



Relative abundance, size and age structure, and stock status of blue cod off Motunau in 2016

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M.P. Beentjes
C.P. Sutton

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EXECUTIVE SUMMARY

Beentjes, M.P.; Sutton, C. (2017). Relative abundance, size and age structure, and stock status of blue cod off Motunau in 2016.

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This report describes the results of blue cod (*Parapercis colias*) fixed and random site potting surveys carried out concurrently off Motunau in January 2016. Estimates are provided for population abundance, size and age structure, sex ratio, total mortality (Z), and spawner-per-recruit. This is the fourth survey in the Motunau fixed site survey time series following surveys in 2005, 2008, and 2012; and the second random site survey with the previous survey in 2012.

2016 fixed site survey

Eighteen fixed sites (6 pots per site, 108 pot lifts) at depths of 10–32 m from three strata off Motunau were surveyed in January 2016.

Mean catch rates of blue cod (all sizes) by stratum were 3–5 kg.pot⁻¹ and survey mean catch rate for all blue cod was 3.32 kg.pot⁻¹ with a CV of 13%. Catch rates for recruited blue cod (30 cm and over) followed the same pattern among strata as for all blue cod and overall was 1.34 kg.pot⁻¹ (CV 15%). The sex ratio was 73–77% male across the three strata and the overall weighted sex ratio was 76% male. The overall weighted mean length for males was 25.8 cm (range 15–44 cm) and 22.4 cm for females (range 10–33 cm).

Thin otolith section ages from 250 males and 144 females were used to estimate the population age, structure with separate age-length keys for males and females. The initial counts from each of the two otolith readers achieved 92% agreement, there was minimal bias between readers, and CV and average percent error were 1.3% and 0.9% respectively. Von Bertalanffy growth parameters (L_{∞} , K , t_0) for males were 42.1 cm, 0.22 yr⁻¹, -0.42 yr; and 33.8 cm, 0.27 yr⁻¹, and -0.38 yr for females. The low maximum ages (12 years for males and 10 years for females) gave improbable von Bertalanffy parameters, especially L_{∞} .

Scaled length frequency distributions for both males and females were unimodal with strong juvenile modes at about 22 and 20 cm respectively, and skewed to the right. Age estimates were 1–12 years for males and 1–10 years for females, but most fish were between three and six years old. The estimated population age distributions indicate knife-edge selectivity to the pot method at three years, and shows strong modes at three, five and six years for both sexes, and a weak mode for four year olds. Mean age was 4.5 years for males and 3.9 years for females.

Total mortality estimates (Z) for age-at-full recruitment of eight years were 0.76. Based on the default M of 0.14, estimated fishing mortality (F) and associated spawner-biomass-per-recruit ratio were 0.62 and 19.2%, respectively.

There was no clear indication of spawning activity during the survey period (applies to fixed and random sites).

2016 random site survey

Twenty one random sites (6 pots per site, 126 pot lifts) at depths of 6–35 m from three strata off Motunau were surveyed in January 2016.

Mean catch rates of blue cod (all sizes) by stratum were 1–7 kg.pot⁻¹ with the lowest catch rates in stratum 2, and the highest in stratum 1. The survey all blue cod catch rate was 2.48 kg.pot⁻¹ with a CV of 27%. Catch rates for recruited blue cod 30 cm and over, followed the same pattern among strata as

for all blue cod and overall was 1.11 kg.pot⁻¹ (CV 29%). The sex ratio was 71–83% male across the three strata and the overall weighted sex ratio was 76% male. The overall weighted mean length for males was 26.5 cm (range 11–43 cm) and 22.2 cm for females (range 11–35 cm).

Scaled length frequency distributions for both males and females were unimodal with strong juvenile modes at about 23 and 22 cm respectively, and skewed to the right. Age estimates were 1–12 years for males and 1–10 years for females, but most males and females were between three and six years old. The estimated population age distributions indicate knife-edge selectivity to the potting method at three years and shows strong modes at three, five and six years for both sexes, and corresponding weak modes for four year olds. Mean age was 4.8 years for males and 3.7 years for females.

Total mortality estimates (Z) for age-at-full recruitment of eight years were 0.75. Based on the default M of 0.14, estimated fishing mortality (F) and associated spawner-biomass-per-recruit ratio were 0.61 and 19.4%, respectively.

Fixed and random site comparison (2016 survey)

The overall catch rates were similar for fixed and random surveys in 2016, but CVs were much higher for random sites, partly because of the higher number of pots with zero catch resulting in increased variance in the site catch. Length distributions were also similar within each of the four strata, but overall blue cod were slightly larger for both males and females in random sites. Sex ratios for fixed and random sites showed a similar pattern among strata, skewed towards males.

Time series trends

Overall catch rates from fixed sites decreased markedly in 2008 and then again in 2016 with a three-fold decline between 2005 and 2016. The proportion of pots with no blue cod displayed an equal but opposite trend to that of the catch rate pattern, and increased from 4% to 12%. Overall blue cod mean size, and the proportion of blue cod 30 cm and over from fixed sites steadily declined from 2005 to 2016, with the biggest decreases in 2016. The sex ratio for all blue cod was around 75% male for all fixed site surveys with no trend.

There was no trend in random site catch rates and sex ratios for the 2012 and 2016 surveys, but mean length declined between surveys.

Summary

Blue cod abundance and mean size off Motunau declined and spatial distribution contracted over the eleven years from 2005 to 2016. The very high estimate of total mortality, truncated age composition, and strongly skewed sex ratio toward males, indicates that the blue cod population off Motunau is heavily fished to the extent that the current fishery (customary, recreational and commercial) may not be sustainable. Further, as nearly all females and most males caught will be of sub-legal size (less than 30 cm), there is also likely to be significant mortality through catch and return of undersize fish.

1. INTRODUCTION

This report describes the Ministry for Primary Industries (MPI) potting surveys of relative abundance, population length/age structure and stock status of blue cod (*Parapercis colias*) off Motunau in January 2016. These are the fourth in the time series with previous surveys in 2005, 2008, and 2012 (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2012).

1.1 Status of the north Canterbury blue cod stocks

Blue cod is a target species most frequently landed by recreational fishers off the South Island (Ministry for Primary Industries 2016). The Quota Management Area BCO 3 extends from the Clarence River, north of Kaikoura, to Slope Point in Southland (Figure 1). In BCO 3, recreational annual take was estimated at 119 t during a 2011–2012 panel survey involving face to face interviews with fishers (Wynne-Jones et al. 2014). Further, blue cod recreational catch in BCO 3 was the highest of any QMA (36% of total national recreational blue cod) with average daily catches of over 13 blue cod taken by 17% of respondents, and the most common method by far was by rod and line. There are no reliable data to determine how the recreational blue cod catch is distributed within BCO 3, but Kaikoura and Motunau are important blue cod fisheries (Hart & Walker 2004).

The commercial catch in BCO 3 is 40–50% higher than the recreational catch with between 166 and 183 t caught in the last five years up to 2014–15 (Ministry for Primary Industries 2016). Nearly all commercially landed blue cod in BCO 3 are caught by potting, and the bulk of this was from Statistical Area 024 off Oamaru (Figure 1).

Within the ‘Kaikoura Marine Area’ established in 2014, the minimum legal size is 33 cm and the daily bag limit is six blue cod (Figure 2). For the rest of north Canterbury from Conway River to Waimakariri River, including Motunau, the minimum legal size is 30 cm, and the daily bag limit is 10 blue cod.

In north Canterbury the two key recreational fishing areas for blue cod and many other species are Kaikoura and Motunau, which are about 90 km apart (Figure 2). Kaikoura offers substantial and varied blue cod habitat with a wide range of depths and a narrow continental shelf, whereas the coastline around Motunau is a relatively shallow wide shelf with less areas of foul. A recreational survey of private fishers and charter boats off Kaikoura and Motunau from January to April 2003 indicated that blue cod was the most common species caught at Motunau, and at Kaikoura it was the most common species caught by charter vessels, but third behind sea perch and rock lobster for private fishers (Hart & Walker 2004). Blue cod were smaller at Motunau (mean 38 cm) than Kaikoura (mean 43.1 cm), and the proportion undersize that were released was also higher at Motunau (57% compared to 39% released, respectively). Catch rates were higher at Motunau, but because more undersize fish were released the overall estimated recreational catch over the four month period was similar at about 3 t for both Kaikoura and Motunau (Hart & Walker 2004). The finding that blue cod at Motunau were smaller on average than at Kaikoura is consistent with length data from the potting surveys of Motunau and Kaikoura in 2004–05 and 2007–08 (Carbines & Beentjes 2006a, 2009).

1.2 Blue cod potting surveys

South Island recreational blue cod stocks are monitored using Ministry for Primary Industries (MPI) potting surveys. These surveys take place predominantly in areas where recreational fishing is common, but in some areas there is substantial overlap between the commercial and recreational fishing grounds, including parts of north Canterbury. Surveys are generally carried out every four years providing data that can be used to monitor local relative abundance, as well as size, age, and sex structure of geographically separate blue cod populations. The surveys provide a means to evaluate the response of

populations to changes in fishing pressure and to management initiatives such as changes to the daily bag limit, minimum legal size, and/or area closures. One method to investigate the status of blue cod stocks is to estimate fishing mortality, the associated spawner-per-recruit ratio (SPR), and the Maximum Sustainable Yield (MSY) related proxy. The recommended Harvest Strategy Standard reference point for blue cod (a low productivity stock) is $F_{45\%SPR}$ (Ministry of Fisheries 2011).

In addition to North Canterbury, there are currently seven other South Island areas surveyed, located in key recreational fisheries: Banks Peninsula (Beentjes & Carbines 2003, 2006, 2009), north Otago (Carbines & Beentjes 2006b, 2011), south Otago (Beentjes & Carbines 2011), Paterson Inlet (Carbines 2007, Carbines & Haist 2014), Foveaux Strait (Carbines & Beentjes 2012), Dusky Sound (Carbines & Beentjes 2006a, 2009, Beentjes & Page 2016), and the Marlborough Sounds (Blackwell 1997, 1998, 2002, 2006, 2008, Beentjes & Carbines 2012).

1.3 Previous North Canterbury blue cod potting surveys

All potting surveys (except Foveaux Strait) originally used a fixed site design, in which sites with predetermined locations (fixed sites) were randomly drawn from a limited pool of such sites (Beentjes & Francis 2011). 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 (Beentjes & Francis 2011). Random sites have now been used as the only site type in Foveaux Strait, or in conjunction with fixed sites in all other South Island blue cod surveys. It is the intention of MPI to transition to a fully random survey design but the deployment of both fixed and random sites allows comparison of catch rates, length and age composition, and sex ratios between the site type survey designs in the interim.

In north Canterbury, MPI blue cod potting surveys were carried out separately for the Motunau and Kaikoura recreational fishing areas. Motunau surveys were carried out in 2005, 2008, and 2012; and Kaikoura surveys in 2004, 2007 and 2011 (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2012). The first two north Canterbury surveys used only fixed sites, whereas the 2012 Motunau and 2011 Kaikoura surveys also included concurrent random site surveys. The first two fixed site surveys were reanalysed in 2012 updating catch-at-age, sex ratios, total mortality (Z), and spawner-per-recruit (SPR) estimates as prescribed by the potting survey standards and specifications (Beentjes 2012).

1.4 Objectives

Overall Objective

1. To estimate age structure and the relative abundance of blue cod (*Parapercis colias*) off north Canterbury

Specific objectives

1. To undertake a potting survey off north Canterbury to estimate relative abundance, size- and age-at-maturity, and sex ratio. Collect otoliths during the survey from pre-recruited and recruited blue cod.
2. To analyse biological samples collected from this potting survey.
3. To estimate the age structure and relative abundance of blue cod off Kaikoura.
4. To estimate the age structure and relative abundance of blue cod off Motunau.

5. To determine stock status of blue cod populations in this area, and compare this with other previous surveys in this area and other survey areas.

The Kaikoura blue cod survey is reported in Beentjes & Page (2017).

In this report we use only the terms defined in the blue cod potting survey standards and specifications (Beentjes & Francis 2011) (Appendix 1).

2. METHODS

2.1 Timing

The blue cod potting survey off Motunau was carried out by the National Institute of Water & Atmospheric Research Ltd (NIWA) from 11 to 18 January 2016, consistent with the previous survey dates and coinciding with the known spawning times in this region.

2.2 Consultation

The Motunau survey was supported and endorsed by Tuahiwi Marae and Motunau Marine Guardians.

2.3 Survey areas

The survey areas for the 2016 Motunau fixed and random site surveys were consistent with the previous surveys. The southern and northern boundaries were determined in 2004 based on discussions with local fishers, the Dunedin Ministry for Primary Industries, and the South Recreational Advisory Committee (Carbines & Beentjes 2006a). Fishers were given charts of the area and asked to mark discrete locations where blue cod are most commonly caught within the survey areas. The survey area was divided into three contiguous inshore strata, from Double Corner to Sail Rock, using the 30 m depth contour as the outer strata boundary (Figure 3). Strata were identical for fixed and random site surveys. Each stratum was assumed to contain roughly random distributions of blue cod habitat and the total area (km²) within each stratum was taken as a proxy for available habitat for blue cod.

2.4 Survey design

2.4.1 Allocation of sites

Full fixed site and full random site surveys were carried out concurrently in Motunau in 2016 (Table 1).

Simulations to determine the optimal allocation of fixed sites among the three strata were carried out with catch rate data from the 2005, 2008, and 2012 fixed site surveys using NIWA's Optimal Station Allocation Program (*allocate*). Simulations were first carried out for fixed sites and constrained to have a minimum of three sites per stratum and a CV of no greater than 12%. Because there were no random sites surveyed in 2005 and 2008, random site allocation was based on data from the 2012 survey constrained to have a minimum of three sites per strata and a CV of no greater than 20%. The simulations indicated that 22 fixed sites and 21 random sites were required to meet the target CVs. In the final design agreed by the Southern Inshore Working Group (SINSWG-2015-42), the number of sites was prorated down to 18 fixed and 21 random sites.

The survey used a two-phase stratified random station design (Francis 1984). For the fixed site survey 15 sites were allocated to phase 1, with the remaining three available for phase 2, consistent with the

proportion of sites allocated to phase 2 in previous surveys (Table 1). For the random site survey 18 sites were allocated to phase 1, with the remaining three available for phase 2, consistent with the proportion of sites allocated to phase 2 in the 2012 survey (Table 1). Allocation of phase 2 stations was based on the mean pot catch rate (kg.pot.⁻¹) of all blue cod per stratum and optimised using the “area mean squared” method of Francis (1984). In this way, stations were assigned iteratively to the stratum in which the expected gain is greatest, where expected gain is given by:

$$expected\ gain_i = area_i^2\ mean_i^2 / (n_i(n_i+1))$$

where for the *i*th stratum *mean_i* is the mean catch rate of blue cod per pot, *area_i* is the fishable stratum area, and *n_i* is the number of sets in phase 1. In the iterative application of this equation, *n_i* is incremented by 1 each time a phase 2 set is allocated to stratum *i*.

Fixed sites

A fixed site has a fixed location (single latitude and longitude or the centre point location of a section of coastline) in a stratum and is available to be used repeatedly on subsequent surveys (Beentjes & Francis 2011). The fixed sites used in a particular survey are randomly selected from the list of all available fixed sites in each stratum. For the 2016 Motunau survey, the 18 allocated fixed sites were randomly selected from the full and larger list of 65 possible fixed sites

Pot configuration and placement for fixed sites is defined in the blue cod potting manual (Beentjes & Francis 2011). Six pots (pot plan 2) were set in a cluster, no further than 0.5 km from the site position, but separated by at least 100 m. Pot placement for fixed sites was ‘directed’ with placement of each pot around the site determined by the skipper using local knowledge and the vessel sonar to locate a suitable area of reef/cobble or biogenic habitat.

Random sites

A random site has a location (single latitude and longitude) generated randomly within a stratum (Beentjes & Francis 2011). Sufficient sites to cover both first and second phase stations were generated for each stratum using the NIWA random station generator program (*Rand_stn* v1.00-2014-07-21) with the constraint that sites were at least 800 m apart. From this list, the allocated number of random sites per stratum to be surveyed was selected in the order they were generated, with the constraint that they were not closer than 400 m to an allocated fixed site (Table 1). If the random site was too close to a fixed site, a new fixed site from the list was selected to avoid biasing random site location which takes priority as the future survey design.

Pot configuration and placement for random sites is defined in the blue cod potting manual (Beentjes & Francis 2011). Random site surveys use systematic pot placement where the position of each pot is arranged systematically with the first pot set 200 m to the north of the site location and remaining pots set in a hexagon pattern around the site, at about 200 m from the site position.

2.4.2 Vessels and gear

The Motunau survey was conducted from F.V. *Navigator* (Registration number 64016), a Motunau-based commercial vessel owned and skippered by Mr Geoff Basher. The *Navigator* was used in 2005 and 2008, but not in 2012 due to maintenance, and instead the F.V. *Legacy* was used (owner and skipper Geoff Basher). The *Navigator* is equipped to set and lift rock lobster and blue cod pots with specifications: 11.9 m length, aluminium monohull, powered by two Yanmar 370 hp diesel engines with twin jets.

Six custom designed and built cod pots were used to conduct the survey (Pot Plan 2 in Beentjes & Francis 2011). Pots were baited with paua viscera in “snifter pottles”. Bait was topped up or replaced after every lift. The same pot design and bait type were used in all previous north Canterbury blue cod potting surveys.

A high-performance, 3-axis (3D) acoustic Doppler current profiler (SonTek/YSI ADP; Acoustic Doppler Profiler, 500 kHz, ADCP) was deployed at each site. The ADCP recorded current flow and direction in 5 m depth bins.

2.4.3 Sampling methods

All sampling methods adhered strictly to the blue cod potting survey standards and specifications (Beentjes & Francis 2011).

At each site, six pots were set and left to fish (soak) for a target period of one hour during daylight hours. As each pot was placed, a record was made of sequential pot number (1 to 6) and the pot identification code (PP2A to PP2F), latitude and longitude from GPS, depth, and time of day. After each site was completed, the next closest site (either random or fixed) in the stratum was sampled. The ADCP was deployed at the centre of each site prior to the setting of pots and recovered after the last pot of each set was lifted. The order that strata were surveyed depended on the prevailing weather conditions, with the most distant strata and/or sites sampled in calm weather.

Pots were lifted aboard using the vessel's hydraulic pot lifter in the order they were set, and the time of each lift was recorded. Pots were then emptied and the contents sorted by species. Total catch weight per pot was recorded for each species to the nearest 10 g using 0–6/6–15 kg Marel motion compensating scales. The number of individuals of each species per pot was also recorded. Total length to the nearest centimetre below actual length, individual fish weight to the nearest 10 g, sex and gonad maturity were recorded for all blue cod. Sagittal otoliths were removed from a representative length range of blue cod males and females over the available length range across all strata. To ensure that otolith collection was spread across the survey area, the following collection schedule was used: collect three otoliths per 1 cm size class for each sex in strata 1 and 2 combined, and also in stratum 3 which is the largest stratum (Appendix 2). Sex and maturity were determined by dissection and macroscopic examination of the gonads (Carbines 1998, Carbines 2004).

Blue cod gonad staging was undertaken using the five stage Stock Monitoring (SM) method used on previous surveys. Gonads were recorded as follows: 1, immature and resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

2.4.4 Data storage

The survey trip code was NAV1601 for the 2016 Motunau survey. At the completion of the survey, trip, station, catch, and biological data were entered into the Ministry for Primary Industries (MPI) *trawl* and *age* databases in accordance with the business rules and the blue cod potting survey standards and specifications (Beentjes & Francis 2011). All analyses were carried out from data extracted from the *trawl* database. Fixed sites were entered into *trawl* table *t_station* in attribute *stn_code* (concatenating stratum number and site label, e.g., 1A, 2B etc.). Similarly, random sites were entered into attribute *stn_code*, but were prefixed with R (e.g., R1A, R2B). Random site locations were also entered into *trawl* table *t_site*. Pot locations were entered in table *t_station* in attribute *station_no* (concatenating set number and pot number e.g., 11 to 16, or 31 to 36 etc.) with no distinction between fixed and random sites. In the *age* database the *sample_no* is equivalent to *station_no* in the *trawl* database. The complete list of all possible Motunau fixed sites was archived in the *trawl* database in table *t_site* after this survey as this had not been carried out hitherto.

ADCP data were sent to the MPI Research Database Manager in spreadsheet format.

2.4.5 Age estimates

Otolith preparation and reading

Preparation and reading of otoliths followed the methods of the blue cod age determination protocol (ADP) (Walsh 2017).

1. Blue cod otolith thin-section preparations were made as follows: otoliths were individually marked on their distal faces with a dot in the centrum using a cold light source on low power to light the otolith from behind. Five otoliths (from five different fish) were then embedded in an epoxy resin mould and cured at 50 °C. Thin sections were taken along the otolith dorso-ventral axis through the centrum of all five otoliths, using a Struers Accutom-50 digital sectioning machine, with a section thickness of approximately 350 µm. Resulting thin section wafers were cleaned and embedded on microscope slides using epoxy resin and covered with a coverslip. Finally, these slides were oven cured at 50°C.
2. Otolith sections were read against a black background using reflected light under a compound microscope at a magnification of 40–100 times. Under reflected light opaque zones appear light and translucent zones dark. Translucent zones were counted (ageing of blue cod otolith thin sections prior to 2015 counted opaque zones to estimate age).
3. Two readers read all otoliths without reference to fish length.
4. When interpreting blue cod zone counts, both ventral and dorsal sides of the otolith were read, mainly from the core toward the proximal surface close to the sulcus.
5. The forced margin method was used: ‘Wide’ (a moderate to wide translucent zone present on the margin), October–February; ‘Line’ (an opaque zone in the process of being laid down or fully formed on the margin), March–April; ‘Narrow’ (a narrow to moderate translucent zone present on the margin), May–September.
6. Where between-reader counts differed, the readers rechecked the count and conferred until agreement was reached, unless the section was a grade 5 (unreadable) or damaged (removed from the collection).
7. Between-reader ageing precision was assessed by the application of the methods and graphical techniques documented in Campana et al. (1995) and Campana (2001); including APE (average percent error) and coefficient of variation (CV).

2.4.6 Data analyses

Analyses of catch rates, sex ratios, scaled length distribution, catch-at-age, Z estimates, and spawner-per-recruit were carried out and presented separately for fixed and random site surveys.

Analyses of catch rates and coefficients of variation (CV), length-weight parameters, scaled length and age frequencies and CVs, sex ratios, mean length, and mean age, were carried out using the equations documented in the blue cod potting survey standards and specifications (Beentjes & Francis 2011).

2.4.6.1 Catch rates

The catch rate (kg.pot^{-1}) estimates are pot-based and the CV estimates are set-based (Beentjes & Francis 2011). Catch rates and 95% confidence intervals (± 1.96 standard error) were estimated for all blue cod and for recruited blue cod (30 cm and over). Catch rates of recruited blue cod are based on the sum of the weights of individual fish 30 cm and over. The stratum areas (km^2) shown in Table 1 were used as the area of the stratum (A_i) when scaling catch rates (equations 3 and 5 in Beentjes & Francis 2011). Catch rates are presented by stratum and overall for fixed and random sites surveys. Catch rates were estimated for individual strata and for all strata combined.

The recruited blue cod (30 cm and over) catch per pot (kg), and individual fish weights for the 2016 Motunau surveys were estimated from the 2015 Kaikoura survey (Beentjes & Page 2017) length-weight

coefficients applied to fish length because during the Motunau surveys the scales malfunctioned and/or some of the recorded weights were not reliable.

2.4.6.2 Length-weight parameters

The length-weight parameters a_k , b_k from the 2015 Kaikoura survey were used in the following equation:

$$w_{lk} = a_k l^{b_k}$$

This calculates the expected weight (g) for a fish of sex k and length l (cm) in the survey catch. These parameters were calculated from the coefficients of sex-specific linear regressions of $\log(\text{weight})$ on $\log(\text{length})$ using all fish for which length, weight, and sex were recorded: b_k is the slope of the regression line, and $\log(a_k)$ is its y -intercept. No length-weight parameters for Motunau were reported or used in the analyses.

2.4.6.3 Growth parameters

Separate von Bertalanffy growth models (von Bertalanffy 1938) were fitted to the 2016 Motunau survey length-age data by sex as follows:

$$L_t = L_\infty(1 - \exp^{-K(t-t_0)})$$

where L_t is the length (cm) at age t , L_∞ is the asymptotic mean maximum length, K is a constant (growth rate coefficient) and t_0 is hypothetical age (years) for a fish of zero length.

2.4.6.4 Scaled length and age frequencies

Length and age compositions were estimated using the NIWA program Catch-at-Age (Bull & Dunn 2002). The program scales the length frequency data by the area of the stratum, number of sets in each stratum, and estimated catch weight determined from the length-weight relationship of individual fish. The latter scaling should be negligible or very close to one if all fish caught during the survey were measured (which they were) and if the actual weight of the catch is close to the estimated weight of the catch. The stratum area (km^2) shown in Table 1 was taken as the area of the stratum (A_t), and the length-weight parameter estimates are from the 2015 Kaikoura survey data for males and females separately.

Length and age frequencies were calculated as numbers of fish from equations 7, 8, and 9 of Beentjes & Francis (2011). The length and age frequencies in this report are expressed as proportions by dividing by total numbers.

Bootstrap resampling (300 bootstraps) was used to calculate CV for proportions- and numbers-at-length and age using equation 12 of Beentjes & Francis (2011). That is, simulated data sets were created by resampling (with replacement) sets from each stratum, and fish from each set (for length and sex information); and also fish from the age-length-sex data that were used to construct the age-length key.

For each survey, catch-at-age was estimated using a single age-length-key (ALK) for each sex, applied to the length data from the entire survey area, and the same ALK was used for both random and fixed sites. Scaled length frequency and age frequency proportions are presented, together with CVs for each length and age class, and the mean weighted coefficients of variation (MWCV).

2.4.6.5 Unsexed fish

All fish, except for 30 very small fish (20 from fixed and 10 from random sites), were sexed during the 2016 Motunau survey because it was not possible with any certainty to assign sex. These fish were not used in ageing or to estimate total mortality (Z), but are used to show the total scaled length frequency and corresponding total scaled age compositions.

2.4.6.6 Sex ratios, and mean length and age

Sex ratios (expressed as percentage male) and mean lengths, for the stratum and survey, were calculated using equations 10 and 11 of Beentjes & Francis (2011) from the stratum or survey scaled LFs. Mean ages were calculated analogously from the scaled age frequencies. Sex ratios were also estimated for recruited blue cod (30 cm and over), and overall survey 95% confidence intervals around sex ratios were generated from the 300 LF bootstraps. The proportion of fish of recruited size was estimated from the scaled LFs.

2.4.6.7 Total mortality estimates

Total mortality (Z) was estimated from catch-curve analysis using the Chapman-Robson estimator (CR) (Chapman & Robson 1960). The CR method was shown to be less biased than the simple regression catch curve analysis (Dunn et al. 2002). Catch curve analysis assumes that the right hand descending part of the curve declines exponentially and that the slope is equivalent to the total mortality Z ($M + F$). This assumes that recruitment and mortality are constant, that all recruited fish are equally vulnerable to capture, and that there are no age estimation errors.

Estimates of total mortality, Z , were calculated for age-at-recruitment values of 5 to 10 y using the maximum-likelihood estimator (equation 13 of Beentjes & Francis (2011). Variance (95% confidence intervals) associated with Z was estimated under three different parameters of recruitment, ageing error, and Z estimate error (equations 14 to 18 of Beentjes & Francis (2011)). Catch-at-age distributions were estimated separately for males and females and then combined, hence providing a single Z estimate for the population.

2.4.6.8 Spawner-per-recruit estimates

A spawner-per-recruit analyses were conducted using CASAL (Bull et al. 2005). The calculations involved simulating fishing with constant fishing mortality, F , in a population with deterministic recruitment, and estimating the equilibrium spawning biomass per recruit (SPR) associated with that value of F (Beentjes & Francis 2011). The %SPR for that F is then simply that SPR, expressed as a percentage of the equilibrium SPR when there is no fishing (i.e., when $F = 0$ and %SPR=100%).

Input parameters used in SPR analyses

Growth parameters von Bertalanffy growth parameters and length-weight coefficients:

Parameter	Males	Females
K (yr^{-1})	0.1711	0.1736
t_0 (yr)	-0.2662	-1.1273
L_∞ (cm)	52.3	40.7
a	0.007506	0.007812
b	3.22040	3.21160

The 2015 Kaikoura survey von Bertalanffy growth parameters were used to model the relationship between the spawner per recruit ratio and fishing mortality, because the 2016 Motunau survey growth curves had few older fish and consequently L_∞ was probably poorly estimated. Similarly, Kaikoura length-weight coefficients were also used for Motunau for the reasons described above in Section 2.4.7.1.

Natural mortality	default assumed to be 0.14. Sensitivity runs were carried out for M values 20% above and below the default (0.11 and 0.17).
Maturity	the following maturity ogive was used: 0, 0, 0, 0.1, 0.4, 0.7, and 1; where 10% of blue cod are mature at 4 years old and all are mature at 7 years.
Selectivity	selectivity to the fishery (recreational/commercial) is described as knife-edge equal to age-at-MLS calculated from the 2016 Motunau survey von Bertalanffy models. Motunau recreational MLS is 30 cm and selectivity was 5.3 years for males and 7.6 years for females.
Fishing mortality (F)	fishing mortality was estimated from the results of the Chapman-Robson analyses and the assumed estimate of M (i.e., $F = Z - M$). The Z value was for age-at-full recruitment (8 years for females), calculated from the 2016 Motunau survey female von Bertalanffy model.
Maximum age	assumed to be 31 years.

Because this was a ‘per-recruit’ analysis, it does not matter what stock-recruit relationship was assumed. However, the calculations are simpler, and the simulated population reaches equilibrium faster, if recruitment is treated as independent of spawning biomass (i.e., has a steepness of 1).

To estimate SPR the CASAL model uses the Baranov catch equation which assumes that M and F are occurring continuously throughout the fishing year. i.e., instantaneous natural and fishing mortality.

The SPR estimates are based on age at recruitment equal to the MLS for females, in this case 8 years as estimated from the Motunau von Bertalanffy growth curve.

2.4.6.9 Analyses of the 2012 Motunau survey

Catch rates, scaled length frequencies, and sex ratios were estimated for the 2012 Motunau survey, consistent with the potting survey standards and specifications (Beentjes & Francis 2011). At the time of writing this survey was not on the MPI trawl database or published and analyses were carried out from raw data provided to NIWA on a spreadsheet. Catch rates of recruited blue cod are based on the sum of the weights of individual fish 30 cm and over. These were estimated from the 2015 Kaikoura survey length-weight coefficients because no individual fish weights were available for the 2012 Motunau survey.

3. RESULTS

3.1 2016 Motunau fixed site survey

3.1.1 Fixed sites surveyed

Eighteen fixed sites (6 pots per site, 108 pot lifts) from three strata off Motunau were fished (Table 1, Figure 4). Depths sampled were 10–32 m (mean = 22 m). Fifteen sites were fished in phase 1 and three in phase 2.

3.1.2 Catch (fixed sites)

A total of 365.7 kg of blue cod (1358 fish) was taken comprising 87% by weight of the catch of all species on the survey (Table 2). Bycatch species included eight teleost fishes, as well as one species of octopus. The three most abundant bycatch species, by number, were leatherjacket (*Meuschenia scaber*), spotty (*Notolabrus celidotus*), and scarlet wrasse (*Pseudolabrus miles*).

3.1.3 Catch rates (fixed sites)

Mean catch rates (kg.pot⁻¹) of blue cod (all blue cod, 30 cm and over) are presented by stratum and overall (Table 3, Figure 5). Mean catch rates of blue cod (all sizes) were 3–5 kg.pot⁻¹ with the lowest catch rates in stratum 3 and the highest in stratum 1 (Table 3, Figure 5). The survey all blue cod catch rate was 3.32 kg.pot⁻¹ with a CV of 13%. Catch rates for recruited blue cod 30 cm and over, followed the same pattern among strata as for all blue cod and overall was 1.34 kg.pot⁻¹ (CV 15%) (Table 3, Figure 5). Of the 108 fixed site pots, 13 (12%) had zero catch of blue cod.

3.1.4 Biological and length frequency data (fixed sites)

Of the 1358 blue cod caught, all but 20 were sexed, and all were measured for length and weighed (Table 4). Sex ratios were 73–77% male across the three strata and the overall weighted sex ratio was 76% male (Table 4). Length was 15–44 cm for males and 10–33 cm for females, although this range varied among strata and the overall weighted mean length was 25.8 cm for males and 22.4 cm for females. The scaled length frequency distributions are generally similar among strata with males dominating, and a strong mode around 22 cm (Figure 6).

3.1.5 Age and growth

Otolith section ages from 250 males and 144 females collected from fixed and random sites were used to estimate the population age structure from Motunau in 2016 (Table 5). The length-age data are plotted and the von Bertalanffy model fits and the growth parameters (K , t_0 and L_∞) are shown for males and females separately (Figure 7). There is a large range in length-at-age for both sexes, and males grow faster and larger than females. The low maximum ages (12 years for males and 10 years for females) has resulted in improbable von Bertalanffy parameters, especially L_∞ . Between-reader comparisons are presented in Figure 8. The first counts of the two readers showed 92% agreement, and overall there was no bias between readers with a CV of 1.3% and average percent error (APE) of 0.9%.

Because the von Bertalanffy growth parameters were unlikely to be indicative of the real growth in the Motunau blue cod population after ages of about 10 years, the Kaikoura 2015 survey growth data were used to model the spawner-per-recruit ratio to fishing mortality (See section 2.4.6.8). Kaikoura blue cod grow faster after age 4 years for males and 5 years for females (Figure 9).

3.1.6 Spawning activity

Gonad stages of blue cod sampled in the early January 2016 Motunau survey are presented for all fish from fixed and random sites combined (Table 6). There was no indication of spawning activity during the survey period with virtually all fish either resting or maturing.

3.1.7 Population length and age composition (fixed sites)

The scaled length frequency and age distributions for the 2016 Motunau fixed site survey are shown for all strata combined, as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Figure 10).

Scaled length frequency distributions for both males and females were unimodal with strong juvenile modes at about 22 and 20 cm respectively, but skewed to the right with overall mean lengths of 25.8 cm and 22.4 cm, respectively (Figure 10). The length distribution for all fish, also shows small numbers of very small unsexed blue cod, only partially vulnerable to capture by the pots. The cumulative distribution plots of length frequency are similar in shape between sexes, but overall females are smaller. The mean weighted coefficients of variation (MWCVs) around the length distributions are 24% for males and 35% for females. Recruited fish (30 cm and over), comprised 24% of males and 4% of females.

Age of blue cod was 1–12 years for males and 1–10 years for females, but most males and females were between three and six years old (Figure 10). The estimated population age distributions indicate virtually knife-edge selectivity to the potting method at three years and show strong modes at three, five and six years, and relatively weak modes for four year olds for both sexes. For females there are very few fish over six years of age and this is represented in the cumulative distribution plots of age frequency (Figure 10). Further, the mean age of females was less than that of males (4.5 for males and 3.9 years for females). The MWCVs around the age distributions were 15% for males and 18% for females, indicating a good representation of the overall population age structure.

3.1.8 Total mortality estimates (Z) and spawner-per-recruit (SPR) (fixed sites)

Fixed site CR total mortality estimates (Z) and 95% confidence intervals are given for a range of recruitment ages (5–10 years) in Table 7. Age-at-full recruitment (AgeR) was assumed to be eight years, equal to the age at which females reach the MLS of 30 cm. The CR Z for AgeR of eight years was 0.76 (95% confidence interval of 0.48–1.09).

The traditional catch curve, based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment of eight years, is shown in Figure 11. There were no blue cod aged over 10 years for females and 12 years for males and this resulted in a very steep slope of the regression line and hence high Z estimates. Further, numbers at age do not follow a classic catch curve shape characterised by smooth ascending and descending limbs, and an intermediate domed portion. This is exemplified by the low numbers of 4 year old fish relative to 3 year olds, and as such is a violation of the catch curve assumption that recruitment is constant. This will have introduced error into the Z estimate which is reflected in the 95% confidence intervals around Z (see Table 7). However, the tight distribution of points around the regression lines gives some confidence in the CR Z estimates.

Mortality parameters (CR Z and F , and M) and spawner-per-recruit estimates at three values of M and age at full recruitment of eight years are shown in Table 8. Based on the default M of 0.14, estimated fishing mortality (F) was 0.62 and associated spawner-per-recruit ratio was 19.2%. (Figure 12). This indicates that at the 2016 level of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 19% of the contribution in the absence of fishing. As described above (Section 3.15) the spawner-per-recruit to fishing mortality curve was modelled using

the Kaikoura von Bertalanffy growth parameters. As blue cod appear to grow faster in Kaikoura than Motunau, using this curve, for a given fishing mortality the spawner per recruit ratio would have been higher and hence the status of Motunau blue cod (based on the spawner per recruit ratio) is likely to be over-estimated.

3.2 2016 Motunau random site survey

3.2.1 Random sites surveyed

Twenty one random sites (6 pots per site, 126 pot lifts) from three strata off Motunau were fished (Table 1, Figure 4). Depths sampled were 6–35 m (mean = 22 m). Eighteen sites were surveyed in phase 1 and three in phase 2.

3.2.2 Catch (random sites)

A total of 360.7 kg of blue cod (1143 fish) was taken comprising 86% by weight of the catch of all species on the survey (Table 2). Bycatch species included seven teleost fishes, rock lobster, and one species of octopus. The three most abundant bycatch species, by number, were leatherjacket (*Meuschenia scaber*), spotty (*Notolabrus celidotus*), and scarlet wrasse (*Pseudolabrus miles*).

3.2.3 Catch rates (random sites)

Mean catch rates (kg.pot⁻¹) of blue cod (all blue cod, 30 cm and over) are presented by stratum and overall (Table 3, Figure 5). Mean catch rates of blue cod (all sizes) were 1–7 kg.pot⁻¹ with the lowest catch rates in stratum 2 and the highest, by a factor of nearly four, in stratum 1 (Table 3, Figure 5). The survey all blue cod catch rate was 2.48 kg.pot⁻¹ with a CV of 27%. Catch rates for recruited blue cod 30 cm and over, followed the same pattern among strata as for all blue cod and overall was 1.11 kg.pot⁻¹ (CV 29%) (Table 3, Figure 5). Of the 126 fixed site pots, 45 (36%) had zero catch of blue cod.

3.2.4 Biological and length frequency data (random sites)

Of the 1143 blue cod caught in random sites, all but 10 were sexed, and all were measured for length and weighed (Table 4). Sex ratios were 71–83% male across the three strata and the overall weighted sex ratio was 76% male (Table 4). Length was 11–43 cm for males and 11–35 cm for females, although this range varied among strata. The survey weighted mean length was 26.5 cm for males and 22.2 cm for females. The scaled length frequency distributions are generally similar among strata with males dominating, and a strong mode around 21 cm, although stratum 1 had a higher proportion of fish over about 23 cm (Figure 13).

3.2.5 Age and growth

See Section 3.1.5 for age and growth description which applies to both fixed and random site surveys.

3.2.6 Spawning activity

See Section 3.1.6 for spawning activity description which applies to both fixed and random site surveys.

3.2.7 Population length and age composition (random sites)

The scaled length frequency and age distributions for the 2016 Motunau random site survey are shown for all strata combined, as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Figure 14).

Scaled length frequency distributions for both males and females were unimodal with strong juvenile modes at about 23 and 22 cm respectively, but skewed to the right with overall mean lengths of 26.5 cm and 22.2 cm, respectively (Figure 14). The length distribution for all fish included small numbers of very small unsexed blue cod, only partially vulnerable to capture by the pots. The cumulative distribution plots of length frequency were similar in shape between sexes, but overall females were smaller and proportionally had fewer larger fish. The mean weighted coefficients of variation (MWCVs) around the length distributions were 31% for males and 41% for females. Recruited fish (30 cm and over), comprised 28% of males and 3% of females.

Age estimates of blue cod were 1–12 years for males and 1–10 years for females, but most males and females were between three and six years old (Figure 14). The estimated population age distributions indicate virtually knife-edge selectivity to the potting method at three years and show strong modes at three, five and six years, and relatively weak modes for four year olds for both sexes. For females there are very few fish over six years of age and this is represented in the cumulative distribution plots of age frequency (Figure 14). Further, the mean age of females was less than that of males (4.8 for males and 3.7 years for females). The MWCVs around the age distributions were 20% for males and 27% for females, indicating a reasonable representation of the overall population age structure.

3.2.8 Total mortality estimates (Z) and spawner-per-recruit (SPR) (random sites)

Random site CR total mortality estimates (Z) and 95% confidence intervals are given for a range of recruitment ages (5–10 y) in Table 7. Age-at-full recruitment (AgeR) is assumed to be eight years, equal to the age at which females reach the MLS of 30 cm. The CR Z for AgeR of eight years is 0.75 (95% confidence interval of 0.47–1.09).

The traditional catch curve, based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment of eight years, is shown in Figure 11. There were no blue cod aged over 10 years for females and 12 years for males and this resulted in a very steep slope of the regression line and hence high Z estimate. Further, numbers at age do not follow a classic catch curve shape characterised by smooth ascending and descending limbs, and an intermediate domed portion. This is exemplified by the low numbers of 4 year old fish relative to 3 year olds, and as such is a violation of the catch curve assumption that recruitment is constant. This will have introduced error into the Z estimate which is reflected in the 95% confidence intervals around Z (see Table 7). However, the tight distribution of points around the regression lines gives some confidence in the CR Z estimates.

Mortality parameters (CR Z and F , and M) and spawner-per-recruit estimates at three values of M and age at full recruitment of eight years are shown in Table 8. Based on the default M of 0.14, estimated fishing mortality (F) was 0.61 and associated spawner-per-recruit ratio was 19.4% (Figure 12). This indicates that at the 2016 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 19% of the contribution in the absence of fishing.

As described above (Section 3.1.5) the spawner-per-recruit to fishing mortality curve was modelled using the Kaikoura von Bertalanffy growth parameters. Because Kaikoura blue cod grow faster than those in Motunau (see Figure 9), this curve has a higher spawner per recruit for a given value of F . Hence the status of Motunau blue cod (based on the spawner per recruit ratio) is likely to be over-estimated.

3.3 Comparison of fixed site and random site surveys in 2016

Catch rates of all blue cod from the 2016 fixed and random site surveys are similar for strata 1 and 3, but in stratum 2 fixed site catch rates were higher with no overlap of confidence intervals (Table 3, Figure 15). The overall catch rates were almost the same in fixed and random sites with overlapping confidence intervals. The CVs and associated confidence intervals are considerably larger for random sites. The recruited fish (30 cm and over) catch rates exhibited the same pattern among strata as all blue cod, and given the confidence intervals there are no differences between strata or overall (Table 3, Figure 15).

The length distributions among the three strata showed similar patterns between fixed and random sites (compare Figures 6 and 13), but overall random site blue cod males were slightly larger (Figure 16). Similarly, the age distributions are almost identical (Figure 16).

Sex ratios for fixed and random sites showed a similar pattern among strata, and the overall (Table 4). Survey sex ratios were 76% male for both fixed and random sites. Recruited sex ratios showed similar patterns, but the overall proportion male was greater to the extent that there were few females over 30 cm (Table 4).

Total mortality and SPR estimates were similar for fixed and random sites surveys with Z estimates of 0.76 and 0.75, and spawner biomass per recruit ratios of 19.2% and 19.4% , respectively, for age at recruitment of 8 years and M of 0.14 (see Table 8, Figure 12).

3.4 Motunau survey time series

3.4.1 Catch rates

Fixed sites – Mean catch rates (kg.pot^{-1}) for all blue cod and recruited blue cod (30 cm and over) from fixed sites are presented for each of the four surveys in the time series (Figure 17). Survey catch rates show two periods of major decline: a drop by nearly one half (46%) between 2005 and 2008, and a second drop of 40% between 2012 and 2016. The overall time series catch rate decline between 2005 and 2016 is 67%. These declines are all statistically significant with no overlap of the confidence intervals. Catch rates for recruited blue cod display a similar decline (Figure 17).

Random sites – Mean catch rates (kg.pot^{-1}) for all blue cod from random sites are presented for the 2012 and 2016 surveys (Figure 18). The decline in overall catch rates between 2012 and 2016, observed for fixed sites, is absent for random site surveys, and catch rates are not statistically different within strata and overall.

Comparison of the all blue cod survey catch rates between fixed and random sites over the time series is shown in Figure 19.

3.4.2 Length distributions

Because blue cod ageing from the previous three surveys was carried out before the age determination protocol was developed, age compositions, total mortality (Z) and SPR estimates from these surveys cannot be compared with those from the 2016 survey. Scaled length, however, can be compared among the four fixed site and two random site surveys.

Fixed sites – scaled length frequency distributions and mean length from fixed sites are similar for the first three surveys (2005, 2008 and 2012), but mean length declined by nearly 4 cm in 2016. This was a result of the strong juvenile male mode in 2016, and a decline in the proportion of blue cod over 30 cm for males (Figure 20).

Random sites – scaled length frequency distributions and mean length from random sites differ between 2012 and 2016 surveys and mean length declined by 1.5 cm. This was a result of the strong juvenile male mode in 2016, and a decline in the proportion of blue cod over 30 cm for both males and females (Figure 21).

In both 2012 and 2016 the random and fixed sites length distributions were similar in shape and size (compare Figures 20 and 21).

3.4.3 Sex ratios

The sex ratio among fixed site surveys for all blue cod and recruited blue cod was consistently around 75% and 95% male, respectively, with no trend (Figure 22). For the two random site surveys, in both years, sex ratios were almost the same as those in fixed sites (Figure 22).

4. DISCUSSION

4.1 General

The 2016 Motunau potting survey provides the fourth fixed site and the second random site survey in the time series of relative abundance and population structure of blue cod from this area. After reviewing the results of the 2016 Motunau survey in December 2016, the Southern Inshore Working Group (SINSWG-2016/38) recommended moving to solely random sites in the next survey round with a target CV of 15%. Suggested design modifications to be investigated included increasing the number of random sites to improve the power to detect change, and subdividing existing strata.

The abundance estimates, and length and age distributions are weighted (scaled) by the area of each stratum in this survey. Scaling by area assumes that the size of each stratum is directly proportional to the amount of blue cod habitat (i.e., it is assumed to be a proxy for habitat), however, this is probably not always the case given the discrete nature of areas of foul and biogenic habitat.

Target CVs around relative abundance (catch rates) were not specified for the 2016 Motunau survey. The 13% CV achieved for the fixed site survey was acceptable, but 27% for the random site survey is higher than desired given that most blue cod surveys achieve CVs of less than 20% (Ministry for Primary Industries 2016). Previous fixed site surveys achieved comparable CVs of 11%, 16%, and 12% for 2005, 2008, and 2012, respectively. The one previous random site survey in 2012 achieved a CV of 19%, 8% better than in 2016. The achieved CVs for both surveys indicate that the survey design and number of sites used are appropriate for fixed, but may require more sites for random surveys. The number of pots with zero catch is considerably higher for random than fixed sites (36% compared to 12%) and this has contributed to the higher variance in catch rates among sites, and hence CVs.

4.2 Motunau 2016 fixed site versus random site surveys

The overall catch rates were similar for fixed and random surveys (see Table 3), and the length distributions were also similar within each of the three strata, but overall blue cod were slightly larger for both males and females in random sites (see Figure 16). In both surveys the length distributions are characterised by a strong predominantly male juvenile mode, and the largest fish were males. The strong juvenile mode appears in the age composition of both fixed and random site surveys as three year old fish indicating good spawning and/or survival in spring/summer of 2012 (see Figures 10 and 14). Previous fixed and random site Motunau surveys show no indications of strong recruitment into the population at this size with modes several centimetres larger on average, suggesting that the 2016 pulse may be unusual (see Figure 21). This is the first Motunau survey for which ageing was carried out using

the blue cod age determination protocol (ADP) and therefore it is not valid to compare age in 2016 with that from previous surveys. The 2014 Dusky Sound survey for which ageing was carried using the ADP, indicates that the strongest age modes are 4 and 5 years old, with a weak left hand tail comprising 3 and 2 year olds (Beentjes & Page 2016). This suggests that full selectivity to the potting method is not reached until 4 to 5 years old in Dusky Sound. The finding that 3 year old blue cod are the dominant cohort off Motunau in 2016 suggests that the 2012 year class is exceptionally strong and can be expected to enhance the fishery in the next few years as it recruits fully to the recreational and commercial fisheries. Conversely, the weak 4 year old cohort may will have the opposite effect (see Figures 10 and 14). The finding that blue cod were slightly larger in random sites may be a result of lower fishing intensity compared to the fixed site 'hot spots'.

Sex ratios for fixed and random sites were similar among strata and overall sex ratios were about 75% male for fixed sites and random sites across all strata (see Table 4). Both surveys indicated that there were very few females of recruited size (30 cm and over) and hence the recreational fishery is based almost exclusively on males.

CR total mortality and SPR estimates were similar for fixed and random sites surveys (see Table 8) and together with results on catch rates, size, age and sex ratios, indicate that the two survey types achieved almost identical results and sampled the same population of blue cod.

4.3 Stock status

The MPI *Harvest Strategy Standard* specifies that a Fishery Plan should include a fishery target reference point, and that this may be expressed in terms of biomass or fishing mortality (Ministry of Fisheries 2011). The most appropriate target reference point for blue cod is F_{MSY} , which is the amount of fishing mortality that results in the maximum sustainable yield. The recommended proxy for F_{MSY} is the level of spawner-per-recruit $F_{\%SPR}$ (Ministry of Fisheries 2011). Based on this and recommendations from the Southern Inshore Working Group, blue cod is categorised as an exploited species with low productivity and the recommended default proxy for F_{MSY} is $F_{45\%SPR}$.

Random site surveys are considered to be superior to fixed sites surveys in design and precision (Stephenson et al. 2009), so estimates of Z and SPR from random site surveys are likely to be more representative of the population. The 2016 random site survey SPR estimate, for the default M value of 0.14, and age at full recruitment of 8 years (based on age to reach MLS for females), was $F_{19\%SPR}$, indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit was reduced to 19% of the contribution in the absence of fishing (see Figure 12). The level of exploitation (F) of Motunau blue cod stocks therefore greatly exceeds the F_{MSY} target reference point of $F_{45\%SPR}$. The estimate of Z and hence F are the parameters that determine the value of SPR. Total mortality (Z) is a product of the slope of the right hand descending curve of age versus population numbers. Note, however that the oldest males and females were only 12 and 10 years old respectively, hence the estimate of Z is based on only a few age classes. Indeed the age distribution of blue cod from the 2016 survey is so truncated that growth cannot be accurately modelled using the von Bertalanffy growth model which requires some larger and older fish to estimate a sensible length at infinity parameter (see Figure 7). The absence of a clear dome on the catch curve may be a result of variable recruitment, and hence violate the catch curve assumption that recruitment is constant (see Figure 11). Estimates of Z , F and SPR should therefore be treated with caution and the Z estimates that fall within the 95% confidence intervals may be plausible.

4.4 Reproductive condition

All four Motunau surveys were carried out in January, so reproductive status is comparable. During the 2005, 2008, and 2012 surveys, virtually all blue cod had maturing gonads, with no indications of

spawning (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2012). In comparison, in 2016 nearly all females were immature/resting and males were 70% resting/immature and 30% maturing. The shift toward a higher proportion of less developed gonads is consistent with the dominance of the juvenile mode in 2016 (see Table 6). Given that some spawning activity is consistently observed in Kaikoura one month earlier, spawning may take place before January in Motunau.

4.5 Time series trends from Motunau surveys

There are now four fixed site surveys in the time series, allowing a cautious attempt to identify and offer explanations for trends. The MPI Southern Inshore Working Group noted, however, that the fixed site time series may not be valid given that fixed sites may be ‘hyperstable’ by virtue of their locations on fishing hot spots and that the meaningful time series should be based on random site surveys (SINSWG-2016/26). Also, because ageing of blue cod from the 2005, 2008, and 2012 surveys were carried out before the age determination protocol was agreed upon, age compositions, total mortality (Z) and SPRs cannot be compared among the surveys.

4.5.1 Trends in catch rates

Overall catch rates from fixed sites decreased markedly in 2008 and then again in 2016 with a three-fold decline between 2005 and 2016 (see Figure 19). For recruited blue cod the decline is even larger, and is more than 4-fold. The proportion of pots with no blue cod catch displays an equal but opposite trend to that of the catch rate pattern, i.e., as catch rates declined, the proportion of pots with zero catch increased from 4% to 12% (Figure 23). This indicates that the distribution of blue cod across the survey area has contracted over time.

Random site catch rates for the 2016 survey were slightly less than in 2012 but the difference is not statistically significant, hence there is no trend (see Figure 19). The absence of a decline in catch rates between 2012 and 2016, as observed for fixed site surveys, may be related to random sites being more often located in areas where fishing intensity is lower than in the fixed site ‘hot spots’. Further, the proportion of random site pots with zero catch is more than double that of fixed sites, reflecting the positioning of some sites in less than optimum blue cod habitat (Figure 23). The proportion of zero catch also increased markedly between 2012 and 2016 surveys, consistent with a contracting fish distribution.

Displacement of recreational fishing effort from the Marlborough Sounds to Kaikoura and Motunau is likely to have occurred in recent years with the restrictions on blue cod fishing in the Marlborough Sounds¹. Further, the establishment of the Kaikoura Marine Area in 2014 with a larger MLS (33 cm compared to 30 cm) and lower daily bag limit (6 compared to 10) than in Motunau may also have further increased effort on the Motunau blue cod fishery.

4.5.2 Trends in length and sex ratio

Overall blue cod mean length from fixed sites steadily declined from 2005 to 2016, with the biggest decreases in 2016 (see Figure 20). These metrics are not always a good indicator of whether population size is increasing or decreasing because it can be biased by strong recruitment events, such as occurred in 2016. It is clear, however, that abundance of larger fish declined over time, for both males and females. Random site surveys also showed a decrease, albeit smaller, in length between 2012 and 2015, and as described for trends in catch rates, this may be a result of less fishing intensity compared to the fixed site ‘hot spots’ (see Figure 21).

¹ Closure of the inner Marlborough Sound to all blue cod fishing in October 2008; a slot limit of 30 to 35 cm and a MDL of 2 blue cod in April 2011; and from 20 December 2015, a MLS of 33 cm and MDL of 2 blue cod within the period 20 December to 31 August.

The sex ratio for all blue cod strongly favoured males on all surveys with no trend, with about 75% of fish male (see Figure 22). There was also no trend in sex ratio of the recruited blue cod which favoured males to an even greater extent (about 95%), as the larger blue cod were male. Blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow (Carbines 2004); the Motunau blue cod population sex and size structure is consistent with this reproductive strategy.

In areas where fishing pressure is known to be high, such as Motunau, inshore Banks Peninsula, and the Marlborough Sounds, the sex ratios are skewed towards males which is contrary to an expected dominance of females resulting from selective removal of the larger final phase male fish (Beentjes & Carbines 2003, 2006, Carbines & Beentjes 2006a, Beentjes & Carbines 2012). In contrast, in Foveaux Strait, offshore Banks Peninsula, and particularly Dusky Sound, females are dominant suggesting that fishing pressure is less intense (Beentjes & Carbines 2009, Carbines & Beentjes 2012, Beentjes & Page 2016). Beentjes & Carbines (2005) suggested that the shift towards a higher proportion of males in heavily fished blue cod populations may be caused by removal of the possible inhibitory effect of large males, resulting in a higher rate (and possibly earlier onset) of sex change by primary females. In Motunau, the heavily skewed sex ratio towards males is similar to the populations in inshore Banks Peninsula, and Marlborough Sounds which are all characterised by small mean size, low catch rates, and high total mortality.

4.5.3 Concluding remarks

In summary, blue cod abundance, size, and distribution off Motunau all declined over the eleven years from 2005 to 2016. The very high estimate of total mortality, truncated age composition, and strongly skewed sex ratio toward males, indicates that the blue cod population off Motunau is heavily fished to the extent that the current fishery (customary, recreational and commercial) may not be sustainable. Further, as nearly all females and most males caught will be of sub-legal size (less than 30 cm), there is also likely to be significant mortality through catch and return of undersize fish.

The strong blue cod 3 year old cohort and the weak 4 year old cohort observed in Motunau in January 2016, were also present in the age compositions in Kaikoura in December 2015, and Banks Peninsula in April 2016 (Beentjes & Fenwick 2017, Beentjes & Page 2017). This consistent pattern suggests that the 2012 spawning event was better than average and/or that natural mortality was low on this cohort on the north east coast of the South Island. Blue cod have a restricted home range (Rapson 1956, Mace & Johnston 1983, Mutch 1983, Carbines & McKenzie 2001, Carbines & McKenzie 2004) and the Motunau, Kaikoura and Banks Peninsula stocks of this species are likely to consist of largely independent sub-populations. However, blue cod are not genetically distinct around the New Zealand mainland (Gebbie 2014) indicating that mixing is occurring on a wider geographical scale than within the restricted home range indicated by tagging studies. It is possible that wider mixing is facilitated by egg and larval drift more than movements by juveniles or adults. Hence the strong 2012 year class, across the north east South Island, may have at least two possible explanations: 1) favourable environmental conditions in one area enhanced spawning and resulted in the source of abundant eggs and larvae that drifted to the other areas, or 2) favourable environmental conditions existed in all areas enhancing localised spawning and survival of eggs and larvae.

5. ACKNOWLEDGMENTS

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Table 1: Effort and catch data for the 2016 Motunau blue cod potting survey.

Stratum	Area		<i>N</i> sets (sites)		<i>N</i> pots (stations)	Catch (blue cod)		Fixed sites	
	(km ²)	Site type	Phase 1	Phase 2		<i>N</i>	kg	Mean	Range
1	41.3	Fixed	3		18	290	83.8	25.3	15–32
2	66.9	Fixed	5		30	368	105.6	21.6	16–26
3	176.1	Fixed	7	3	60	700	176.3	20.7	10–30
Total	284.3	Fixed	15	3	108	1 358	365.7	21.7	10–32

Stratum	Area		<i>N</i> sets (sites)		<i>N</i> pots (stations)	Catch (blue cod)		Random sites	
	(km ²)	Site type	Phase 1	Phase 2		<i>N</i>	kg	Mean	Range
1	41.3	Random	3	2	30	577	217.1	23.5	13–32
2	66.9	Random	8		48	185	52.7	24	9–35
3	176.1	Random	7	1	48	381	90.5	18.8	6–32
Total	284.3	Random	18	3	126	1 143	360.3	21.9	6–35

Table 2: Total catch and numbers of blue cod and bycatch species caught on the 2016 Motunau fixed site and random site potting surveys. Percent of the catch by weight is also shown.

Common name	Species	Fixed sites			
		Code	Number	Catch (kg)	% catch
Blue cod	<i>Parapercis colias</i>	BCO	1 358	365.7	86.9
Southern conger	<i>Conger verreauxi</i>	CVR	3	25.0	5.9
Leatherjacket	<i>Meuschenia scaber</i>	LEA	30	12.5	3.0
Common octopus	<i>Macroctopus maorum</i>	OCT	3	5.8	1.4
Scarlet wrasse	<i>Pseudolabrus miles</i>	SPF	9	5.0	1.2
Spotty	<i>Notolabrus celidotus</i>	STY	20	3.0	0.7
Banded Wrasse	<i>Notolabrus fucicola</i>	BPF	4	1.6	0.4
Sea perch	<i>Helicolenus percoides</i>	SPE	3	1.5	0.4
Dwarf scorpion fish	<i>Scorpaena papillosa</i>	RSC	2	0.5	0.1
Tarakihi	<i>Nemadactylus macropterus</i>	NMP	1	0.4	0.1
Totals			1 433	421	
Common name	Species	Random sites			
		Code	Number	Catch (kg)	% catch
Blue cod	<i>Parapercis colias</i>	BCO	1 143	360.3	86.3
Southern conger eel	<i>Conger verreauxi</i>	CVR	3	22.0	5.3
Leatherjacket	<i>Meuschenia scaber</i>	LEA	27	14.7	3.5
Common octopus	<i>Macroctopus maorum</i>	OCT	5	6.8	1.6
Banded Wrasse	<i>Notolabrus fucicola</i>	BPF	8	5.4	1.3
Scarlet wrasse	<i>Pseudolabrus miles</i>	SPF	10	4.6	1.1
Spotty	<i>Notolabrus celidotus</i>	STY	16	2.7	0.6
Rock lobster	<i>Jasus edwardsii</i>	CRA	1	0.6	0.1
Tarakihi	<i>Nemadactylus macropterus</i>	NMP	2	0.2	0.0
Dwarf scorpion fish	<i>Scorpaena papillosa</i>	RSC	1	0.1	0.0
Totals			1 216	417.4	

Table 3: Mean catch rates for all blue cod, and recruited blue cod (30 cm and over) from the 2016 Motunau fixed site and random site potting surveys. Catch rates are pot-based, and s.e. and CV are set-based. s.e., standard error; CV coefficient of variation.

		Fixed sites survey							
Stratum	Site type	Pot lifts (N)	All blue cod			Recruited blue cod			
			Catch rate (kg.pot ⁻¹)	s.e.	CV (%)	Catch rate (kg.pot ⁻¹)	s.e.	CV (%)	
1	Fixed	18	4.66	0.79	17.0	1.93	0.46	23.6	
2	Fixed	30	3.52	0.83	23.7	1.74	0.57	32.8	
3	Fixed	60	2.94	0.58	19.7	1.05	0.22	21.3	
Overall	Fixed	108	3.32	0.42	12.7	1.34	0.20	15.2	

		Random sites survey							
Stratum	Site type	Pot lifts (N)	All blue cod			Recruited blue cod			
			Catch rate (kg.pot ⁻¹)	s.e.	CV (%)	Catch rate (kg.pot ⁻¹)	s.e.	CV (%)	
1	Random	30	7.24	3.45	47.7	3.69	1.84	50.0	
2	Random	48	1.10	0.49	44.8	0.64	0.37	58.3	
3	Random	48	1.89	0.68	35.9	0.69	0.25	36.9	
Overall	Random	126	2.48	0.66	26.8	1.11	0.32	29.0	

Table 4: Weighted mean lengths for the 2016 Motunau fixed site and random site potting surveys for all blue cod. Weighted sex ratio (percent male) is given for all blue cod and recruited blue cod (30 cm and over). m, male; f, female; u, unsexed. –, no data.

Stratum	Site type	Sex	N	Fixed site survey				
				Length (cm)			Percent male	
				Mean	Minimum	Maximum	All blue cod	Recruited
1	Fixed	m	222	26.1	16.0	41.7	76.6	96.7
		f	68	22.3	17.0	31.0		
		u	0	–	–	–		
2	Fixed	m	268	26.5	16.7	44.3	73.3	96.7
		f	96	22.0	10.1	30.6		
		u	4	13.7	11.7	15.8		
3	Fixed	m	520	25.4	15.0	40.7	76.0	93.0
		f	164	22.6	15.0	33.5		
		u	16	12.4	9.6	14.7		
Overall	Fixed	m	1 010	25.8	15.0	44.3	75.6	94.8
		f	328	22.4	10.1	33.5		
		u	20	12.7	9.6	15.8		

Stratum	Site type	Sex	N	Random site survey				
				Length (cm)			Percent male	
				Mean	Minimum	Maximum	All blue cod	Recruited
1	Fixed	m	477	28.6	18.0	40.4	82.8	94.9
		f	99	25.4	17.1	35.3		
		u	1	17.2	17.2	17.2		
2	Fixed	m	129	26.2	11.7	43.1	70.9	97.9
		f	53	21.1	15.2	31.2		
		u	3	12.3	10.4	13.7		
3	Fixed	m	276	25.2	11.7	39.1	73.6	98.3
		f	99	21.2	11.3	31.2		
		u	6	12.8	11.5	14.1		
Overall	Fixed	m	882	26.5	11.7	43.1	76.3	96.5
		f	251	22.2	11.3	35.3		
		u	10	13.1	10.4	17.2		

Table 5: Otolith ageing data used in the catch-at-age, Z estimates and SPR analyses for the 2016 Motunau survey.

Survey	No. otoliths	Length of aged fish (cm)		Age (years)	
		Minimum	Maximum	Minimum	Maximum
Total	412	9	44	1	12
Male	250	12	44	1	12
Female	144	15	33	2	10
Unsexed	18	9	15	1	2

Table 6: Gonad stages of blue cod from Motunau in early January 2016 for all blue cod. 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

Sex	Gonad stage (%)					N
	1	2	3	4	5	
Males	70.3	29.3	0.3	0.0	0.1	1 892
Females	99.8	0.2	0.0	0.0	0.0	579

Table 7: Chapman-Robson total mortality estimates (Z) and 95% confidence intervals of blue cod for the fixed and random site 2016 Motunau potting surveys. AgeR, age at full recruitment (years).

		Fixed site survey	
AgeR	Z	95% CIs	
		Lower	Upper
5	0.65	0.44	0.88
6	0.87	0.58	1.22
7	0.55	0.37	0.77
8	0.76	0.48	1.09
9	1.57	0.83	2.98
10	0.85	0.35	1.9

		Random site survey	
AgeR	Z	95% CIs	
		Lower	Upper
5	0.62	0.42	0.88
6	0.81	0.53	1.15
7	0.56	0.37	0.79
8	0.75	0.47	1.09
9	1.71	0.91	2.84
10	0.83	0.35	1.9

Table 8: Mortality parameters (CR Z and F , and M) and Spawner-per-recruit (F_{SPR}) estimates at three values of M for age at full recruitment (AgeR) of 8 years for blue cod from the 2016 Motunau fixed and random site potting surveys. AgeR is the age at which females reach MLS of 30 cm. F , fishing mortality; M , natural mortality; Z , total mortality

		Fixed site survey		
AgeR	M	Z	F	F_{SPR}
8	0.11	0.76	0.65	$F_{14.5\%}$
8	0.14	0.76	0.62	$F_{19.2\%}$
8	0.17	0.76	0.59	$F_{24.1\%}$

		Random site survey		
AgeR	M	Z	F	F_{SPR}
8	0.11	0.75	0.64	$F_{14.6\%}$
8	0.14	0.75	0.61	$F_{19.4\%}$
8	0.17	0.75	0.58	$F_{24.4\%}$

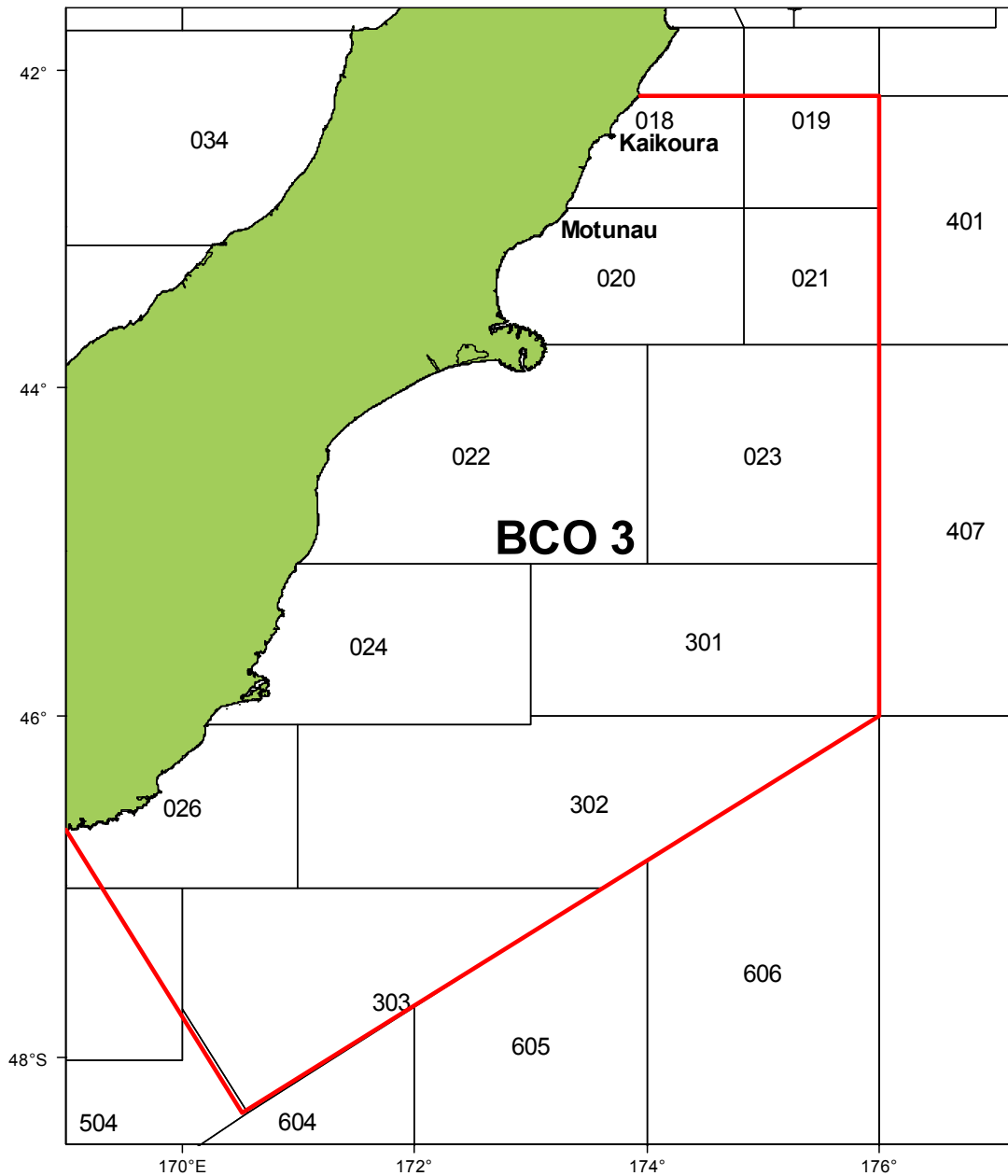


Figure 1: Blue cod Quota Management Area BCO 3 (red border) and statistical areas. The north Canterbury potting survey locations of Kaikoura and Motunau are shown.

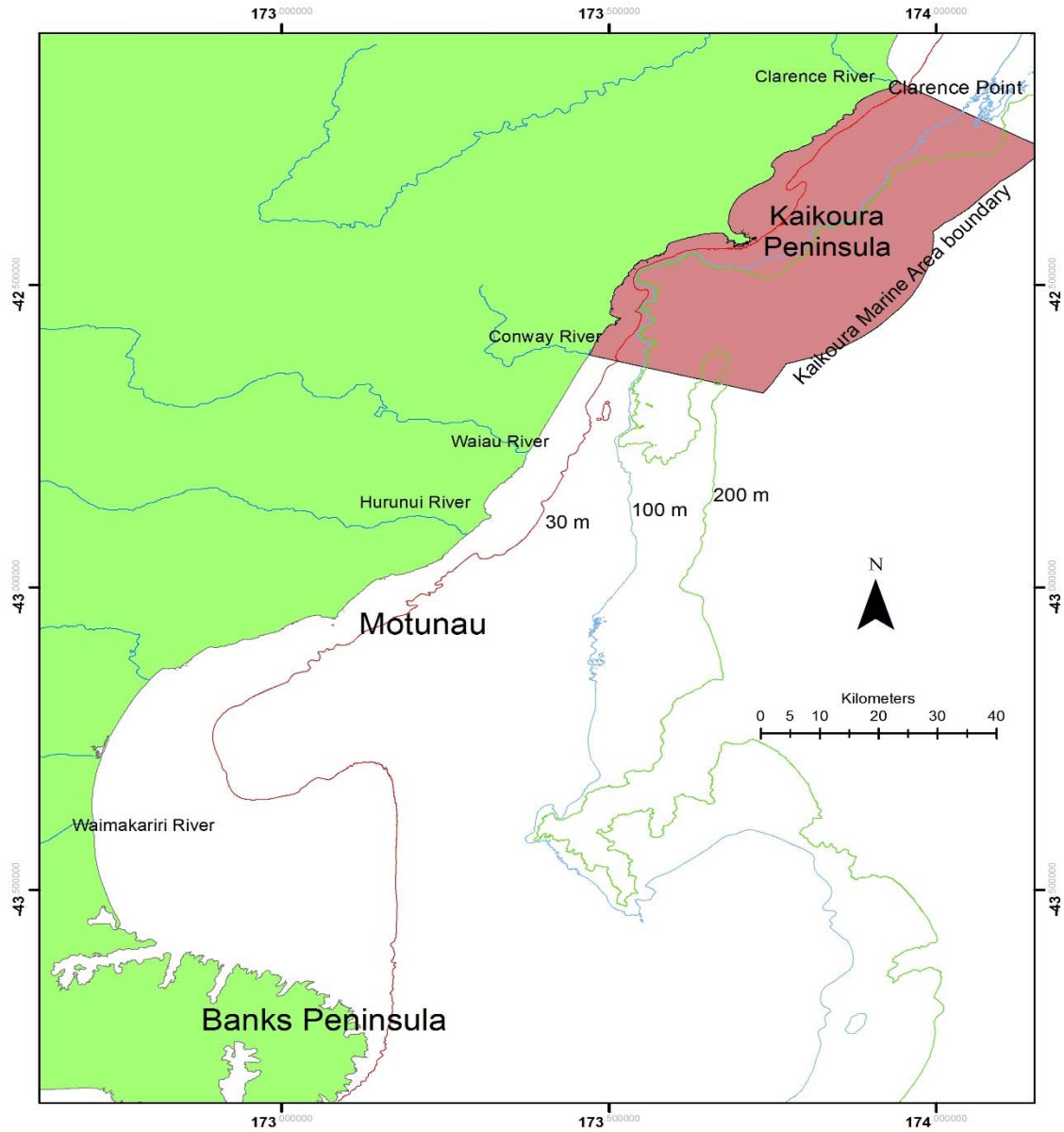


Figure 2: Map of north Canterbury coastline showing locations of Motunau and the Kaikoura Marine Area.

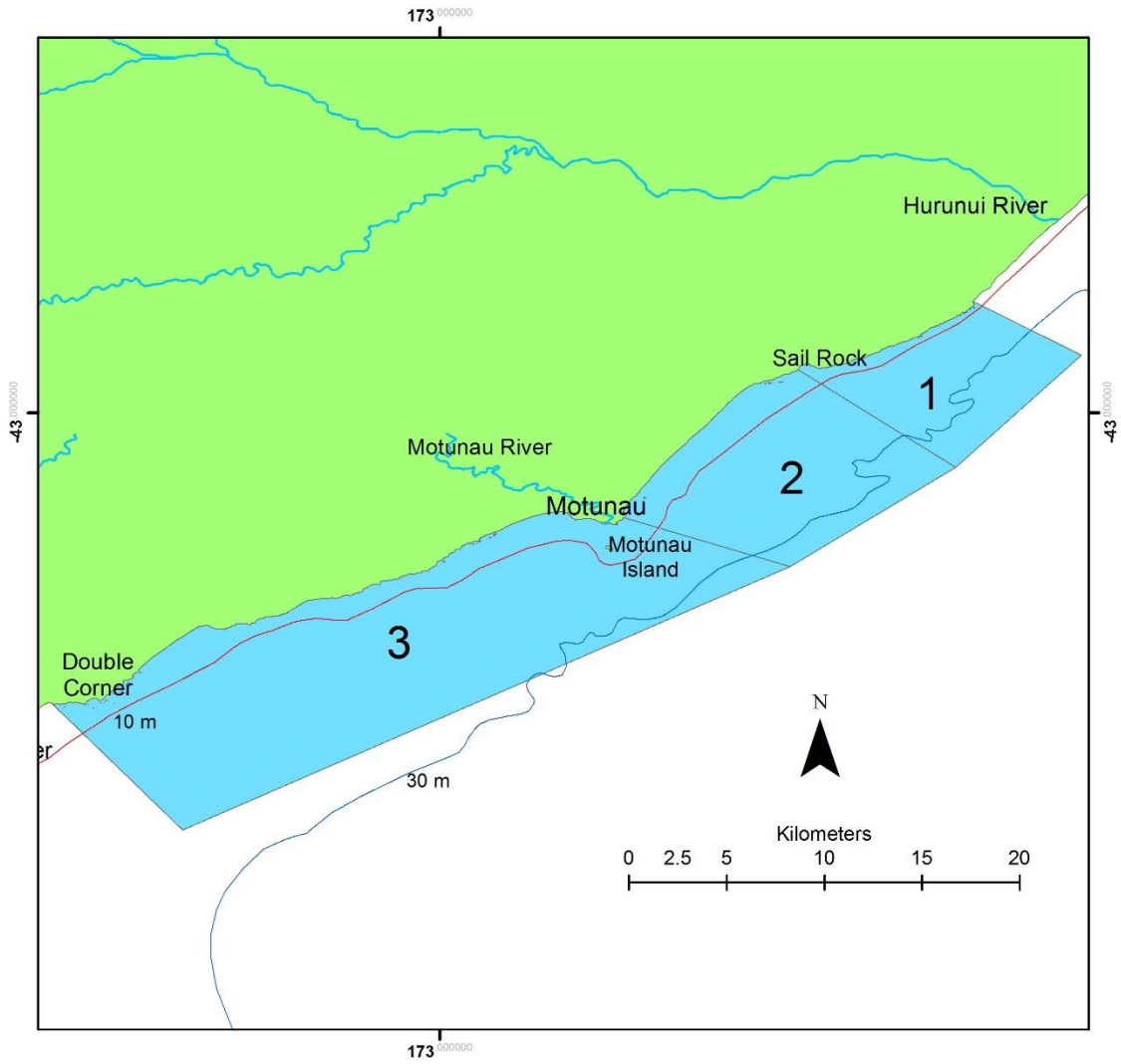


Figure 3: Map of Motunau potting survey strata (1, 2, and 3) for fixed and random site surveys.

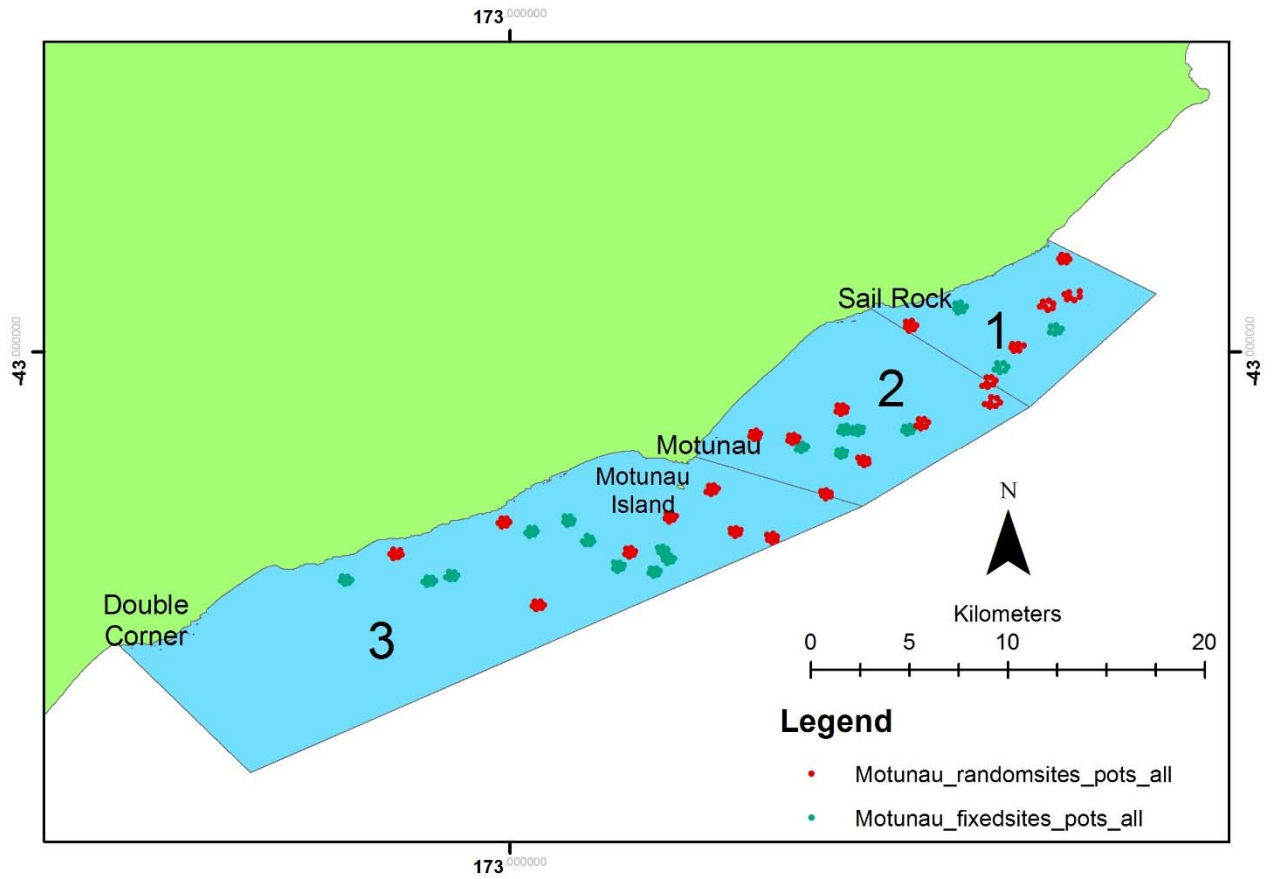


Figure 4: Map of Motunau strata and pot locations for the fixed and random sites surveyed in 2016.

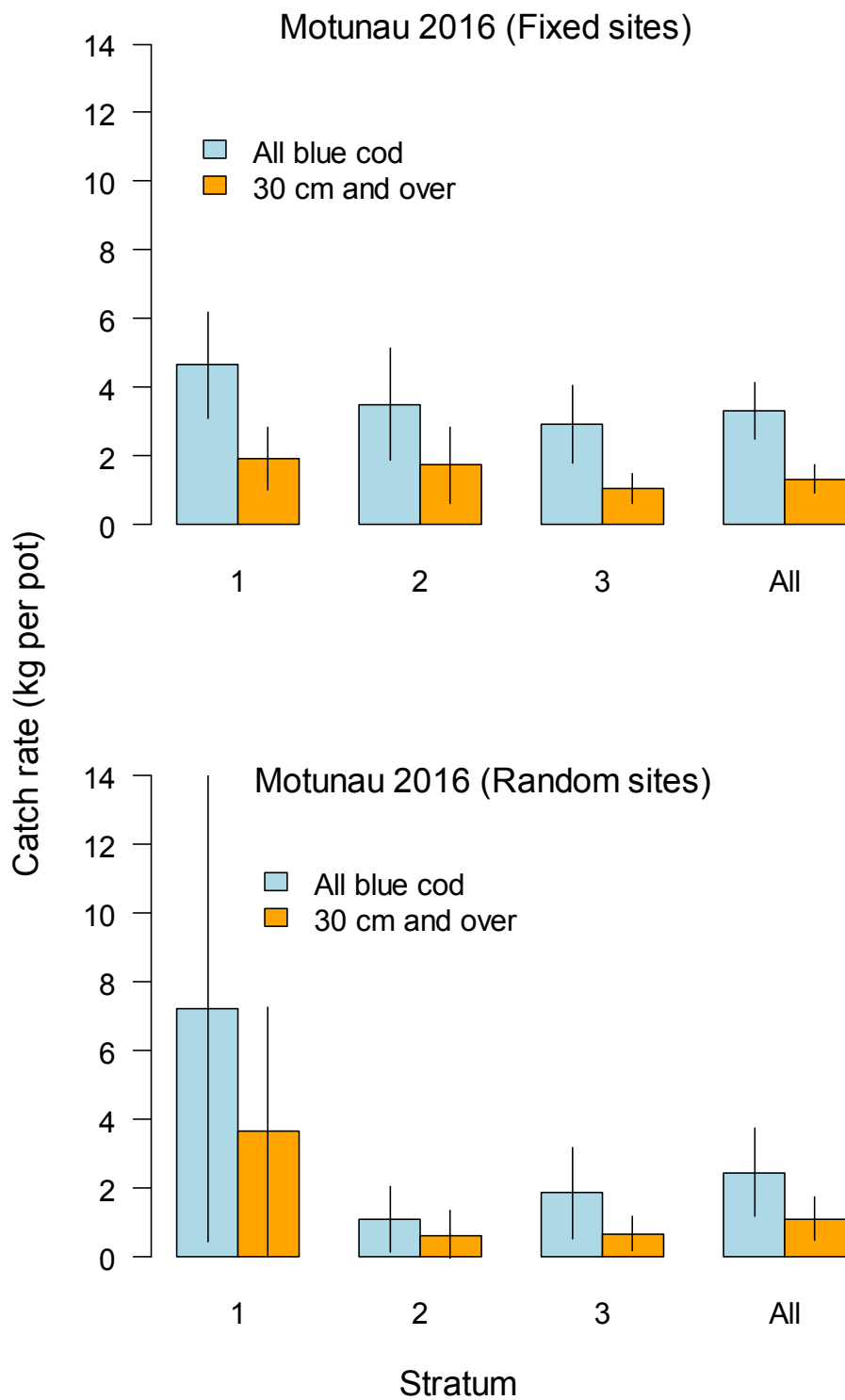


Figure 5: Catch rates (kg.pot⁻¹) of all blue cod and recruited blue cod (30 cm and over) for the 2016 Motunau fixed site (top panel) and random site (bottom panel) surveys. Error bars are 95% confidence intervals. See Figure 3 for location of strata.

2016 Motunau (fixed sites)

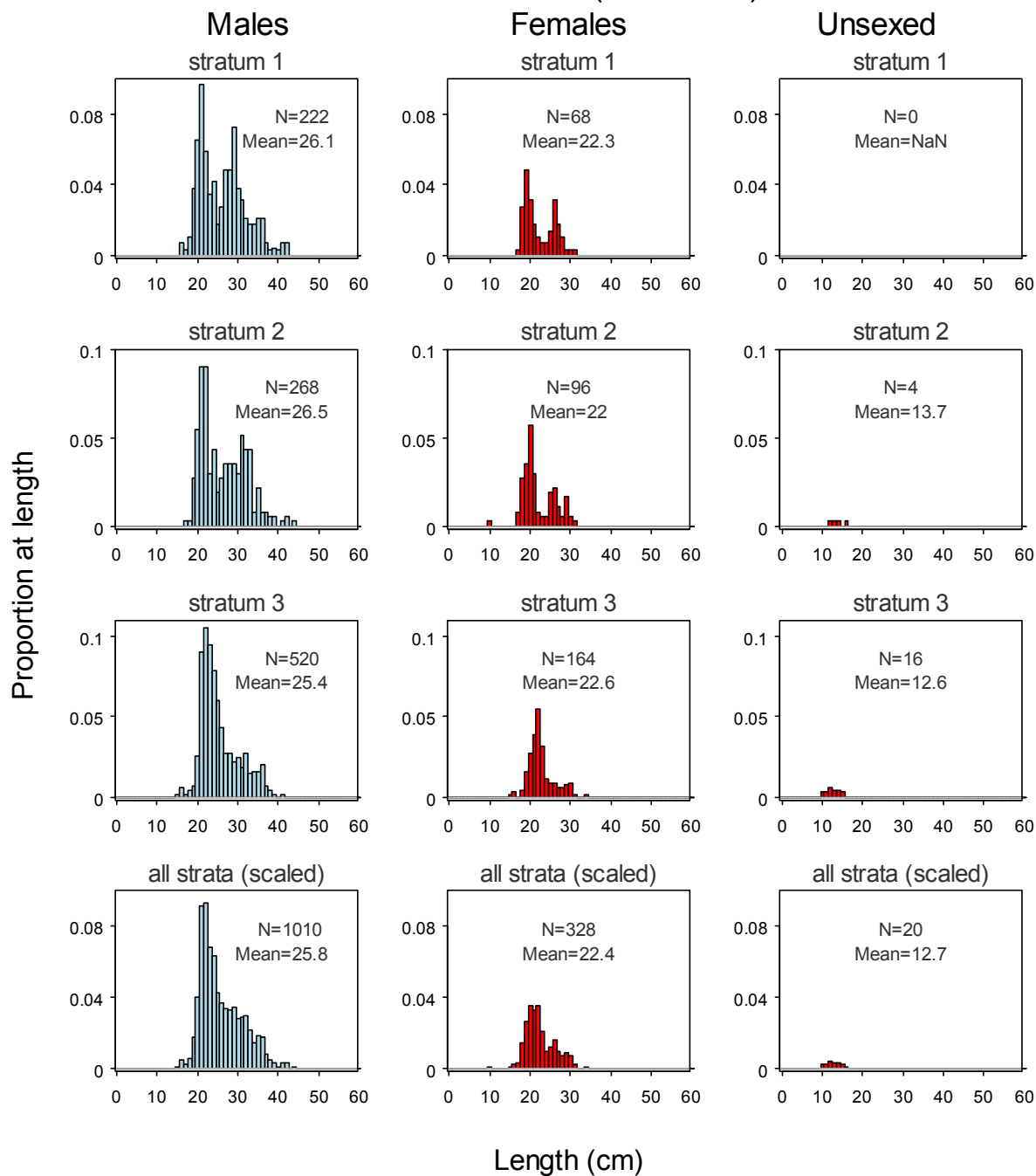


Figure 6: Scaled length frequency distributions by strata and overall for the 2016 Motunau fixed site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum.

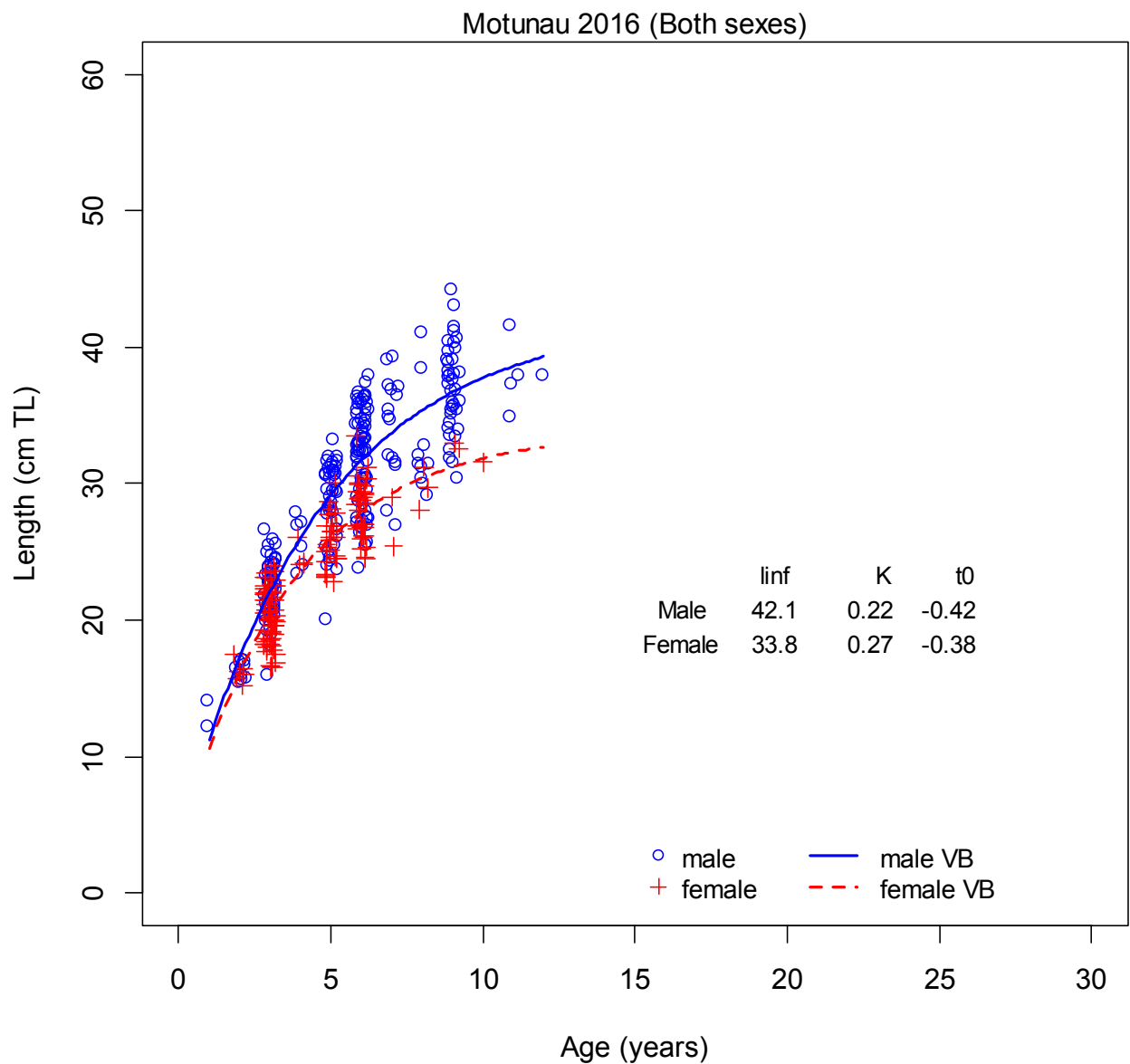


Figure 7: Observed blue cod age and length data by sex for the 2016 Motunau survey with von Bertalanffy (VB) growth models fitted to the data. N= 250 males and 144 females.

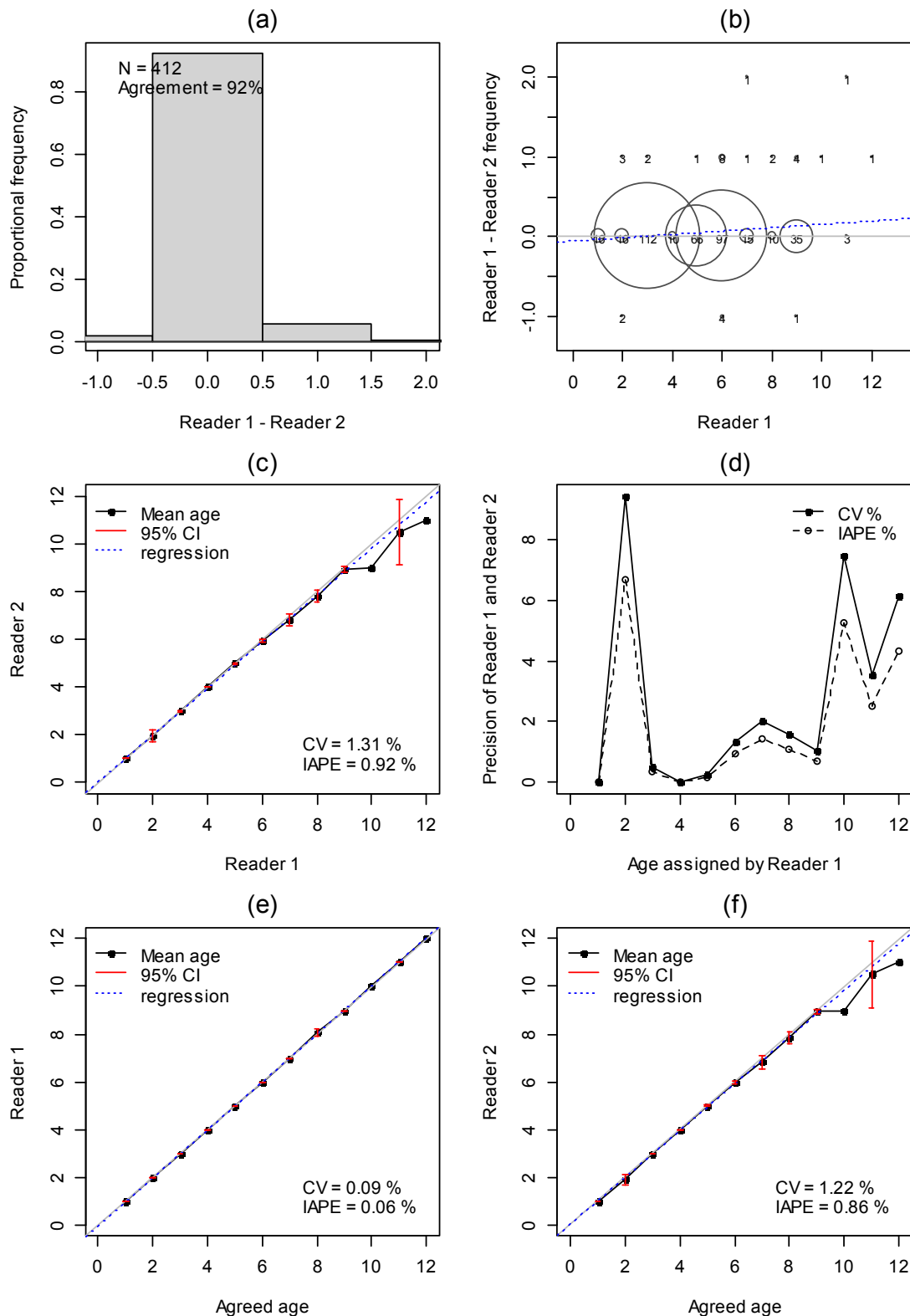


Figure 8: Blue cod age otolith reader comparison plots between reader 1 and reader 2 for the 2016 Motunau survey: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age bin are annotated and proportional to circle size; (c) Age bias plot, showing the correspondence of ages between reader 1 and reader 2 for all ages; (d) precision of readers; (e and f) reader age compared with agreed age. In panels b and c, solid lines show perfect agreement, dashed lines show the trend of a linear regression of the actual data.

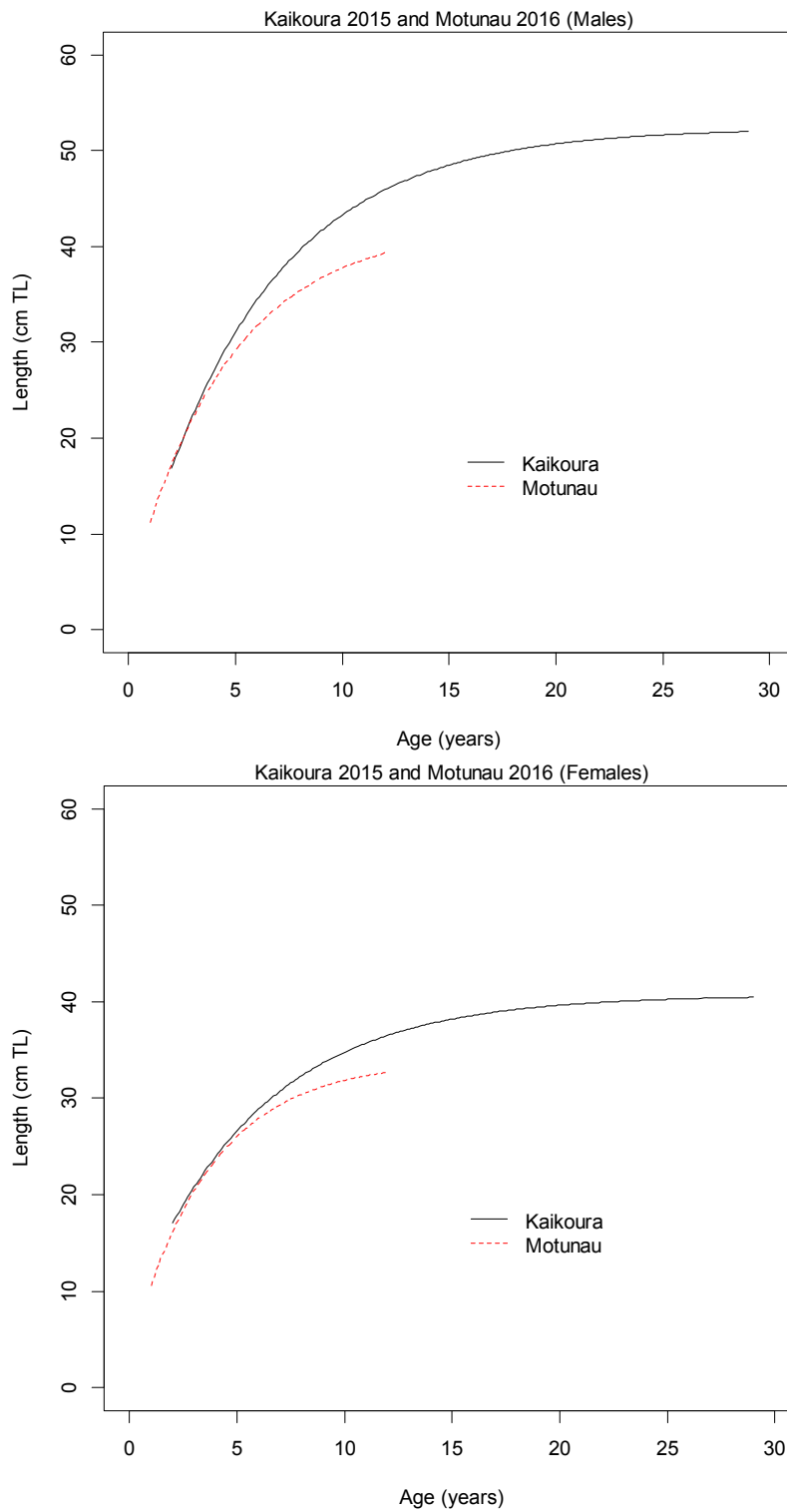


Figure 9: von Bertalanffy growth models fitted to male (top panel) and female (bottom panel) blue cod length age data from the Kaikoura 2015 and Motunau 2016 surveys.

2016 Motunau survey (fixed sites)

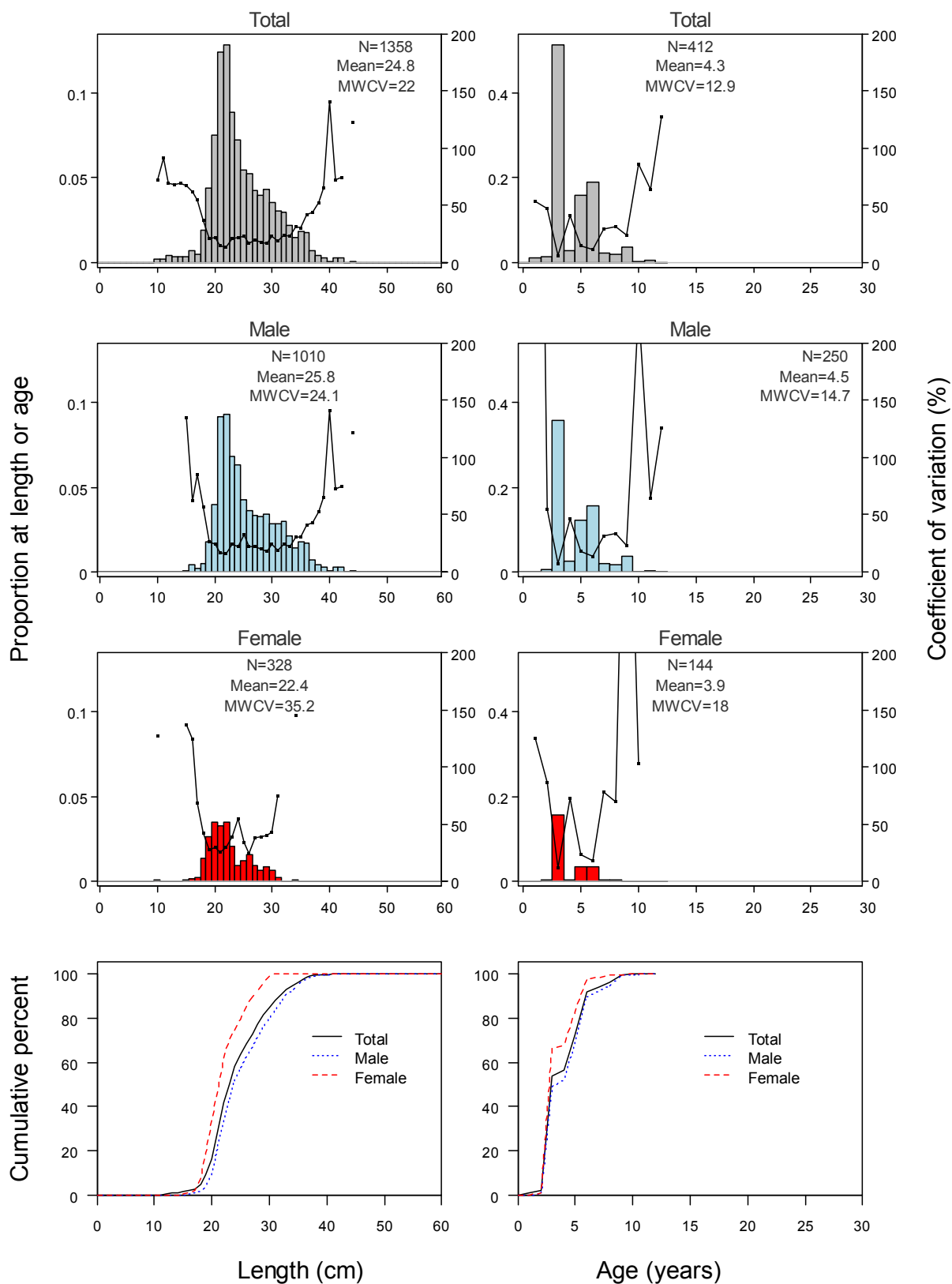


Figure 10: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2016 Motunau fixed site blue cod potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

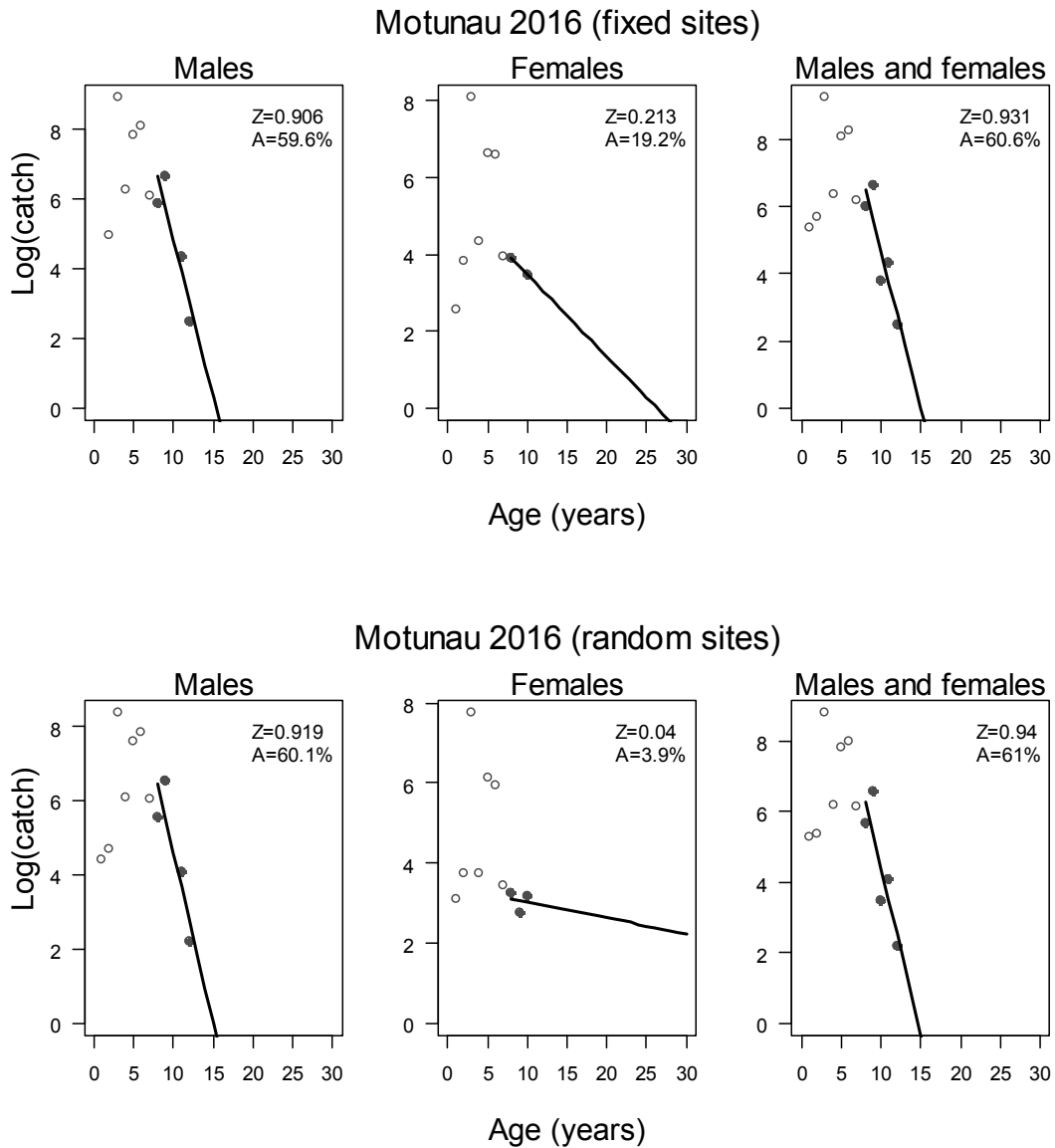


Figure 11: Motunau 2016 fixed site (top panel) and random site (bottom panel) survey catch curves (natural log of catch numbers versus age). The regression line is plotted from age at full recruitment of 8 years (i.e., dark points on the graph). Z, instantaneous total mortality; A, the annual mortality rate or the proportion of the population that suffers mortality in a given year.

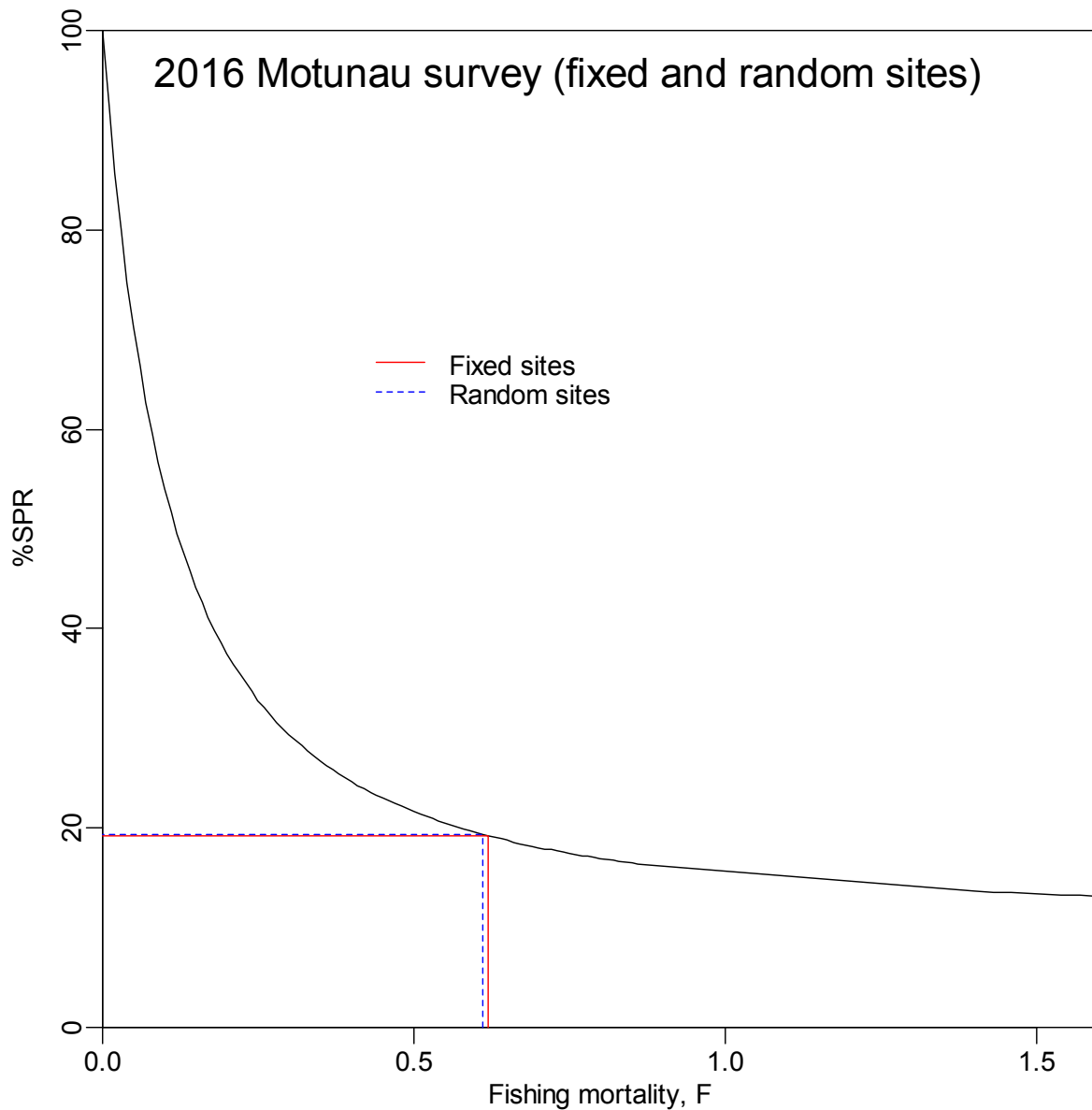


Figure 12: Spawner-per-recruit (SPR) as a function of fishing mortality (F) for 2016 Motunau fixed and random site surveys. The %SPR is 19.2% corresponding to the F value of 0.62 for fixed sites, and 19.4% and 0.61 for random sites, respectively. In this plot $M = 0.14$, and F value is for age of full recruitment equal to 8 years for females.

2016 Motunau (random sites)

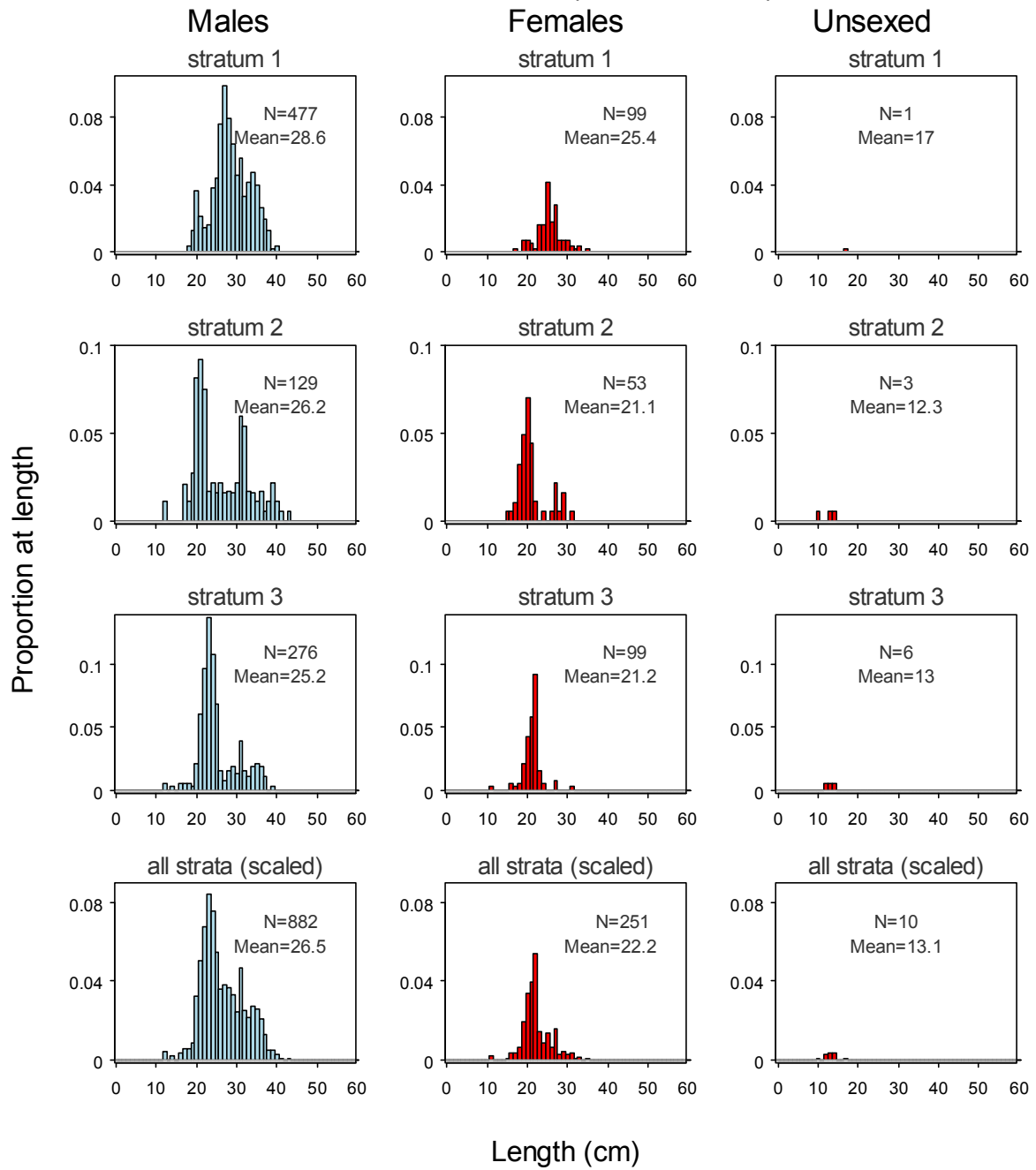


Figure 13: Scaled length frequency distributions by strata and overall for the 2016 Motunau random site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum.

2016 Motunau survey (random sites)

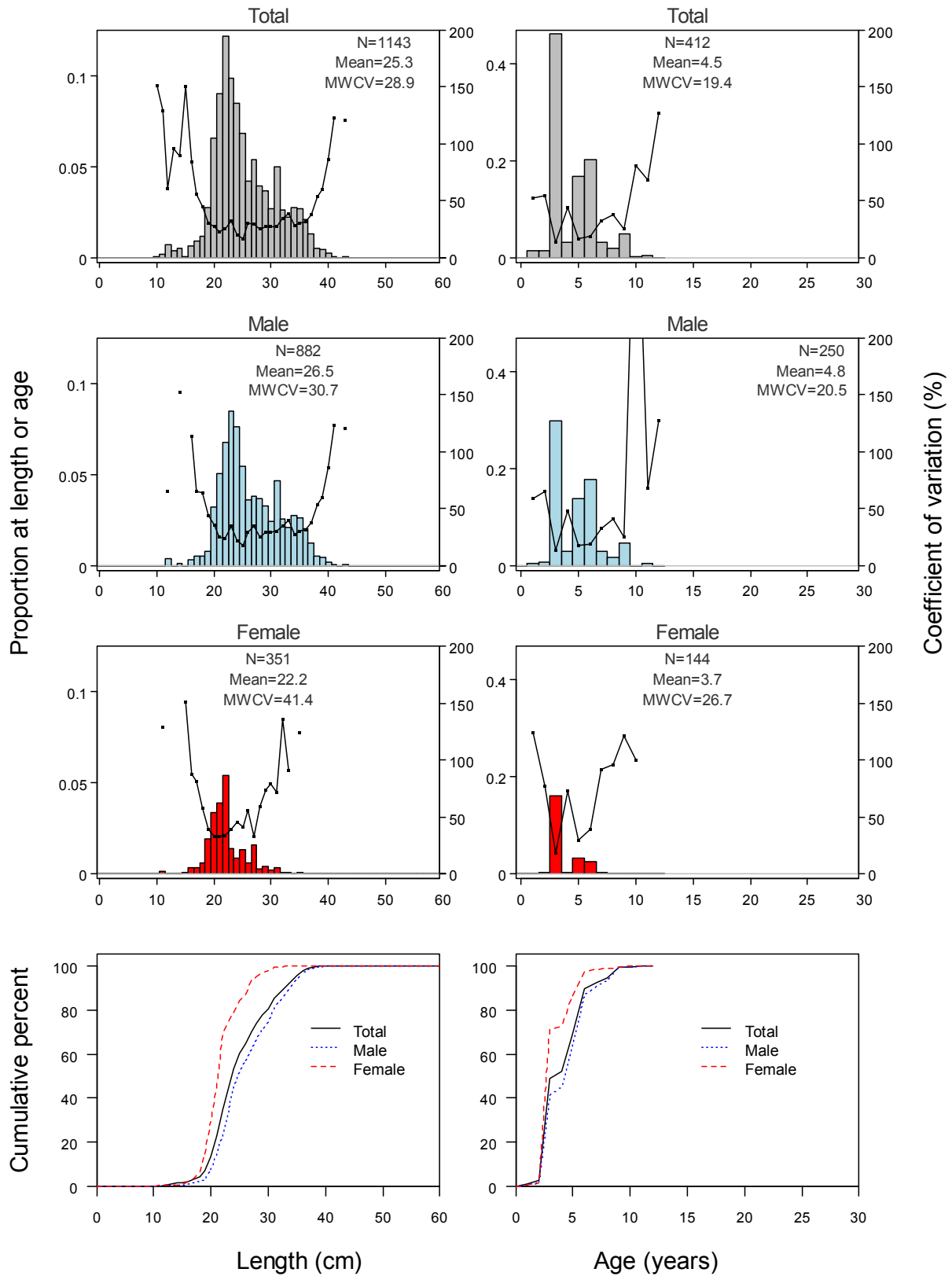


Figure 14: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2016 Motunau random site blue cod potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

2016 Motunau survey

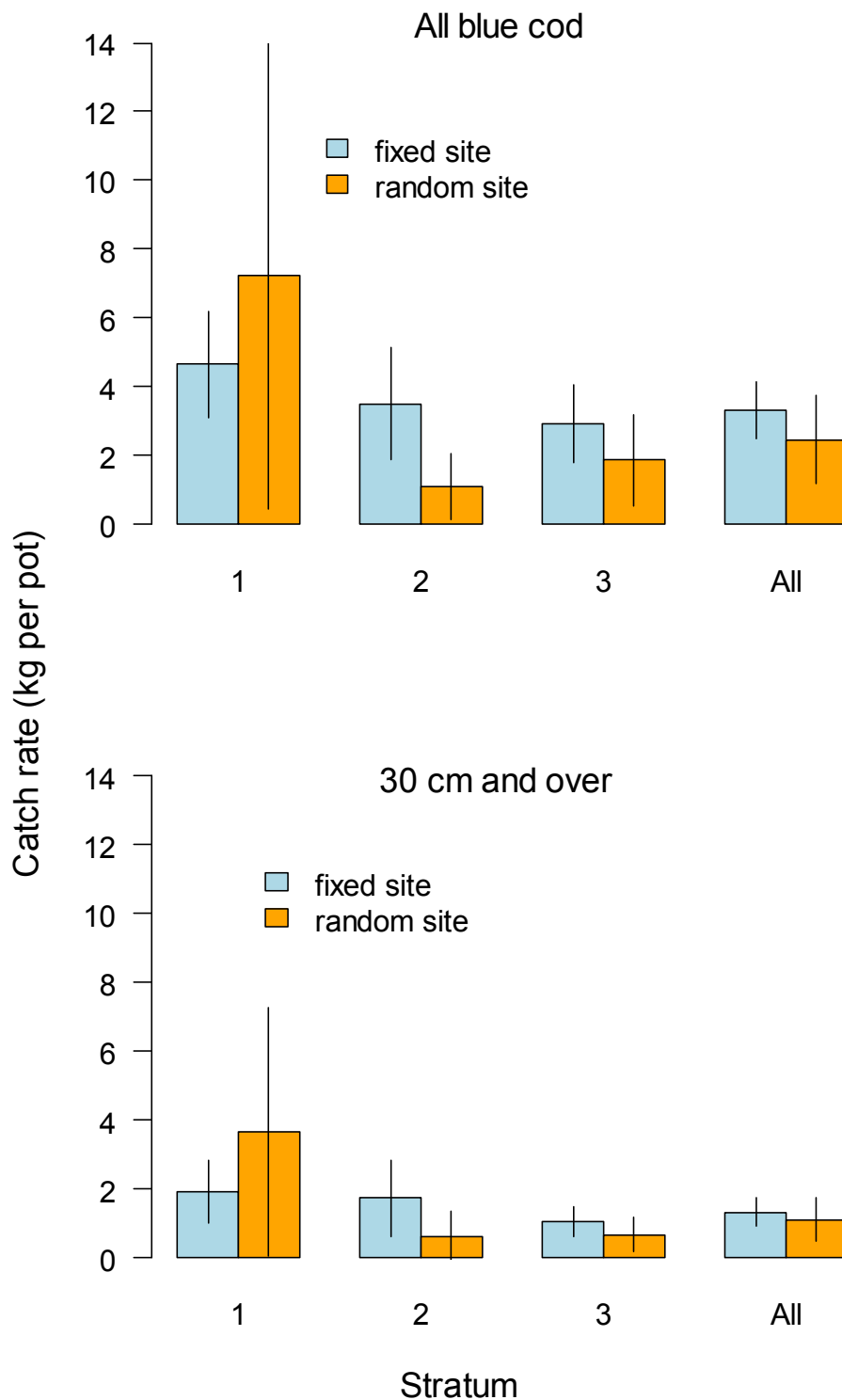


Figure 15: Catch rates (kg.pot⁻¹) of all blue cod (top panel) and recruited (30 cm and over, bottom panel) for the 2016 Motunau fixed and random site surveys. Error bars are 95% confidence intervals.

Motunau 2016 (fixed versus random sites)

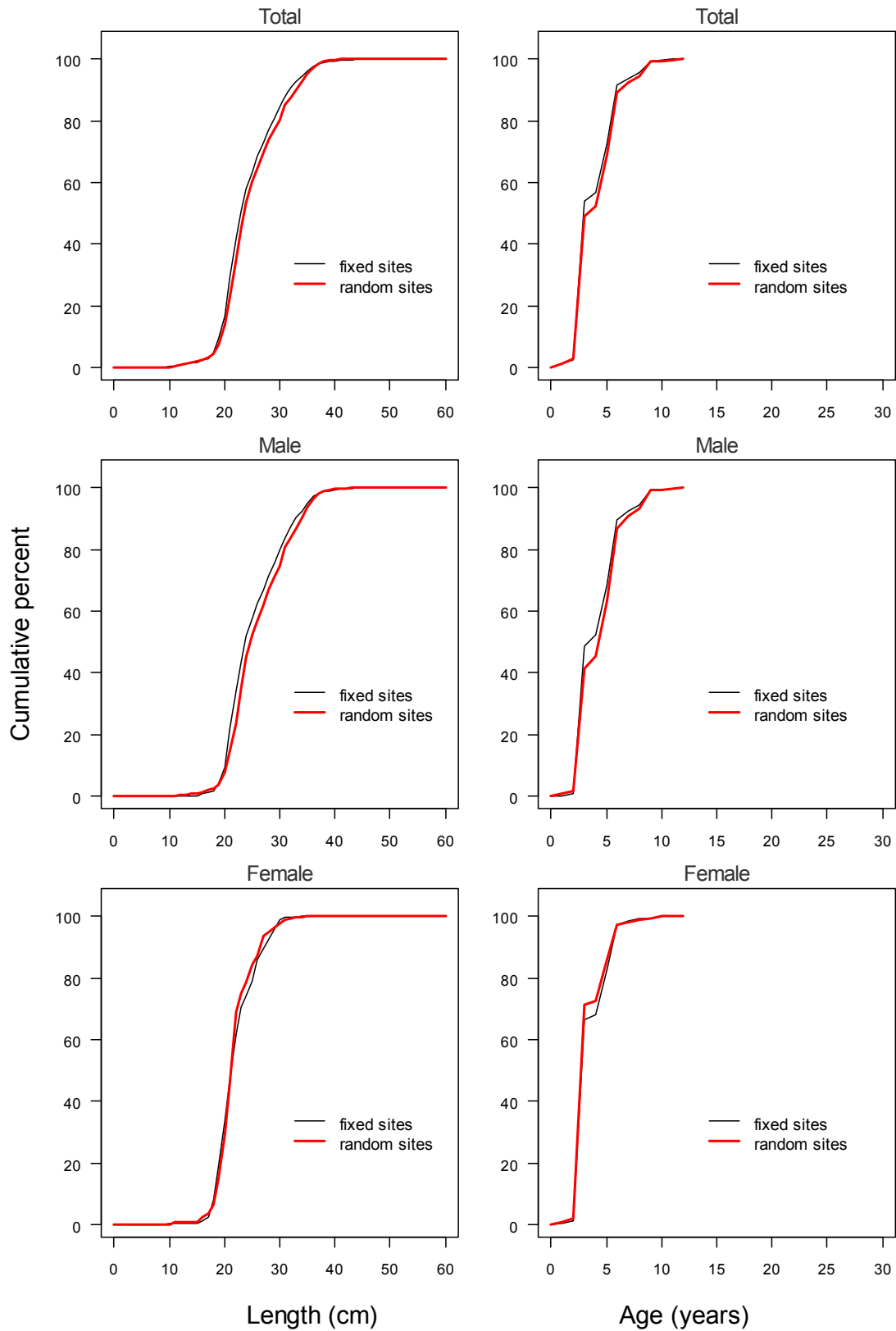


Figure 16: Cumulative distributions of scaled length and age frequencies for total, male, female, and unsexed blue cod from the 2016 Motunau blue cod fixed site and random site potting surveys.

Motunau fixed site surveys

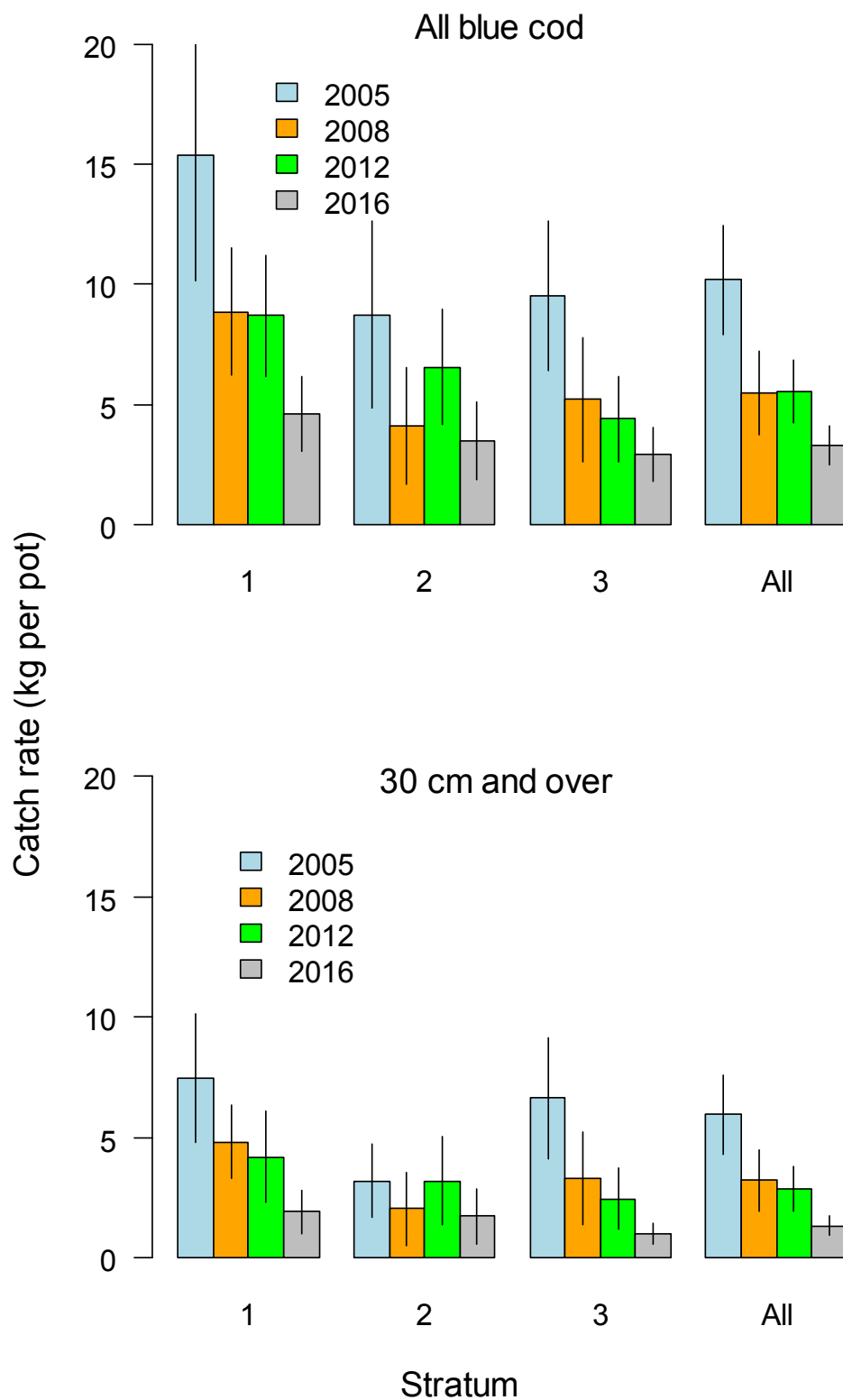


Figure 17: Catch rates ($\text{kg}\cdot\text{pot}^{-1}$) of all blue cod (top panel) and recruited blue cod (30 cm and over, bottom panel) for the Motunau fixed site potting surveys in 2005, 2008, 2012, and 2016. Error bars are 95% confidence intervals.

Motunau random site surveys

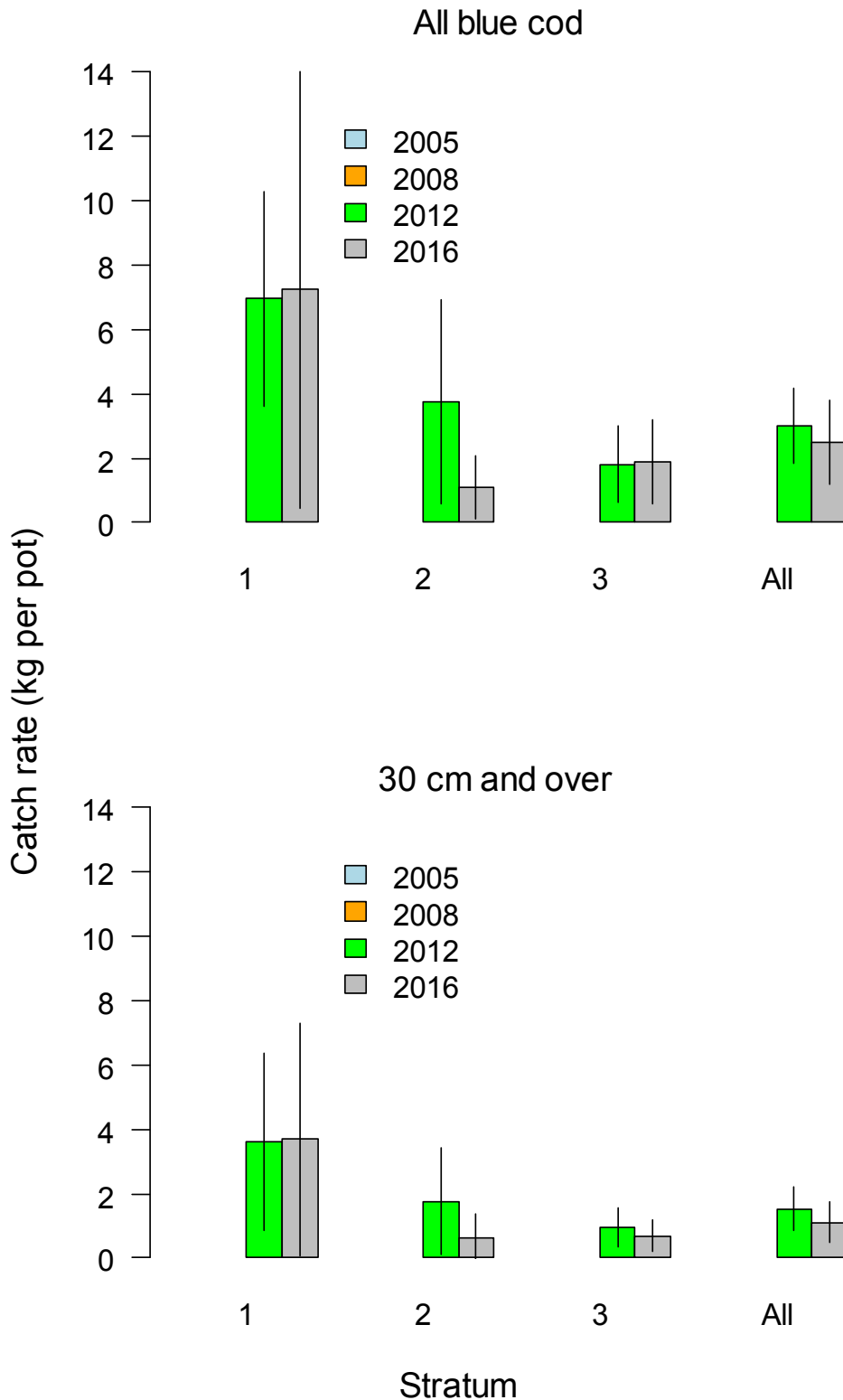


Figure 18: Catch rates ($\text{kg}\cdot\text{pot}^{-1}$) of all blue cod (top panel) and for recruited blue cod (30 cm and over, bottom panel) for the Motunau fixed site potting surveys in 2012 and 2016. There were no random site surveys in 2005 and 2008. Error bars are 95% confidence intervals.

Motunau fixed and random site surveys

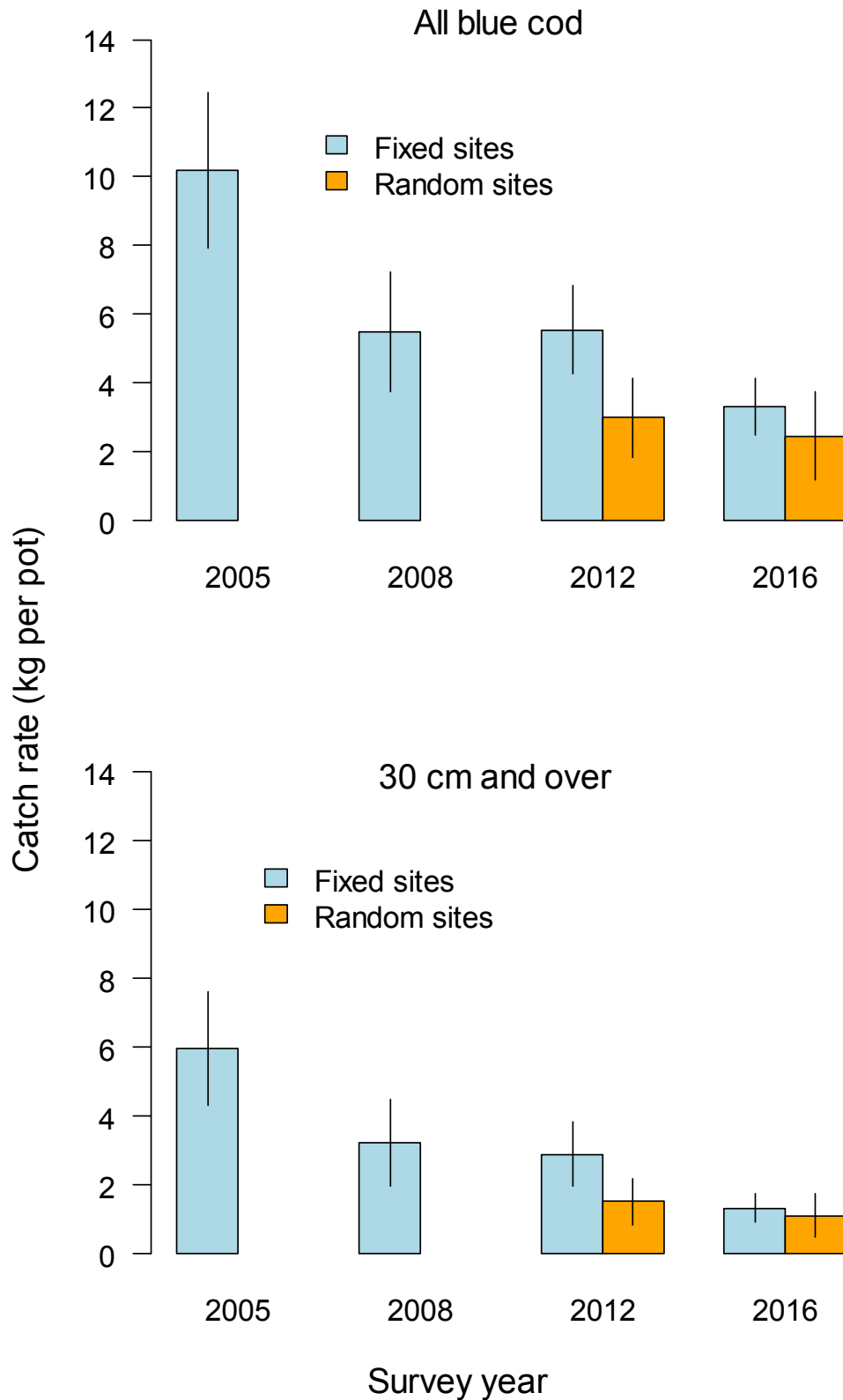


Figure 19: Catch rates (kg.pot⁻¹) of all blue cod (top panel) and for recruited (30 cm and over, bottom panel) for the Motunau fixed site potting surveys in 2005, 2008, 2012, and 2016; and random site surveys in 2012 and 2016. Error bars are 95% confidence intervals

Motunau (fixed site surveys)

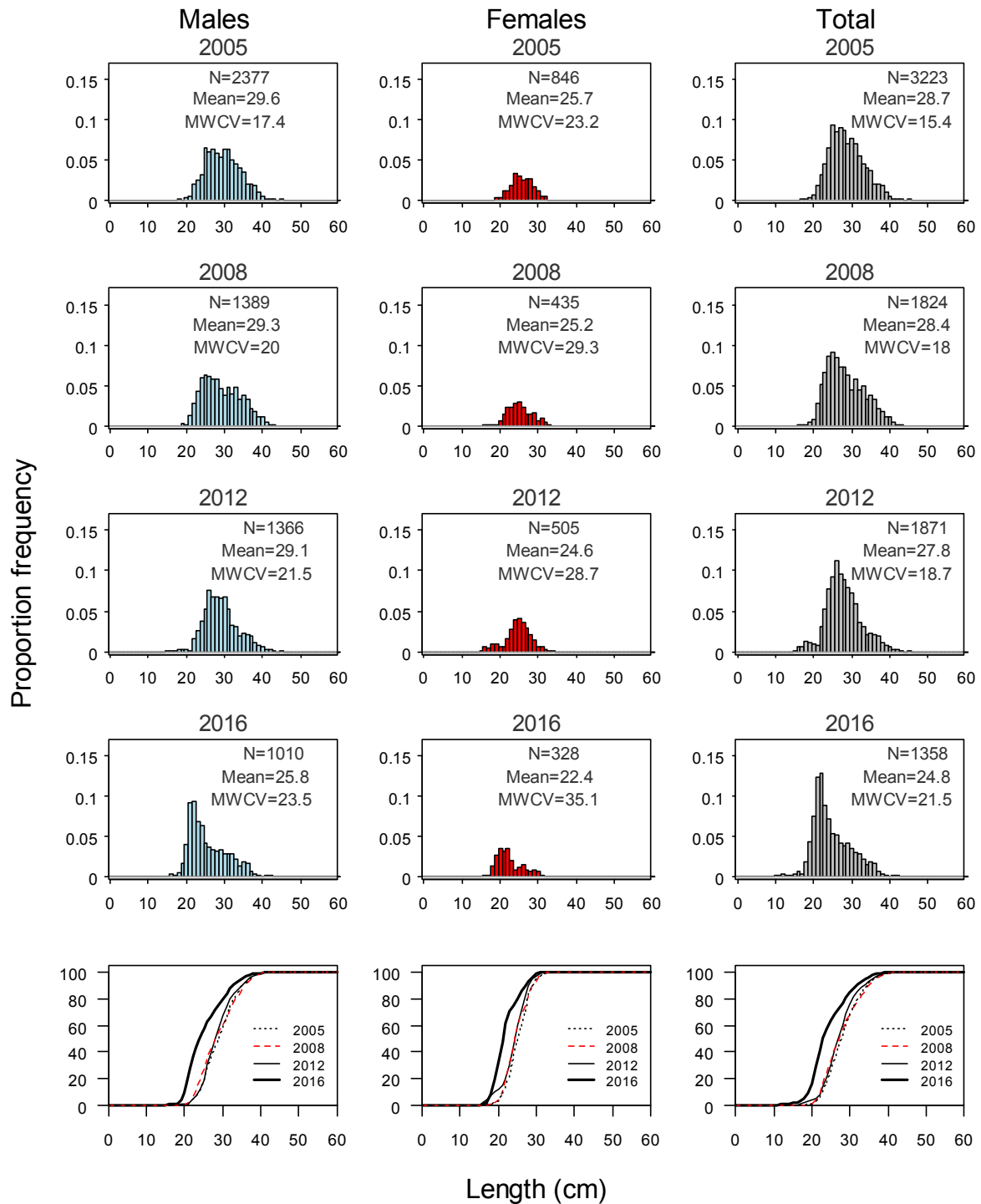


Figure 20: Scaled length frequency and cumulative distributions of scaled length frequencies for total, male, and female blue cod from Motunau fixed site blue cod potting surveys in 2005, 2008, 2012, and 2016.

Motunau (random site surveys - 2012 and 2016)

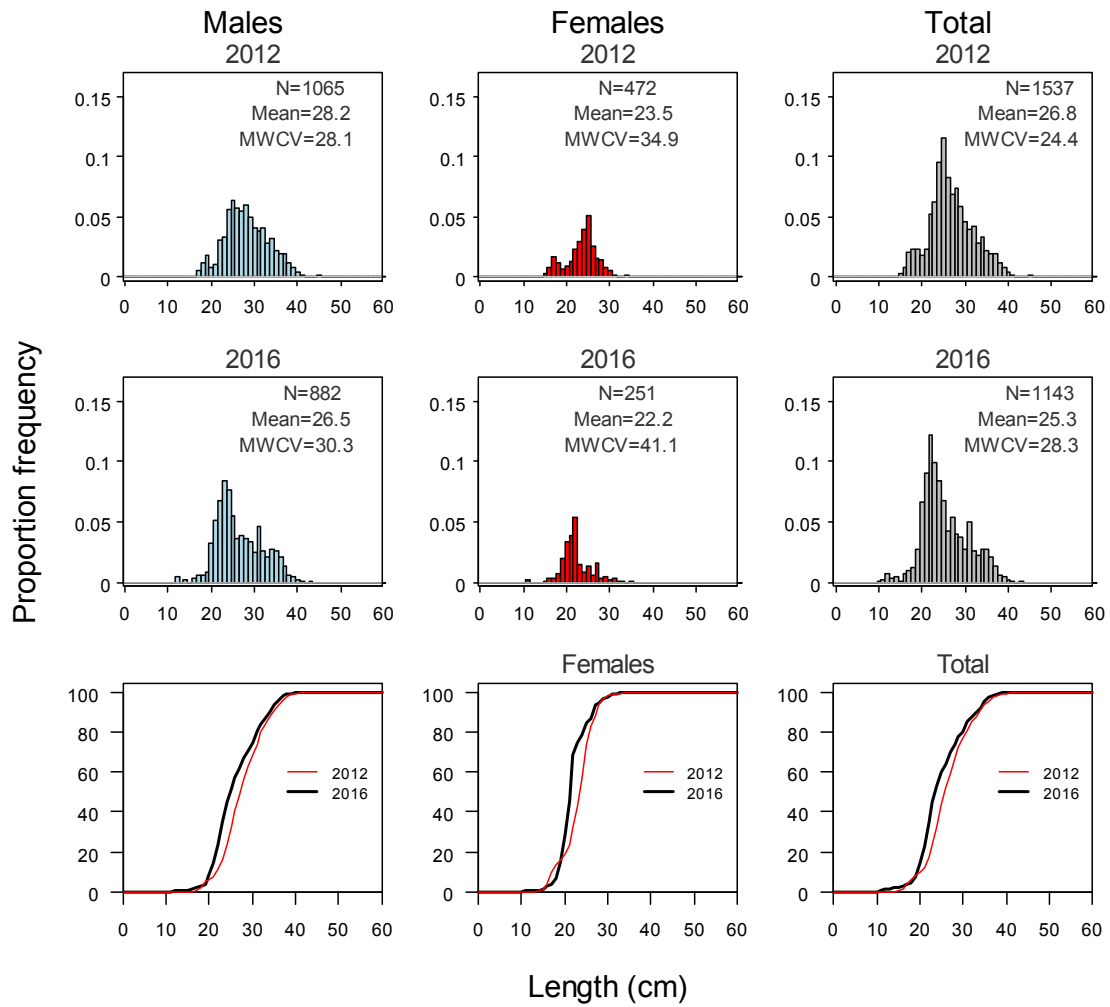


Figure 21: Scaled length frequency and cumulative distributions of scaled length frequencies for total, male, and female blue cod from Motunau random site blue cod potting surveys in 2012 and 2016.

Motunau fixed and random site surveys

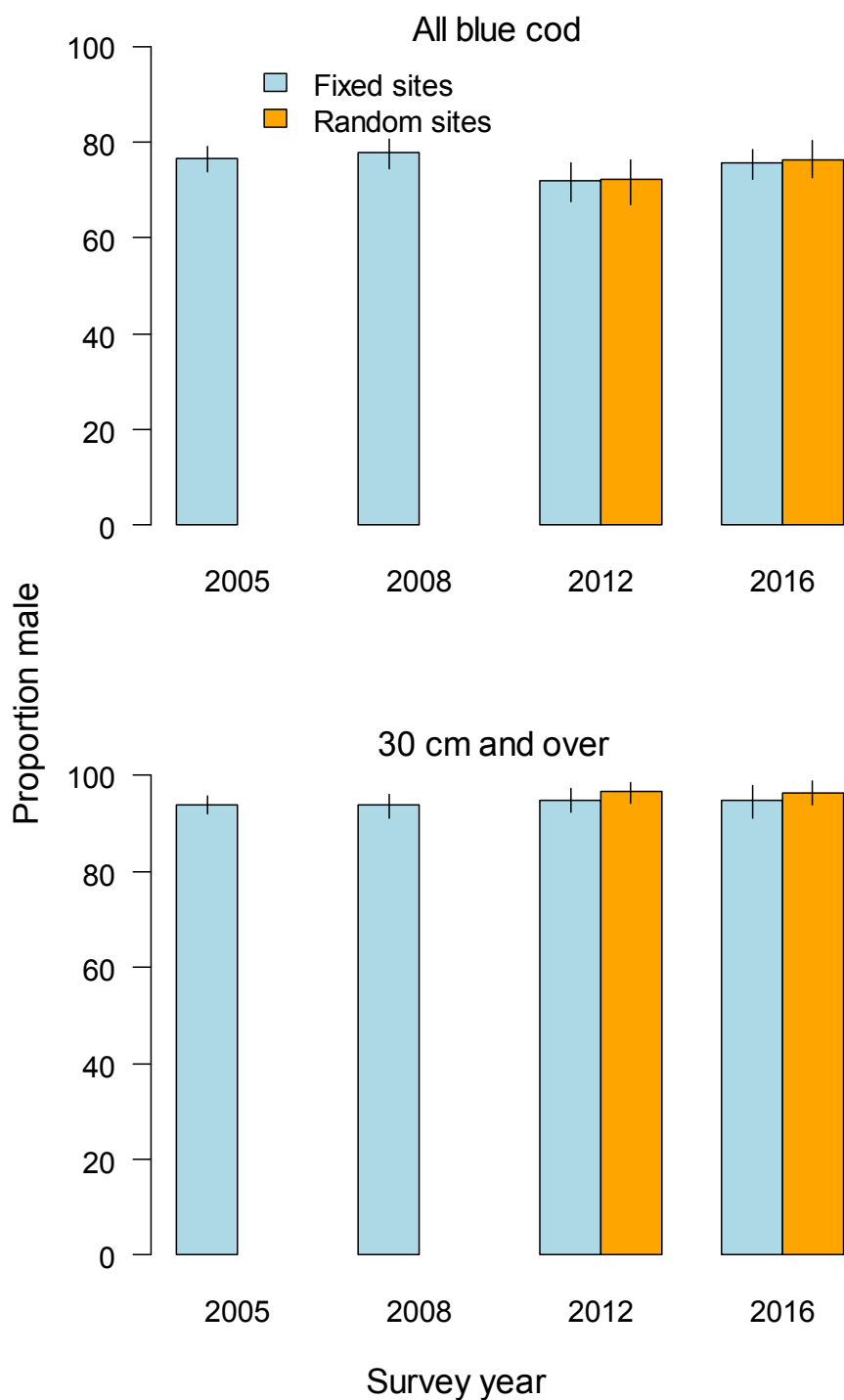


Figure 22: Sex ratio (percent male) of scaled length frequencies of all blue cod (top panel) and recruited blue cod (30 cm and over, bottom panel) for the Motunau fixed site potting surveys in 2005, 2008, 2012, and 2016; and random site potting surveys in 2012 and 2016. Error bars are 95% confidence intervals.

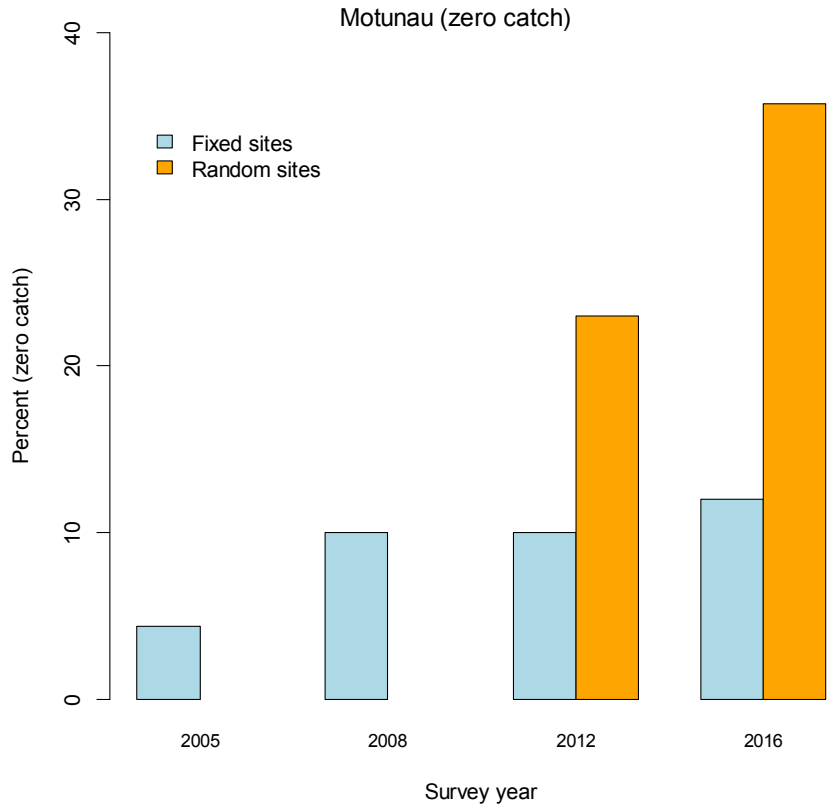


Figure 23: Proportion of pots with no blue cod catch for the Motunau fixed site potting surveys in 2005, 2008, 2012, and 2016; and random site potting surveys in 2012 and 2016.

Appendix 1: Glossary of terms used in this report (modified from Beentjes & Francis 2011). See the potting survey standard and specifications for more details.

Fixed site	A site that has a fixed location (single latitude and longitude or the centre point location of a section of coastline) in a stratum and is available to be used repeatedly on subsequent surveys in that area. The fixed sites used in a particular survey are randomly selected from the list of all available fixed sites in each stratum. Fixed sites are sometimes referred to as index sites or fisher-defined sites and were defined at the start of the survey time series (using information from recreational and commercial fishers)
Pot number	Pots are numbered sequentially (1 to 6 or 1 to 9) in the order they are placed during a set. In the Marlborough Sounds nine pots are used.
Pot placement	There are two types of pot placement: Directed —the position of each pot is directed by the skipper using local knowledge and the vessel SONAR to locate a suitable area of reef/cobble or biogenic habitat. Systematic —the position of each pot is arranged systematically around the site or along the site for a section of coastline. For the former site, the position of the first pot is set 300 m to the north of the site location and remaining pots are set in a hexagon pattern around the site, at about 300 m from the site position.
Random site	A site that has the location (single latitude and longitude) generated randomly within a stratum, given the constraints of proximity to other selected sites for a specific survey.
Site	A geographical location near to which sampling may take place during a survey. A site may be either fixed or random (see below). A site may be specified as a latitude and longitude or a section of coastline (for the latter, use the latitude and longitude at the centre of the section).
Site label	An alphanumeric label of no more than four characters, unique within a survey time series. A site label identifies each fixed site and also specifies which stratum it lies in. Site labels are constructed by concatenating the stratum code with an alpha label (A–Z) that is unique within that stratum. Thus, sites within stratum 2 could be labelled 2A, 2B, and sites in stratum 3 could be labelled 3A, 3B etc. Site labels for random sites are constructed in the same way but prefixed with R (e.g., R4A, R4B etc).
Station	The position (latitude and longitude) at which a single pot (or other fishing gear such as ADCP) is deployed at a site during a survey, i.e., it is unique for the trip.
Station number	A number which uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be <i>station_no</i> 234. This convention is important in enabling users of the <i>trawl</i> database to determine whether two pots are from the same set. Note that the set numbers for potting surveys are not recorded anywhere else in the <i>trawl</i> database.

Appendix 2. Numbers of otoliths collected during the 2016 Motunau survey for males and females, by strata and length class. Lgth, length.

Lgth (cm)	Stratum			Male totals	Stratum			Female totals
	1	2	3		1	2	3	
12		1		1				
13								
14			1	1				
15			3	3		1	1	2
16	3	1	1	5		4	3	7
17		1	2	3	1	2	1	4
18		1		1	5	2	3	10
19	2		1	3	5	1	3	9
20	6	1	3	10	2	7	2	11
21	4	2	2	8		3	7	10
22	2	2	4	8	1	2	10	13
23	2	1	8	11	3		5	8
24	4		7	11	4	4	2	10
25	5		5	10	4	1	3	8
26	4		3	7	5	3	9	17
27	8		4	12	2	2	1	5
28	5		6	11	2	3	5	10
29	4		6	10	1	6	2	9
30	3	3	10	16		2	3	5
31	5	3	10	18	1	1	1	3
32	2	5	10	17	1			1
33	3	3	7	13	1		1	2
34	3	2	6	11				
35	5	1	8	14				
36	3		10	13				
37	4	1	4	9				
38	5	2	1	8				
39	1	3	2	6				
40	3		1	4				
41	3	1		4				
42								
43		1		1				
44		1		1				
Totals	89	36	125	250	38	44	62	144