Fisheries New Zealand

Tini a Tangaroa

Relative abundance, size and age structure, and stock status of blue cod off Kaikoura in 2017

New Zealand Fisheries Assessment Report 2018/37

M.P. Beentjes
M. Page

ISSN 1179-5352 (online)
ISBN 978-1-77665-987-6 (online)

October 2018

New Zealand Government

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-and-resources/publications

http://fs.fish.govt.nz go to Document library/Research reports

Contents

EXECUTIVE SUMMARY

Beentjes, M.P.; Page, M. (2018). Relative abundance, size and age structure, and stock status of blue cod off Kaikoura in 2017.

New Zealand Fisheries Assessment Report 2018/37 44 p.

This report describes the results of the random-site blue cod (*Parapercis colias*) potting survey carried out off Kaikoura in December 2017. Estimates are provided for population abundance, size and age structure, sex ratio, total mortality (Z), and spawner biomass-per-recruit ratio. This is the third survey in the Kaikoura random-site survey time series, following those in 2011 and 2015.

Twenty-nine random sites (6 pots per site, producing 174 pot lifts) at depths of 11–121 m from five strata off Kaikoura, were surveyed in December 2017.

Mean catch rates of blue cod (all sizes) by stratum were 0–7 kg.pot^{-1} with the lowest catch rates in stratum 2a (inshore from South Bay to Hikurangi Marine Reserve), and the highest in stratum 4 (offshore of Kaikoura Peninsula). The survey blue cod mean catch rate was 1.9 kg.pot^{-1} with a CV of 16%. Catch rates for recruited blue cod (33 cm and over) followed the same pattern among strata as for all blue cod and overall was 0.91 kg.pot^{-1} (CV 19%). Of the 174 random-site pots, 52 (30%) had zero catch of blue cod. The sex ratios were 0–89% male across the five strata and the overall weighted sex ratio was 45% male. The overall weighted mean length for males was 28.4 cm (range 17–51 cm) and 28.6 cm for females (range 17–45 cm). The scaled length frequency distribution for males was unimodal with a strong peak at about 27 cm. The female distribution was bimodal with a strong peak at about 25 cm.

Otolith thin section ages from 149 males and 128 females were used to estimate the population age structure. The initial counts from each of the two otolith readers achieved 88% agreement, there was minimal bias between readers, and CV and average percent error were 1.2% and 0.9%, respectively. Von Bertalanffy growth parameters (L_∞, K, t_0) were 54.5 cm, 0.14 yr $^{-1}$, -0.28 yr for males; and 44.0 cm, 0.16 yr $^{-1}$, and -0.60 yr for females. Sexed based age-length-keys (one each for males and females) were used to estimate the population age composition. Age ranged from 2–19 years for males and 2–20 years for females, but most blue cod were 3–5 years old. The estimated population age distributions indicate knife-edge selectivity to the potting method at three years with strong modes at three, and especially five years for both sexes, but particularly for males. The age distribution also shows a corresponding weak mode for four-year-olds. Mean age was 5.2 years for males and 6.4 years for females.

Log transformed numbers at age did not produce a straight line, suggesting a violation of the catch curve assumption that recruitment is constant. Z and SPR estimates are consequently not reliable as reflected in the broad 95% confidence intervals. Total mortality (Z) for age-at-full recruitment of eight years was estimated at 0.41 (95% confidence interval 0.27–0.57). Based on the default M of 0.14, estimated fishing mortality (F) was 0.27 and the associated spawner biomass-per-recruit ratio was 34% (95% confidence interval 26–49%).

There was indication of spawning activity during the survey period with about 28% of females and 6% of males maturing or running ripe, suggesting that spawning had not peaked. Gonad stage by stratum indicated that nearly all spawning activity occurred off Kaikoura Peninsula, with the only running ripe fish found in stratum 4 at 100–200 m.

Comparing the results of the 2017 survey with those from 2011 and 2015 revealed catch rates by stratum were similar over time, i.e., catch rates were consistently highest in stratum 4, and lowest in stratum 2. For Kaikoura overall, there was no trend in relative abundance.

Scaled length frequency distributions and mean length were similar with any difference due to the strong recruitment of mainly juvenile male blue cod in 2015, progressing through to strong modes in 2017.

The sex ratio for all the surveys was 47–55% male for all blue cod, and 45–55% male for recruited blue cod, with no clear trends.

Age compositions can be validly compared only between the 2015 and 2017 surveys because blue cod ageing from the 2011 survey was carried out before the new age determination protocol was developed. The 3-year-old age class in 2015 progressed through to a strong 5-year-old age class for both sexes in 2017. Similarly, the strong 5 and 6-year old age classes progressed through to strong 7 and 8-year-old age classes in 2017, particularly apparent for females.

The proportion of pots with zero catch for all the surveys was 29–37% with no clear trends.

There were no clear indications that the blue cod population off Kaikoura surveyed in 2017 was adversely impacted by the November 2016 earthquake.

1. INTRODUCTION

This report describes the random-site potting survey of blue cod (*Parapercis colias*) relative abundance, population length/age structure and stock status off Kaikoura in December 2017. This is the third in the time series with previous random-site surveys in 2011 and 2015 (Beentjes & Page 2017, Carbines & Haist 2018d). The 2017 survey was carried out specifically to assess whether the November 2016 Kaikoura earthquake had any effect on the local blue cod population.

1.1 Status of the north Canterbury blue cod stocks

Blue cod is the finfish species most frequently targeted and landed by recreational fishers off the South Island (Ministry for Primary Industries 2017). 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 by 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 catch) 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. This was supported by the National Blue Cod Strategy Report by MPI in 2017 (Ministry for Primary Industries 2017) where recreational blue cod fishers were surveyed on-line nationally to gauge perceptions of the status of the New Zealand wide blue cod fishery. Results from that survey ranked BCO 3 as the most important Quota Management Area in New Zealand, in line with the 2011–12 panel survey. There are no reliable data to determine how the recreational blue cod catch was distributed within BCO 3, but Kaikoura and Motunau are important blue cod fisheries in north Canterbury (Hart & Walker 2004). The perception from the 2017 on-line survey was that at Kaikoura the three top issues of concern were the total allowable commercial catch (TACC), concentrated effort on small areas, and recreational bag limits (Ministry for Primary Industries 2017).

The commercial catch from BCO 3 was about 40–50% higher than the recreational catch with 166–183 t caught annually in the last seven years up to 2016–17 (Fisheries New Zealand 2018). Nearly all commercially landed blue cod in BCO 3 was caught by potting, and the bulk of this was from Statistical Area 024 off Oamaru (Figure 1).

The ‘Kaikoura Marine Area’ was established in 2014 by the Department of Conservation (DOC) with consultation from Kaikōura Marine Guardians, and extends from Clarence Point south to Conway River out to the territorial sea boundary (12 n. miles) (Figure 2). Within this area the minimum legal size is 33 cm and the daily bag limit is six blue cod. Before 2014, and 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 2014 the 10 ha. Hikurangi Marine Reserve was also established between Goose and South Bays, extending out 24 km over the Kaikoura Canyon (Figure 2).

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 3). 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 under-size 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 fisheries are monitored using potting surveys. These surveys take place predominantly in areas where blue cod 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 and provide data that can be used to monitor local relative abundance, size, age, and sex structure of geographically separate blue cod populations. The surveys provide a measure of the response of populations to changes in fishing pressure and management initiatives such as changes to the daily bag limit, minimum legal size, and area closures. The 2017 survey was carried out to assess the impact of the November 2016 Kaikoura earthquake on the local blue cod population. 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 target reference point for blue cod (a low productivity stock) is $F_{45\%SPR}$ (Ministry of Fisheries 2011) - i.e., target fishing mortality should be at or below a level that reduces the spawner biomass to 45% of that if there was no fishing when it would be 100%.

In addition to Kaikoura, there are currently eight other South Island areas surveyed, located in key recreational fisheries: Motunau (Carbines & Beentjes 2006a, 2009, Beentjes & Sutton 2017, Carbines & Haist 2018d), Banks Peninsula (Beentjes & Carbines 2003, 2006, 2009, Beentjes & Fenwick 2017, Carbines & Haist 2017b), north Otago (Carbines & Beentjes 2006b, 2011, Carbines & Haist 2018b), south Otago (Beentjes & Carbines 2011, Carbines & Haist 2018c), Paterson Inlet (Carbines 2007, Carbines & Haist 2014, 2018a), Foveaux Strait (Carbines & Beentjes 2012, Carbines & Haist 2017a), Dusky Sound (Carbines & Beentjes 2006a, 2009, Beentjes & Page 2016), and the Marlborough Sounds (Blackwell 1997, 1998, 2002, 2006, 2008, Beentjes & Carbines 2012, Beentjes et al. 2017, Beentjes et al. 2018).

1.3 Previous Kaikoura blue cod potting surveys

All potting surveys (except Foveaux Strait) originally used a fixed site design, with predetermined (fixed) locations randomly selected from a limited pool of such sites (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). Following this recommendation, the surveys are in transition to a fully random survey design and the interim sampling of both fixed and random sites allows comparison of catch rates, length and age composition, and sex ratios between the survey designs. Random sites were used as the only site type in Foveaux Strait, or have changed to solely random-site surveys in south Otago (2013) and Kaikoura 2017 (this survey). For other areas the most recent surveys included both fixed and random sites.

Previous Kaikoura surveys were carried out in October 2004, 2007, 2011 and 2015 (Carbines & Beentjes 2006a, 2009, Beentjes & Page 2017, Carbines & Haist 2018d). The first two Kaikoura potting surveys used only fixed sites, whereas the 2011 and 2015 surveys also included concurrent random-site surveys. The current 2017 Kaikoura survey is the first solely random-site survey, following the recommendation of the Southern Inshore Working Group (SINSWG-2016/38) in 2016 that the next survey should be solely random with a target CV of 15%.

1.4 The 2017 Kaikoura survey

The 14 November 2016 earthquake caused considerable damage, including a varying degree of coastal uplift. The uplift resulted in high mortality of many subtidal or intertidal organisms that were exposed above the tide line, and potentially, other unknown subtidal impacts. To assess the ecological impact of the earthquake and inform future marine management options to optimise recovery of biota and habitats in the region, Fisheries New Zealand contracted the National Institute of Water and Atmospheric Research Ltd (NIWA) to conduct a blue cod potting survey off Kaikōura in December 2017. This survey took place two years after the last survey in 2015, and two years earlier in the repeat-cycle than planned, with the key purpose of assessing whether the earthquake had had any impact on the blue cod population.

1.5 Objectives

Overall Objective

To conduct and analyse a blue cod potting survey along coastal Kaikoura.

Specific objectives

1. To undertake a potting survey off Kaikoura 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 determine stock status of blue cod populations in this area, and compare this with other previous surveys in this area and other survey areas.

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

2. METHODS

2.1 Timing

A potting survey off Kaikoura was carried out by NIWA from 1–12 December 2017. The survey dates were consistent with previous surveys and coincided with the known spawning times in this region.

2.2 Consultation with tangata whenua

Te Korowai o Te Tai ō Marokura (Guardians of the Kaikoura Marine Management Area) were consulted and endorsed this project.

2.3 Survey area

The survey area for the 2017 Kaikoura fixed site survey was identical to that from the previous surveys, except that stratum 2 was split into two strata, north (2A) and south (2B) of the Hikurangi Marine Reserve (Figure 4). The boundaries of the Kaikoura survey area were drawn in 2004, based on discussions with local fishers, Dunedin Fisheries New Zealand (formerly Ministry of Fisheries) 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 were most commonly caught off Kaikoura. From this information, the survey area off Kaikoura was subdivided into three contiguous strata from Kaikoura Peninsula to Haumuri Bluffs; two inshore strata (strata 2 and 3) out to 100 m depth, and one offshore stratum from 100 to 200 m depth (stratum 4). In addition, the survey area included two discrete offshore areas south of Haumuri Bluffs (Conway Rocks and Bushett Shoal), which were treated as one stratum (Figure 4). Stratum 2 was subdivided in 2017 with the aim of improving the survey precision, and in addition the area of overlap with the marine reserve was removed. Each stratum was assumed to contain roughly random distributions of blue cod habitat and the total area (km^2) within each stratum was taken as a proxy for available habitat for blue cod.

2.4 Survey design

2.4.1 Allocation of sites

Simulations to determine the optimal allocation of random sites among the five strata were carried out using catch rate data from the 2011 and 2015 random-site surveys using NIWA's Optimal Station Allocation Program (*allocate*). Simulations were constrained to have a minimum of three sites per stratum and a CV (coefficient of variation) of no greater than 15%. The simulations indicated that 29 random sites were required to achieve the target CV.

The survey used a two-phase stratified random station design (Francis 1984) with 24 sites allocated to phase 1, and the remaining five available for phase 2, consistent with the proportion of phase 2 sites used in previous surveys (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*.

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.

Pot configuration and placement for random sites is defined in the blue cod potting manual (Beentjes & Francis 2011). Random-site surveys used systematic pot placement where the position of each pot was 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 Wellington-based NIWA inshore research vessel R.V. *Ikatere* was used on the 2017 Kaikoura survey. The *Ikatere* is an aluminium-alloy catamaran with a length of 13.9 m, beam of 4.85 m and is equipped with a 322 Hamilton water jet unit, and powered by twin Cummins QSC engines rated at 500HP, capable of 25 knots cruising speed. The *Ikatere* was skippered by Simon Wadsworth and Matt

McGlone, both of whom have considerable experience in commercial blue cod potting, and the latter was skipper on the 2013 and 2017 Marlborough Sounds blue cod surveys using the R.V. *Ikatere*. Previous random-site surveys in 2011 and 2015 were carried out on the F.V. *Mystique II* (Registration number 901093), a Kaikoura-based commercial vessel.

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 surveys.

A high-performance, 3-axis (3D) acoustic Doppler current profiler (ADCP, RDI Instruments, 600 kHz) was deployed at each site. The ADCP recorded current flow and direction in 1 m depth bins above the seafloor as well as bottom water temperature.

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), latitude and longitude from GPS, depth, and time of day. After each site was completed, the next closest site 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: Kaikoura – collect three otoliths per 1 cm size class for each sex in strata 1, 2A and 2B combined, and strata 3 and 4 combined (Appendix 2). Sex and maturity were determined by dissection and macroscopic examination of the gonads (Carbines 1998, 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 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.

2.4.4 Data storage

The 2017 Kaikoura survey trip code was IKA1706. At the completion of the survey, trip, station, catch, and biological data were entered into the *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. Random sites were entered into attribute *stn_code*, 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.). In the *age* database the *sample_no* is equivalent to *station_no* in the *trawl* database.

ADCP data were sent to the 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 ºC. 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 50ºC.
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 are presented for the 2017 random-site survey.

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). Fish length was recorded to the nearest millimetre on the survey, but following standard protocol, all lengths were rounded down to the nearest centimetre for analyses of the scaled length distribution, and mean length (i.e., using data extracted from t_lgth in the *trawl* database).

2.4.6.1 Catch rates

The catch rate (kg.pot^{-1}) estimates were pot-based and the CV estimates were 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 (33 cm and over). Catch rates of recruited blue cod were based on the sum of the weights of individual recruited fish. The stratum areas (km^2) shown in Table 1 were used as the area of the stratum (A_t) when scaling catch rates (equations 3 and 5 in Beentjes & Francis 2011). Catch rates are presented by stratum and overall. Catch rates were estimated for individual strata and for all strata combined.

2.4.6.2 Length-weight parameters

The length-weight parameters a_k, b_k from the 2017 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(weight) on log(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.

2.4.6.3 Growth parameters

Separate von Bertalanffy growth models (von Bertalanffy 1938) were fitted to the 2017 Kaikoura 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 2017 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. 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 but five blue cod were sexed during the 2017 Kaikoura survey. The unsexed 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. These fish were found to have tags and were returned alive after length and tags details were recorded.

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 (33 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). Catch curve analyses measure the sequential decline of cohorts annually. 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 CR 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.

A traditional catch curve was also plotted from the natural log of catch (numbers) against age and a regression line fitted to the descending curve from age-at-full recruitment. Although the Z estimate from the traditional catch curve was not used, it provides a diagnostic tool to investigate how Z is being estimated. This is particularly important when there are not many age classes, with potential for strong or weak year classes to introduce bias.

2.4.6.8 Spawner-per-recruit estimates

A spawner-per-recruit analysis was conducted using CASAL (Bull et al. 2005). The calculations involved simulating fishing with constant fishing mortality (*F*), 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})	0.1418	0.1607
t_0 (yr)	-0.2839	-0.6017
L_∞ (cm)	54.54	44.02
a	0.007186	0.006461
b	3.1256	3.2502

Natural mortality	default assumed to be 0.14. Sensitivity analyses 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 2017 Kaikoura survey von Bertalanffy models. The Kaikoura recreational MLS is 33 cm and selectivity was 6.27 years for males and 8.0 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).
Maximum age	assumed to be 31 years.

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.

2.4.6.9 Analyses of 2011 Kaikoura survey

The 2011 Kaikoura survey (trip_code MYS1101) was analysed as part of the 2015 survey analyses and report (Beentjes & Page 2017). At that time the 2011 survey was not on the *trawl* database or published, so analyses were carried out from raw survey data provided to NIWA on a spreadsheet. Catch rates of recruited blue cod were based on the sum of the weights of individual fish 30 cm and over, and 33 cm and over. These fish weights were estimated from the 2015 Kaikoura survey length-weight coefficients because no individual fish weight data were available for the 2011 survey at that time. The 2011 survey analyses were not updated from the *trawl* database extract or 2011 survey length weight relationships as part of this report. The results of the 2011 survey, have since been published (Carbines & Haist 2018d).

3. RESULTS

3.1 2017 Kaikoura random-site survey

Twenty-nine random sites (6 pots per site, producing 174 pot lifts) from five strata off Kaikoura were surveyed from 1–12 December 2017 (Table 1, Figure 5). Depths sampled were 11–121 m (mean = 53 m). Twenty-four sites were carried out in phase-one and five in phase-two.

3.1.1 Catch and catch rates

A total of 700.1 kg of blue cod (1524 fish) was taken, comprising 94.5% by weight of the catch of all species on the survey (Table 2). Bycatch species included eight teleost fishes, as well as octopus, hagfish and crayfish. The three most abundant bycatch species, by number, were girdled wrasse (*Notolabrus cinctus*), sea perch (*Helicolenus percoides*), and scarlet wrasse (*Pseudolabrus miles*).

Mean catch rates (kg.pot^{-1}) of blue cod (all blue cod, and 33 cm and over) are presented by stratum and overall (Table 3, Figure 5). Mean catch rates of blue cod (all sizes) by stratum were 0–6.9 kg.pot^{-1} with the zero catch in stratum 2a (inshore from South Bay to Hikurangi Marine Reserve), and the highest in stratum 4, offshore of Kaikoura Peninsula (Table 3, Figure 5). The all-blue-cod survey catch rate was 1.9 kg.pot^{-1} with a CV of 16%. Catch rates for recruited blue cod (33 cm and over) followed the same pattern among strata as for all blue cod and was 0.91 kg.pot^{-1} (CV 19%) (Table 3, Figure 5). Of the 174 random-site pots, 52 (30%) had zero catch of blue cod.

3.1.2 Biological and length frequency data

Of the 1524 blue cod caught, all but five were sexed, measured for length, and weighed (Table 4). The five unsexed fish were measured for length and released alive. The sex ratios were 0–89% male across the five strata and the overall weighted sex ratio was 45% male (Table 4). Length was 17–51 cm for males and 17–45 cm for females, although this range varied among strata and the overall weighted mean length was 28.4 cm for males and 28.6 cm for females. The scaled length frequency distributions were similar in strata 1 and 3 with modes at about 28 cm and 25 cm for males and females, although sample sizes were low for females in stratum 1 (Figure 6). By contrast, in stratum 4, the 25 cm female mode was absent, fish tended to be larger, and females were more than twice as abundant than males.

3.1.3 Age and growth

Otolith section ages from 149 males and 128 females collected from the 2017 random-site survey were used to estimate the population age structure from Kaikoura in 2017 (Table 5). The length-age data are plotted and the von Bertalanffy model fits and 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 particularly for males; and males grow faster and are the largest fish. The 2017 fitted von Bertalanffy curves are similar to the 2015 survey (Figure 8).

Between-reader comparisons are presented in Figure 9. The first counts of the two readers showed 88% agreement, and overall there was no bias between readers with a CV of 1.2% and average percent error (APE) of 0.9%.

3.1.4 Spawning activity

Gonad stages of blue cod sampled in the early December 2017 Kaikoura survey are presented for all fish combined and by stratum (Table 6a and 6b). There were indications of spawning activity during the survey period with about 28% of females and 6% of males maturing or running ripe, suggesting that spawning had not peaked. Gonad stage by stratum results suggest that nearly all spawning activity occurred off Kaikoura Peninsula, with the only running ripe fish found in stratum 4 at depths of 100–200 m.

3.1.5 Population length and age composition

The scaled length frequency and age distributions for the 2017 Kaikoura 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 10).

The scaled length frequency distribution for males was unimodal with a strong peak at about 27 cm and an overall mean length of 28 cm. The female distribution was bimodal with a strong peak at about 25 cm and the overall mean length is 29 cm (Figure 10). The cumulative distribution plots of length frequency are similar between sexes with the only real difference resulting from the higher proportion of larger females over 30 cm. The mean weighted coefficients of variation (MWCVs) around the length distributions were 32% for males and 33% for females. Recruited fish (33 cm and over) included 19% of males and 29% of females by number.

Age estimates were 2–19 years for males and 2–20 years for females, but most males and females were 3–5 years old (Figure 10). The estimated population age distributions indicate knife-edge selectivity to the potting method at three years with strong modes at three and especially five years for both sexes, but particularly for males. The age distribution also shows a corresponding weak mode for four-year-olds. The cumulative distribution plots of age frequency show clearly that females had a much higher proportion of older fish than males, driven largely by the strong male three and five-year-old cohorts (Figure 10). The mean age of females was greater than that of males (5.2 for males and 6.4 years for females). The MWCVs around the age distributions were 22% for males and 36% for females, the latter was higher than desired to provide a good representation of the overall population age structure.

3.1.6 Total mortality estimates (*Z*) and spawner-per-recruit (SPR)

Chapman-Robson 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 33 cm. The CR Z for AgeR of eight years is 0.41 (95% confidence interval of 0.27–0.57).

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 for diagnostic purposes (Figure 11). There were few blue cod aged between 10 and 20 years of age which has influenced the slope of the regression line and hence Z. The natural log of numbers-at-age does not follow the ideal straight line descending limb, suggesting that the assumption of constant recruitment had been sufficiently violated to detract from the results. Although the CR estimation is less sensitive to age classes with few fish, this will have introduced error (and probably bias) into the Z estimate, which is reflected in the wide 95% confidence intervals around Z (see Table 7).

Mortality parameters (CR *Z* and *F*, and *M*) and spawner-per-recruit (SPR) 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 0.27 and associated spawner-per-recruit was 33.8% (Figure 12). At the 2017 levels of fishing mortality, the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 34% of the contribution in the absence of fishing. The 95% confidence intervals around the SPR ratios were 26–49% (Table 8).

Stratum 1 is mostly outside the Kaikoura Marine Area (see Figure 4) where the MLS is 30 cm, not 33 cm. The resulting spawner-per-recruit estimate may not be representative of blue cod in this stratum.

3.2 Kaikoura random-site survey time series (2011, 2015, 2017)

Mean catch rates (kg.pot^{-1}) for all blue cod and recruited blue cod are presented in Figure 13. The relative differences in catch rates among strata are preserved over time, i.e., catch rates were consistently highest in stratum 4, and lowest in stratum 2. For Kaikoura overall, there was no trend in abundance (Figure 13).

The scaled length frequency distributions and mean length were similar for all three surveys with any difference due to the strong recruitment of mainly juvenile male blue cod in 2015, progressing through to strong modes in 2017 (male mode 27 cm, female mode 25 cm) (Figure 14).

The sex ratio for all surveys was 47–55% male for all blue cod, and 45–55% male for recruited blue cod, with no clear trends (Figure 15).

Age compositions can be validly compared only for the 2015 and 2017 random-site surveys because blue cod ageing from the 2011 random-site survey was carried out before the new age determination protocol was developed (Figure 16). The 3-year-old age class in 2015 progressed through to a strong 5-year-old age class for both sexes in 2017. Similarly, the strong 5 and 6-year old age classes progressed to strong 7 and 8-year-old age classes in 2017, particularly for females. Chapman Robson total mortality estimates (Z) increased between 2015 and 2017, with a corresponding decrease in the SPR estimates (see Figure 12). The reasons for this are discussed below.

The proportion of pots with zero catch for the three random-site surveys ranged from 29–37% with no clear trends (Figure 17).

4. DISCUSSION

4.1 General

The 2017 Kaikoura potting survey was the third random-site survey in the time series of relative abundance and population structure of blue cod from this area, after previous surveys in 2011 and 2015. Fixed-site surveys were carried out in 2004, 2007 and then concurrently with the random-site surveys in 2011 and 2015. The fixed-site surveys were discontinued after the 2015 survey because the random-site design is more accurate, statistically robust and more likely to represent the entire blue cod population (Stephenson et al. 2009). Differences in catch rate trends among equivalent strata between the 2011 and 2015 fixed and random surveys, and larger blue cod from random surveys (Beentjes & Page 2017, Carbines & Haist 2018d), suggests that there is no suitable way of quantitatively linking the fixed-site series with the random-site series. Accordingly, the results from the four fixed-site surveys will not be discussed further in this report.

4.2 Blue cod habitat

The abundance estimates, length and age distributions, and sex ratio were weighted (scaled) by the area of each stratum in this survey. Multibeam echosounder seabed surveys in 2017 and 2018 from Cape Campbell to Haumuri Bluffs, after the November 2016 Kaikoura earthquake, provided high resolution coastal bathymetry maps showing locations of discrete substrates such as rocky reefs, rippled sand and soft muddy bottom (Figure 18) (Neil et al. 2018). These substrate maps may be useful for re-stratifying future surveys, and also provide blue cod generalised habitat maps that shows that the strata with the most comprehensive rocky reef habitat are also those with the highest catch rates (i.e., strata 3 and 4) (see Figure 5). In contrast, stratum 2 has vast areas of rippled sand and the lowest catch rates. Scaling by strata area assumes that the size of each stratum is directly proportional to the amount of blue cod habitat, although the recent high resolution coastal bathymetry maps indicate that some strata clearly have more habitat suited to blue cod than others.

4.3 Survey precision

The survey design CV around relative abundance (catch rates) was not specified in the project objectives for the 2017 Kaikoura survey, but a CV of around 15% is generally targeted. The achieved CV of 16% in 2017 was similar to that from the previous random-site surveys (17% for 2011 and 19% for 2015) (Beentjes & Page 2017, Carbines & Haist 2018d). The achieved CV indicates that the survey design and number of sites used (25–29) are appropriate for Kaikoura random-site surveys.

4.4 Cohort progression

The progression of the strong 3-year-old age class in 2015 to the strong 5-year-old age class in 2017 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. Growth estimates indicate that males will be on average 6-years-old and females 8-years-old when they reach the current MLS of 33 cm within the Kaikoura Marine Area (see Figure 7). Outside this area, males will be 5.5 years old and females 6.5 years old when they reach the current MLS of 30 cm. The relatively high numbers of blue cod from the 2012 year-class in the 2017 survey, compared to the 2015 survey, indicates that blue cod are not fully selected to the potting method until at least 4 to 5 years old, a finding supported by the age composition in other areas surveyed.

The strong blue cod 2012 year-class (3-year-olds) and the weak 2011 year-class (4-year-olds) observed in Kaikoura in December 2015, were also present in the age compositions from Motunau in January 2016, and Banks Peninsula in April 2016 (Beentjes & Fenwick 2017, Beentjes & Sutton 2017). In 2017, the 2012 year-class had grown to form a strong 5-year-old cohort in Kaikoura and it is reasonable to expect the 2012 year-class also to be strong in Motunau and Banks Peninsula as this cohort grows through these populations. This consistent pattern suggests that the 2012 spawning event on the northeast coast of the South Island was more successful than average and/or that natural mortality was low, possibly as a result of favourable environmental conditions. Blue cod have a restricted home range (Rapson 1956, Mace & Johnston 1983, Mutch 1983, Carbines & McKenzie 2001, Carbines & McKenzie 2004) and the Kaikoura, Motunau, and Banks Peninsula stocks of this species are likely to consist of largely independent sub-populations. However, there is no evidence that blue cod are genetically distinct around the New Zealand mainland (Gebbie 2014) suggesting that mixing is occurring on a wider geographical scale than within the restricted home range indicated by tagging studies. Mechanisms for genetic mixing are unknown. Hence, the strong 2012 year-class, across the northeast South Island, may have at least two possible explanations: 1) a strong spawning event in one area, resulted in abundant eggs and larvae drifting to other areas, or 2) strong spawning events in all three areas, enhancing localised spawning and survival of eggs and larvae.

4.5 Sex change and sex ratio

In 2017, sex ratio in the deeper stratum 4 (offshore of Kaikoura Peninsula in 100–200 m, see Figure 4) strongly favoured females, whereas the sex ratio was skewed towards males in other strata, and blue cod were larger overall in stratum 4. This finding was consistent across the three random surveys (Beentjes & Page 2017, Carbines & Haist 2018d). Sex ratios favouring females are uncommon in heavily exploited blue cod populations. The high proportion of females off Kaikoura Peninsula in deeper water appears to be due to spawning behaviour involving both larger fish and more females than males, since nearly all spawning condition blue cod were caught in strata 3 and 4, and running ripe blue cod were only caught in stratum 4 (see Table 6b).

Blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow (Carbines 2004); the Kaikoura 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 were strongly 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, Beentjes & Sutton 2017). 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) suggest 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. While the sex ratio is close to parity for Kaikoura for all surveys, this is strongly influenced by stratum 4 (offshore of Kaikoura Peninsula in 100–200 m) where abundance is consistently the highest and the proportion male was much lower than females. As discussed above, this is probably related to spawning behaviour off Kaikoura Peninsula with spawning condition females confined to stratum 4. For the other strata, the sex ratio favours males, especially in stratum 2 (inshore south Bay to Haumuri Bluffs) which also had the lowest abundance and the smallest fish.

4.6 Stock status

The *Harvest Strategy Standard* specifies that a Harvest Strategy 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 $\mathrm{F_{MSY}}$ is the level of spawner-per-recruit $\mathrm{F_{\%SPR}}$ (Ministry of Fisheries 2011). Blue cod is categorised as an exploited species with low productivity (on account of complexities of sex change) and the recommended default proxy for $\mathrm{F_{MSY}}$ is $\mathrm{F_{45\%SPR}}$.

Growth rates were similar in 2015 and 2017, but there were differences in length and age compositions that resulted in increased CR total mortality estimates (*Z*) in 2017 and a corresponding reduction in the SPR estimate (see Figure 12). The 2015 random-site survey *Z* was 0.23 and the SPR estimate, (M value of 0.14, and age at full recruitment of 8 years) was $\mathrm{F_{58\%SPR}}$ ($\mathrm{F_{42\%}}$–$\mathrm{F_{86\%}}$, 95% CIs), indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit was reduced to 58% of the contribution in the absence of fishing (see Figure 12). In 2017, Z increased to 0.41 and the SPR estimate decreased to $\mathrm{F_{34\%SPR}}$ ($\mathrm{F_{26\%}}$–$\mathrm{F_{49\%}}$, 95% CIs). These results suggest that the level of exploitation (F) of Kaikoura blue cod stocks was below the F_{MSY} target reference point of $\mathrm{F_{45\%SPR}}$, in 2015 (under-exploited) and above the target in 2017 (over-exploited). However, a change in total mortality and SPR of this magnitude in two years seems implausible, and examination of the traditional catch curves provides some explanation. Total mortality (*Z*) is a product of the slope of the right hand descending curve of age versus population numbers. The wide scatter of numbers at age and the absence of a clear dome on the catch curve may be a result of variable recruitment, and hence a violation of the catch curve assumption that recruitment is constant (see Figure 11). Females were the main contributors to increased mortality in 2017. The point estimates of *Z*, *F* and SPR in both 2015 and 2017 should therefore be treated with caution and Z and SPR estimates that fall within the 95% confidence intervals may be plausible.

4.7 Reproductive condition

All Kaikoura blue cod surveys (fixed and random) were carried out in December, so reproductive status is temporally comparable. Proportions of each gonad stage for fixed and random surveys were almost identical in the 2011 survey (Carbines & Haist 2018d), so gonad stage data were combined for fixed and random surveys in 2011 and 2015 (Figure 19). All five surveys show indications of spawning activity in December for both sexes, with variable proportions in the running-ripe condition. Blue cod are considered to be serial or batch-spawners with a protracted spawning period that can extend from June to January, with peak spawning occurring later in southern latitudes (Beer et al. 2013). During the spawning period, individuals can spawn multiple times (Pankhurst & Conroy 1987), and it seems likely they will transition between the ripe and running-ripe conditions during this period. There were always higher proportions of females than males in the combined ripe/running-ripe conditions from the Kaikoura surveys, possibly related to the reproductive strategy where a large male will hold a territory, attracting multiple females. The Kaikoura surveys occurred during the protracted spawning period, but whether this is the peak spawning period, is unknown.

4.8 Management implications

The increase in MLS from 30 cm to 33 cm and the reduction in bag limit from 10 to 6 blue cod within the Kaikoura Marine Area took place in March 2014. There were no clear indications that these regulations have had an effect on blue cod random survey catch rates or size of blue cod in 2015 and 2017. Displacement of recreational fishing effort from the Marlborough Sounds to Kaikoura is likely to have occurred in recent years with the restrictions on blue cod fishing in the Marlborough Sounds. Without information on recreational fishing effort, however, it is difficult to gauge the impacts of the increase in MLS and reduction in MDL within the Kaikoura Marine Area. For example, it may be that the benefits of these measures were diminished or offset by increased fishing effort.

There are no clear indications that the blue cod population off Kaikoura surveyed in 2017 was adversely impacted by the November 2016 earthquake.

5. ACKNOWLEDGMENTS

This research was carried out by NIWA under contract to the Ministry for Primary Industries (Project KAI201609). We thank the skipper and crew of NIWA research vessel *Ikatere*, Dane Buckthought and Keren Spong (NIWA) and Cameron Walsh (Stock Monitoring Services) for preparing and reading otoliths, Peter McMillan, Rosemary Hurst (NIWA) and Marc Griffiths (Fisheries New Zealand) for reviewing the manuscript, and Marianne Vignaux for editorial comments.

6. REFERENCES

Beentjes, M.P.; Carbines, G.D. (2003). Abundance of blue cod off Banks Peninsula in 2002. *New Zealand Fisheries Assessment Report 2003/16*. 25 p.

Beentjes, M.P.; Carbines, G.D. (2005). Population structure and relative abundance of blue cod (*Parapercis colias*) off Banks Peninsula and in Dusky Sound, New Zealand. *New Zealand Journal of Marine and Freshwater Research 39*: 77–90.

Beentjes, M.P.; Carbines, G.D. (2006). Abundance of blue cod off Banks Peninsula in 2005. *New Zealand Fisheries Assessment Report 2006/1*. 24 p.

Beentjes, M.P.; Carbines, G.D. (2009). Abundance, size and age composition, and mortality of blue cod off Banks Peninsula in 2008. *New Zealand Fisheries Assessment Report 2009/25*. 46 p.

Beentjes, M.P.; Carbines, G.D. (2011). Relative abundance, size and age structure, and stock status of blue cod off south Otago in 2010. *New Zealand Fisheries Assessment Report 2011/42*. 60 p.

Beentjes, M.P.; Carbines, G.D. (2012). Relative abundance, size and age structure, and stock status of blue cod from the 2010 survey in Marlborough Sounds, and review of historical surveys. *New Zealand Fisheries Assessment Report 2012/43*. 137 p.

Beentjes, M.P.; Fenwick, M. (2017). Relative abundance, size and age structure, and stock status of blue cod off Banks Peninsula in 2016. *New Zealand Fisheries Assessment Report 2017/30*. 81 p.

Beentjes, M.P.; Francis, R.I.C.C. (2011). Blue cod potting surveys: standards and specifications. Version 1. *New Zealand Fisheries Assessment Report 2011/29*. 47 p.

Beentjes, M.P.; Michael, K.; Pallentin, A.; Parker, S.; Hart, A. (2017). Blue cod relative abundance, size and age structure, and habitat surveys of Marlborough Sounds in 2013. *New Zealand Fisheries Assessment Report 2017/61*. 110 p.

Beentjes, M.P.; Page, M. (2016). Relative abundance, size and age structure, and stock status of blue cod in Dusky Sound in 2014. *New Zealand Fisheries Assessment Report 2016/42*. 51 p.
Beentjes, M.P.; Page, M. (2017). Relative abundance, size and age structure, and stock status of blue cod off Kaikoura in 2015. *New Zealand Fisheries Assessment Report 2017/16*. 54 p.
Beentjes, M.P.; Page, M.; Sutton, C.; Olsen, L. (2018). Relative abundance, size and age structure, and stock status of blue cod from the 2017 survey in Marlborough Sounds, and review of historical surveys. *New Zealand Fisheries Assessment Report 2018/33*. 103 p.
Beentjes, M.P.; Sutton, C. (2017). Relative abundance, size and age structure, and stock status of blue cod off Motunau in 2016. *New Zealand Fisheries Assessment Report 2017/17*. 54 p.
Beer, N.A.; Wing, S.R.; Carbines, G. (2013). First estimates of batch fecundity for Parapercis colias, a commercially important temperate reef fish. *New Zealand Journal of Marine and Freshwater Research 47*: 587–594.
Blackwell, R.G. (1997). Abundance, size composition, and sex ratio of blue cod in the Marlborough Sounds, September 1995. *NIWA Technical Report 88*. 52 p.
Blackwell, R.G. (1998). Abundance, size and age composition, and yield-per-recruit of blue cod in the Marlborough Sounds, September 1996. *NIWA Technical Report 30*. 47 p.
Blackwell, R.G. (2002). Abundance, size and age composition of recruited blue cod in the Marlborough Sounds, September 2001. Final Research Report for Ministry of Fisheries Research Project BCO2001/01. (Unpublished report held by Fisheries New Zealand, Wellington.)
Blackwell, R.G. (2006). Abundance and size composition of recruited blue cod in the Marlborough Sounds, September 2004. Final Research Report for Ministry of Fisheries Research Project BCO2004/01. 18 p. (Unpublished report held by Fisheries New Zealand, Wellington.)
Blackwell, R.G. (2008). Abundance and size composition of recruited blue cod in the Marlborough Sounds, September 2007. Final Research Report for Ministry of Fisheries Research Project BCO2006/01 24 p. (Unpublished report held by Fisheries New Zealand, Wellington.)
Bull, B.; Dunn, A. (2002). Catch-at-age: User Manual v1.06.2002/09/12. *NIWA Internal Report 114*. 23 p. (Unpublished report held in NIWA Library, Wellington.)
Bull, B.; Francis, R.I.C.C.; Dunn, A.; McKenzie, A.; Gilbert, D.J.; Smith, M.H. (2005). CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v2.07-2005/08/21. *NIWA Technical Report 127*. 272 p.
Campana, S.E. (2001). Accuracy, precision, and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology 59*: 197–242.
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.
Carbines, G.; Haist, V. (2014). Relative abundance, size and age structure, and stock status of blue cod in Paterson Inlet of BCO 5 in 2010. *New Zealand Fisheries Assessment Report 2014/14*. 49 p.
Carbines, G.; Haist, V. (2017a). Relative abundance, population structure, and stock status of blue cod in the Foveaux Strait in 2014. Experimental evaluation of pot catchability and size selectivity. *New Zealand Fisheries Assessment Report 2017/63*. 61 p.
Carbines, G.; Haist, V. (2017b). Relative abundance, size and age structure, and stock status of blue cod off Banks Peninsula in 2012. *New Zealand Fisheries Assessment Report 2017/37*. 126 p.
Carbines, G.; Haist, V. (2018a). Relative abundance, population structure, and stock status of blue cod in Paterson Inlet in 2014. Concurrent fixed and random site potting surveys. *New Zealand Fisheries Assessment Report 2018/09*. 59 p.
Carbines, G.; Haist, V. (2018b). Relative abundance, population structure, and stock status of blue cod off north Otago in 2013. Concurrent fixed and random site potting surveys. *New Zealand Fisheries Assessment Report 2018/07*. 58 p.
Carbines, G.; Haist, V. (2018c). Relative abundance, population structure, and stock status of blue cod off south Otago in 2013. Estimates of pot catchability and size selectivity. *New Zealand Fisheries Assessment Report 2018/08*. 69 p.
Carbines, G.; Haist, V. (2018d). Relative abundance, size and age structure, and stock status of blue cod off Kaikoura and north Canterbury in 2011–12. Comparisons of potting survey designs and estimates of pot catchability and size selectivity. *New Zealand Fisheries Assessment Report 2018/06*. 97 p.

Carbines, G.D. (1998). Blue cod age validation, tagging feasibility and sex inversion. Final Research Report for Ministry of Fisheries Project SOBCO4. 74 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Carbines, G.D. (2004). Age, growth, movement and reproductive biology of blue cod (*Parapercis colias*-Pinguipedidae): Implications for fisheries management in the South Island of New Zealand. Unpublished Ph.D. thesis, University of Otago, Dunedin, New Zealand. 224 p.

Carbines, G.D. (2007). Relative abundance, size, and age structure of blue cod in Paterson Inlet (BCO 5), November 2006. *New Zealand Fisheries Assessment Report 2007/37*. 31 p.

Carbines, G.D.; Beentjes, M.P. (2006a). Relative abundance of blue cod off north Canterbury in 2004–2005. *New Zealand Fisheries Assessment Report 2006/30*. 26 p.

Carbines, G.D.; Beentjes, M.P. (2006b). Relative abundance of blue cod off North Otago in 2005. *New Zealand Fisheries Assessment Report 2006/29*. 20 p.

Carbines, G.D.; Beentjes, M.P. (2009). Relative abundance, size and age structure, and mortality of blue cod off north Canterbury (BCO 3) in 2007–08. *New Zealand Fisheries Assessment Report 2009/37*. 56 p.

Carbines, G.D.; Beentjes, M.P. (2011). Relative abundance, size and age structure, and stock status of blue cod off north Otago in 2009. *New Zealand Fisheries Assessment Report 2011/36*. 57 p.

Carbines, G.D.; Beentjes, M.P. (2012). Relative abundance, size and age structure, and stock status of blue cod in Foveaux Strait in 2010. *New Zealand Fisheries Assessment Report 2012/39*. 66 p.

Carbines, G.D.; McKenzie, J (2001). Movement patterns and stock mixing of blue cod in Southland (BCO 5). Final Research Report for Ministry of Fisheries Research Project BCO9702. 16 p. (Unpublished report held by the Ministry for Primary Industries, Wellington.)

Carbines, G.D.; McKenzie, J. (2004). Movement patterns and stock mixing of blue cod in Dusky Sound in 2002. *New Zealand Fisheries Assessment Report 2004/36*. 28 p.

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

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.

Fisheries New Zealand (2018). Fisheries Assessment Plenary, May 2018: stock assessments and stock status. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand, Wellington, New Zealand. 1674p.

Francis, R.I.C.C. (1984). An adaptive strategy for stratified random trawl surveys. *New Zealand Journal of Marine and Freshwater Research 18*: 59–71.

Gebbie, C.L. (2014). Population genetic structure of New Zealand blue cod *(Parapercis colias*) based on mitochondrial and microsatellite DNA markers. 89p. MSc. thesis, Victora Univserity of Wellington.

Hart, A.M.; Walker, N.A. (2004). Monitoring the recreational blue cod and sea perch fishery in the Kaikoura - North Canterbury area. *New Zealand Fisheries Assessment Research Report 2004/45*. 30 p.

Mace, J.T.; Johnston, A.D. (1983). Tagging experiments on blue cod (*Parapercis colias*) in the Marlborough Sounds, New Zealand. *New Zealand Journal of Marine and Freshwater Research 17*: 207–211.

Ministry for Primary Industries (2017). National Blue cod Strategy. Summary Report of results and feedback. (http://www.mpi.govt.nz/news-and-resources/publications/). 153 p.

Ministry of Fisheries (2011). Operational guidelines for New Zealand's harvest strategy standard (Revision 1). 78 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Mutch, P.G. (1983). Factors influencing the density and distribution of the blue cod (*Parapercis colias*) (Pisces: Mugilodae). Unpublished MSc thesis, University of Auckland, New Zealand. 76 p.

Neil, H. L.; Mackay, K..; Mackay, E.J.; Kane, T.; Wilcox, S.; Smith, R. (2018). Beneath the waves: Kaikōura -Cape Campbell. NIWA Chart, Miscellaneous Series. Published by the National Institute of Water and Atmospheric Research Ltd.

Pankhurst, N.W.; Conroy, A.M. (1987). Seasonal changes in reproductive condition and plasma levels of sex steroids in the blue cod *Parapercis colias* (Bloch and Schneider) Mugiloididae. *Journal of Fish Physiology and Biochemistry 4*: 15–26.

Rapson, A.M. (1956). Biology of the blue cod (*Parapercis colias* Forster) of New Zealand. Unpublished PhD thesis, Victoria University, Wellington, New Zealand. 103 p.

Stephenson, P.; Sedberry, G.; Haist, V. (2009). Expert review panel report. Review of blue cod potting surveys in New Zealand. Draft 14 May 2009. BCOREV-2009-22, 14 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

von Bertalanffy, L. (1938). A quantitative theory of organic growth. *Human Biology 10*: 181–213.

Walsh, C. (2017). Age determination protocol for blue cod (*Parapercis colias*). *New Zealand Fisheries Assessment Report 2017/15*. 34 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*. 139 p.

7. TABLES AND FIGURES

Table 1: Effort and catch data for the 2017 Kaikoura random-site blue cod potting survey.

Stratum	Area (km^2)	Site type	*N* sets (sites) Phase 1	Phase 2	*N* pots (stations)	Catch (blue cod) *N*	kg	Depth (m) Mean	Range
1	26.4	Random	5		30	254	80.4	36.1	25–42
2a	37.8	Random	3		18	0	0	26.5	16–43
2b	58.7	Random	4		24	3	0.3	28.6	11–49
3	24.8	Random	8	1	54	711	287.4	68.0	27–103
4	15.7	Random	4	4	48	556	332	106.9	86–121
Total	163.4	Random	24	5	174	1 524	700.1	53.2	11–121

Table 2: Total catch and numbers of blue cod and bycatch species caught on the 2017 Kaikoura random-site blue cod potting survey. Percent of the catch by weight is also shown.

Common name	Species	Random sites Code	Number	Catch (kg)	% catch
Blue cod	*Parapercis colias*	BCO	700.1	1 524	94.5
Common octopus	*Octopus maorum*	OCT	12.7	3	1.7
Sea perch	*Helicolenus percoides*	SPE	8.3	20	1.1
Scarlet wrasse	*Pseudolabrus miles*	SPF	6.4	19	0.9
Girdled wrasse	*Notolabrus cincta*	GPF	4.7	22	0.6
Hagfish	*Eptatretus cirrhatus*	HAG	2	1	0.3
Red cod	*Pseudophycis bachus*	RCO	1.4	1	0.2
Tarakihi	*Nemadactylus macropterus*	NMP	1.3	7	0.2
Leatherjacket	*Meuschenia scaber*	LEA	1.1	2	0.1
Southern bastard cod	*Pseudophycis barbata*	SBR	1.1	2	0.1
Crayfish	*Jasus edwardsii*	CRA	0.9	1	0.1
Red scorpion fish	*Scorpaena papillosa*	RSC	0.8	5	0.1
Totals			740.8	1607	100

Table 3: Mean catch rates for all blue cod, and recruited blue cod (33 cm and over) from the 2017 Kaikoura random-site blue cod potting survey. Catch rates are pot-based, and s.e. and CV are set-based. s.e., standard error; CV coefficient of variation; NA, not applicable.

		All blue cod			Recruited blue cod ≥ 33 cm		
Stratum	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)
1	30	2.68	1.48	55.2	0.74	0.40	53.5
2a	18	0.00	NA	NA	0.00	NA	NA
2b	24	0.01	0.01	100.0	0.00	NA	NA
3	54	5.32	0.90	17.0	2.23	0.77	34.4
4	48	6.92	1.31	19.0	4.72	1.14	24.2
Overall	174	1.91	0.30	15.9	0.91	0.17	18.9

Table 4: Descriptive statistics for blue cod caught on the 2017 Kaikoura random-site blue cod potting survey. Outputs are raw for each stratum, and weighted overall. Sex ratio is also given for recruited blue cod (33 cm and over). m, male; f, female; u, unsexed. –, no data.

	Random site survey						
			Length (cm)			Percent male	
Stratum	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited blue cod ≥ 33 cm
1	m	171	27.2	17.1	43.3	67.6	88.7
	f	83	23.8	17.0	35.2		
	u	–		–	–	–	–
2a	m	–	–	–	–	–	–
	f	–	–	–	–	–	–
	u	–	–	–	–	–	–
2b	m	–	–	–	–	–	–
	f	3	18.3	17.4	19.8	0	0
	u	–	–	–	–	–	–
3	m	420	28.4	17.9	48.3	60.1	53.2
	f	286	28.4	18.9	43.3		
	u	5	34.0	29.3	38.3	–	–
4	m	171	32.3	23.5	51.3	30.9	24.5
	f	385	32.7	23.0	45.0		
	u	–	–	–	–	–	–
Overall	m	762	28.4	17.1	51.3	55.4	44.8
	f	757	28.6	17.0	45.0		
	u	5	28.5	29.3	38.3		

Table 5: Otolith ageing data used in the catch-at-age, Z estimates and SPR analyses for the 2017 Kaikoura random-site blue cod potting survey.

		Length of aged fish (cm)		Age (years)	
Survey	No. otoliths	Minimum	Maximum	Minimum	Maximum
Total	277	17	51	2	20
Male	149	17	51	2	19
Female	128	17	45	2	20

Table 6a: Gonad stages (%) of blue cod from the 2017 Kaikoura random-site blue cod potting survey in early December 2017 for all blue cod by sex. 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.

	Gonad stage (%)					
Sex	1	2	3	4	5	*N*
Males	51.8	41.6	6.3	0.1	0.1	762
Females	62.0	6.7	24.3	3.4	3.6	757

Table 6b: Gonad stages (numbers) of blue cod from 2017 Kaikoura random-site blue cod potting survey in early December 2017 for all blue cod by stratum and sex.

	Male gonad stage (*N*)					
Stratum	1	2	3	4	5	Stratum totals (*N*)
1a	2	1				3
1b	96	69	3			168
3	240	159	20		1	420
4	57	88	25	1		171
Gonad totals (*N*)	395	317	48	1	1	762

	Female gonad stage (N)					
Stratum	1	2	3	4	5	Stratum totals (*N*)
1a	1					1
1b	78	4				82
2b	3					3
3	228	15	23	6	14	286
4	159	32	161	20	13	385
Gonad totals (*N*)	469	51	184	26	27	757

Table 7: Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals of blue cod for the random-site 2017 Kaikoura random-site blue cod potting survey. AgeR, age at full recruitment.

		95% CIs	
AgeR	*Z*	Lower	Upper
5	0.58	0.4	0.82
6	0.34	0.24	0.47
7	0.45	0.3	0.62
8	0.41	0.27	0.57
9	0.32	0.2	0.46
10	0.38	0.24	0.57

Table 8: Mortality parameters (Chapman Robson *Z*, *F* and *M*) and spawner-per-recruit ($F_{SPR\%}$) point-estimates at three values of *M* for blue cod from the 2017 Kaikoura random-site blue cod potting survey. The mortality parameters and spawner-per-recruit estimates are also given for the default *M* (0.14) and the 95% confidence interval values of Z. AgeR = 8, where AgeR is the age at which females reach MLS of 33 cm. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality; LowerCI, lower 95% confidence interval; UpperCI, Upper 95% confidence interval.

M	*Z*	*F*	$F_{\%SPR}$	Estimate
0.11	0.41	0.3	$F_{25.5\%}$	Point
0.14	0.41	0.27	$F_{33.8\%}$	Point
0.17	0.41	0.24	$F_{42.3\%}$	Point
0.14	0.27	0.13	$F_{49.4\%}$	LowerCI
0.14	0.57	0.43	$F_{26.5\%}$	UpperCI

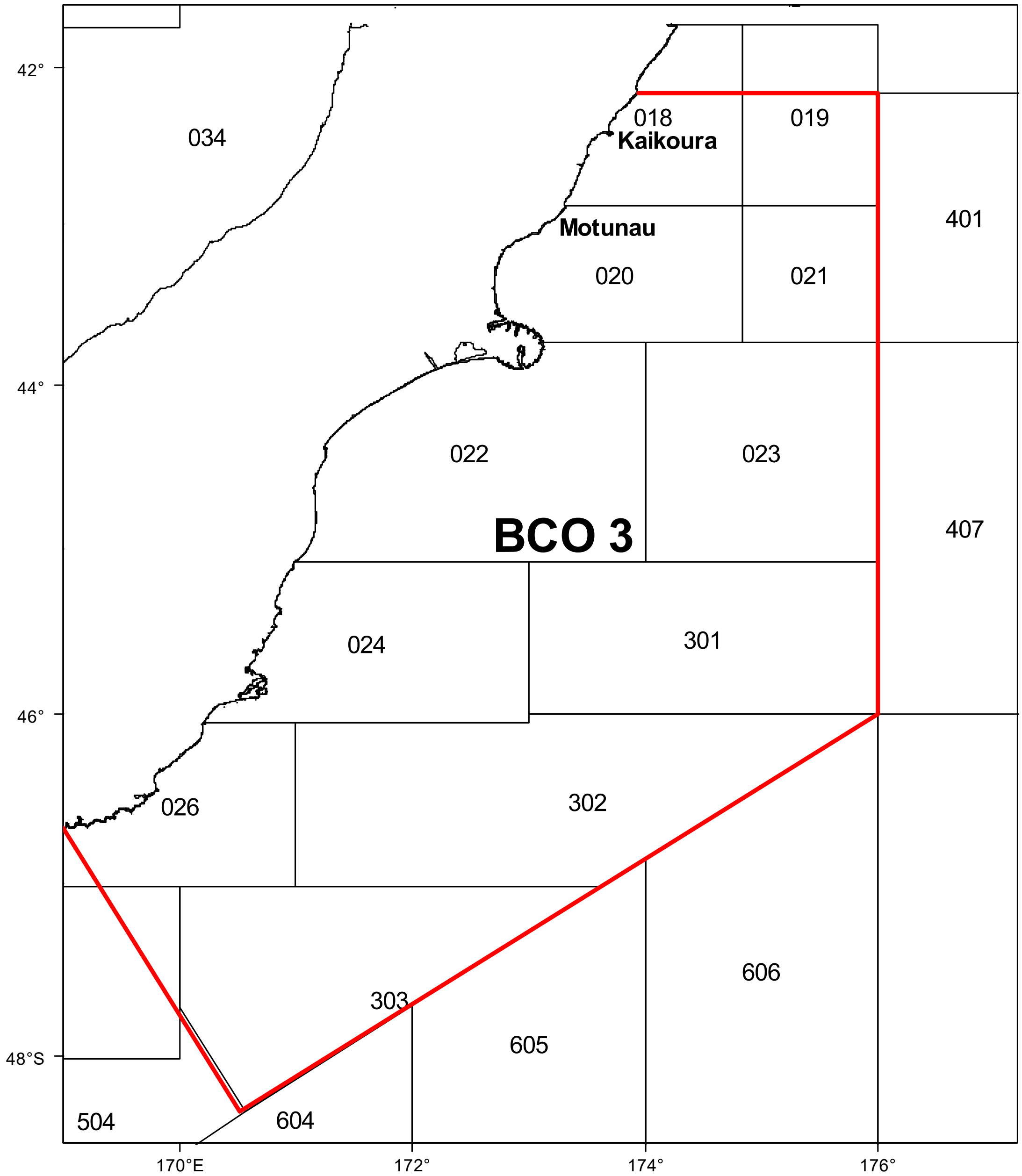

Figure 1: Blue cod Quota Management Area BCO 3 (red border) and statistical areas. The north Canterbury potting survey locations of Kaikoura and Motunau are shown.

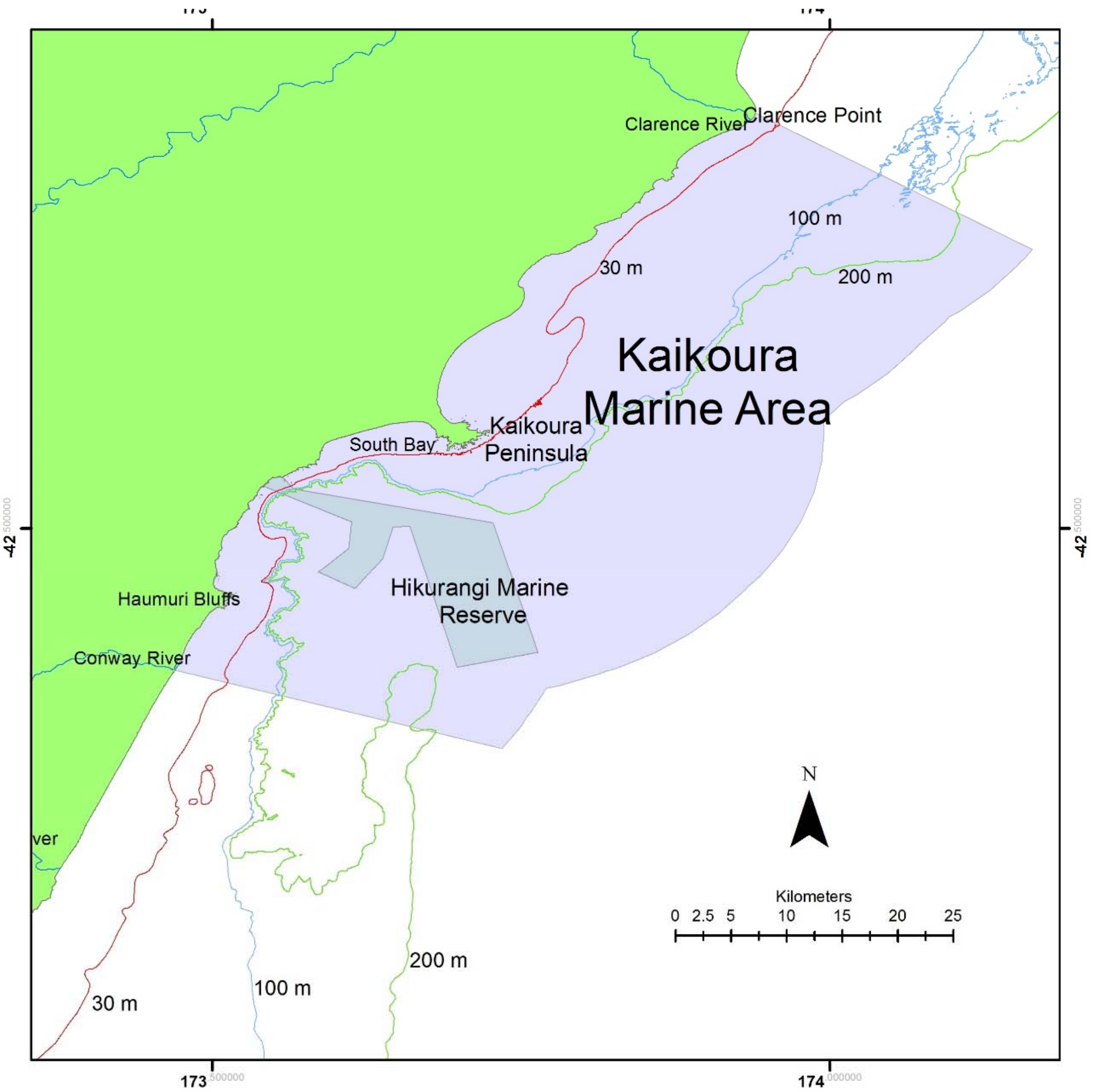

Figure 2: Map of north Canterbury region showing the Kaikoura Marine Area and Hikurangi Marine Reserve, both established in 2014. Within the Kaikoura Marine Area the recreational blue cod minimum legal size is 33 cm, and daily bag limit is six. Elsewhere in north Canterbury it is 30 cm and ten blue cod.

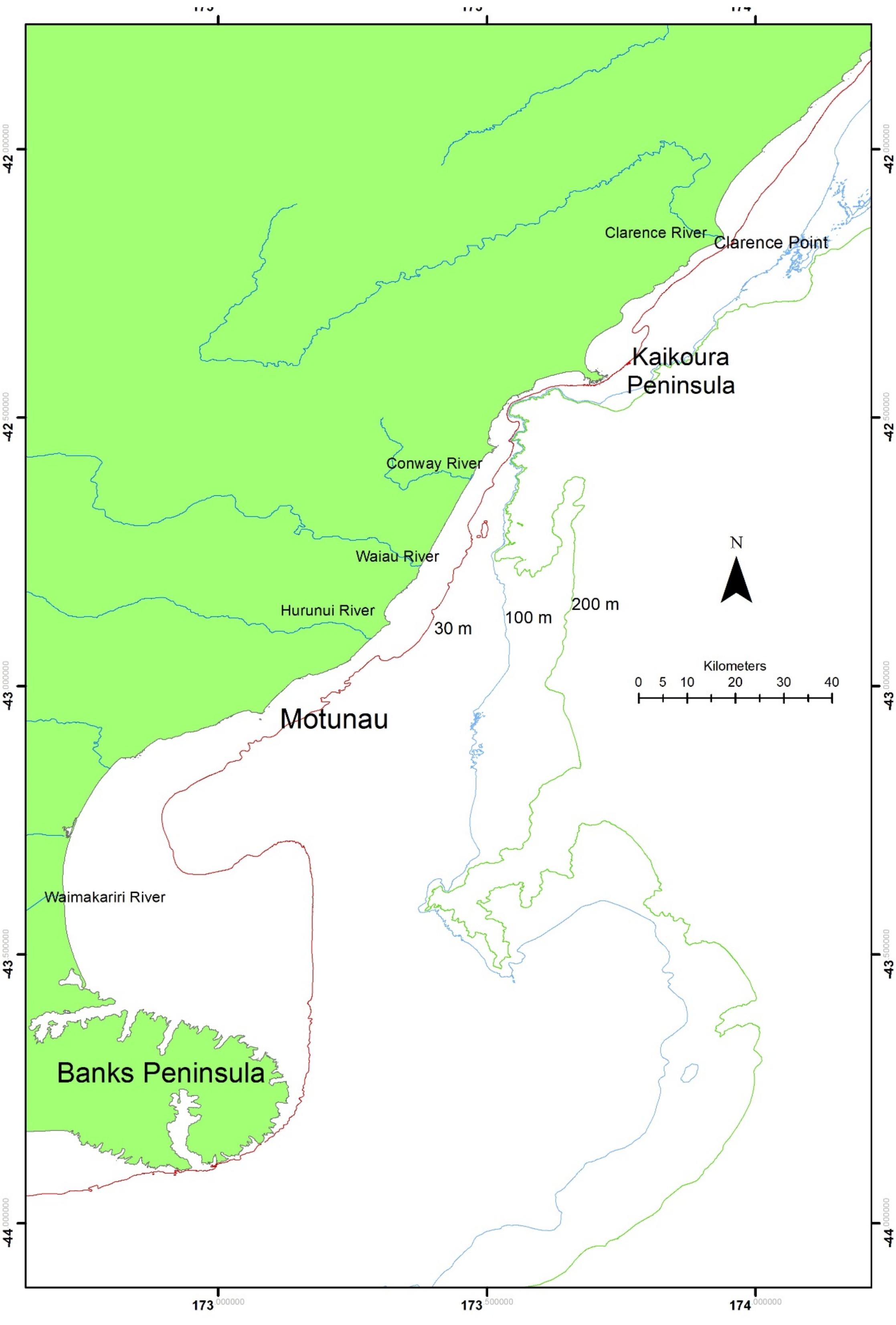

Figure 3: Map of north Canterbury region showing the potting survey areas Kaikoura and Motunau.

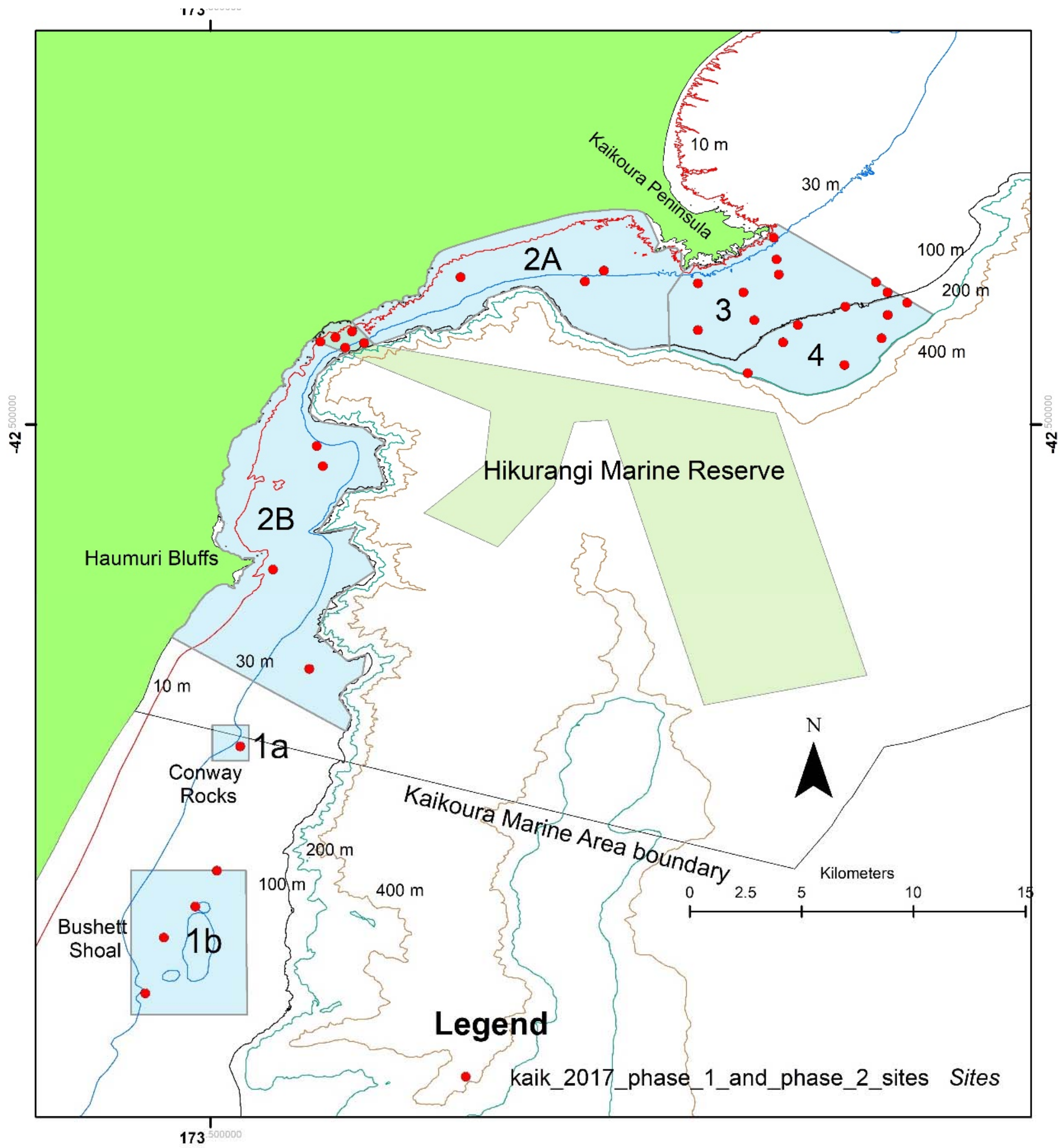

Figure 4: Kaikoura strata and pot locations for the 2017 random-site blue cod potting survey. The Hikurangi Marine Reserve and Kaikoura Marine Area are also shown.

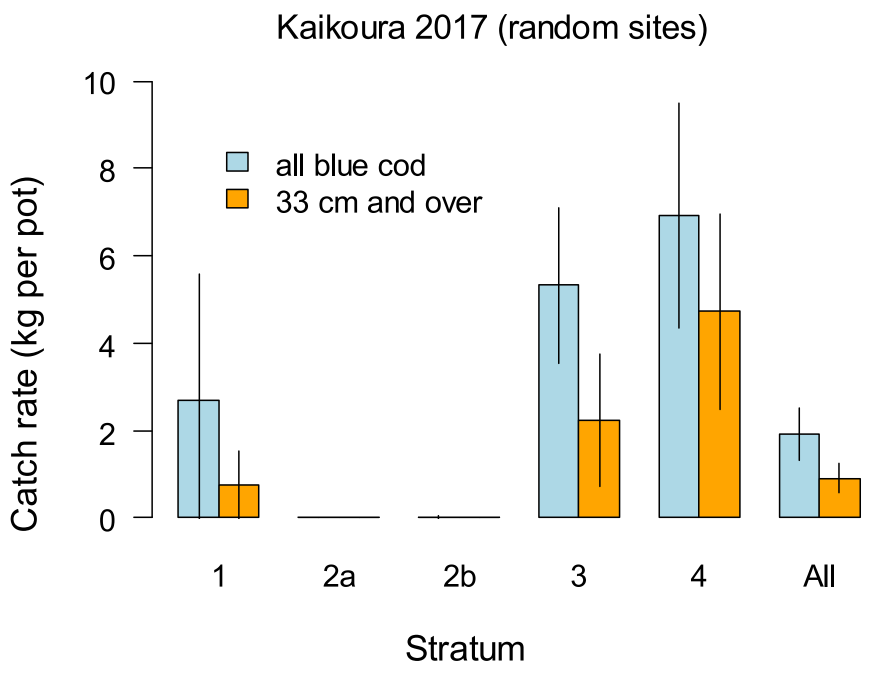

Figure 5: Catch rates (kg.pot^{-1}) of all blue cod and recruited blue cod (33 cm and over) by strata, and for Kaikoura overall for the 2017 Kaikoura random site survey. Error bars are 95% confidence intervals.

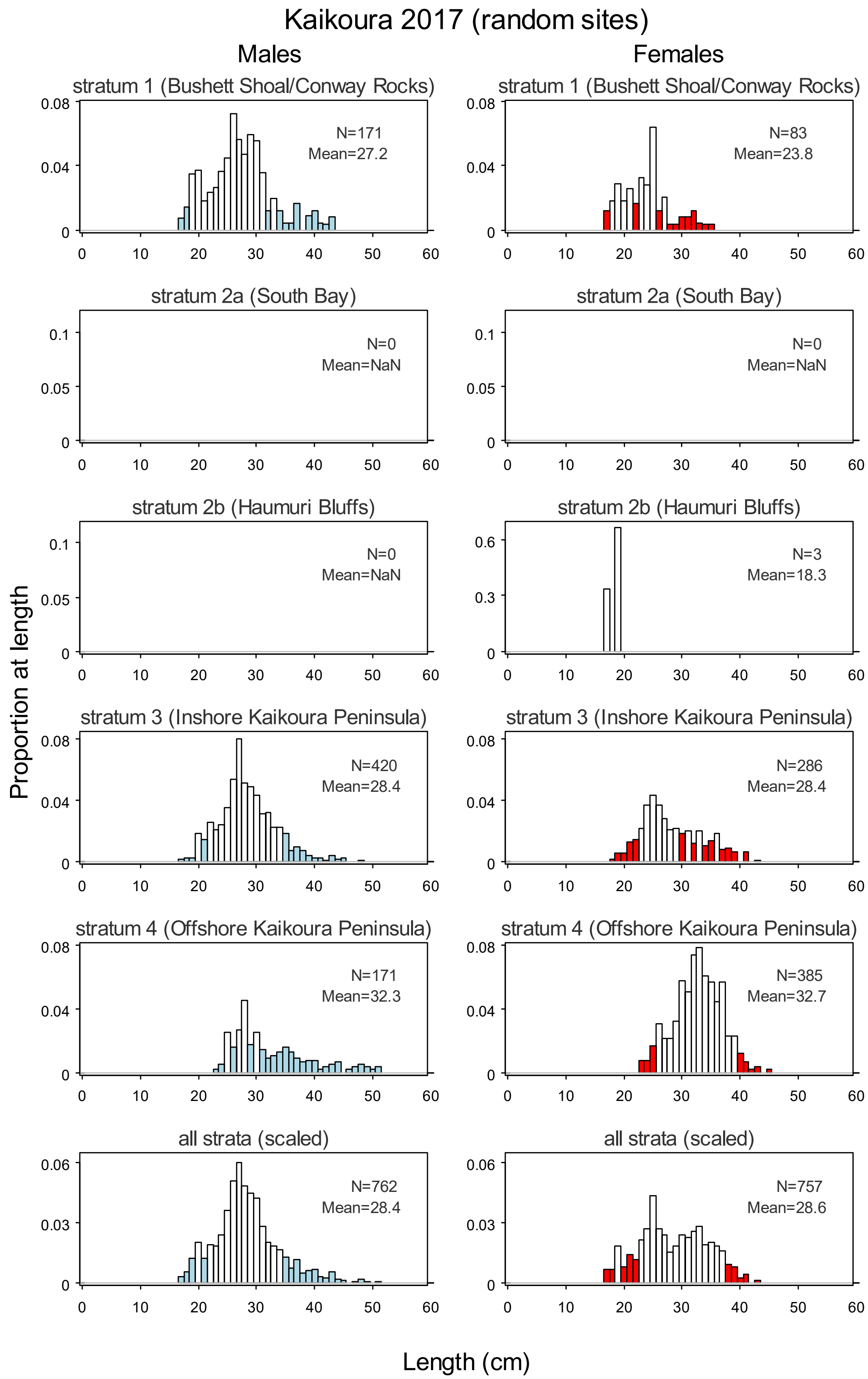

Figure 6: Scaled length frequency distributions by strata and overall for the 2017 Kaikoura random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. Five unsexed fish in stratum 3 are not shown (29 cm, 29 cm, 36 cm, 36 cm, 39cm).

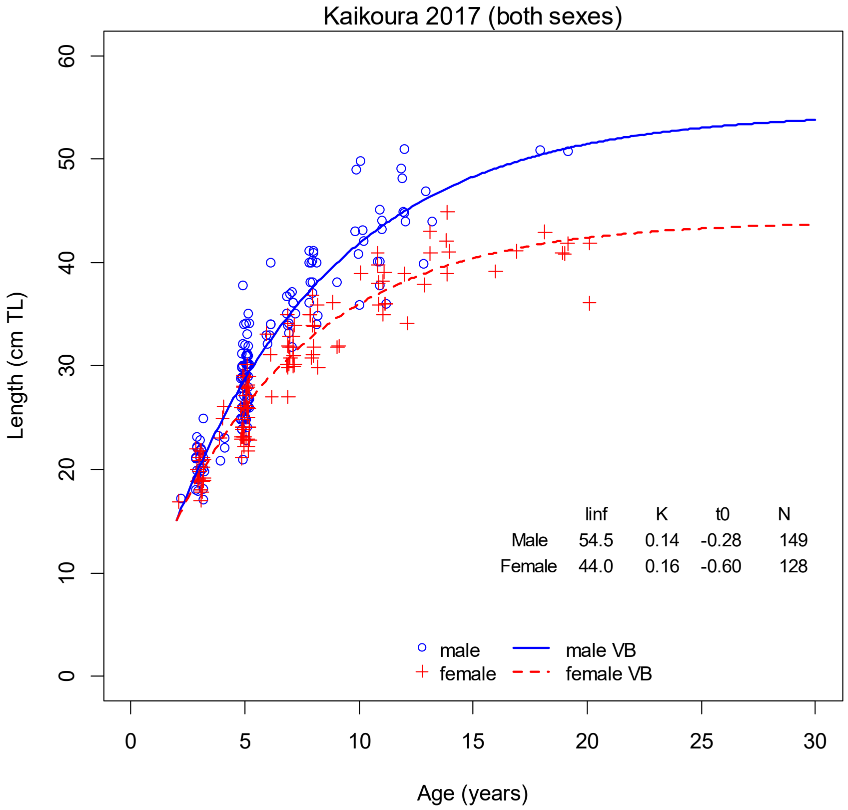

Figure 7: Observed blue cod age and length data by sex for the 2017 Kaikoura survey with von Bertalanffy (VB) growth models fitted to the data. Linf, average size at the maximum age (cm); K, Brody growth coefficient (yr^{-1}); t0, age when the average size is zero.

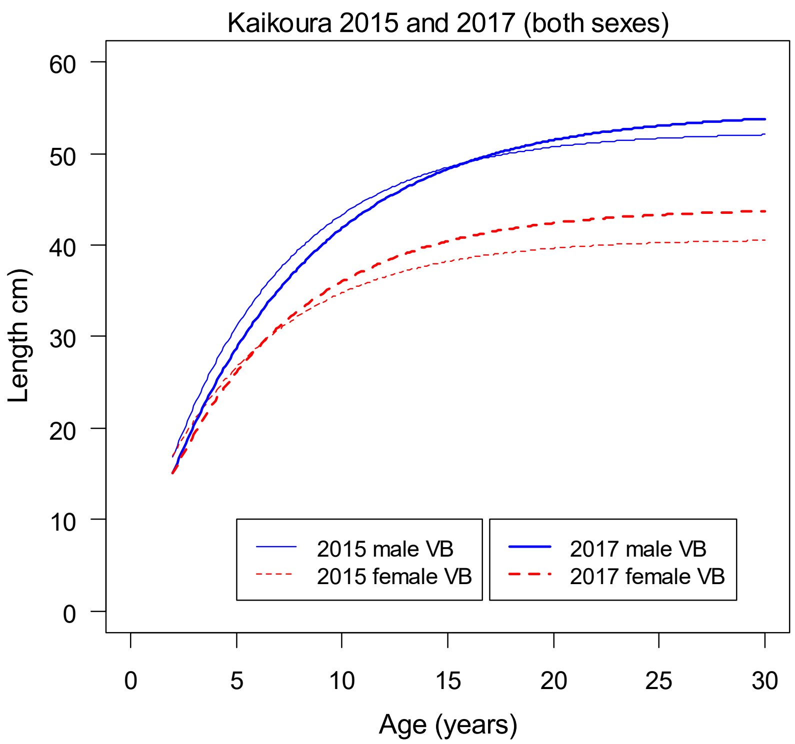

Figure 8: von Bertalanffy growth models fitted to the Kaikoura 2015 and 2017 blue cod surveys age and length data

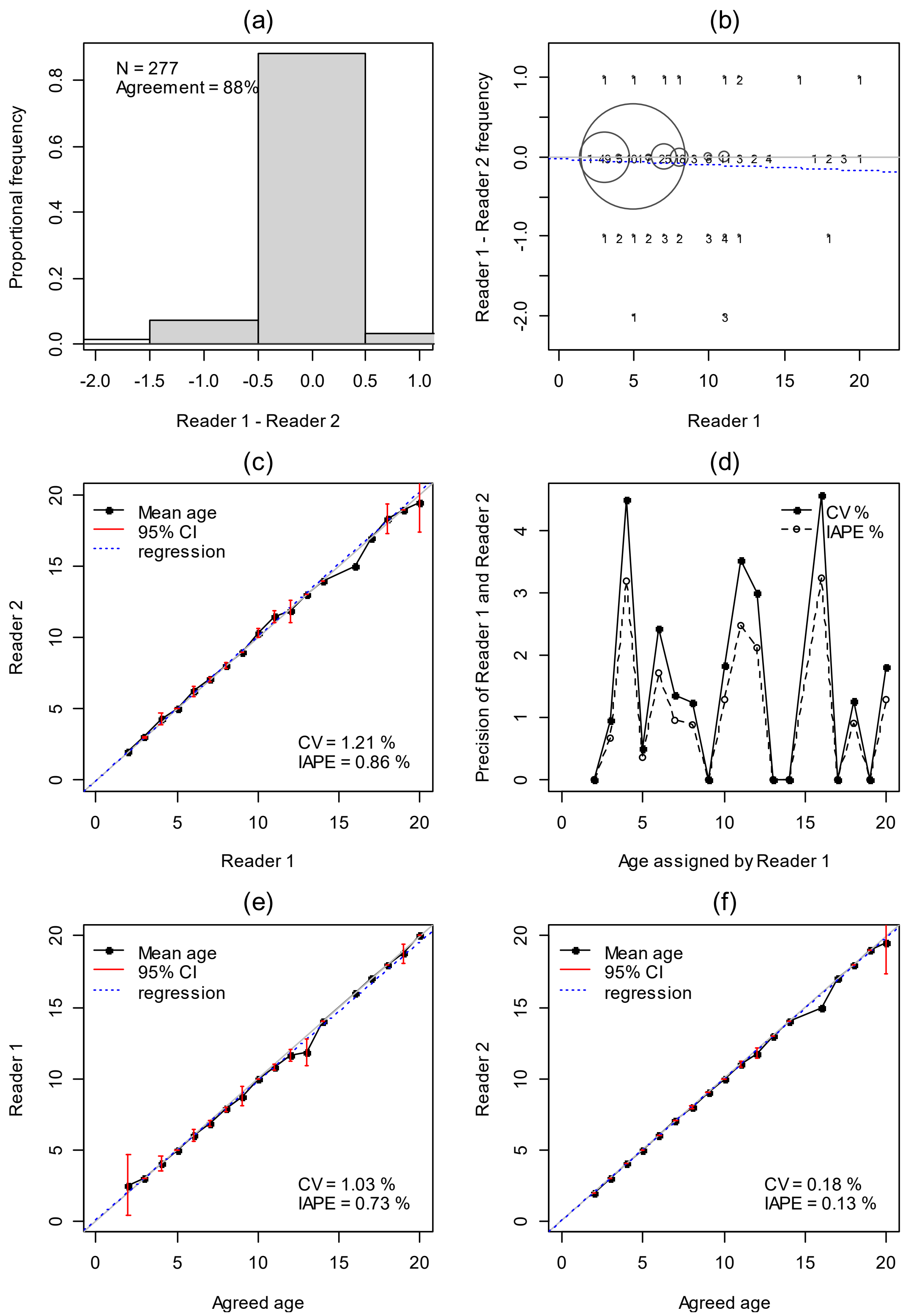

Figure 9: Blue cod age otolith reader comparison plots between reader 1 and reader 2 for the 2017 Kaikoura survey: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age bin 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.

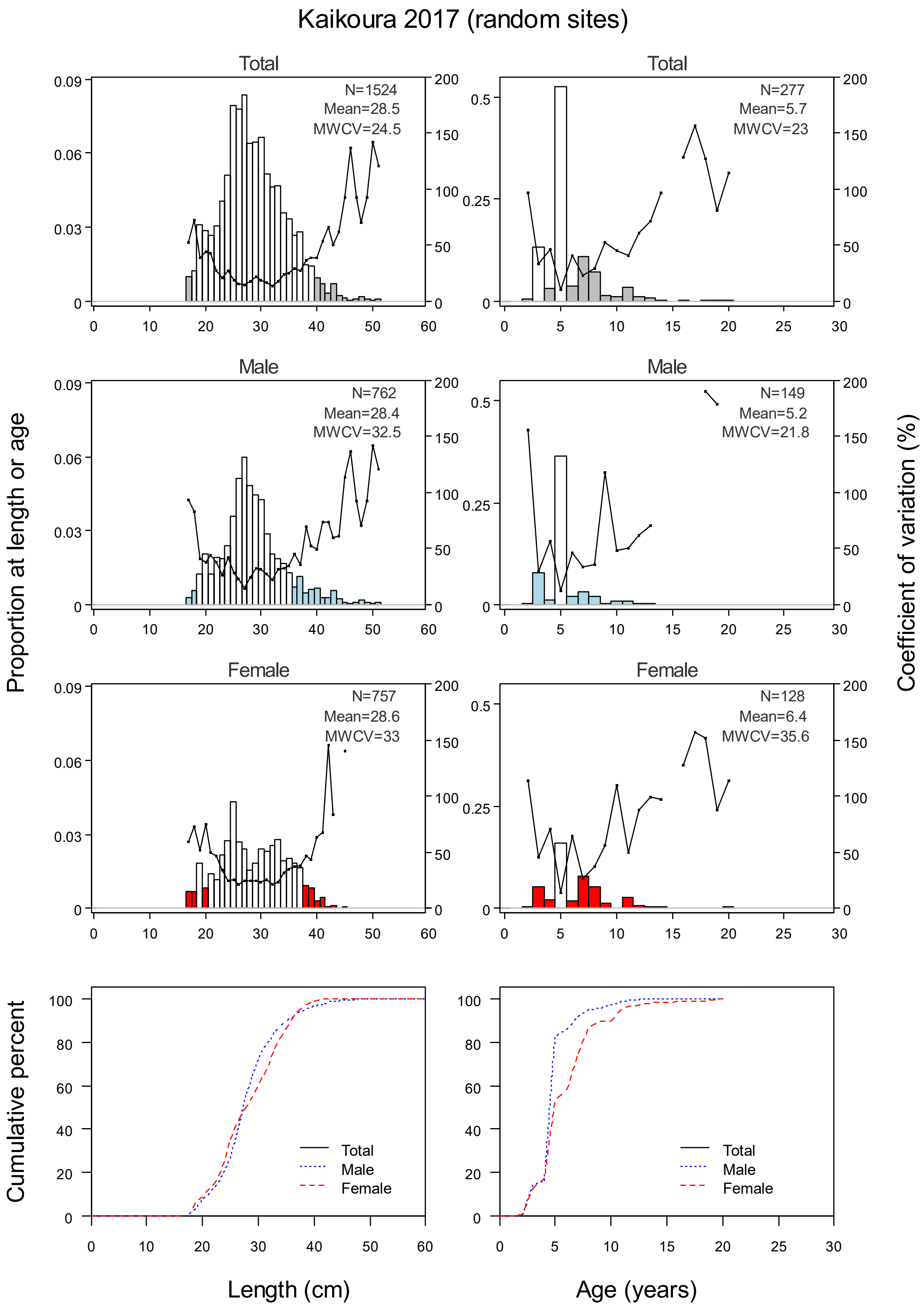

Figure 10: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2017 Kaikoura Random site blue cod potting survey (N, sample size; MWCV, mean weighted coefficient of variation).

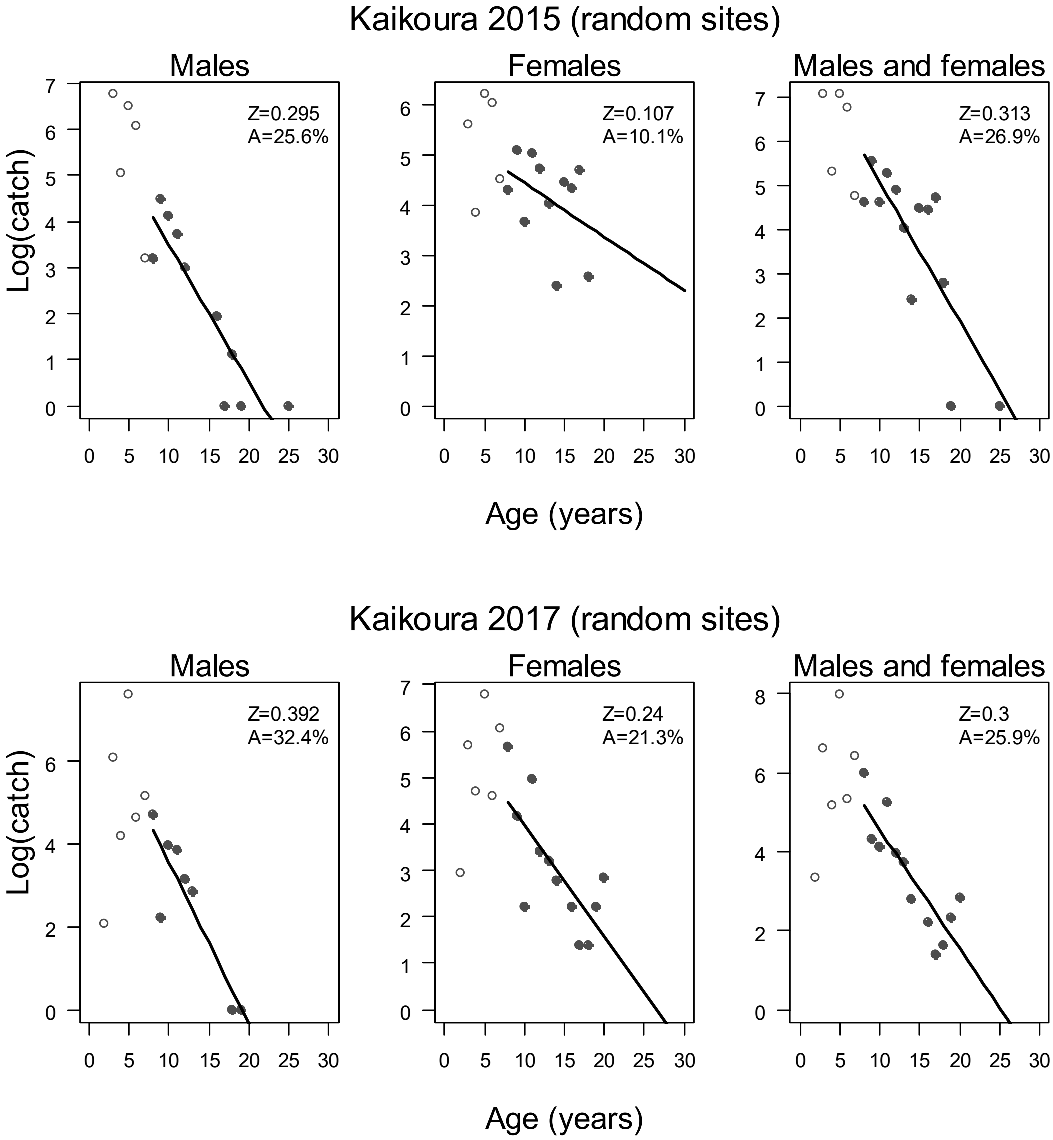

Figure 11: Catch curves (natural log of catch numbers versus age) for Kaikoura 2015 and 2017 random-site surveys. The regression line is plotted from age at full recruitment of 8 years (i.e., dark points on the graph). Z, instantaneous total mortality; A, the annual mortality rate or the proportion of the population that suffers mortality in a given year.

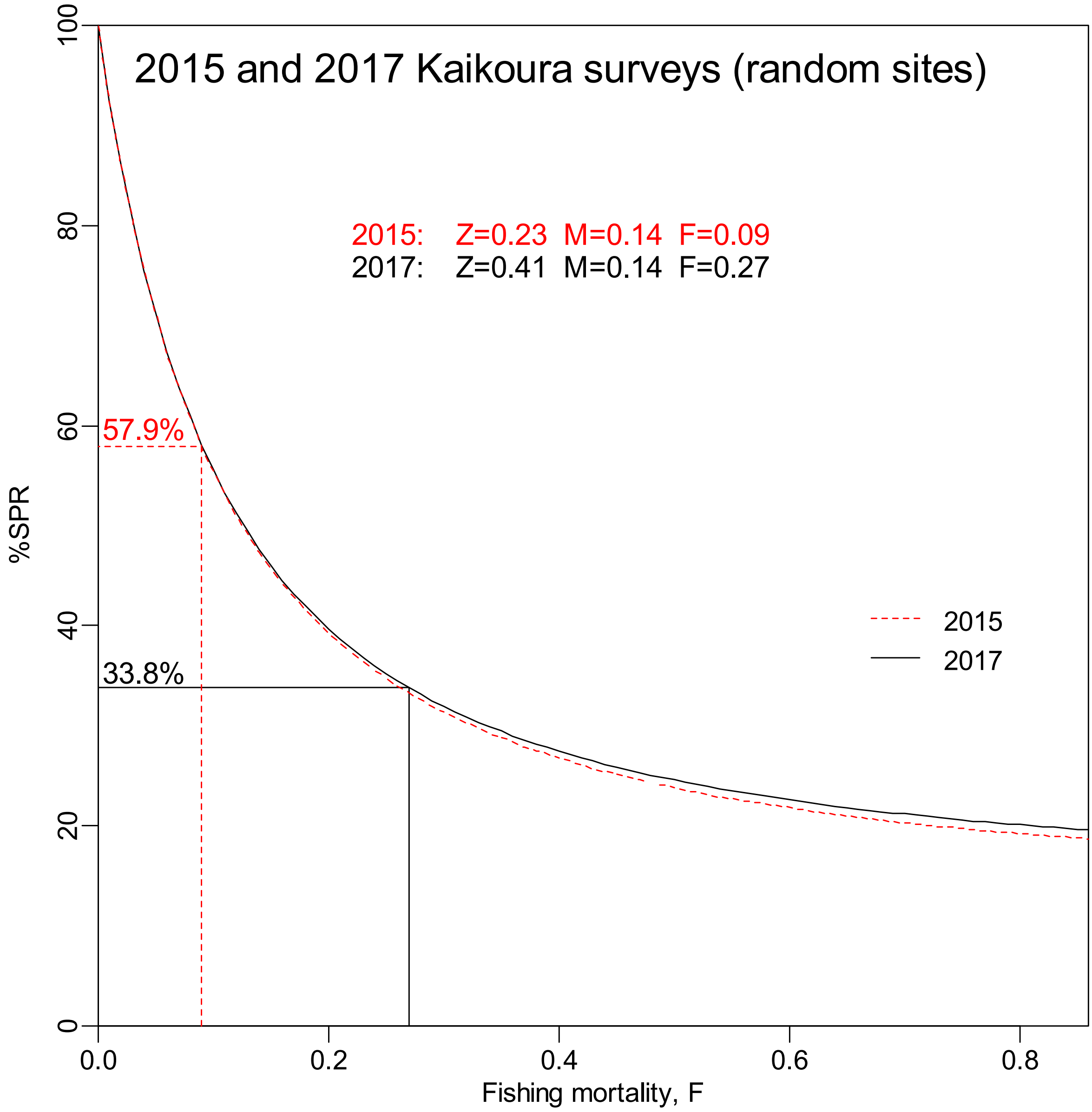

Figure 12: Spawner-per-recruit (SPR) as a function of fishing mortality (*F*) for 2017 Kaikoura random-site surveys. The SPR is also shown for the 2015 random site survey. In this plot *M* = 0.14, and the *F* value is for age of full recruitment equal to 8 years for females.

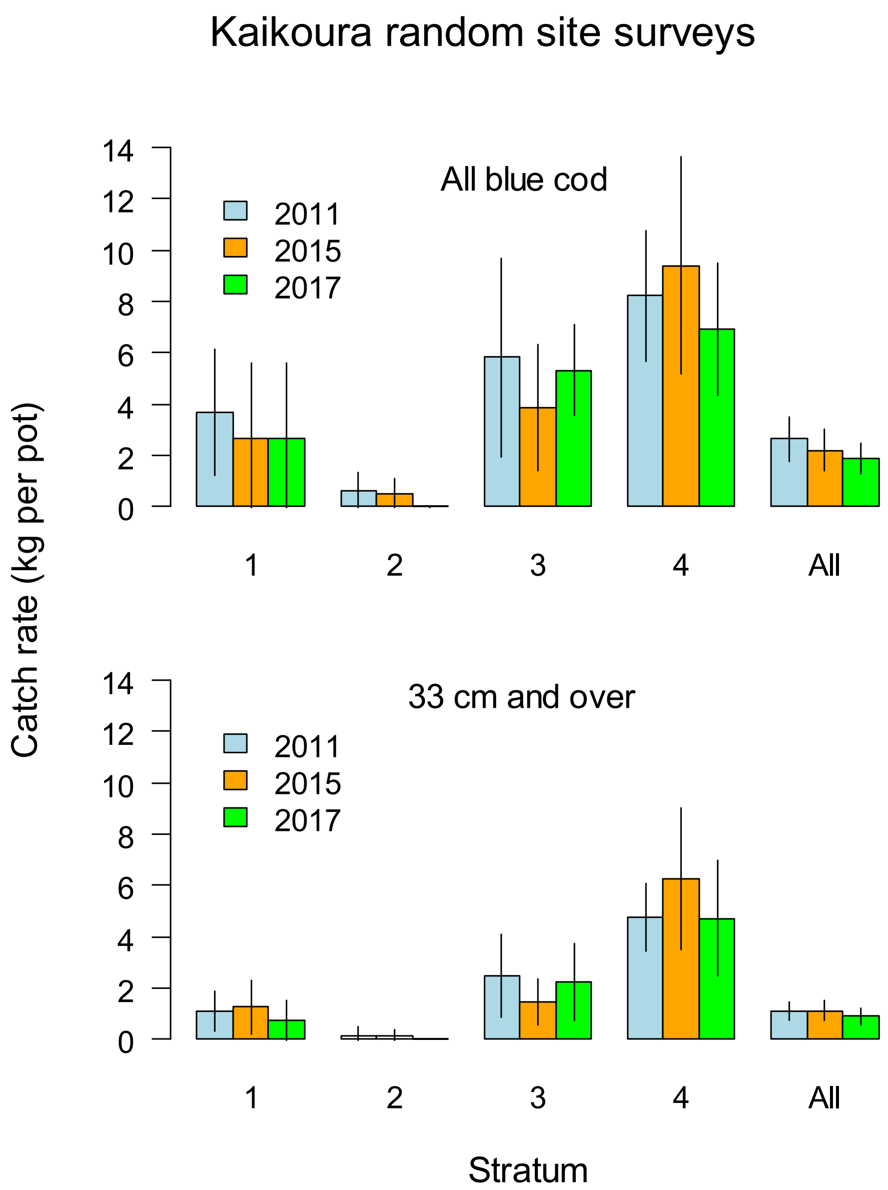

Figure 13: Catch rates (kg.pot^{-1}) of all blue cod and for recruited blue cod (33 cm and over) for the Kaikoura random-site potting surveys in 2011, 2015 and 2017. Error bars are 95% confidence intervals. Strata 2a and 2b are combined to allow comparison between years.

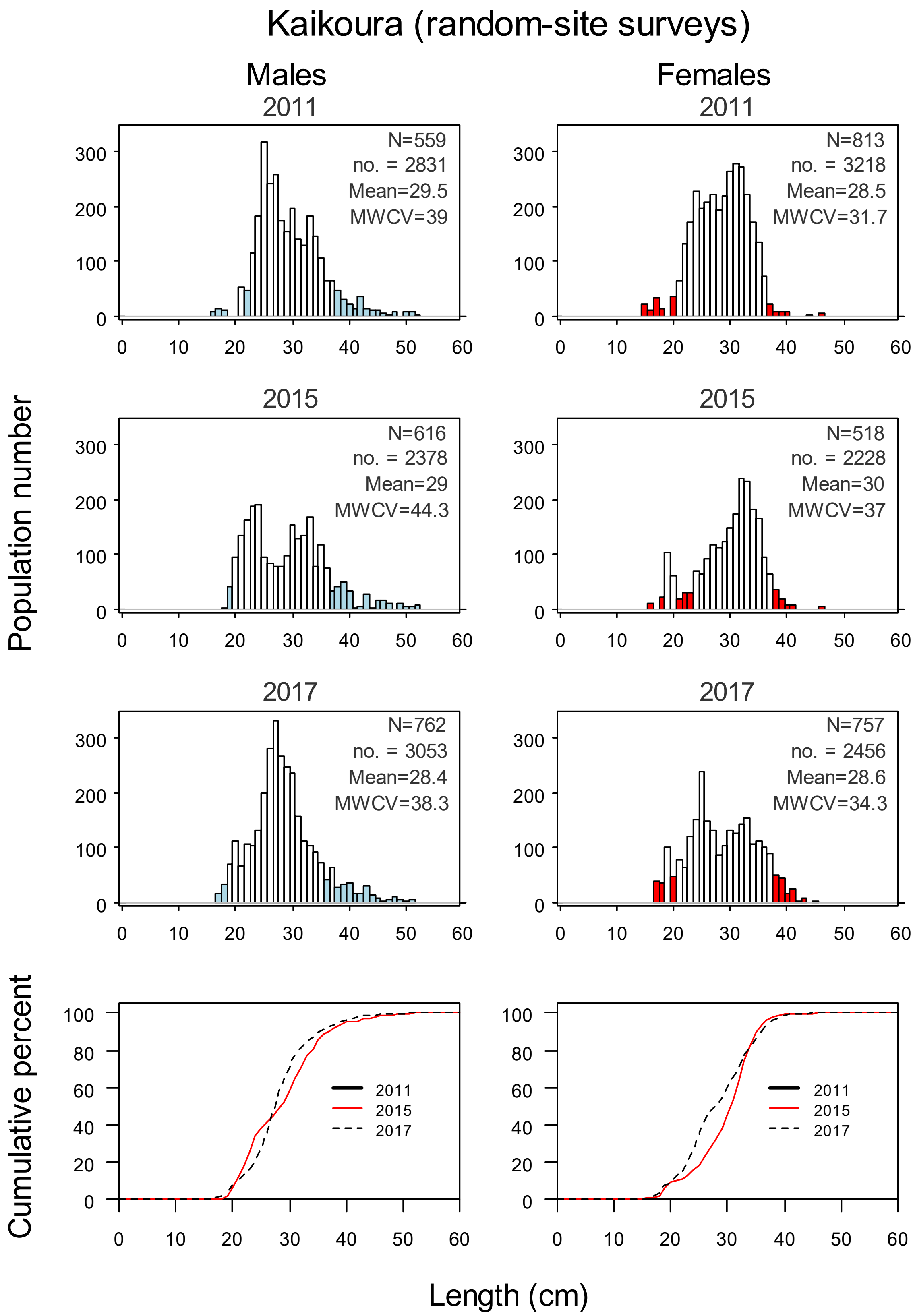

Figure 14: Scaled length frequency and cumulative distributions for male and female blue cod from Kaikoura random site blue cod potting surveys in 2011, 2015, and 2017. N, sample numbers; no, population number; Mean, mean length (cm); MWCV, mean weighted coefficient of variation.

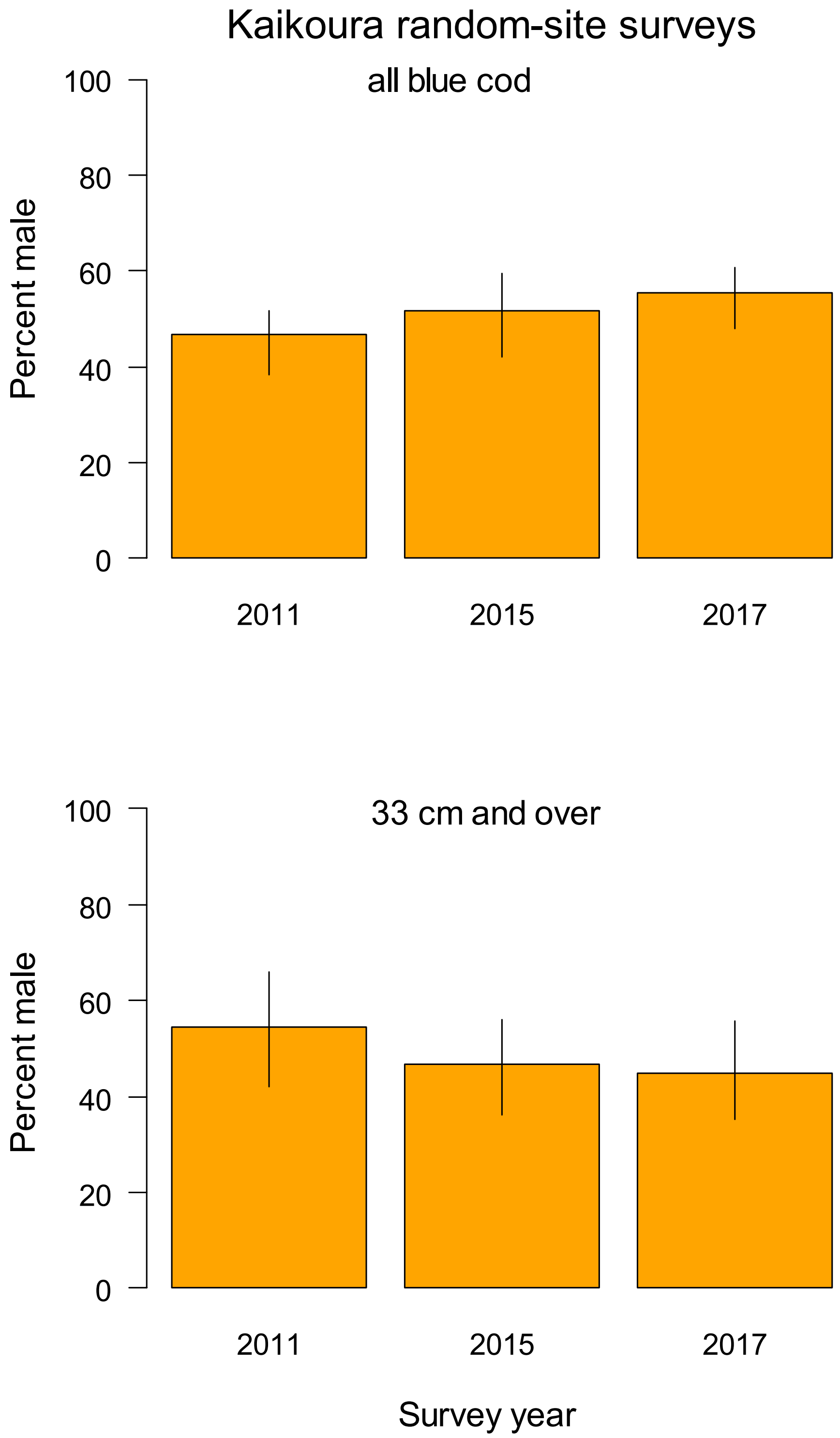

Figure 15: Proportion of males in the Kaikoura random-site potting surveys in 2011, 2015 and 2017.

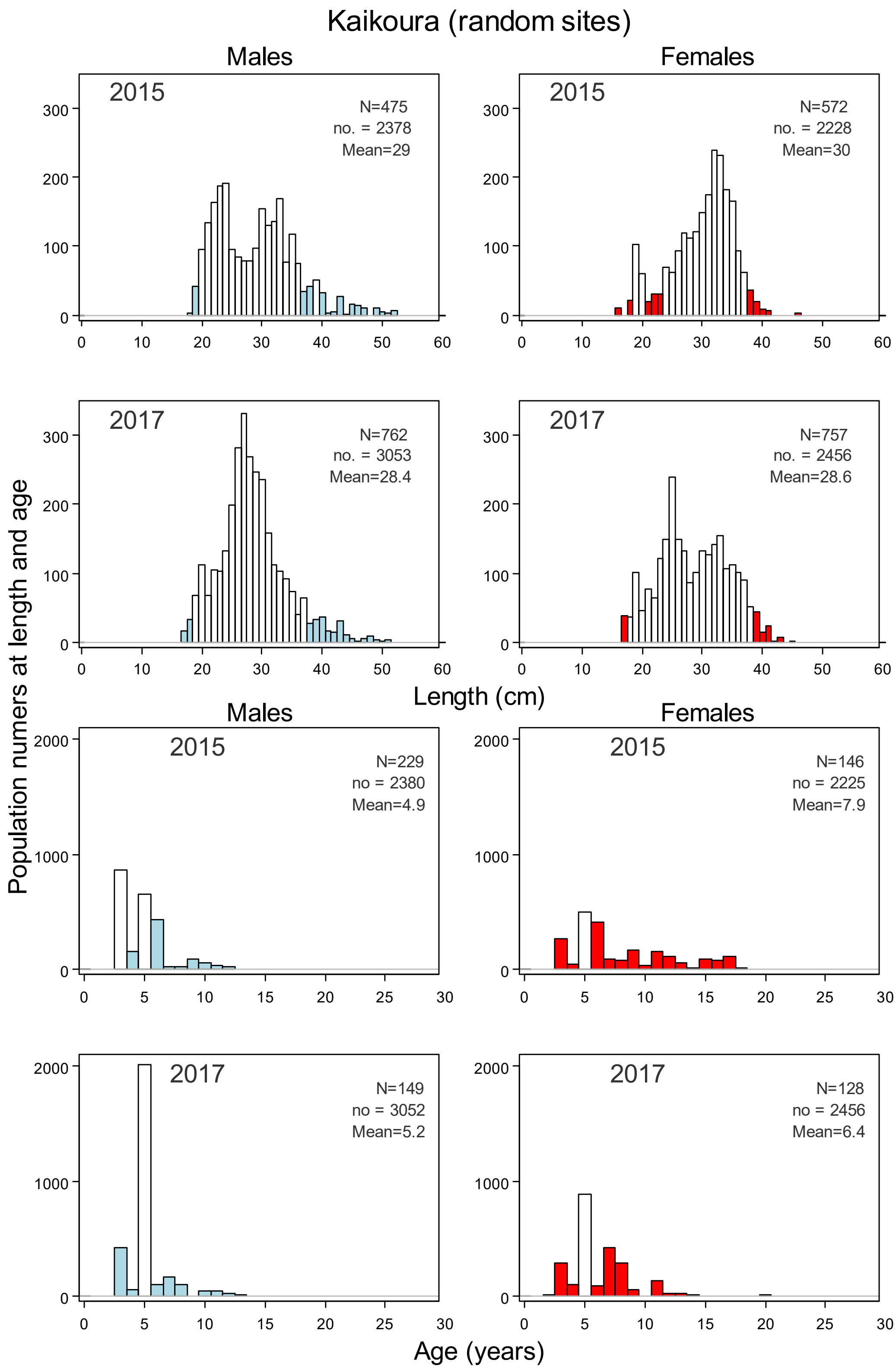

Figure 16: Scaled length frequency and age frequency distributions for male and female blue cod for all strata in the 2015 and 2017 Kaikoura random-site blue cod potting surveys (N, sample size; no, population number; Mean, mean length(cm)). Maximum age was 19 years for males and 20 for years for females.

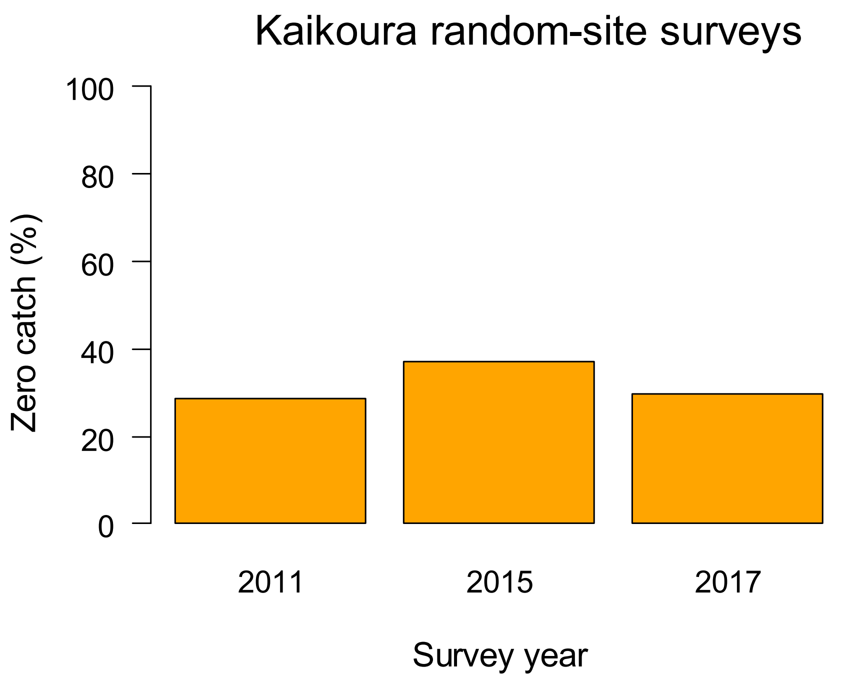

Figure 17: Proportion of pots with zero blue cod catch for the Kaikoura random-site potting surveys in 2011, 2015 and 2017. N= 156, 150, and 174 pots for each survey, respectively.

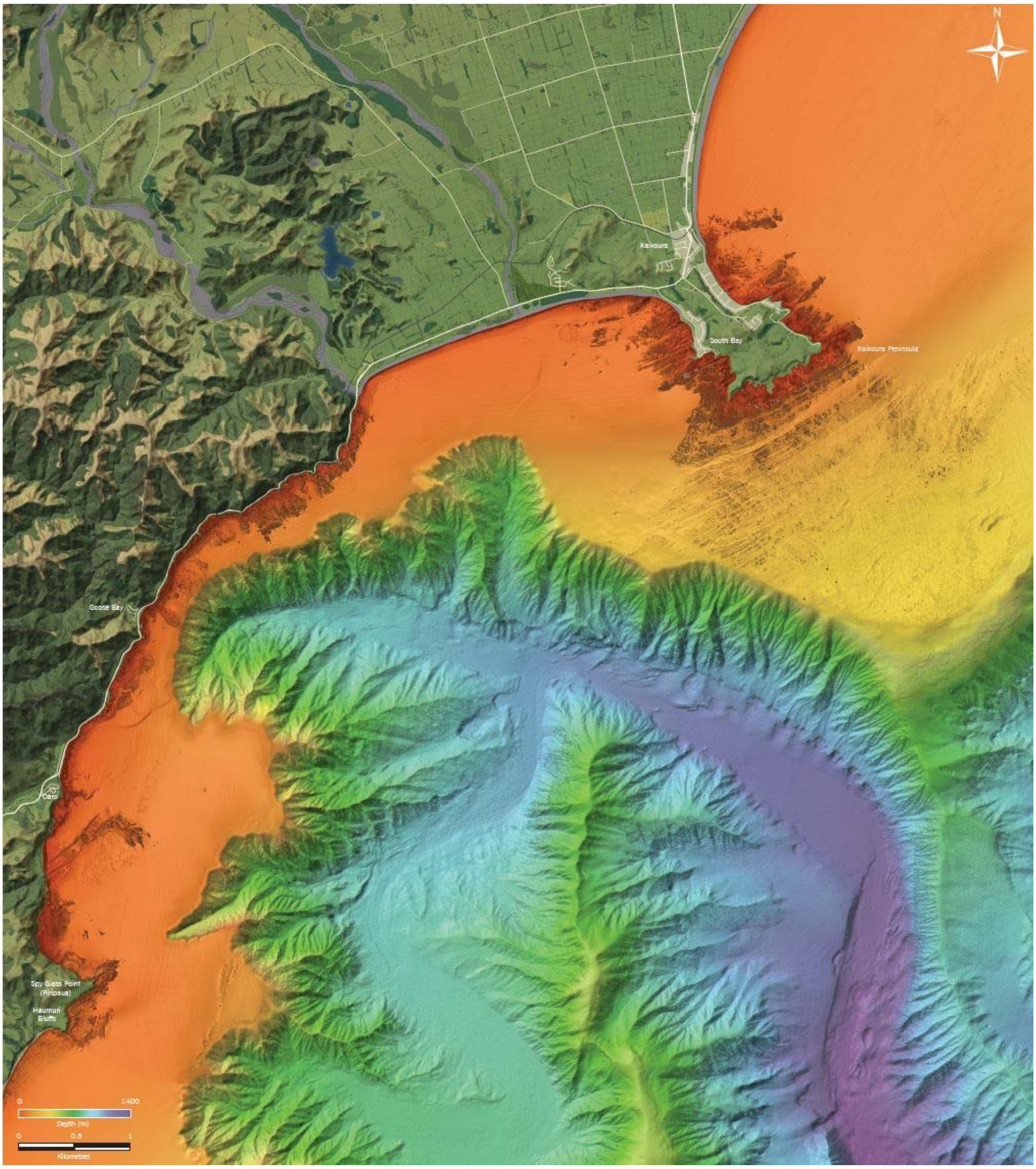

Figure 18: Map of the Kaikoura coast seafloor from the multibeam echosounder survey in 2017 and 2018 (map from Neil et al. 2018).

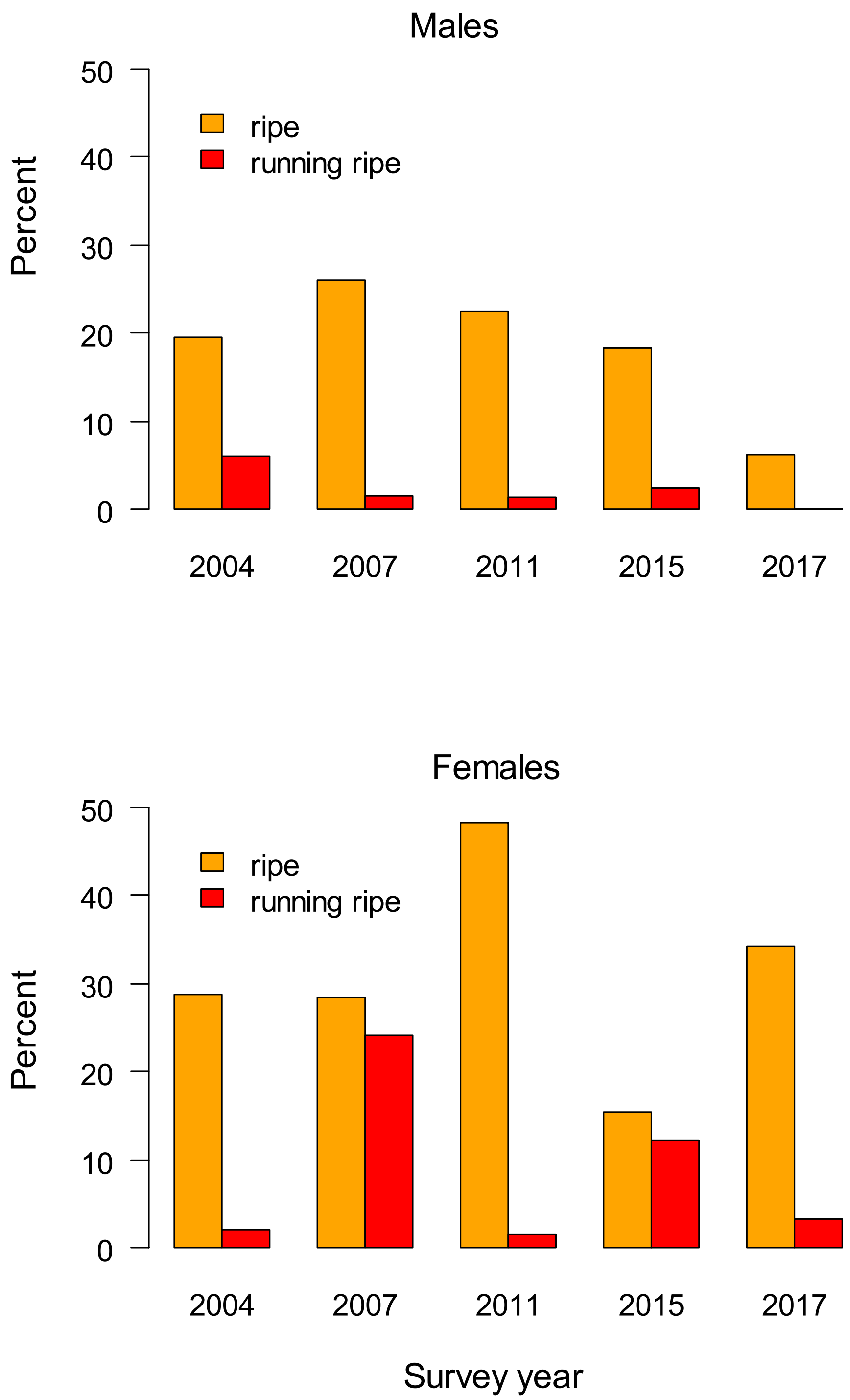

Figure 19: Percent of blue cod in the ripe or running ripe reproductive condition on Kaikoura blue cod potting surveys (all data combined for fixed and random-site surveys in 2011 and 2015).

8. APPENDICES

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 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 (1–6 or 1–9) in the order they are placed during a set. In the Kaikoura survey six pots were 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 echosounder 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 first pot is set 200 m to the north of the site location and remaining pots are set in a hexagon pattern around the site, at about 200 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. A site may be specified as a latitude and longitude or a section of coastline (for the latter, the latitude and longitude at the centre of the section is used).
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 *station_no* 234. This convention is important in enabling users of the *trawl* 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 *trawl* database.

Appendix 2. Numbers of otoliths collected during the 2017 Kaikoura survey for males and females, by strata and length class. Strata 2a and 2b are combined. Lgth, length.

	Males					Females				
	Strata					Strata				
Lgth (cm)	1	2	3	4	Male totals	1	2	3	4	Female totals
16										
17	2		1		3	3	1			4
18	2		1		3	4		1		5
19	5		1		6	3		2		5
20	3		3		6	3				3
21	3		3		6	3		3		6
22	5		2		7	3		3		6
23	2		2		4	5		3	1	9
24	3		2	1	6	4		2	1	7
25	3		3		6	2		1	2	5
26	5		2	1	8	1		2	2	5
27	3		2		5	4		4		8
28	4		1	2	7	1		1	2	4
29	3		3	2	8	1		2	2	5
30	3		3		6	2			5	7
31	4		3		7	2			3	5
32	3		1		4	3			3	6
33	3		1	1	5	1			3	4
34	3			4	7	1			2	3
35	1		1	2	4	1			5	6
36	1			3	4				3	3
37	4			1	5				3	3
38				2	2				4	4
39	2		1	1	4				3	3
40	3			3	6				3	3
41	1		1		2			2	3	5
42	1			1	2				1	1
43	2		1		3				2	2
44				3	3					
45			2		2				1	1
46				1	1					
47										
48				3	3					
49				1	1					
50				1	1					
51				2	2					
52										
53										
Totals	74	0	40	35	149	47	1	26	54	128