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# Relative abundance, size and age structure, and stock status of blue cod off Kaikōura in 2023

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# Contents

## PLAIN LANGUAGE SUMMARY

South Island recreational blue cod fisheries are monitored by Fisheries New Zealand using potting surveys. The results of the Kaikōura surveys are important for assessing the status of the blue cod stock in this region.

This report describes the results of the random-site blue cod potting survey carried out in Kaikōura in December 2023 and compares these with the four previous surveys.

The length frequency distributions and mean length were generally similar among the five surveys. Survey mean catch rates show a progressive decline over time, dropping by 49% between 2011 and 2023. The sex ratio over the surveys was 47–60% male with indications that males are becoming more common in the population. The estimated fishing mortality ($F$) in 2023 was nearly double the target reference of $F = 0.15$ indicating that overfishing is occurring.

The catch rates of blue cod caught in the Hikurangi Marine Reserve over three surveys (2017, 2019 and 2023) indicate that abundance has not changed much over this period, and while greater than adjacent strata, abundance was only about one quarter of that in other parts of the survey area outside the reserve. Size of fish in the Marine Reserve was also not larger than in other parts of the survey area, but blue cod were of better condition.

# EXECUTIVE SUMMARY

**Beentjes, M.P.** [1]**; Page, M. (2024). Relative abundance, size and age structure, and stock status of blue cod off Kaikōura in 2023.**

***New Zealand Fisheries Assessment Report 2024/78. 61 p.***

This report describes the results of the random-site blue cod (*Parapercis colias*) potting survey carried out off Kaikōura in December 2023. Estimates are provided for population abundance, size and age structure, sex ratio, total mortality (*Z*), and fishing mortality (*F*). This is the fifth survey in the Kaikōura random-site survey time series, following those in 2011, 2015, 2017, and 2019. Results are also presented for a concurrent blue cod survey of the Hikurangi Marine Reserve off Kaikōura.

Twenty-eight random sites (167 valid pot lifts) at depths of 18–147 m from five strata off Kaikōura were surveyed in December 2023 using the R.V. *Ikatere*. Survey mean catch rate of blue cod (all sizes) was 1.35 kg pot$^{-1}$ (coefficient of variation, CV 15.9%), and 0.71 kg pot$^{-1}$ (CV 18.4%) for recruited-blue-cod (33 cm and over). Of the 167 pots, 36% had zero catch of blue cod. The overall weighted sex ratio was 60% male and mean lengths were 28.6 cm for males (range 16–51 cm, *N* = 588) and 27.9 cm for females (range 15–44 cm, *N* = 452). The scaled length frequency distributions for both sexes were not well defined with a unimodal peak at about 30 cm for males, and three modes for females at about 19 cm, 27 cm, and 35 cm. Age estimates were 2–17 years for both males and females, but 80% were 7 years and under, and nine years and under, respectively. Mean age was 5.8 years for males and 6.8 years for females. The estimated population age distributions showed strong modes at 6 and 9 years for both sexes, plus 11 years for females. The Chapman Robson (CR) male total mortality estimate (*Z*) for age of recruitment at 7 years was 0.49, and corresponding *F* was 0.32, which was double the reference target of *F* = 0.15 (i.e., 0.87*M*). About 10% of males and 15% of females were mature or running ripe and nearly all spawning activity observed occurred off Kaikōura Peninsula, mostly in stratum 4 from 100–150 m depth. Females had a slightly higher Fulton's condition factor than males across all strata, and there was no clear difference in condition among strata.

Time series analyses of the five random-site surveys indicate: 1) the survey mean catch rates (excluding the marine reserve) show a progressive decline over time, dropping by 49% between 2011 and 2023; 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, and in 2023, strong recruitment of fish under 25 cm; 3) modal progression of strong age classes was apparent throughout the time series and supports the ageing methodology based on counts of annual growth rings; 4) the sex ratio for all the surveys was 47–60% male for all blue cod with indications that males are becoming more common in the population, although stratum 4 was consistently female dominated; 5) the proportion of pots with zero catch was 29–37%, with no trend; 6) the CR male total mortality (*Z*) estimates ranged from 0.29 in 2015 to 0.92 in 2019, and associated fishing mortality (*F*) estimates from 0.12 to 0.75. All male *F* estimates were well above the target reference point except in 2015. A cautious approach should be taken when interpreting *Z* and *F* estimates because there were relatively few age classes included in these estimates and recruitment was highly variable.

In the Hikurangi Marine Reserve, five random sites (29 valid pots) were surveyed in December 2023 in depths of 7–115 m. A total of 42.5 kg (92 fish) blue cod was sampled for length and returned alive. Bycatch was almost exclusively banded wrasse (*Notolabrus fucicola*). The mean catch rate of blue cod (all sizes) was 1.42 kg pot$^{-1}$ (CV 52%) and for recruited blue cod, 0.72 kg pot$^{-1}$ (CV 70%); 62% of pots had zero catch of blue cod. Mean length (unsexed) was 28.1 cm (18–45 cm). The catch rates of blue cod caught in the Hikurangi Marine Reserve over the three surveys (2017, 2019, and 2023) indicate that abundance has not changed much over this period. Size composition was comparable with that in strata 3 and 4, but blue cod were of better condition in the marine reserve.

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## 1. INTRODUCTION

This report describes the random-site potting survey of blue cod (*Parapercis colias*) off Kaikōura in December 2023, providing estimates of relative abundance, population length/age structure, and stock status. This is the fifth in the random-site survey time series with previous surveys in 2011, 2015, 2017, and 2019 (Beentjes & Page 2017, 2018, Carbines & Haist 2018d, Beentjes & Page 2021). The 2017 random-site survey was carried out specifically to assess whether the November 2016 Kaikōura earthquake had any effect on the local blue cod population. In addition to the main survey in 2023, results are presented for a concurrent blue cod survey of the Hikurangi Marine Reserve south of Kaikōura, following similar surveys in 2017 and 2019.

### 1.1 Kaikōura blue cod fisheries

Blue cod has a wide depth range, from a few metres depth to about 150 m, and occurs in a range of habitats including: reef edges, shingle/gravel, biogenic reefs, and sandy bottoms close to rocky outcrops. Blue cod is the third most common recreational species caught in New Zealand with a total catch of 223 t (413 000 fish) estimated from the 2022–23 panel survey involving face to face interviews with fishers, plus estimates from charter vessels and recreational take from commercial vessels (Heinemann et al. 2021, Fisheries New Zealand 2024). 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 blue cod recreational catch in 2022–23 was 67 t, equating to 30% of the national total, the second highest of any QMA, behind BCO 5 at 42%. The equivalent BCO 3 estimates in 2011–12 and 2017–18 were 131 t and 109 t, respectively, indicating a declining recreational take over a 13-year period. Recreational boat ramp fishing surveys have consistently shown that the north Canterbury areas of Kaikōura and Motunau are important blue cod fisheries (Hart & Walker 2004, Kendrick et al. 2011, Kendrick & Hanley 2021). The most recent recreational survey of north Canterbury produced harvest estimates of about 21 t of blue cod in the Kaikōura area, all caught by line, accounting for almost 30% of the total BCO 3 panel-survey estimates of recreational catch (Maggs et al. 2023).

The BCO 3 commercial catch had been stable for 20 years at about the level of the TACC (160 t) before a reduction in the TACC in 2021–22 to 130 t, with similar catches in the last two years (Fisheries New Zealand 2024). Most commercially landed blue cod in BCO 3 is caught by cod potting (67 %) or bottom trawl (22%) (Holmes et al. 2022). The pot catch is taken predominantly from Statistical Area 024 off Oamaru, and to a lesser extent in area 026 off the Catlins. The 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[2] 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 2024). On 1 July 2020, the MLS was increased to 33 cm for the entire South Island with different regional daily bag limits reflecting assumed stock status; from Clarence River to Hurunui River out to 12 nmi, the DBL is currently 10 blue cod.

### 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

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

substantial overlap between the commercial and recreational fishing grounds. 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. In addition to Kaikōura, there are currently eight other key recreational South Island fisheries surveyed: Marlborough Sounds, Motunau, Banks Peninsula, north Otago, south Otago, Foveaux Strait, Paterson Inlet, and Dusky Sound (see Appendix 1 for survey details and references).

All South Island potting surveys except Foveaux Strait and south Otago originally used a fixed-site design (Appendix 1) with predetermined (fixed) locations randomly selected from a limited pool of such sites (Beentjes & Francis 2011, Beentjes 2019). Fixed sites represented 'good' fishing spots or locations where blue cod were known to be abundant. 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. 2024) A random site is a location (single latitude and longitude) randomly generated within a stratum (Appendix 2). Following this recommendation, surveys transitioned to a fully random-site design with interim sampling of both fixed and random sites to allow comparison of catch rates, length and age composition, and sex ratios between the two survey designs. Random sites were used as the only site type in Foveaux Strait and all other surveys, with the exception of Dusky Sound, have now transitioned to a fully random survey design.

## 1.3 Previous Kaikōura blue cod potting surveys

Previous Kaikōura surveys were carried out in December 2004, 2007, 2011, 2015, 2017, and 2019 (Carbines & Beentjes 2006a, 2009, Beentjes & Page 2017, 2018, Carbines & Haist 2018d, Beentjes & Page 2021). Fixed-site surveys were carried out in 2004 and 2007, with concurrent fixed and random-sites surveys in 2011 and 2015, before fully transitioning to solely random-sites in 2017. 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. In 2017 and 2019, the inshore portion (< 100 m) of the Hikurangi Marine Reserve was surveyed to gauge the effectiveness of prohibiting fishing on blue cod within the reserve.

## 1.4 Status of the Kaikōura blue cod stock

Previously, the standard method of assessing the stock status of blue cod around the South Island by Fisheries New Zealand was to estimate fishing mortality ($F$) and the associated spawner-biomass-per-recruit ratio ($SPR$), which was used as a proxy for $F_{MSY}$ (maximum sustainable yield biomass) (Beentjes & Page 2021, Fisheries New Zealand 2024). Spawner-biomass-per-recruit is defined as the expected lifetime contribution to the spawning biomass for the average recruit to a fishery. The recommended Harvest Strategy Standard maximum sustainable yield 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 (the total weight of sexually mature fish in the stock) to 45% of that if there was no fishing.

The Fisheries New Zealand Stock Assessment Plenary meeting on 18 July 2022 agreed that the standard $SPR$ was no longer appropriate as a target reference point for blue cod in Marlborough Sounds because few females currently grow large enough to recruit to the fishery and the standard spawner-per-recruit approach does not model blue cod sex change dynamics (Beentjes et al. 2022b, Fisheries New Zealand 2024). The Plenary meeting also recommended $F$=0.87$M$ (natural mortality) as an alternative $B_{MSY}$ proxy target reference point or overfishing threshold for Marlborough Sounds blue cod based on the study of Zhou et al. (2012), where $Z$ (total mortality) and $F$ was estimated from the male-only age composition in the population. In both cases, the age-at-full recruitment was taken as the male average age at minimum legal size plus one year to ensure that more than 50% of males are recruited to the fishery. Following the presentation of the 2023 Kaikōura survey results to the Inshore Finfish Working Group (14 October 2024), and based on the same rationale applied to the 2021 Marlborough Sounds, the 2022 north Otago, the 2022 south Otago, and the 2023 Foveaux Strait surveys (Beentjes et al. 2022b, Beentjes & Fenwick 2023a, 2023b, Beentjes & Miller 2024a), the working group agreed that *SPR* was also no longer appropriate as a target reference point for Kaikōura blue cod. Hence *SPR* analyses for the 2023 Kaikōura survey are not presented in this report; instead, *F* of males was compared with the target reference point of $F$=0.87$M$.

### 1.5 Objectives

This is one of the final reporting requirements for Fisheries New Zealand research project BCO2023-04 describing the results of the Kaikōura survey. The Motunau blue cod survey is reported by Beentjes & Miller (2024b).

#### 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 estimate the age structure by sex and relative abundance of blue cod off Kaikōura.

3. To estimate the age structure by sex and relative abundance of blue cod off Motunau.

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

5. Broader outcomes.

In this report, we use the terms defined in the blue cod potting survey standards and specifications (Beentjes & Francis 2011, Beentjes 2019) (Appendix 2).

## 2. METHODS

### 2.1 Timing

A two-phase random stratified potting survey off Kaikōura was carried out by NIWA from 4 to 14 December 2023 (excluding mobilisation and demobilisation). In addition, the Hikurangi Marine Reserve (less than about 100 m depth) was concurrently surveyed from 12 to 13 December. The survey dates were consistent with previous surveys and coincided with the known blue cod 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), and tangata whenua Ngāti Kurī were consulted, and both endorsed the 2023 Kaikōura blue cod potting survey.

### 2.3 Survey area

The survey area for the 2023 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, and the area of overlap with the marine reserve was removed (Figure 3). The subdivision of stratum 2 in 2017 was aimed at improving the survey precision.

The boundaries of the Kaikōura survey area were originally drawn in 2004, based on discussions with local fishers, Ministry of Fisheries (now Fisheries New Zealand), 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). 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 in less than 100 m (previously part of stratum 2) with an area of 1.5 $km^2$ was also surveyed in 2023 (Figure 3).

## 2.4 Survey design

### Allocation of sites to strata

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, 2017, and 2019 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 coefficient of variation (CV) of no greater than 15%. The simulations indicated that 25 random sites across the five strata were required to achieve the target CV.

In the core strata, a two-phase stratified random station design (Francis 1984) was used with 22 sites initially allocated to phase 1, and the remaining three available for allocation in phase 2, consistent with the proportion of phase 2 sites used in previous surveys. The actual number of phase 1 sites was 24, with two extra sites sampled in stratum 4 due to concerns around possible loss of electronic-data; the data was subsequently recovered, and accordingly an extra phase 2 site was allocated, bringing the total sites in the core strata to 28 (Table 1). A minimum of one site was allocated to both of 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:

$$\textit{expected gain}_i = \textit{area}_i^{\,2}\ \textit{mean}_i^{\,2} \,/\, (n_i(n_i+1))$$

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 $i$.

Five random sites were nominally allocated to the marine reserve, which is the maximum number that can 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.

## 2.5 Vessels and gear

The Wellington-based NIWA inshore research vessel R.V. *Ikatere* was used for the 2023 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 Richard Leppard who has considerable experience in commercial blue cod potting. The previous random-site surveys in 2017 and 2019 were also carried out using *Ikatere* whereas the 2011 and 2015 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 (Nortek Signature 500 kHz) was deployed at each site. The ADCP recorded current flow and direction in 1 m depth bins above the seafloor. A temperature sensor (Seabird SBE56 Temperature Logger) was also attached to the ADCP frame to record bottom water temperature during the set.

An electronic fish measuring board and datalogger was used to measure fish length. Marel motion compensating scales (0–6/6–15 kg) was used to weigh the catch and individual blue cod.

## 2.6 Sampling methods

All sampling methods adhered strictly to the blue cod potting survey standards and specifications (Beentjes & Francis 2011, Beentjes 2019).

The at-sea data capture system includes an electronic measuring board, and a data logger with the NIWA programme 'trawl coordinator' installed to record station and biological data. Additionally, QGIS software was used for spatial data collection. The advantage of this method over paper forms is improved accuracy, fewer errors, and real-time error checking, including visualisation of the vessel position in relation to the strata boundaries, which avoids pots being placed outside the survey area or in the neighbouring stratum. Paper forms were carried as backup.

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.

Both 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 and that larger and smaller fish were adequately sampled, the following collection schedule was used:

1) Collect all blue cod otoliths in strata 1a, 1b, 2a, 2b (there were only 80 fish in 2019 in these strata);
2) Collect all blue cod otoliths for males over 38 cm and below 20 cm;
3) Collect all blue cod otoliths for females over 35 cm and below 20 cm;
4) Collect 4 blue cod otoliths per 1 cm size class, for each sex in strata 3 and 4.

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.

## 2.7 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, total catch weight per pot for each species, and the number of individuals of each species per pot was recorded. Blue cod from each pot were then transferred directly into bins with circulating water whereas bycatch species were immediately released alive. Numbers, total length and individual weight of blue cod were recorded before being returned to the water within 5 minutes of capture, and 10 m from their location of capture. All fish were returned alive to the water via the vessel moon pool.

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 111231-MAR). Roger Williams (Department of Conservation) joined the vessel to assist on the marine reserve survey for a day.

## 2.8 Data storage

The 2023 Kaikōura survey trip code was IKA2309. 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 containing current speed and direction were sent to the Fisheries New Zealand Research Database Manager in raw form (.adcp2) and also in a customised version with user friendly variable naming and corrections for magnetic declination to the compass data (.mat). The raw temperature file from the temperature logger was also provided (.cnv). Mean bottom temperature and mean current speed were extracted for each site and stored in *t_station* and *t_stat_comm*.

## 2.9 Age estimates

To assess reader competency in ageing before reading the 2023 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).

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.

## 2.10 Data analyses

Analyses of catch rates, sex ratios, scaled length distribution, catch-at-age, and mortality estimates (*Z* and *F*), were carried out and are presented for the 2023 Kaikōura random-site survey.

Analyses of catch rates and CVs, 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.

### 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.

### Length-weight parameters

The length-weight parameters $a_k$, $b_k$ from the 2023 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. Separate length weight coefficients were estimated for the unsexed fish caught in the marine reserve.

### Growth parameters

von Bertalanffy growth models (von Bertalanffy 1938) for each sex were fitted to the 2023 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 $t$, $L_\infty$ 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 2023, von Bertalanffy growth models were fitted to the combined length and age data from the last four surveys (2015, 2017, 2019, and 2023) to provide more representative growth parameters.

### 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 2023 Kaikōura survey data for males and females separately, excluding the marine reserve. For the marine reserve, the length-weight parameters for the unsexed fish caught in the reserve were used in the estimates of the scaled length composition, because they were substantially different from the main survey core strata.

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).

Catch-at-age was estimated using a single age-length key (ALK) from the 2023 survey for each sex applied to the scaled 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).

### Unsexed fish

All blue cod caught during the 2023 Kaikōura survey were sexed, except one small fish in stratum 2b, and those in the marine reserve (because these were returned to the sea alive). The unsexed fish in the marine reserve were used to generate the total scaled length frequency compositions but were not included in age composition analyses or to estimate total mortality.

### 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 (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.

### Total mortality (*Z*) and fishing mortality (*F*) 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 years 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. Unlike previous analyses for the Kaikōura surveys, a second set of *Z* estimates were made using only ages of males. The male-only Z was estimated because there are often very few females larger than the MLS in heavily fished populations and the fishing mortality of males is more informative. Fishing mortality was estimated from the results of the Chapman-Robson analyses and the current default estimate of *M* (i.e., $F = Z–M$) was assumed to be 0.17, revised from 0.14 in 2019 (Doonan 2020). Age-at-full recruitment (AgeR), was assumed to be equal to the average age at which males reached the MLS of 33 cm (selectivity based on the combined 2015 to 2023 surveys von Bertalanffy growth coefficients) plus one year (i.e., 7 years of age in this case). Sensitivity analyses of *F* were carried out for *M* values 20% above and below the default (0.14 and 0.20).

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.

### Condition factor

Fulton's condition factor (*K*) (Nash et al. 2006) was estimated for blue cod as follows:

$$K = 100w/l^{b}$$

where $l$ is the total length (centimetres) and $w$ is the fish weight (grams) and $b = 3$.

## 2.11 Analyses of previous surveys

As part of the 2023 survey report, Chapman Robson *Z* and *F* were re-estimated for the previous surveys with valid ageing (2015, 2017 and 2019), using only male ages, under the current default *M* of 0.17, revised from 0.14 in 2019 (Doonan 2020). Age-at-full recruitment (AgeR), was assumed to be equal to the average age at which males reached the MLS of 33 cm plus one year, i.e., 7 years of age in all cases. Selectivity was based on the von Bertalanffy growth coefficients for combined 2015 to 2023 Kaikōura surveys. These analyses allowed time series of *F* to be compared among the last four Kaikōura surveys.

# 3. RESULTS

The results are presented firstly for the main survey area (excluding the marine reserve), referred to as the Kaikōura 2023 random-site survey, and secondly for the Hikurangi Marine Reserve.

## 3.1 Kaikōura 2023 random-site survey

Twenty-eight random sites (6 pots per site, producing 168 pot lifts) from five strata off Kaikōura were surveyed from 4 to 14 December 2023 (Table 1). One pot in stratum 4 was deemed invalid because the door opened and fish escaped on hauling, leaving 167 valid pots in the analyses data set. Depths sampled were 18–147 m (mean = 60 m). Twenty-four sites were carried out in phase-one and four in phase-two, all in stratum 1(1b) (Figure 3). Random-site systematic pot placement configuration is shown for seven sites in the 2023 survey (Figure 4).

### 3.1.1 Blue cod catch rates, length and sex ratio

A total of 452.5 kg of blue cod (1041 fish) was taken from the five strata (Table 1), comprising 90% by weight of the catch of all species on the survey (Table 2a). Bycatch species included 10 teleost fishes, crayfish and octopus. The three most abundant bycatch species, by number, were scarlet wrasse (*Pseudolabrus miles*), sea perch (*Helicolenus percoides*), and girdled wrasse (*Notolabrus cinctus*).

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 0–5.03 kg $pot^{-1}$ with very low or zero catches in strata 2a and 2b, and relatively high catches in stratum 4 (offshore Kaikōura Peninsula) (Table 3, Figure 5). The all-blue-cod survey catch rate was 1.35 kg $pot^{-1}$ with a CV of 15.9%. 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 0.71 kg $pot^{-1}$ (CV 18.4%) (Table 3, Figure 5). Of the 167 valid random-site pots, 60 (35.9%) had zero catch of blue cod.

The bubble plot catch rates of blue cod by site (kg $site^{-1}$) showed that most large catches were in offshore stratum 4, but the single largest was in stratum 1. Of the six sites in strata 2a and 2b, all but one had zero catch (Figure 6).

Of the 1041 blue cod caught, all were measured for length and weighed, and all but one small fish in stratum 2b were sexed (Table 4). The sex ratios were 28–70% male across the three strata, ignoring stratum 2a where only 4 fish were caught, and the overall weighted sex ratio was 60.4% male for all blue cod and 61.8% males for recruited blue cod (33 cm and over) (Table 4). Length range was 16–51 cm for males and 15–44 cm for females. Weighted mean length was 28.6 cm for males and 27.9 cm for females. There were no fish caught in stratum 2b and the sample size in strata 2a was too low to comment on the length distribution (Figure 7). The scaled length frequency distributions for males in strata 1, 3 and 4 were unimodal with the largest fish in stratum 4; it was similar for females, but with indications of a second juvenile mode in stratum 1. The modes of the distributions were broadly similar for both sexes in strata 1 and 3, but males were more numerous and tended to have proportionally more large fish (greater than 35 cm) (Figure 7). By contrast, in stratum 4, females tended to be larger overall than in strata 1 and 3, and there were nearly three times as many females than males.

### 3.1.2 Age and growth

Otolith section ages from 231 males and 172 females collected from the 2023 random-site survey were used to estimate the population age structure from Kaikōura in 2023 (Table 5, Appendix 3). The length-age data are plotted and the von Bertalanffy model fits and growth parameters ($K$, $t_0$, and $L_\infty$) are shown for males and females separately for 2023, and for the previous three surveys (Figure 8). As in previous surveys, in 2023, there was a large range in length-at-age, particularly for males, males grew faster, and were the largest fish. In all surveys, the oldest fish were females, except in 2023, where the oldest fish were 17 years for both sexes. The 2015 and 2017 fitted von Bertalanffy curves were similar, but in 2019 and 2023, the $L_\infty$ value was inflated because older males, which normally sit on the flat part of the curve, were absent (Figure 8). The combined length-age data for the 2015, 2017, 2019 and 2023 surveys and the von Bertalanffy model fits and growth parameters are shown in Figure 9.

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 2023 survey otoliths are presented in Figure 10. The first counts by the two readers showed 87% agreement, and, overall, there was no bias between readers with a CV of 1.7% and index of average percent error (IAPE) of 1.2%.

The length-weight parameters from the 2023 Kaikōura survey were $a$ = 0.008572 and $b$ = 3.1623 for males ($N$ = 587, range = 16–51 cm); $a$ = 0.010135 and $b$ = 3.1142 for females ($N$ = 451, range = 15–44 cm); and $a$ = 0.009307 and $b$ = 3.1388 for males and females combined ($N$ = 1040, range = 15–51 cm), where two outliers were not used.

### 3.1.3 Condition

The mean condition factors for the 2023 survey blue cod were similar for both sexes (1.48 for males, and 1.49 for females (Table 7). The condition median and range by sex and stratum shown in Figure 11, also showed little difference between the sexes (excluding stratum 2 where only 3 fish were sexed). There was no clear difference in condition among strata, except inside the marine reserve, where the condition factor was about 25% better overall than from the other strata (Table 7, Figure 11).

### 3.1.4 Spawning activity

Gonad stages of blue cod sampled in the 2023 Kaikōura survey are presented by sex for the survey overall, and by sex and stratum (Tables 8a and 8b). About 80% of males and females were in the immature/resting or maturing state, although there were indications of spawning activity during the survey period with about 10% of males and 15% of females mature or running ripe. As blue cod are serial or batch-spawners, assigning the proportion of fish that are spawning should be viewed with caution. Six to eight percent of fish had spent gonads indicating that spawning had occurred recently (Table 8a). Gonad stage by stratum suggested that for females, most of the spawning activity was occurring off Kaikōura Peninsula in the deeper stratum 4 where the only female running ripe fish were found. Males in the mature condition were predominantly in strata 3 and 4 (Table 8b).

### 3.1.5 Population length and age composition

The scaled length frequency and age distributions for the 2023 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 12).

The scaled length frequency distribution for males was unimodal, but not well defined with a peak at about 30 cm, and an overall mean length of 28.6 cm. The female distribution was also not well defined and appeared to be tri-modal, with peaks at about 19 cm, 27cm, and 35 cm, and an overall mean length of 27.9 cm (Figure 12). The cumulative distribution plots of length frequency were similar between sexes with the only real difference observed for fish over 35 cm because the largest fish were males (Figure 12). The mean weighted coefficients of variation (MWCVs) around the length distributions were 34% for males and 38% for females. The proportion of males by number that was recruited (33 cm and over) was 28.9%, and for females this proportion was 27.2%.

Age estimates were 2–17 years for both males and females, but 80% of males and females were 7 years and under and nine years and under, respectively (Figure 12). The estimated population age distributions indicated almost knife-edge selectivity to the potting method at three years of age with strong modes at six and nine years for both sexes, plus eleven years for females. There were also corresponding weak modes for eight- and ten-year-olds, with no males of age ten years. The cumulative distribution plots of age frequency showed that females had a higher proportion of older fish than males (Figure 12). The mean age of females was one year greater than that of males (5.8 for males and 6.8 years for females). The MWCV around the age distributions overall was 22% and, by sex, 25% for males and 33% for females.

### 3.1.6 Mortality estimates (*Z* and *F*)

Chapman-Robson (CR) total male mortality estimates (*Z*) and 95% confidence intervals for the 2023 Kaikōura random-site survey are given for a range of recruitment ages (5–10 years) in Table 9. Age-at-full recruitment (AgeR) was assumed to be equal to the average age at which males reached the MLS of 33 cm plus 1 year (i.e., 7 years of age in all cases) (see growth curve in Figure 9). The male CR *Z* for AgeR of 7 years for Kaikōura in 2023 was 0.49 $yr^{-1}$ (95% confidence interval of 0.34–0.66) (Table 9).

The traditional catch curves, based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from male age-at-full recruitment plus one year (i.e., 7 years), is shown for diagnostic purposes (Figure 13). There were few blue cod older than 7 years of age which has influenced the slope of the regression line and hence *Z*. The steepness of the descending curves, and hence high *Z* values, were a direct result of the lack of recruited older age classes in the population (Figure 13). The natural log of numbers-at-age largely follows the ideal straight-line descending limb, and this suggests that the assumption of constant recruitment had not been violated to a great extent, and gives confidence in the CR *Z*. 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 was reflected in the wide 95% confidence intervals around *Z* (see Table 9) (Dunn et al. 2002).

The 2023 Kaikōura survey male mortality parameters (CR *Z* and *F*) at three values of *M* and age-at-full recruitment of 7 years are shown in Table 10. Based on the default *M* of 0.17, male estimated fishing mortality (*F*) in 2023 was 0.32 (95% confidence intervals 0.17–0.49).

## 3.2 Hikurangi Marine Reserve

In the Hikurangi Marine Reserve, five random sites (6 pots per site, producing 30 pot lifts) were surveyed from 12–13 December 2023 (see Table 1, Figure 3). One pot was deemed invalid because it was not hauled within an acceptable soak time, leaving 29 valid pots in the analyses data set. Depths sampled were 7–115 m (mean = 24 m) (Table 1). A total of 42.5 kg of blue cod (92 fish) was sampled from the marine reserve stratum comprising 83% of the catch by weight (Table 2b). Bycatch was almost exclusively banded wrasse (*Notolabrus fucicola*). All blue cod and bycatch were returned to the sea alive with no indications of handling mortality.

The mean catch rate of blue cod (all sizes) was 1.42 kg $pot^{-1}$ with a CV of 51.8% (Table 3, Figure 5). The catch rate for recruited blue cod (33 cm and over) was 0.72 kg $pot^{-1}$ (CV 70.2%). Of the 29 valid random-site pots, 18 (62%) had zero catch of blue cod.

All 92 blue cod caught were measured for length and individually weighed, but no attempt was made to sex these fish (Table 4). Mean length was 28.1 cm, ranging from 18 to 41 cm. The sample size was too low to comment on the length distribution, which has no discernible shape or modes (Figure 7).

The length-weight parameters from the marine reserve survey were $a$ = 0.039254, and $b$ = 2.7729 for unsexed fish ($N$ = 90, range = 18–41 cm.) There were two outliers that were excluded.

The mean condition factors for the 2023 marine reserve survey was 1.85 for the unsexed fish, and along with the median, was much higher than from the other strata (Table 7, Figure 11).

### 3.3 Kaikōura random-site survey time series (2011, 2015, 2017, 2019, 2023)

Mean catch rates (kg pot$^{-1}$) for all blue cod and recruited blue cod for each of the five random-site surveys are presented in Figure 14. The relative differences in catch rates among strata were generally maintained over time; i.e., catch rates were consistently highest in stratum 4 and lowest in stratum 2. The 2019 catch rates in stratum 1 were low compared with previous years but the confidence intervals around the estimates were large. The mean survey catch rates (all excluding the marine reserve) showed a progressive decline over time, dropping by 49% between 2011 and 2023 (Figure 14). The decline over time was also reflected in the individual strata catch rates.

Catch rate bubble plots for each of the five random-site surveys were consistent with the strata and overall survey trends, showing declining catch rates over time (Figure 15). The single largest catch rates tended to be in strata 3 and 4. Very few blue cod have been caught in strata 2A and 2B over the time series, and no blue cod have been caught in stratum 2B in the last two surveys.

The scaled length frequency distributions and mean length were generally similar for all five surveys with differences due to the strong recruitment of juveniles in 2015, progressing through to strong modes in 2017 and 2019, particularly for males. In 2023, there was also strong recruitment of fish under 25 cm (Figure 16). The proportions of the largest males and females (over 40 cm) has remained reasonably constant over time.

The sex ratios across all surveys was 47–60% male for all blue cod, and 45–62% male for recruited blue cod, with indications that males are becoming more common in the population (Figure 17). The survey sex ratio was driven by data from strata 3 and 4, where catch rates were highest and where most fish were caught. In both strata, male sex ratios have been increasing over time. The dominance of males in stratum 3, and females in the adjacent and deeper stratum 4, was typical of the sex ratio in this time series (Figure 18).

Age compositions can be validly compared for only the 2015, 2017, 2019, and 2023 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 19). 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 19). Subsequently, the 2017 survey 5-, 7-, and 8-year-old age classes were evident in 2019 as 7-, 9-, and 10-year-olds. Further, the strong 3-year-old age class in 2017 had also progressed through to 2019, where it appeared as a strong 5-year-old age class. Although there are four years between 2019 and 2023, there was evidence of the strong 5-and 7-year-old age classes progressing through to 9- and 11-year olds (Figure 19). These results indicate that modal progression of strong year classes was apparent and supports the ageing methodology based on counts of annual growth rings.

The proportion of pots with zero catch for the five random-site surveys ranged from 29% to 37% with no clear trend (Figure 20).

The Chapman Robson male total mortality estimates ($Z$) for age of recruitment at 7 years have ranged from 0.29 yr$^{-1}$ in 2015 to 0.92 yr$^{-1}$ in 2019, and associated fishing mortality estimates followed the same pattern ranging from 0.12 yr$^{-1}$ to 0.75 yr$^{-1}$ (Table 10, Figure 21). Although male $F$ has varied among the surveys, the wide confidence intervals indicate that these annual differences were not likely to be statistically significant, apart from in 2019. All male $F$ estimates were well above the target reference point of $F$=0.15 (i.e., 0.87×$M$) except 2015; the $F$ in 2023 of 0.32 yr$^{-1}$ was double that of the reference

$F$ (Figure 21). The slopes of the right-hand limbs of the catch curves can vary considerably depending on the number of recruited age classes (see Figures 13 and 19), and the strength of the first recruited age class. With so few age classes compared to virgin stocks, and highly variable recruitment, the slope can be strongly affected by one age class, such as in 2019, when there was a very strong 7-year-old age class (see Figure 19). A cautious approach should therefore be taken when interpreting $Z$ and $F$ estimates where so few age classes are included and recruitment is so variable.

The condition factors ($K$) for the 2015, 2017, 2019, and 2023 Kaikōura surveys are presented for each sex as density plots, scatter plots of condition on total length, and median box and whisker plots (Figure 22). Data from the 2011 random site survey and fixed site surveys were not of sufficient quality or quantity to be included in these analyses. Scatter plots of condition on total length are only given for 2019 and 2023 surveys to explore the relationship of these variables. The mean condition factors and standard errors are shown in Table 7. The condition analyses for the four surveys indicate: 1) condition was slightly better in 2015 than in the following three surveys when condition was similar; 2) in all four surveys condition was slightly better for females; and 3) larger fish had better condition factor (Figure 22). All surveys occurred at the same time of year and there were negligible numbers of fish in running ripe spawning state on these surveys so annual differences were not associated with spawning condition. Regardless, it was legitimate to include all fish in the analyses, and not just the immature fish with undeveloped gonads, because all data sets had similar length ranges (Figure 22).

The catch rates of blue cod caught in the Hikurangi Marine Reserve in 2017, 2019 and 2023 indicated that abundance has not changed much over this period (see Figure 14). Length distributions were not well defined due to low sample numbers but were generally similar over the three surveys with no clear trends in size (Figure 23). The proportion of empty pots was about 30 to 40% higher in the contiguous strata outside the marine reserves (Figure 24).

# 4. DISCUSSION

## 4.1 General

The 2023 Kaikōura random-site potting survey was the fifth in the time series of relative abundance and population structure of blue cod from this area, after previous surveys in 2011, 2015, 2017, and 2019. 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. 2024). 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 was exceptionally high and more than three times as high as that for the 2023 random-site survey (Figure 25). 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 has been steadily declining since 2007.

## 4.2 Blue cod habitat

The abundance estimates, length and age distributions, and sex ratios 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 26) (Neil et al. 2018). Survey strata with the highest catch rates (i.e., strata 3 and 4) are over the area of the most comprehensive rocky reef habitat off Kaikōura Peninsula (see Figures 5 and 6). In contrast, stratum 2 has vast areas of rippled sand and the lowest catch rates, often with no catch. Scaling by strata area assumes that the size of each stratum is directly proportional to the amount of blue cod habitat, although the 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 2023 appear to be steadily declining and, notwithstanding the overlapping confidence intervals around the estimates, the declines have occurred in strata 3 and 4, where catch rates have been consistently the highest, and this has driven the survey trend (see Figure 14).

The survey CV around relative abundance (catch rates) was not specified in the project objectives for the 2023 or previous Kaikōura surveys, but a CV of around 15% is generally considered to be the target level of precision. The achieved CV of 16% in 2023 was an acceptable level of precision and similar to that from the previous random-site surveys (2011, 17%; 2015, 19%; 2017, 16%; 2019, 10%) (Beentjes & Page 2017, 2018, Carbines & Haist 2018d, Beentjes & Page 2021). The achieved CVs indicate that the survey design and number of sites used (25–29) are appropriate for Kaikōura random-site surveys, however, if abundance continues to decline, more sites might be required to achieve the target CV. The results of a GLM analyses after the 2019 survey, indicated that stratum has the most influence on catch rates and emphasises the importance of informed stratification in the survey design of the Kaikōura time series (Beentjes & Page 2021).

## 4.4 Cohort progression

### Kaikōura

Cohort progression of blue cod age classes is apparent over the four surveys from 2015 to 2023, showing both nominally strong and weak year classes (see Figure 19). The advantage of having three surveys conducted within four years (2015 to 2019) was that cohorts could be easily tracked between surveys, providing validation of the ageing methodology based on annual winter ring deposition on sagittal otoliths, and indicates that these surveys were consistently sampling the same sub-population (Beentjes 2021). The progression and relative strength of the 2012 year-class (i.e., 3-year-old in 2015) from 2015 through to 2023 (11-year-olds) suggest that this year class was exceptionally strong. 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[3] (see Figure 9). Hence, the faster growing 2012 year-class males will have fully recruited to the fishery in 2018 and females in 2020. There were, however, no indications of a commensurate increase in all blue cod or recruited abundance in the 2019 or 2023 surveys, 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 and fishing pressure needs to be reduced on the older age classes. 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, and, in 2023, by 6-year-olds.

### Other areas

The strong 2012 year-class (3-year-olds) and the weak 2011 year-class (4-year-olds) observed in Kaikōura in December 2015 (see Figure 19) 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 2021). The recruitment patterns for the Kaikōura surveys are most similar to those of nearby Motunau (Beentjes & Miller 2024b) including the most recent 2023 and 2024 surveys respectively, and indicate that the closer the populations are to each other, the more similar are their patterns in recruitment strength. These consistent recruitment strength patterns suggest that spawning events and/or survival of subsequent life-

[3] Outside the Kaikōura Marine Area, the MLS was 30 cm until July 2020 when it increased to 33 cm. At MLS of 30 cm, males were about 5.5 years old and females 6.5 years old when they recruited to the fishery.

history stages off the east coast of the South Island are somehow linked. 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 2021).

## 4.5 Sex change and sex ratio

In all five Kaikōura random-site surveys, sex ratio in the deeper stratum 4 (offshore of Kaikōura Peninsula in 100–200 m) strongly favoured females, whereas the sex ratio was skewed towards males in other strata (see Figure 18), and blue cod were consistently larger overall in stratum 4 (see Figure 7). Sex ratios of blue cod populations that favour females are extremely uncommon, particularly in exploited populations, and this spatially restricted high concentration of females is unique to this area in terms of potting survey results. The high proportion of females off Kaikōura Peninsula in deeper water appears to be related to spawning behaviour involving both larger fish and more females than males. This is because most spawning condition blue cod (maturing or running ripe) were caught in strata 3 and 4, and running ripe females were all caught in stratum 4 (see Table 8b).

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 2021). In contrast, the monandric condition is where fish always begin life 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). The Kaikōura blue cod population sex and size structure is consistent with the diandric reproductive strategy with both small males and large females present in the population. The blue cod sex ratio was close to parity (1:1) on the first four surveys, but in favour of males in 2023 (60% male) (see Figure 17).

In terms of length, females tend to dominate below about 40 cm and males increasingly at lengths above 40 cm until all blue cod in the population are males (Figure 27). There is a steep increase in the proportion of males that occurs from 40 or 45 cm which may be related to the sex transition from female to male, and/or because females don't grow as large as males. However analogous plots of percent male versus age shows almost the opposite trends with the proportion of males declining with age (Figure 28), because the oldest fish in the population are usually the slower growing females, most of which are below the MLS. These length and age sex ratio plots are likely to differ from those of most gonochoristic species, where the proportion of males would be close to one-to-one throughout and then decline for the largest and oldest fish, which are usually females.

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, the ratio is more balanced and can sometimes favour females, indicating that fishing pressure is less intense (Beentjes & Carbines 2009, Carbines & Beentjes 2012, Beentjes & Page 2016, Beentjes & Miller 2024a). 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 level 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 the first 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 $F_{\mathrm{MSY}}$, which is the amount of fishing mortality that results in the maximum sustainable yield. The recommended proxy for $F_{\mathrm{MSY}}$ 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 proxy for $F_{\mathrm{MSY}}$ has been $F_{45\%SPR}$. However, as discussed in Section 1.4, the Inshore Finfish Working Group agreed that *SPR* is no longer appropriate as a target reference point for Kaikōura blue cod and, instead, recommended $F$=0.87$M$ as an overfishing threshold (Zhou et al. 2012), where $Z$ and $F$ are estimated from the male-only age composition in the population. This is the fifth survey area, after Marlborough Sounds, north Otago, south Otago, and Foveaux Strait for which Fisheries New Zealand has replaced *SPR* with $F$=0.87$M$ as an overfishing threshold.

The 2023 Kaikōura random-site survey $Z$ for males was 0.49 $yr^{-1}$, where $M$ = 0.17 and age-at-full recruitment is 7 years of age, with a resulting $F$ of 0.32 $yr^{-1}$ (95% confidence intervals 0.17–0.49) (see Table 10). Relative to the target reference point of $F$=0.15 ($F$=0.87$M$), the estimated $F$ in 2023 was nearly double this target, indicating that overfishing is occurring.

The 2015, 2017, 2019 and 2023 $F$ estimates were 0.12, 0.30, 0.75, and 0.32 $yr^{-1}$ respectively, indicating that fishing mortality was higher than the target of $F$=0.15 in the last three surveys (see Table 10, Figure 21). However, these changes in both $Z$ and $F$ of this magnitude in eight years seems implausible. The truncated age compositions (males in this case) combined with variable recruitment had major effects on the stability and magnitude of CR $Z$ and $F$ estimates. The point estimates of $Z$ and $F$ should therefore be treated with caution and estimates that fall within the 95% confidence intervals may be plausible.

Growth rates for blue cod under about 40 cm were similar in 2015, 2017, 2019 and 2023, but the *linf* (average size at maximum age) varied substantially among the surveys and gave unrealistically high estimates for 2019 and 2023 (see Figure 8). These unrealistically high estimates of *linf* were a direct result of a lack of older fish in the population that would be expected to be present in virgin or lightly fished populations given that blue cod can live to around 30 years of age and grow to as large as 60 cm.

## 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 29). All five surveys show indications of spawning activity in December for both sexes, with highly variable proportions in the running-ripe condition (Figure 29). 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 they will be transitioning between the mature and running-ripe conditions within a short period, possibly less than 24 hours. There were nearly always higher proportions of females than males in the combined mature/running-ripe conditions from the Kaikōura surveys (Figure 29), 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 concentration of spawning activity off the Kaikōura Peninsula indicates that spawning activity can vary geographically within the survey area (see Table 8b). Whether blue cod are migrating to this deeper water to spawn is unknown.

## 4.8 Management implications

The MLS was increased from 30 cm to 33 cm and the DBL reduced from 10 to 6 blue cod within the Kaikōura Marine Area in March 2014. Subsequently in July 2020 the MLS outside the marine area in the wider north Canterbury was increased to 33 cm with a bag limit remaining at 10 blue cod per day. There are no clear indications that these output controls have had a positive impact on blue cod catch rates, size of blue cod, age composition, and fishing mortality as estimated from the 2015, 2017, 2019, and 2023 random-site surveys with catch rates (i.e., abundance) progressively declining and age structure severely truncated (see Figure 25).

There have been four recreational fishing surveys carried out in North Canterbury covering the years 2003, 2009, 2012–13, and most recently in 2021–22 (Hart & Walker 2004, Kendrick et al. 2011, Kendrick & Hanley 2021, Maggs et al. 2023). For the Kaikōura area, the harvest by private-vessel recreational fishers has been progressively increasing and in 2021–22, nearly three times as many blue cod were harvested (retained) than in 2003 over the same period (January to April) (Figure 30). Comparison over the full fishing year was possible only for 2012–13 and 2021–22, and indicated that the harvest had increased by 80% over the nine-year period (Maggs et al. 2023). Further, the Kaikōura charter vessel harvest increased by 30% between 2012–13 and 2021–22, and more than 60% of the total Kaikōura recreational blue cod harvest was from Kaikōura based charter vessels in 2021–22. This trend of increasing recreational harvest has occurred despite the reductions in DBL and increase in MLS in the Kaikōura Marine Area in 2014 and outside the area in 2020, indicating that effort has increased to compensate. 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.

## 4.9 Status of blue cod 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 (Beentjes 2023). Hikurangi Marine Reserve was established in March 2014 affording nearly ten years of no fishing up to the time of the December 2023 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 2). The abundance estimates of blue cod inside the Hikurangi Marine Reserve on the 2017, 2019, and 2023 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 14). There were too few fish caught in adjacent strata to compare size with those in the marine reserve, but size composition was comparable to that in the wider survey area (compare Figures 16 and 23), notwithstanding the relatively small sample sizes from the marine reserve. Hence, based on three surveys it appears that, despite the small size of this marine reserve, it is partially working as intended with fish more abundant than in adjacent fished areas, although there has not been an increase in fish density inside the reserve observed over the three surveys and fish are not larger overall than directly outside the reserve. The maximum density of blue cod in the reserve 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 where some fishing is likely to have occurred.

Compared with Long Island Marine Reserve in the Queen Charlotte Sound where abundance is about eight times greater and blue cod mean length 3–5 cm larger inside than outside the marine reserve, Hikurangi Marine Reserve has only been moderately effective in restoring blue cod to pre-fishing levels, (Beentjes et al. 2022b, Beentjes 2023). Banded wrasse, however, were much more abundant inside the reserve than in the wider survey area and this may be a direct result of the absence of fishing (see Table 2a and b). The finding that blue cod were in much better condition inside the reserve (see Table 7 and Figure 11), is consistent with blue cod inside and outside Long Island Marine Reserve (Beentjes 2023), and may be related to changed and more productive ecosystems following cessation of exploitation or to some physiological differences related to sex change which may not be occurring to the same extent within the marine reserve.

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## 7. TABLES

**Table 1: Effort and catch data for the 2023 Kaikōura random-site blue cod potting survey for valid pots. mr, marine reserve; exclmr, excluding marine reserve; inclmr, including marine reserve. One pot in stratum 4 and one pot in the marine reserve were deemed invalid and not included in the analyses.**

| | 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 | 4 | 54 | 428 | 135.3 | 40 | 18–58 |
| 2A | 37.8 | Random | 3 | | 18 | 4 | 1.2 | 50 | 43–62 |
| 2B | 58.7 | Random | 3 | | 18 | 0 | 0 | 22 | 18–29 |
| 3 | 24.8 | Random | 6 | | 36 | 278 | 104.7 | 66 | 39–83 |
| 4 | 15.7 | Random | 7 | | 41 | 331 | 211.3 | 123 | 102–147 |
| mr | 1.5 | Random | 5 | | 29 | 92 | 42.5 | 24 | 7–115 |
| Total exclmr | 163.4 | Random | 24 | 4 | 167 | 1 041 | 452.5 | 60 | 18–147 |
| Total inclmr | 164.9 | Random | 29 | 4 | 196 | 1 133 | 495.0 | 52 | 7–115 |

**Table 2: Total catch and numbers of blue cod and bycatch species caught on the 2023 Kaikōura random-site blue cod potting survey. a) main survey area, b) Hikurangi Marine Reserve. Percent of the catch by weight is also shown.**

**a)**

| Common name | Species | Code | Catch (kg) | Number | % catch |
|---|---|---|---|---|---|
| Blue cod | *Parapercis colias* | BCO | 452.5 | 1 041 | 90.0 |
| Sea perch | *Helicolenus percoides* | SPE | 14.2 | 32 | 2.8 |
| Scarlet wrasse | *Pseudolabrus miles* | SPF | 14.0 | 38 | 2.8 |
| Octopus | *Octopus Maorum* | OCT | 9.8 | 3 | 1.9 |
| Girdled wrasse | *Notolabrus cinctus* | GPF | 5.7 | 22 | 1.1 |
| Tarakihi | *Nemadactylus macropterus* | NMP | 3.8 | 8 | 0.8 |
| Maori chief | *Notothenia angustata* | MCH | 0.8 | 3 | 0.2 |
| Leatherjacket | Meuschenia scaber | LEA | 0.6 | 1 | 0.1 |
| Banded Wrasse | *Notolabrus fucicola* | BPF | 0.3 | 2 | 0.1 |
| Rock lobster | *Jasus edwardsii* | CRA | 0.3 | 1 | 0.1 |
| Hairy Conger | *Bassanago hirsutus* | HCO | 0.3 | 1 | 0.1 |
| Red cod | *Pseudophycis bachus* | RCO | 0.2 | 1 | 0.0 |
| Southern bastard cod | *Pseudophycis barbata* | SBR | 0.1 | 1 | 0.0 |
| Totals | | | 502.6 | 1 154 | 100 |

**b)**

| Common name | Species | Code | Catch (kg) | Numbers | % catch |
|---|---|---|---|---|---|
| Blue cod | *Parapercis colias* | BCO | 42.5 | 92 | 83.3 |
| Banded Wrasse | *Notolabrus fucicola* | BPF | 15.9 | 17 | 16.5 |
| Tarakihi | *Nemadactylus macropterus* | NMP | 0.1 | 1 | 0.2 |
| Totals | | | 58.5 | 110 | 100 |

**Table 3: Valid pot lifts and mean catch rates for all blue cod and recruited blue cod (33 cm and over) from the 2023 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. One pot in stratum 4 and one pot in the marine reserve were deemed invalid and not included in the analyses.**

| | | 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 | 54 | 2.51 | 1.078 | 43.0 | 1.02 | 0.585 | 57.1 |
| 2A | 18 | 0.07 | 0.067 | 100.0 | 0.05 | 0.049 | 100.0 |
| 2B | 18 | 0.00 | 0.000 | NA | 0.00 | 0.000 | NA |
| 3 | 36 | 2.94 | 0.397 | 13.5 | 1.15 | 0.220 | 19.2 |
| 4 | 41 | 5.03 | 1.144 | 22.7 | 3.78 | 0.871 | 23.1 |
| mr | 29 | 1.42 | 0.733 | 51.8 | 0.72 | 0.502 | 70.2 |
| Overall (exclmr) | 167 | 1.35 | 0.215 | 15.9 | 0.71 | 0.131 | 18.4 |
| Overall (inclmr) | 196 | 1.35 | 0.213 | 15.8 | 0.71 | 0.130 | 18.2 |

**Table 4: Descriptive statistics for blue cod caught on the 2023 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.**

| | | | Length (cm) | | | Percent male | |
|---|---|---|---|---|---|---|---|
| Stratum | Sex | N | Mean | Minimum | Maximum | All blue cod | Recruited blue cod ≥ 33 cm |
| 1 | m | 298 | 27.3 | 16.5 | 44.0 | 69.7 | 97.2 |
| | f | 130 | 22.9 | 15.1 | 38.0 | | |
| 2A | m | 2 | 31.1 | 23.0 | 39.1 | 66.7 | 100 |
| | f | 1 | 20.4 | 20.4 | 20.4 | | |
| | u | 1 | 14.9 | 14.9 | 14.9 | | |
| 2B | m | 0 | – | – | – | – | – |
| | f | 0 | – | – | – | – | – |
| 3 | m | 196 | 29.2 | 18.8 | 44.9 | 70.5 | 83.4 |
| | f | 82 | 27.6 | 19.0 | 35.9 | | |
| 4 | m | 92 | 36.2 | 23.7 | 51.3 | | |
| | f | 239 | 33.1 | 23.9 | 44.3 | 27.7 | 30.3 |
| mr | u | 92 | 28.1 | 17.9 | 41.1 | | |
| Overall (exclmr) | m | 588 | 28.6 | 16.5 | 51.3 | 60.4 | 61.8 |
| | f | 452 | 27.9 | 15.1 | 44.3 | | |
| | u | 1 | 14.9 | 14.9 | 41.1 | | |
| Overall (inclmr) | m | 588 | 28.6 | 16.5 | 51.3 | 60.4 | 61.8 |
| | f | 452 | 27.9 | 15.1 | 44.3 | | |
| | u | 93 | 27.7 | 14.9 | 41.1 | | |

**Table 5: Otolith ageing data collected from the 2023 Kaikōura random-site blue cod potting survey.**

| | | Length of aged fish (cm) | | Age (years) | |
|---|---|---|---|---|---|
| Survey | No. otoliths | Minimum | Maximum | Minimum | Maximum |
| Male | 231 | 16 | 51 | 2 | 17 |
| Female | 172 | 15 | 44 | 2 | 17 |
| Total | 403 | 15 | 51 | 2 | 17 |

**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 7: Mean condition factor (*K*) of blue cod for the 2015, 2017, 2019, and 2023 Kaikōura random-site surveys. $K = wt*100/l^b$, where *wt* = weight (g), *l* =length (cm), and *b* = 3. *excludes the marine reserve; mr, marine reserve.**

| Survey | Sex | Mean condition (*K*) | Standard error | Number |
|---|---|---|---|---|
| 2015 | Males | 1.560 | 0.0044 | 1 091 |
| | Females | 1.606 | 0.0045 | 1 090 |
| | Both sexes | 1.583 | 0.0032 | 2 181 |
| 2017 | Males | 1.484 | 0.0044 | 762 |
| | Females | 1.524 | 0.0059 | 757 |
| | Both sexes* | 1.504 | 0.0037 | 1 519 |
| 2019 | Males | 1.528 | 0.0096 | 504 |
| | Females | 1.545 | 0.0095 | 656 |
| | Both sexes* | 1.537 | 0.0068 | 1 160 |
| 2023 | Males | 1.481 | 0.0052 | 588 |
| | Females | 1.491 | 0.0054 | 452 |
| | Both sexes* | 1.486 | 0.0038 | 1 041 |
| | Unsexed (mr) | 1.848 | 0.0245 | 92 |

**Table 8a: Gonad stages (%) of blue cod from the 2023 Kaikōura random-site blue cod potting 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 | 61.4 | 20.7 | 9.5 | 0.2 | 8.2 | 588 |
| Females | 61.3 | 17.5 | 14.4 | 0.7 | 6.2 | 452 |

**Table 8b: Gonad stages (numbers) of blue cod from 2023 Kaikōura random-site blue cod potting survey by sex and stratum.**

| | Male gonad stage (*N*) | | | | | |
|---|---|---|---|---|---|---|
| Stratum | 1 | 2 | 3 | 4 | 5 | Stratum totals (*N*) |
| 1 | 208 | 40 | 8 | | 42 | 298 |
| 2A | | 2 | | | | 2 |
| 2B | | | | | | 0 |
| 3 | 135 | 36 | 24 | 1 | | 196 |
| 4 | 18 | 44 | 24 | | 6 | 92 |
| Gonad totals (*N*) | 361 | 122 | 56 | 1 | 48 | 588 |

| | Female gonad stage (*N*) | | | | | |
|---|---|---|---|---|---|---|
| Stratum | 1 | 2 | 3 | 4 | 5 | Stratum totals (*N*) |
| 1 | 118 | 3 | | | 9 | 130 |
| 2A | | 1 | | | | 1 |
| 2B | | | | | | 0 |
| 3 | 76 | 5 | 1 | | | 82 |
| 4 | 83 | 70 | 64 | 3 | 19 | 239 |
| Gonad totals (*N*) | 277 | 79 | 65 | 3 | 28 | 452 |

**Table 9: Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals (CI) for male blue cod from the 2023 Kaikōura random-site blue cod potting survey. Male *Z* estimates are also shown for previous surveys in 2015, 2017, and 2019. AgeR, age-at-full recruitment.**

| | | | 95% CIs | |
|---|---|---|---|---|
| Survey | AgeR | *Z* | Lower | Upper |
| 2023 | 5 | 0.42 | 0.29 | 0.58 |
| | 6 | 0.63 | 0.44 | 0.87 |
| | 7 | 0.49 | 0.34 | 0.66 |
| | 8 | 0.57 | 0.39 | 0.79 |
| | 9 | 0.96 | 0.61 | 1.36 |
| | 10 | 0.56 | 0.38 | 0.8 |
| 2019 | 5 | 0.48 | 0.33 | 0.68 |
| | 6 | 0.51 | 0.35 | 0.70 |
| | 7 | 0.92 | 0.64 | 1.27 |
| | 8 | 0.38 | 0.26 | 0.51 |
| | 9 | 0.61 | 0.40 | 0.92 |
| | 10 | 0.67 | 0.40 | 1.02 |
| 2017 | 5 | 0.92 | 0.59 | 1.32 |
| | 6 | 0.38 | 0.26 | 0.55 |
| | 7 | 0.47 | 0.32 | 0.66 |
| | 8 | 0.45 | 0.30 | 0.63 |
| | 9 | 0.40 | 0.25 | 0.59 |
| | 10 | 0.62 | 0.34 | 0.96 |
| 2015 | 5 | 0.57 | 0.36 | 0.8 |
| | 6 | 0.5 | 0.33 | 0.73 |
| | 7 | 0.29 | 0.19 | 0.42 |
| | 8 | 0.37 | 0.24 | 0.53 |
| | 9 | 0.52 | 0.31 | 0.81 |
| | 10 | 0.54 | 0.29 | 0.87 |

**Table 10: Chapman Robson total (*Z*) and fishing (*F*) mortality point estimates at three values of natural mortality (*M*) for male blue cod from the Kaikōura random-site potting survey time series. *AgeR* is the age-at-recruitment at which males reach MLS of 33 cm plus one year. The upper and lower 95% confidence interval (CI) *Z* and *F* estimates are also given for the default *M* (0.17)**

| Survey | AgeR | *M* | Male *Z* | Male *F* | Estimate type |
|---|---|---|---|---|---|
| 2023 | 7 | 0.14 | 0.49 | 0.35 | Point |
| | 7 | 0.17 | 0.49 | 0.32 | Point |
| | 7 | 0.20 | 0.49 | 0.29 | Point |
| | 7 | 0.17 | 0.34 | 0.17 | Lower CI |
| | 7 | 0.17 | 0.66 | 0.49 | Upper CI |
| 2019 | 7 | 0.14 | 0.92 | 0.78 | Point |
| | 7 | 0.17 | 0.92 | 0.75 | Point |
| | 7 | 0.20 | 0.92 | 0.72 | Point |
| | 7 | 0.17 | 0.64 | 0.47 | Lower CI |
| | 7 | 0.17 | 1.27 | 1.10 | Upper CI |
| 2017 | 7 | 0.14 | 0.47 | 0.33 | Point |
| | 7 | 0.17 | 0.47 | 0.30 | Point |
| | 7 | 0.20 | 0.47 | 0.27 | Point |
| | 7 | 0.17 | 0.32 | 0.15 | Lower CI |
| | 7 | 0.17 | 0.66 | 0.49 | Upper CI |
| 2015 | 7 | 0.14 | 0.29 | 0.15 | Point |
| | 7 | 0.17 | 0.29 | 0.12 | Point |
| | 7 | 0.20 | 0.29 | 0.09 | Point |
| | 7 | 0.17 | 0.19 | 0.02 | Lower CI |
| | 7 | 0.17 | 0.42 | 0.25 | Upper CI |

## 8. FIGURES

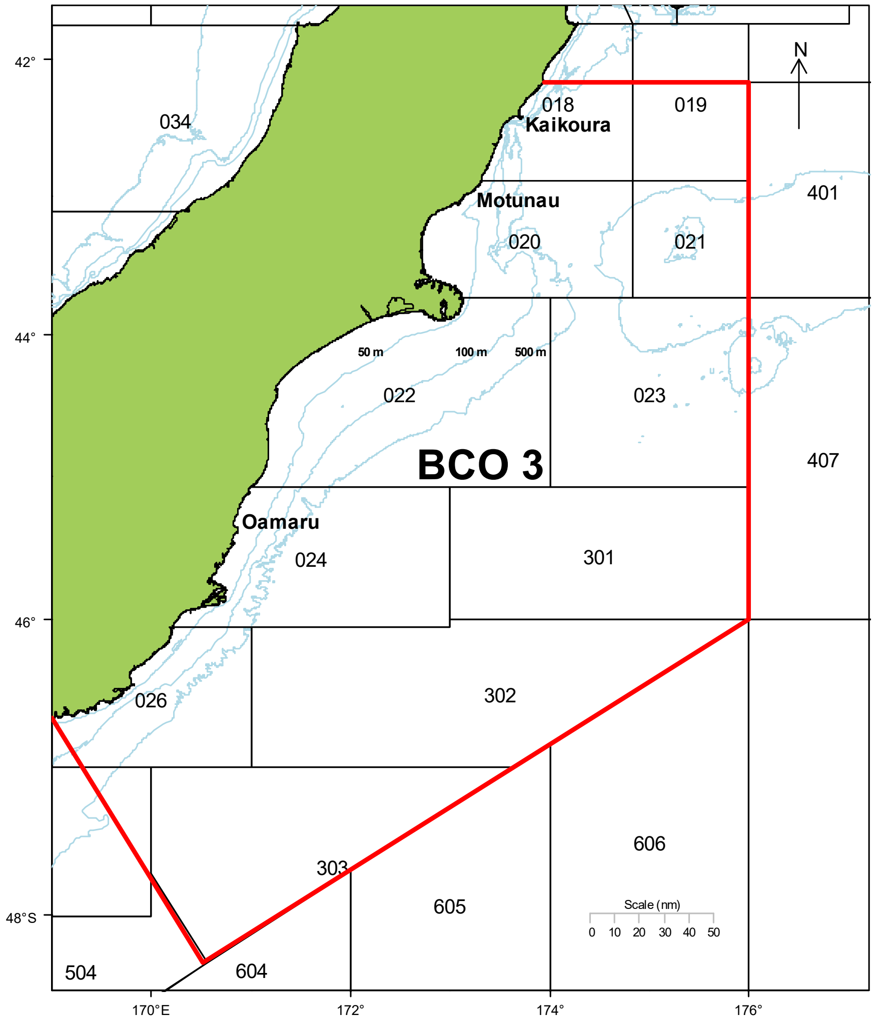


**Figure 1: Blue cod Quota Management Area BCO 3 (red border) and statistical areas. The north Canterbury potting survey locations of Kaikōura and Motunau are shown.**

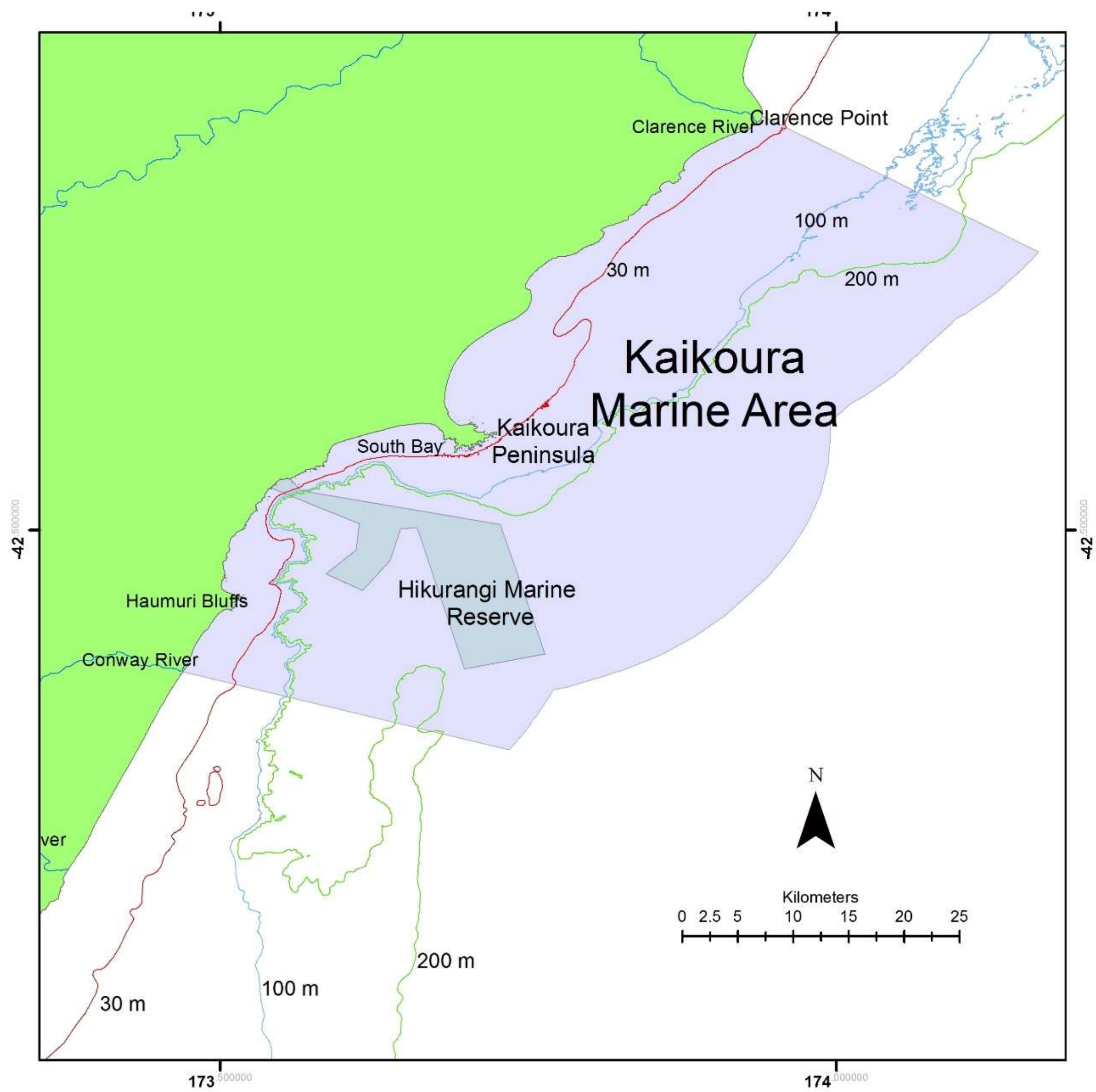


**Figure 2: Map of north Canterbury region showing the Kaikōura Marine Area and Hikurangi Marine Reserve, both established in 2014. Within the Kaikōura Marine Area, the recreational blue cod minimum legal size is 33 cm, and daily bag limit is six. Elsewhere in north Canterbury, these limits were 10 blue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

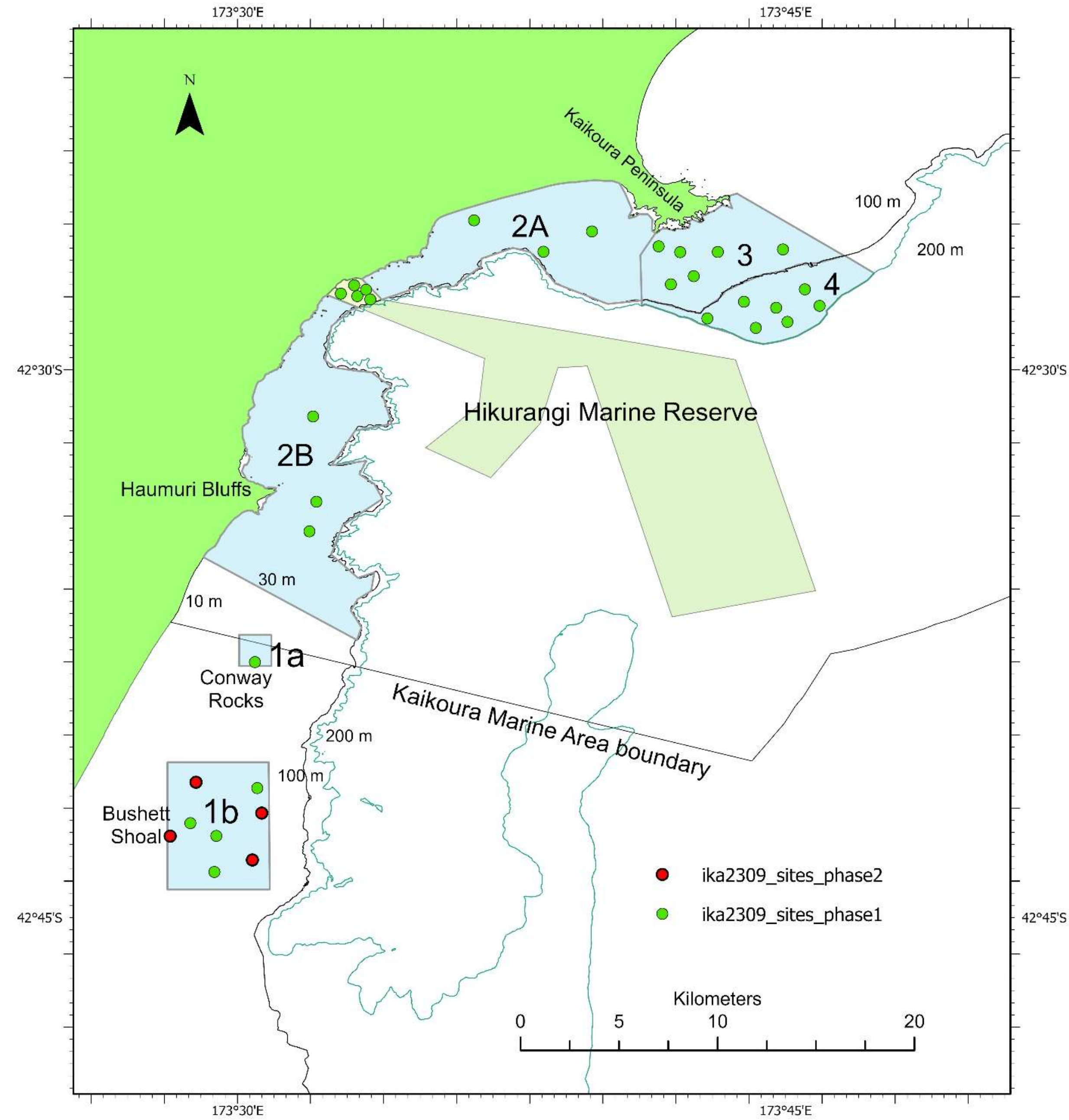


**Figure 3: Kaikōura strata and pot site locations for the 2023 random-site blue cod potting survey. The Hikurangi Marine Reserve and Kaikōura Marine Area are also shown. Green circles are phase 1 sites and red circles, phase 2 sites.**

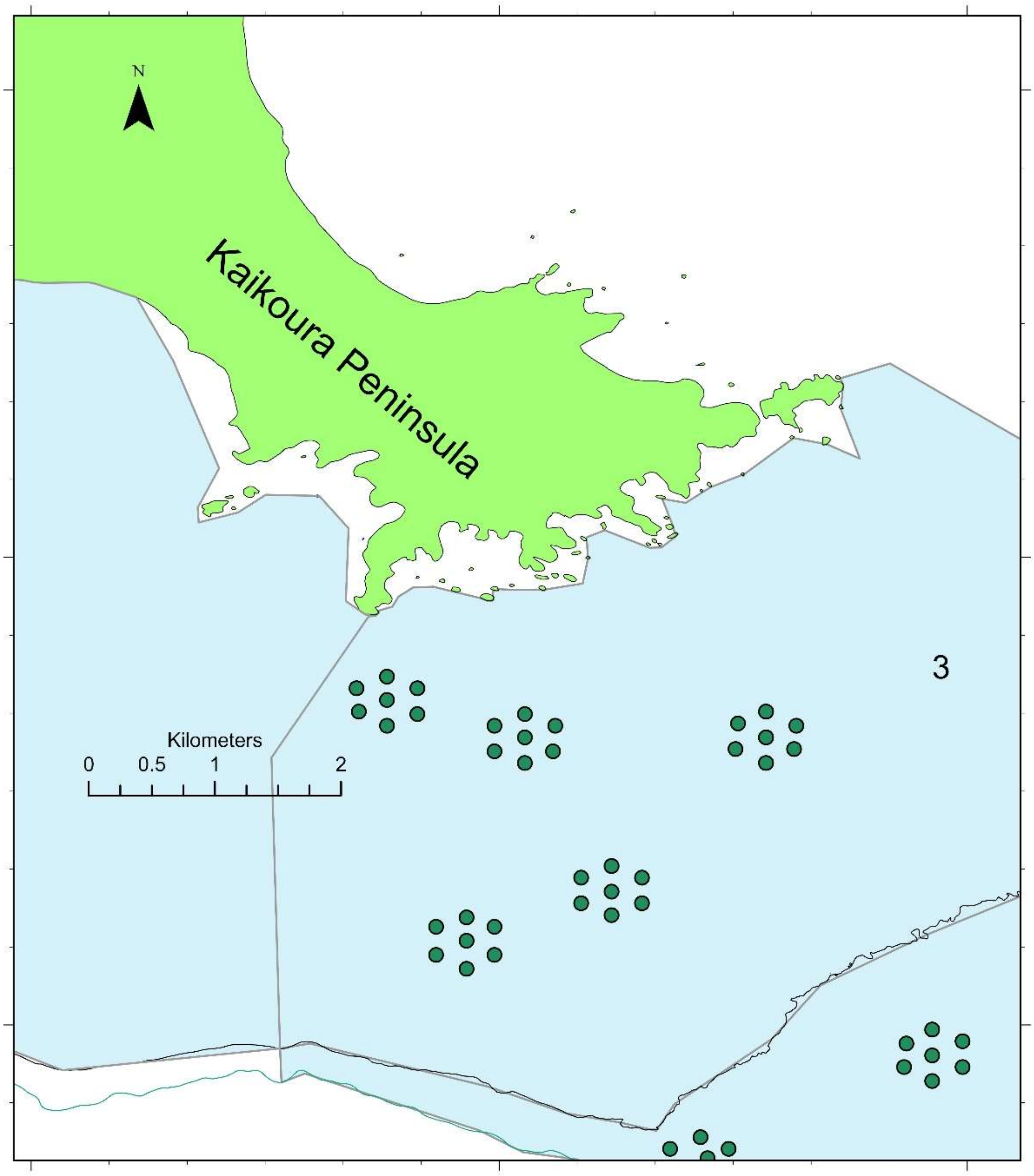


**Figure 4: Kaikōura 2023 random-site blue cod potting survey pot placement example for seven random sites in strata 3 and 4 showing how six pots were placed in a hexagon pattern around the central random-site location.**

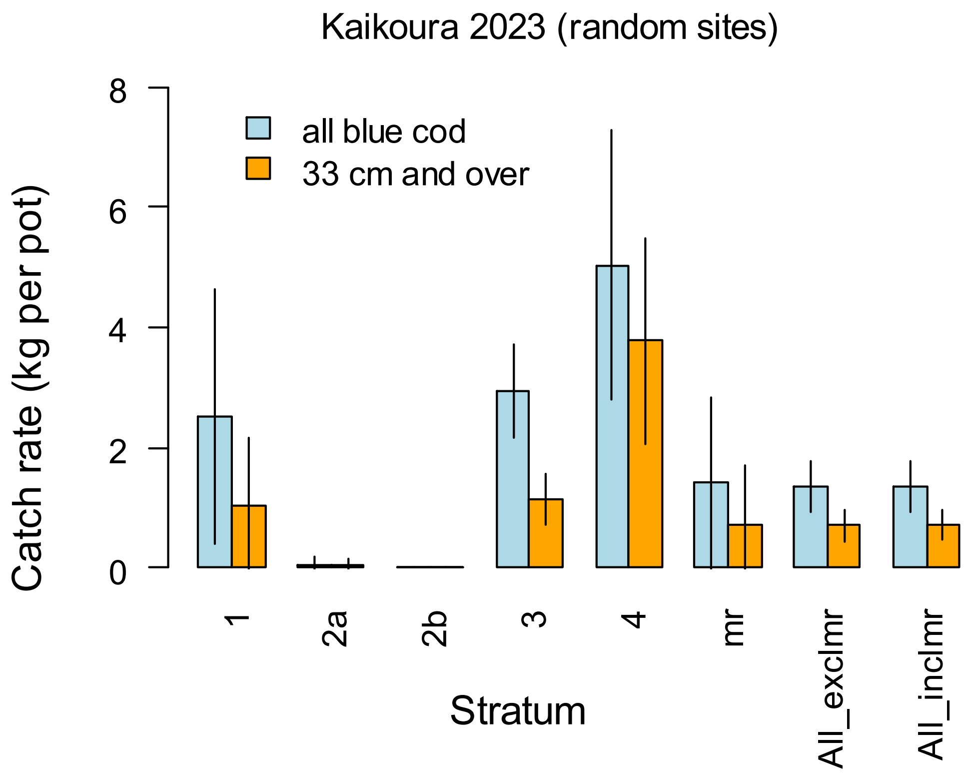


**Figure 5: Catch rates (kg pot$^{-1}$) of all blue cod and recruited blue cod (33 cm and over) by strata, and overall for the 2023 Kaikōura random site survey. Error bars are 95% confidence intervals. mr, marine reserve; All_exclmr, excluding marine reserve; All_inclmr, including marine reserve.**

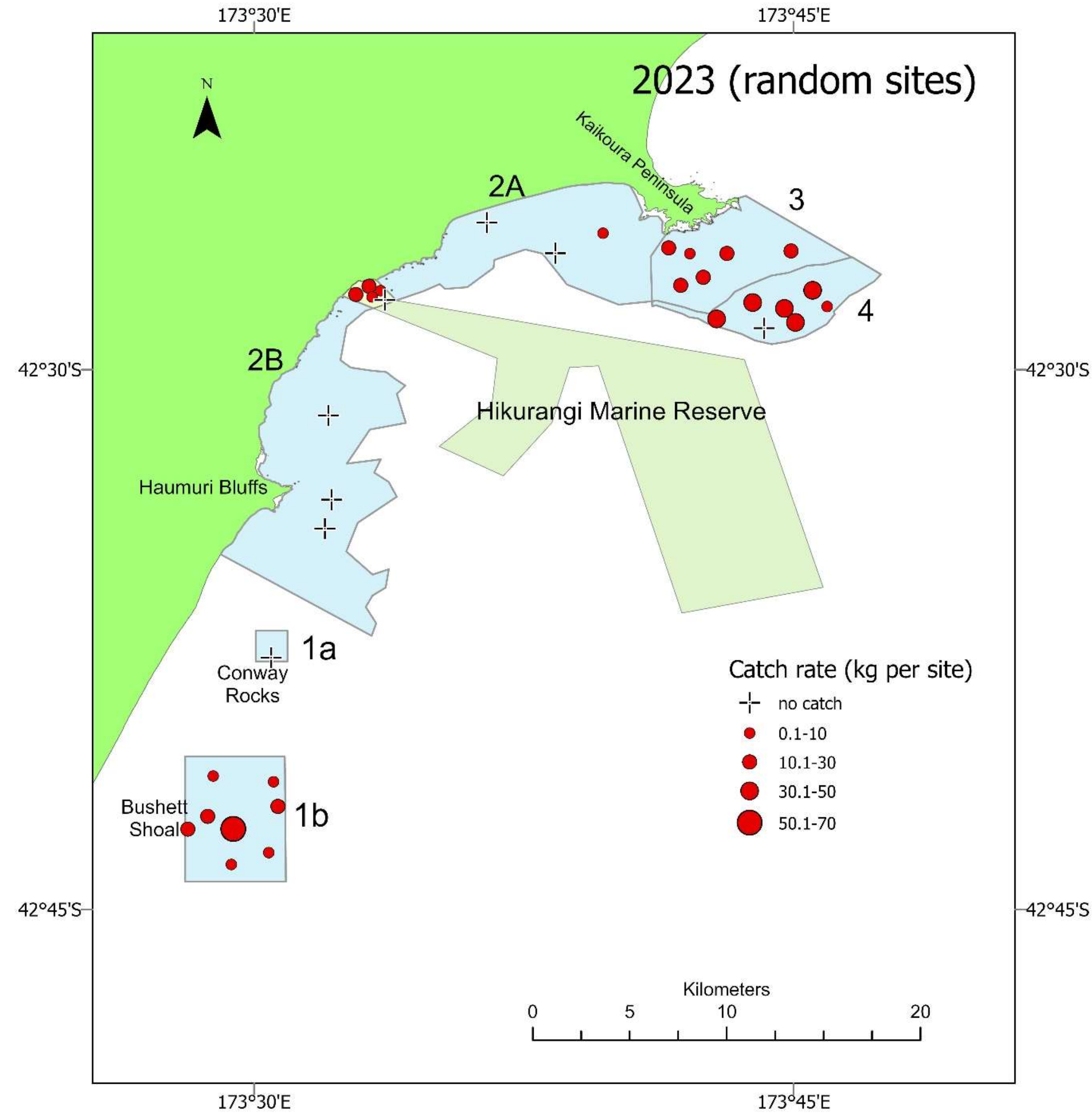


**Figure 6: Strata and site positions showing relative blue cod catch rates (kg site$^{-1}$) for the 2023 Kaikōura random-site blue cod potting survey.**

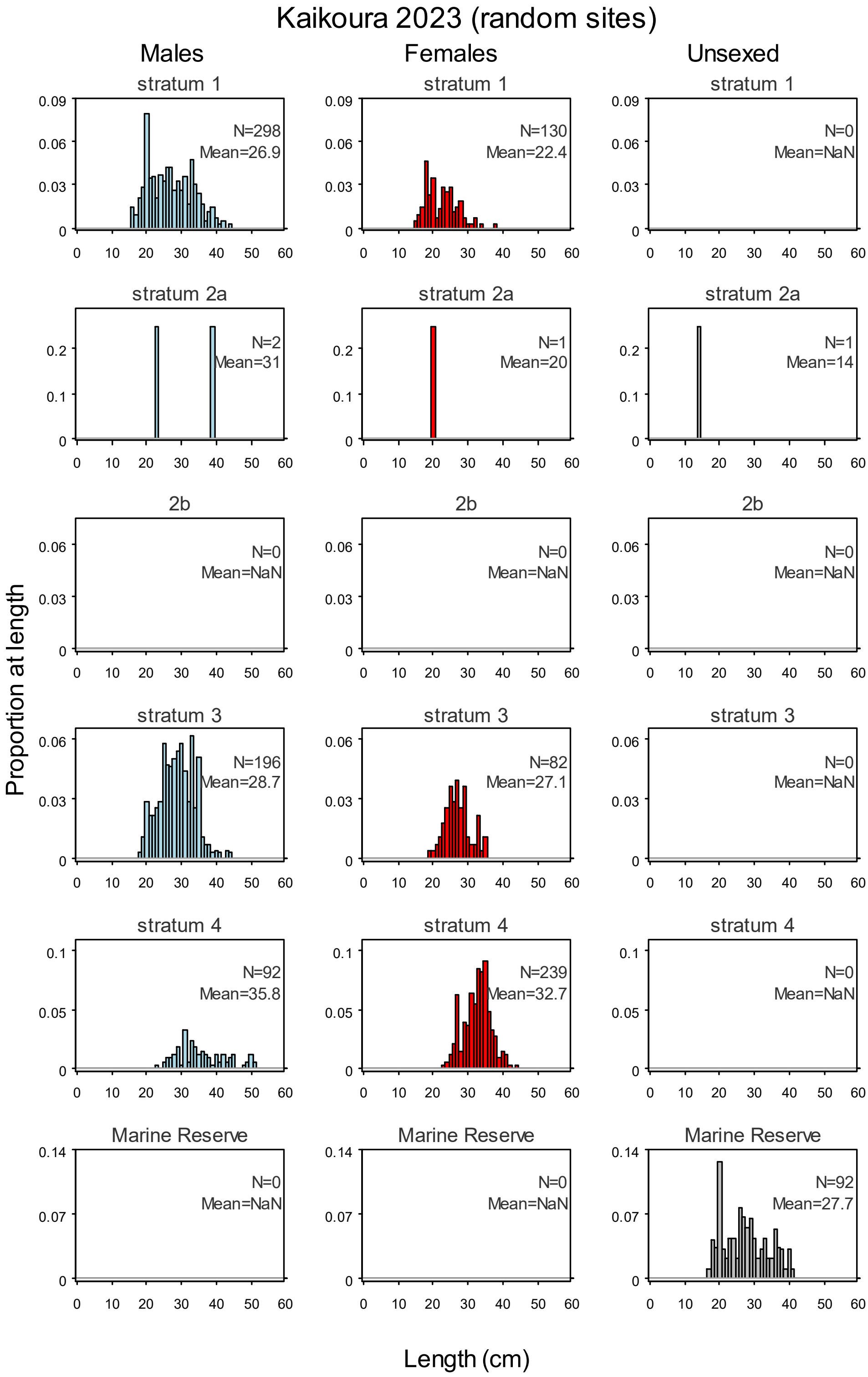


**Figure 7: Scaled length frequency distributions by strata and overall for the 2023 Kaikōura random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. The length frequency distribution within the marine reserve is also shown.**

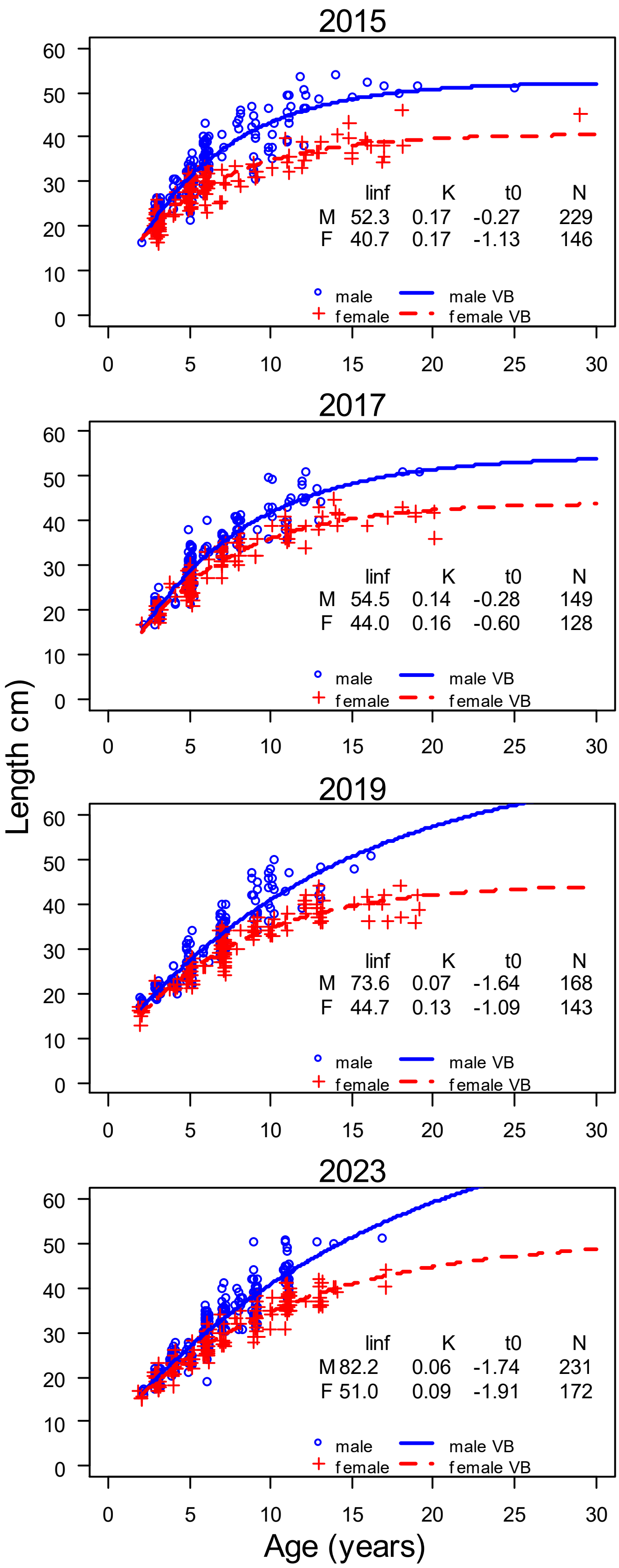


**Figure 8: Observed blue cod age and length data by sex for the 2015, 2017, 2019, and 2023 Kaikōura surveys with von Bertalanffy growth models fitted to the data. linf, average size at the maximum age (cm); K, Brody growth coefficient ($yr^{-1}$); t0, age when the average size is zero; N, number of fish aged.**

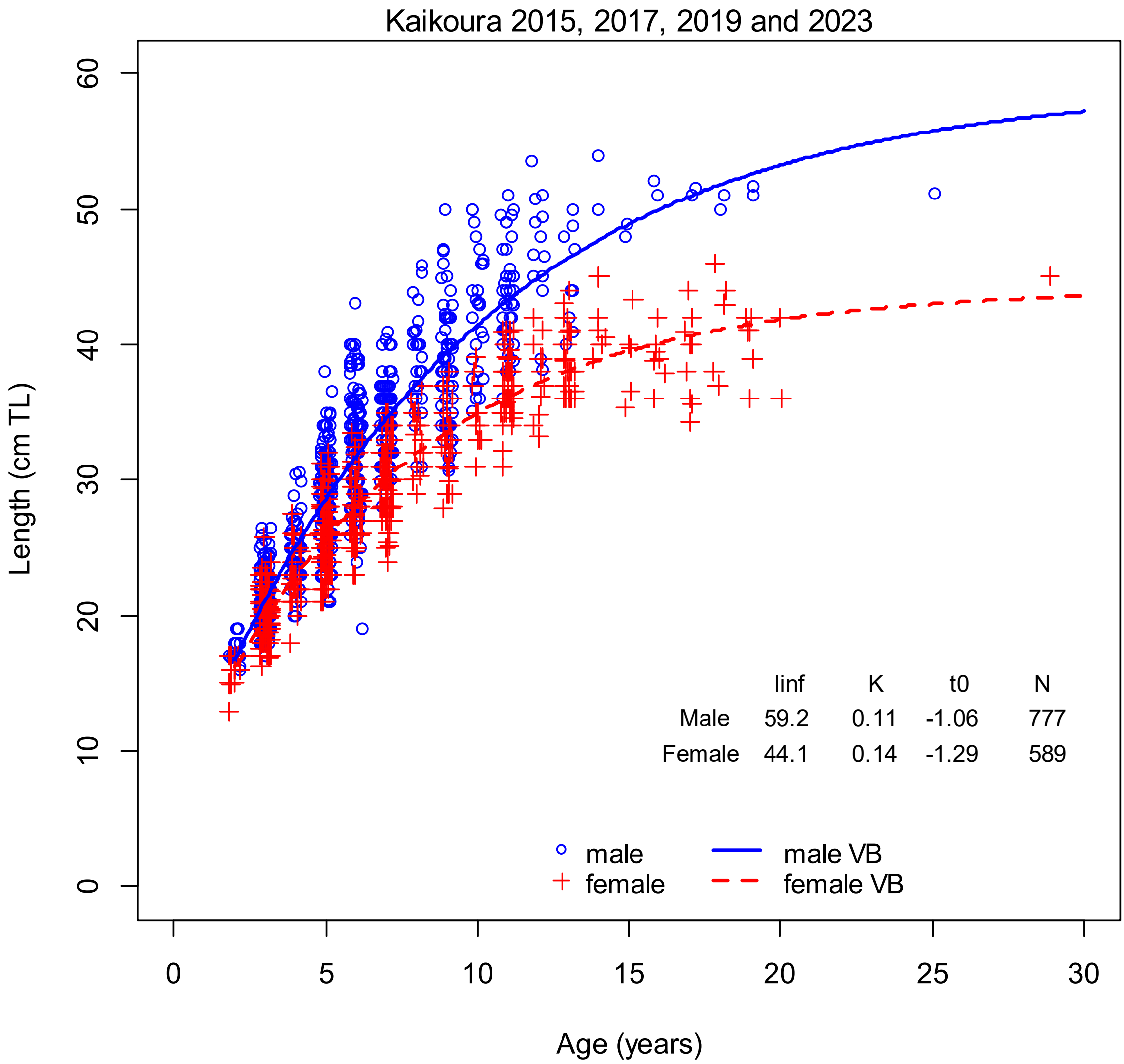


**Figure 9: von Bertalanffy growth models fitted to combined age and length data from the 2015, 2017, 2019, and 2023 Kaikōura blue cod surveys. linf, average size at the maximum age (cm); K, Brody growth coefficient ($yr^{-1}$); t0, age when the average size is zero; N, number of fish aged.**

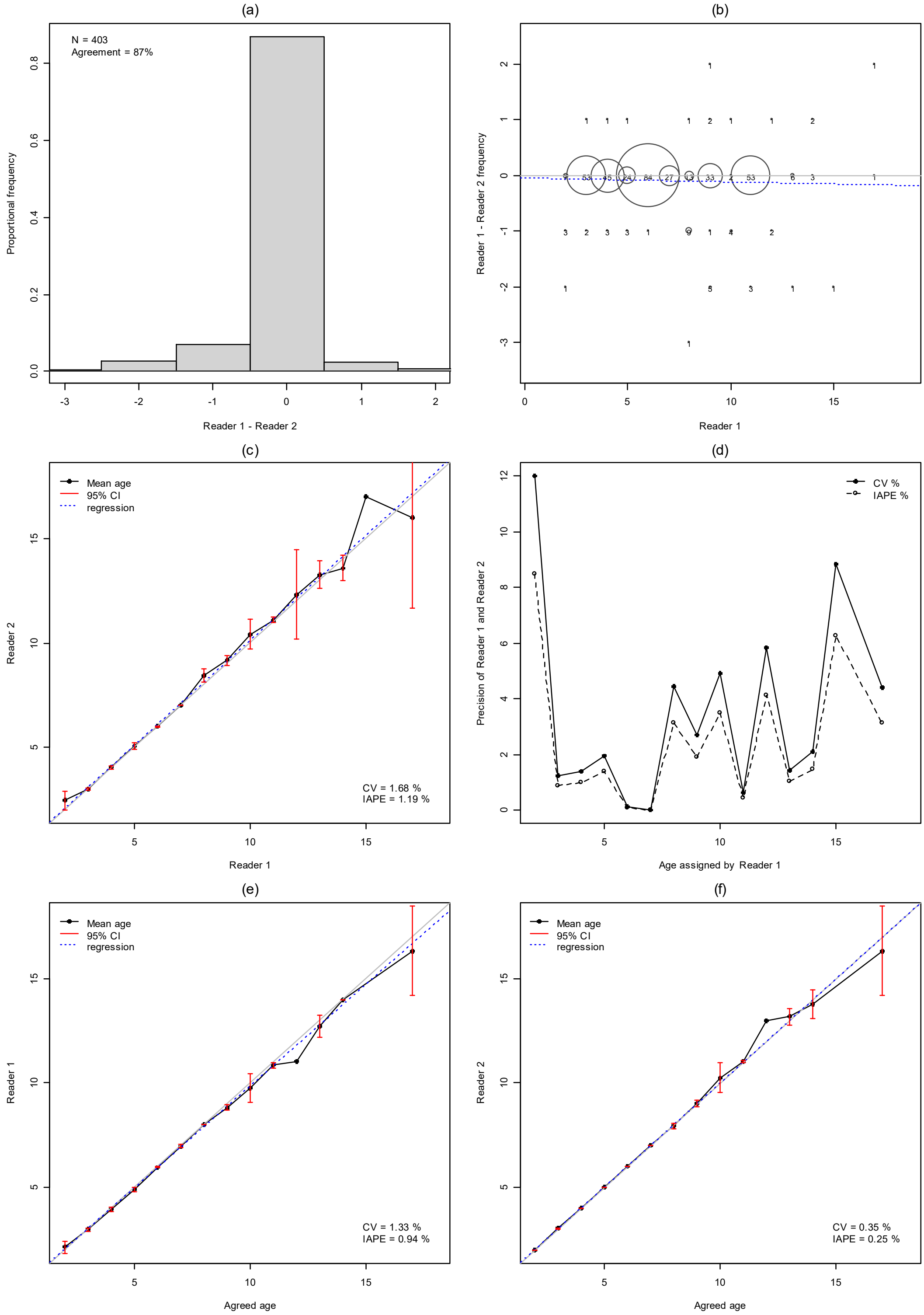


**Figure 10: Otolith reader comparison plots between reader 1 and reader 2 for blue cod from the 2023 Kaikōura survey. (a) Histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age 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, while dashed lines show the trend of a linear regression of the actual data.**

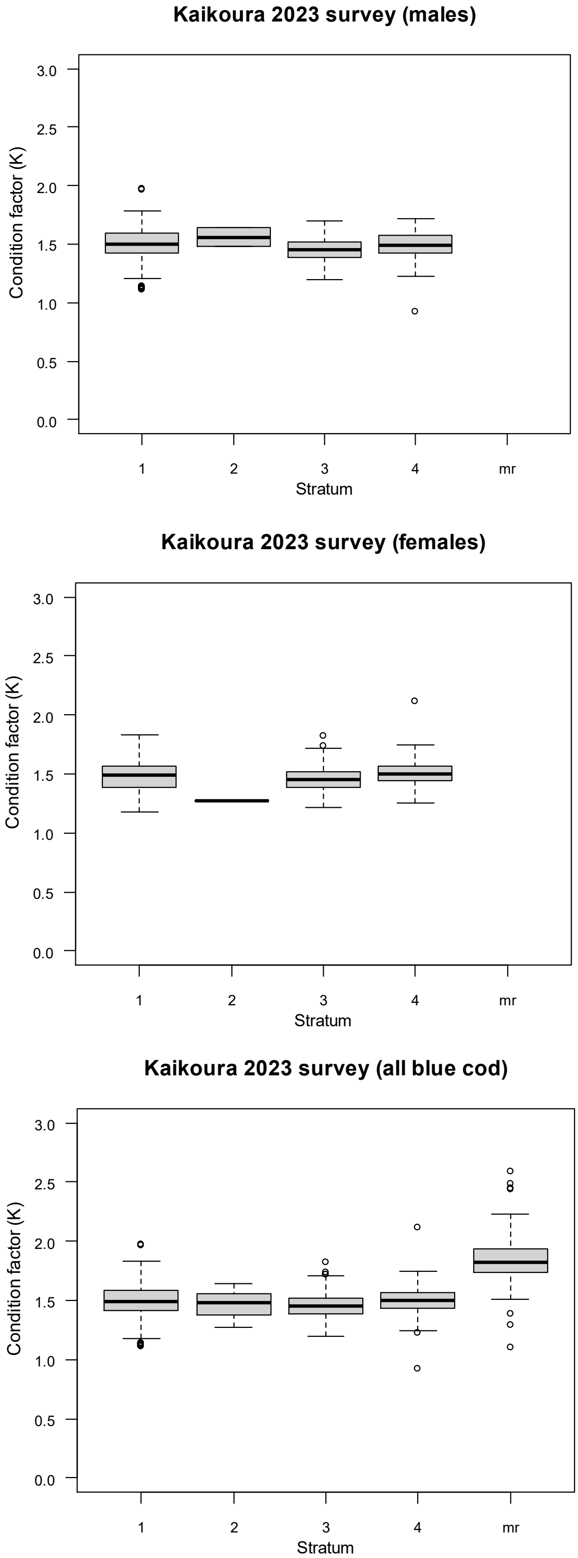


**Figure 11: Median box and whisker plots of condition factor (*K*) of blue cod for males, females, and all blue cod including the marine reserve from the Kaikōura 2023 random-site potting survey. $K = wt \times 100/l^b$, where *wt* = weight (g), *l*=length (cm), and *b* = 3. Strata 2A and 2B have been combined for these analyses where only four fish were caught, one of which was unsexed.**

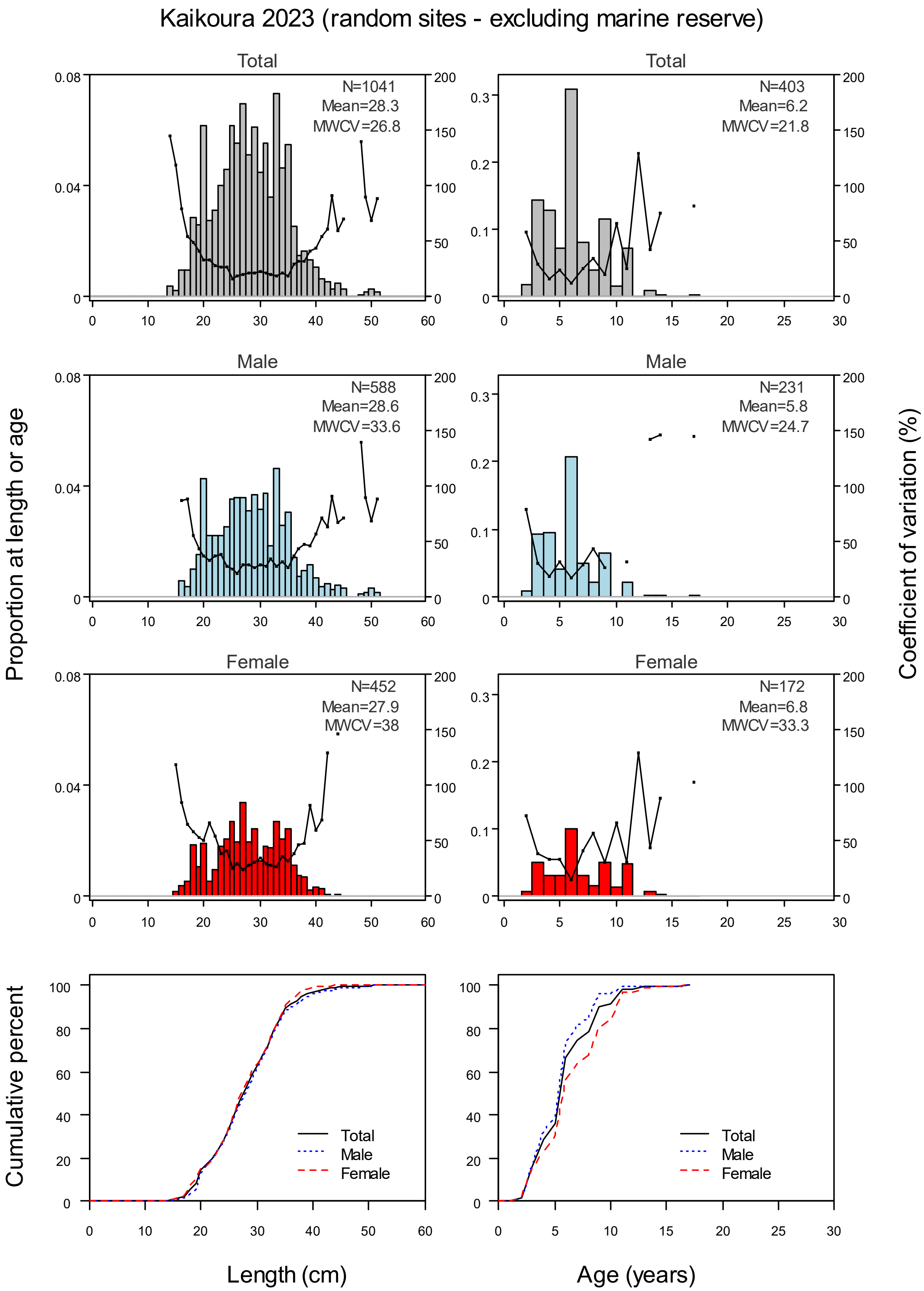


**Figure 12: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (excluding Hikurangi Marine Reserve) in the 2023 Kaikōura random-site blue cod potting survey. N, sample size; MWCV, mean weighted coefficient of variation, %.**

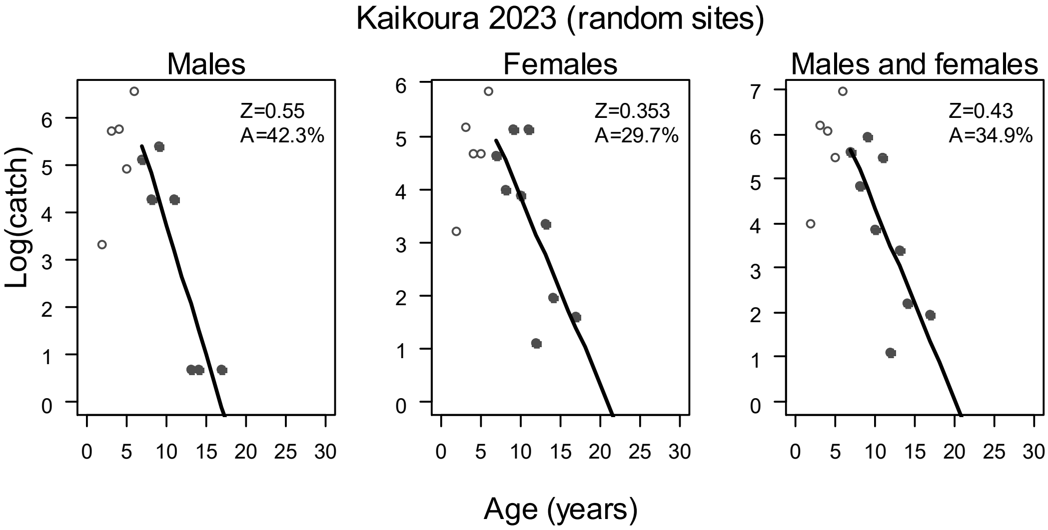


**Figure 13: Catch curves (natural log of blue cod catch numbers versus age) for the 2023 Kaikōura random-site survey. The regression line is plotted from male age at full recruitment plus one year (i.e., 7 years - the dark points on the graph). *Z*, instantaneous total mortality; *A*, the annual mortality rate or the proportion of the population that suffers mortality in a given year.**

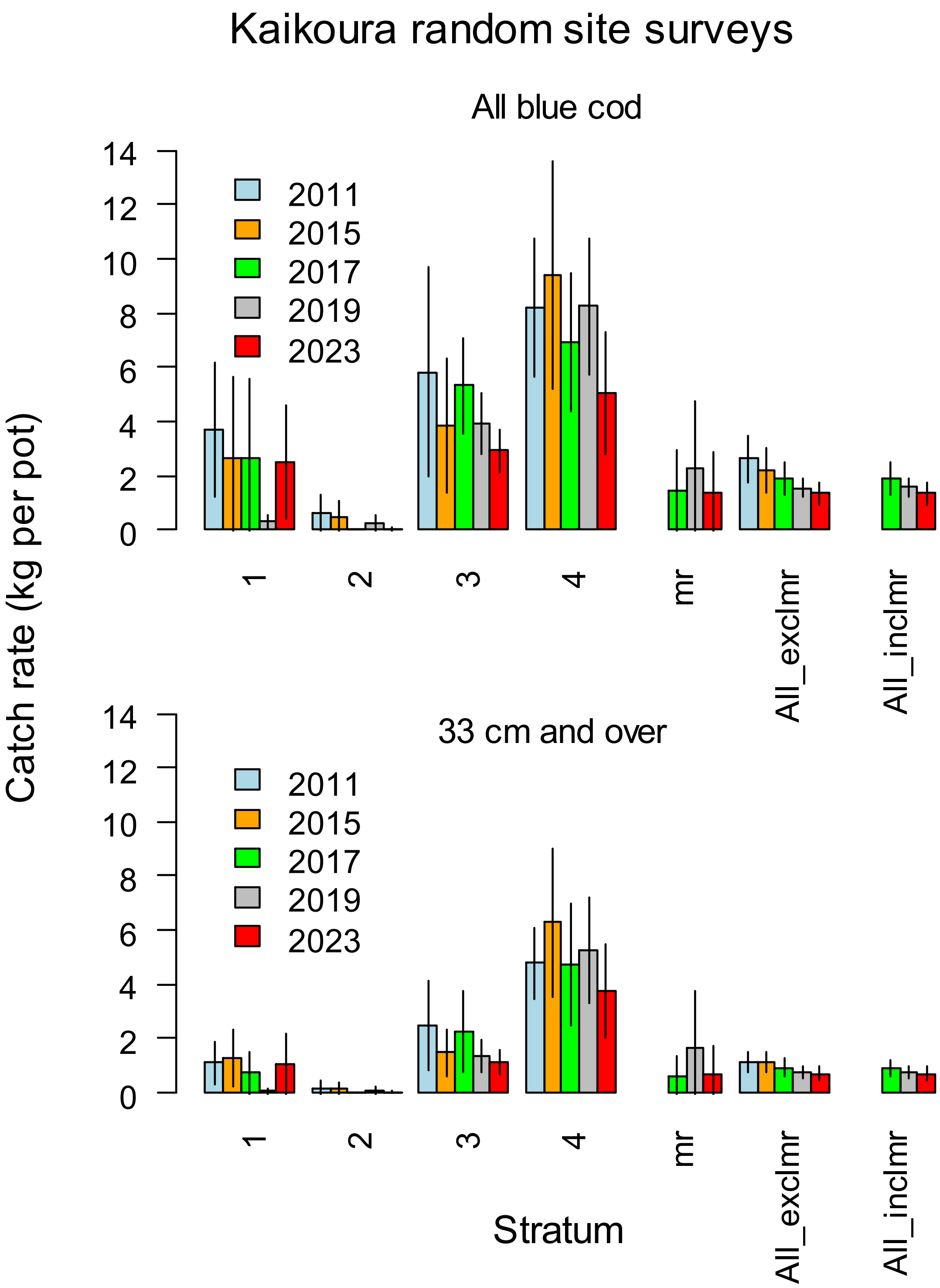


**Figure 14:** Catch rates (kg pot$^{-1}$) of all blue cod and recruited blue cod (33 cm and over) for the Kaikōura random-site potting surveys in 2011, 2015, 2017, 2019 and 2023. Error bars are 95% confidence intervals. Strata 2A and 2B are combined to allow comparison between years.

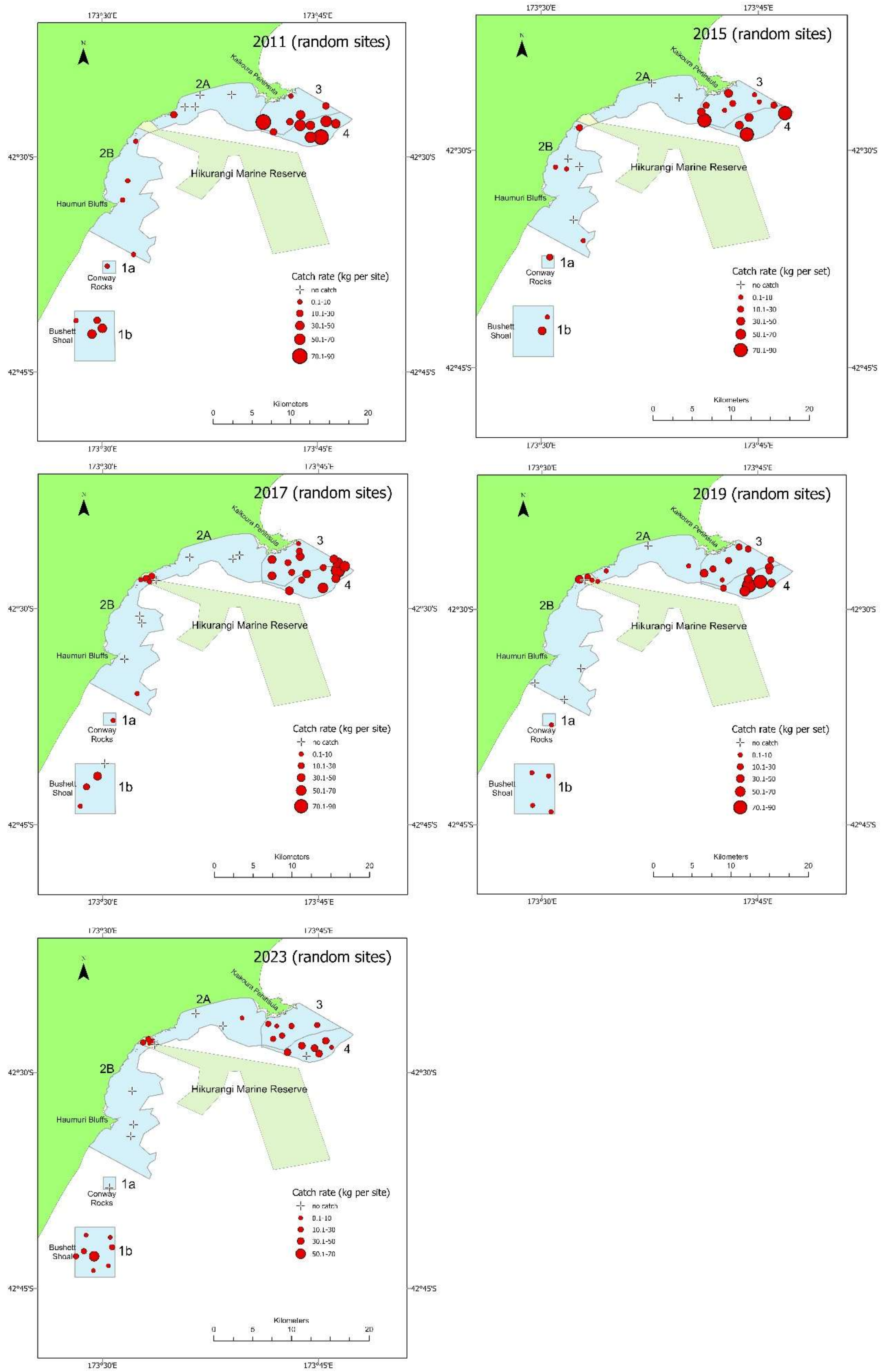


**Figure 15: Strata and site positions showing relative blue cod catch rates (kg site$^{-1}$) for the 2011, 2015, 2017, 2019, and 2023 Kaikōura random-site blue cod potting surveys.**

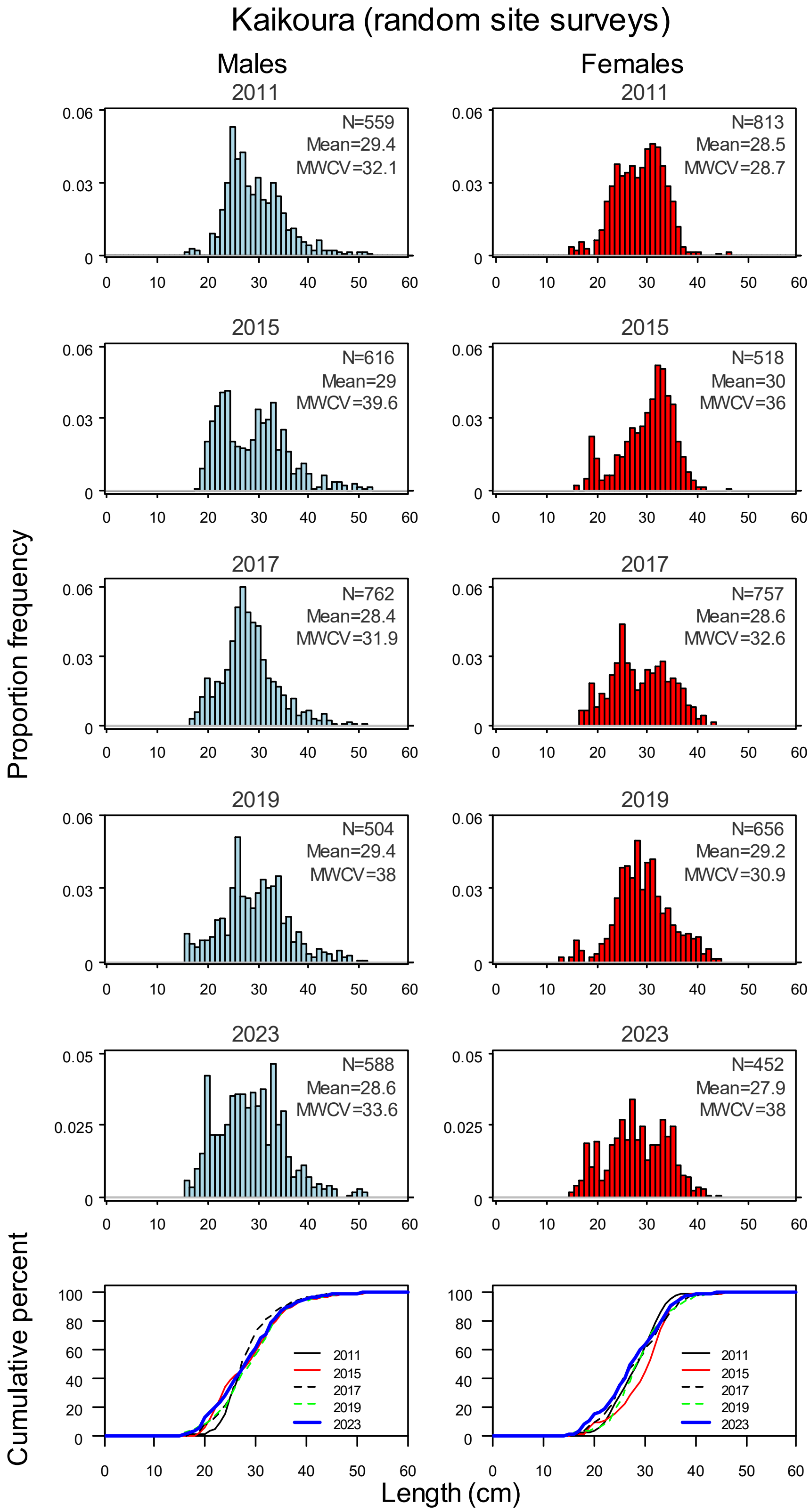


**Figure 16: Scaled length frequency and cumulative distributions for male and female blue cod from Kaikōura random-site potting surveys in 2011, 2015, 2017, 2019, and 2023. N, sample numbers; no, population number; Mean, mean length (cm); MWCV, mean weighted coefficient of variation, %.**

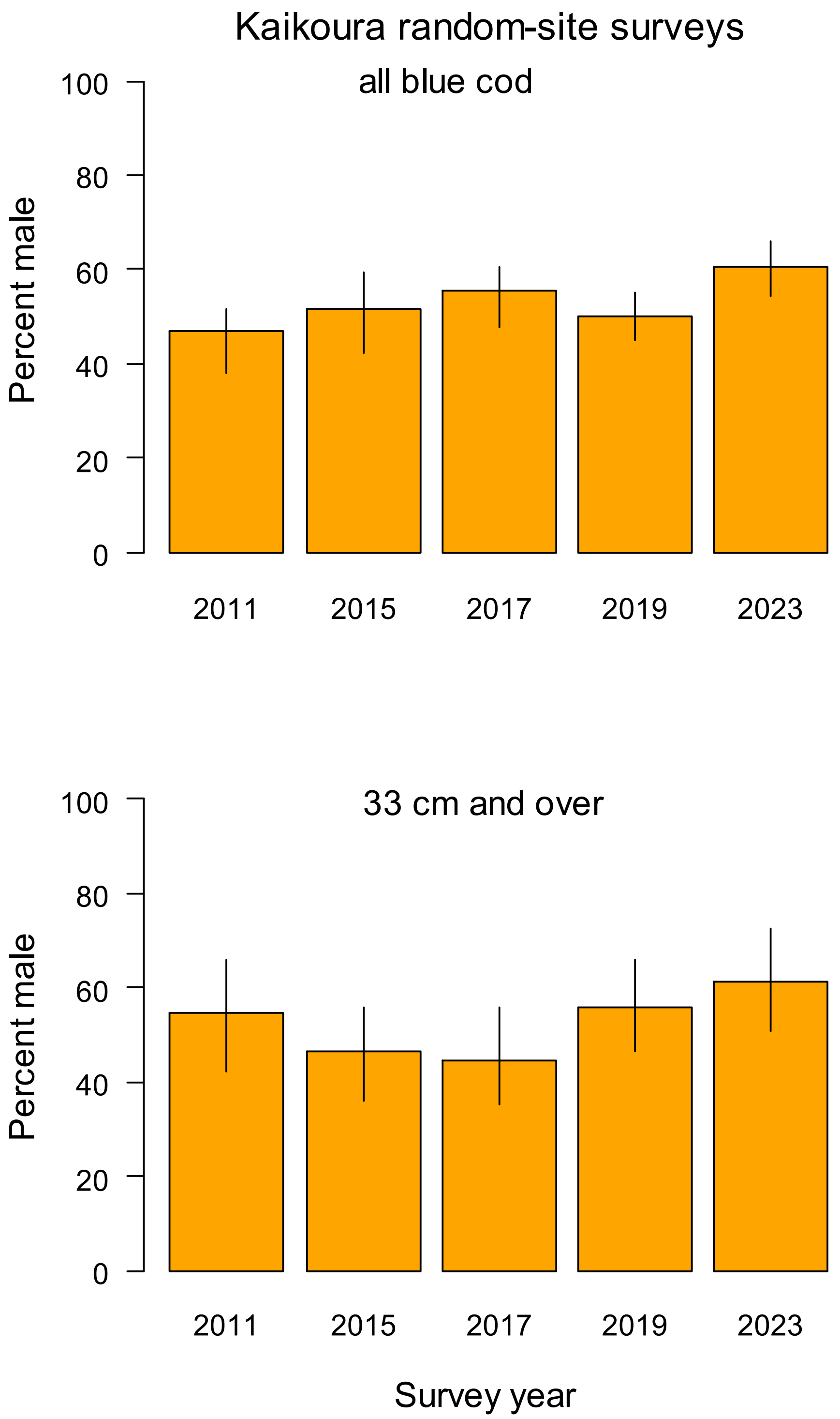


**Figure 17: Proportion of males in the catch from Kaikōura random-site potting surveys in 2011, 2015, 2017, 2019, and 2023. Error bars are 95% confidence intervals.**

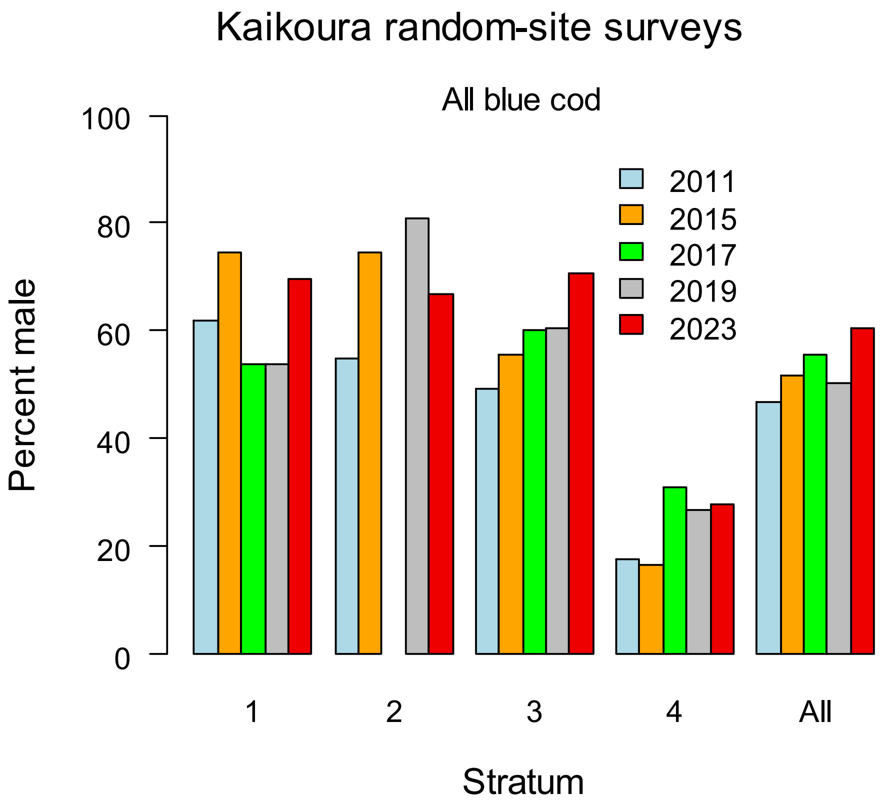


**Figure 18: Proportion of males in the catch from Kaikōura random-site potting surveys by stratum in 2011, 2015, 2017, 2019, and 2023. Strata 2A and 2B are combined to allow comparison between years.**

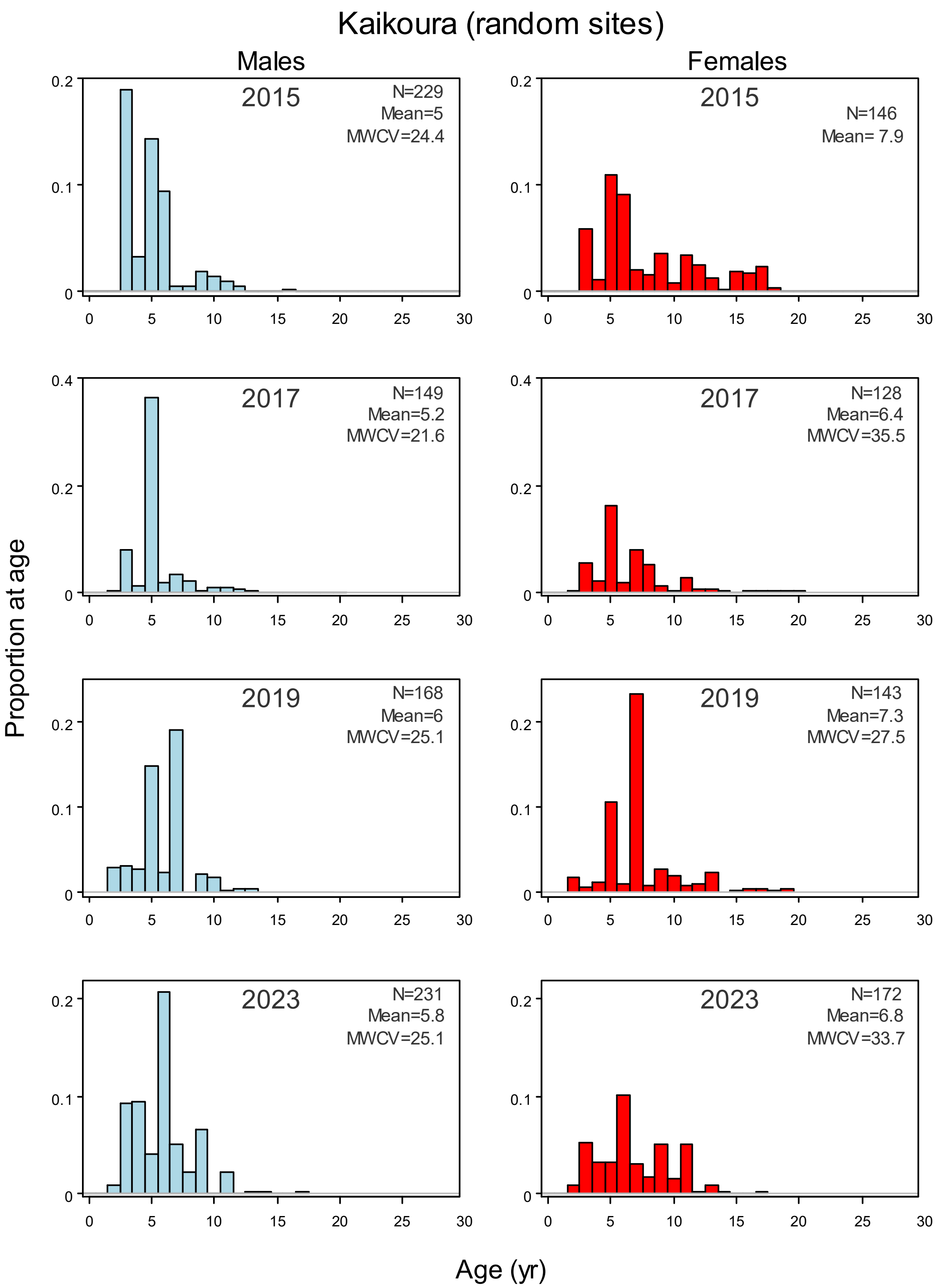


**Figure 19: Scaled age frequency distributions for male and female blue cod for all strata in the 2015, 2017, 2019, and 2023 Kaikōura random-site blue cod potting surveys. N, sample size; Mean, mean length (cm); MWCV, mean weighted coefficient of variation, %.**

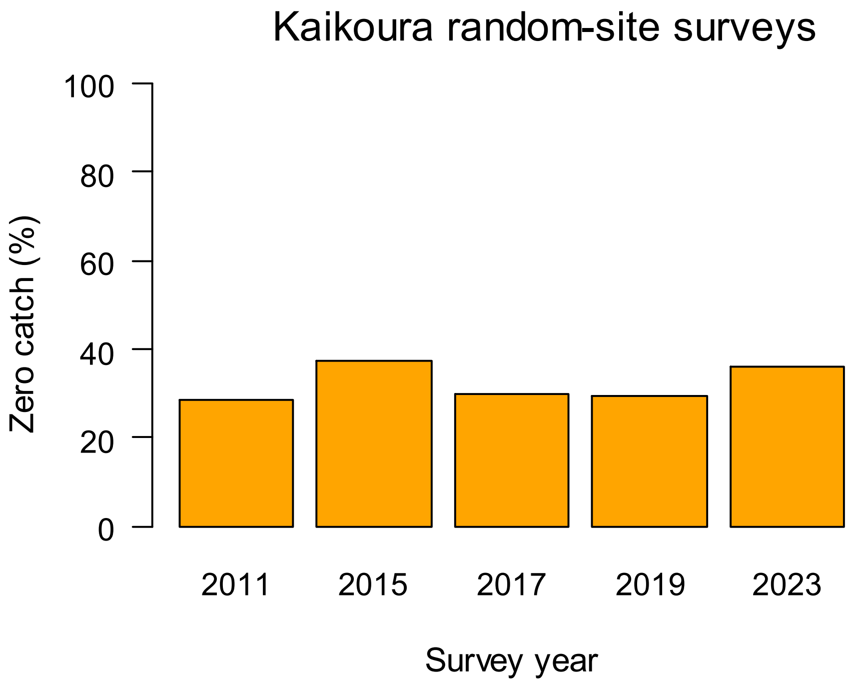


**Figure 20:** **Proportion of pots with zero blue cod catch for the Kaikōura random-site potting surveys in 2011, 2015, 2017, 2019, and 2023. N= 156, 150, 174, 162, and 167 pots for each survey, respectively.**

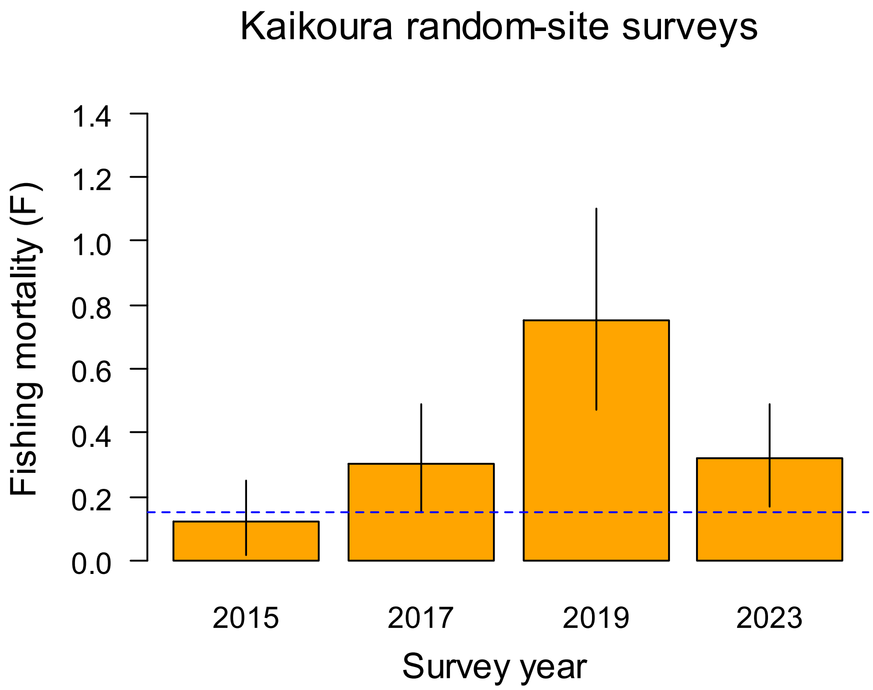


**Figure 21:** **Fishing mortality (*F*) for male blue cod from the 2015, 2017, 2019, and 2023 Kaikōura random-site potting surveys with error bars representing 95% confidence intervals. Fishing mortality was estimated from Chapman Robson total mortality (*Z*), where natural mortality (*M*) was 0.17, and the age at recruitment was the age at which males reach the minimum legal size of 33 cm plus one year (i.e., 7 years of age). The dashed blue horizontal line represents the *F* target reference point of 0.15. Plot data are also tabulated in Table 10.**

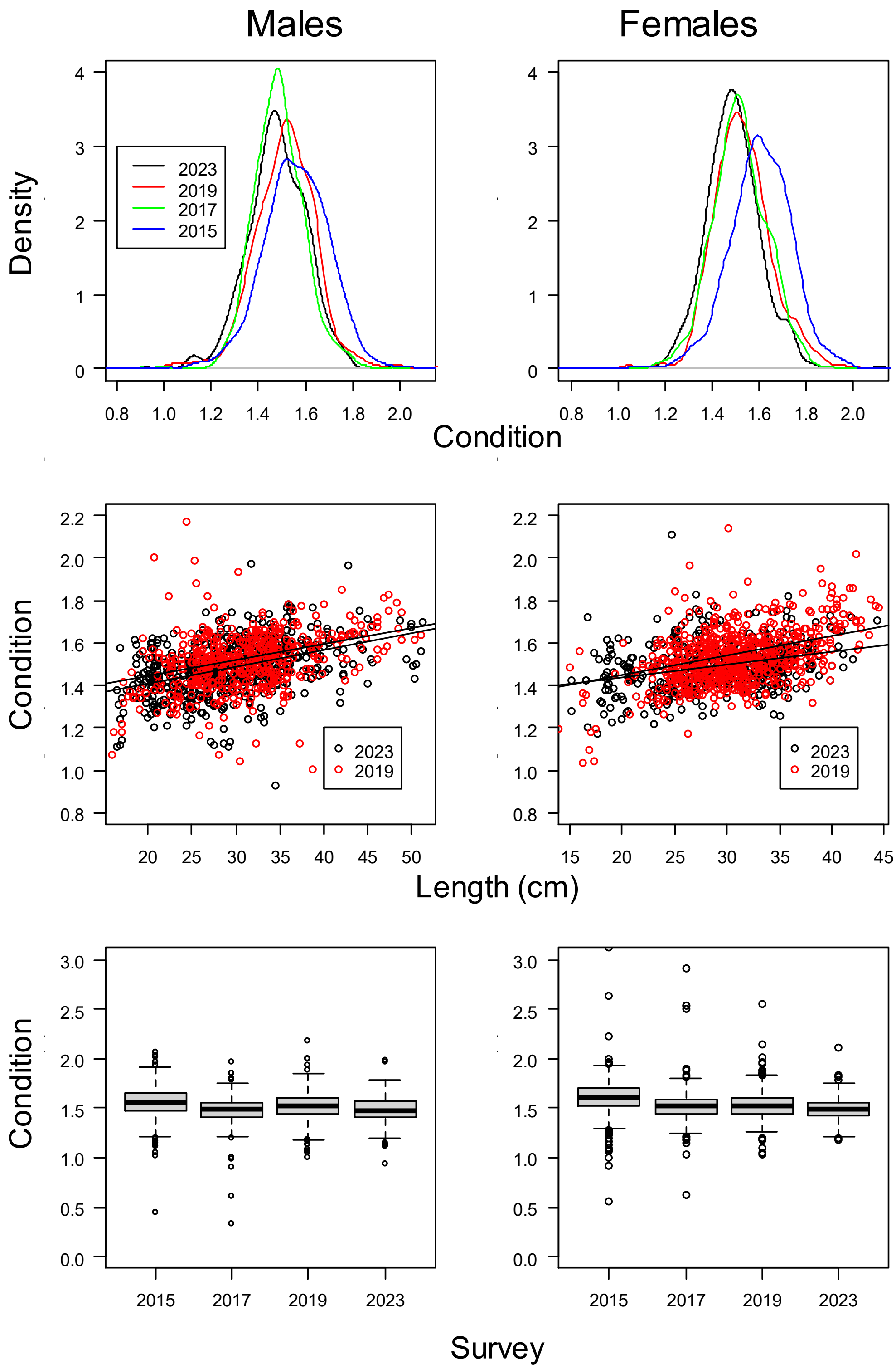


**Figure 22: Condition factor (*K*) of blue cod by sex from the Kaikōura random-site potting surveys in 2015, 2017, 2019, and 2023, including density plots of condition (top), scatter plots of condition by length for 2019 and 2023 surveys (centre), and median box and whisker plots of condition for all four surveys (bottom). $K = wt \times 100/l^b$, where $wt$ = weight (g), $l$=length (cm), and $b$ = 3. The lines passing through the scatter plots are linear regression fits to the data. The marine reserve fish are not included in these plots for 2017, 2019 and 2023.**

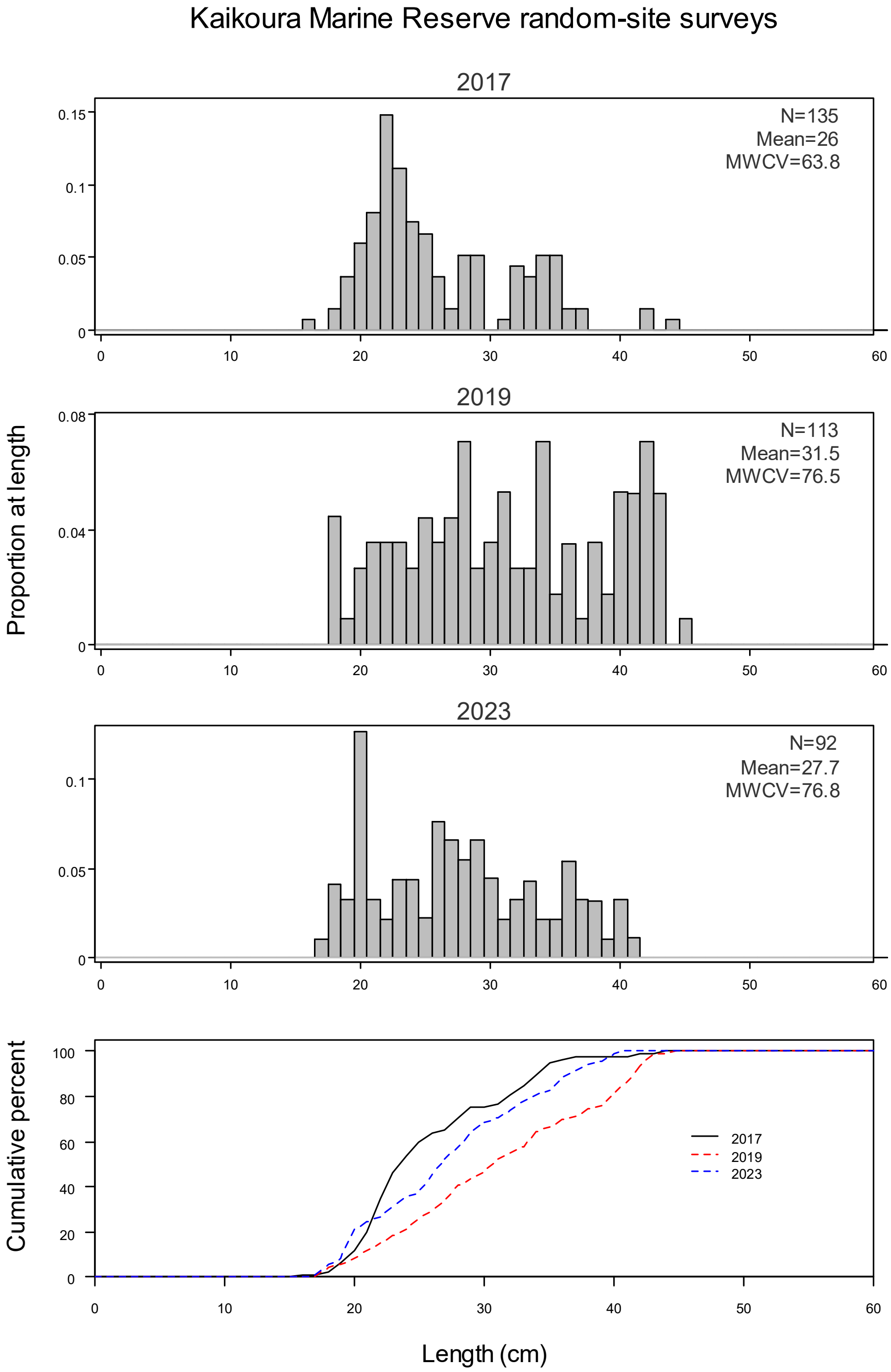


**Figure 23: Scaled length frequency and cumulative distributions for unsexed blue cod from Kaikōura 2017, 2019, and 2023 random-site blue cod potting surveys of the Hikurangi Marine Reserve. N, sample numbers; Mean, mean length (cm); MWCV, mean weighted coefficient of variation, %.**

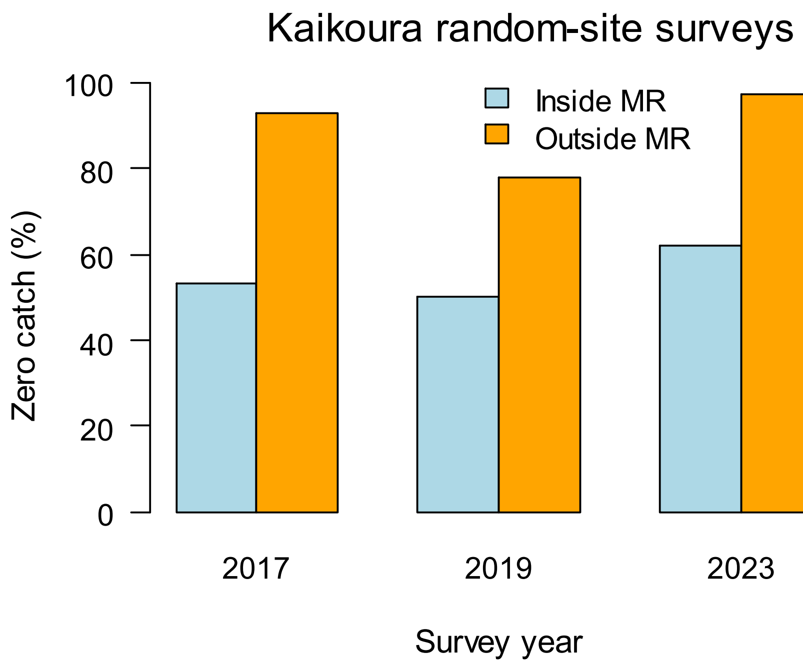


**Figure 24: Proportion of pots with zero blue cod catch from random-site potting surveys inside and outside the Hikurangi Marine Reserve (MR) in 2017, 2019, and 2023. Outside includes contiguous strata 2A and 2B. N = 30 and 42 pots, respectively, in 2017; 30 and 36 pots in 2019; and 29 and 36 pots in 2023.**

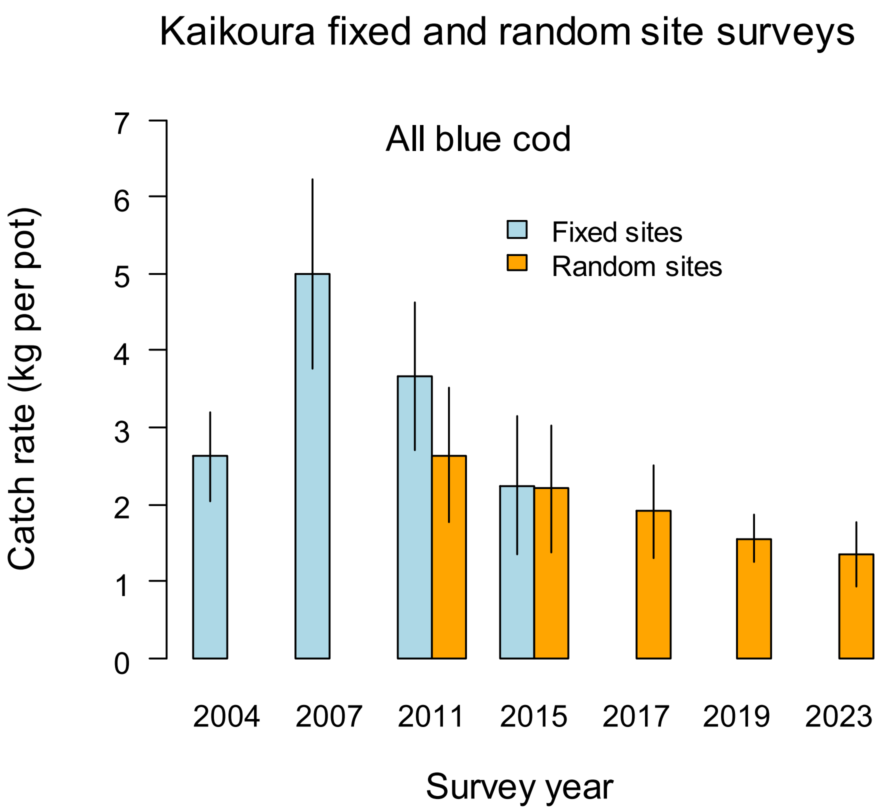


**Figure 25: Catch rates (kg $pot^{-1}$) of all blue cod for the Kaikōura fixed-site and random-site potting surveys. Error bars are 95% confidence intervals. Strata 2A and 2B are combined to allow comparison between years.**

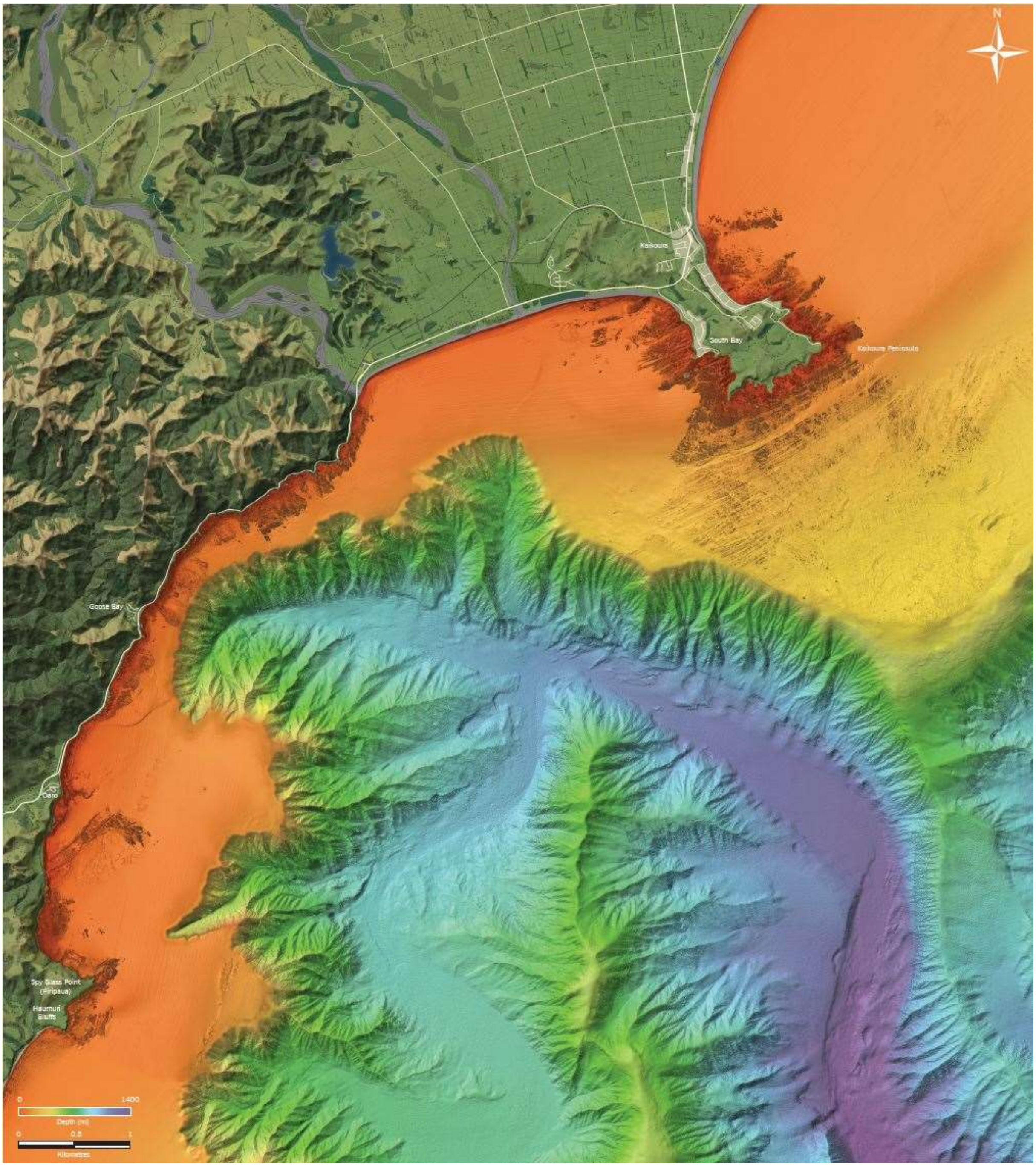


**Figure 26: Map of the Kaikōura coast seafloor from the multibeam echosounder survey in 2017 and 2018 (map from Neil et al. 2018).**

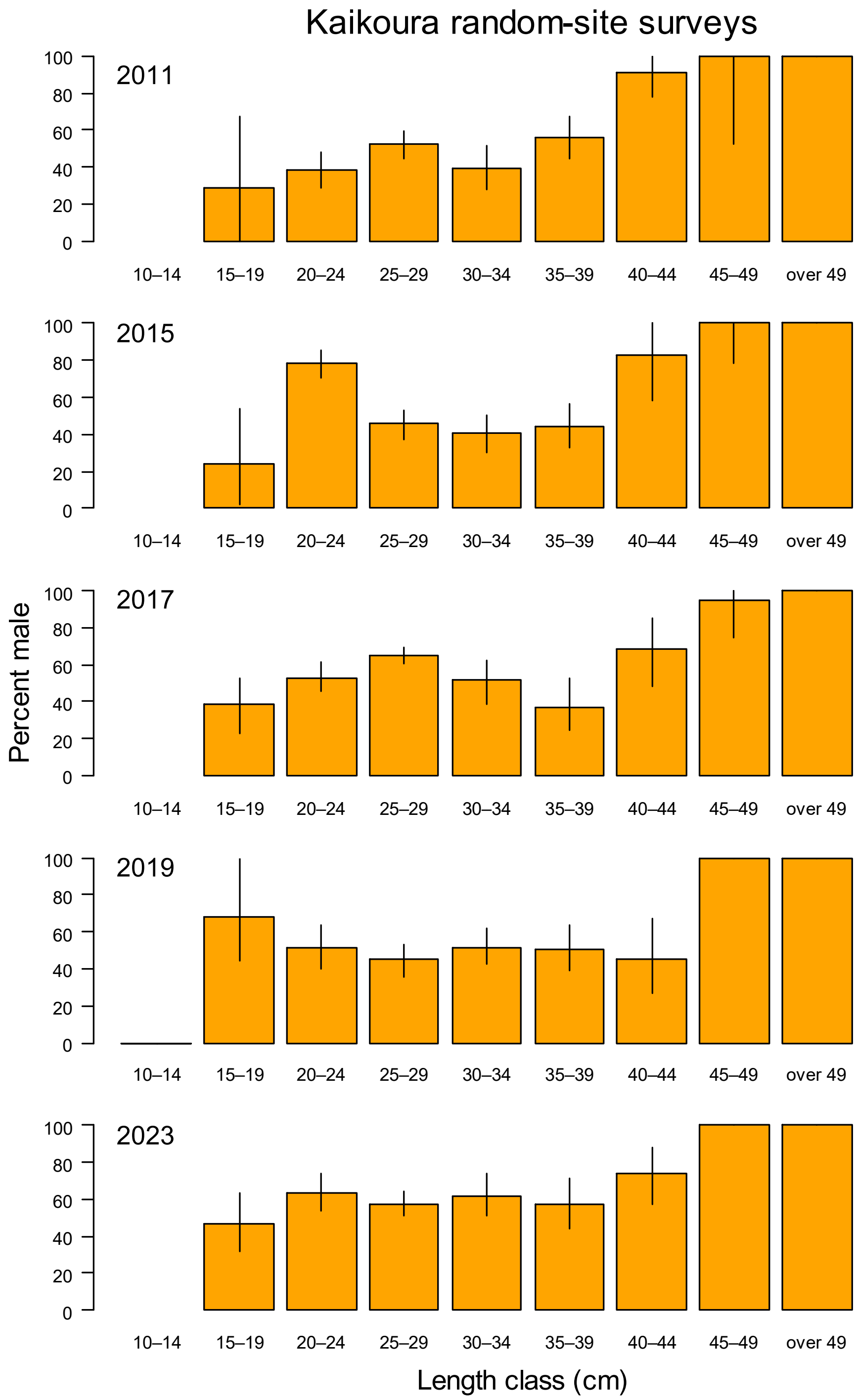


**Figure 27: Blue cod sex ratio (percent male) by 5 cm length classes and over 49 cm, for the 2011, 2015, 2017, 2019, and 2023 Kaikōura random-site potting surveys. The errors bars are 95% confidence intervals.**

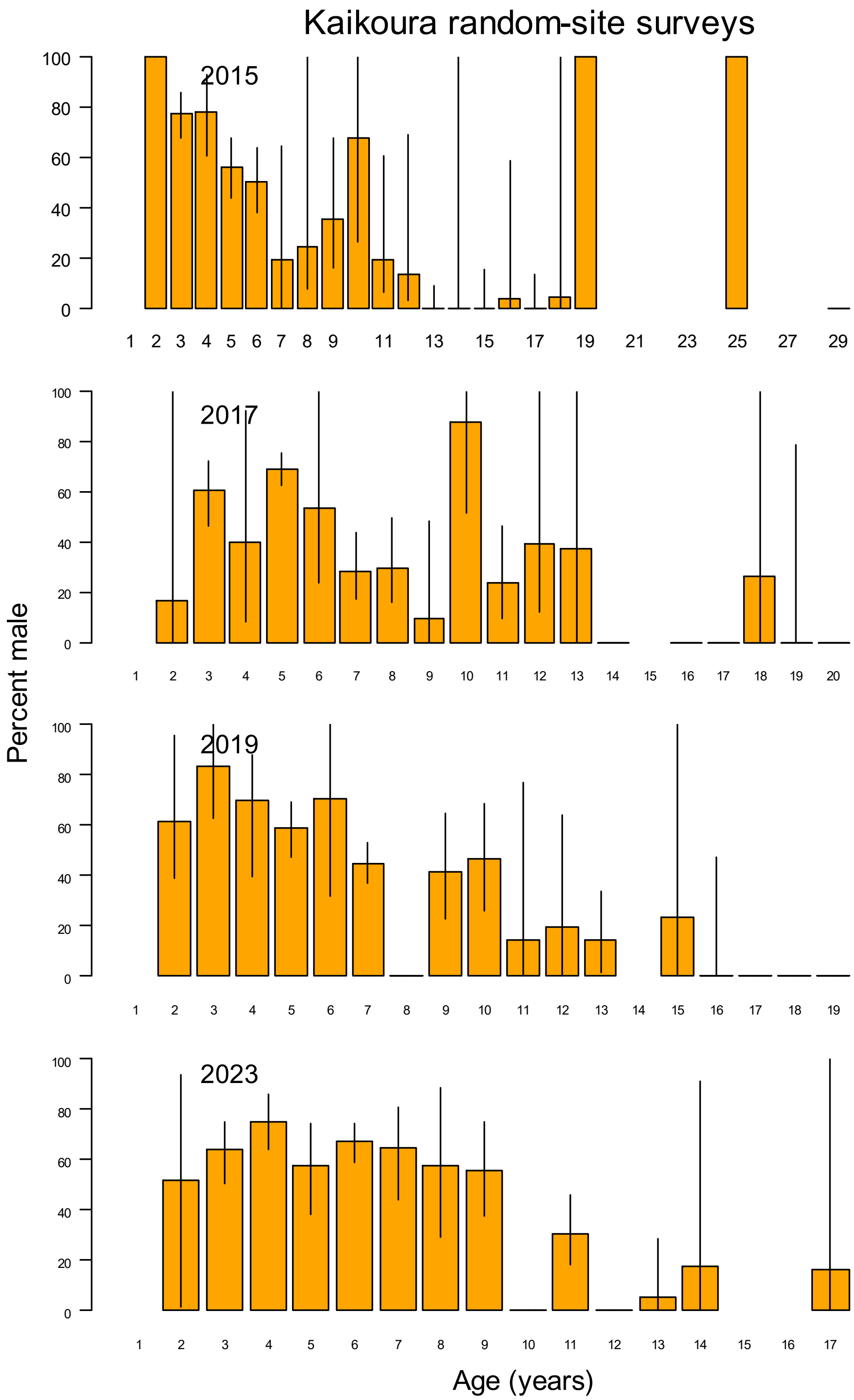


**Figure 28: Blue cod sex ratio (percent male) by age class for the 2015, 2017, 2019, and 2023 Kaikōura random-site potting surveys. The errors bars are 95% confidence intervals.**

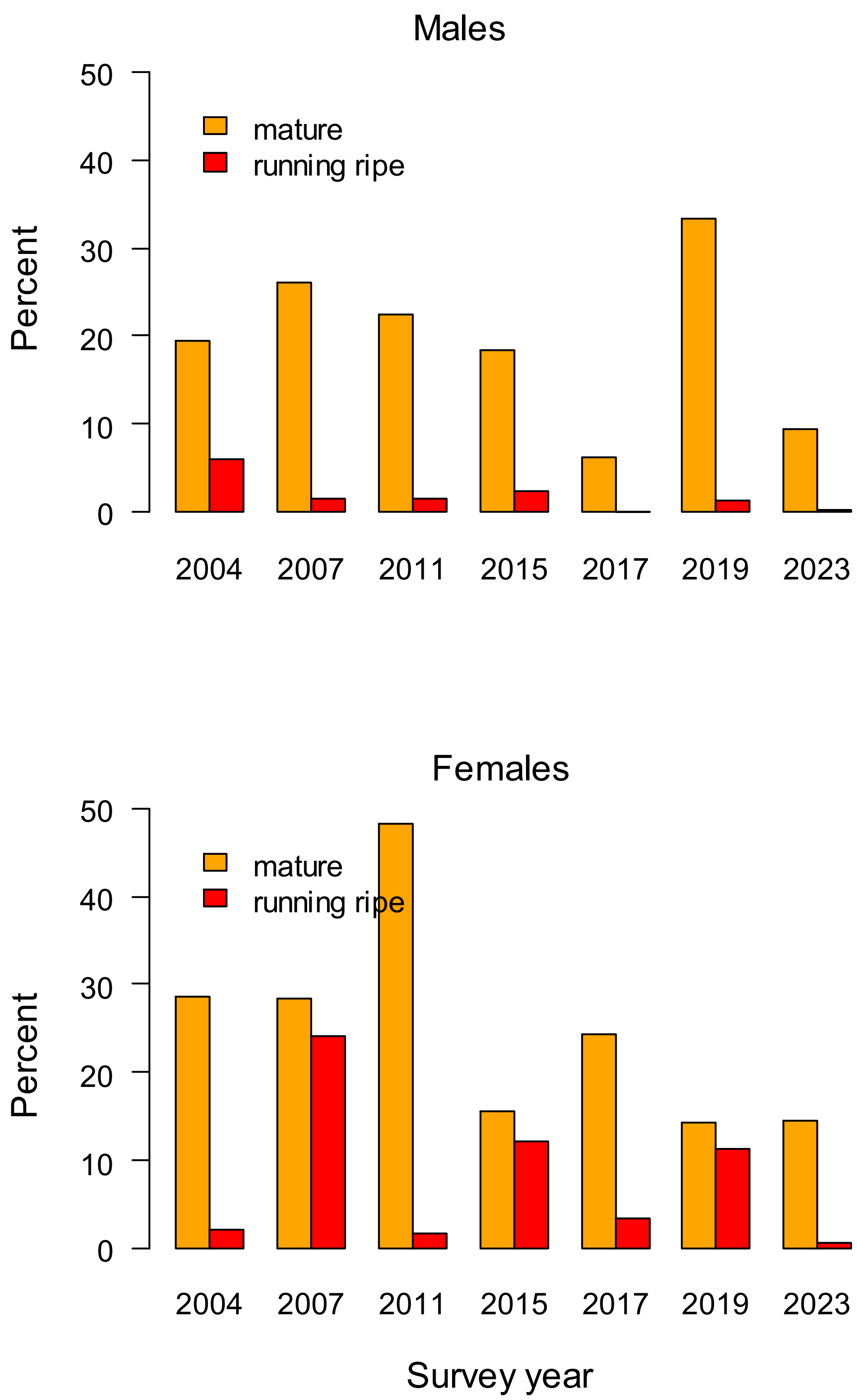


**Figure 29: Percent of blue cod in the mature or running-ripe reproductive condition from Kaikōura blue cod potting surveys (all data combined for fixed- and random-site surveys in 2011 and 2015). Proportions of the other three gonad stages are not shown, i.e., resting/immature, maturing, and spent.**

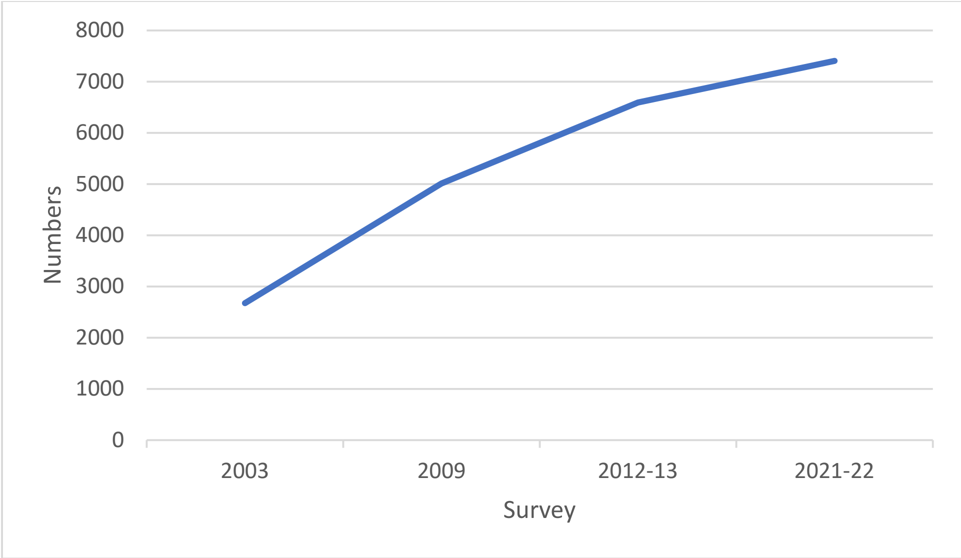


**Figure 30: Recreational fishery survey blue cod harvest estimates in numbers by the Kaikōura private-vessels recreational fishery. Surveys were conducted in 2003, 2009, 2012–13 and 2021–22. (data from Maggs et al. 2023, restricted to January-April.).**

# 9. APPENDICES

**Appendix 1: Blue cod potting survey details. Fisheries New Zealand blue cod potting surveys carried out for nine South Island recreational fisheries. See Appendix 2 for definitions of fixed-site and random-site surveys, and directed and systematic pot placement.**

| Survey area | Survey year | Survey design type | Pot placement | References |
|---|---|---|---|---|
| | | | | |
| Marlborough Sounds | 1995, 1996, 2001, 2004, 2007, 2008 | Fixed-site | Directed | (Blackwell 1997, 1998, 2002, 2005, 2008) |
| | 2010 | Fixed- and partial random-site | Directed and systematic | (Beentjes & Carbines 2012) |
| | 2013 | Fixed- and random-site | Directed and systematic | (Beentjes et al. 2017) |
| | 2017 | Fixed- and random-site | Directed and systematic | (Beentjes et al. 2018) |
| | 2021 | Random-site | Systematic | (Beentjes et al. 2022b) |
| Kaikōura | 2004, 2007 | Fixed-site | Directed | (Carbines & Beentjes 2006a, 2009) |
| | 2011, 2015 | Fixed- and random-site | Directed and systematic | (Carbines & Haist 2012, Beentjes & Page 2017) |
| | 2017, 2019, 2023 | Random-site | Systematic | (Beentjes & Page 2018) (Beentjes & Page 2021), 2023 this report |
| Motunau | 2005, 2008 | Fixed-site | Directed | (Carbines & Beentjes 2006a, 2009) |
| | 2012, 2016 | Fixed- and random-site | Directed and systematic | (Carbines & Haist 2012, Beentjes & Sutton 2017) |
| | 2020, 2024 | Random-site | Systematic | (Beentjes & Miller 2021, 2024b) |
| Banks Peninsula | 2002, 2005, 2008 | Fixed-site | Directed | (Beentjes & Carbines 2003, 2006, 2009) |
| | 2012 | Fixed- and random-site | Directed and systematic | (Carbines & Haist 2017b) |
| | 2016 | Fixed- and random-site | Directed and systematic | (Beentjes & Fenwick 2017) |
| | 2021 | Random-site | Systematic | (Beentjes et al. 2022a) |
| North Otago | 2005, 2009 | Fixed-site | Directed | (Carbines & Beentjes 2006b, 2011b) |
| | 2013, 2018 | Fixed- and random-site | Directed and systematic | (Carbines & Haist 2018b, Beentjes & Fenwick 2019a) |
| | 2022 | Random-site | Systematic | (Beentjes & Fenwick 2023a) |
| South Otago | 2010 | Fixed- and random-site | Directed and systematic | (Beentjes & Carbines 2011) |
| | 2013, 2018, 2022 | Random-site | Systematic | (Carbines & Haist 2018c, Beentjes & Fenwick 2019b, 2023b) |
| Foveaux Strait | 2010, 2014, 2018, 2023 | Random-site | Systematic | (Carbines & Beentjes 2012, Carbines & Haist 2017a, Beentjes et al. 2019, Beentjes & Miller 2024a) |
| Paterson Inlet | 2006 | Fixed-site | Directed | (Carbines 2007) |
| | 2010, 2014 | Fixed- and random-site | Directed and systematic | (Carbines & Haist 2014, 2018a) |
| | 2018 | Random-site | Systematic | (Beentjes & Miller 2020) |
| Dusky Sound | 2002, 2008 | Fixed-site | Directed | (Carbines & Beentjes 2003, 2011a) |
| | 2014 | Fixed- and random-site | Directed and systematic | (Beentjes & Page 2016) |

## Appendix 2: 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 3: Numbers of otoliths collected during the 2023 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 |
| 15 | | | | | | | 2 | | | | | 2 |
| 16 | 1 | | | | | 1 | 1 | | | | | 1 |
| 17 | 4 | | | | | 4 | 3 | | | | | 3 |
| 18 | 6 | | | 1 | | 7 | 5 | | | | | 5 |
| 19 | 5 | | | 3 | | 8 | 4 | | | 1 | | 5 |
| 20 | 6 | | | 4 | | 10 | 6 | | | 1 | | 7 |
| 21 | 5 | | | 4 | | 9 | 3 | | | 2 | | 5 |
| 22 | 6 | | | 4 | | 10 | 4 | | | 3 | | 7 |
| 23 | 5 | | | 4 | | 9 | 5 | | | 5 | | 10 |
| 24 | 5 | | | 4 | | 9 | 5 | | | 4 | | 9 |
| 25 | 6 | | | 4 | | 10 | 4 | | | 4 | | 8 |
| 26 | 5 | | | 3 | | 8 | 5 | | | 4 | | 9 |
| 27 | 5 | | | 4 | | 9 | 5 | | | 4 | | 9 |
| 28 | 5 | | | 4 | | 9 | 5 | | | 4 | | 9 |
| 29 | 5 | | | 4 | | 9 | 2 | | | 4 | | 6 |
| 30 | 4 | | | 3 | | 7 | 1 | | | 3 | | 4 |
| 31 | 4 | | | 5 | | 9 | 1 | | | 2 | 1 | 4 |
| 32 | 6 | | | 4 | | 10 | 3 | | | 2 | | 5 |
| 33 | 6 | | | 4 | | 10 | | | | 4 | | 4 |
| 34 | 4 | | | 4 | | 8 | 1 | | | 1 | 1 | 3 |
| 35 | 5 | | | 4 | | 9 | | | | 3 | 9 | 12 |
| 36 | 4 | | | 3 | | 7 | | | | | 11 | 11 |
| 37 | 2 | | | 2 | 1 | 5 | | | | | 10 | 10 |
| 38 | 4 | | | 2 | 2 | 8 | 1 | | | | 9 | 10 |
| 39 | 5 | | | 1 | 1 | 7 | | | | | 3 | 3 |
| 40 | 3 | | | 1 | 4 | 8 | | | | | 5 | 5 |
| 41 | 1 | | | 1 | 2 | 4 | | | | | 4 | 4 |
| 42 | 2 | | | | 4 | 6 | | | | | 1 | 1 |
| 43 | | | | 1 | 2 | 3 | | | | | | |
| 44 | 1 | | | 1 | 3 | 5 | | | | | 1 | 1 |
| 45 | | | | | 4 | 4 | | | | | | |
| 46 | | | | | | | | | | | | |
| 47 | | | | | | | | | | | | |
| 48 | | | | | 1 | 1 | | | | | | |
| 49 | | | | | 2 | 2 | | | | | | |
| 50 | | | | | 4 | 4 | | | | | | |
| 51 | | | | | 2 | 2 | | | | | | |
| Totals | 120 | 0 | 0 | 79 | 32 | 231 | 66 | 0 | 0 | 51 | 55 | 172 |