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Catch-at-age of yellowtail kingfish (*Seriola lalandi*) caught by New Zealand recreational fishers 2014–15

New Zealand Fisheries Assessment Report 2016/45

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Holdsworth, J.C.; McKenzie, J.R.; Walsh, C.; Bian. R.; Ó Maolagáin, C. (2016). Catch-at-age of yellowtail kingfish (*Seriola lalandi*) caught by New Zealand recreational fishers, 2014–15.

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This report presents the results of Objective 2 of the Ministry for Primary Industries project "To monitor the status of kingfish (*Seriola lalandi*) stocks in KIN 1" (KIN2014/01). The length frequency and age-length key sampling approach was employed during the 2014–15 fishing year to estimate catch-at-age for kingfish caught by recreational fishers in the Northland/Hauraki Gulf and Bay of Plenty/East Cape regions. Length samples came entirely from recreational catches on rod and reel, pursuant to a spatially stratified sampling design based on the results of a similar study in 2009–10 and recent catch data. Sagittal otoliths were removed from a subsample of retained fish to determine age, with length and sex recorded. The derived age structure from sampling the recreational fishery is used in estimating total mortality (Z).

During the 2014–15 study, a total of 2833 kingfish were measured including some undersized fish that were not part of the catch-at-age analysis. The targeted sample sizes were 2000 fish measured for length with a subsample of 500 otolith pairs from fish over the minimum legal size of 75 cm. The kingfish sample from the Northland/Hauraki Gulf region achieved 1183 length measurements and 271 otolith pairs, while in the Bay of Plenty/East Cape region, 1039 fish were measured and 213 otolith pairs collected. Overall, 32% of measured kingfish were retained and the rest released.

Thin section otolith preparations were viewed under transmitted light using the protocols established in 2009–10. For combined region otolith samples, overall reader agreement was 61%, with between-reader CV and IAPE precision estimates 4.34% and 3.07% respectively, while those between each reader and the final agreed age were less than 3%.

East Northland/Hauraki Gulf catches were largely dominated by young kingfish from the 2011 to 2008 year classes (4- to 7-year-olds), the 2010 year class (5-year-olds) singularly the most dominant, accounting for more than one-third of the total catch by number. The catch from the Bay of Plenty/East Cape region comprised a slightly broader age composition, with the 2009 year class (6-year-olds) being the most dominant and making up about one-quarter of the total catch by number.

A 29 year old, 134 cm kingfish was caught at the King Bank and a 28 year old, 130 cm fish weighing 29 kg was caught at Ranfurly Bank. These are new maximum age estimates recorded for this species in New Zealand and possibly worldwide.

Spatial differences in age composition were evident between inshore and offshore samples in each region, with fish older than 15 years poorly represented in inshore areas compared to banks, pinnacles and islands fished offshore outside the 200 m depth contour.

Some variability in the relative year class strengths inferred from catch-at-age estimates was evident for the KIN 1 regions in 2014–15, and most likely reflects between-region differences in recruitment and fishing mortality, as well as sampling error. Although not presented for the KIN 1 stock as a whole, mean weighted coefficients of variation for the age compositions of the regions sampled are likely to be acceptable and ranged between 0.21 (Northland/Hauraki Gulf) and 0.30 (Bay of Plenty/East Cape) meeting the target MWCV of 30%.

Chapman and Robson total mortality estimates (Z) were derived assuming age at full recruitment of six years old. Inshore areas in both regions produced markedly lower Z estimates in 2014–15 than in 2009–10. Mortality estimates based on inshore and offshore areas differed. Although movement has been recorded between inshore and offshore areas through tag-recapture studies, the relationship between these areas is unquantified. The Northern Inshore Working Group felt there was no valid approach for combining

inshore and offshore age compositions within a region for the purpose of estimating regional total mortality (Z), recommending instead that for management purposes the total mortality estimates derived offshore age frequencies were most appropriate.

Equilibrium fishing mortalities were derived from a spawner-biomass-per-recruit analysis using growth estimates for female kingfish, natural mortality of 0.2, and age at maturity of 6 years old. A revised estimate of the $F_{\%40SSB/R}$ reference target for kingfish is 0.13 as derived using the recent Bay of Plenty female von Bertalanffy growth parameters. The total mortality corresponding to 40% SSB/R for females equates approximately to 0.33. None of the 2014–15 derived Z estimates are higher than that for the Bay of Plenty/East Cape offshore and Northland/Hauraki Gulf offshore areas, suggesting that overfishing of kingfish in these areas was unlikely.

Options for future monitoring of this high value fishery include a repeat of a catch-at-age project with an emphasis on offshore areas. Amateur Charter Vessel logbook data for monitoring kingfish catch, and eventual CPUE analysis, would be improved if the number of undersize and legal fish release was recorded separately. Total catch in weight is not well recorded in logbook data and having a periodic sample of length distribution of the recreational catch will be required.

1. INTRODUCTION

1.1 Overview

Kingfish have been recorded from latitude 29° to 46° S (Kermadec Islands to Foveaux Strait), but are predominantly found around the North Island, and also at the top of the South Island in summer. Juveniles are often associated with rafts of floating debris or seaweed. Adult kingfish are large predatory fish that can exceed one and a half metres in length. They usually occur in schools ranging from a few fish to well over one hundred individuals. Adult kingfish tend to occupy a semi-pelagic existence and occur mainly in open coastal waters, preferring areas adjacent to rocky outcrops, reefs and pinnacles, particularly around offshore islands. However, kingfish are not restricted to these habitats and are sometimes caught or observed in open sandy bottom areas and within shallow enclosed bays and harbours.

The biology and fisheries for kingfish in New Zealand have been summarised by Walsh et al. (2003). Kingfish stock structure was investigated and fin ray counts were found to be different between west coast fish and northeast coast fish, while one parasite marker showed a difference between Hawke Bay and the northeast coast (Smith et al. 2004). The study concluded that there were separate stocks contained within the Tasman current on the west coast and the east Auckland current and East Cape current on the east coast, with little mixing between them. Further work was conducted on age, growth, maturity and natural mortality (McKenzie et al. 2005). Biological parameters are summarised in the kingfish plenary report (Ministry for Primary Industries 2016). Stock monitoring options were reviewed and catch sampling mainly from the recreational charter boat target fishery was selected as more likely to reflect the underlying stock than commercial set net or trawl data (McKenzie et al. 2014).

Age structure provides a tool with which exploitation rate can be measured, allowing for both temporal and spatial comparisons. Monitoring age structure also provides a means to better evaluate the response of a population to changes in regulations. Spawning Stock Biomass per-recruit (SSB/R) analysis suggests that total mortality rates (Z) in the order of 0.3 are likely to produce the maximum sustainable yield for kingfish (Holdsworth et al. 2013).

During the 2009–10 fishing year the age composition of the KIN 1 target recreational charter boat fleet catch was sampled for the purpose of estimating total mortality (Z). Sampling was conducted according to two spatial strata: East Northland/Hauraki Gulf and Bay of Plenty (Holdsworth et al. 2013). With the exception of samples obtained from the White Island in the Bay of Plenty, sampling occurred in coastal areas or islands inside the 100 m depth contour. As offshore White Island samples had proportionally more fish in older age classes than the onshore Bay of Plenty samples, the White Island total mortality (Z) estimate, as derived from catch-curve analysis, was lower than that derived using the onshore data (Holdsworth et al. 2013). Neither the Bay of Plenty onshore nor offshore Z estimates were indicative of high exploitation as determined by SSB/R. The Northern Inshore Working Group (NINSWG) felt that because of the lack of offshore sampling in East Northland, older kingfish were unlikely to have been well represented and therefore the likely level of exploitation of East Northland kingfish could not be determined.

This report presents results from investigations undertaken pursuant to Ministry contract KIN2014/01 to again sample the KIN 1 target charter boat fishery for the purpose of estimating total mortality (Z). Sampling during the 2014–15 fishing year was again based on regional strata (Northland/Hauraki Gulf and Bay of Plenty/East Cape), but this time care was taken to sample both inshore and offshore areas.

The contracted research study had two objectives:

1. To characterise the fisheries in order to inform and review the sampling design.

2. To conduct representative sampling to determine the length, sex, and age composition of the recreational charter boat landings of kingfish in KIN 1 for the 2014–15 fishing year to monitor the

KIN 1 stock. The target coefficient of variation (CV) for the catch-at-age will be 30% (mean weighted CV across all age classes).

Objective 2 had three specific analytical sub-components:

- Estimate the age structure of the KIN 1 population/s;
- Estimate total fishing mortality (Z) using a suitable catch curve approach allowing for uncertainty in key parameters (i.e. age at full recruitment and sample selectivity issues);
- Provide an estimate of F_{MSY} based on spawner biomass per recruit analyses (e.g. $F_{40\%SBR}$).

This project contributes to the overall objective 'to monitor the status of kingfish (*Seriola lalandi*) stocks in KIN 1.

1.2 Description of the fishery

Recreational fishery

Yellowtail kingfish (*Seriola lalandi*) is New Zealand's premier small gamefish species. New Zealand has a reputation for the largest yellowtail kingfish in the world, and 21 of 22 world records are held by New Zealand anglers (the woman's 1 kg line class record was caught in Australia) (IGFA 2016). The all-tackle record is shared by two Bay of Plenty anglers who caught 52 kg specimens in 1984 and 1987. In New Zealand, and in this report, this species is mainly referred to as kingfish. Small kingfish are occasionally caught when targeting snapper or kahawai by inshore recreational fishers. Larger specimens are targeted by fishers on charter boats and by an increasing number of private fishers with specialist fishing gear or by spearfishermen.

The National Panel Survey in 2011–12 provides the most recent amateur harvest estimates for kingfish in KIN 1 and nationwide (Wynne-Jones et al. 2014). The number of fish harvested is less than estimated in previous surveys (1991 to 1996 Telephone Diary Surveys) but the average size is larger (Bradford 1998). In part this is due to an increase in the minimum legal size (MLS) from 65 cm to 75 cm for recreational fishers in 2004. The bag limit for kingfish is 3 per angler per day. The mean weights for kingfish were calculated from 1263 fish measured at boat ramps in 2011–12 (Hartill & Davey 2015). The National Panel Survey (NPS) estimates that 80% of the national harvest estimate of 660 t came from KIN 1 (Table 1). Kingfish is the third largest New Zealand recreational fishery by harvest weight, behind snapper and kahawai. Rod and line was the predominant method and about 90% of catch was caught from trailer boats and launches (Wynne-Jones et al. 2014). This is a year-round fishery with a peak in summer months and low catch over winter (Figure 1).

Table 1: Amateur harvest estimates of yellowtail kingfish by QMA from the National Panel Survey.

QMA.KIN	Fishers (n)	Events (n)	Harvest (n)	CV	Mean weight (kg)	Harvest (t)	CV
1	219	324	52056	0.13	10.28	535.30	0.13
2	28	35	4025	0.24	10.09	40.60	0.24
3	2	2	289	0.71	9.97	2.89	0.71
7	12	17	2079	0.38	9.97	20.73	0.38
8	35	46	6252	0.25	10.01	62.60	0.25
Total	296	424	64700	0.11	10.23	662.12	0.11

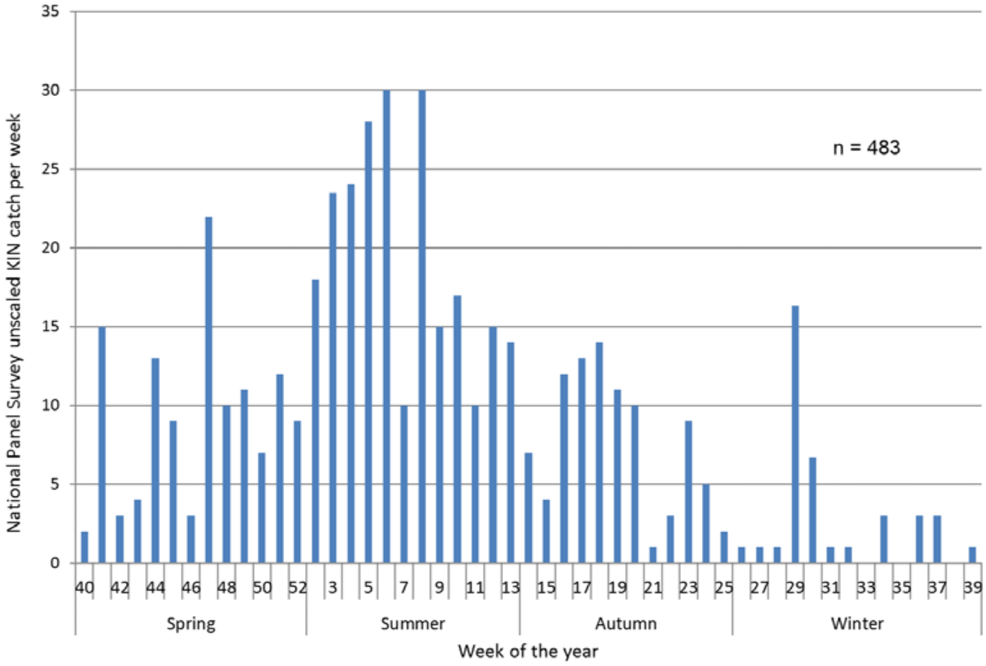

Figure 1: Kingfish caught per week recorded in the National Panel Survey 2011–12 fishing year.

The Ministry for Primary Industries (MPI) instigated a compulsory charter boat logbook scheme in 2010 which requires activity reports and records of catch for selected species. Over 300 vessels were registered and started reporting activity, including fishing effort, during the 2010–11 fishing year (October to September). The kingfish catch has been reported as the total number caught, including undersized fish, and the number retained since October 2011 for charter trips in KIN 1 and KIN 2. The seasonality of the total catch for 2014–15 in all areas shows relatively consistent numbers per week from mid-spring to mid-autumn and low catch during winter (Figure 2). Just 18% of the catch is retained as many charter boats have a limit of 1 kingfish retained per angler and in some areas a voluntary minimum size of 100 cm.

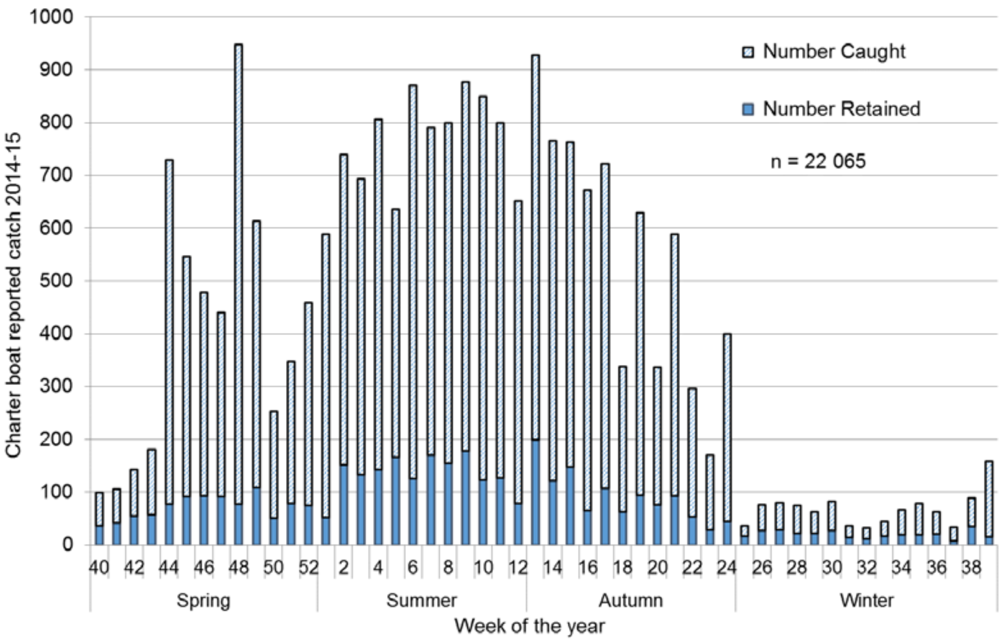

Figure 2: Kingfish caught per week recorded by amateur charter vessels from KIN 1 2014–15 fishing year.

Fishing clubs affiliated to the New Zealand Sport Fishing Council keep records of the fish presented at their weigh stations. They recorded 835 kingfish landed in 2013–14 and a further 274 tagged and released. Not all tag data is processed through clubs and the New Zealand Gamefish Tagging Programme recorded details on 500 kingfish tagged and released that year, with over 90% of these measured on release. While not providing a complete record of catch, these records may be used to identify the size distribution of recreational catch by area (Figure 3). Northland/Hauraki Gulf inshore areas have a higher proportion of small fish and the two offshore areas have the same mode (106 to 109 cm).

Kingfish catches reported in sport fishing club records show seasonal peaks in different geographic locations that reflect in part the availability of other, larger species. Thus, in Northland/Hauraki Gulf the peak season tends to be autumn, when the migratory species have largely deserted coastal waters. In Cook Strait, kingfish are encountered mainly in summer. From East Cape to Hawke Bay, most fishing also occurs in summer (McKenzie et al. 2014).

The recreational allowance in KIN 1 is 459 t and is significantly higher than in other fishery management areas (Table 2).

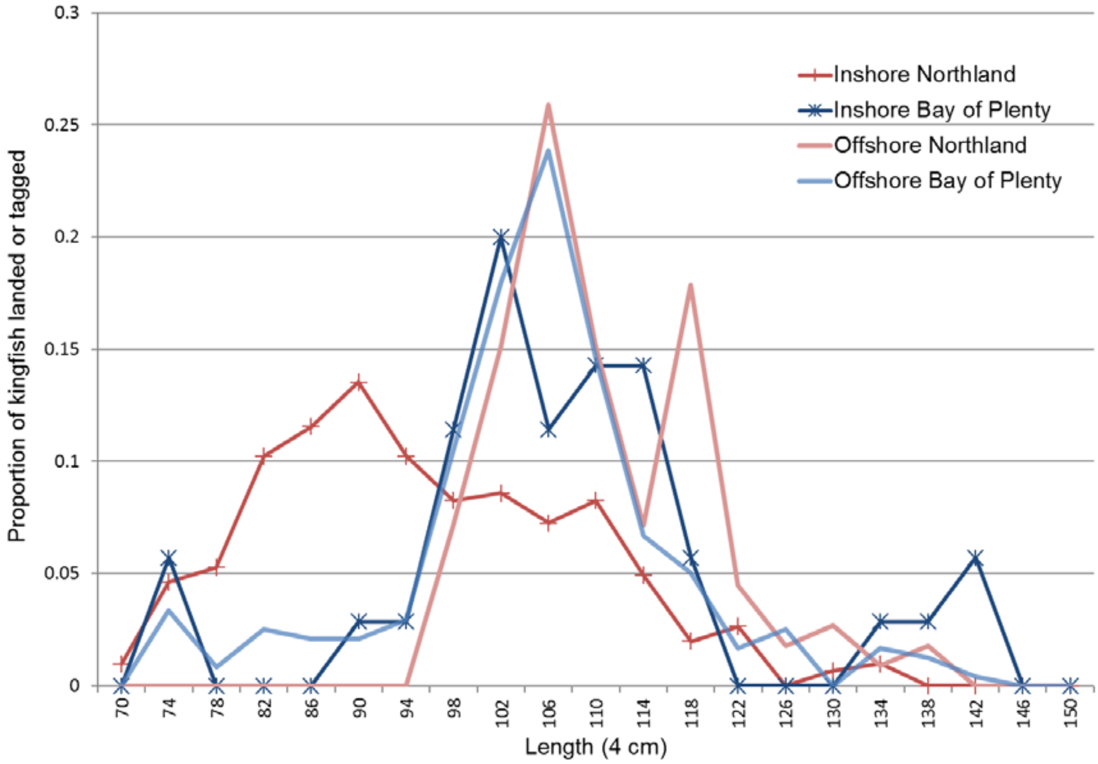

Figure 3: Kingfish proportion by length from club and tagging data for 2013–14 in Northland/Hauraki Gulf and Bay of Plenty/East Cape regions.

Customary fishery

Kingfish is an important traditional food for Mäori, but no quantitative information about customary catch is currently available. The extent of the traditional fisheries for kingfish is described in the Muriwhenua Fishing Report. Given the coastal distribution of the species and its inclination to strike lures, it is likely that Mäori caught considerable numbers.

Regulations provide for Tangata tiaki/kaitiaki (once appointed) to report customary catch that they have authorised. Tangata tiaki/kaitiaki appointments currently cover only parts of the fishery and therefore traditional customary harvest authorised by them, while recorded, will be incomplete for the fishery as a whole. The customary allowance in KIN 1 is 76 t (Table 2).

Commercial fishery

Commercial landings of kingfish are reported largely as bycatch of inshore set net, trawl and bottom longline fisheries. From 1991 to late 2003 targeting of kingfish (at the time a non-QMS species) was prohibited unless the species was authorised on a fisher's permit. A few permit holders were authorised to target kingfish, and most of their catch was taken using set nets. A MLS of 65 cm has been in place since October 1993 for all methods except trawl. The trawl exemption with respect to MLS was removed in December 2000.

The main commercial fishing areas for kingfish are the east coast (QMAs 1 and 2) and west coast (QMA 8) of the North Island. The largest commercial catches generally come from QMA 1. Reported commercial catch in KIN 1 peaked at 378 t in 1992–93 and declined steadily to 49 t in 2003–04 and has increased to 100 t since then. Kingfish were introduced into the quota management system in 2003 and the Total Allowable Commercial Catch (TACC) in KIN 1 is 91 t (Table 2).

Table 2: Recreational and customary non-commercial allowances, TACCs and TACs by fishstock and the boundaries of QMAs (Ministry for Primary Industries 2016).

Fishstock	Recreational allowance	Customary non-commercial allowance	Other sources of fishing related mortality	TACC	TAC
KIN 1	459	76	47	91	673
KIN 2	65	18	24	63	170
KIN 3	1	1	0	1	3
KIN 4	1	1	0	1	3
KIN 7	10	2	2	7	21
KIN 8	31	9	7	45	92
KIN 10	1	0	0	1	2

1.3 Movement of tagged fish

Around 22 000 kingfish have been tagged and released in the New Zealand gamefish tagging programme since 1975, with more than 1460 recaptures made (Holdsworth et al. 2016). Most of these fish have been tagged off the north and east coasts of the North Island. While yellowtail kingfish are capable of extensive movements (five trans-Tasman trips have been recorded), more than 80% of recaptures are made in the same MPI fisheries statistical area as release. Releases and recaptures can be summarised by General Statistical Area on the north and east coasts (Table 3). There is limited movement between Northland and the Bay of Plenty. The most movement out of the statistical area of release is recorded from Statistical Areas 003 (Cavalli Island to Bream Tail) and 010 (Whakatane to Cape Runaway, including White Island); which have the highest number of fish tagged. The highest proportion of kingfish recaptured in different statistical areas come from area 008 (32%), and area 012 and 013 which have low sample sizes (Table 3).

The displacement distance of tagged fish is the shortest possible distance by sea between the release and recapture locations. Some tagged kingfish move long distances, but 94% of recaptures of fish at liberty for more than 30 days were within 100 nautical miles of the release point. Kingfish from the West Coast North Island and East Cape to Hawke Bay have the highest median displacement distance (Figure 4). Kingfish tagged from the Three Kings Islands and White Island show a degree of residency, even after extended periods. The median displacement distances for the rest of East Northland and Bay of Plenty are 4 n. miles and 7 n. miles respectively (Figure 4).

While only 6.5% of kingfish tagged at White Island have displacement distances more than 10 n. miles, individual fish have been recaptured from Northland to the Mernoo Bank; and Ranfurly Bank fish have been recaptured on the west Coast of the North Island and in the South Island (Figure 5). More kingfish tagged inshore in the Bay of Plenty move more than 10 n. miles (46% from 009 and 55% from 010), with only two of the 67 fish recaptured at White Island (Figure 6).

Table 3: Release and recapture statistical areas for kingfish at liberty for more than 30 days from Northland and Hauraki Gulf areas (areas 002–007, 047–048 pink) and Bay of Plenty areas (areas 008–011 blue).

		Recapture statistical area														
		048	047	002	003	005	006	007	008	009	010	011	012	013	014	Total
Release statistical area	048	29	1													30
	047	1	28													29
	002			58	12		2									72
	003	1	1	12	108	4	2	3	2	2					1	136
	005				1	5		1								7
	006				1	1	2									4
	007				1		2	13								16
	008			1	1	1			23	5	2			1		34
	009				2		1		4	70	17			1		95
	010			1	4	2			4	19	470	4	1	3	3	511
	011									2	1	24	1	2		30
	012	1							1	1	2	5	10	6	4	30
	013				1						1			5	3	10
	014													1	1	2
	Total	32	30	72	131	13	9	17	34	99	493	33	12	19	12	1006

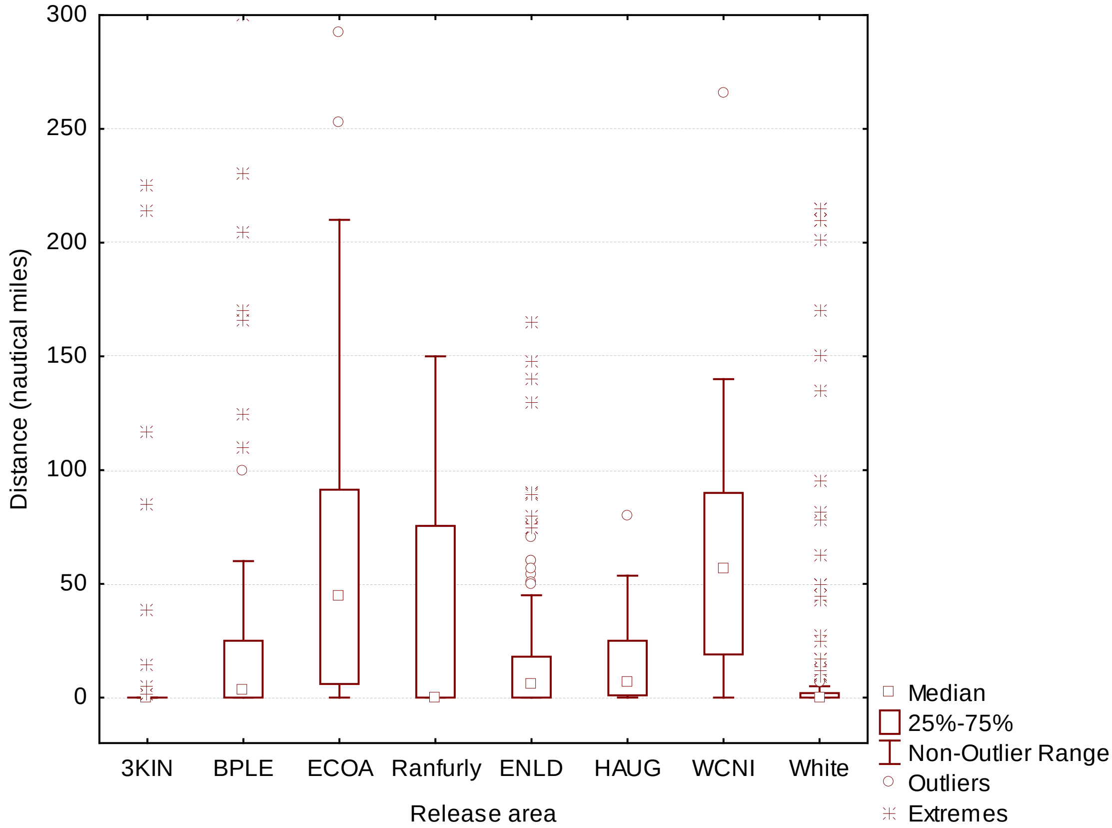

Figure 4: Kingfish displacement distance for recaptured fish more than 30 days at liberty by area tagged (Three Kings, Bay of Plenty, East Coast, Ranfurly Bank, East Northland, Hauraki Gulf, West Coast North Island and White Island).

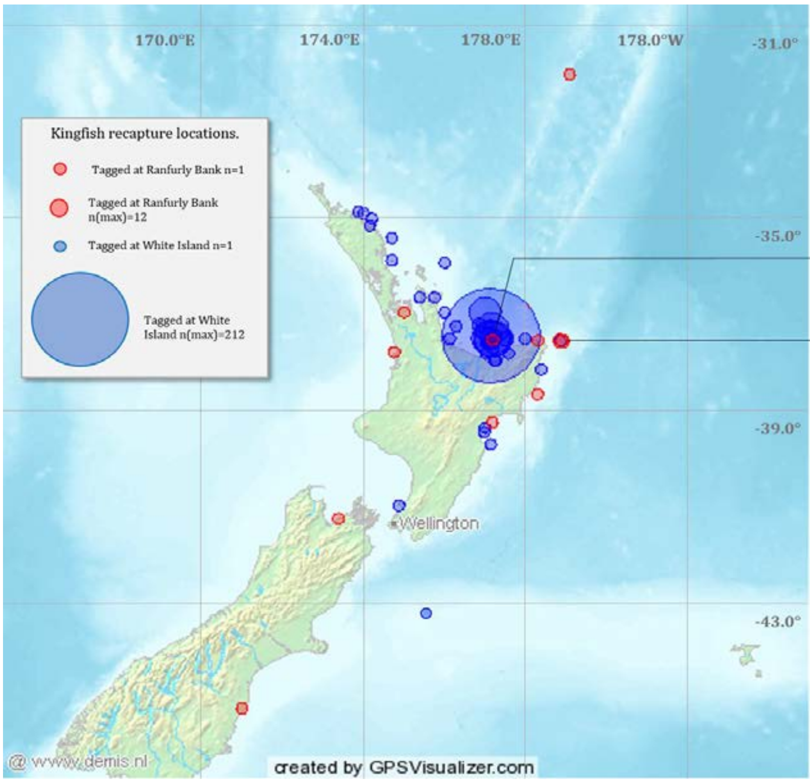

Figure 5: Recapture locations of kingfish tagged at White Island between 1983 and 2014 (n = 577 blue) and Ranfurly Bank between 1991 and 2014 (n = 35 red).

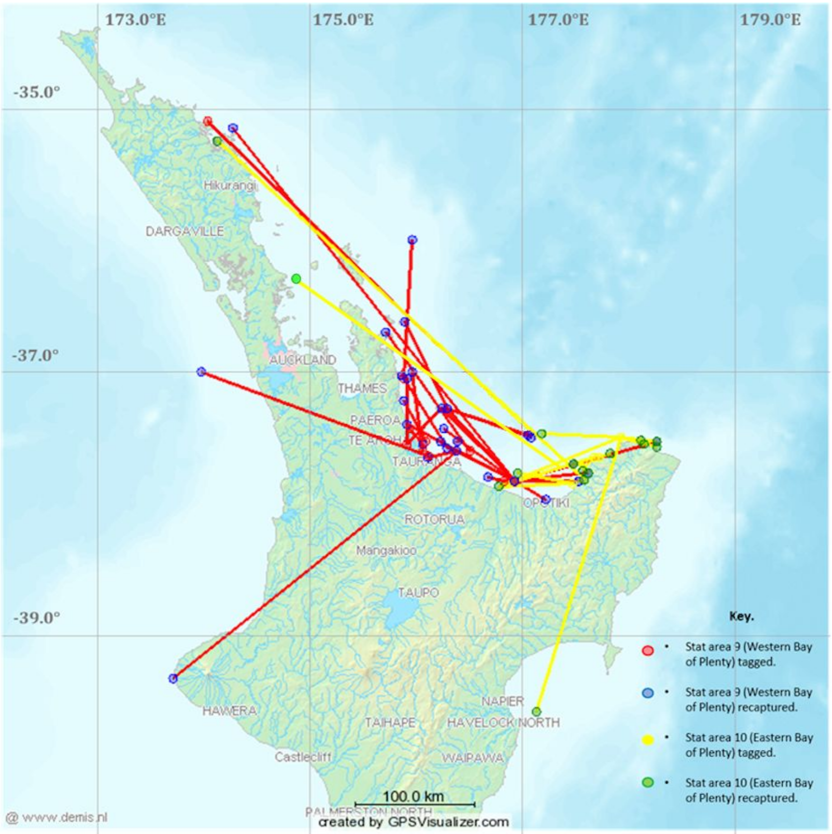

Figure 6: Release and recapture locations of kingfish tagged at inshore areas of Statistical Area 009 (n = 47 red lines) and Statistical Area 010 (n = 30 yellow lines).

1.4 Sexual dimorphism

Stratified sampling of yellowtail kingfish landed by commercial fishers in New South Wales (Australia) was conducted between 1998 and August 2000 (Stewart et al. 2004). The coast of NSW (latitude 29° S to 37.3° S) was divided into three regions. Forty seven tonnes of kingfish, representing 16% of total landings, were measured during the study. The results showed that the fishery was dominated by fish smaller than 65 cm fork length. Estimates of kingfish ages were made by counting annual marks in otoliths. Estimated ages ranged up to 21 years, however the fishery was dominated by 2 and 3 year old fish. There were no differences in the growth rates of kingfish from the three regions along the NSW coast, from Lord Howe Island, or between males and females (Stewart et al. 2004).

Thompson et al. (1999) found no differences in the growth rates of males and females for the closely related *Seriola dumerili* from the Gulf of Mexico, but did report sex related differences in their maximum sizes. Males were rarely found to be older than 7 years, whereas females were found up to 15 years. This is hypothesized to be the result of age related differential mortality, with males dying at younger ages than females. No evidence of this was found in the Australian study, but the authors caution that few large fish were sampled (Stewart et al. 2004).

McKenzie et al. (2005) provide von Bertalanffy growth curves for male and female kingfish from the Bay of Plenty which suggest that female kingfish grow to a larger average size than males, although this could not be statistically ratified using a Kimura (1980) likelihood ratio test.

1.5 Stock monitoring

An MPI project (KIN2004/01) investigated the feasibility of establishing a stock monitoring project for kingfish. Some of the conclusions of the report (McKenzie et al. 2014) were that:

- Implementation of a 3–5 year charter boat based monitoring programme would be highly feasible in KIN 1;
- A method that catches a wide range of adult kingfish age classes is preferable for stock monitoring purposes;
- The simulations indicate that MWCV scores of 0.2 could be achieved from age collections of between 400 and 450 otoliths and length samples of between 150 and 200 trips.

A catch-at-age project (KIN2009/01) was run in 2009–10 to determine the length, sex, and age composition of the recreational charter boat catch of kingfish in KIN 1 (Holdsworth et al. 2013). The target sample size was 500 otoliths and 2000 lengths, which were split evenly between East Northland/Hauraki Gulf and Bay of Plenty. Data were collected from late January 2010 to November 2010. Age length keys for the two areas were used to convert fish lengths to ages. The results included:

- The East Northland sample was dominated by young fish less than 8 years old, with few fish older than 12 years;
- Spatial differences in age composition were evident within the Bay of Plenty samples; with fish older than 15 years poorly represented in inshore areas when compared to the offshore location of White Island. The age structure of the Bay of Plenty inshore samples was nevertheless broader than those from East Northland;
- Assuming full recruitment as 5 year olds in East Northland the total mortality estimate was 0.77 and assuming 5 or 6 years in the Bay of Plenty produces a total mortality estimate of 0.34–0.42.
- The conclusion was that the Bay of Plenty stock is about fully utilised while East Northland inshore area was affected by mortality and emigration;
- However, there may be explanations, other than fishing mortality, for the lack of older fish in the East Northland sample.

2. METHODS

2.1 Sampling Design

An age-length key approach (Davies et al. 2003) was used to derive age composition estimates for the Northland/Hauraki Gulf and Bay of Plenty/East Cape regions. All length samples came entirely from recreational catches on rod and reel, pursuant to a spatially stratified sampling design. As it was not essential that otolith samples used to derive the age-length keys came solely from the recreational fishery, shortfalls in some length classes were supplemented with a few commercially caught fish. All kept kingfish sampled for age data were sexed. It was not possible to sex all fish sampled for length, as many were released. Thus the otolith key was also used to key out the sample sex ratios by length and age (i.e. as an age-length-sex key) pursuant to the assumption that sex, as well as age (within a given area) were randomly distributed relative to length.

The sampling design was intended to spread sampling effort across the Northland/Hauraki Gulf and Bay of Plenty/East Cape regions (Figure 7). Following the recommendations from the 2009–10 catch-at-age survey two additional offshore areas were added to the survey area. The Three Kings Islands and King Bank areas (KIN 8) and Ranfurly Bank (KIN 2) are outside the KIN 1 quota management area but are important offshore areas accessed by the same charter fleet involved in this fishery. Available evidence from meristic and parasite markers indicate that the Three Kings Islands area, East Northland, Bay of Plenty and Ranfurly Bank are likely to be part of a single stock contained within the East Auckland current and East Cape current (Smith et al. 2004).

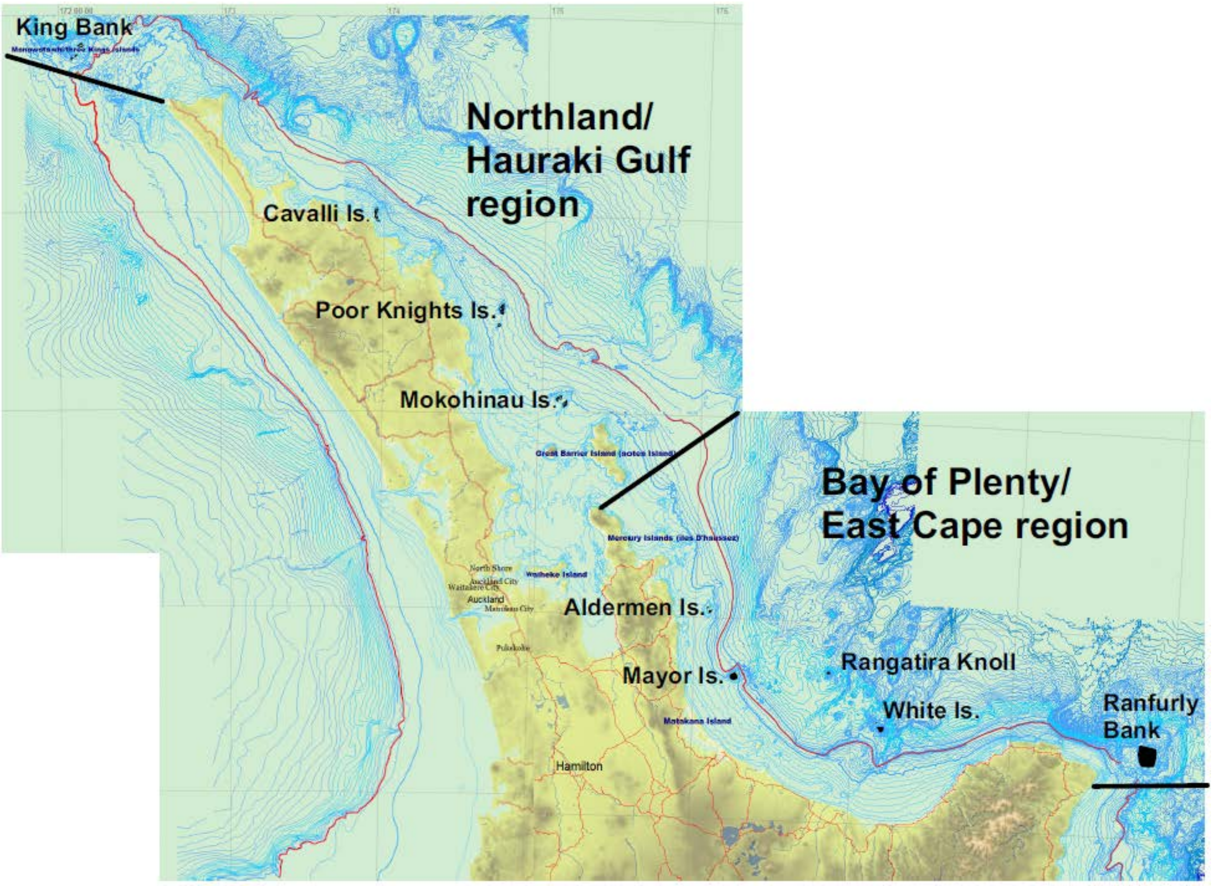

Figure 7: The boundaries of the two regions used in this survey which include offshore areas of the Three Kings Islands and King Bank in the north and Ranfurly Bank in the south. Offshore areas are outside the continental shelf (200 m depth contour, red line) of the North Island.

Existing data sources were used to characterise the recreational kingfish fishery and to investigate its spatial and temporal character. These included:

- The results of the previous catch-at-age study in 2009–10 (Holdsworth et al. 2013).
- The New Zealand Gamefish Tagging Programme kingfish tag and release (n = 22 000) and recapture data (n = 1460) since 1975 (Table 3).
- New Zealand Sport Fishing Council landed catch records with individual weights, dates and locations from club records since 1999.
- Detailed records and overall results of kingfish kept by amateur fishers was provided by MPI from the National Panel Survey conducted in 2011–12 (Table 1, Figure 1).
- Kingfish catch by event from Amateur Charter Vessel (ACV) logbook records where kingfish were targeted or caught was provided by MPI, initially from 2010–11 to 2013–14 and subsequently for the 2014–15 fishing year (Figure 2).

There are difficulties in determining the appropriate distribution of sampling effort because the population distribution of kingfish is not known. To provide a fishery dependent indication of kingfish distribution catch records from recreational fisheries were summarised by statistical areas (Table 4).

Table 4: Proportion of recreational catch by area from existing data sources and the proposed proportion of length data to be collected in the 2014–15 kingfish monitoring project. Note the NZSFC club rules favour fish larger than 100 cm. The 2009–10 project recorded all fish larger than 75 cm but fish from the Three kings and Ranfurly Bank were not sampled. Amateur Charter Vessel data is for all kingfish caught above and below 75 cm from trips targeting kingfish.

	NZSFC club data 1999–2009	Kingfish monitoring project lengths 2009–10	NZSFC club data 2013–14	ACV logbooks 2013–14	Proposed sample size kingfish monitoring project 2014–15
MPI statistical area			Proportion of catch by area		
3 Kings in 047 & 048	0.18	not included	0.17	0.26	0.15
002 East Northland	0.08	0.15	0.07	0.06	0.10
003 East Northland	0.24	0.38	0.35	0.17	0.20
005, 006, & 007 Hauraki Gulf	0.02	0.04	0.03	0.03	0.05
008 Bay of Plenty	0.06	0.20	0.00	0.10	0.10
009 Bay of Plenty	0.12	0.05	0.05	0.02	0.05
010 Bay of Plenty	0.23	0.18	0.23	0.16	0.20
Ranfurly Bank in 011	0.08	not included	0.11	0.21	0.15
Sample size	8 397	2 102	689	12 948	2 000

The key elements of sampling design presented to and approved by the NINSWG in November 2014 (NINSWG-2014/41) were:

- The two areas to be sampled: Bay of Plenty and East Cape combined, with targets of 1000 length measurements (greater than 75 cm) and 250 otolith sets; and Northland and Hauraki Gulf combined with targets of 1000 length measurements (greater than 75 cm) and 250 otolith sets;
- Fishers to be asked to measure fish smaller than 75 cm but these not to be included in the length measurement targets;
- Vessel trip to be the sampling unit. These will be spread across the main statistical areas;
- Sampling to start in mid-October in order to include the spring fishery in the Bay of Plenty;
- Avid kingfish fishers will be recruited to measure all their kingfish catch and to retain heads;
- Fishers who provided good data in 2009–10 to be encouraged to participate.

- A $10 handling fee to be paid to fishers for collection and holding of each frozen kingfish head until collection.
- A large proportion of kingfish are caught and released so sampling at sea to be required;
- The well-established practice of measuring kingfish prior to tag and release was encouraged;
- Sampling kits to be provided and fishers to be trained to measure to the nearest millimetre to encourage accurate measurements.
- Trained observers to assist in training and sample collection at sea. The use of observers helps to spread sampling effort, reduce burden on charter skippers and ensure data quality.
- Observers also to coordinate head sample collection and remove and label some otoliths.

Charter boat operators and avid private fishers were initially recruited using telephone and email. This was followed with a one-on-one meeting for each fisher who indicated a keen interest in the programme. During this meeting, fishers were introduced to the project objectives and the requirements of their time and effort to produce successful data. A detailed training session was provided to each fisher on the required methods of measuring and sexing kingfish, and how to remove and freezer store the heads of retained kingfish. Specifically, fishers were asked:

1. To record the date, general locality of capture, fishing method and fish length of each kingfish encountered for the duration of the programme.
2. To accurately measure all landed kingfish using the measuring board provided, including length measurements of all kingfish that are released back to the sea.
3. For each retained kingfish - to assess and record the sex, to remove and label the head using the waterproof head-tags provided in the sampling kit, and to freeze and store the kingfish head until collection by Blue Water Marine Research staff.

Fishers were regularly contacted by telephone, email, in person and through a monthly newsletter service. This enabled any questions or problems with the programme to be readily identified and resolved; regular communication maintained higher levels of fisher interest in the programme; and it also allowed for frozen kingfish heads to be regularly retrieved from frozen storage.

Kingfish heads were collected from fishers via either direct pick-up by Blue Water Marine Research staff or courier delivery service. Kingfish heads were slowly defrosted at ambient temperature prior to removal of otoliths. Data listed on each head-tag was double checked with the associated length/gender data sheet retrieved from the fisher.

For otolith removal, each kingfish head was mounted on a spike protruding from a timber board. A sharpened knife was driven along the top of the skull using a rubber mallet to expose the brain cavity. Two sagittae otoliths were gently extracted from the semicircular canals beneath the brain using dissection forceps. Otoliths were rinsed in freshwater and dried to remove associated tissue and placed in plastic vials stored in labelled envelopes. The completed collection was sent to NIWA Wellington for preparation and reading. A small portion of otoliths from juvenile fish (12–50 cm) collected from East Northland in the mid-1990s were included with the sample.

2.2 Otolith preparation and ageing of kingfish

Kingfish otolith preparation and ageing, using the thin section technique, generally followed that described by McKenzie et al. (2014). With an aim of improving reader accuracy and increasing between-reader agreement from the previous catch-at-age study in 2009–10 (Holdsworth et al. 2013), a similar rigorous approach was implemented in the current study, the focus being on three main facets: the interpretation and location of what was thought to be the first annulus; forcing an expected margin on the reader relative to the otolith collection date; and allowing both readers access to otolith images of varying readability from previous collections.

Opaque zones, which appear dark in thin section preparations under transmitted light, were counted from the core to the otolith proximal edge, the primary axis being the dorsal sulcus region, as the ventral sulcus was often unclear. The formation of an opaque zone signified that one fully deposited opaque and translucent zone had been previously laid down, indicative of a full year of growth. An opaque zone was usually fully formed on the otolith edge around December, but this varied with age, indicating that the translucent zone had probably been completed 2–3 months earlier.

Otoliths were read by two readers without prior knowledge of the other's zone count or of the fish length. For otoliths where both readers agreed on the zone count, the age was determined from this count. When readers disagreed, then the otolith was reviewed again with a third experienced reader present to determine the likely source of error and the agreed count, or discarded from the set as unreadable. It was envisaged that discarding a random uninterpretable otolith from the age-length key should have minimal effect on the sample collections and is likely to improve the precision in estimates of catch-at-age. The forced margin method was implemented *a priori* to determine the margin type (wide, line, narrow) based on the month in which the fish was sampled, and considered essential for maintaining accuracy of age estimation in year-round sampling. To determine the age of a fish using the forced margin for the fishing year in which the sample collection took place, 'wide' readings were increased by 1 year and 'line' and 'narrow' readings remain the same as the zone count. Age was defined as the rounded whole year from a nominal birth date of 1 January.

A readability scale ranked 1–5 was used for ageing kingfish otoliths. However, the scale is not mandatory or used in any manner to determine which otoliths are used in the final age selection for catch-at-age analysis, other than those ranked 5 (unreadable) which are already removed from the collection.

Other techniques used by Holdsworth et al. (2013) were also utilised and included the use of a dorso-sulcal distance range (310–380 μm) from the core to first opaque zone to identify the location of the first annulus, as well as comparing the size of otoliths from juvenile kingfish (thought to be 0+ in age) collected from fish aggregation devices (FADs) between February and August 2002. The first opaque zone is generally unclear in adult kingfish thin sections, and unlike the second zone, was found to be problematic in previous kingfish ageing (McKenzie et al. 2014). Dimpling on the distal otolith surface and sulcul groove also provided useful checks for what was thought to be the first annulus and subsequent annual zone deposition.

Otolith reading precision was quantified by carrying out between-reader comparison tests after Campana et al. (1995), including those between each reader and the agreed age. The Index of Average Percentage Error, IAPE (Beamish & Fournier 1981) and mean coefficient of variation (CV) (Chang 1982) were calculated for each test. Kingfish catch summary and age data are stored on the MPI databases administered by NIWA.

2.3 Catch-at-age estimation

Age-length-sex keys were applied to length-frequency observations collected pursuant to a spatial stratified sampling design to derive proportional age and length estimates by sex. Analyses were undertaken using NIWA Catch-at-length and age software in R. Mean-weighted coefficients of variation (MWCV) were estimated by sex and overall using a bootstrapping routine (1000 bootstraps).

2.4 Growth parameter estimates

A von Bertalanffy growth model was fitted to the length-age data, by sex, using the model:

$$L_t = L_\infty\,(1 - \exp^{-K[t\,-\,t0]})$$

Where L_t was the length (cm) at age t, L_∞ the asymptotic mean maximum length, K was a constant (growth rate coefficient), and t_0 was the hypothetical age (in years) that the fish has zero length. A Kimura (1980) likelihood-ratio was used to test for sex-related growth differences in the data.

2.5 Mortality estimates

Total mortality (Z) was estimated from catch-curve analysis using the Chapman-Robson estimator (CR, Chapman & Robson 1960). The CR method has been shown to be less biased than the simple regression catch curve analysis (Dunn et al. 2002). Catch curve analysis assumes that the catch of fully recruited age classes declines exponentially with age and that the slope is equivalent to equilibrium total mortality experienced by the population, the sum of natural and fishing mortality, Z = (M + F). Implicit in this analysis are the assumptions that recruitment and mortality are constant, that all fully recruited fish are equally vulnerable to capture, and that there are no age estimation errors.

3. RESULTS

3.1 Kingfish sample 2014–15

During this study a total of 2833 kingfish were measured. This included some undersized fish that provide new insight into the proportion of small kingfish at offshore locations but were not part of the catch-at-age analysis. In the Northland/Hauraki Gulf region, data was collected from 45 vessels and 199 trips recording lengths for 1183 kingfish 75 cm and greater and 271 otolith pairs were collected. In the Bay of Plenty/East Cape region data was collected from 27 vessels and 171 trips; 1039 kingfish 75 cm and greater were measured and 213 otolith pairs collected. Overall, 32% of measured kingfish were retained.

The proportion of lengths targeted by area and the proportion collected in this study are compared in Table 5.

Distribution across the MPI Statistical Areas was adequate. Many of the fish caught in the Hauraki Gulf were below the 75 cm length used as the minimum for the age-length key.

The number of length measurements and otoliths collected from the Bay of Plenty/East Cape region was below the target by the end of July 2015, particularly across the smaller size classes (i.e., 75 to 100 cm) and were therefore underrepresented in the sample. The survey period in this region was extended to September 2015 with targeted observer trips, continued sampling from charter boats and requests for samples from commercial landings.

Table 5: Target proportion of survey lengths, proportion of kingfish catch reported by Amateur Charter Vessels including fish above and below 75 cm from trips targeting kingfish and the actual sample sizes achieved in 2014–15 by area.

MPI Statistical Area	Proposed sample size kingfish monitoring project lengths 2014–15	ACV logbook catch 2014–15	Kingfish lengths collected in 2014–15
	Proportion of lengths or catch by statistical area		
3 Kings in 047 & 048	0.15	0.27	0.14
002 East Northland	0.10	0.04	0.08
003 East Northland	0.20	0.19	0.31
005, 006, & 007 Hauraki Gulf	0.05	0.02	0.01
008 Bay of Plenty	0.10	0.08	0.06
009 Bay of Plenty	0.05	0.01	0.02
010 Bay of Plenty	0.20	0.15	0.29
Ranfurly Bank in 011	0.15	0.24	0.09
Sample size	2 000	15 500	2 224

Table 6: The proportion of catch and mean length of survey kingfish by method and region.

				Method
Region	Lure or Jig	Natural bait	Speargun	Trawl
Northland/Hauraki Gulf				
Proportion	0.22	0.78	0.003	
Average Length	91.5	95.8	131.8	
SD	11.49	13.17	20.92	
Bay of Plenty/East Cape				
Proportion	0.31	0.68	0.003	0.01
Mean Length	91.5	98.6	121.5	83.9
SD	13.13	15.1	11.51	10.51

The majority of kingfish 75 cm and greater were caught on natural bait or jigs in both areas. The average length of fish caught on natural baits was larger than caught on jigs or lures, and obvious selectivity for large fish when using a speargun (Table 6). Fish sourced from commercial trawl catch in the Bay of Plenty and by spearfishers were used to supplement the age-length key but not the length distributions (Table 6).

Fishers were asked to measure kingfish nose to fork length to the nearest millimetre to encourage accurate measuring. Lengths were rounded down to the whole centimetre. The distribution of all lengths collected shows more sublegal kingfish and slightly more fish over 110 cm in the Bay of Plenty/East Cape region sample compared to the Northland/Hauraki Gulf region which comprised more kingfish in the mid-size range, 83 to 98 cm (Figure 8).

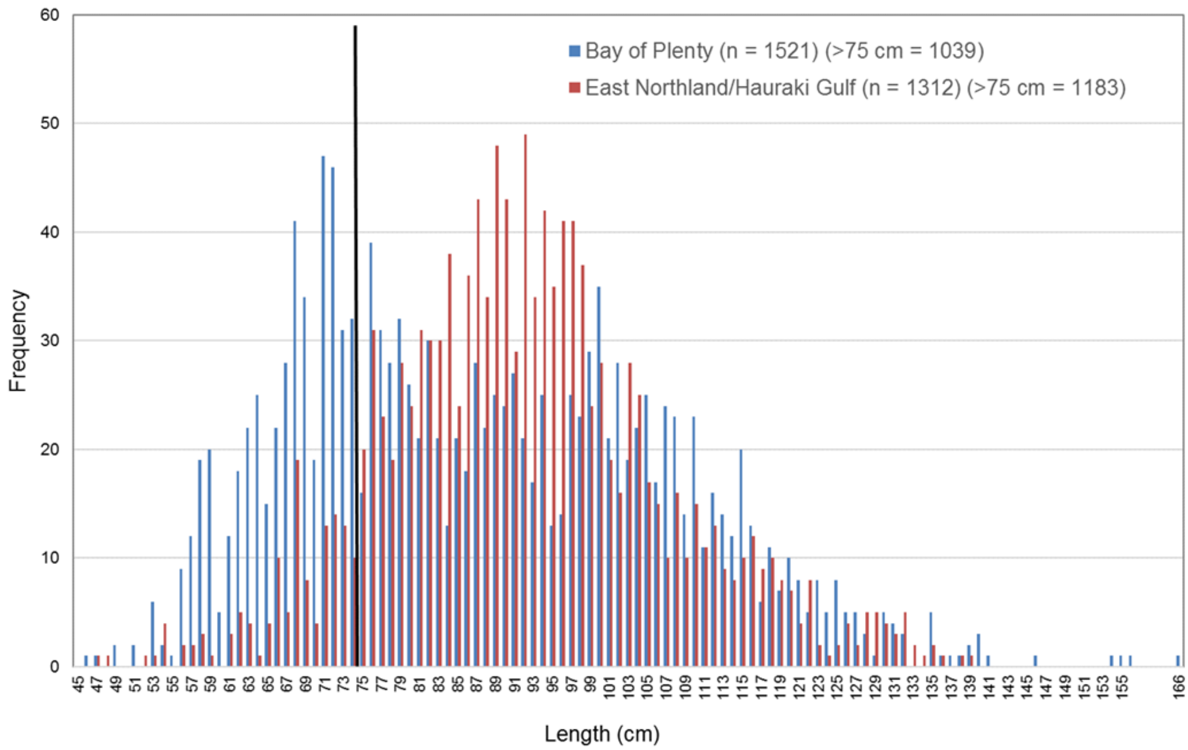

Figure 8: Kingfish survey length distribution by area in 2014–15, minimum legal size shown at 75 cm.

Otoliths were collected from a broad distribution of length classes in the Northland/Hauraki Gulf region, while some smaller length classes were not well represented in otolith samples from the Bay of Plenty/East Cape region (Figure 9). The target sample size was 10 otoliths per 2 cm size bin. While this cannot be achieved for larger fish in a survey of this scale, there were many more fish over 115 cm in Northland/Hauraki Gulf sample than in the 2009–10 survey.

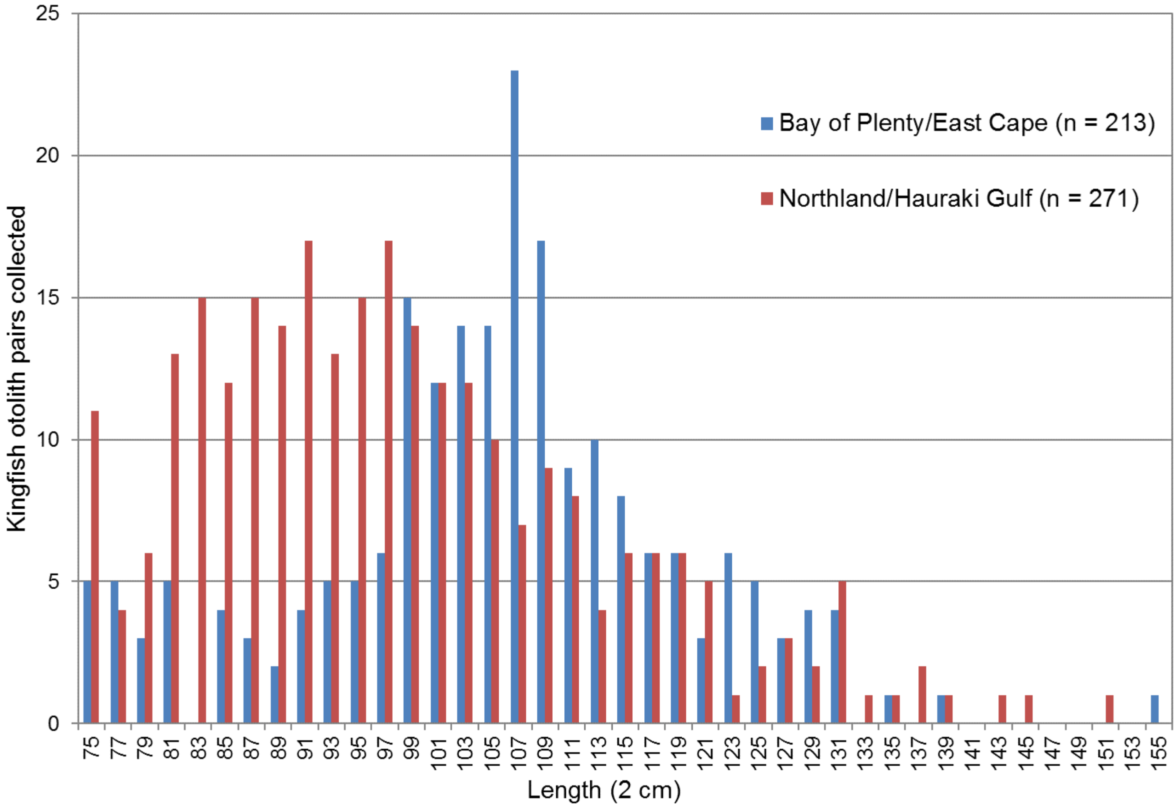

Figure 9: Number of otoliths collected by area in 2014–15.

3.2 Reader error in estimating ages of kingfish

Total sample sizes of 268 and 210 otoliths were successfully aged from the Northland and Bay of Plenty kingfish collections respectively in 2014–15, encompassing an overall combined length range of 69 to 156 cm, with representation in consecutive centimetre size classes 75–132 cm, which made up 98% of the total. Only four otoliths were unable to be aged from the East Northland collection and three from the Bay of Plenty.

Between-reader tests for Northland/Hauraki Gulf and Bay of Plenty/East Cape kingfish otolith collections combined, based on graphical comparisons, are given in Figure 10. They show a reasonable level of consistency exists between readers up to an age of about 15 years with an overall percentage agreement of 61%, although some systematic differences (bias) in first counts of kingfish otoliths between the readers does exist. The slight positive weighting of the histogram, the relative clustering of plotted points about the zero line, and the slight deviation from the one-to-one line on the age-bias plot indicate that reader 1 more often underestimated age compared to reader 2, particularly for older fish (Figure 10a-c). The between-reader CV and IAPE were 4.34% and 3.07% respectively (Figure 10c) and the profile shows that precision varied across age classes (Figure 10d). Comparisons of the age-bias plots for the two readers with the agreed age indicate that reader 1 mainly displayed negative bias in estimating age in the older age classes compared to reader 2, who displayed both positive and negative bias, although both readers showed similar levels of precision with CV and IAPE estimates less than 3% (Figure 10e and f).

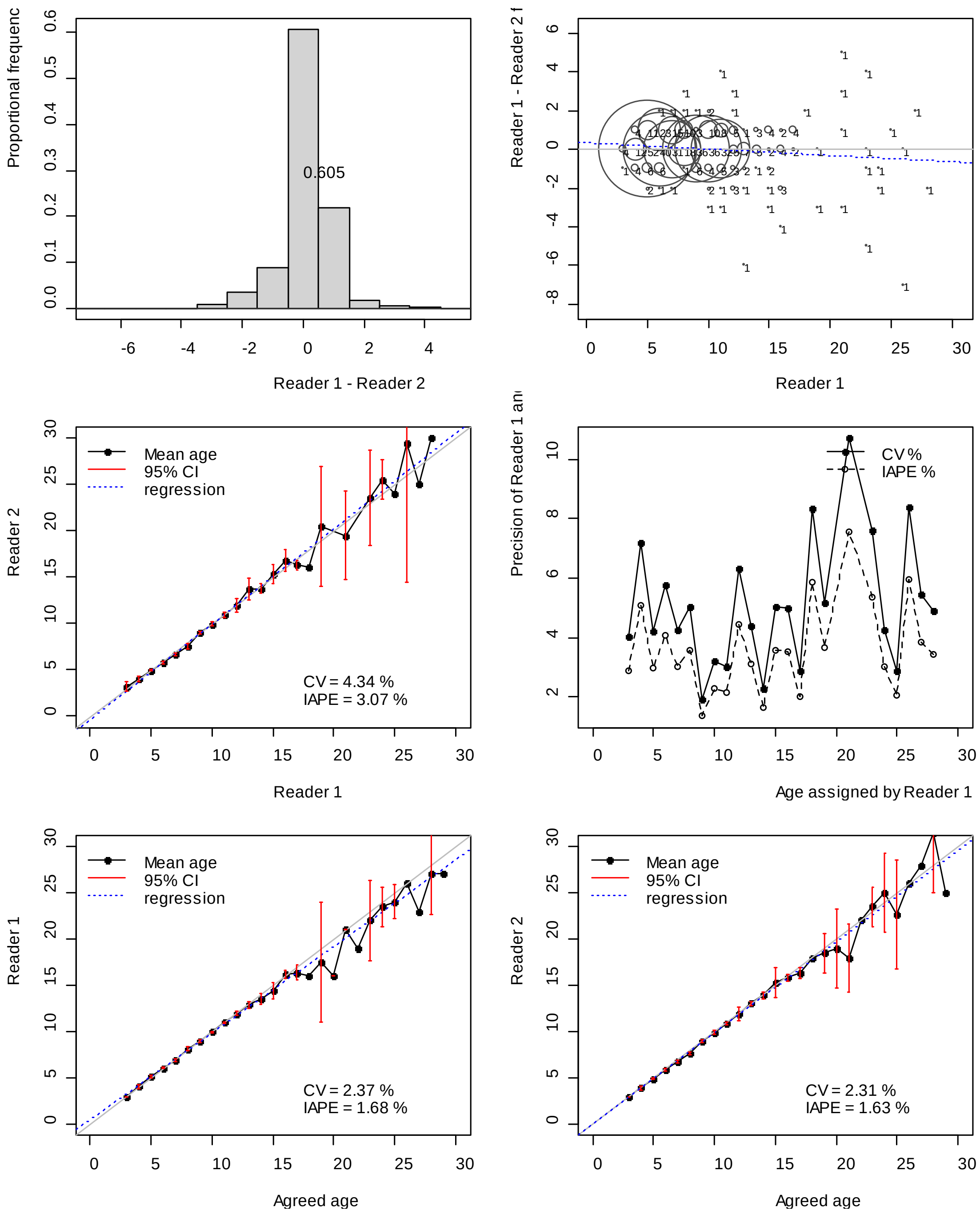

Figure 10: Results of between-reader comparison test (reader 1 and 2) for Northland/Hauraki Gulf and Bay of Plenty/East Cape otoliths combined, collected in 2014–15 (*n* = 478): (a) histogram of differences between readings for the same otolith; (b) differences between readers for a given age assigned by reader 1; (c) bias plot between readers; (d) CV and IAPE profiles (precision) relative to the age assigned by reader 1; (e) bias plot between reader 1 ((f) reader 2) and agreed age. The expected one-to-one (solid line) and actual relationship (dashed line) between readers are overlaid on (b) and (c), and between reader 1 and 2 and the agreed age on (e) and (f).

3.3 Catch-at-length and age

In the Northland/Hauraki Gulf region there was a mode in length at 92 cm and mean lengths of 91.0 cm (sd 10.94) for males and 95.7 cm (sd 13.84) for females. The Bay of Plenty/East Cape region sample had more than one mode and mean lengths of 104.7 cm (sd 12.84) for males and 109.3 cm (sd 13.84) for females (Figure 11).

The age distribution for kingfish sampled from Northland/Hauraki Gulf was dominated by young kingfish five to seven years of age, with few fish 15 years and older (Figure 12). A strong mode of five year olds from the 2010 year class made up more than one-third of the total catch in 2014–15. The mean age of the Northland/Hauraki Gulf distribution was 7.1 years and the mean weighted coefficient of variation (MWCV) was 0.21. A broader age composition was apparent in the Bay of Plenty/East Cape region and comprised a strong mode of six year old kingfish from the 2009 year class and a good number of fish occupying the 9 to 11 year old age classes (Figure 12). The mean age of the Bay of Plenty/East Cape distribution was 8.6 years and the MWCV was 0.30. Young kingfish grew rapidly and started to recruit to the fishery (minimum legal size of 75 cm) as three year olds and were fully recruited at 5 or 6 years.

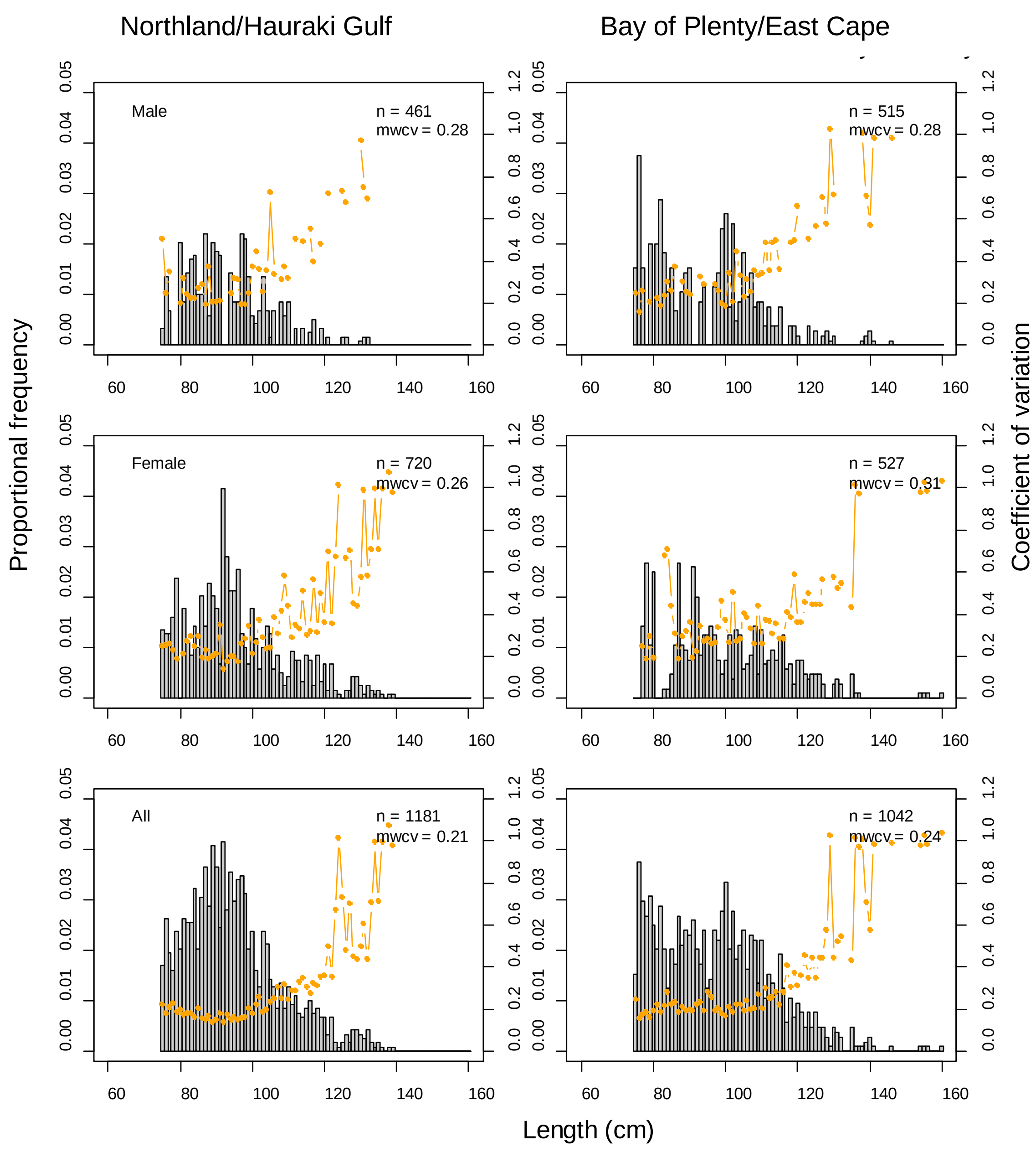

Figure 11: Length frequency of kingfish caught in the recreational fishery, sampled in 2014–15 separated by sex and region. The line represents the CV for each age.

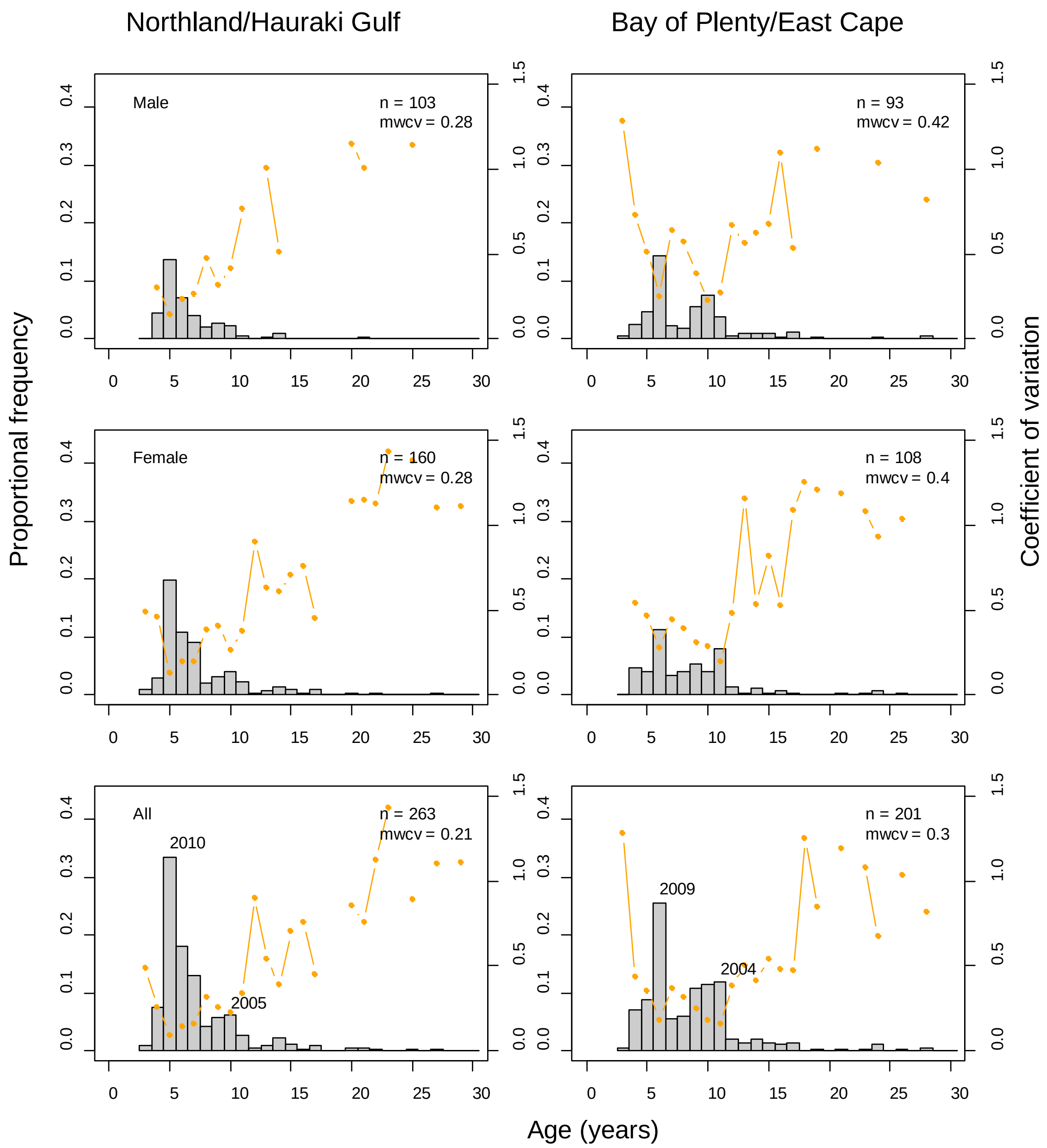

Figure 12: Frequency distributions of kingfish caught in the recreational fishery, sampled in 2014–15 separated by sex and region. The line represents the CV for each age.

The oldest fish sampled in Northland was 29 years of age, a 134 cm fish caught at the King Bank. The oldest fish sampled in Bay of Plenty was 28 years, a 130 cm fish caught at Ranfurly Bank.

Spatial differences in length and age composition were evident between inshore and offshore samples in both areas. More fish longer than 120 cm and older than 15 years came from offshore locations such as the Three Kings Area in Northland and White Island, Rangatira Knoll and Ranfurly Bank in the Bay of Plenty (Figures 13 and 14). The Northland/Hauraki Gulf inshore cumulative proportion of age classes has more four and five year olds and is distinctly different to the other areas (Figure 15).

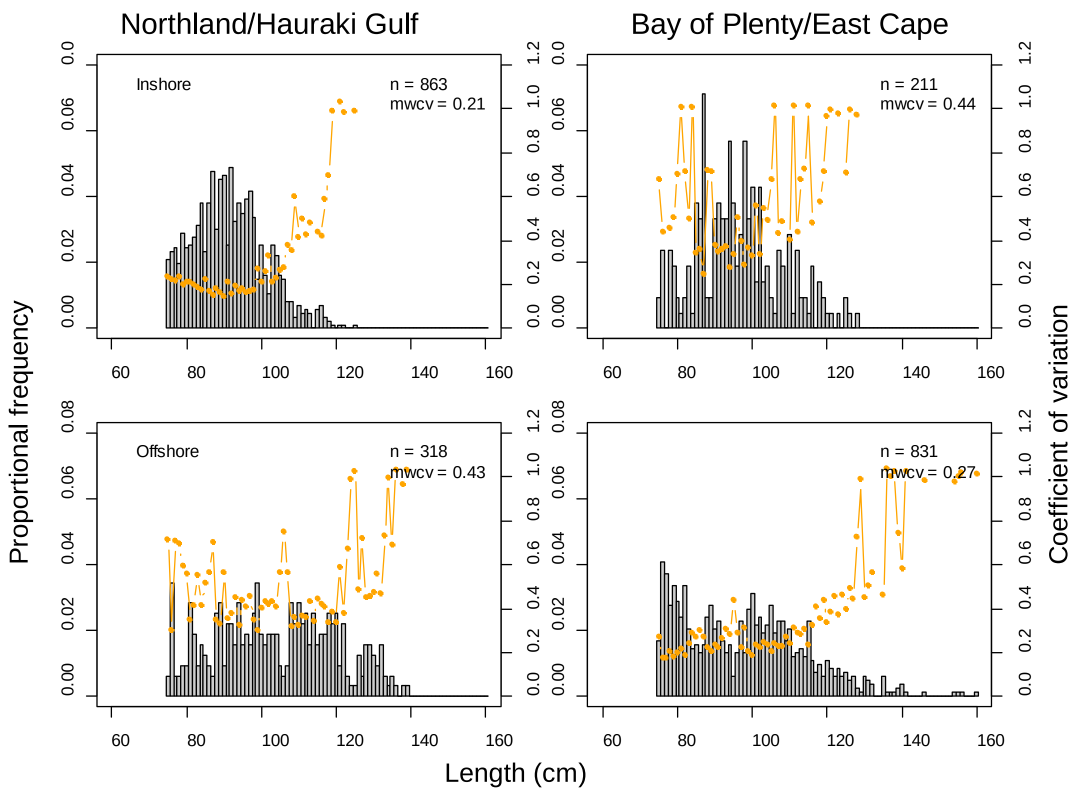

Figure 13: Length frequency (cm) of kingfish caught in the recreational fishery, sampled in 2014–15 separated by inshore and offshore and region. The line represents the CV for each length.

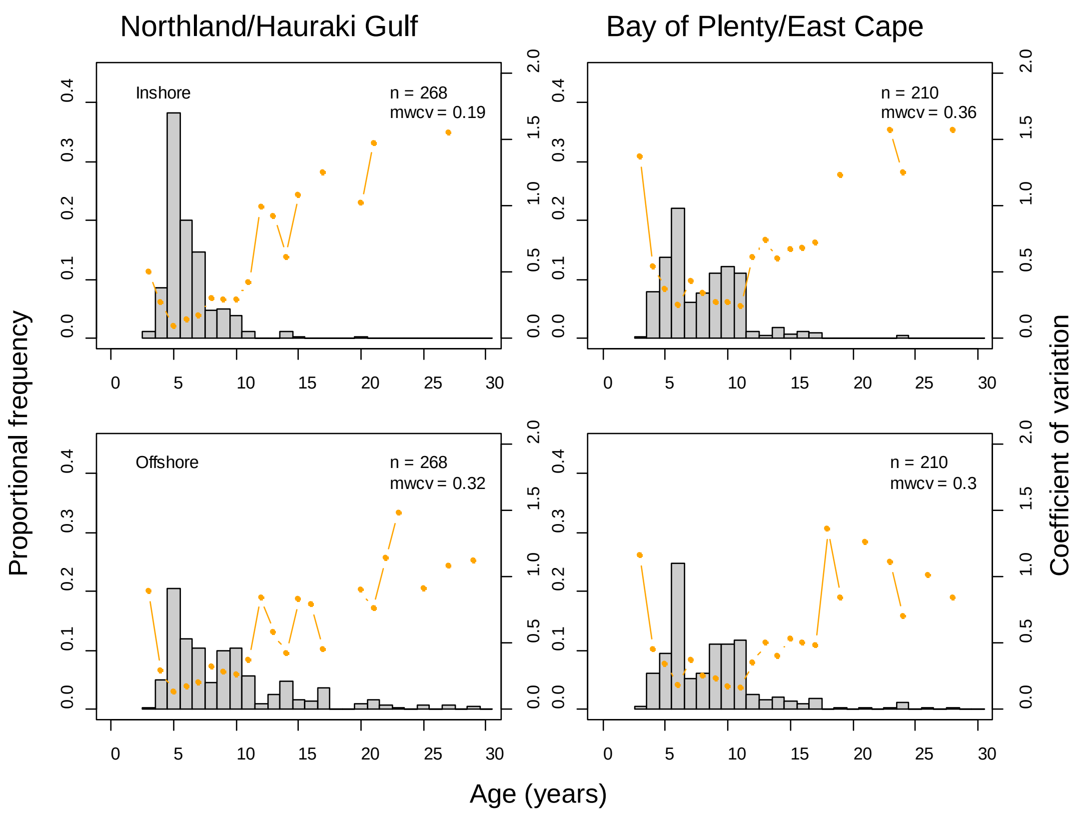

Figure 14: Age frequency distributions of kingfish caught in the recreational fishery, sampled in 2014–15 separated by inshore (top) and offshore (bottom) and region.

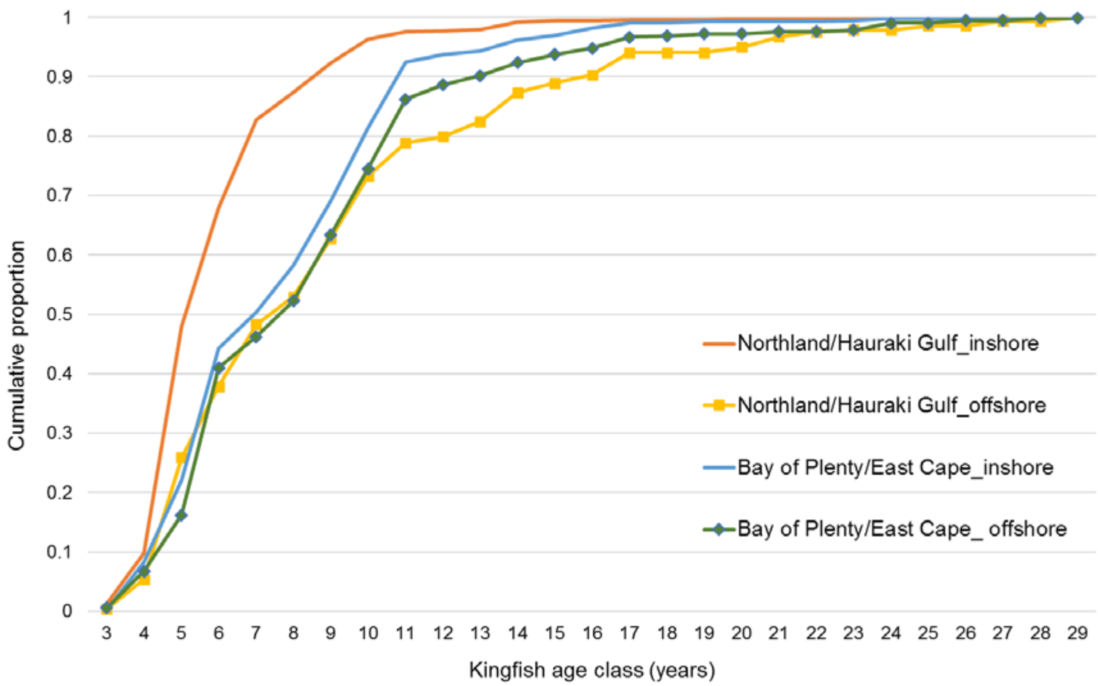

Figure 15: Cumulative proportion of age classes for inshore and offshore by region in 2014–15.

3.4 Growth estimates

Growth estimates (von Bertalanffy growth curves) were derived from age samples collected in 2014–15 with the addition of juvenile fish caught under FADs in 2002 (McKenzie et al. 2005) to inform the shape of the left-hand side of the curve. Clear differences in the growth between male and female kingfish were evident in the age data from both sub regions (Figure 16). These data suggest that female kingfish grow to a larger maximum size than males. Sex-related growth differences were found to be significant ($P < 0.001$). In contrast, male and female growth rates in in both KIN 1 regions were similar (Figure 17).

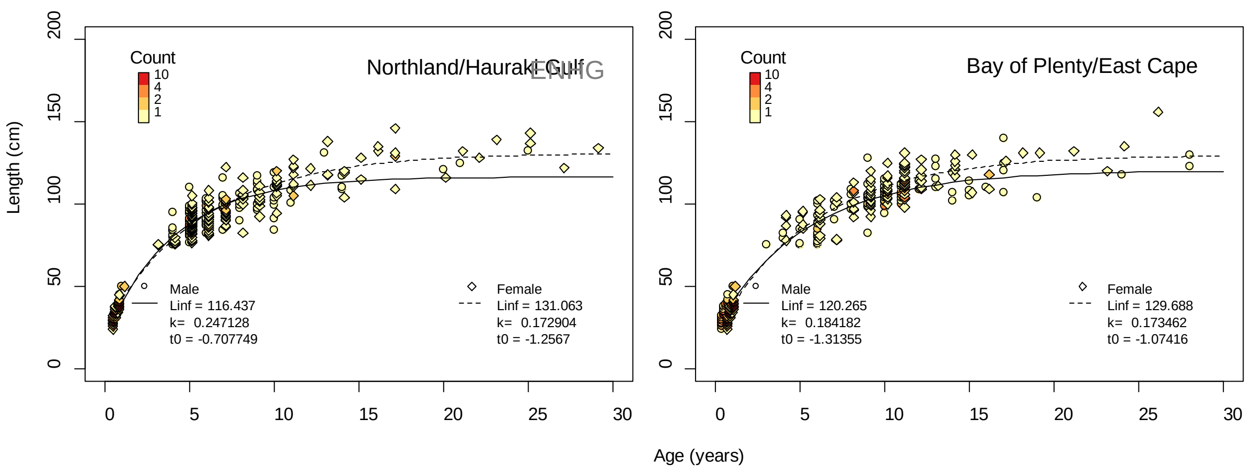

Figure 16: Length-at-age observations for male and female kingfish (points) and the von Bertalanffy growth model fits (lines) by region. Fish older than three years and larger than 74 cm are from 2014–15 samples. Juvenile fish samples (thought to be 0+) collected from East Northland FADs in 2002 are also plotted.

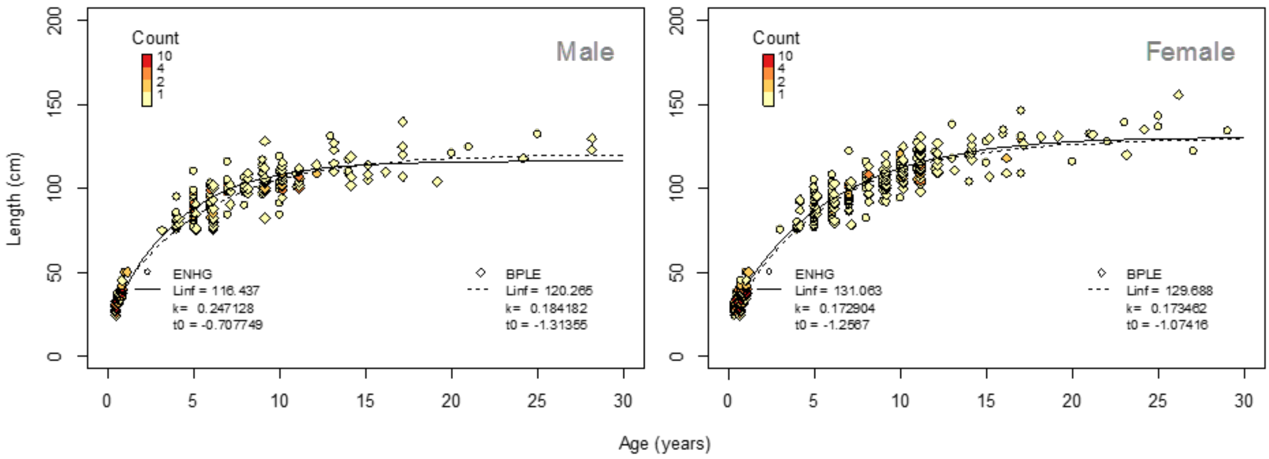

Figure 17: Length-at-age observations for Northland/Hauraki Gulf and Bay of Plenty/East Cape (points) and the von Bertalanffy growth model fits (lines) by sex. Fish older than three years and larger than 74 cm are from 2014–15 samples. Juvenile fish samples (thought to be 0+) collected from East Northland FADs in 2002 are also plotted.

3.5 F%SSB/R (revised)

The MPI Harvest Strategy Standard operational guidelines for a species with kingfish growth and natural mortality correspond to a target biomass of 35% virgin biomass ($B0_{35\%}$) as derived from a stock assessment or as a fishing mortality that achieves 40% Spawning Stock Biomass per recruit as derived from an equilibrium per-recruit analysis ($F_{\%40SSB/R}$).

Age and length data collected in 2014–15 from the Bay of Plenty are likely to better represent female kingfish growth than the 2009–10 Bay of Plenty collected data (Holdsworth et al. 2013) because more samples were collected from the older age classes in the recent series. We provide a revised estimate of the $F_{\%40SSB/R}$ reference target for kingfish (Table 7) as derived using the recent Bay of Plenty female von Bertalanffy growth parameters (Figure 17; Appendix 1).

Table 7: Reference fishing mortalities (F) derived from the per recruit analysis pursuant to 2014–15 Bay of Plenty sample growth dynamics given in Appendix 1. Reference total mortalities (Z) are in Table 8 pursuant to an assumed natural mortality rate (M) of 0.20.

	F (Z)	SSB/R (%)
FSSB/R	0.13 (0.33)	40%
$F_{0.1}$	0.22 (0.42)	25%

3.6 Total Mortality estimates

Chapman and Robson total mortality estimates (Z) were derived assuming age at full recruitment corresponded to the age class with peak abundance, i.e. 6 years old (Table 8). Both inshore areas produced markedly lower Z estimates in 2014–15 than 2009–10 (Table 8). The NINSWG favoured the mortality estimates as derived from the recent sampling (Table 8) because more comprehensive sampling was achieved for inshore and offshore strata in both regions in 2014–15.

Mortality estimates based on inshore and offshore areas also differed due to proportionally fewer older fish in the inshore samples (Section 3.4; Table 8). Although movement has been recorded between inshore and offshore areas, the relationship between these areas is unquantified. The NINSWG concluded that there was no valid approach for combining inshore and offshore age frequencies by region for the purpose of estimating regional total mortality (Z), recommending instead that only the offshore total mortality estimates be used for management purposes.

The mean weighted CVs (MWCVs) on the Northland and Bay of Plenty age distributions for offshore fish were 0.32 and 0.30 respectively (Figure 14), being consistent with the programme design target MWCV of 0.30 for deriving “acceptable” total mortality estimates.

Table 8: Kingfish total mortality estimates (Chapman and Robson) derived from recreational catch-at-age from 2009–10 and 2014–15 assuming full recruitment at 6 years old with bootstrap MWCVs in brackets.

	2009–10		2014–15	
Region	NLD/HG	BOP/EC	NLD/HG	BOP/EC
Inshore Z	0.87 (0.12)	0.50 (0.14)	0.49 (0.08)	0.29 (0.09)
Offshore Z	–	0.30 (0.14)	0.19 (0.08)	0.25 (0.07)

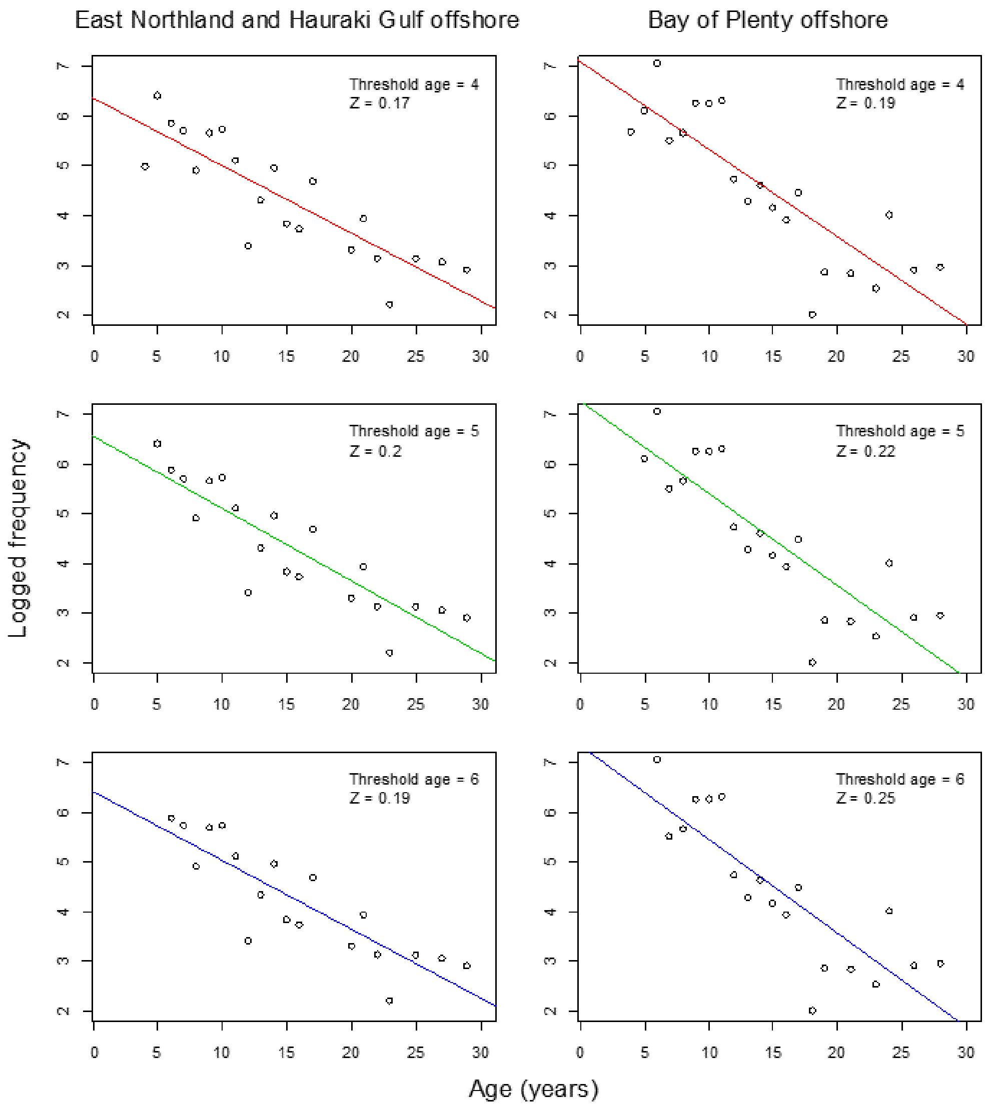

Figure 18: Catch curve distribution of age classes for offshore locations by region assuming full recruitment at 4 years (top), 5 years (middle) and 6 years (bottom).

The catch curves for offshore areas show that the residuals are evenly distributed around the regression lines (Figure 18). This indicates that the recruitment patterns are unlikely to have undue leverage on mortality estimation. There was very little variation in the total mortality estimates relative to the assumed age of full recruitement (Figure 18; Appendix 2).

Total mortality estimates for Northland/Hauraki Gulf and Bay of Plenty/East Cape offshore areas ranged from 0.17 to 0.26 (Table 8; Appendix 2). As none of these Z estimates were higher than the revised management target of 0.33 (Section 3.7), the Northern Inshore Working Group concluded that kingfish populations in the Bay of Plenty and Northland offshore areas were unlikely to have been in an over-exploited state in 2014–15.

3.7 Amateur fisheries charter vessel reporting

Charter boat operators in the recreational fishery had to register and start reporting fishing effort in 2010. If a boat moved more than six miles or changed target species this was reported as a separate fishing event as summarised in Table 9. Kingfish catch reporting was required in KIN 1 and KIN 2 from October 2011 and other areas from 2013, although some skippers reported catch prior to that. The number of kingfish caught from ACV trips targeting kingfish in our survey area is presented in Table 10. The number of fishing events targeting kingfish have declined in inshore Bay of Plenty while they have increased for offshore Bay of Plenty/East Cape and offshore Northland, and a similar pattern is shown in the number of all kingfish caught from target events (Tables 9 and 10).

Table 9: Number of events targeting kingfish in survey area by fishing year.

Year	Inshore Bay of Plenty	Inshore Northland/ Hauraki Gulf	Offshore Bay of Plenty/East Cape	Offshore Northland	Total
2010–11	307	657	25	21	1 010
2011–12	394	619	106	40	1 159
2012–13	187	472	131	64	854
2013–14	175	682	230	143	1 230
2014–15	163	549	252	140	1 104
Total	1 226	2 979	744	408	5 357

Table 10: Number of all kingfish caught in survey area from target events (includes kept and released fish) by fishing year.

Year	Inshore Bay of Plenty	Inshore Northland/ Hauraki Gulf	Offshore Bay of Plenty/East Cape	Offshore Northland	Total
2010–11	122	585	38	13	758
2011–12	5 476	3 476	1 175	168	10 295
2012–13	2 623	2 805	3 326	1 303	10 057
2013–14	2 308	3 632	4 280	3 188	13 408
2014–15	1 493	3 762	5 999	4 086	15 340
Total	12 022	14 260	14 818	8 758	49 858

There is potential for using this data to track catch and effort trends in the recreational fishery especially if the number of legal kingfish released can be determined and data quality can be maintained.

4. DISCUSSION

This project set out to collect data from the kingfish recreational charter fishery in north eastern New Zealand in a comparable way to the 2009–10 kingfish monitoring project (Holdsworth et al. 2013). The 2014–15 programme sampled additional offshore locations (outside the continental shelf) at the Three Kings Islands, King Bank and Ranfurly Bank to help provide a better sample of offshore locations. White Island provided the only data from the offshore fishery in 2009–10. Results from 2014–15 showed the size and age structure in offshore locations to be broader than inshore locations, with more large and old kingfish present.

The presence of older kingfish offshore within KIN 1 raises questions about the degree of connectivity between onshore and offshore habitats. Tag-recapture data from New Zealand Gamefish Tagging Programme fishers has shown a high degree of residence of large kingfish at offshore locations such as White Island (Holdsworth & Saul 2014, Holdsworth et al. 2016). While recaptured fish have shown some offshore movement there is also reciprocal movement from offshore to inshore. Tagging data from the east coast of Australia indicates that small kingfish (smaller than 62 cm) move less than medium sized fish of 63–90 cm (Gillanders et al. 2001). Long distance movements in eastern Australia indicate that the kingfish population is likely to be well mixed and that it is unlikely that more than one stock exists (Gillanders et al. 2001).

A study in 2002 measured and aged kingfish from recreational catch. Of the 1352 fish measured, 68% came from White Island, 24% from Ranfurly Bank and 8% from inshore areas. None of the inshore fish in 2002 were larger than 102 cm and they were dropped from the analysis as they were unlikely to be representative of the full adult population (McKenzie et al. 2005). Over several studies in New Zealand there has consistently been a higher proportion of large fish caught offshore using the same recreational fishing gear and methods as inshore. In 2002, 5% of the kingfish measured from White Island were larger than 120 cm. In the 2010 study, 7% of fish from White Island were larger than that, while in 2014–15 9% were larger than 120 cm. Just 1% of fish sampled from coastal areas in 2009–10 and 2014–15 were larger than 120 cm.

There are a number of possible explanations for there being fewer large fish in the recreational catch inshore:

- When large fish are hooked in relatively shallow water it can be hard to stop them from getting to the bottom and wrapping the line in weed or rock and busting off. So rod and reel fishing may catch fewer of the very large fish that are hooked inshore.
- The combined fishing pressure on kingfish from all sectors may be higher in inshore waters than remote offshore locations. If the inshore population is resident and of limited size, fishing mortality may be high.
- Large kingfish may prefer offshore habitats and become resident there. For example, a very high proportion of kingfish tagged at White Island are recaptured in that area. The availability of large kingfish inshore is more seasonal and less consistent than offshore.

Without a robust method for combining inshore and offshore areas, future work on monitoring the age structure of the KIN 1 stock should consider a more structured design that splits sampling effort across four strata, inshore and offshore within each region. The size of kingfish caught on jigs is generally smaller than those caught on baits and the effect of this selectivity on total mortality estimates should be determined.

Three kingfish with gamefish tags were recaptured and aged from the King Bank in 2015. Two measured at release were at liberty for long periods and can therefore provide additional information on growth rates. A female kingfish tagged in May 2012 measured at 108 cm was recaptured in April 2015. It measured 118 cm on recapture, so had grown 10 cm in almost 3 years and was aged at 11 years old. Another female kingfish tagged at the King Bank in May 2010 measuring 101 cm on release, was 111 cm on recapture in 2015, so had grown 10 cm in 5 years, and was aged at 10 years old. These fish show differences in annual growth rate although both are within the bounds of observed catch-at-age in this study.

A 21 year old tagged kingfish re-caught at the King Bank in June 2015 measured 132 cm and weighed 27 kg. This female fish had been at liberty for just 22 days. All three kingfish had been tagged at the King Bank so no significant movement was recorded.

The kingfish monitoring projects show regional differences in the age structure within KIN 1 with strong year classes more consistent within regions than between regions. For example, in Northland/Hauraki Gulf, the 5-year-olds were the singularly most dominant age class in both the 2009–10 and 2014–15 samples across both sexes. For the Bay of Plenty/East Cape, the 6-year-olds were the strongest age class for the 2009–10 and 2014–15 samples, inshore and offshore, and across sexes. While some variations in the relative strengths of a few age classes between regions in KIN 1 were evident and may be indicative of spatial patterns in recruitment, fishing mortality, as well as sampling error, a reasonable level of consistency was apparent across other year classes. The progression of a strong 2005 Northland year class and a strong 2004 Bay of Plenty year class first seen in the 2009–10 study is also seen in 2014–15.

A protocol used for ageing kingfish in 2009–10 (Holdsworth et al. 2013) was repeated in this current study. The rigorous approach should have maintained accuracy and precision in age estimates, despite only achieving moderate between-reader agreement (61%) and CV (over 4%) for initial reads. Using two readers to read the entire otolith collections independently, and reviewing all remaining disagreements collaboratively with a third experienced reader, is expected to result in age estimates that are more robust than those determined from initial estimates alone or by using a single reader. A high level of consistency in relative year class strength was more apparent between sexes within a region, than between regions. This is indicative of the high precision in ageing kingfish in 2014–15. Nevertheless, further work may be required to validate the location of the first annual growth zone in the otoliths of wild kingfish as recent research has proved inconclusive (Francis et al. 2014). Furthermore, a publication of a kingfish age determination protocol would allow for ageing procedures to be documented and provide a useful guide to ensure that accuracy and precision is maintained in the future ageing of kingfish.

The Northern Inshore Working Group (NINSWG) concluded that the sampling programme had done a satisfactory job of describing the age composition of the recreational KIN 1 fishery by region. However, there was no agreed approach for combining the 2014–15 onshore and offshore age samples for the purposes of estimating total mortality (Z). The Group recommended that the viability of using catch and effort data from the Amateur Charter Vessel logbook programme should be investigated as a monitoring tool in KIN 1. As the proportion of kingfish released by recreational charter boats is high (82% in 2014–15) it is likely that obtaining a reliable CPUE series would require changes to the statutory charter boat data collection form, so that released fish below the MLS (75 cm) would be recorded separately. A time series of charter vessel CPUE would take several years to collect. The NINSWG recommended that, until such an alternative monitoring option became available for KIN 1, total mortality estimates derived from age sampling of the offshore KIN 1 recreational fishery be accepted for management purposes. The NINSWG further recommended that age sampling of the KIN 1 recreational fishery should be repeated in five years as specified by the Medium Term Research Plan for Inshore Finfish.

The target per recruit ($F_{\%40SSB/R}$) harvest reference point for kingfish was revised to F=0.13 (total mortality 0.33) under the current study. As none of the total mortality estimates (Z), as derived from offshore sampling data, were higher than the revised $F_{\%40SSB/R}$ management target, the NINSWG concluded that kingfish populations in the Bay of Plenty and Northland regions of KIN 1 were unlikely to have been in an over-exploited state in 2014–15.

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6. REFERENCES

Beamish, R.J.; Fournier, D.A. (1981). A method for comparing the precision of a set of age determinations. *Canadian Journal of Fisheries and Aquatic Sciences 38*: 982–983.

Bradford, E. (1998). Modelling recreational fisheries NIWA Final Research Report for project REC9702. 59 p. (Unpublished report held by NIWA library, Wellington.).

Campana, S.E.; Annand, M.C.; McMillan, J.I. (1995). Graphical and statistical methods for determining the consistency of age determinations. *Transactions of the American Fisheries Society 124*: 131–138.

Chang, W.Y.B. (1982). A statistical method for evaluating the reproducibility of age determination. *Canadian Journal of Fisheries and Aquatic Sciences 39*: 1208–1210.

Chapman, D.G.; Robson, J. (1960). The analysis of a catch curve. *Biometrics 16*, 354–368.

Davies, N.M.; Hartill, B.; Walsh, C. (2003). A review of methods used to estimate snapper catch-at-age and growth in SNA 1 and SNA 8. *New Zealand Fisheries Assessment Report 2003/10*. 63 p.

Dunn, A.; Francis, R.I.C.C.; Doonan, I.J. (2002). Comparison of the Chapman-Robson and regression estimators of Z from catch-curve data when non-sampling stochastic error is present. *Fisheries Research 59*: 149–159.

Francis, M.P.; McKenzie, J.; Ó Maolagáin, C. (2014). Attempted validation of the first annual growth zone in kingfish (*Seriola lalandi*) otoliths. *New Zealand Fisheries Assessment Report 2014/08.* 19 p.

Gillanders, B.M.; Ferrell, D.J.; Andrew, N.L. (2001). Estimates of movement and life-history parameters of yellowtail kingfish (*Seriola lalandi*): how useful are data from a cooperative tagging programme? *Marine and Freshwater Research, 52*: 179–192.

Hartill, B; Davey, N. (2015). Mean weight estimates for recreational fisheries in 2011–12. *New Zealand Fisheries Assessment Report 2015/25.* 37 p.

Holdsworth, J.C.; McKenzie, J.R.; Walsh, C.; van der Straten, K.M.; Ó Maolagáin, C. (2013). Catch-at-age of yellowtail kingfish (*Seriola lalandi*) caught by recreational fishers in KIN 1, *New Zealand. New Zealand Fisheries Assessment Report 2013/3. 31 p.*

Holdsworth, J.C; Saul, P.J. (2014). New Zealand billfish and gamefish tagging, 2012–13. *New Zealand Fisheries Assessment Report 2014/11.* 26 p.

Holdsworth, J.C.; Saul, P.J.; Boyle, T.; Sippel, T. (2016). Synthesis of New Zealand gamefish tagging data, 1975 to 2014. *New Zealand Fisheries Assessment Report 2016/24*. 63 p.

IGFA (2016). 2016 world record game fishes. Published by International Game Fish Association. Florida, USA.

Kimura, D.K. (1980). Likelihood methods for the von Bertalanffy growth curve U.S. *Fisheries Bulletin 77*: 765- 776.

McKenzie, J.R.; Smith, M.; Hartill, B. (2014). Review of stock monitoring options for kingfish (*Seriola lalandi lalandi*) based on an analysis of the commercial and recreational fisheries up to 2006. *New Zealand Fisheries Assessment Report 2014/38*. 23 p.

McKenzie, J.R.; Smith, M.; Watson, T.; Francis, M.; Ó Maolagáin, C.; Poortenaar, C.; Holdsworth, J. (2005). Age, growth, maturity and natural mortality of New Zealand kingfish (*Seriola lalandi lalandi*). Unpublished report held by the Ministry for Primary Industries, Wellington, New Zealand. Project KIN2000/01.

Ministry for Primary Industries (2016). Report from the Fisheries Assessment Plenary May 2016: stock assessments and yield estimates. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington, New Zealand. 1556 p.

Smith, M.; Diggles, B.; McKenzie, J.R.; Kim, S.; Ó Maolagáin, C.; Notman, P.; Griggs, L.H. (2004). Kingfish stock structure. Unpublished report held by the Ministry for Primary Industries, Wellington, New Zealand. Project KIN2002/01.

Stewart, J.; Ferrell, D.J.; van der Walt, B. (2004). Sizes and ages in commercial landings with estimates of growth, mortality, and yield per recruit of yellowtail kingfish (*Seriola lalandi*) from New South Wales, Australia. *Marine and Freshwater Research, 55*: 489–497

Thompson, B.; Beasley, M.; Wilson, C. (1999). Age distribution and growth of greater amberjack, *Seriola dumerili* from the north-central Gulf of Mexico. *Fisheries Bulletin 97*: 362–371.

Walsh, C.; McKenzie, J.; McGregor, G.; Poortenaar, C.; Hartill, B.; Smith, M. (2003). Information available for the management of New Zealand kingfish (*Seriola lalandi lalandi*) stocks. *New Zealand Fisheries Assessment Report 2003/25.* 57 p.

Wynne-Jones, J.; Gray, A.; Hill, L.; Heinemann, A. (2014). National panel survey of marine recreational fishers 2011–12: Harvest Estimates. *New Zealand Fisheries Assessment Report 2014/67*. 147 p.

7. APPENDICES

Appendix 1: Female kingfish productivity parameters used in the calculation of yield per recruit relative to 2009–10 and 2014–15 Bay of Plenty growth estimates.

VB parameters		
	K	0.173
	Linf	129
	t0	-1.07
Length (cm) weight (kg) relationship		
	a	0.0000365
	b	2.762
Age at maturity (100%)		6
Age at selection (100%)		4
Natural mortality (m)		0.2

Appendix 2: Catch-curve estimates of total mortality (Z) as derived from offshore sampling by area and assumed age of full recruitment (CVs in brackets).

	Age at full recruitment				
Area	**4**	**5**	**6**	**7**	**8**
East Northland	0.17 (0.06)	0.20 (0.08)	0.19 (0.09)	0.19 (0.10)	0.20 (0.11)
Bay of Plenty	0.19 (0.04)	0.22 (0.05)	0.25 (0.07)	0.22 (0.07)	0.26 (0.08)

Appendix 3: Estimated proportion at age and CVs for kingfish in KIN 1, 2014–15.

CV, coefficient of variation.

Appendix 3a: Estimates of proportion at age and CVs (by sex) for kingfish caught from the Northland/Hauraki Gulf region in 2014–15.

	Northland/Hauraki Gulf					
Age	Male		Female		All	
(years)	Proportion	CV	Proportion	CV	Proportion	CV
3	0.0000	-	0.0102	0.49	0.0102	0.49
4	0.0456	0.30	0.0301	0.46	0.0757	0.26
5	0.1363	0.14	0.1977	0.13	0.3340	0.09
6	0.0708	0.23	0.1088	0.19	0.1797	0.15
7	0.0408	0.27	0.0902	0.20	0.1310	0.16
8	0.0216	0.48	0.0197	0.39	0.0413	0.31
9	0.0283	0.32	0.0305	0.41	0.0587	0.26
10	0.0221	0.41	0.0399	0.26	0.0620	0.23
11	0.0058	0.76	0.0220	0.38	0.0278	0.34
12	0.0000	-	0.0040	0.90	0.0040	0.90
13	0.0027	1.00	0.0076	0.63	0.0103	0.54
14	0.0097	0.51	0.0128	0.61	0.0226	0.39
15	0.0000	-	0.0106	0.70	0.0106	0.70
16	0.0000	-	0.0038	0.76	0.0038	0.76
17	0.0000	-	0.0102	0.45	0.0102	0.45
18	0.0000	-	0.0000	-	0.0000	-
19	0.0000	-	0.0000	-	0.0000	-
20	0.0017	1.14	0.0025	1.14	0.0042	0.85
21	0.0032	1.01	0.0017	1.15	0.0049	0.76
22	0.0000	-	0.0021	1.13	0.0021	1.13
23	0.0000	-	0.0008	1.43	0.0008	1.43
24	0.0000	-	0.0000	-	0.0000	-
25	0.0017	1.14	0.0004	1.38	0.0021	0.89
26	0.0000	-	0.0000	-	0.0000	-
27	0.0000	-	0.0023	1.10	0.0023	1.10
28	0.0000	-	0.0000	-	0.0000	-
29	0.0000	-	0.0017	1.11	0.0017	1.11
30	0.0000	-	0.0000	-	0.0000	-
n	103		160		263	

Appendix 3b: Estimates of proportion at age and CVs (by sex) for kingfish caught from the Bay of Plenty/East Cape region in 2014–15.

	Bay of Plenty/East Cape					
Age	Male		Female		All	
(years)	Proportion	CV	Proportion	CV	Proportion	CV
3	0.0051	1.28	0.0000	-	0.0051	1.28
4	0.0249	0.73	0.0458	0.54	0.0707	0.44
5	0.0461	0.51	0.0413	0.46	0.0874	0.35
6	0.1425	0.25	0.1122	0.28	0.2547	0.18
7	0.0225	0.64	0.0331	0.44	0.0556	0.37
8	0.0193	0.57	0.0397	0.39	0.0590	0.32
9	0.0567	0.39	0.0525	0.31	0.1092	0.25
10	0.0747	0.23	0.0394	0.29	0.1141	0.18
11	0.0389	0.27	0.0803	0.19	0.1192	0.16
12	0.0054	0.67	0.0148	0.48	0.0202	0.38
13	0.0106	0.56	0.0022	1.16	0.0128	0.50
14	0.0099	0.63	0.0115	0.53	0.0214	0.42
15	0.0099	0.67	0.0036	0.82	0.0135	0.54
16	0.0029	1.10	0.0083	0.52	0.0112	0.48
17	0.0122	0.53	0.0024	1.09	0.0146	0.48
18	0.0000	-	0.0013	1.25	0.0013	1.25
19	0.0022	1.12	0.0013	1.21	0.0034	0.84
20	0.0000	-	0.0000	-	0.0000	-
21	0.0000	-	0.0029	1.19	0.0029	1.19
22	0.0000	-	0.0000	-	0.0000	-
23	0.0000	-	0.0026	1.08	0.0026	1.08
24	0.0038	1.03	0.0067	0.93	0.0106	0.68
25	0.0000	-	0.0000	-	0.0000	-
26	0.0000	-	0.0029	1.03	0.0029	1.03
27	0.0000	-	0.0000	-	0.0000	-
28	0.0047	0.82	0.0000	-	0.0047	0.82
29	0.0000	-	0.0000	-	0.0000	-
30	0.0000	-	0.0000	-	0.0000	-
n	93		108		201	

Appendix 3c: Estimates of proportion at age and CVs for kingfish caught from inshore and offshore areas of the Northland/Hauraki Gulf region in 2014–15.

	Northland/Hauraki Gulf			
Age	Inshore		Offshore	
(years)	Proportion	CV	Proportion	CV
3	0.0125	0.50	0.0038	0.89
4	0.0852	0.27	0.0500	0.30
5	0.3820	0.10	0.2048	0.13
6	0.2000	0.14	0.1206	0.17
7	0.1477	0.18	0.1038	0.21
8	0.0470	0.30	0.0466	0.32
9	0.0492	0.30	0.0986	0.28
10	0.0399	0.29	0.1043	0.26
11	0.0124	0.43	0.0566	0.37
12	0.0017	0.99	0.0102	0.85
13	0.0019	0.92	0.0257	0.58
14	0.0126	0.61	0.0487	0.43
15	0.0029	1.09	0.0157	0.83
16	0.0000	-	0.0142	0.79
17	0.0012	1.25	0.0372	0.45
18	0.0000	-	0.0000	-
19	0.0000	-	0.0000	-
20	0.0023	1.02	0.0094	0.90
21	0.0012	1.48	0.0173	0.76
22	0.0000	-	0.0079	1.14
23	0.0000	-	0.0031	1.48
24	0.0000	-	0.0000	-
25	0.0000	-	0.0079	0.91
26	0.0000	-	0.0000	-
27	0.0004	1.55	0.0073	1.09
28	0.0000	-	0.0000	-
29	0.0000	-	0.0063	1.12
30	0.0000	-	0.0000	-
n	268		268	

Appendix 3d: Estimates of proportion at age and CVs for kingfish caught from inshore and offshore areas of the Bay of Plenty/East Cape region in 2014–15.

Age (years)	Bay of Plenty/East Cape			
	Inshore		Offshore	
	Proportion	CV	Proportion	CV
3	0.0032	1.37	0.0056	1.16
4	0.0802	0.54	0.0622	0.45
5	0.1374	0.37	0.0946	0.34
6	0.2218	0.25	0.2475	0.19
7	0.0614	0.44	0.0524	0.38
8	0.0779	0.35	0.0604	0.25
9	0.1101	0.27	0.1113	0.23
10	0.1217	0.28	0.1111	0.17
11	0.1115	0.24	0.1171	0.16
12	0.0118	0.61	0.0245	0.35
13	0.0062	0.74	0.0156	0.50
14	0.0189	0.60	0.0217	0.40
15	0.0074	0.68	0.0137	0.53
16	0.0126	0.69	0.0108	0.50
17	0.0089	0.72	0.0187	0.48
18	0.0000	-	0.0016	1.36
19	0.0019	1.23	0.0038	0.84
20	0.0000	-	0.0000	-
21	0.0000	-	0.0036	1.26
22	0.0000	-	0.0000	-
23	0.0012	1.57	0.0027	1.11
24	0.0047	1.25	0.0119	0.70
25	0.0000	-	0.0000	-
26	0.0000	-	0.0039	1.01
27	0.0000	-	0.0000	-
28	0.0012	1.57	0.0041	0.85
29	0.0000	-	0.0000	-
30	0.0000	-	0.0000	-
n	210		210	