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Tini a Tangaroa

Relative abundance, size and age structure, and stock status of blue cod off Kaikōura in 2019

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M.P. Beentjes,
M. Page

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This report describes the results of the random-site blue cod (*Parapercis colias*) potting survey carried out off Kaikōura in December 2019. Estimates are provided for population abundance, size and age structure, sex ratio, total mortality (*Z*), and spawner biomass-per-recruit ratio. This is the fourth survey in the Kaikōura random-site survey time series, following those in 2011, 2015, and 2017. In addition, results are presented for a concurrent blue cod survey of the Hikurangi Marine Reserve off Kaikōura.

Twenty-seven random sites (6 pots per site, producing 162 pot lifts) at depths of 8–125 m from five strata off Kaikōura were surveyed in December 2019 using the R.V. *Ikatere*. Survey mean catch rate of blue cod (all sizes) was 1.56 kg pot^{-1} (coefficient of variation, CV 10%) and 0.76 kg pot^{-1} (CV 14.2%) for recruited blue cod (33 cm and over). Of the 162 pots, 30% had zero catch of blue cod. The overall weighted sex ratio was 50% male and mean lengths were 29.4 cm for males (range 16–51 cm) and 29.2 cm for females (range 14–44 cm). The survey length frequency distribution for males was bimodal with peaks at about 25 cm and 34 cm, and the female distribution was less clearly bimodal with probable peaks at about 25 cm and 30 cm. Age estimates were 2–16 years for males and 2–19 years for females, but most males and females were 5 or 7 years old. The estimated population age distributions showed strong modes at five and especially seven years for both sexes, but particularly for females and a corresponding weak mode for six-year-olds. Mean age was 6.0 years for males and 7.3 years for females. Chapman Robson total mortality (*Z*) for age-at-full recruitment of eight years was estimated at 0.27 (95% confidence interval 0.19–0.36). Based on the default *M* of 0.17 (previously 0.14), estimated fishing mortality (*F*) was 0.1 and the associated spawner biomass-per-recruit ratio was 62% (95% confidence interval 48–89%). The revised spawner-per-recruit ratios for 2015 and 2017 based on *M* of 0.17 were 72% and 42%. Traditional catch curve analyses did not produce a straight line on the descending limb for any of these surveys, suggesting a violation of the catch curve assumption that recruitment is constant. There were also few blue cod aged older than eight years of age which has influenced the regression line slopes and hence Z estimates. The conclusion is that *Z* and *SPR* estimates are not reliable. A third of females and a quarter of males were mature or running ripe, and nearly all spawning activity occurred off Kaikōura Peninsula, mostly in stratum 4 at 100–125 m.

Time series analyses of the four random-site surveys indicate 1) mean catch rates generally declined slightly over time but this was not statistically significant; 2) length frequency distributions and mean length were similar with differences due to the strong recruitment of juveniles in 2015, progressing through to strong modes in 2017 and 2019; 3) modal progression of strong age classes was apparent and supports the ageing methodology based on counts of annual growth rings; 4) the sex ratio for all the surveys was 47–55% male for all blue cod with no trend, although stratum 4 was consistently female dominated; 5) the proportion of pots with zero catch was 29–37%, with no trend.

In the Hikurangi Marine Reserve, five random sites (6 pots per site, producing 30 pot lifts) were surveyed in depths of 8–39 m. A total of 113 fish was sampled for length and returned alive. The mean catch rate of blue cod (all sizes) was 2.25 kg pot^{-1} (CV 56.2%) and for recruited blue cod was 1.67 kg pot^{-1} (CV 64.8%). Half of the 30 pots had zero catch of blue cod. Mean length (unsexed) was 31.5 cm (18–45 cm).

Catch rates in the 2017 and 2019 marine reserve surveys were substantially higher than for adjacent strata but were still only about 25% of those in stratum 4, where blue cod were most abundant. Size composition is comparable with that in strata 3 and 4, where blue cod are most abundant.

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 Kaikōura in December 2019. This is the fourth in the time series with previous random-site surveys in 2011, 2015, and 2017 (Beentjes & Page 2017, 2018, Carbines & Haist 2018d). The 2017 survey was carried out specifically to assess whether the November 2016 Kaikōura earthquake had any effect on the local blue cod population. In addition, results are presented for a concurrent blue cod survey of the Hikurangi Marine Reserve off Kaikōura following a similar survey in 2017.

1.1 Status of the north Canterbury blue cod stocks

Blue cod is the third most common recreational species caught in New Zealand with a total catch of 292 t (nearly 600 000 fish) estimated during the 2017–18 panel survey involving face to face interviews with fishers (Wynne-Jones et al. 2019). Blue cod can be caught from a few metres deep to about 150 m in a range of habitats including reef edges, shingle/gravel, biogenic reefs, or sandy bottoms close to rocky outcrops. Quota Management Area (QMA) BCO 3 extends from the Clarence River, north of Kaikōura, to Slope Point in Southland (Figure 1) and within this area the 2017–18 recreational take of blue cod was estimated at 98 t (Wynne-Jones et al. 2014). Further, blue cod recreational catch in BCO 3 was the highest of any QMA (34% of total national recreational blue cod catch) with average daily catches of over 13 blue cod taken by 18% of respondents, and the most common method by far was by rod and line. This was supported by the National Blue Cod Strategy Report in 2017 (Ministry for Primary Industries 2017) for which 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 blue cod Quota Management Area in New Zealand, in line with the 2017–18 panel survey. There are no reliable data to determine how the recreational blue cod catch was distributed within BCO 3, but Kaikōura and Motunau are important blue cod fisheries in north Canterbury (Hart & Walker 2004). The perception from the 2017 on-line survey was that at Kaikōura the three top issues of concern were the total allowable commercial catch (TACC), concentrated recreational effort on small areas, and recreational bag limits (Ministry for Primary Industries 2017).

The commercial catch from BCO 3 is about 40–50% higher than the recreational catch with 169–177 t caught annually in the five years up to 2018–19 (Fisheries New Zealand 2020). Nearly all commercially landed blue cod in BCO 3 was caught by cod potting (67 %) or bottom trawl (22%) (NIWA, unpublished data). Most of the pot catch is from Statistical Area 024 (87%), off Oamaru, and bottom trawl catch is spread throughout Statistical Areas 018, 020, 022, 024, and 026 (Figure 1).

The 'Kaikōura Marine Area' was established in 2014 by the Department of Conservation (DOC) after 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). The 10 416 ha. Hikurangi Marine Reserve was also established in 2014 between Goose Bay and South Bay, extending 24 km seaward over the Kaikōura Canyon (Figure 2). Within the Kaikōura Marine Area, the minimum legal size (MLS) is 33 cm and the daily bag limit (DBL) is six blue cod. There are two taiāpure[1] within the Kaikōura Marine Area (not shown in Figure 2) where the DBL is two blue cod. Before the establishment of the Kaikōura Marine Area in 2014, the MLS was 30 cm and the DBL was 30 blue cod until 2001 when it was reduced to 10 blue cod for all of north Canterbury (Fisheries New Zealand 2020).

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, such as Foveaux Strait.

[1] Te Taumanu o Te Waka a Māui Taiāpure which surrounds the Kaikōura Peninsula, and Oaro-Haumuri Taiāpure between Oaro and Haumuri Bluffs.

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 intervention, such as changes to the daily bag limit, minimum legal size, and area closures. One method to investigate the status of blue cod stocks is to estimate fishing mortality, the associated spawner-per-recruit ratio (*SPR*) and the Maximum Sustainable Yield (*MSY*) related proxy. The recommended Harvest Strategy Standard 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 Kaikōura, 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, Beentjes & Fenwick 2019a), south Otago (Beentjes & Carbines 2011, Carbines & Haist 2018c, Beentjes & Fenwick 2019b), Paterson Inlet (Carbines 2007, Carbines & Haist 2014, 2018a, Beentjes & Miller 2020), Foveaux Strait (Carbines & Beentjes 2012, Carbines & Haist 2017a, Beentjes et al. 2019), 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 Kaikōura 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. Following this recommendation, all survey series began the transition to fully random survey designs with interim sampling of both fixed and random sites allowing comparison of catch rates, length and age composition, and sex ratios between the survey designs. Random sites were the only site type used in Foveaux Strait, and all other areas except Dusky Sound have now transitioned to solely random-site surveys.

Previous Kaikōura surveys were carried out in December 2004, 2007, 2011, 2015, and 2017 (Carbines & Beentjes 2006a, 2009, Beentjes & Page 2017, Carbines & Haist 2018d). The first two Kaikōura potting surveys used only fixed sites, whereas in 2011 and 2015 concurrent fixed- and random-site surveys were carried out. The 2017 survey was carried out two years earlier than planned to assess the impact of the November 2016 Kaikōura earthquake on the local blue cod population, and was the first solely random-site survey, following the recommendation of the Southern Inshore Working Group (SINSWG-2016/38). In 2017 the first survey of the inshore portion (shallower than 100 m) of the Hikurangi Marine Reserve was carried out.

1.4 Objectives

Overall Objective

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

Specific Objectives

1. To undertake a potting survey off North Canterbury to estimate relative abundance, size- and age-at-maturity, and sex ratio. Collect otoliths during the survey from pre-recruited and recruited blue cod.

2. To analyse biological samples collected from this potting survey.

3. To estimate the age structure and relative abundance of blue cod off Kaikōura.

4. To estimate the age structure and relative abundance of blue cod off Motunau.

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

The Motunau blue cod survey is reported by Beentjes & Miller (2021).

In this report we use the terms defined in the blue cod potting survey standards and specifications (Beentjes & Francis 2011, Beentjes 2019) (Appendix 1).

2. METHODS

2.1 Timing

A potting survey off Kaikōura was carried out by NIWA from 1 to 11 December 2019; this survey also included the inshore depths (less than about 100 m) of the Hikurangi Marine Reserve. 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 Kaikōura Marine Management Area) were consulted by Fisheries New Zealand and endorsed this project.

2.3 Survey area

The survey area for the 2019 Kaikōura random-site core strata survey was identical to that for the previous surveys, except that in 2017 stratum 2 was split into two strata, north (2A) and south (2B) of the Hikurangi Marine Reserve (Figure 3). The boundaries of the Kaikōura survey area were drawn in 2004, based on discussions with local fishers, 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 Kaikōura. From this information, the survey area off Kaikōura was subdivided into three contiguous strata from Kaikōura 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 (strata 1a and 1b) (Figure 3). 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 within each stratum was taken as a proxy for available habitat for blue cod.

The inshore part of the Hikurangi Marine Reserve (previously part of stratum 2 in less than 100 m) with an area of 1.5 km^2 was also surveyed in 2019 (Figure 3).

2.4 Survey design

2.4.1 Allocation of sites

Simulations to determine the optimal allocation of random sites among the five core strata (1a and 1b combined) were carried out using NIWA's Optimal Station Allocation Program (*allocate*) based on catch rate data from the 2011, 2015, and 2017 random-site surveys. Stratum 2 catch rates in 2011 and 2015 were reassigned to the new sub-divided strata 2a and 2b. 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 27 random sites were required to achieve the target CV.

In the core strata survey a two-phase stratified random station design (Francis 1984) was used with 22 sites allocated to phase 1, and the remaining five available for allocation in phase 2, consistent with the proportion of phase 2 sites used in previous surveys (Table 1). A minimum of one site was allocated to strata 1a and 1b to ensure that both sub-strata were sampled. 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 ith 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.

Five random sites were nominally allocated to the marine reserve, the maximum number that be accomodated within this stratum.

Random sites

A random site has a location (single latitude and longitude) generated randomly within a stratum (Beentjes 2019). 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 in the core strata. From this list, the allocated number of random sites per stratum to be surveyed was selected in the order they were generated. In the marine reserve, sites were at least 500 m apart and all five sites generated were surveyed.

Pot configuration and placement for random sites is defined in the blue cod potting manual (Beentjes 2019). Consistent with previous random-site surveys in Kaikōura, systematic pot placement was used 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 for the 2019 Kaikōura 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 cruising at 25 knots. The *Ikatere* was skippered by Simon Wadsworth who has considerable experience in commercial blue cod potting. The previous random-site survey in 2017 was also carried out using *Ikatere* whereas the 2015 and 2011 surveys used the F.V. *Mystique II* (Registration number 901093), a Kaikōura-based commercial vessel.

Six custom designed and built cod pots were used to conduct the survey (Pot Plan 2 given by Beentjes & Francis 2011). Pots were baited with 700 g of paua (*Haliotis iris*) 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, Beentjes 2019).

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. Following pot placement, the following environmental data were recorded: wind direction, speed, and force; air temperature and pressure; water clarity using secchi disc, sea condition, and colour; swell height and direction; bottom type and contour; surface temperature. These variables and their units are defined in the potting manual (Beentjes 2019).

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. The proportion of the bait remaining in the snifter pottle was recorded. Pots were then emptied and the contents sorted by species. Total catch weight per pot was recorded for each species to the nearest 10 g using 0–6/6–15 kg Marel motion compensating scales. The number of individuals of each species per pot was also recorded. Total length to the nearest centimetre below actual length, individual fish weight to the nearest 10 g, sex, and gonad maturity were recorded for all blue cod. Sagittal otoliths were removed from a representative length range of blue cod males and females over the available length range across all strata. To ensure that otolith collection was spread across the survey area, the following collection schedule was used: collect three otoliths per one-centimetre 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.

Marine reserve

Pot placement and sampling of blue cod in the Hikurangi Marine Reserve was carried out using the standard random-site methodology described above. Pots were cleaned with freshwater, dried, and fouling organisms removed prior to deployment in the marine reserve. After hauling, blue cod from each pot were transferred directly into bins with circulating water using rubber gloves. Numbers and total length of blue cod were recorded and fish were returned alive to the water within 5 minutes, within 10 m from their location of capture. To reduce potential mortality, catch weight per pot and individual fish weight were not recorded in each set, but instead these parameters were estimated from the length-weight relationship of fish caught in the main potting survey. All fish were returned to the water using a 130 mm PVC pipe extending 1 m below the surface and irrigated with the deck hose. To reduce blue cod handling time and the risk of mortality, bycatch was not recorded.

Freya Hjorvarsdottir (Senior Fisheries Analyst, Fisheries New Zealand) joined the vessel to assist on the marine reserve survey for a day. All sampling within the reserve was permitted under a Department of Conservation Special Permit issued to NIWA (Authorisation to undertake specified scientific study within a marine reserve, Authorisation number 81770-MAR).

2.4.4 Data storage

The 2019 Kaikōura survey trip code was IKA1916. 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, Beentjes 2019). All analyses were carried out using data extracted from the *trawl* and *age* databases. Random sites were entered into attribute *stn_code*, prefixed with R (e.g., R1aA, R2aB, R3A, R4A). 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 Fisheries New Zealand Research Database Manager.

2.4.5 Age estimates

To assess reader competency in ageing before reading the 2019 survey otoliths, the two readers aged a subsample of 50 reference otolith preparations with the aim of achieving a score for Index of Average Percentage Error (IAPE) (Beamish & Fournier 1981), and mean coefficient of variation ((Chang 1982) of below 1.50% and 2.12%, respectively (Walsh 2017).

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 50 ºC.
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 appear dark. Translucent zones were counted (ageing of blue cod otolith thin sections prior to 2015 counted opaque zones to estimate age).
3. Two readers initially read all otoliths without reference to fish length, sex, or previous age estimates.
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 by Campana et al. (1995) and Campana (2001); including APE (average percent error) and coefficient of variation.

2.4.6 Data analyses

2.4.6.1 General

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 2019 random-site survey.

Analyses of catch rates and coefficients of variation, 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, Beentjes 2019). 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). Length was also rounded down when producing the age-length-keys for catch-at-age analyses and for estimating von Bertalanffy parameters.

The Hikurangi Marine Reserve was surveyed during the 2017 Kaikōura survey but the results were not documented in the survey report because the data were not loaded in the *trawl* database at the time of writing (Beentjes & Page 2018). The data have subsequently been loaded into the *trawl* database and in the current report the 2017 and 2019 marine reserve surveys are analysed and compared.

2.4.6.2 Catch rates

The catch rate (kg pot^{-1}) estimates were pot-based and the CV estimates were set-based (Beentjes & Francis 2011, Beentjes 2019). 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 (shown in Table 1 were used as the area of the stratum (A_t) when scaling catch rates (equations 3 and 5 given by Beentjes & Francis 2011). Catch rates are presented by stratum and overall, including and excluding the marine reserve.

2.4.6.3 Length-weight parameters

The length-weight parameters a_k, b_k from the 2019 Kaikōura 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.

2.4.6.4 Growth parameters

von Bertalanffy growth models (von Bertalanffy 1938) for each sex were fitted to the 2019 Kaikōura survey length-age data 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. In addition, because there were few older males in 2019, von Bertalanffy growth models were fitted to the combined length and age data from the last three surveys (2015, 2017, and 2019) to provide more representative growth parameters for input into spawner per recruit analyses.

2.4.6.5 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 shown in Table 1 was taken as the area of the stratum (A_t), and the length-weight parameter estimates are from the 2019 Kaikōura survey data for males and females separately.

Length and age frequencies were calculated as numbers of fish from equations 7, 8, and 9 of the manual (Beentjes & Francis 2011, Beentjes 2019). The length and age frequencies are expressed as proportions by dividing by total numbers.

Bootstrap resampling (300 bootstraps) was used to calculate CVs for proportions- and numbers-at-length and at-age using equation 12 of the manual (Beentjes & Francis 2011, Beentjes 2019). 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) from the 2019 survey for each sex applied to the length data from the entire survey area. Scaled length frequency (LF) and age frequency proportions are presented, together with CVs for each length and age class, and the mean weighted coefficients of variation (MWCVs).

2.4.6.6 Unsexed fish

All blue cod caught during the 2019 Kaikōura survey were sexed, except those in the marine reserve. The unsexed fish in the marine reserve were used in the total scaled length frequency compositions and were not included in age composition analyses or to estimate total mortality.

2.4.6.7 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 length frequencies. 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.

2.4.6.8 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 illustrate how well data conform to the assumptions made for estimating Z from age structure. This is particularly important when there are not many age classes, with potential for strong or weak year classes to introduce bias.

2.4.6.9 Spawner-per-recruit estimates

Spawner-per-recruit analyses were conducted using CASAL (Bull et al. 2005). The calculations involved simulating fishing with constant fishing mortality 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%). To allow valid comparison between years (i.e., 2015, 2017, and 2019) the spawner-per-recruit ratios for the 2015 and 2017 surveys were reanalysed using the default M value of 0.17 which was previously 0.14; The von Bertalanffy growth parameters used in the revised spawner-per-recruit calculations were taken from the 2015 and 2017 surveys, respectively.

Input parameters used in 2019 survey SPR analyses

Growth parameters — von Bertalanffy growth parameters are from the combined length and age data from the 2015, 2017, and 2019 Kaikōura surveys, and length-weight coefficients are from the 2019 Kaikōura survey:

Parameter	Males	Females
K (yr^{-1})	0.1238	0.1479
t_0 (yr)	-0.8799	-1.2099
L_∞ (cm)	56.6	43.3
a	0.008665	0.006859
b	3.1626	3.2343

Natural mortality — default assumed to be 0.17. (revised from 0.14 in 2019, see Beentjes 2019). Sensitivity analyses were carried out for *M* values 20% above and below the default (0.14 and 0.20).

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 von Bertalanffy models from the combined length and age data for the 2015, 2017, and 2019 Kaikōura surveys. The Kaikōura recreational MLS is 33 cm and selectivity was 6.2 years for males and 8.49 years for females.

Fishing mortality — 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.

2.4.6.10 The GLM model on environmental data

The influence of environmental variables on blue cod survey pot catch rates were investigated using a forward stepwise Generalised Linear Model (GLM) (McCullagh & Nelder 1989), with the individual pot catch (log-normal transformation) modelled as the response variable. Zero pot catches were assigned a nominal value of 0.01 kg. Data from the four random-site Kaikōura surveys were included in the analyses (2011, 2015, 2017, and 2019).

The predictor variables used in the model were fishing year, stratum, depth, time of day, tide status, bottom contour, bottom type, sea colour, sea condition, water clarity (secchi disc), swell height, cloud cover, moon phase, barometric pressure, surface water temperature, wind speed, latitude, and longitude. Variables were treated as categorical, except depth, water clarity, wind speed, barometric pressure, surface water temperature, latitude, longitude, and moon phase; these were entered as continuous variables. The variable ‘bait’ (percentage bait left when hauled) was only recorded in the last two surveys (2017 and 2019) so could not be used in the GLM model.

The variable ‘time of day’ of pot set was assigned to categories as follows:

0600–0800 h	morning_early	1401–1600 h	afternoon_mid
0801–1000 h	morning_mid	1601–1800 h	afternoon_late
1001–1200 h	morning_late	1801–2000 h	evening_early
1201–1400 h	afternoon_early	2001–2200 h	evening_late

The stepwise fitting method began with a basic model in which fishing year was the only predictor and iteratively included predictors until there was insufficient improvement in the model. For all analyses, the improvement in the residual deviance, i.e., (new deviance - old deviance) / (saturated deviance - null deviance) and termed R^2, was used as the criterion for including predictors. At each step, the predictor giving the greatest improvement in R^2 was included, providing that its inclusion resulted in an improvement in R^2 of at least 0.5%.

3. RESULTS

The results are presented firstly for the main survey area (excluding the marine reserve) referred to as the 2019 Kaikōura random-site survey, and secondly for the Hikurangi Marine Reserve.

3.1 2019 Kaikōura random-site survey

Twenty-seven random sites (6 pots per site, producing 162 pot lifts) from five strata off Kaikōura were surveyed from 1 to 11 December 2019 (Table 1, Figure 3). Depths sampled were 8–125 m (mean = 57 m). Twenty-two sites were carried out in phase 1 and five in phase 2.

3.1.1 Catch and catch rates

A total of 594.9 kg of blue cod (1160 fish) was taken from the five strata, 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 crayfish. The three most abundant bycatch species, by number, were scarlet wrasse (*Pseudolabrus miles*), sea perch (*Helicolenus percoides*), and banded wrasse (*Notolabrus fucicola*).

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 4). Mean catch rates of blue cod (all sizes) by stratum were 0.01–8.3 kg pot^{-1} with very low catches in strata 1, 2a, and 2b and relatively high catches in strata 3 and 4 (inshore and offshore Kaikōura Peninsula) (Table 3, Figure 4). The all-blue-cod survey catch rate was 1.56 kg pot^{-1} with a CV of 10.4%. Catch rates for recruited blue cod (33 cm and over) followed the same pattern among strata as for all blue cod and the recruited blue cod survey catch rate was 0.76 kg pot^{-1} (CV 14.2%) (Table 3, Figure 4). Of the 162 random-site pots, 49 (30%) had zero catch of blue cod.

3.1.2 Biological and length frequency data

Of the 1160 blue cod caught, all were sexed, measured for length, and weighed (Table 4). The sex ratios were 27–81% male across the four strata (excluding 2b where only one fish was caught) and the overall weighted sex ratio was 50% male (Table 4). Length was 16–51 cm for males and 14–44 cm for females, although this range varied among strata and the overall weighted mean length was 29.4 cm for males and 29.2 cm for females. The sample sizes in strata 1, 2a, and 2b were too low to comment on the length distributions (Figure 5). The scaled length frequency distributions in stratum 3 had modes at about 25 cm and 33 cm for males and a single female mode at about 25 cm; males tended to be larger overall, and there were 20% more males than females (Figure 5). By contrast, in stratum 4 fish tended to be larger overall than in stratum 3, and there were more than twice as many females than there were males.

3.1.3 Age and growth

Otolith section ages from 168 males and 143 females collected from the 2019 random-site survey were used to estimate the population age structure from Kaikōura in 2019 (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 6). There is a large range in length-at-age particularly for males; and males grow faster and are the largest fish, whereas the oldest fish are females. The 2015 and 2017 fitted von Bertalanffy curves are similar, but in 2019 the L_∞ value is inflated because older males, which normally sit on the flat part of the curve, are absent (Figure 6). The combined length-age data for the 2015, 2017, and 2019 surveys and the von Bertalanffy model fits and growth parameters are shown in Figure 7.

The two readers achieved CV and IAPE scores below the targets when ageing 50 otoliths from the blue cod reference collection (Table 6). Between-reader comparisons of the 2019 survey otoliths are presented in Figure 8. The first counts by the two readers showed 87% agreement, and, overall, there was no bias between readers with a CV of 1.5% and index of average percent error (IAPE) of 1.1%.

3.1.4 Spawning activity

Gonad stages of blue cod sampled in the 2019 Kaikōura survey are presented by sex for the survey overall and by stratum (Table 7a and 7b). There were indications of spawning activity during the survey period with about a third of females and a quarter of males mature or running ripe, suggesting that spawning may not have peaked (Table 7a). Gonad stage by stratum suggests that for females all spawning activity was occurring off Kaikōura Peninsula (strata 3 and 4) at this time, with most running ripe fish found in the deeper stratum 4 at about 100–125 m (Table 7b). The male gonad stages, however, showed indications of spawning in other strata and there were similar numbers of mature and running ripe fish in stratum 4 (Table 7b).

3.1.5 Population length and age composition

The scaled length frequency and age distributions for the 2019 Kaikōura random-site survey are shown for all strata combined (excluding the marine reserve) as histograms and cumulative frequency line plots for males, females, and both sexes combined (Figure 9).

The scaled length frequency distribution for males is bimodal with peaks at about 25 cm and 34 cm, and an overall mean length of 29.4 cm. The female distribution is less clearly bimodal, with probable peaks at about 25 cm and 30 cm, and an overall mean length of 29.2 cm (Figure 9). There is also a small and distinct juvenile mode apparent in the female distribution. The cumulative distribution plots of length frequency are similar between sexes with the only real difference because the smallest fish are females and the largest fish are males (Figure 9). The mean weighted coefficients of variation (MWCVs) around the length distributions were 37% for males and 31% for females. Recruited fish (33 cm and over) included 31.0% of males and 24.2% of females by number.

Age estimates were 2–16 years for males and 2–19 years for females, but most males and females were 5 and 7 years old (Figure 9). The estimated population age distributions indicate knife-edge selectivity to the potting method at two years with strong modes at five and especially seven years for both sexes, but particularly for females. The age distribution also shows a corresponding weak mode for six-year-olds. The cumulative distribution plots of age frequency show clearly that females had a higher proportion of older fish than males (Figure 9). The mean age of females was greater than that of males (6.0 for males and 7.3 years for females). The MWCV around the age distributions overall was 19%, and by sex was 25% for males and 27% for females.

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 8. 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 0.27 (95% confidence interval of 0.19–0.36).

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 10). There were few blue cod aged older than eight 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, and this suggests 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 8).

Estimates of mortality (CR *Z* and *F*, and *M*) and spawner-per-recruit (*SPR*) ratios at three values of *M* and at an age-at-full-recruitment of eight years are shown in Table 9. Based on the default *M* of 0.17 (previously 0.14), estimated fishing mortality was 0.1 and associated spawner-per-recruit ratio was 62.0% (Figure 11). At the 2019 levels of fishing mortality, the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 62% of the contribution in the absence of fishing. The 95% confidence interval around the *SPR* ratio was 48–89% (Table 9). The revised spawner-per-recruit ratios for 2015 and 2017 were 72% and 42% (Figure 11).

Stratum 1 is mostly outside the Kaikōura Marine Area (see Figure 3) where, at the time of the survey, the MLS was 30 cm, not 33 cm. The resulting spawner-per-recruit ratio estimate may not be representative of blue cod in this stratum.

3.2 Hikurangi Marine Reserve

In the Hikurangi Marine Reserve five random sites (6 pots per site, producing 30 pot lifts) were surveyed on 10 December 2019 (see Table 1, Figure 3). Depths sampled were 8–39 m. A total of 67.4 kg of blue cod (113 fish) was sampled from the marine reserve stratum and returned to the sea alive.

The mean catch rate of blue cod (all sizes) was 2.25 kg pot^{-1} with a CV of 56.2%. The catch rate for recruited blue cod (33 cm and over) was 1.67 kg pot^{-1} (CV 64.8%) (see Table 3, Figure 4). Of the 30 random-site pots, 15 (50%) had zero catch of blue cod.

All 113 blue cod caught were measured for length, but no attempt was made to sex these fish (see Table 4). Mean length was 31.5 cm and ranged from 18 to 45 cm. The sample size was too low to comment on the length distribution, which has no discernible shape (see Figure 5).

3.3 Kaikōura random-site survey time series (2011, 2015, 2017, 2019)

Mean catch rates (kg pot^{-1}) for all blue cod and recruited blue cod for each of the four surveys are presented in Figure 12. The relative differences in catch rates among strata are generally preserved over time; i.e., catch rates were consistently highest in stratum 4 and lowest in stratum 2. The 2019 catch rates in stratum 1 are, however, low compared with previous years but the confidence intervals around the estimates are large. The mean survey catch rates (all excluding the marine reserve) show a general but slight decline over time, with a statistically significant difference ($P<0.05$) between the mean pot catch of 2011 and 2019 surveys (two-sample t-test) (Figure 12).

The scaled length frequency distributions and mean length were similar for all four surveys with differences due to the strong recruitment of juveniles in 2015, progressing through to strong modes in 2017 and 2019, particularly for males (Figure 13).

The sex ratio for all surveys was 47–55% male for all blue cod, and 45–56% male for recruited blue cod, with no clear trend (Figure 14). The survey sex ratio is driven by data from strata 3 and 4, where catch rates are highest and where most fish are caught. The dominance of males in stratum 3 and females in the adjacent but deeper stratum 4 is typical of the sex ratio in this time series (Figure 15).

Age compositions can be validly compared only for the 2015, 2017, and 2019 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 7- and 8-year-old age classes in 2017, particularly for females (Figure 16). Subsequently, the 2017 survey 5-, 7-, and 8-year-old age classes are evident in 2019 as 7-, 9-, and 10-year-olds. Further, the strong 3-year-old age class in 2017 has also progressed through to 2019 where it appears as a strong 5-year-old age class (Figure 16). These results indicate that modal progression of strong year classes is apparent and supports the ageing methodology based on counts of annual growth rings.

Chapman Robson total mortality estimates are variable; they increase between 2015 and 2017 before decreasing in 2019, with a corresponding decrease and then increase in the *SPR* estimates (see Figure 11). The reasons for this are discussed below in section 4.6.

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

3.4 The GLM model on environmental data

The results of the stepwise GLM indicated that 55% of the variability in the random-site survey catch rates could explained by the six variables shown below.

Predictors	R^2
fishing year	0.012
stratum	0.490
sea colour	0.512
bottom contour	0.524
depth	0.533
time of day	0.541
bottom type	0.546

Stratum explained 49% of the variability with the five remaining variables combined explaining 6%. Depth is to some extent correlated with stratum; the deeper offshore stratum 4 consistently has the highest catch rates and the shallow inshore stratum 2 has the lowest catch rates.

4. DISCUSSION

4.1 General

The 2019 Kaikōura random-site potting survey was the fourth in the time series of relative abundance and population structure of blue cod from this area, after previous surveys in 2011, 2015, and 2017. Fixed-site surveys were carried out in 2004 and 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-site surveys, and the capture of larger blue cod during the random-site surveys (Beentjes & Page 2017, Carbines & Haist 2018d), suggest that there is no suitable way of quantitatively linking the fixed-site series with the random-site series. The 2007 fixed-site survey catch rate and, to a lesser extent that for the 2011 fixed-site survey, were exceptionally high and more than double that for the 2019 random-site survey (Figure 18). Notwithstanding the differences in catch rates that can be ascribed to the survey design (fixed or random), there are strong indications that blue cod biomass declined substantially between 2007 and 2019.

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 Kaikōura earthquake, provided high resolution coastal bathymetry maps showing locations of discrete substrates such as rocky reefs, rippled sand, and soft muddy bottom (Figure 19) (Neil et al. 2018). These substrate maps may be useful for re-stratifying future surveys and provide blue cod generalised habitat maps showing that strata with the most comprehensive rocky reef habitat are also those with the highest catch rates (i.e., strata 3 and 4) (see Figure 4). 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 Catch rates and survey precision

The blue cod random-site survey catch rates off Kaikōura from 2011 to 2019 appear to be stable, but, notwithstanding the confidence interval around the estimates, there are indications of a decline in the 2019 abundance in southern stratum 1 and to some extent stratum 2 (see Figure 12). In strata 3 and 4, directly off Kaikōura Peninsula, where catch rates are consistently the highest, there are no trends in abundance.

The survey CV around relative abundance (catch rates) was not specified in the project objectives for the 2019 Kaikōura survey, but a CV of around 15% is generally targeted. The achieved CV of 10% in 2019 was an improvement on those from the previous random-site surveys (2011, 17%; 2015, 19%; 2017, 16%) (Beentjes & Page 2017, 2018, Carbines & Haist 2018d). The achieved CVs indicate that the survey design and number of sites used (25–29) are appropriate for Kaikōura random-site surveys. The results of the GLM indicate that stratum has the most influence on catch rates and emphasise the importance of informed stratification in the survey design of the Kaikōura time series.

4.4 Cohort progression

Kaikōura

Cohort progression of blue cod age classes is apparent over the three surveys from 2015 to 2019, showing both nominally strong and weak year classes (see Figure 16). The advantage of having three surveys conducted within four years is that cohorts can be tracked between surveys and this has provided validation of the ageing methodology based on annual winter ring deposition on sagittal otoliths. The progression and relative strength of the 2012 year-class (i.e., 3-year-old in 2015) from 2015 through to 2019 suggest that this year class was exceptionally strong with the expectation that, as it recruits fully to the recreational and commercial fisheries, these will be enhanced. Growth estimates indicate that males are on average 6 years old and females 8 years old when they reach the current MLS of 33 cm within the Kaikōura Marine Area[2] (see Figure 7). Hence, the faster growing 2012 year-class males will have fully recruited to the fishery in 2018 and females will do so in 2020. There were, however, no indications of a commensurate increase in all blue cod or recruited abundance in the 2019 survey possibly because, apart from two strong cohorts (5- and 7-year-olds), other cohort strengths are comparatively weak and there are fewer older age classes. This suggests that for abundance to increase substantially a number of strong recruitment pulses is required to offset those from the poor to average years. Unlike 2015 and 2017, the 3-year-old age class appears to be relatively weak in 2019 and the population was dominated by 5- and 7-year-olds.

The relatively higher numbers of 5-year-old blue cod in both 2017 and 2019 compared with the numbers of this cohort at age three in previous surveys, indicates that blue cod are not fully selected to the survey potting gear until at least 4 to 5 years old, a finding supported by the age composition in other areas surveyed.

Other areas

The strong blue cod 2012 year class (3 year olds) and the weak 2011 year class (4 year olds) observed in Kaikōura in December 2015 (see Figure 16) were also present in the age compositions from Motunau in 2016, Banks Peninsula in 2016, and north and south Otago in 2018 (Beentjes & Fenwick 2017, Beentjes & Sutton 2017, Beentjes & Fenwick 2019a, 2019b, Beentjes 2020). The recruitment patterns for the Motunau surveys in 2016 and 2020 (Beentjes & Miller 2021) are most similar to those of nearby

[2] Outside the Kaikōura Marine Area, where the current MLS of 30 cm, males will be 5.5 years old and females 6.5 years old when they recruit to the fishery so both sexes of the 2012 year-class are fully recruited to the fishery.

Kaikōura and indicate that the closer the populations are to each other, the more similar are their patterns in recruitment strength. This consistent recruitment strength pattern suggests that the 2012 spawning event and/or survival of subsequent life-history stages off the east coast of the South Island was more successful than average. Blue cod have a restricted home range (Rapson 1956, Mace & Johnston 1983, Mutch 1983, Carbines & McKenzie 2001, Govier 2001, Carbines & McKenzie 2004, Rodgers & Wing 2008) with only small numbers of blue cod travelling any distance from their tagging location. Blue cod off Kaikōura, Motunau, Banks Peninsula, and Otago are therefore 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) and this suggests that egg or larval dispersion coupled with the occasional larger scale movements of individuals is sufficient to prevent genetic isolation occurring. Hence, the strong and weak year classes often common off the east coast South Island are more likely to be regulated by fisheries-independent environmentally driven events that act at the scale of the east coast of the South Island or wider and impact localised spawning and survival of eggs, larvae, and juvenile fish (Beentjes 2020).

4.5 Sex change and sex ratio

In all four random-site surveys, sex ratio in the deeper stratum 4 (offshore of Kaikōura Peninsula in 100–200 m, see Figure 3) strongly favoured females, whereas the sex ratio was skewed towards males in other strata (Figure 15), and blue cod were larger overall in stratum 4 (see Figure 5). Sex ratios of blue cod favouring females are uncommon, particularly in exploited blue cod populations. The high proportion of females off Kaikōura Peninsula in deeper water in 2019 appears to be related to spawning behaviour involving both larger fish and the presence of more females than males, because all spawning condition blue cod were caught in strata 3 and 4, and running ripe blue cod were virtually all caught in stratum 4 (see Table 7b). Again, this segregation of spawning blue cod by strata is common to all four surveys (Beentjes & Page 2017, 2018, Carbines & Haist 2018d).

Blue cod are sequential protogynous hermaphrodites with some (but not all) females changing into males as they grow (sex reversal) (Carbines 2004). Blue cod are a diandric species where males either develop directly from the undifferentiated state without sex inversion (primary males) or begin life as female and become male following sex inversion (secondary males) (Reinboth 1980, Beentjes 2020). The monandric condition is where life always begins as female and males develop only through sex inversion —this occurs in six Australian reef species of the same genus as blue cod (*Parapercis* spp.) (Stroud 1982). Kaikōura blue cod population sex and size structure is consistent with this diandric reproductive strategy with both small males and large females present in the population. In areas where fishing pressure is known to be high, such as Motunau, inshore Banks Peninsula, and the Marlborough Sounds, the sex ratios are strongly skewed towards males which is contrary to an expected dominance of females resulting from selective removal of the larger 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; this suggests 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 more 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 females. The reduced levels of behavioural interaction between males and females has been shown to lead to enhanced sex inversion in other protogynous fish species (Fishelson 1970, Robertson 1972, Warner 1984, Sato et al. 2018). Although the sex ratio is close to parity for Kaikōura for all four random-site surveys, this is strongly influenced by stratum 4 (offshore from Kaikōura Peninsula in 100–200 m) where abundance is consistently the highest and the proportion of males consistently low. As discussed above, this is probably related to spawning behaviour off Kaikōura Peninsula with spawning condition females largely confined to stratum 4. For the other strata which have lower abundance and the generally smaller fish, the sex ratio favours males. Factors affecting sex change and sex ratios in blue cod are not well understood.

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 F_{MSY} is the level of spawner-per-recruit $F_{\%SPR}$ (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 F_{MSY} is $F_{45\%SPR}$.

Growth rates and von Bertalanffy parameters were similar in 2015, 2017, and 2019, but there were differences in length and age compositions that had major effects on the CR total mortality and corresponding *SPR* estimates (see Figure 11). The 2015, 2017, and 2019 random-site SPR estimates[3] were $F_{72\%SPR}$, $F_{42\%SPR}$, and $F_{62\%SPR}$ respectively, indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit was reduced to 72%, 42%, and 62% of the contribution in the absence of fishing (see Figure 11). These results suggest that the level of exploitation (F) of Kaikōura blue cod stocks was below the F_{MSY} target reference point of $F_{45\%SPR}$, in 2015 and 2019 (under-exploited) and just above the target in 2017 (over-exploited). However, changes in total mortality and *SPR* of this magnitude in four years seems implausible, and examination of the traditional catch curves provides some explanation. Total mortality 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 are due to variable recruitment and, hence, violate the catch curve assumption that recruitment is constant (see Figure 10). Further, because there are relatively few older age classes in a species that has a maximum age of around 30 years, Z can fluctuate widely between surveys. The point estimates of Z, F, and *SPR* 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 Kaikōura 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 20). 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 mature and running-ripe conditions during this period. There were nearly always higher proportions of females than males in the combined mature/running-ripe conditions from the Kaikōura surveys, possibly related to the haremic reproductive strategy of blue cod where a large male will hold a territory, attracting four to five females (Mutch 1983). The Kaikōura surveys occurred during the protracted spawning period, but whether this is the peak spawning period is unknown. The virtual absence of spawning in other strata indicates that spawning activity can vary geographically within the survey area.

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 Kaikōura Marine Area took place in March 2014. There are no clear indications that these regulations have had an effect on blue cod catch rates, size of blue cod, or age composition as measured by the 2015, 2017, and 2019 random-site surveys. Indeed, catch rates in the southern strata 1[4] and especially 2 (2a

[3] The 2015 and 2017 *SPR* estimates were revised used M of 0.17 which replaced 0.14 as the default.

[4] Stratum 1 (1a and 1b) is outside the Kaikōura Marine Area where, at the time of the survey, the MLS was 30 cm and DBL was ten blue cod.

and 2b) appear to be declining (see Figure 12). Displacement of recreational fishing effort from the Marlborough Sounds to Kaikōura 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 over time, however, it is difficult to gauge the impacts of the increase in MLS and reduction in MDL within the Kaikōura Marine Area. For example, it may be that the benefits of these measures were diminished or offset by increased fishing effort. The last recreational survey of Kaikōura was carried out in 2003 (Hart & Walker 2004) and the most recent recreational fisheries panel survey in 2017–18 provides catch data only at the level of QMA, i.e., BCO 3.

4.9 Status of blue cod stocks inside the Hikurangi Marine Reserve

The expectation of establishing a no-take marine reserve is that fish within this zone will become more abundant and attain greater overall length and age. Hikurangi Marine Reserve was established in March 2014 affording nearly six years of no fishing up to the time of the December 2019 survey. Although the marine reserve is just over 10 000 ha in size, the area of suitable habitat shallower than 200 m in the reserve is relatively small at only about 150 ha (see Figure 3). The abundance estimates of blue cod inside the Hikurangi Marine Reserve on the 2017 and 2019 random-site surveys were substantially higher than for adjacent strata 2a and 2b, but only about 25% of those in stratum 4, where blue cod were most abundant (see Figure 12). There were too few fish caught in adjacent strata to compare size with those in the marine reserve, but size composition is comparable to that in strata 3 and 4 (compare Figures 5 and 21), notwithstanding the relatively small sample sizes from the marine reserve. Hence, based on two surveys it appears that, despite the small size of this marine reserve, it is effectively working as intended with fish more abundant than in adjacent fished areas. The maximum density of blue cod in this area may be less than off Kaikōura Peninsula because of the nature of the habitat and oceanography. Further, although blue cod have restricted movement, there is likely to be some movement of blue cod in and out of the marine reserve, particularly at the boundaries.

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7. TABLES AND FIGURES

Table 1: Effort and catch data for the 2019 Kaikōura random-site blue cod potting survey. mr, marine reserve; exclmr, excluding marine reserve; inclmr, including marine reserve.

	Area		*N* sets (sites)		*N* pots	Catch (blue cod)		Depth (m)	
Stratum	(km^2)	Site type	Phase 1	Phase 2	(stations)	*N*	kg	Mean	Range
1	26.4	Random	5		30	56	9.7	46.6	29–80
2a	37.8	Random	3		18	21	9.3	30.5	8–67
2b	58.7	Random	3		18	1	0.1	23.9	12–39
3	24.8	Random	7	1	48	490	186.5	71.8	30–104
4	15.7	Random	4	4	48	592	389.3	112.8	97–125
mr	1.5	Random	5		30	113	67.4	19.1	8–39
Total exclmr	163.4	Random	22	5	162	1160	594.9	57.2	8–125
Total inclmr	164.9	Random	27	5	192	1273	662.3	50.8	8–125

Table 2: Total catch and numbers of blue cod and bycatch species caught on the 2019 Kaikōura random-site blue cod potting survey, excluding the marine reserve. Percent of the catch by weight is also shown.

		Random sites			
Common name	Species	Code	Number	Catch (kg)	% catch
Blue cod	*Parapercis colias*	BCO	1 160	594.9	95.57
Scarlet wrasse	*Pseudolabrus miles*	SPF	20	9.4	1.51
Sea perch	*Helicolenus percoides*	SPE	19	8.2	1.32
Banded Wrasse	*Notolabrus fucicola*	BPF	15	3.7	0.59
Tarakihi	*Nemadactylus macropterus*	NMP	5	2.1	0.34
Girdled wrasse	*Notolabrus cinctus*	GPF	10	1.9	0.31
Rock lobster	*Jasus edwardsii*	CRA	3	0.9	0.14
Dwarf scorpionfish	*Scorpaena papillosa*	RSC	4	0.8	0.13
Spotted Wrasse	*Notolabrus celidotas*	STY	2	0.4	0.06
Yellow cod	*Parapercis gilliesii*	YCO	1	0.2	0.03
Totals			1 239	622.5	100.00

Table 3: Mean catch rates for all blue cod and recruited blue cod (33 cm and over) from the 2019 Kaikōura 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; mr, marine reserve; exclmr, excluding marine reserve; inclmr, including marine reserve.

		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	0.32	0.136	42.0	0.05	0.048	100.0
2a	18	0.52	0.258	50.0	0.21	0.113	54.8
2b	18	0.01	0.006	100.0	0.00	0.000	NA
3	48	3.93	0.564	14.4	1.34	0.300	22.4
4	48	8.26	1.277	15.5	5.25	0.986	18.8
mr	30	2.25	1.263	56.2	1.67	1.083	64.8
Overall (exclmr)	162	1.56	0.163	10.4	0.76	0.109	14.2
Overall (inclmr)	192	1.57	0.162	10.3	0.77	0.108	14.0

Table 4: Descriptive statistics for blue cod caught on the 2019 Kaikōura random-site blue cod potting survey. Outputs are raw for each stratum and weighted for the survey overall. Sex ratio is also given for recruited blue cod (33 cm and over). m, male; f, female; u, unsexed. –, no data; mr, marine reserve; inclmr, including marine reserve; exclmr, excluding marine reserve.

	Random site survey						
			Length (cm)			Percent male	
Stratum	Sex	No.	Mean	Minimum	Maximum	All blue cod	Recruited blue cod ≥ 33 cm
1	m	30	22.5	16.2	38.8	53.9	100
	f	26	20.9	13.9	30.0		
2a	m	17	30.4	20.4	38.8	81.1	100
	f	14	25.6	23.5	27.5		
2b	m	1	16.0	16.0	16.0	100	NA
	f	–	–	–	–		
3	m	296	29.2	17.3	44.5	60.5	84.2
	f	194	27.5	20.1	40.0		
4	m	160	35.9	23.7	51.0	26.9	36.7
	f	432	32.6	22.0	44.5		
mr	u	113	31.5	18.1	45.0	–	–
Overall (exclmr)	m	504	29.4	16.0	51.0	50.0	56.1
	f	656	29.2	13.9	44.5		
Overall (inclmr)	m	504	29.4	16.0	51.0	50.0	56.1
	f	656	29.2	13.9	44.5		
	u	113	31.5	18.1	45.0		

Table 5: Otolith ageing data collected from the 2019 Kaikōura random-site blue cod potting survey.

		Length of aged fish (cm)		Age (years)	
Survey	No. otoliths	Minimum	Maximum	Minimum	Maximum
Male	168	17	51	2	16
Female	143	13	44	2	19
Total	311	13	51	2	19

Table 6: Reader comparison scores determined from ageing 50 randomly selected blue cod reference otolith samples ranging in age from 2 to 23 years. IAPE, Index of Average Percentage Error; CV, mean coefficient of variation.

	IAPE (%)	CV (%)	Agreed age (%)	Pass/Fail
Target	1.50	2.12	–	–
Reader 1	1.48	2.09	80	Pass (1st attempt)
Reader 2	1.40	1.98	82	Pass (1st attempt)

Table 7a: Gonad stages (%) of blue cod from the 2019 Kaikōura random-site blue cod potting survey in 2019 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; *N*, number of fish.

	Gonad stage (%)					
Sex	1	2	3	4	5	*N*
Males	29.2	35.3	33.3	1.2	1.0	504
Females	59.1	12.8	14.2	11.4	2.4	656

Table 7b: Gonad stages (numbers) of blue cod from 2019 Kaikōura random-site blue cod potting survey for all blue cod by stratum and sex.

	Male gonad stage (*N*)					
Stratum	1	2	3	4	5	Stratum totals (*N*)
1	23	6	1			30
2a	5	8	3		1	17
2b	1					1
3	104	112	74	3	3	296
4	14	52	90	3	1	160
Gonad totals (*N*)	147	178	168	6	5	504

	Female gonad stage (*N*)					
Stratum	1	2	3	4	5	Stratum totals (*N*)
1	25	1				26
2a	2	2				4
2b						0
3	163	16	6	5	4	194
4	198	65	87	70	12	432
Gonad totals (*N*)	388	84	93	75	16	656

Table 8: Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals of blue cod for the 2019 Kaikōura random-site cod potting survey. AgeR, age-at-full recruitment.

		95% CIs	
AgeR	*Z*	Lower	Upper
5	0.38	0.27	0.51
6	0.39	0.28	0.52
7	0.61	0.44	0.84
8	0.27	0.19	0.36
9	0.35	0.24	0.49
10	0.34	0.24	0.47

Table 9: 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 2019 Kaikōura random-site potting survey. The mortality parameters and spawner-per-recruit estimates are also given for the 95% confidence interval values of *Z* for the default *M* (0.17). AgeR = 8, where AgeR is the age at which females reach MLS of 33 cm. *M*, natural mortality; *Z*, total mortality; *F*, fishing mortality; LowerCI, lower 95% confidence interval; UpperCI, upper 95% confidence interval.

M	*Z*	*F*	$F_{\%SPR}$	Estimate
0.14	0.27	0.13	$F_{49.8\%}$	Point
0.17	0.27	0.1	$F_{62.0\%}$	Point
0.20	0.27	0.07	$F_{74.0\%}$	Point
0.17	0.19	0.02	$F_{88.6\%}$	LowerCI
0.17	0.36	0.19	$F_{48.0\%}$	UpperCI

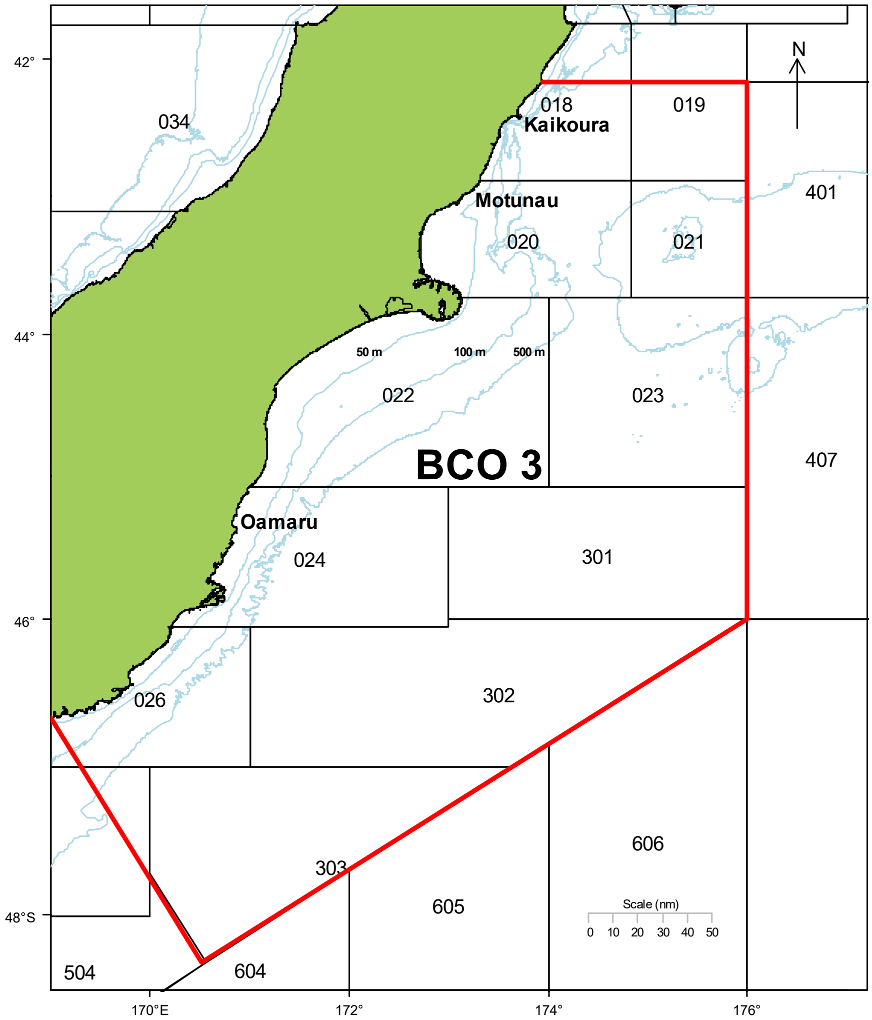

Figure 1: Blue cod Quota Management Area BCO 3 (red border) and statistical areas. The north Canterbury potting survey locations of Kaikōura and Motunau are shown.

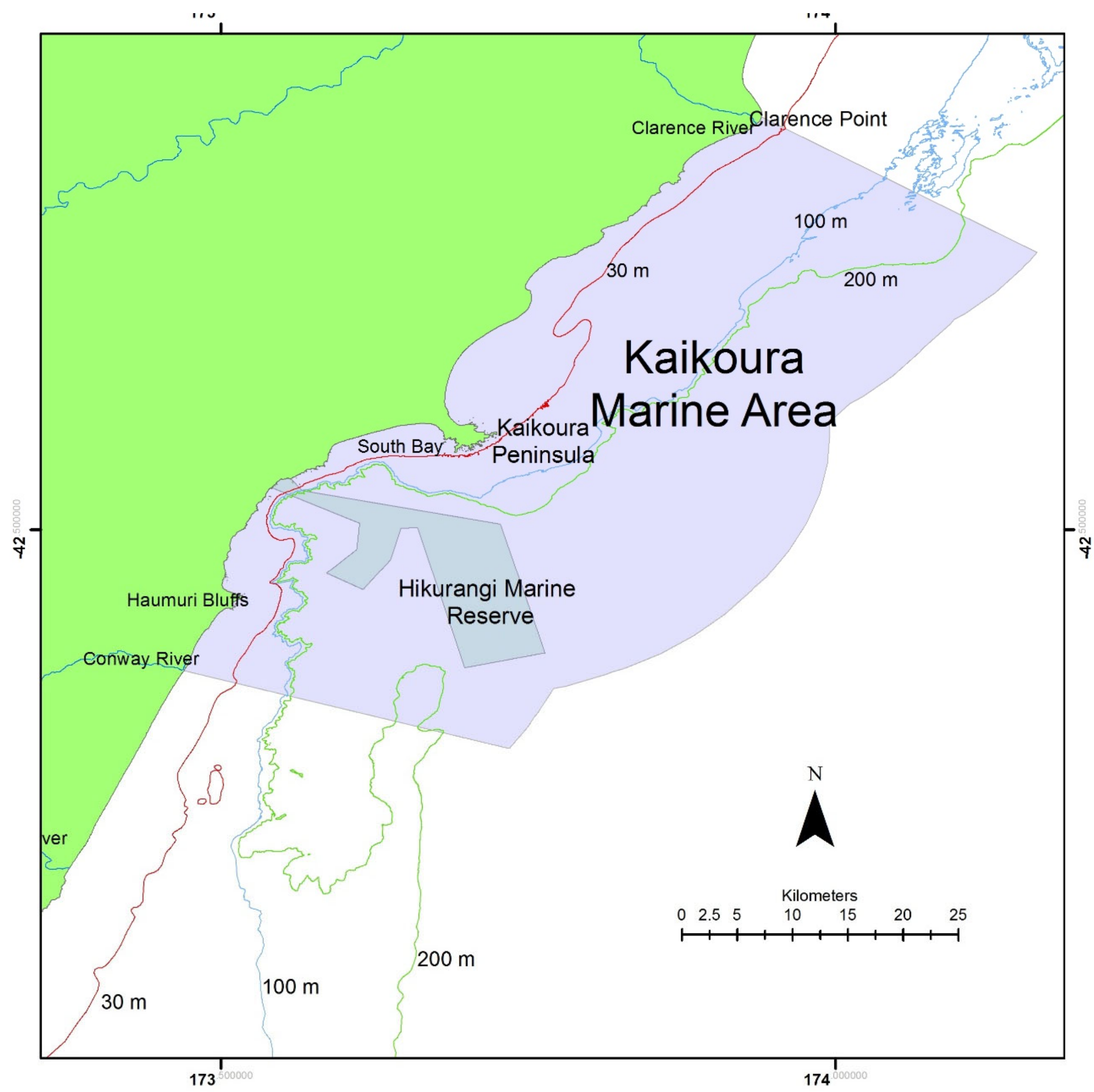

Figure 2: Map of north Canterbury region showing the Kaikōura Marine Area and Hikurangi Marine Reserve, both established in 2014. Within the Kaikōura Marine Area, the recreational blue cod minimum legal size is 33 cm, and daily bag limit is six. Elsewhere in north Canterbury these limits were 30 cm and 10 blue cod, changing to 33 cm and 2 blue cod on 1 July 2020.

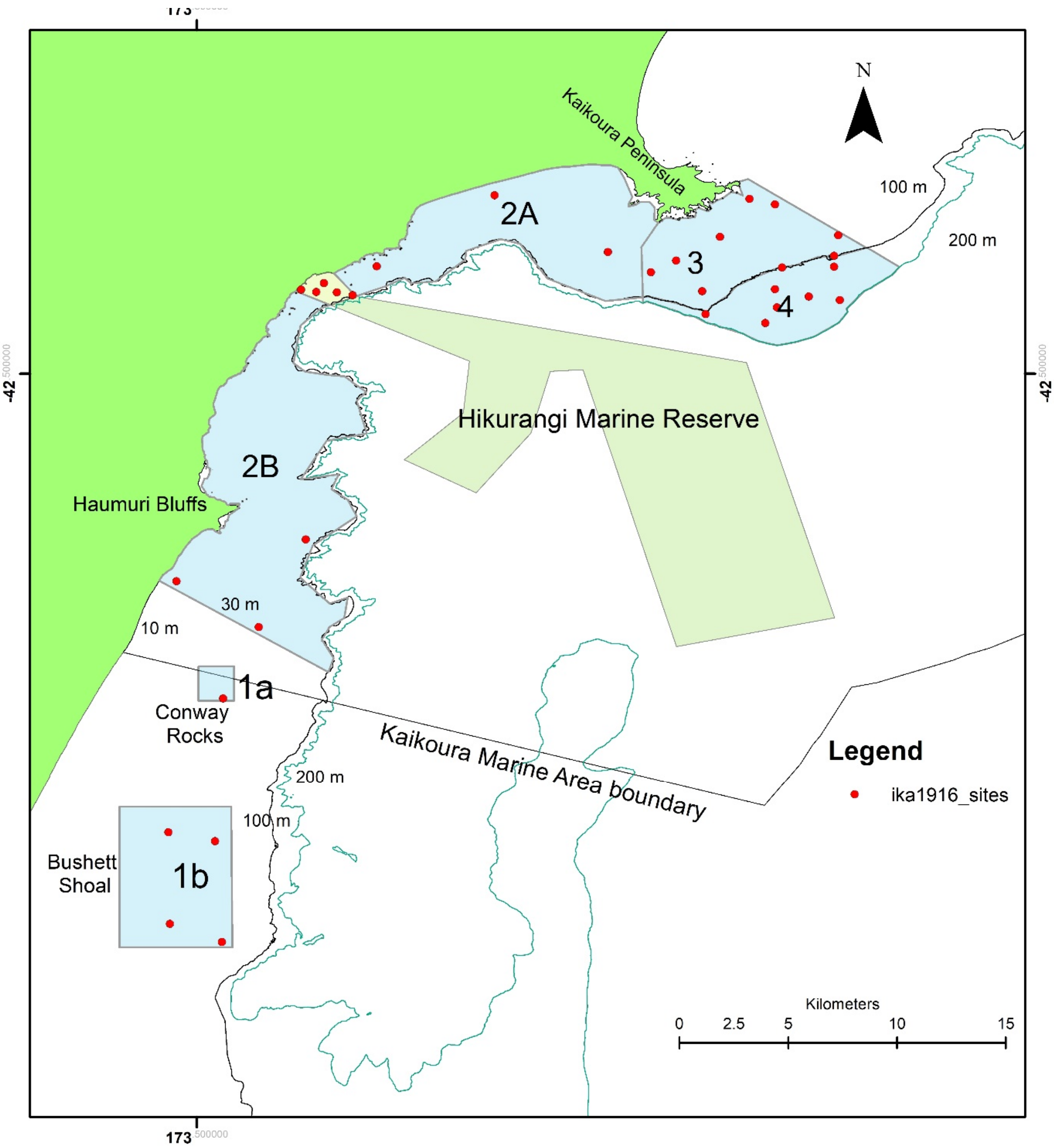

Figure 3: Kaikōura strata and pot locations for the 2019 random-site blue cod potting survey. The Hikurangi Marine Reserve and Kaikōura Marine Area are also shown.

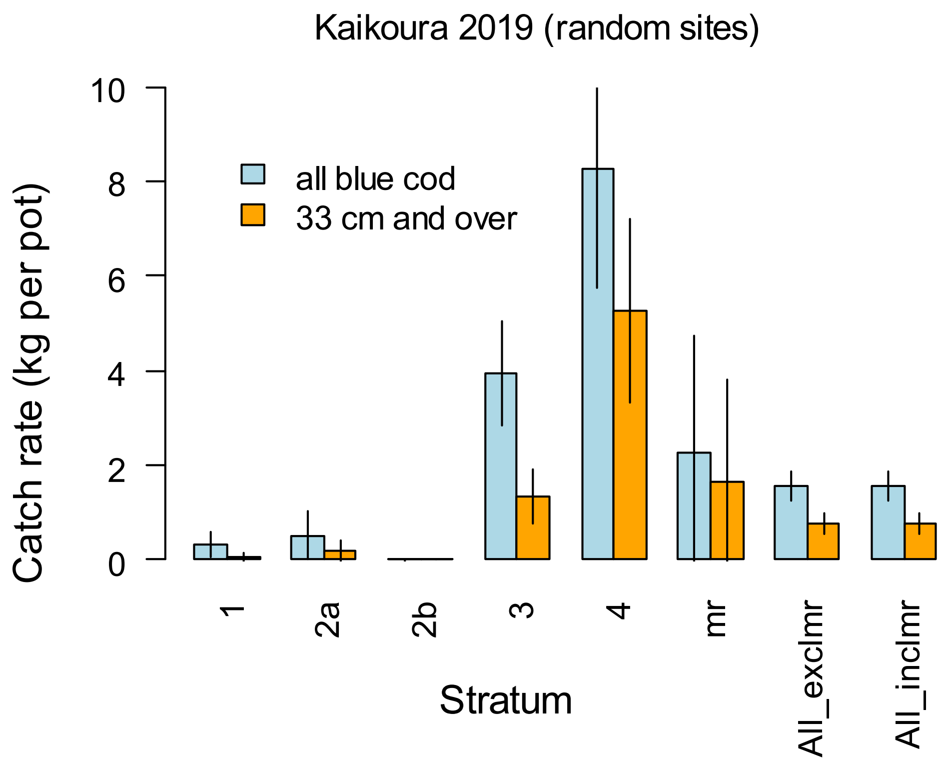

Figure 4: Catch rates (kg pot^{-1}) of all blue cod and recruited blue cod (33 cm and over) by strata, and for Kaikōura overall for the 2019 Kaikōura random site survey. Error bars are 95% confidence intervals. All_exclmr, excluding marine reserve; All_inclmr, including marine reserve.

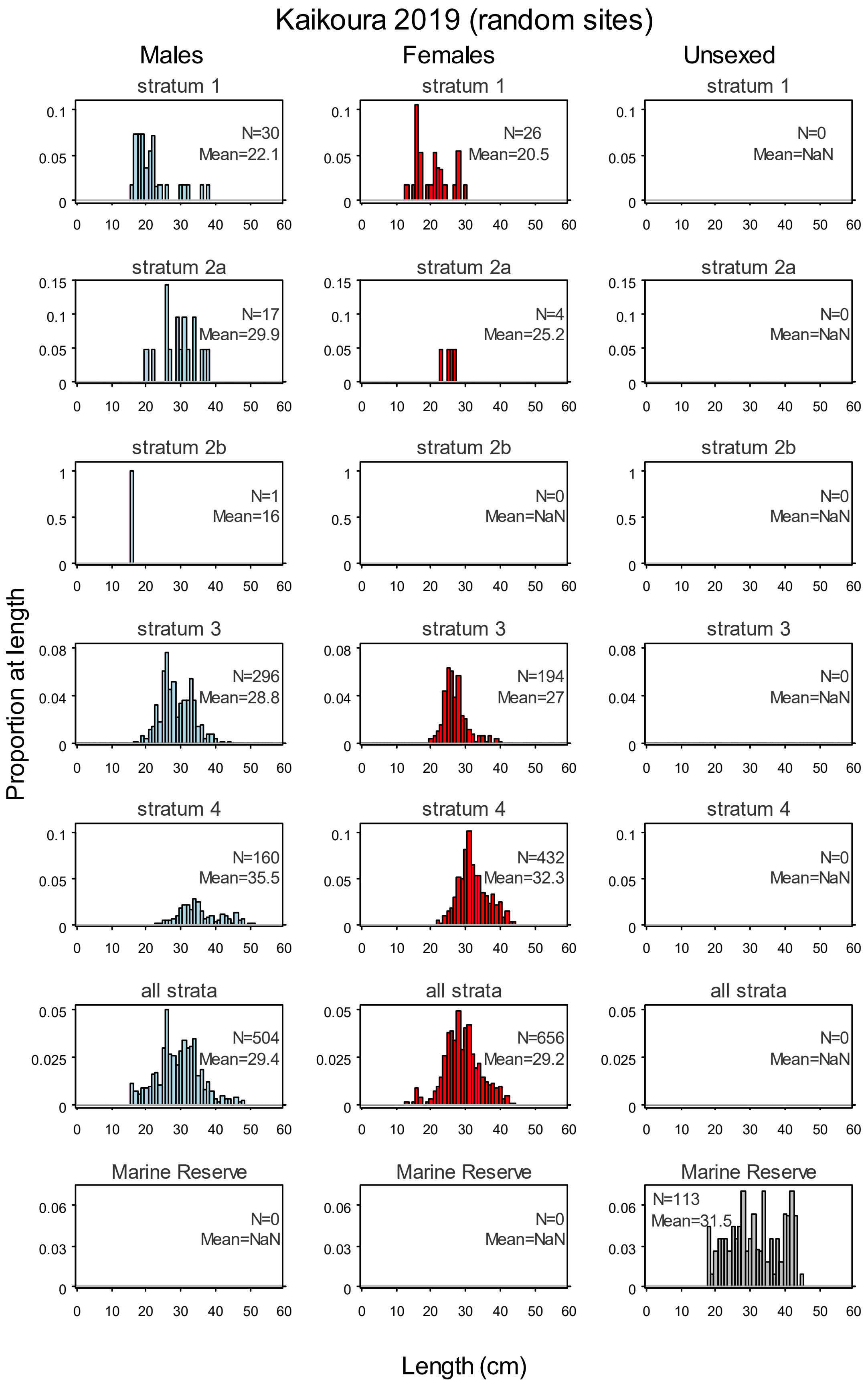

Figure 5: Scaled length frequency distributions by strata and overall for the 2019 Kaikōura random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. The length frequency distribution within the marine reserve is also shown.

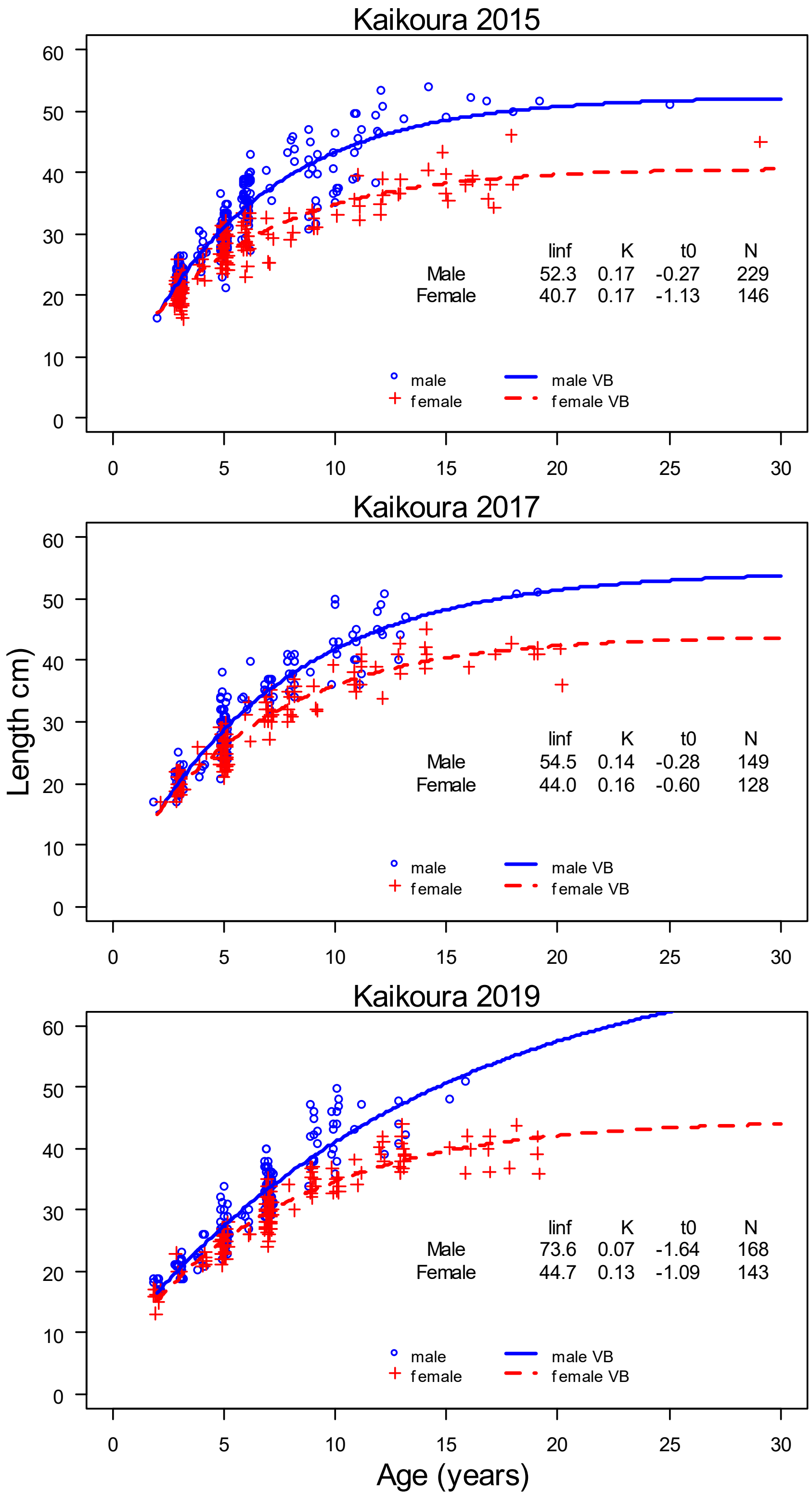

Figure 6: Observed blue cod age and length data by sex for the 2015, 2017, and 2019 Kaikōura surveys with von Bertalanffy (VB) growth models fitted to the data. linf, average size at the maximum age (cm); K, Brody growth coefficient (yr^{-1}); t0, age when the average size is zero; N, number of fish aged.

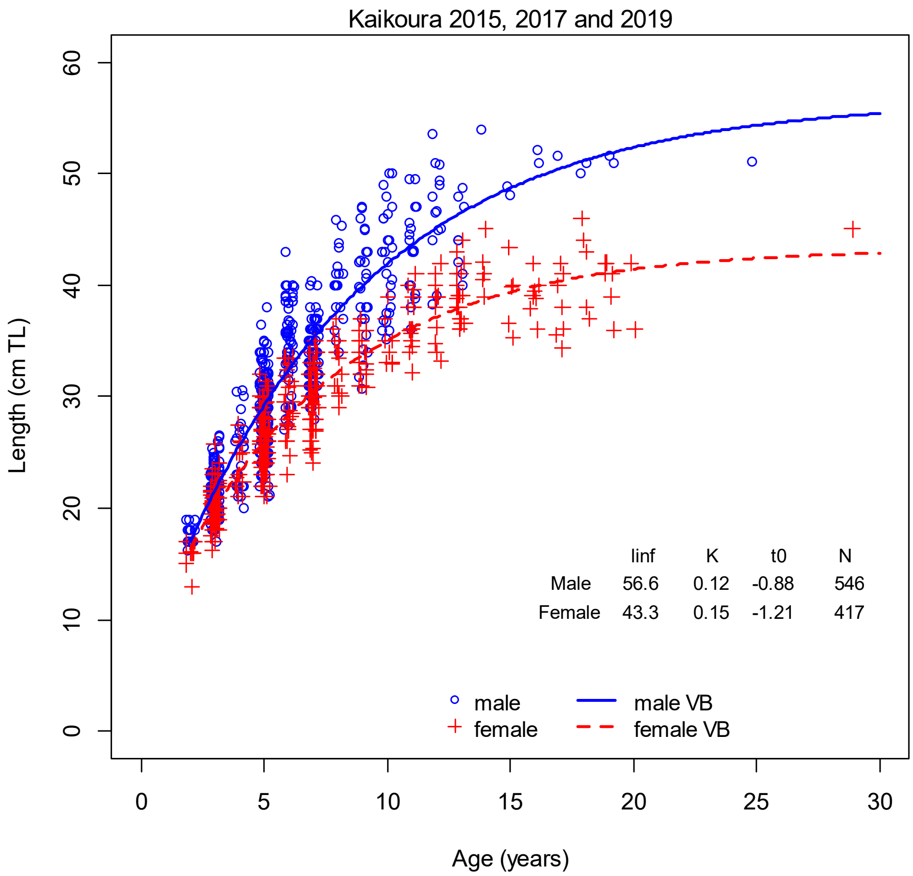

Figure 7: von Bertalanffy growth models fitted to combined age and length data from the 2015, 2017, and 2019 Kaikōura blue cod surveys. linf, average size at the maximum age (cm); K, Brody growth coefficient (yr^{-1}); t0, age when the average size is zero; N, number of fish aged.

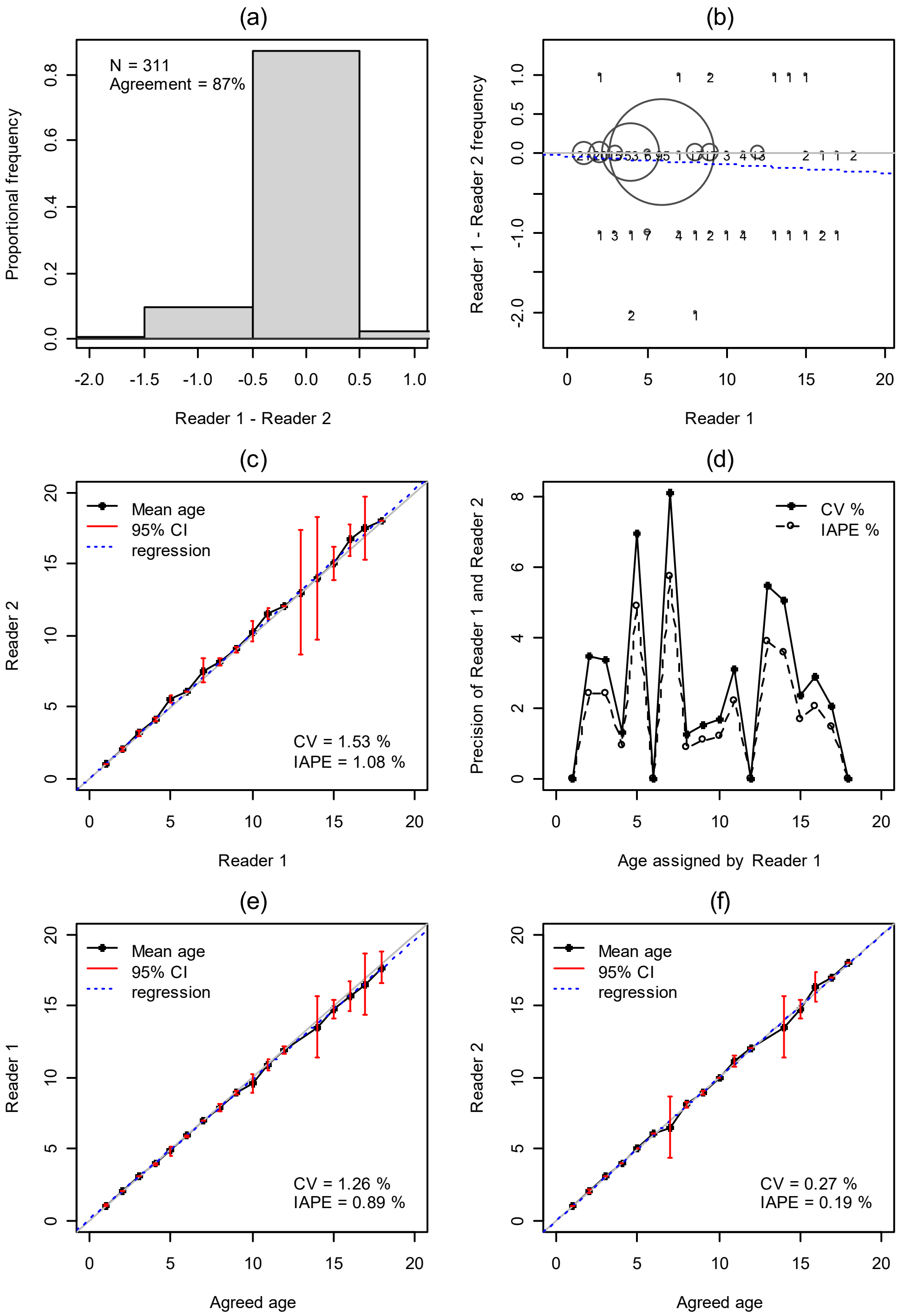

Figure 8: Blue cod age otolith reader comparison plots between reader 1 and reader 2 for the 2019 Kaikōura survey: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age bin 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. IAPE, Index of Average Percentage Error; CV, mean coefficient of variation; CI, confidence interval; N, number of otoliths read.

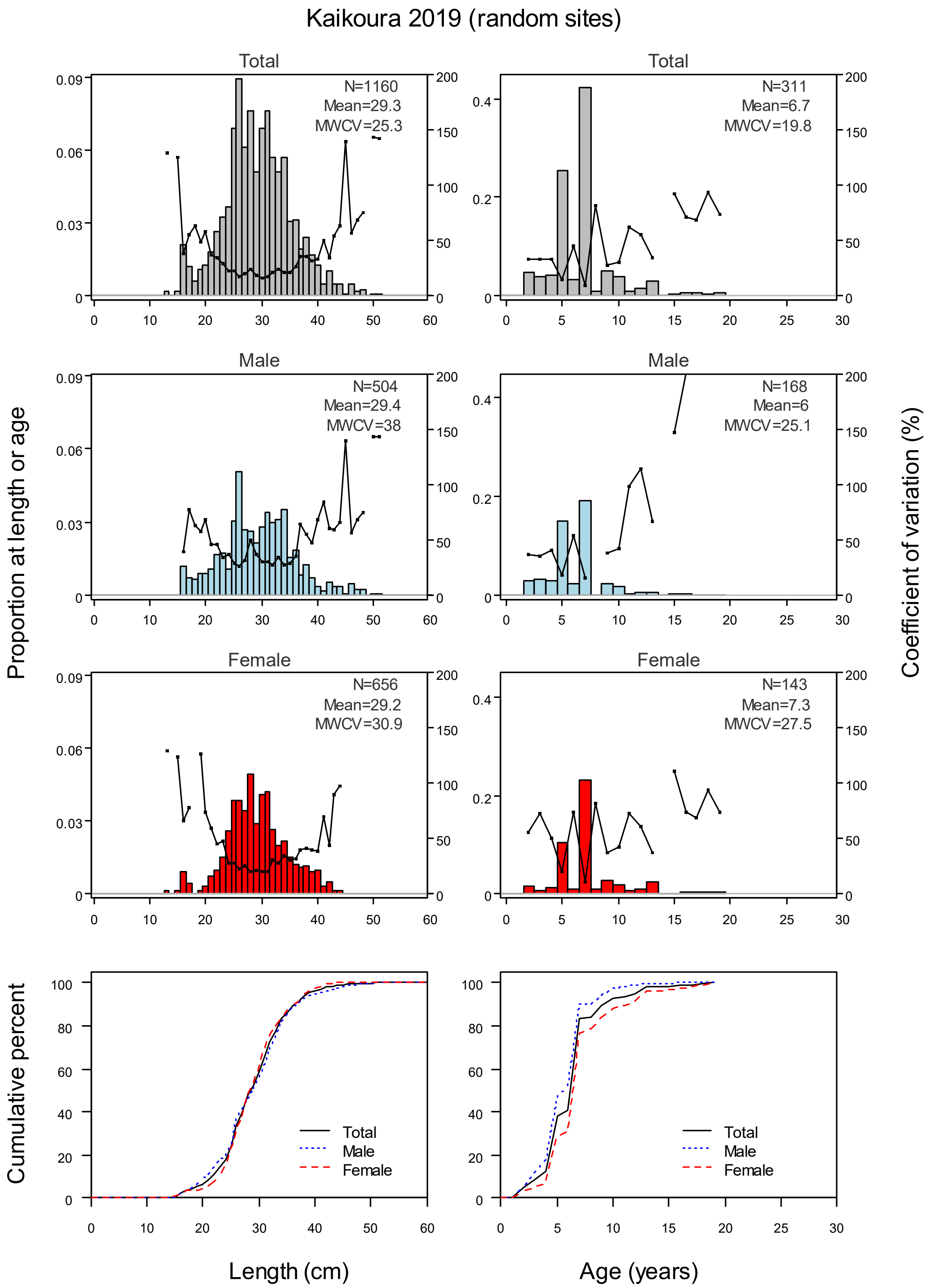

Figure 9: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (excluding Hikurangi Marine Reserve) in the 2019 Kaikōura random-site blue cod potting survey. N, sample size; MWCV, mean weighted coefficient of variation, %.

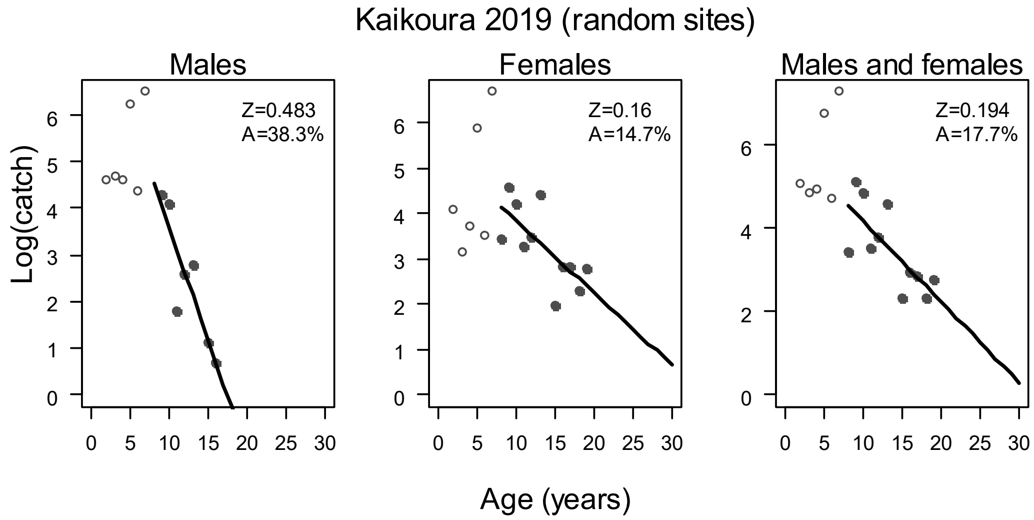

Figure 10: Catch curves (natural log of blue cod catch numbers versus age) for the 2019 Kaikōura random-site survey. The regression line is plotted from age-at-full recruitment of 8 years (i.e., dark points on the graph). *Z*, instantaneous total mortality; *A*, the annual mortality rate or the proportion of the population that suffers mortality in a given year.

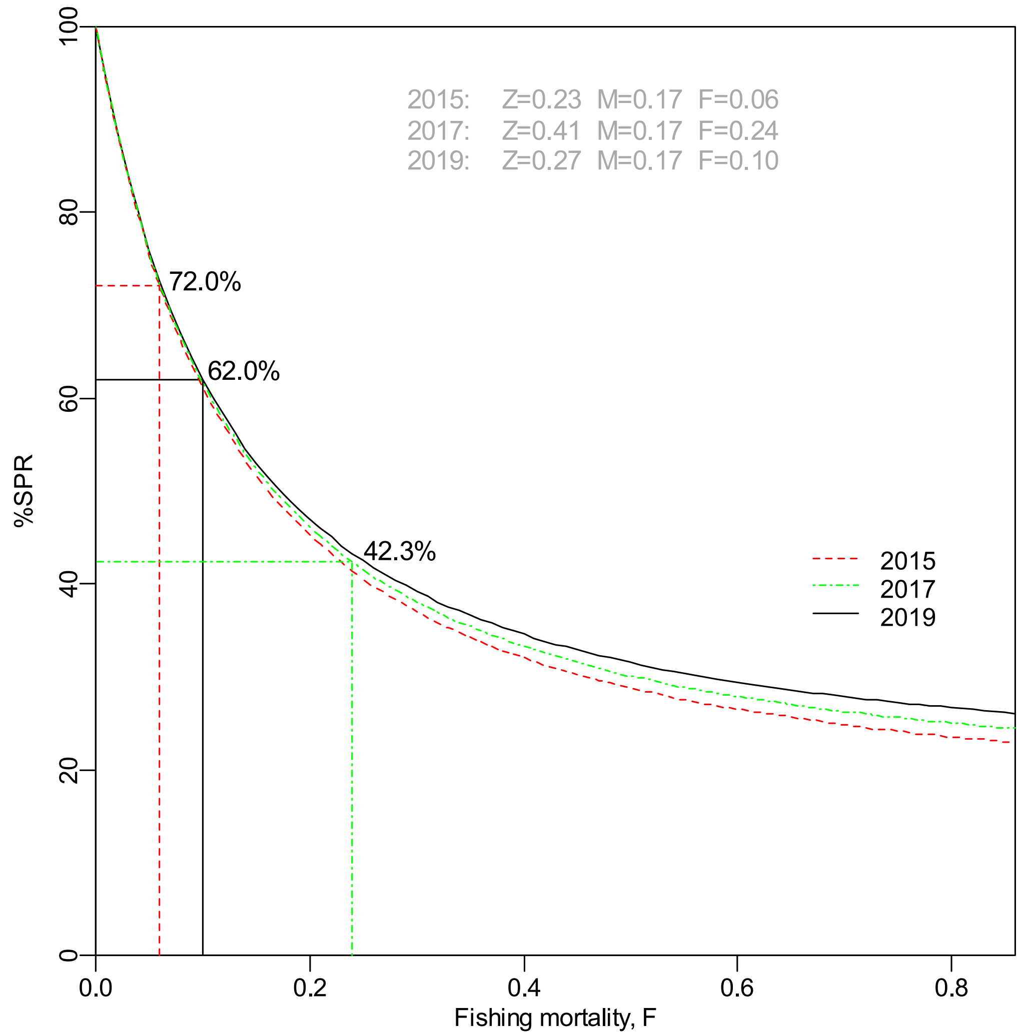

Figure 11: Spawner-per-recruit (*SPR*) as a function of fishing mortality (*F*) for 2019 Kaikōura random-site surveys. The *SPR* is also shown for the 2015 and 2017 random site surveys. In this plot *M* = 0.17, and the *F* value is for age of full recruitment equal to 8 years for females. *Z* estimates are from the Chapman-Robson method.

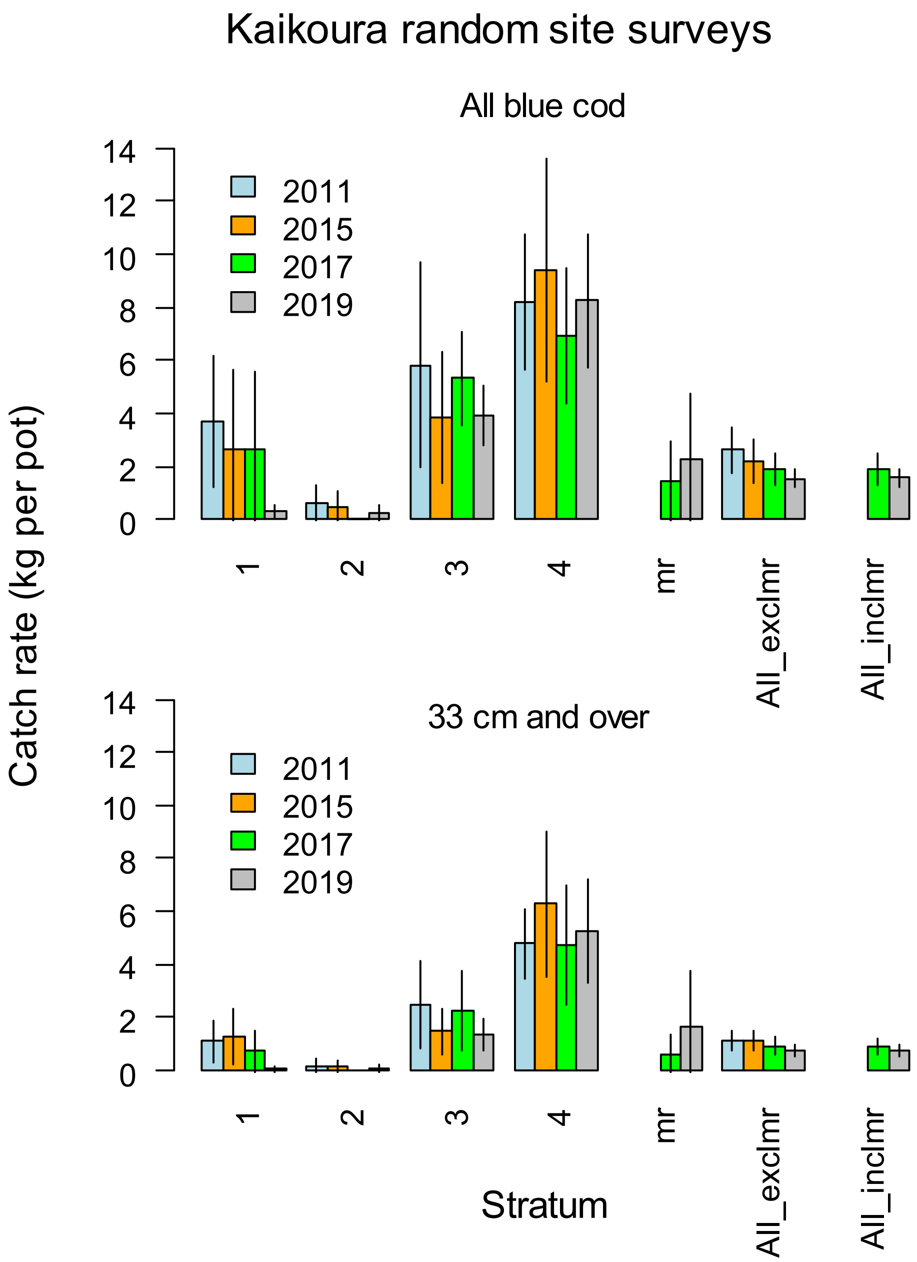

Figure 12: Catch rates (kg pot^{-1}) of all blue cod and recruited blue cod (33 cm and over) for the Kaikōura random-site potting surveys in 2011, 2015, 2017 and 2019. Error bars are 95% confidence intervals. Strata 2a and 2b are combined to allow comparison between years.

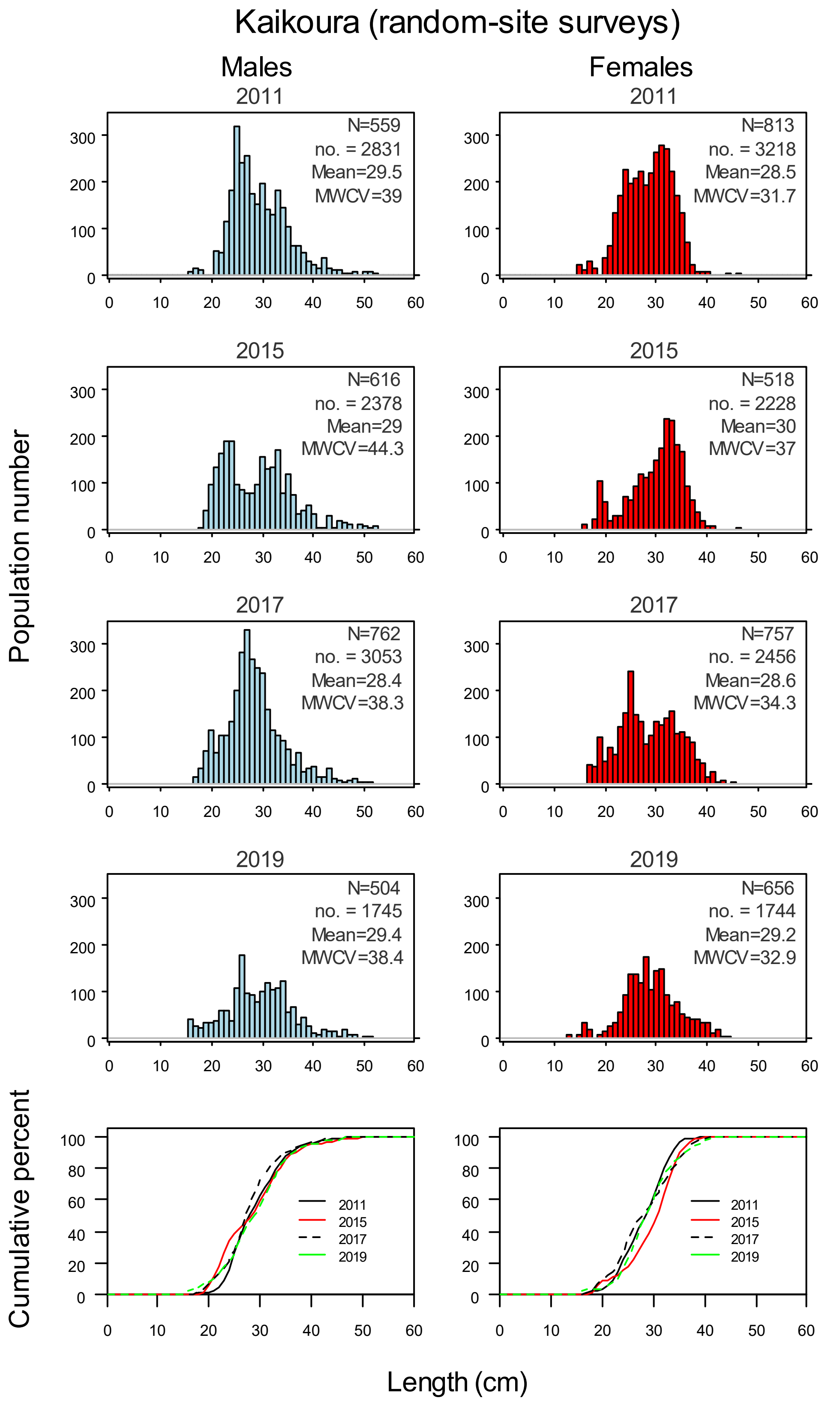

Figure 13: Scaled length frequency and cumulative distributions for male and female blue cod from Kaikōura random-site potting surveys in 2011, 2015, 2017, and 2019. N, sample numbers; no, population number; Mean, mean length (cm); MWCV, mean weighted coefficient of variation, %.

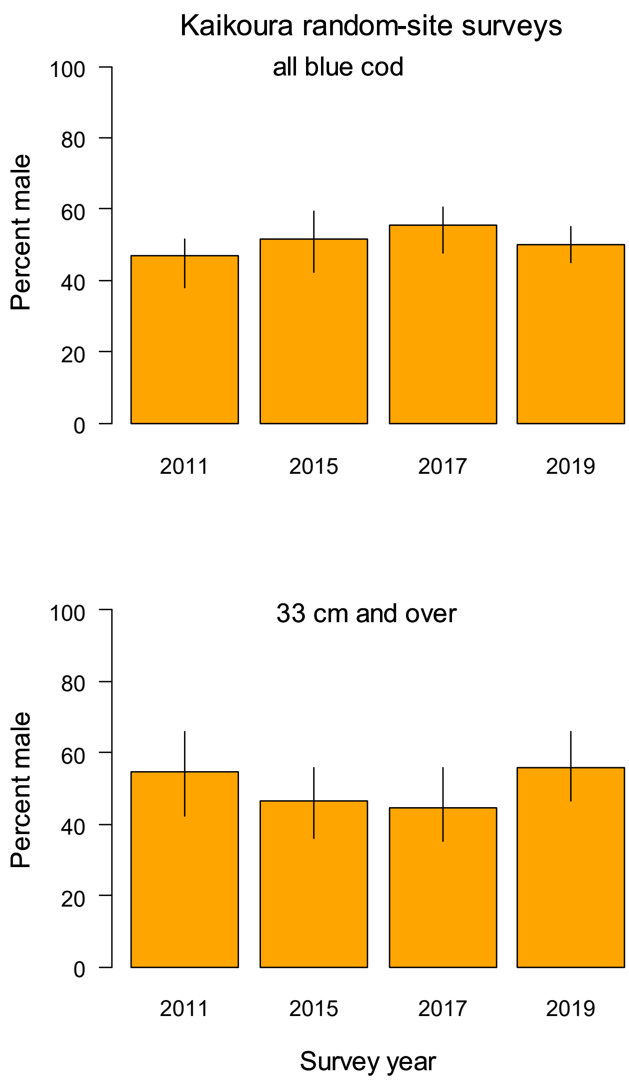

Figure 14: Proportion of males in the catch from Kaikōura random-site potting surveys in 2011, 2015, 2017, and 2019.

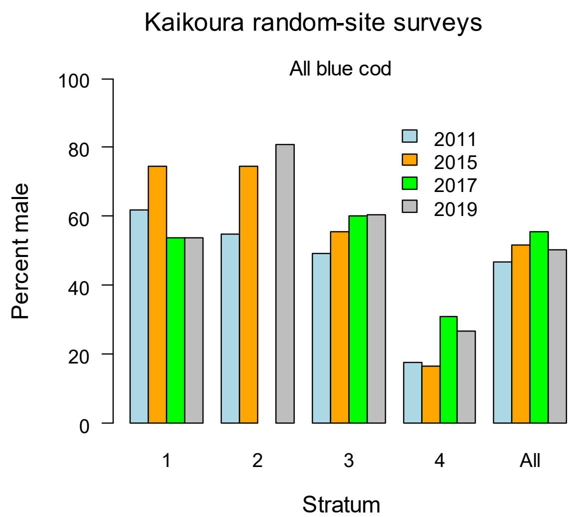

Figure 15: Proportion of males in the catch from Kaikōura random-site potting surveys by stratum in 2011, 2015, 2017, and 2019. Strata 2a and 2b are combined to allow comparison between years.

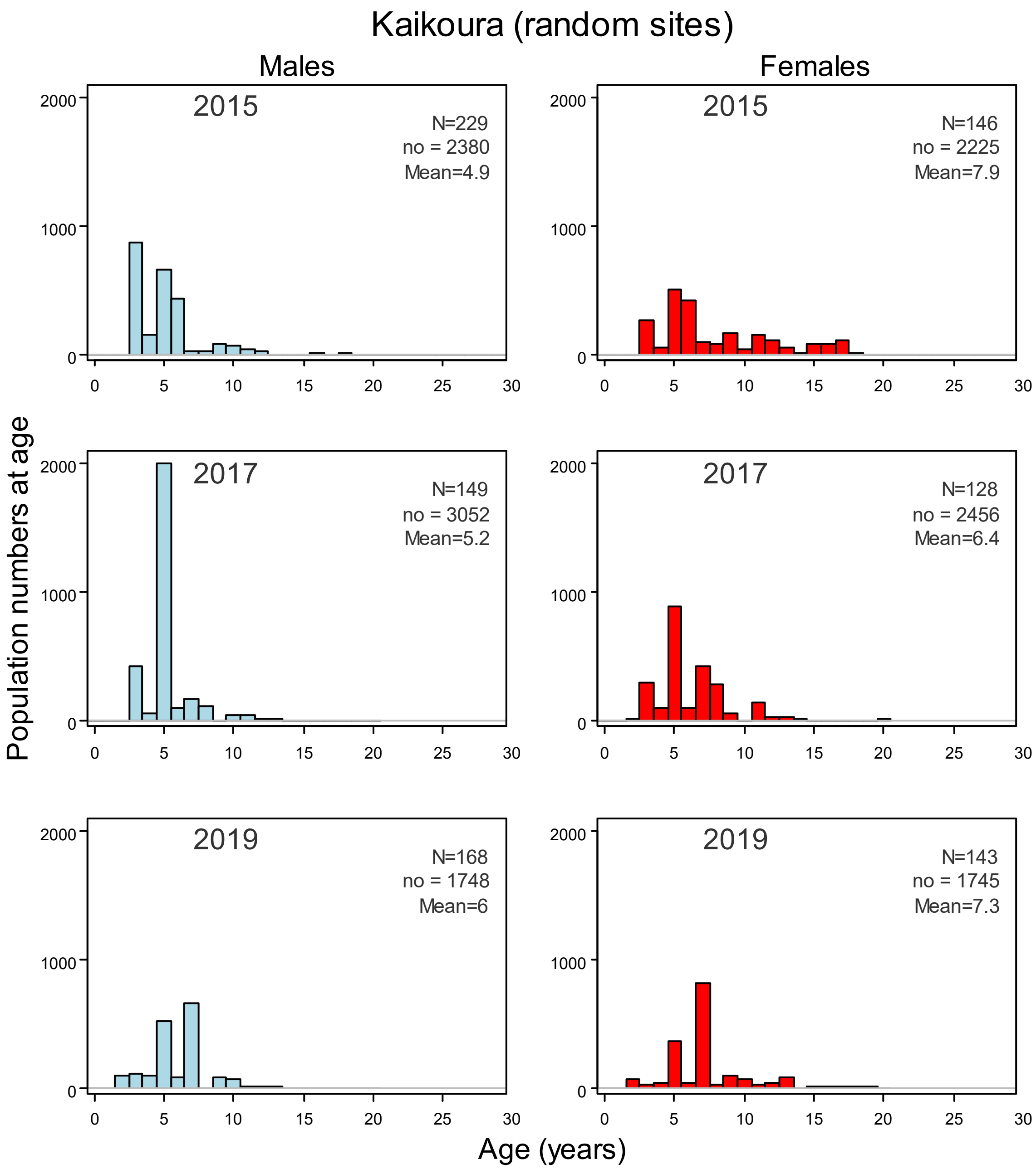

Figure 16: Scaled age frequency distributions for male and female blue cod for all strata in the 2015, 2017, and 2019 Kaikōura random-site blue cod potting surveys. N, sample size; no, population number; Mean, mean length (cm).

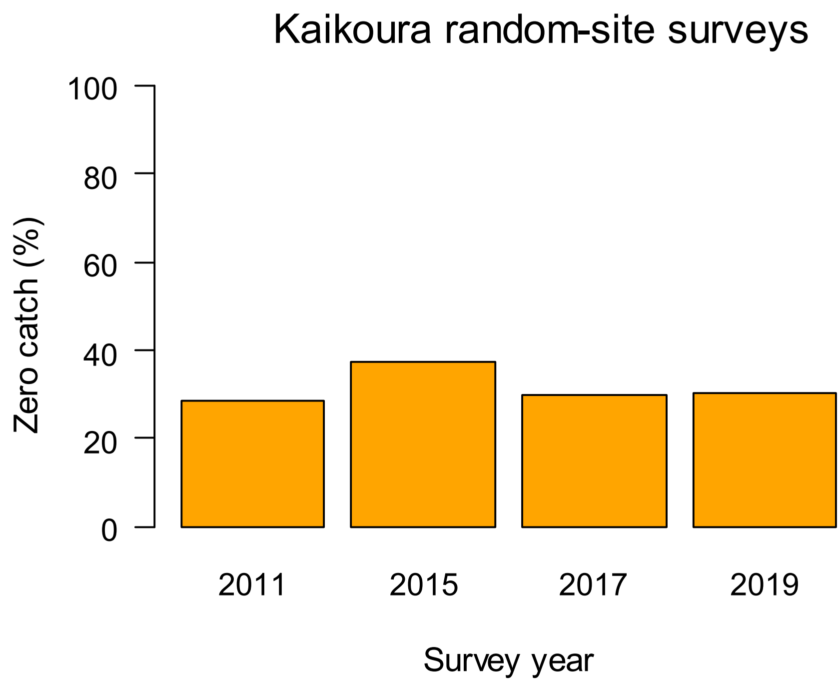

Figure 17: Proportion of pots with zero blue cod catch for the Kaikōura random-site potting surveys in 2011, 2015, 2017, and 2019. N= 156, 150, 174 and 162 pots for each survey, respectively.

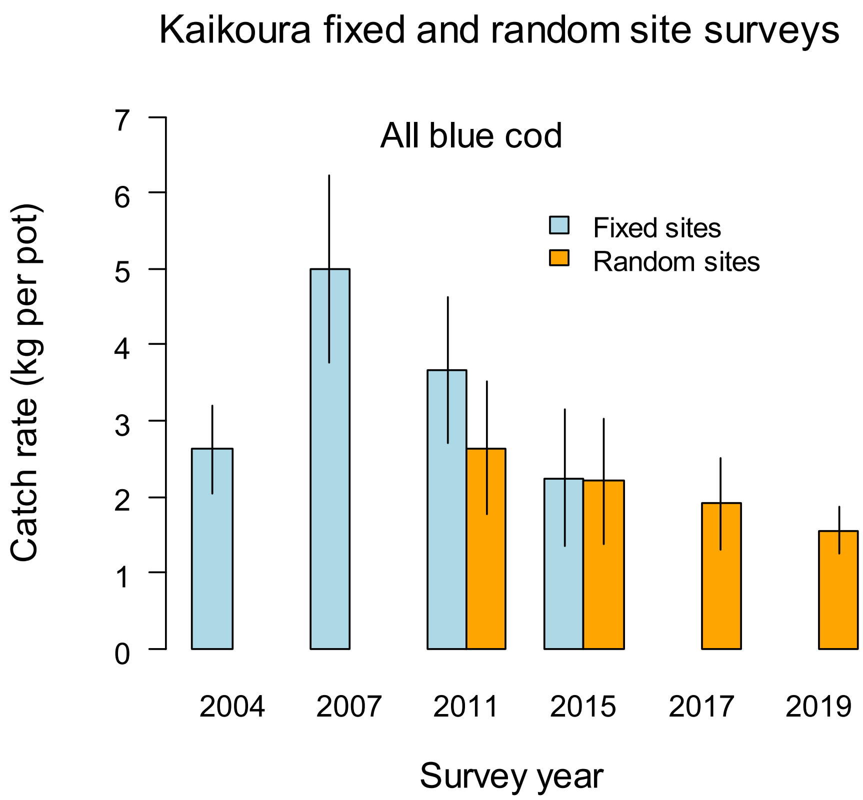

Figure 18: Catch rates (kg pot^{-1}) of all blue cod for the Kaikōura fixed-site and random-site potting surveys. Error bars are 95% confidence intervals. Strata 2a and 2b are combined to allow comparison between years.

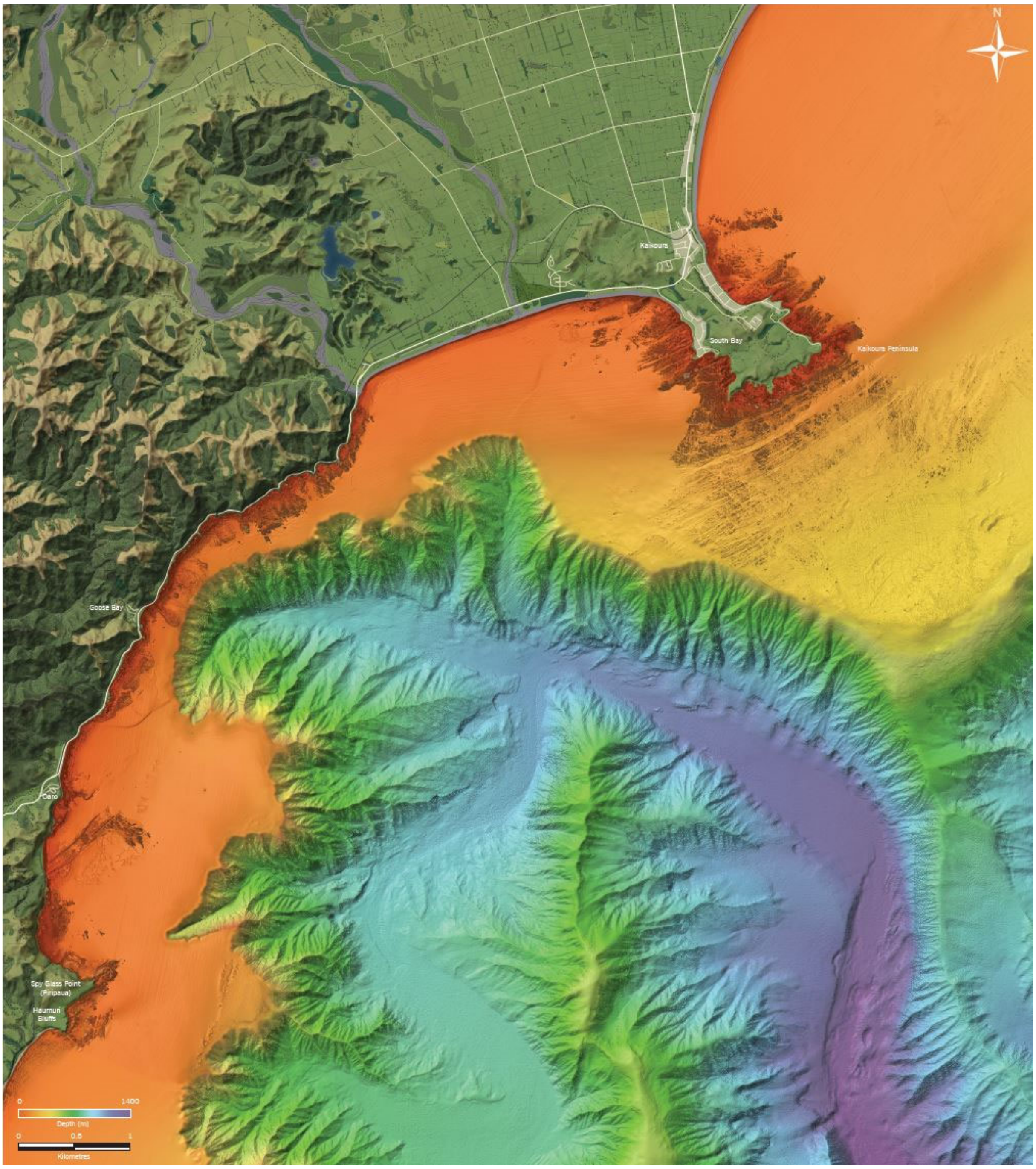

Figure 19: Map of the Kaikōura coast seafloor from the multibeam echosounder survey in 2017 and 2018 (map from Neil et al. 2018).

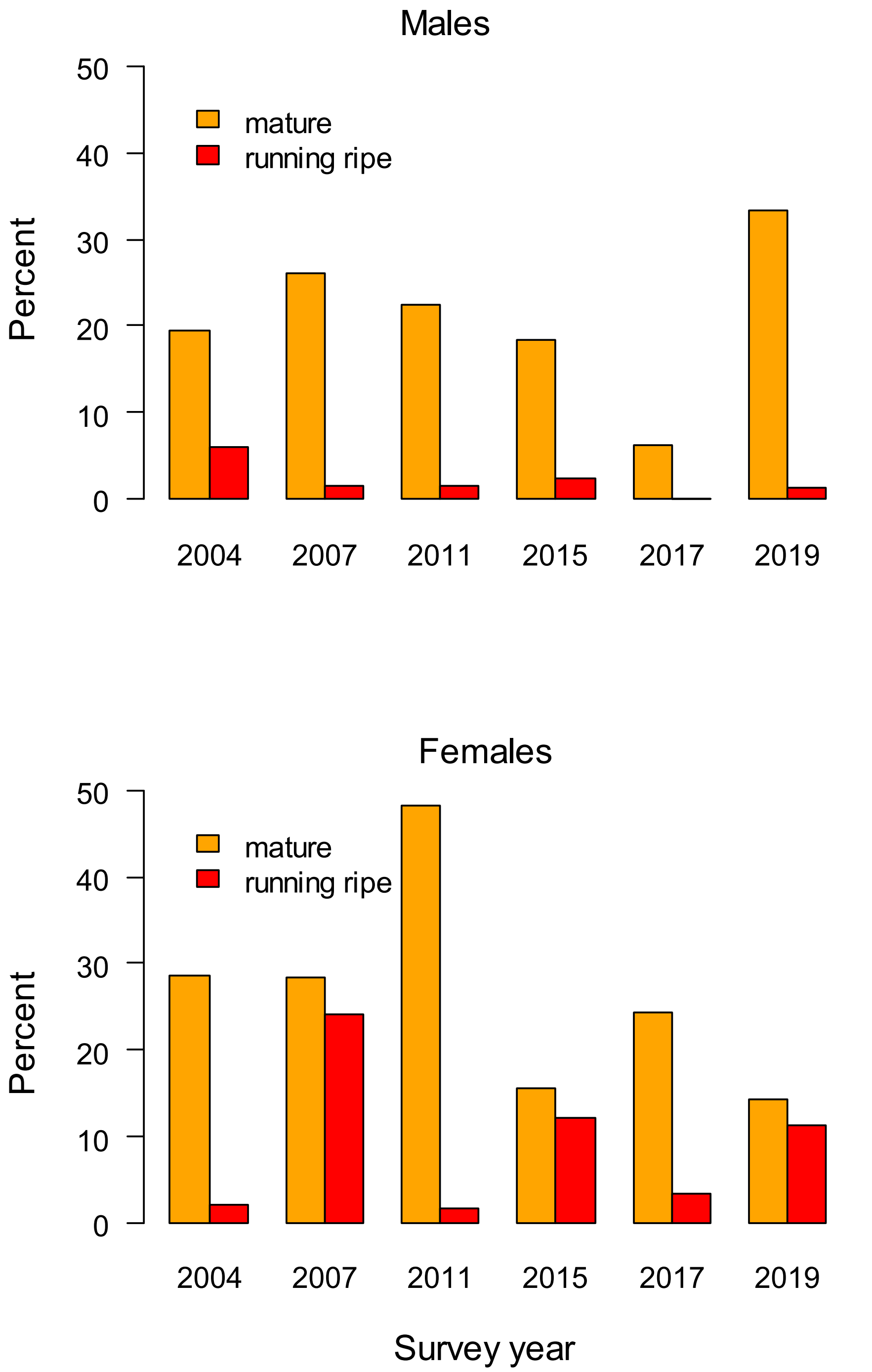

Figure 20: Percent of blue cod in the mature or running-ripe reproductive condition from Kaikōura blue cod potting surveys (all data combined for fixed- and random-site surveys in 2011 and 2015).

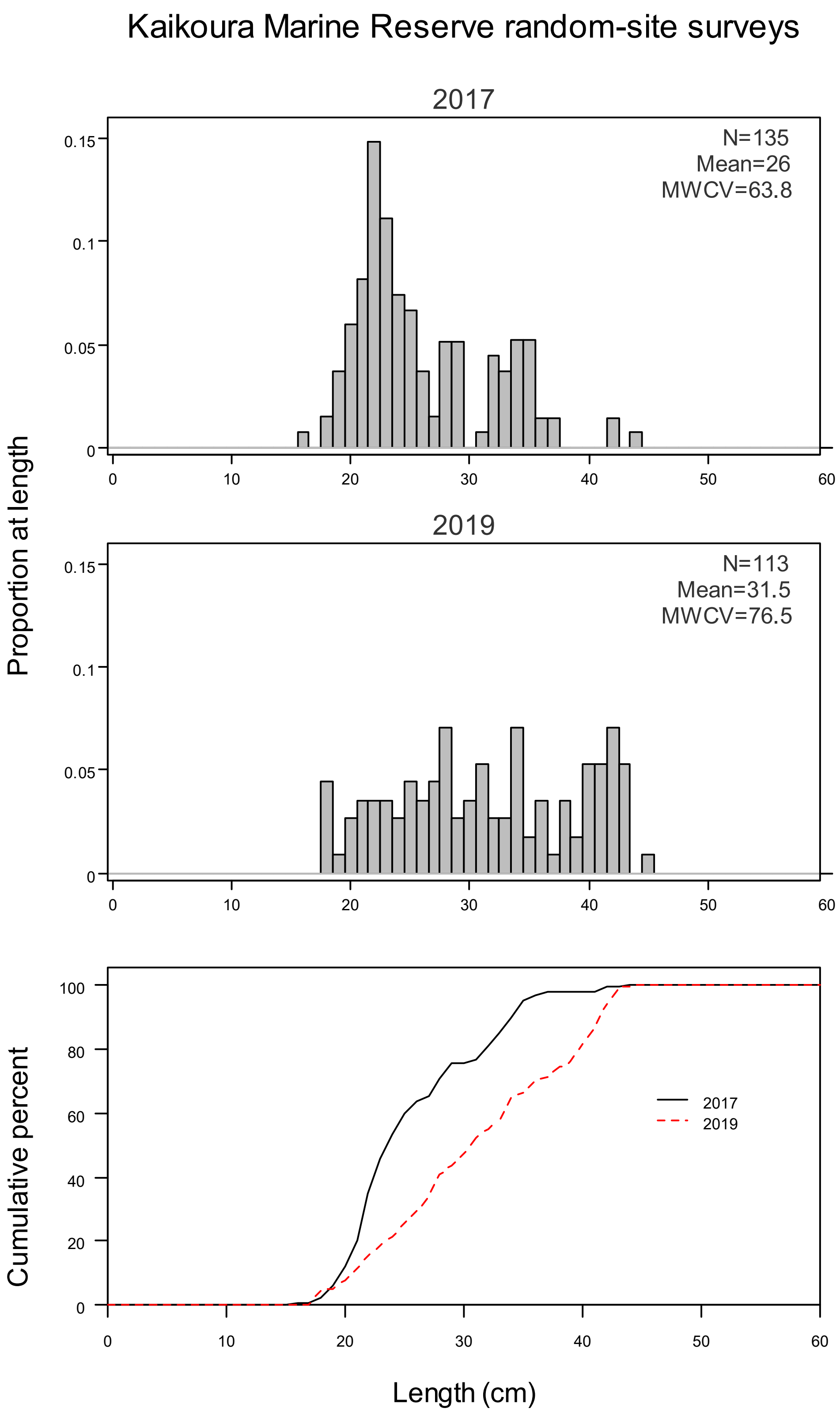

Figure 21: Scaled length frequency and cumulative distributions for unsexed blue cod from Kaikōura 2017 and 2019 random-site blue cod potting surveys of the Hikurangi Marine Reserve. N, sample numbers; Mean, mean length (cm); MWCV, mean weighted coefficient of variation, %.

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 Kaikōura 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 2019 Kaikōura survey for males and females, by strata and length class. Strata 1a and 1b are combined. Lgth, length.

	Males						Females					
	Stratum						Stratum					
Lgth (cm)	1	2a	2b	3	4	Totals	1	2a	2b	3	4	Totals
13							1					1
14												
15							1					1
16							5					5
17	4			1		5	3					3
18	4					4						
19	4			3		7						
20	2			1		3	1			1		2
21	3			5		8	3			1		4
22	4	1		4		9	2			2	1	5
23	1			5		6	2	1		3		6
24				3		3	1			3	1	5
25				3		3		1		3	3	7
26	1	3		4		8		1		4	3	8
27		1		4	1	6	1	1		2	3	7
28				3		3	3			4	3	10
29		2		2	3	7				3	3	6
30	1	1		3	3	8	1			3	3	7
31	1	2		3	4	10				2	3	5
32	1	1		4	3	9				3	3	6
33				3	3	6				4	3	7
34		2		5	3	10				4	3	7
35				3	3	6				2	3	5
36	1	1		3	3	8				4	3	7
37		1		2	2	5				3	3	6
38		1		3	2	6					4	4
39				2		2				2	3	5
40				2	1	3				2	3	5
41					2	2					2	2
42				1	2	3				2	3	5
43				1	2	3						
44				1	2	3					2	2
45					1	1						
46					3	3						
47					3	3						
48					3	3						
49												
50					1	1						
51					1	1						
Totals	27	16	0	74	51	168	24	4	0	57	58	143