack of data from subsurface waters, and the correlation between surface and bottom temperatures at hoki depths is often weak. This data gap is being addressed in part by the MOANA project by placing thermal sensors on fishing vessels (https://www.moanaproject.org/). Temperature data collected from the NIWA trawl surveys show that marine heatwaves only seem to influence water temperatures above the mixed layer depth (R. O'Driscoll, NIWA, pers. comm.). However, unexplained warming has been detected in the Tasman Sea to 800 m depth off the west coast South Island from XBT profiles (Sutton & Bowen 2019). The effects of marine heatwaves on plankton productivity and knock-on trophic effects on hoki fisheries are not currently understood in New Zealand.

6. STOCK ASSESSMENT

The most recent stock assessment was completed in 2022. The 2022 assessment updated the 2021 assessment which followed a review of input data and model assumptions completed between 2018 and 2020 (Dunn & Langley 2018, Langley 2020). There was no assessment completed in 2020. The 2021 assessment differed substantially from 2019, in having different assumptions for natural mortality, maturation, and migrations, and spatially restructured fisheries dependent data with revised selectivity assumptions. A high-level summary of these changes is presented under the 'Changes to Model Structure and Assumptions' in Section 8 "Status of the Stocks" of this report, and in full detail by Dunn & Langley (2018) and Langley (2020). The general-purpose stock assessment programme, CASAL (Bull et al 2012), was used to perform the analyses.

Recent trends in standardised CPUE have varied by area but are all at or above the long-term average and have been relatively stable on the Chatham Rise for the last 14 years. The WCSI and Sub-Antarctic CPUE remained at similar levels in 2020–21, with WCSI CPUE increasing slightly and Sub-Antarctic CPUE indices decreasing slightly. Standardised CPUE in Cook Strait has increased since 2014. CPUE is not used in the stock assessment because it does not accurately index abundance over the long term.

Survey abundance indices are shown in Table 14. The Chatham Rise trawl survey biomass in January 2022 was 9% higher than that in 2020. The relative biomass of recruited hoki (ages 3+ years and older) on the Chatham Rise in 2022 also increased (by 8%) from that in 2020 and there was an above average estimate for 2+ hoki (2019 year class). The most recent Sub-Antarctic trawl survey estimate in November-December 2020 (2021 fishing year) was similar to that in 2016, and higher than that in 2018. The acoustic survey biomass in Cook Strait in 2021 was 75% higher than the equivalent index from the 2019 survey, reversing the decreasing trend observed in the time series since 2015. The 2018 WCSI acoustic survey was down 47% on 2013 and was the lowest in the time series.

Table 14: Abundance indices ('000 t) used in the stock assessment (* data new to this assessment). Years are fishing years (1990 = 1989–90). – no data. Biomass estimates are for all age classes in core survey area. [Continued on next page]

Year	Acoustic survey WCSI Winter[1]	Trawl survey Sub-Antarctic December[2]	Trawl survey Sub-Antarctic April[3]	Trawl survey Chatham Rise January[4]	Acoustic survey Cook Strait Winter[5]
1988	266	–	–	–	–
1989	165	–	–	–	–
1990	169	–	–	–	–
1991	227	–	–	–	88
1992	229	80	68	122	–
1993	380	87	–	186	283
1994	–	100	–	147	278
1995	–	–	–	121	194
1996	–	–	89	153	92
1997	445	–	–	158	141
1998	–	–	68	87	80
1999	–	–	–	109	114
2000	263	–	–	72	–
2001	–	56	–	60	102
2002	–	38	–	74	145
2003	–	40	–	53	104
2004	–	14	–	53	–
2005	–	18	–	85	59
2006	–	21	–	99	60
2007	–	14	–	71	104
2008	–	46	–	77	82
2009	–	47	–	144	166
2010	–	65	–	98	–

Table 14 [continued]

Year	Acoustic survey WCSI Winter[1]	Trawl survey Sub-Antarctic December[2]	Trawl survey Sub-Antarctic April[3]	Trawl survey Chatham Rise January[4]	Acoustic survey Cook Strait Winter[5]
2011	–	–	–	94	141
2012	283	46	–	88	–
2013	233	56	–	124	168
2014	–	–	–	102	–
2015	–	31	–	–	204
2016	–	–	–	115	–
2017	–	38	–	–	102
2018	123	–	–	122	–
2019	–	31	–	–	91
2020	–	–	–	90	–
2021	–	38*	–	–	159
2022				97*	

1. survey_WC_abundance
2. survey_SA_summer_abundance (truncated at age 3)
3. survey_SA_autumn_abundance
4. survey_CR_summer_abundance (truncated at age 2)
5. survey_CS_spawning_abundance

6.1 Methods

Model structure

The general-purpose stock assessment programme, CASAL (Bull et al 2012), was used to perform the stock assessment modelling. As with previous assessments, the model used in the 2021–22 assessment was a total catch-history age-based model. The model partitioned the population into two sexes, 18 age groups (1 to 17 and a plus group, 18+), two stocks [eastern (E) and western (W)], and four areas (Chatham Rise (CR), West Coast South Island (WC), Sub-Antarctic (SA), and Cook Strait (CS)). It is assumed that the adult fish of the two stocks do not mix: those from the western stock spawn off the west coast South Island and spend the rest of the year in the Sub-Antarctic; the eastern fish move between their spawning ground, Cook Strait, and their home ground, the Chatham Rise. Juvenile fish from both stocks live on Chatham Rise, but natal fidelity is assumed (i.e., all fish spawn in the area in which they were spawned). There is little direct evidence of natal fidelity for hoki, though its life history characteristics would indicate that 100% natal fidelity is unlikely (Horn 2011).

The model is not partitioned into mature and immature fish. The proportion mature was defined using an assumed logistic ogive, set to be the same for both stocks, with a_{50} and a_{to95} parameters of (3, 3) for male and (4, 4) for female. The main reason maturity was assumed rather than estimated is because the observations of mature fish-at-age are different in different sub-fisheries of the spawning fishery, with no overall proportion mature-at-age calculated. There are three autumn observations in the Sub-Antarctic of proportions of females that will spawn that year, but these were not fitted because the proportions mature in the base model were not estimated.

The model's annual cycle divides the fishing year into five time steps and includes four types of migration (Table 15). The first type of migration involves only newly spawned fish, all of which are assumed to move from the spawning grounds (Cook Strait and the west coast South Island) to arrive at the Chatham Rise at time step 2 and approximate age 1.6 y. The second affects only young western fish, some of which are assumed to migrate, at time step 3, from the Chatham Rise to the Sub-Antarctic. The last two types of migrations relate to spawning. Each year fish migrate from their home ground (the Chatham Rise for eastern fish, the Sub-Antarctic for western fish) to their spawning ground (Cook Strait for eastern fish, the west coast South Island for western fish) at time step 4. At time step 1 in the following year all spawners return to their home grounds.

The above describes the two-stock model structure. A one-stock model was also constructed as a sensitivity to the combined predictions of the two-stock model. In the one-stock model there were no migrations, and all fishery and survey selectivity ogives were allowed to be more flexible (default double normal). The data used in both models was the same. In the one-stock model, an absence of older fish (e.g., on Chatham Rise) can be attributed to domed selectivity, whereas in the two-stock model it can be attributed to migration. In general, the one-stock model produced improved fits to composition data, but reduced quality of fits to abundance data. Overall, the model outputs were similar to the two-stock model when presented as combined-stock outputs.

Table 15: Annual cycle of the assessment two stock model, showing the processes taking place at each time step, their sequence within each time step, and the available biomass observations. Any fishing and natural mortality within a time step occurred after all other processes, with half of the natural mortality occurring before and after the fishing mortality. An age fraction of, say, 0.25 for a time step means that a 2+ fish was treated as being of age 2.25 in that time step, etc. The last column ('Prop mort') shows the proportion of that time step's total mortality that was assumed to have taken place when each observation is made.

					Observations	
Step	**Approx. months**	**Process**	**M fraction**	**Age fraction**	**Label**	**Prop mort**
1	Oct-Nov	post-spawning migrations: WC->SA, CS->CR	0.17	0.25	–	
2	Dec-Mar	recruitment at age 1+ to CR (for both stocks)	0.33	0.60	survey_SA_summer_abundance	0.5
		non-spawning fisheries (CR, SA)			survey_CR_summer_abundance	0.6
3	Apr-Jun	migration: CR->SA	0.25	0.90	survey_SA_autumn_abundance	0.1
4	End Jun	spawning migrations: SA->WC, CR->CS	0.00	0.90		
5	Jul-Sep	increment ages	0.25	0.00	survey_CS_spawning_abundance	0.5
		spawning fisheries (WC, CS, PUY)			survey_WC_abundance	0.5

Data and error assumptions

Five series of abundance indices were used in the assessment (Table 14). New data were available from a trawl survey on Chatham Rise in January 2022 (Stevens & Ballara in press) and an acoustic survey of the Cook Strait in July-August 2021 (Escobar-Flores & O'Driscoll in prep). The age data used in the assessment (Table 16) were similar to those used in the 2021 assessment, but with one additional year of data.

The error distributions assumed were multinomial (Bull et al 2012) for the at-age data and lognormal for all other data. The weight assigned to each data set was controlled by the effective sample size for each observation, calculated from the observation error, and a reweighting procedure for the data sets following Francis (2011).

Two alternative sets of CVs were used for the biomass indices. The 'total' CVs represent an estimate of the total uncertainty associated with these data. For the trawl survey indices, these were calculated as the sum of an observation-error CV (which was calculated using the standard formulae for stratified random surveys, e.g., Livingston & Stevens 2002), and an additional 'process' error CV, which was either estimated or set at 0.1 for the Chatham Rise and Sub-Antarctic summer and autumn surveys (note that CVs are added as squares: $CV_{total}^2 = CV_{process}^2 + CV_{observation}^2$). For final model MCMC runs, the process-error CVs were set at 0.1. The CVs of the biomass indices are shown in Table 17.

Table 16: Age data used in the assessment. Years are model years (1990 = 1989–90). All age data from 2021–2022 are new inputs for the 2022 assessment. Age data follow the revised fishery stratification (see Table 18) and so are not directly comparable with previous assessments. Data from Puysegur were first included in 2021.

Area	Label	Data type	Years	Source of age data
PUY	fishery_PUY_spwn_age	Catch-at-age	1990–1992, 1994–1997, 2000–2005	Otoliths
WC	fishery_WC_inside_age	Catch-at-age	2000–2010, 2012–2021	Otoliths
	fishery_WC_north	Catch-at-age	1988–2021	Otoliths
	fishery_WC_south_age	Catch-at-age	1988–2021	Otoliths
SA	fishery_SA_auck_age	Catch-at-age	2001, 2003, 2004, 2006–2021	Otoliths
	fishery_SA_snares_age	Catch-at-age	2001, 2006–2021	Otoliths
	fishery_SA_suba_age	Catch-at-age	2001, 2002, 2003, 2009, 2012, 2016, 2018, 2019, 2021	Otoliths
	survey_SA_summer_age	Trawl survey	1992–94, 2001–10, 2012–13, 2015, 2017, 2019, 2021	Otoliths
	survey_SA_autumn_age	Trawl survey	1992, 1996, 1998	Otoliths
CS	fishery_CS_spwn_age	Catch-at-age	1990–2005, 2007–2010, 2014–2021	Otoliths
CR	fishery_CR_deep_age	Catch-at-age	2001–2021	Otoliths
	fishery_CR_shallow_age	Catch-at-age	1999–2019, 2021	Otoliths
	survey_CR_summer_age	Trawl survey	1992–2014, 2016, 2018, 2020, 2022	Otoliths

Table 17: Coefficients of variation (CVs) used with biomass indices in the assessment. Total CVs include both observation error CVs and process error CVs. Observation error CVs are shown for CR_summer, SA_summer, and SA_autumn, and the process error CVs either estimated or set to 0.1 for MPD (Mode of the Posterior Distribution) runs. Total CVs shown here for CS and WC. Years are fishing years (1990 = 1989–90).

survey_CR_summer_abundance	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Observation	0.08	0.10	0.10	0.08	0.10	0.08	0.11	0.12	0.12	0.10	0.11	0.09

survey_CR_summer_abundance	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2016	2018
Observation	0.12	0.11	0.08	0.11	0.11	0.15	0.14	0.10	0.15	0.10	0.14	0.16

survey_CR_summer_abundance	2020	2022
Observation	0.14	0.10

survey_SA_summer_abundance	1992	1993	1994	2001	2002	2003	2004	2005	2006	2007	2008	2009
Observation	0.07	0.06	0.09	0.13	0.16	0.14	0.13	0.12	0.13	0.11	0.16	0.14

survey_SA_summer_abundance	2012	2013	2015	2017	2019	2021
Observation	0.15	0.15	0.13	0.17	0.11	0.12

survey_SA_autumn_abundance	1992	1996	1998
Observation	0.08	0.09	0.11

survey_CS_spawning_abundance	1991	1993	1994	1995	1996	1997	1998	1999	2001	2002	2003	2005
Total	0.41	0.52	0.91	0.61	0.57	0.40	0.44	0.36	0.30	0.34	0.34	0.32
Observation	0.12	0.15	0.14	0.12	0.09	0.12	0.10	0.09	0.12	0.12	0.17	0.11

survey_CS_spawning_abundance	2007	2008	2009	2011	2013	2015	2017	2019	2021
Total	0.46	0.30	0.39	0.35	0.30	0.33	0.36	0.36	0.41
Observation	0.26	0.06	0.11	0.14	0.15	0.18	0.17	0.12	0.15

survey_WC_abundance	1988	1989	1990	1991	1992	1993	1997	2000	2012
Total	0.60	0.38	0.40	0.73	0.49	0.38	0.60	0.28	0.34
Observation	0.12	0.15	0.06	0.10	0.17	0.07	0.10	0.14	0.15

survey_WC_abundance	2013	2018
Total	0.35	0.46
Observation	0.18	0.15

For the acoustic indices, the total CVs were calculated using a simulation procedure intended to include all sources of uncertainty (O'Driscoll 2002). The observation-error CVs were calculated using standard formulae for stratified random acoustic surveys (e.g., Coombs & Cordue 1995) and included only the uncertainty associated with between-transect (and within-stratum) variation in total backscatter.

The observation CVs for the otolith-based, at-age data were calculated by a bootstrap procedure, which included an explicit allowance for age estimation error. No observation-error CVs were available for the observer length frequency based data from the non-spawning fisheries, so an ad hoc procedure was used to derive observation errors, which were forced to be higher than those from the spawning fisheries (Francis 2004b). The age ranges used in the model varied amongst data sets (Table 18). In all cases, the last age for these data sets was treated as a plus group.

Table 18: Age ranges used for at-age data sets.

	Age range	
Data set	**Lower**	**Upper**
survey_SA_autumn_age	2	15+
survey_CR_summer_age	2	13+
survey_SA_summer_age	4	15+
survey_CR_SHI_age	2	9+
survey_SA_SHI_age	2	10+
Survey_SA_AEX_age	2	6+
fishery_PUY_spwn_age	2	18+
All other fisheries	1	18+

The catch for each year was divided among the 10 fisheries in the model according to area and month (Table 19). This division was based on estimated catch data from the catch and effort logs, and the resulting values were then scaled up to sum to the HOK 1 MHR total. The method of dividing the catches (Table 19) was similar to that used in the 2021 assessment, except that the definitions of the fisheries were different. The catch totals used in the model (Table 20) were unchanged, except for revisions to the previously assumed catch for 2021.

For the 2021–22 fishing year, catches by fishery were defined using 103 700 tonnes (56 050 tonnes eastern stock; 47 650 tonnes western stock) based on industry advice.

Table 19: The division of annual catches by area and months into the 10 model fisheries. The small amount of catch reported from the west coast North Island and Challenger areas, typically about 100 t per year, has been distributed pro rata across all fisheries.

Fishery	Description	Areas/months
CR_deep	Chatham Rise deep (effort depth ≥475m), non-spawning	CR, CS (Oct-May), ECNI, ECSI (Oct-May)
CR_shallow	Chatham Rise shallow (effort depth <475m), non-spawning	CR, CS (Oct-May), ECNI, ECSI (Oct-May)
CS	Cook Strait spawning	CS (Jun-Sep), ECSI (Jun-Sep)
SA_auck	Sub-Antarctic Auckland Islands, non-spawning	Sub-Antarctic Auckland Islands
SA_snares	Sub-Antarctic Snares shelf, non-spawning	Sub-Antarctic Snares, Puysegur (Oct-May)
SA_suba	Sub-Antarctic excluding Auckland Islands and Snares shelf, non-spawning	Sub-Antarctic
PUY_spn	Puysegur spawning fishery	Puysegur (Jun-Sep)
WC_inside	WCSI south of 42.5 inside the line	West coast inside
WC_north	WCSI north of 42.5 and includes inside the line	West coast north
WC_south	WCSI south of 42.5 outside the line	West coast south

Further assumptions

Two key outputs from the assessment are B_0 — the average spawning stock biomass that would have occurred over the period of the fishery had there been no fishing — and the time series of year class strengths (YCSs). For example, the YCS for 1970 comprised fish spawned in the winter of 1970 that first arrived in the model in area Chatham Rise at age 1.6 y, in about December 1971, which was in model year 1972. Associated with B_0 was an estimated mean recruitment, R_0, which was used, together with a Beverton-Holt stock-recruit function and the YCSs, to calculate the recruitment in each year. The first five YCSs (for years 1970 to 1974) were set equal to 1 (because of the lack of at-age data for the early years), but all remaining YCSs (for 1975 to 2020) were estimated. The model corrects for bias in estimated YCSs arising from ageing error. YCSs were constrained to average to 1 over the years 1975 to 2018, so that R_0 may be thought of as the average recruitment over that period. R_0 and a set of YCSs were estimated separately for each stock. The B_0 for each stock was calculated as the spawning biomass that would occur given no fishing and constant recruitment, R_0, and the initial biomass before fishing (B_{INIT}) was set equal to B_0. The steepness of the stock-recruitment relationship was assumed fixed at 0.75 for both stocks (Francis 2009).

Table 20: Model catch history (t) by fishery and fishing year (1972 means fishing year 1971–72), as used in this assessment. Years are fishing years (1990 = 1989–90). The 2022 catch is assumed, based on industry advice. [Continued on next page]

Year	CR_ deep	CR_ shallow	CS_ spwn	PUY_ spwn	SA_ auck	SA_ snares	SA_ suba	WC_ inside	WC_ north	WC_ south	Total
1972	3 500	500						1 700	3 300	10	9 010
1973	3 500	500						1 700	3 300	10	9 010
1974	5 200	800						1 700	3 300	10	11 010
1975	31 300	4 700						3 400	6 600	10	46 010
1976	32 200	4 800						10 200	19 700	100	67 000
1977	33 100	4 900						20 500	39 400	100	98 000
1978	2 600	400						1 700	3 300	10	8 010
1979	5 200	800						6 100	11 800	10	23 910
1980	7 000	1 000						6 800	13 100	10	27 910
1981	7 000	1 000						8 500	16 400	100	33 000
1982	6 100	900						8 500	16 400	100	32 000
1983	8 700	1 300		10	1 300	1 700	400	9 100	17 400	100	40 010
1984	8 700	1 300		10	1 700	2 300	600	12 100	23 200	100	50 010
1985	8 700	1 300		10	1 500	1 900	500	10 300	19 700	100	44 010
1986	14 800	2 200		100	3 500	4 700	1 100	24 800	47 600	200	99 000
1987	14 800	2 200		200	6 800	9 000	2 200	47 700	91 700	300	174 900
1988	7 100	1 100	7 400	300	10 300	13 700	3 300	72 500	139 300	500	255 500
1989	5 500	800	5 700	200	8 200	11 000	2 600	57 800	111 200	400	203 400
1990	9 395	4 738	14 955	7 249	660	9 646	1 596	1 765	78 955	79 716	208 675
1991	25 377	5 788	30 500	4 849	1 748	8 244	6 798	1 180	72 352	55 711	212 547
1992	36 353	13 237	25 435	4 756	2 496	17 039	11 252	754	64 421	36 356	212 099
1993	35 703	10 424	22 023	1 682	3 635	14 258	7 492	1 039	83 763	11 799	191 818
1994	17 841	8 335	36 115	2 349	865	8 562	2 246	1 647	95 943	18 293	192 196

Table 20 [continued]

Year	CR_ deep	CR_ shallow	CS_ spwn	PUY_ spwn	SA_ auck	SA_ snares	SA_ suba	WC_ inside	WC_ north	WC_ south	Total
1995	34 429	12 212	35 100	795	2 089	7 254	4 376	2 384	54 153	23 839	176 631
1996	39 467	20 683	60 218	2 217	1 665	9 233	2 377	4 249	42 781	25 906	208 796
1997	47 453	22 174	57 506	5 530	6 576	11 468	4 071	7 964	62 161	21 249	246 152
1998	61 925	26 810	46 546	1 691	9 153	10 176	6 269	7 765	71 292	27 217	268 844
1999	53 808	27 733	41 592	2 234	7 985	11 221	5 213	7 220	50 504	36 836	244 346
2000	40 898	20 424	41 623	2 469	13 985	13 821	6 377	14 137	64 632	23 954	242 320
2001	37 837	17 921	34 831	5 752	11 391	12 690	7 040	21 574	43 405	37 257	229 698
2002	31 644	11 011	24 591	4 814	9 018	7 456	14 209	21 825	45 597	25 299	195 464
2003	28 339	14 055	41 721	5 588	7 921	3 485	9 153	16 477	37 983	19 401	184 123
2004	27 932	8 815	40 957	724	4 778	2 604	4 687	18 784	14 334	11 995	135 610
2005	26 339	6 658	26 277	5 446	2 654	2 293	1 399	7 893	15 759	9 459	104 177
2006	24 904	11 806	20 501	1 211	1 232	4 843	883	5 220	17 783	15 985	104 368
2007	34 006	6 791	18 803	250	1 780	5 388	651	3 109	23 678	6 541	100 997
2008	34 170	7 274	17 910	133	2 801	4 557	1 525	914	16 936	3 082	89 302
2009	34 426	7 872	15 890	120	2 201	6 394	1 326	1 151	16 692	2 705	88 777
2010	34 410	7 528	16 366	106	2 527	8 365	1 550	2 933	31 060	2 357	107 202
2011	32 709	10 616	13 272	1 097	3 272	7 805	1 657	7 509	35 453	5 411	118 801
2012	34 901	8 187	15 407	894	2 973	11 195	1 988	8 487	35 554	10 492	130 078
2013	32 250	9 467	18 577	460	4 257	7 819	2 518	6 858	35 180	14 181	131 567
2014	31 033	7 850	17 346	400	5 784	7 406	7 115	10 355	44 026	15 019	146 334
2015	36 486	8 289	19 785	1 296	4 575	9 370	3 013	13 388	49 840	15 478	161 520
2016	29 841	10 707	19 558	928	2 406	2 716	1 644	16 172	37 372	15 333	136 677
2017	34 996	9 115	17 123	926	2 490	6 036	4 914	16 737	32 547	16 678	141 562
2018	31 893	9 814	21 579	947	3 694	4 919	7 011	17 095	18 408	20 054	135 414
2019	36 444	6 561	22 673	1 026	2 440	4 366	2 494	14 987	14 335	17 130	122 456
2020	30 141	5 445	19 818	257	3 013	3 906	1 211	13 725	17 941	12 248	107 705
2021	32 682	5 904	16 818	104	1 216	1 577	489	13 100	17 124	11 690	100 704
2022	35 673	5 564	14 813	243	3 495	3 736	1 350	11 643	14 795	12 388	103 700

In model runs natural mortality (M) by sex was assumed to be constant over time, and the same for each stock, with female $M = 0.25$ y^{-1} and male $M = 0.30$ y^{-1}. An alternative model was run with higher M for males to resolve patterns in sex ratio by age class.

The model used 17 selectivity ogives (11 for the eastern and western spawning and non-spawning fisheries and six for the trawl surveys on the Chatham Rise and Sub-Antarctic) and two migration ogives (Chatham Rise to Sub-Antarctic migration, defined separately for males and females).
Prior distributions were assumed for all parameters. Bounds for the acoustic catchability parameters were calculated by O'Driscoll et al (2016) (who called them overall bounds); for YCS, bounds were set at the 0.001 and 0.999 quantiles of their distributions (Table 21). Prior distributions for all other parameters were assumed to be uniform, with bounds that were wide enough so as not to affect point estimation, or, for some ogive parameters, deliberately set to constrain the ogive to a plausible shape.

Table 21: Assumed prior distributions for key parameters. Parameters are bounds for uniform; mean (in natural space) and CV for lognormal; and mean and SD for normal and beta.

Parameter	Description	Distribution	Values		Reference
recruitment[E].YCS	year-class strengths (E)	lognormal	1	0.95	Francis (2004a)
recruitment[W].YCS	year-class strengths (W)	lognormal	1	0.95	Francis (2004a)
q[survey_CS_spawning_q].q	catchability, CS acoustic survey	lognormal	0.55	0.90	O'Driscoll et al (2016)
q[survey_WC_spawning_q].q	catchability, WC acoustic survey	lognormal	0.39	0.77	O'Driscoll et al (2016)

The final models, taken to MCMC, are summarised in Table 22. Models 2022A and 2022B are alternative base models, because they only differ in the assumed natural mortality for males (M set at 0.35 y^{-1} for males in Model 2022B).

Table 22: Characteristics for final model runs.

Model	Short name	Main assumptions
2022A	Base2021 with SA selectivity shifts	Two spawning stocks, that spawn on the CS and WC. Recruits from both stocks reside on CR as juveniles. Western-spawned fish migrate to SA (estimated ogive; further testing of this parameterisation required). Mature WC-stock fish migrate from SA to WC to spawn and mature CR-stock fish from CR to CS to spawn. After spawning, all mature fish return (WC to SA and CS to CR).
2022B	Base2021 with M (male) = 0.35	

Bayesian posterior distributions were estimated for models 2022A and 2022B using a Markov chain Monte Carlo (MCMC) approach. For each model, a chain of length 8 million was completed, with adaptive step size allowed during the first 4.5 million samples. The initial 1.5 million samples of each chain were discarded, and the remaining 6.5 million samples were concatenated and thinned to produce a posterior sample of size 6500.

Calculation of fishing intensity and B_{MSY}

Due to complications in calculating fishing intensity (U) when there are multiple fisheries and stocks, a simplified version was calculated as the catch in biomass divided by the estimated spawning stock biomass (*SSB*). For a given stock and run, the corresponding reference fishing intensities were estimated using the same equation (catch/*SSB*), and by running the model to equilibrium using a range of constant future catch levels, until the stock level at equilibrium was sufficiently close to the stock level reference point.

The 2022 assessment was conducted in two steps. First, a set of initial model runs was carried out generating point estimates (which estimate the Mode of the Posterior Distribution). Their purpose was to investigate model structure and assumptions to decide which runs to carry forward as final runs. The final runs used MCMC parameter estimation.

Deterministic B_{MSY} estimates are no longer calculated, for the following reasons. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge (current biomass must be known exactly, to calculate the target catch) and annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders). Second, it assumes perfect knowledge of the stock-recruitment relationship, which is very poorly known (Francis 2009). Third, the closeness of B_{MSY} to the soft limit permits the limit to be breached too easily and too frequently, given, for example, a limited period of low recruitment. Fourth, it would be very difficult with such a low biomass target to avoid the biomass occasionally falling below 20% B_0, the default soft limit according to the Harvest Strategy Standard.

Instead, the target range of 35% B_0 to 50% B_0 is used as a proxy for the likely range of credible B_{MSY} estimates.

6.2 Results

Model estimates are presented for the spawning stock biomass (Table 23), year class strengths (Figure 4), fishing intensity (Figure 5), and biomass trajectories with projections (Figure 6). The current western biomass was estimated to be 28% B_0 (median value for the base two stock model, Model 2022A) and 31% B_0 (Alternative base model, Model 2022B). Current eastern biomass estimates were 51% B_0 (Model 2022A) and 55% B_0 (Model 2022B). The current total biomass was estimated to be 40% B_0 (Model 2022A) and 43% B_0 (Model 2022B).

Table 23: Estimates of spawning biomass ('000 tonnes) (medians of marginal posterior, with 95% confidence intervals in parentheses). B_{2022} is the biomass in mid-season 2022. See Table 22 for the associated run numbers.

B_0 ('000t)			B_{2022} ('000t)			B_{2022}/B_0		
Eastern	Western	Total	Eastern	Western	Total	Eastern	Western	Total
Model 2022A								
682 (622, 747)	1 161 (1 107, 1 227)	1 843 (1 729, 1 974)	351 (243, 477)	327 (242, 442)	678 (485, 919)	0.51 (0.38, 0.65)	0.28 (0.22, 0. 36)	0.40 (0.30, 0.51)
Model 2022B								
689 (626, 757)	1 167 (1 110, 1 239)	1 856 (1 736, 1 996)	381 (266, 517)	362 (270, 481)	743 (536, 998)	0.55 (0.41, 0.70)	0.31 (0.24, 0.40)	0.43 (0.33, 0.55)

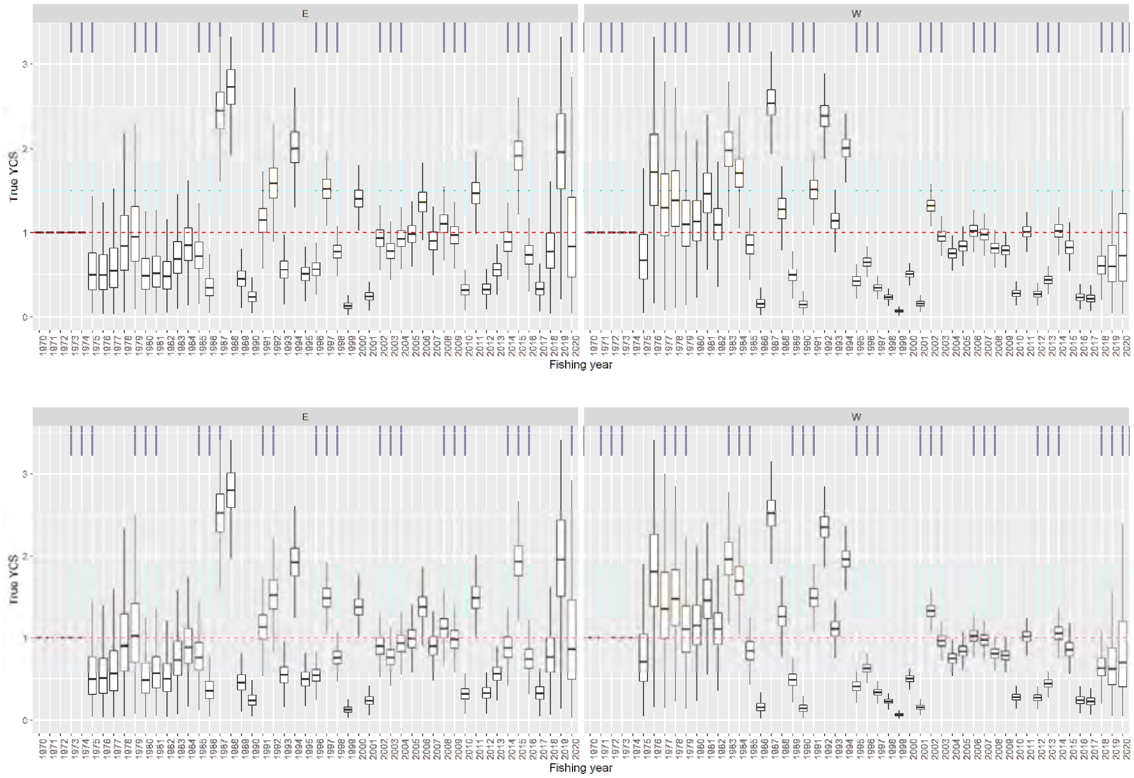
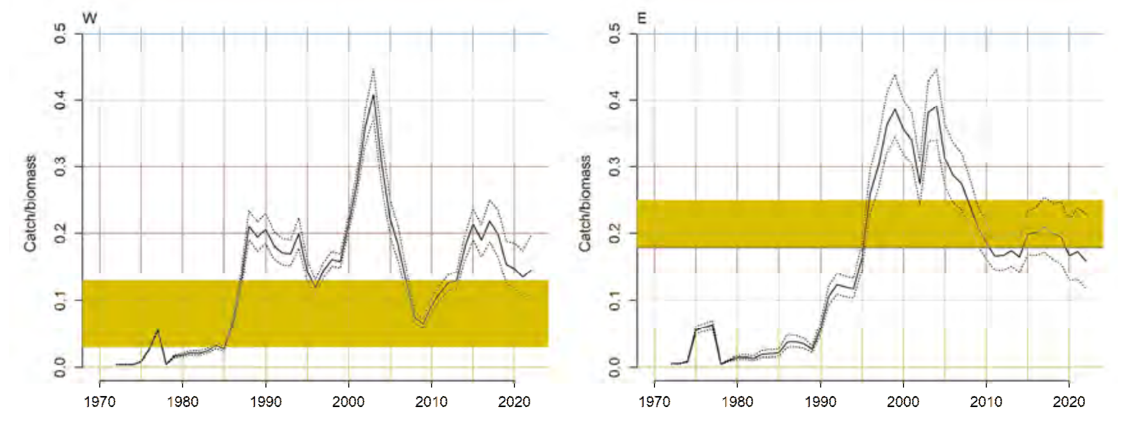


Figure 4: Year class strengths (YCS) for eastern (left) and western (right) stocks from model 2022A (top) and 2022B (bottom) from MCMC samples. Years are model years (1990 = 1989–90).

Fishing intensity for the western stock was estimated to be at or near all-time highs in 2002–2003 and is now substantially lower (Figure 5). For the eastern stock, fishing intensity peaked in 1999 and then again in 2004–2005 and is now lower.

Biomasses of both stocks were at their lowest points from about 2004 to 2006 (lowest values being at about 30% B_0 for the eastern stock and 20% B_0 for the western stock) (see Figure 6), after the western stock experienced seven consecutive years of poor recruitment from 1995 to 2001 inclusive and the eastern stock had below average recruitment over the same period (Figure 4). Both stocks then increased to above the target range of 35–50% B_0, then declined, with the eastern stock towards the top of the management target range and the western stock towards the lower bound of the target range, providing long-term recruitment levels are assumed. Recruitment to the western stock following the 1995–2001 period of poor recruitment remained low for two more years, then was estimated to have been above average for about five years before dropping again, with recruitment below average for 2011–2019. The recruitment patterns were similar for the eastern stock over these years, except for two strong year classes in 2011 and 2015.

Recent recruitment:



Long-term recruitment:

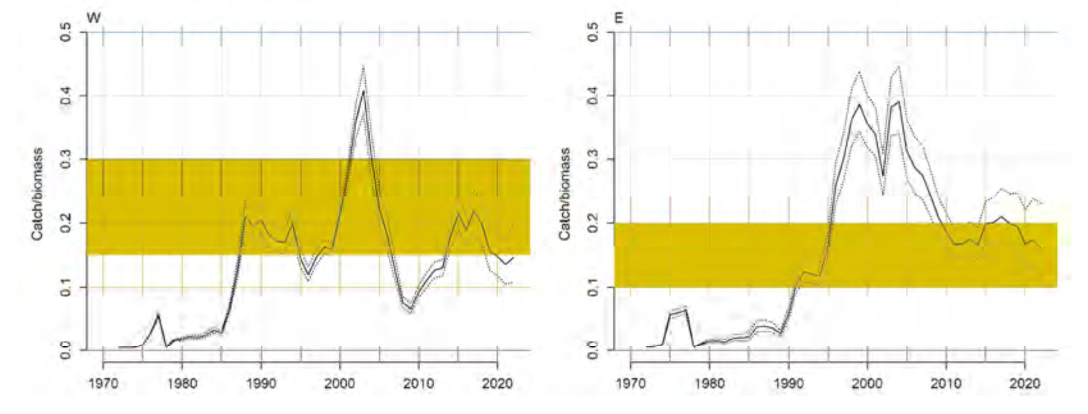


Figure 5: Fishing intensities, *U* (from MCMCs) for model 2022A, plotted by stock. Shown are medians (solid black line) with 95% confidence intervals (dotted lines). Also shown shaded in orange is the management range where the upper bound is the reference level $U_{35\%B_0}$ and the lower bound $U_{50\%B_0}$ which are the fishing intensities that would cause the spawning biomass to tend to 35% B_0 and 50% B_0, respectively, under recent recruitment (top) or long-term recruitment (bottom).

6.3 Sensitivities

A number of sensitivities were conducted at the MPD level. The results are shown in Table 24. The sensitivities that had the largest effect on stock status were the natural mortality sensitivities, with lower natural mortality having the largest effect on status of the eastern stock, and higher natural mortality having the largest effect on status of the western stock.

The single-area single-stock model (Model 2022C) has the least assumptions on movement, timing, and location. In this model, there is only one region and one stock, and selectivity ogives are used as proxies for the other dynamics. This is a useful model to include as a sensitivity if any of the assumptions in the base model are incorrect. The 2021 assessment included MCMC results from this model, but in the 2022 assessment the Fisheries New Zealand Deepwater Working Group decided more work was required on this model for it to be accepted. The MPD results for Model 2022C are still reported here as the concerns of the working group largely related to the performance of the MCMC chains.

Table 24: MPD sensitivities. Biomass estimates are in thousands of tonnes. Total estimates for model 2022A sensitivities are the sum of the estimates for the East and West stocks.

	East			West			Total		
Model description	B_0	B_{2022}	B_{2022}/B_0	B_0	B_{2022}	B_{2022}/B_0	B_0	B_{2022}	B_{2022}/B_0
Base2022A: *M*(male)=0.3, *M*(female)=0.25; *h*=0.75; Maturation: logistic (male)=2,2 (female)=3,3; cv.process_error=0.10; SA selectivity shifts not included	669	300	0.45	1 182	376	0.32	1 851	676	0.37
Base2022: *M*(male)=0.35, *M*(female)=0.25	722	411	0.57	1 182	370	0.31	1 904	781	0.41
Base2022: *M*(male)=0.35, *M*(female)=0.3	775	490	0.65	1 261	430	0.34	2 036	920	0.45
Base2022: *M*(male)=0.25, *M*(female)=0.20	763	307	0.40	1 197	274	0.23	1 960	581	0.30
Base2022: *h*=0.70	703	384	0.55	1 151	333	0.29	1 854	717	0.39
Base2022: *h*=0.80	737	384	0.52	1 193	330	0.28	1 930	714	0.37
Base2022: maturation logistic (male)=1,2; (female)=2,3	749	436	0.58	1 201	347	0.29	1 950	783	0.40
Base2022: maturation logistic (male)=3,2; (female)=4,3	695	324	0.47	1 133	330	0.29	1 828	654	0.36
Model 2022C: single stock model							2 096	925	0.44

6.4 Projections

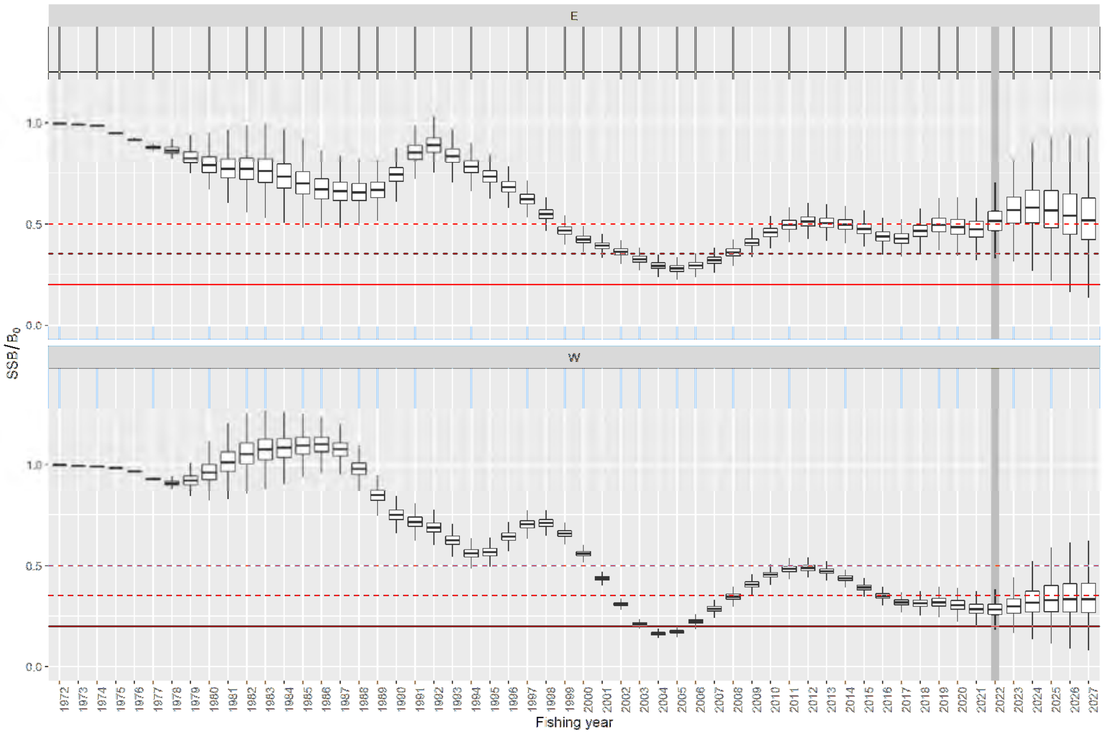
Five-year projections were carried out for the two model runs. Estimates of recruitment for 2019 and 2020 were based on observations. Future recruitments (2021 onwards) were randomly selected based on two scenarios: (i) recruitments estimated for 2009–2018 (recent recruitment), and (ii) recruitments estimated for 1975–2020 (long-term recruitment). Total future annual catches were assumed to be constant at the TACC of 110 000 tonnes (45000 tonnes western stock; 65 000 tonnes eastern stock). These future catches were apportioned by fishery using average proportions from the 2020 and 2021 fishing years. The projections indicated that the eastern biomass would remain fairly constant over the next 5 years and likely above the top of the target range (see Figure 6, Tables 25, 26a, b). The western biomass is projected to increase under long-term recruitment and remain constant under recent recruitment (see Figure 6, Tables 25, 26a, b).

For both eastern and western stocks, the estimated probability of being less than the soft or the hard limit at the end of the five-year projection period was less than 10% (Tables 26a, b).

Table 25: Projected median *SSB* (% B_0) for 2022 to 2027 from the base model (2022A), assuming future estimated catch levels of 110 000 tonnes (65 000 tonnes eastern stock; 45 000 tonnes western stock), and with recruitment levels randomly selected from: 2009–2018 estimates (recent recruitment); 1975–2020 (long-term recruitment).

Recruitment	**Stock**	**2022**	**2023**	**2024**	**2022**	**2026**	**2027**
Recent	All	37	40	42	43	42	41
	East	51	57	58	57	54	52
	West	28	30	32	33	33	33
Long-term	All	37	40	43	45	47	49
	East	51	57	59	58	57	56
	West	28	30	33	36	40	44

Recent recruitment



Long term recruitment

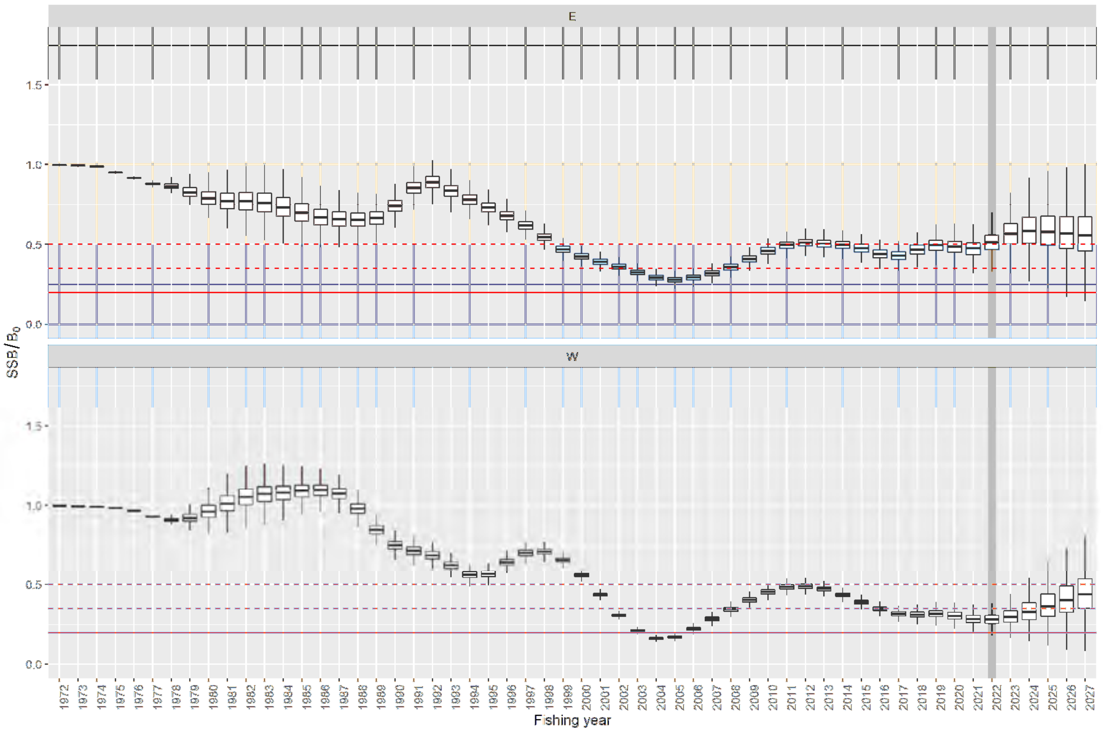


Figure 6: Projected spawning biomass (as % B_0) from the base model (2022A) under two recruitment scenarios: recent (2009–2018) (top block); long-term (1975–2020) (bottom block), for eastern stock (upper plot in each block), western stock (lower plot in each block). The horizontal dashed red lines represent the target management range of 35–50% B_0. The horizontal red solid line shows 20% B_0.

Table 26a: Projected probabilities (to two decimal places) from the base model (2022A) of *SSB* being below, within, or above various levels of *%* B_0 for 2022 to 2027, assuming future estimated catch levels of 110 000 tonnes (65 000 tonnes eastern stock; 45 000 tonnes western stock) and with recruitment levels randomly selected from 2009–2018 estimates (recent recruitment).

	2022	2023	2024	2022	2026	2027
EAST 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<35% B_0)	0.01	0.01	0.01	0.03	0.06	0.11
P (35≤SSB<50% B_0)	0.41	0.23	0.22	0.27	0.32	0.34
P (SSB≥50% B_0)	0.58	0.76	0.76	0.69	0.62	0.55
WEST 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20% B_0)	0.01	0.01	0.02	0.04	0.06	0.07
P (SSB<35% B_0)	0.94	0.82	0.63	0.55	0.51	0.49
P (35≤SSB<50% B_0)	0.05	0.17	0.31	0.33	0.34	0.35
P (SSB≥50% B_0)	0.00	0	0.04	0.08	0.09	0.09
ALL 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20%B_0)	0.00	0.01	0.01	0.02	0.03	0.04
P (SSB<35% B_0)	0.48	0.41	0.32	0.29	0.29	0.30
P (35≤SSB<50% B_0)	0.23	0.20	0.26	0.30	0.33	0.34
P (SSB≥50% B_0)	0.29	0.38	0.40	0.39	0.35	0.32

Table 26b: Projected probabilities (to two decimal places) from the base model (2022A) of *SSB* being below, within, or above various levels of *%* B_0 for 2022 to 2027, assuming future estimated catch levels of 110 000 tonnes (65 000 tonnes eastern stock; 45 000 tonnes western stock) and with recruitment levels randomly selected from 1975–2020 estimates (long-term recruitment).

	2022	2023	2024	2022	2026	2027
EAST 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<35% B_0)	0.01	0.01	0.01	0.03	0.04	0.07
P (35≤SSB<50% B_0)	0.41	0.23	0.21	0.24	0.27	0.28
P (SSB≥50% B_0)	0.58	0.77	0.77	0.73	0.69	0.65
WEST 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20% B_0)	0.01	0.01	0.02	0.02	0.02	0.02
P (SSB<35% B_0)	0.94	0.81	0.59	0.42	0.30	0.23
P (35≤SSB<50% B_0)	0.05	0.18	0.35	0.42	0.45	0.42
P (SSB≥50% B_0)	0.00	0.00	0.05	0.14	0.23	0.33
ALL 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20% B_0)	0	0.01	0.01	0.01	0.01	0.01
P (SSB<35% B_0)	0.48	0.41	0.3	0.22	0.17	0.15
P (35≤SSB<50% B_0)	0.23	0.2	0.28	0.33	0.36	0.35
P (SSB≥50% B_0)	0.29	0.38	0.41	0.43	0.46	0.49

7. FUTURE RESEARCH CONSIDERATIONS

- The Sub-Antarctic q estimated in the current model is much larger than Chatham Rise q. Understanding why this is happening could help understand the Chatham Rise/Sub-Antarctic dynamic, and by changing selectivities and/or migration the model could estimate relative qs that are more intuitive.
- The migration from the Chatham Rise to the Sub-Antarctic is important for the eastern/western stock dynamic in the model, but it is difficult to estimate due to confounding with selectivities. Combining the Chatham Rise and Sub-Antarctic is one option to avoid the issue. This would mean the Chatham Rise and Sub-Antarctic combined area would consist of all juvenile western and eastern stock fish, which would then migrate to the appropriate spawning grounds, and then return. Alternatively, structuring sensitivities that explore this migration could help highlight plausible dynamics.

- More abundance data including LFs, otoliths, and gonad staging need to be collected from the Pegasus Canyon and surrounding areas to determine the importance or relevance of these areas, including enabling the development of a consistent index of hoki abundance. Any temporal or areal differences in the availability of hoki in the Cook Strait and Pegasus spawning fisheries could then be integrated into the model.
- The single-area single-stock model (Model 2022C) requires further refinement and evaluation.
- Some trends in mean size-at-age (growth rates) are not accounted for in the model. This affects the conversion of catches in tonnes to mortality in numbers.
- Length to weight ratios change when fish are about to spawn, which also affects the conversion of catches in tonnes to mortality in numbers. This is currently not accounted for in the model.
- Currently the Chatham Rise summer survey has knife edge selectivity at 2 years, but there are still patterns in the resulting composition residuals. Because the Chatham Rise is important for the eastern/western stock split dynamics in the model, this could be an important area to resolve.
- There are strong patterns in proportions by sex in spawning fisheries that are still not resolved. This could relate to natural mortality, because a higher natural mortality for males goes some way to resolving the issue. This, along with assumptions about maturation, affects the migration of fish to the spawning grounds (and hence fisheries), but it is not well informed. Both should be further explored.
- The potential impacts on model results of mature fish not spawning every year should be investigated, noting that previous studies have been conducted to estimate the average percentage of mature fish not migrating to spawn.
- Males are assumed to have higher natural mortality than females in the model. The values for these could be explored further by focusing on the composition data, especially in the spawning fisheries.
- The last estimated biomass from the west coast South Island acoustics survey is from 2018, which was a low point, but the model is reliant on the Sub-Antarctic summer survey for the western stock abundance observations after this, and it is flat for the most recent few years. The utility of the west coast South Island acoustics survey should be re-examined.
- Alternative catch histories could be constructed, particularly for the period of operation of surimi vessels off the west coast of the South Island (1986 to the mid-1990s) following the large increase in hoki quota, as these vessels are believed to have under-reported their catches.
- The potential effects of cryptic mortality should be investigated, focusing on years of high juvenile abundance where density-dependent effects may occur.
- Consider making better use of the CPUE data, for example by examining whether it can be used to track young fish when they leave the Chatham Rise and arrive at the Stewart-Snares shelf. The size of fish indexed by the CPUE also needs to be considered.
- Consider expressing fishing intensity as the catch divided by the biomass of hoki of particular age and older rather than as catch/*SSB*.
- Improve knowledge of habitats of particular significance for hoki.
- Evaluate the Chatham Rise trawl survey data to improve knowledge of spatial patterns in hoki length, age, and abundance.
- A Management Strategy Evaluation to investigate the robustness of the current monitoring and assessment regime (including frequency of current surveys, the utility of additional surveys, target reference points, frequency of assessment, etc.) under the current stock paradigm and alternative stock assumptions. The study should also investigate alternative harvest strategies related to spatial distribution of catch between the main fisheries.
- Consider inclusion of CR_deep age and length data for the July-September period for the most recent three years as well as collection of more data in the current year.
- Review the sub-Antarctic stock assessment area boundaries, with consideration of biologically-relevant factors, e.g., temperature or depth.
- Define the appropriate observer coverage to provide consistent annual LF and AF sampling from the Sub-Antarctic fisheries.
- Develop an ALK (age-length-key) for the Sub-Antarctic by sampling in proportion to catch.
- Conduct spatial and temporal analysis of age structure for the hoki fishery.

8. STATUS OF THE STOCKS

Stock Structure Assumptions

Hoki are assessed as two intermixing biological stocks, based on the presence of two main areas where simultaneous spawning takes place (Cook Strait and the WCSI), and observed and inferred migration patterns of adults and juveniles:

- Adults of the western stock occur off the west coast of the North and South islands and the area south of New Zealand including Puysegur, Stewart-Snares shelf, and the Sub-Antarctic;
- Adults of the eastern stock occur off the east coast of the South Island, Cook Strait, and the ECNI up to North Cape;
- Juveniles of both biological stocks occur on the Chatham Rise including Mernoo Bank.

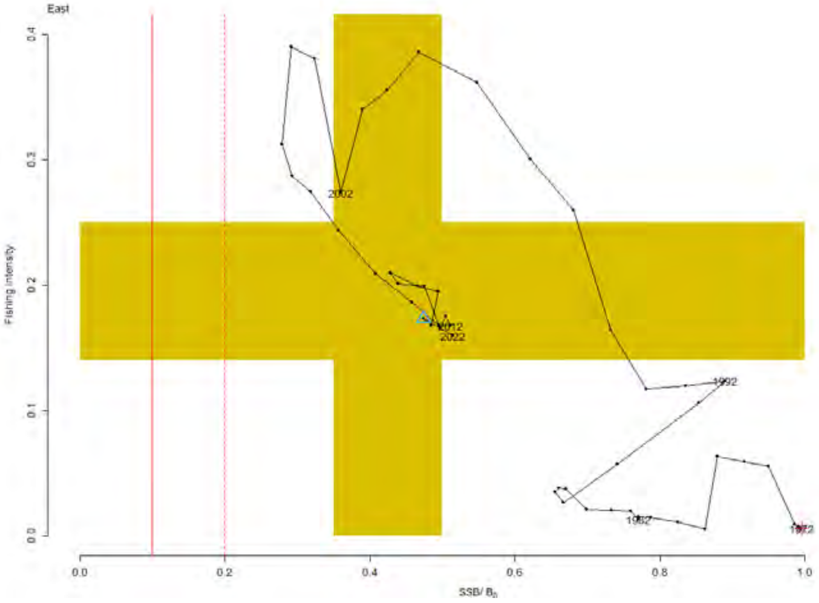
Both of these biological stocks lie within the HOK 1 Fishstock boundaries.

- **Eastern Hoki Stock**

Stock Status	
Year of Most Recent Assessment	2022
Assessment Runs Presented	Two stock (Base case: 2022A)
Reference Points	Target: 35–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{35\%B0}$
Status in relation to Target	B_{2022} was estimated to be 51% B_0. Very Likely (> 90 %) to be above the lower end of the target range About as Likely as Not (40–60%) to be above the upper end of the range
Status in relation to Limits	B_{2022} is Very Unlikely (< 10%) to be below the Soft Limit and Exceptionally Unlikely (< 1%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is Unlikely (< 40%) to be occurring

Historical Stock Status Trajectory

Recent recruitment:



Trajectory over time of fishing intensity (*U*) and spawning biomass (% *B₀*), for the eastern hoki stock from the start of the assessment period in 1972 (represented by a red asterisk) to 2022 (blue triangle). The red solid vertical line at 10% *B₀* represents the hard limit, the red dashed line at 20% *B₀* is the soft limit, and the shaded area represents the management target ranges in biomass and fishing intensity, with fishing intensity estimated using recent recruitment. Biomass and fishing intensity estimates are medians from MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has fluctuated with a slight increase since 2016–17
Recent Trend in Fishing Intensity or Proxy	Declining since 2016–17
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	- The trawl surveys of the Chatham Rise in 2022 suggested an above average 2019 year class and a weak 2020 year class, but based on the other datasets in the model, the 2019 year class appeared to be the eastern stock rather than the western stock. Early predictions of the stock split for high year classes are always uncertain. - CPUE indices from the Chatham Rise fishery have remained relatively stable over the last 10 years.

Projections and Prognosis	
Stock Projections or Prognosis	The eastern stock is projected to remain above the target over the next five years.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For current catch or agreed catch limit: Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch causing Overfishing to continue or to commence	For current catch: Unlikely (< 40%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2022	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl and acoustic surveys) - Proportions-at-age data from the commercial fisheries and trawl surveys - Estimates of fixed biological parameters	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	- Commercial CPUE	3 – Low Quality: does not track stock biomass over the long term
Changes to Model Structure and Assumptions	Changes from the 2021 model: - Selectivity caps free for spawning males - Sub-Antarctic summer survey minimum age extended to 3 years from 4 years - Selectivity shifts as applied to Sub-Antarctic selectivity estimated in the Stock Synthesis model were not applied - West coast north fishery not split at 2000	
Major Sources of Uncertainty	- Stock structure and migration patterns, in particular the migration from the Chatham Rise to the Sub Antarctic - Estimates of *q* for the Chatham Rise trawl survey (relative to the Chatham Rise trawl survey) - The actual split of recruitment between the eastern and western stocks for the three most recent year classes	

Qualifying Comments

Model fits to the Cook Strait composition data are still poor, and this dataset was down-weighted to reduce its effect on the rest of the model.

Fishery Interactions

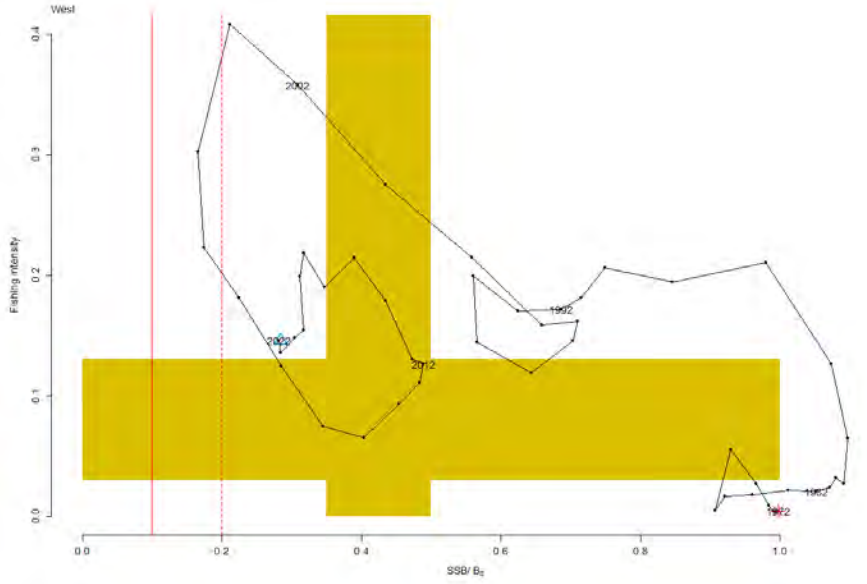
Hoki, hake, ling, silver warehou, and white warehou are frequently caught together, and trawl fisheries targeting these species are, as of 2018, considered one combined trawl fishery. The main non-target species caught in the combined fishery off the west coast South Island and Sub-Antarctic are rattails, javelinfish, and spiny dogfish. Incidental captures of protected species have been recorded for New Zealand fur seals, basking sharks, and seabirds. The only target method of capture in the hoki fishery is trawling using either bottom or midwater gear. Bottom trawling is likely to have effects on benthic community structure and function.

- **Western Hoki Stock**

Stock Status	
Year of Most Recent Assessment	2022
Assessment Runs Presented	Two stock (Base case: 2022A)
Reference Points	Target: 35–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{35\%B0}$
Status in relation to Target	B_{2022} was estimated to be 28% B_0. Unlikely (< 40%) to be above the lower end of the target range Exceptionally Unlikely (< 1%) to be above the upper end of the target range
Status in relation to Limits	B_{2022} is Unlikely (< 40%) to be below the Soft Limit and Very Unlikely (< 10%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is About as Likely as Not (40–60 %) to be occurring

Historical Stock Status Trajectory

Recent recruitment:



Trajectories over time of fishing intensity (*U*) and spawning biomass (% *B₀*), for the western hoki stock from the start of the assessment period in 1972 (represented by a red asterisk) to 2022 (blue triangle). The red solid vertical line at 10% *B₀* represents the hard limit, the red dashed line at 20% *B₀* is the soft limit, and the shaded area represents the management target ranges in biomass and fishing intensity, with fishing intensity estimated using recent recruitment. Biomass and fishing intensity estimates are medians from MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has been declining since 2011–12 to 2020–21 but has been similar in the last year.
Recent Trend in Fishing Intensity or Proxy	Declining for the last 5 years but has increased slightly in 2021–22.
Other Abundance Indices	
Trends in Other Relevant Indicators or Variables	- The trawl survey of the Chatham Rise in 2022 suggested an above average 2019 year class and a weak 2020 year class but, based on the other datasets in the model, the 2019 year class appeared to be eastern stock rather than western stock. Early predictions of the stock split for high year classes are always uncertain. - The trawl survey of the WCSI northern area showed an increase in hoki abundance from 2018 to 2021 although there was high uncertainty in the 2021 estimate. - CPUE indices from the WCSI North fishery increased by about 60% in 2019/20–2020/21 from a relatively low level in 2016/17 to 2018/19.

Projections and Prognosis	
Stock Projections or Prognosis	If future recruitment remains similar to recent recruitment, the biomass of the western hoki stock is expected to slowly increase over the next five years at assumed future catch levels.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For current catch or agreed catch limit: Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For current catch or agreed catch limit: About as Likely as Not (40–60%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2022	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl and acoustic surveys) - Proportions at age data from the commercial fisheries and trawl surveys - Estimates of fixed biological parameters	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	- Commercial CPUE - WCSI trawl survey biomass estimate - Some years of age data	3 – Low Quality: does not track stock biomass 3 – Low Quality: not considered to index spawning biomass 3 – Low quality: currently not used as it was not thought to be representative of the fishery
Changes to Model Structure and Assumptions	Changes from the 2021 model: - Selectivity caps free for spawning males - Sub-Antarctic summer survey minimum age extended to 3 years from 4 years	

	- Selectivity shifts not applied to Sub-Antarctic selectivity - Selectivity of West coast north fishery not split at 2000
Major Sources of Uncertainty	- Stock structure and migration patterns, in particular the migration from the Chatham Rise to the Sub Antarctic - Estimates of q for the Sub-Antarctic trawl survey (relative to the Chatham Rise trawl survey) - The actual split of recruitment between the eastern and western stocks for the three most recent year classes

Qualifying Comments
-

Fishery Interactions
Hoki, hake, ling, silver warehou, and white warehou are frequently caught together, and trawl fisheries targeting these species are, as of 2018, considered one combined trawl fishery. The main non-target species caught in the combined fishery off the west coast South Island and Sub-Antarctic are rattails, javelinfish, and spiny dogfish. Incidental captures of protected species have been recorded for New Zealand fur seals, basking sharks, and seabirds. The only target method of capture in the hoki fishery is trawling using either bottom or midwater gear. Bottom trawling is likely to have effects on benthic community structure and function.

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