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Relative abundance, size and age structure, and stock status of blue cod off south Otago in 2022

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M.P. Beentjes,
M. Fenwick

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Fisheries Science Editor
Fisheries New Zealand
Ministry for Primary Industries
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This report describes the results of the random-site potting survey for blue cod (*Parapercis colias*) off south Otago in March–April 2022. Estimates are provided for population relative abundance, size and age structure, sex ratio, total mortality (Z), and fishing mortality (F). The 2022 potting survey was the fourth in the south Otago time series, with previous surveys in 2010, 2013, and 2018. The 2010 survey was a dual random-site and fixed-site experimental survey in three of the six strata; subsequent surveys were solely random-site surveys covering all six strata.

Forty-six random sites (6 pots per site, producing 276 pot lifts) at depths of 10–136 m from six strata were sampled in 2022. The survey mean catch rate was 1.94 kg pot^{-1} (CV 17%) for all blue cod and 1.05 kg pot^{-1} (CV 27%) for recruited blue cod (33 cm and over); 44% of pots had zero catch of blue cod. The overall weighted sex ratio was 70% male. Otolith thin section ages from 478 males and 256 females were used to estimate the age structure of the survey catch. The overall weighted mean length was 26.6 cm (range 11–57 cm) for males and 23.1 cm (range 11–50 cm) for females, and weighted mean age was 4.2 years (1–25 years) for males and 4.1 years for females (1–29 years). The estimated population age distributions had strong modes at four, seven, and nine years for males, and four and seven years for females. The age distributions also exhibited weak modes for six- and eight-year-olds for males, and six-year-olds for females. There was little indication of spawning activity during the survey period with 0.5% of males and 0.2% of females maturing or running ripe; 20% of males were spent, suggesting that spawning had peaked prior to the survey.

Survey abundance (total blue cod mean catch rate) from the last three random-site surveys (2013, 2018, and 2022) when all six strata were surveyed, declined four-fold between the 2013 and 2018 and was statistically significant (t-test, $p < 0.0001$). There was no statistically significant change in abundance between 2018 and 2022. The length distributions were broadly similar across the three years, especially females, although the 2013 survey had proportionately more large, recruited fish and a very strong pre-recruit mode. The proportion of pots with zero catch for the three random-site surveys ranged from 34 to 56%, peaking in 2018, but with no long-term trend, and the sex ratios were 57–70% male for all blue cod and 75–88% male for recruited blue cod, with no clear trend. The age distributions display clear evidence of highly variable recruitment, with intermittent strong and weak year classes progressing through the fishery between 2018 and 2022.

Estimated total mortality (Z) for males for age-at-full recruitment of 7 years was 0.45 (95% confidence interval 0.30–0.63). Based on the default natural mortality (M = 0.17), male F was 0.28 (95% confidence intervals 0.13–0.47), which is nearly two times higher than the target reference point of F=0.15 (F=0.87M) indicating that overfishing is occurring.

[1] Both authors: National Institute of Water and Atmospheric Research (NIWA), New Zealand.

1. INTRODUCTION

This report describes the random-site potting survey of blue cod (*Parapercis colias*) off south Otago in March–April 2022. This is the fourth potting survey of blue cod off south Otago: a dual fixed and random-site experimental survey was carried out in 2010, and solely random-site surveys were conducted in 2013 and 2018 (Beentjes & Carbines 2011, Carbines & Haist 2014b, Beentjes & Fenwick 2019b).

1.1 South Otago blue cod fishery

Blue cod is the third most common recreational finfish species caught in New Zealand with a total catch of 292 t (nearly 600 000 fish) estimated during the 2017–18 national panel survey involving face-to-face interviews with fishers (Wynne-Jones et al. 2019). Blue cod can be caught in a few metres to about 150 m depth, in a diverse range of habitats, including reef edges, shingle/gravel, biogenic reefs, or sandy bottoms close to rocky outcrops. The BCO 3 Quota Management Area (QMA) extends from the Clarence River, north of Kaikōura, to Slope Point in Southland (Figure 1). In BCO 3, recreational annual take was estimated at 98 t (Wynne-Jones et al. 2019), the highest of any QMA and 33% of the total national recreational blue cod catch. There are no reliable data to determine how the recreational blue cod catch was distributed within BCO 3; however, north and south Otago are becoming increasingly popular with recreational fishers as they offer relatively high catches and bag limits of 10 and 15 blue cod, respectively, compared with only two fish per day off the Canterbury area.

The area from Taiaroa Heads to Sand Hill Point, just west of Te Waewae Bay (out to 12 nautical miles) and known as the 'Southern Area,' was assigned a 'traffic light' colour of green on 1 July 2020 by Fisheries New Zealand as part of the National Blue Cod Management Plan. Within areas designated as green, the daily bag limit (DBL) is 15 blue cod and the minimum legal size (MLS) is 33 cm, as is the MLS throughout the South Island. A green sustainability rating indicates that the fishing pressure on blue cod stocks in south Otago is considered to be more sustainable than in the bordering orange areas of north Otago and Westland (DBL = 10), or the Tasman and Canterbury areas (DBL = 2), which are designated red areas.

The mean commercial catch from BCO 3 over the last 10 fishing years, up to 2020–21, was 172 t, 76% higher than the most recent estimated annual recreational catch of 98 t (Wynne-Jones et al. 2019, Fisheries New Zealand 2022). About three-quarters of all commercially landed blue cod in BCO 3 is caught by potting and 20% is caught by bottom trawling. The bulk of the commercial potting catch was from north Otago (Statistical Area 024), with much smaller amounts from south Otago (Statistical Area 026) and, until the late 1990s, from Kaikōura Statistical Area 018 (Figure 1) (Holmes et al. 2022). Electronic reporting system (ERS) data show that blue cod off south Otago are caught offshore by commercial fishers from about 30 to 80 m depth, mostly between Otago Peninsula and the Clutha River Mouth (pers. comm., Tony Brett, Fisheries New Zealand), presumably associated with optimal blue cod habitat. There is a clear overlap between the spatial pattern of commercial fishing and the blue cod research survey strata. The two main access points for recreational fishers in south Otago are Port Chalmers and Taieri Mouth, which are about 50 km apart and have permanent boat ramps (Figure 2). Access elsewhere is by launching from beaches.

1.2 South Otago bathymetry and substrate

The continental shelf off the south Otago coast is about 40 km wide but narrows to about 12 km off Otago Peninsula where it is incised by six relict canyons (Taieri, Hoopers, Saunders, Papanui, Taiaroa, and Karitane canyons) (Carter et al. 1985) (Figure 2). The main hydraulic feature is the warm saline Southland Current which originates from the Tasman Sea and travels through Foveaux Strait, north-eastward along the continental shelf of the southern South Island (Carter et al. 1985). The Southland current is centred around 100 m depth off Otago with cooler neritic water inshore and the cold, less saline, sub-Antarctic water offshore of the slope. A frame-building bryozoan community forms a discrete band, 25 km in length, off the Otago Peninsula in 75 to 110 m depths (Batson & Probert 2000) (Figure 2). This area is thought to be important as habitat for invertebrate species and nursery grounds for commercially important finfish and shellfish, including juvenile blue cod (Batson 2000).

The south Otago coast has considerable areas of foul ground compared with other parts of the New Zealand coastline, and trawling is limited to discrete areas between areas of foul. South Otago has substantial blue cod habitat, such as biogenic reefs, both inshore and offshore, across a relatively flat sloping shelf, but also includes the heads of several canyons that form part of the Otago Canyon Complex. The survey area lies on the inner and mid continental shelf, which slopes gently away to the east, but also includes the heads of Saunders Canyon, and to a lesser extent Papanui Canyon, which form at about 200 m (Figure 2).

The sediments off south Otago have a mix of sand, gravel, and rock areas, distributed in patches, with rock dominating inshore strata 1 and 2 (Figure 3). Stratum 3, at the head of Saunders Canyon, is predominantly sand with some gravel. There is no mud substrate within the survey area.

1.3 South Island blue cod potting surveys

South Island recreational blue cod fisheries are monitored by Fisheries New Zealand using potting surveys. These surveys are located in the most important blue cod recreational fishery areas, although there is substantial overlap between the commercial and recreational fishing grounds for some surveys, i.e., Foveaux Strait, north and south Otago. Surveys are generally carried out every four years to monitor local relative abundance, size, age, and sex structure of geographically separate blue cod populations supporting important recreational fisheries. 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 south Otago, there are currently eight other key recreational South Island fisheries surveyed: Marlborough Sounds, Kaikōura, Motunau, Banks Peninsula, north Otago, Paterson Inlet, Foveaux Strait, 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 solely fixed-site design (Appendix 2) with predetermined (fixed) locations randomly selected from a limited pool of such sites (Beentjes & Francis 2011, Beentjes 2019). Fixed sites represent ‘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 that recommended blue cod would be more appropriately surveyed using random-site potting surveys (Stephenson et al. 2009). A random site is a location (single latitude and longitude) generated randomly 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.

Previous south Otago surveys were carried out in 2010, 2013, and 2018 (Beentjes & Carbines 2011, Carbines & Haist 2018c, Beentjes & Fenwick 2019b). The first survey used both fixed and random sites and compared directed and systematic pot placement at each site type, whereas all subsequent surveys were solely random-site surveys with systematic plot placement (Table 1).

1.4 Stock status of south Otago blue cod

Tagging experiments indicate that blue cod have a restricted home range (Rapson 1956, Mace & Johnston 1983, Mutch 1983, Carbines & McKenzie 2001, Carbines & McKenzie 2004) and that stocks of this species are likely to consist of many largely independent sub-populations (Carbines 2004). This suggests that blue cod are susceptible to localised and serial depletion. However, blue cod are not genetically distinct around the New Zealand mainland (Gebbie 2014), indicating that some genetic mixing is occurring on a wider geographical scale than within the restricted home range indicated by tagging studies.

Monitoring the sex ratio of these cod populations is particularly important because blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow, with the largest fish in the populations being invariably males (Carbines 2004). In heavily fished blue cod populations, sex ratios strongly skewed towards males are often observed (Beentjes & Carbines 2009, Beentjes 2021, Beentjes & Miller 2021, Beentjes et al. 2022a). This is thought to result from the removal of the inhibitory effect of large males and a consequently higher rate (and possibly earlier onset) of sex change by primary females (Beentjes & Carbines 2005, Beentjes 2021).

Previously, the standard method of assessing the stock status of blue cod throughout 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 B_{MSY} (maximum sustainable yield biomass) (Beentjes & Fenwick 2019b, Fisheries New Zealand 2022). 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 2022). The Plenary also recommended F=0.87M (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 are 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 2022 south Otago survey results to the Inshore Finfish Working Group (17 April 2022), and based on the same rationale applied to the 2021 Marlborough Sounds and 2022 north Otago surveys (Beentjes et al. 2022b, Beentjes & Fenwick 2023), the working group agreed that SPR is also no longer appropriate as a target reference point for south Otago blue cod. Hence SPR analyses for the 2022 south Otago survey are not presented in this report; instead, F of males was compared with the target reference point of F=0.87M.

1.5 Objectives

This report fulfils the final reporting requirement for Fisheries New Zealand research project BCO2021-02.

Overall Objective

To estimate relative abundance, maturity state, sex ratio, and age structure of blue cod (*Parapercis colias*) between Otago Peninsula and the Catlins.

Specific objectives

1. To undertake a potting survey between Otago Peninsula and the Catlins (BCO 3) to estimate relative abundance, age structure, size- and age-at-maturity, and sex ratio and to collect otoliths from pre-recruited and recruited blue cod.
2. To analyse biological samples collected from the potting survey.
3. To determine stock status of blue cod populations in this area and compare to other survey areas.

2. METHODS

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

2.1 2022 survey timing and area

A two-phase random stratified potting survey off south Otago was carried out by the National Institute of Water and Atmospheric Research Ltd (NIWA) from 23 March to 28 April 2022, the timing of which was consistent with previous surveys (Table 1).

The survey area and six strata for the 2022 south Otago random-site survey were identical to those for the 2013 and 2018 surveys (Figure 2). The 2010 survey was experimental and included only three of the six strata (strata 1, 3, and 6). Of the six strata, two are contiguous with the coast in depths less than about 30 m, three are offshore between Otago Peninsula and the Clutha River Mouth in depths from about 30 to 70 m, and one is a deeper, isolated stratum in depths of 100–200 m, directly east of Otago Peninsula, on the edge of Saunders Canyon (Figure 2). These strata were defined after discussions with local recreational and commercial fishers in 2009 and are assumed to be areas where blue cod were most abundant and where they have historically been targeted. Each stratum was assumed to contain roughly random distributions of blue cod habitat and the total area (in square kilometres) within each stratum was taken as a proxy for available habitat for blue cod. Strata were defined before seabed substrate sediment maps were available (Figure 3).

2.2 Allocation of sites

Simulations using NIWA's Optimal Station Allocation Program (*allocate*, Francis 2006) were carried out using catch rates from the 2013 and 2018 random-site surveys to determine the optimal allocation of sites among the 6 strata. Simulations were constrained to have a minimum of three sites per stratum and a coefficient of variation (CV) of no greater than 20%. The simulations informed the allocation within strata and indicated that 46 random sites were required to achieve a CV of 20%.

The 2022 random-site survey used a two-phase stratified random station design (Francis 1984) with 41 sites allocated to phase 1 and the remaining five available for phase 2 (11% of total sites) (Table 2), consistent with the proportion of phase 2 sites used in 2013 and 2018.

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 was greatest, where expected gain is given by:

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

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

Sufficient sites to cover both first and second phase stations were generated for each stratum using the NIWA random station generator program (*Rand_stn* v1.00-2014-07-21) with the constraint that sites were at least 800 m apart. From this list, the allocated number of random sites per stratum to be surveyed was selected in the order they were generated.

Pot configuration and placement for random sites is defined in the blue cod potting manual (Beentjes & Francis 2011, Beentjes 2019). The 2022 random-site surveys in south Otago used systematic pot placement, where the position of each pot was arranged systematically, with the first pot set 200 m to the north of the site location and remaining pots set in a hexagon pattern around the site, at about 200 m from the site position.

2.3 Vessels and gear

As in 2018, the 2022 survey was carried out using the F.V. *Chivalair* (registration number 901254) owned and skippered by Mr. John Pile who has considerable experience in commercial blue cod potting in this area (Table 1). The *Chivalair* is a 13 m length fibreglass monohull, powered by a 500 hp Volvo Penta engine with propeller propulsion designed for rock lobster and blue cod potting. The survey operated out of Port Chalmers and Taieri Mouth ports for northern and southern sites, respectively. Taieri Mouth port is only navigable at mid to high tide because of the dynamic sand bar at the river mouth.

Six custom designed and built cod pots were used to conduct the survey (Pot Plan 2: specifications given by Beentjes 2019). Pots were baited with 700 g of pāua viscera in 'snifter pottles' and replaced after every lift. The same pot design and bait were used in all previous south Otago blue cod potting 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.

2.4 Sampling methods

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

At each site, six pots were set and left to fish (soak) for a target period of one hour during daylight hours. As each pot was placed, a record was made of sequential pot number (1 to 6), latitude and longitude from GPS, depth, and time of day. After each site was completed, the next closest site in the stratum was sampled. The order that strata were surveyed depended on the prevailing weather conditions and, for southern sites, access to Taieri Mouth port across the sand bar. The most distant or offshore strata and sites tended to be sampled in calm weather. 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. After 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; and surface water 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 were 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 millimetre, 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, five otoliths per 1 cm size class for each sex were targeted across the survey, except in stratum 3, where all otoliths were taken (Appendix 3). To ensure that adequate numbers of large and small fish and females were included, additional otoliths were collected from all blue cod under 20 cm, all males over 40 cm, and all females over 35 cm.

Sex and maturity of blue cod 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.

2.5 Data storage

The 2022 south Otago survey trip code was CHV2201. At the completion of the survey, trip, station, catch, and biological data were entered into the *trawl* database in accordance with the business rules and the blue cod potting survey standards and specifications (Beentjes 2019). All catch rate and length- and sex-based analyses were carried out from data extracted from the *trawl* database. Catch-at-age analyses were based on the ageing results provided by the otolith readers. At the completion of the catch-at-age analyses, after any possible errors in the age and length data were identified and corrected, age data were entered into the *age* database. Random sites were entered into attribute *stn_code*, prefixed with R (e.g., R1A, R2B); the numerical character identifies the stratum and the alpha character the site. 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). The *sample_no* in the *age* database is equivalent to *station_no* in the *trawl* database.

ADCP data containing current speed and direction were sent to the 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).

2.6 Age estimates

Otolith preparation and reading

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

1. Blue cod otolith thin-section preparations were made as follows: otoliths were individually marked on their distal faces with a dot in the centrum using a cold light source on low power to light the otolith from behind. Five otoliths (from five different fish) were then embedded in an epoxy resin mould and cured at 50 °C. Thin sections were taken along the otolith dorso-ventral axis through the centrum of all five otoliths using a Struers Accutom-50 digital sectioning machine, with a section thickness of approximately 350 µm. Resulting thin section wafers were cleaned and embedded on microscope slides using epoxy resin and covered with a coverslip. Finally, these slides were oven cured at 50 °C.
2. Otolith sections were read against a black background using reflected light under a compound microscope at a magnification of 40–100 times. Under reflected light, opaque zones appear light and translucent zones 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 IAPE (Index of Average Percent Error) and coefficient of variation.

2.7 Data analyses

Analyses of catch rates, sex ratios, scaled length distribution, catch-at-age, and *Z* and *F* estimates (males only), were carried out and are presented for the 2022 south Otago random-site survey.

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

2.7.1 Catch rates

The catch rate (kg pot^{-1}) estimates were pot-based and the CV estimates were set-based (Beentjes & Francis 2011). Catch rates were scaled by the area and number of sets and pots in a stratum, where 6 pots were used on all sets. 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 (33 cm and over) were based on the sum of the weights of individual recruited fish, of which, all were weighed on the 2022 survey. The stratum areas (square kilometres) shown in Table 2 were used as the area of the stratum (A_t) when scaling catch rates (equations 3 and 5 of Beentjes (2019)). Catch rates are presented by stratum and overall.

2.7.2 Length-weight parameters

The length-weight parameters, a_k and b_k, from the 2022 south Otago random-site survey were calculated from the coefficients of sex-specific linear regressions of log-transformed weight on log-transformed length using all fish for which length, weight, and sex were recorded, where b_k is the slope of the regression line, and log(a_k) is its *y*-intercept. The following equation:

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

calculates the expected weight (g) for a fish of sex *k* and length *l* (cm) in the survey catch.

2.7.3 Growth parameters

Separate von Bertalanffy growth models (von Bertalanffy 1938) were fitted to the 2022 south Otago survey length-age data by sex as follows:

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

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

2.7.4 Scaled length and age frequencies

Length and age compositions were estimated using the NIWA program *Catch-at-Age* (Bull & Dunn 2002). The program scales the length frequency data by the area of the stratum, number of sets in each stratum, and estimated catch weight determined from the length-weight relationship of individual fish. The latter scaling should be negligible or very close to one if all fish caught during the survey were measured (which they were) and if the actual weight of the catch is close to the estimated weight of the catch. The stratum areas are given in Table 2 and the sex-specific length-weight parameters were estimated from the 2022 south Otago survey.

Length and age frequencies were calculated as numbers of fish from equations 7, 8, and 9 of Beentjes (2019). The length and age frequencies in this report are expressed as proportions by dividing by total numbers.

Bootstrap resampling (300 bootstraps) was used to calculate the CV for proportions- and numbers-at-length and -age using equation 12 of Beentjes (2019). That is, simulated data sets were created by resampling (with replacement) sets from each stratum, fish from each set (for length and sex information), and fish from the age-length-sex data that were used to construct the age-length key.

Catch-at-age was estimated using an age-length-key (ALK) for each sex applied to the length data from the entire survey area. Scaled length and age frequency proportions are presented with CVs for each length and age class and the mean weighted coefficients of variation (MWCV).

2.7.5 Sex ratios, mean length, and mean age

Sex ratios (expressed as percentage male) and mean lengths were calculated for the stratum and survey using equations 10 and 11 of Beentjes (2019) from the stratum or survey scaled length frequencies. Mean ages were calculated analogously from the scaled age frequencies. Sex ratios were also estimated for recruited blue cod (33 cm and over) and overall survey 95% confidence intervals around sex ratios were generated from the 300 length frequency bootstraps.

2.7.6 Total mortality estimates

Total mortality (Z) was estimated from a 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, but usually provides a higher Z value, as it excludes age classes with few fish (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 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 using only male ages and a Z estimate was output for males only. 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). 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 was fitted to the descending curve from age-at-full recruitment. Although the Z estimate from the traditional catch curve was not used, it provides a diagnostic tool to investigate how well Z is being estimated. This is particularly important when there are not many age classes, and there is potential for strong or weak year classes to introduce bias.

2.7.7 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). The exponent '3' in Fulton's equation was replaced with the length-weight coefficient (b) for males and females from the survey (Bolger & Connolly 1989).

2.7.8 Analyses of previous south Otago surveys

The 2010 and 2013 south Otago surveys were re-analysed as part of the 2018 survey report (Beentjes & Fenwick 2019b) to ensure consistency and compliance with the analytical methods in the potting manual (Beentjes & Francis 2011, Beentjes 2019); analyses used only survey data extracted from the Fisheries New Zealand *trawl* database. Catch rates of recruited blue cod were based on the sum of the weights of individual fish 30 cm and over (MLS in 2018), estimated from the published length-weight coefficients of the respective 2010 and 2013 surveys (Beentjes & Carbines 2011, Carbines & Haist 2018c). Catch rates of recruited fish in the 2010, 2013, and 2018 surveys were again updated in the current survey analyses for fish 33 cm and over (MLS in 2023) to allow comparison across the time series. No ageing analyses were carried out for the 2010 and 2013 surveys because, although blue cod otoliths were collected and aged from these surveys, ageing was not compliant with the ADP for blue cod (Walsh 2017) and therefore ages cannot be assumed to be accurate.

3. RESULTS

3.1 2022 random-site survey

3.1.1 Sites surveyed and catch

Forty-six random sites (6 pots per site, producing 276 pot lifts) from six strata off south Otago were surveyed in March–April 2022 (Table 2, Figure 4). Depths sampled were 10–136 m (mean = 55 m). Forty-one sites were sampled in phase 1 and five in phase 2. Random-site systematic pot placement configuration is shown for a few sites in the 2022 survey (Figure 5).

A total of 711.6 kg of blue cod (1970 fish) was taken, comprising 91.5% by weight of the catch of all species on the survey (Table 3). Bycatch species included eight teleost fishes, as well as octopus, brittle star, starfish, and crab species. The most abundant teleost bycatch species, by number, were tarakihi (*Nemadactylus macropterus*) and scarlet wrasse (*Pseudolabrus miles*) (Table 3).

3.1.2 Blue cod catch rates, length, and sex ratio

Mean catch rates (kg pot^{-1}) of blue cod (all blue cod, and recruited blue cod 33 cm and over) are presented by stratum and overall for the 2022 survey (Table 4, Figure 6). Mean catch rates of blue cod (all sizes) by stratum were 0–5.56 kg pot^{-1} with the lowest catch (zero) in stratum 2 (inshore, off Taieri Mouth) and the highest catch rate in stratum 6 (offshore, south of Taieri Mouth) (Table 4, Figure 6). The overall survey catch rate was 1.94 kg pot^{-1} with a CV of 16.8%. Catch rates for recruited blue cod followed a similar pattern among strata as for all blue cod, except for stratum 4, where few recruited blue cod were caught, and the overall survey catch rate was 1.05 kg pot^{-1} (CV 27.5%) (Table 4, Figure 6). Of the 276 random-site pots, 122 (44.2%) had zero catch of blue cod.

The catch rates of blue cod by site (kg $site^{-1}$) showed that the largest individual catches were in strata 5 and 6 (Figure 7).

3.1.3 Biological and length frequency data

All 1970 blue cod caught on the survey were measured for length and weighed and all but 5 small fish (under 13 cm) were sexed (Table 5). The sex ratios were 35–84% male across the five strata that caught blue cod and the overall weighted sex ratio was 70.1% male (Table 5). Length range was 11–57 cm for males and 11–50 cm for females. Weighted mean length was 26.6 cm for males and 23.1 cm for females. The scaled length frequency distributions for strata 1–3 had few fish and were poorly defined, whereas most fish were caught in strata 4–6. The modes of the distributions were broadly similar for both sexes, but males tended to have more smaller (less than 20 cm) and larger (greater than 35 cm) fish (Figure 8).

3.1.4 Age and growth

Otolith thin-section ages from 478 males and 256 females collected from the 2022 random-site survey were used to estimate the population age structure (Table 6). The von Bertalanffy model fits indicated a large range in length-at-age, particularly for males, which grew faster than females and were the largest individuals (Figure 9). Some of the slower growing males may be secondary males, having changed sex. Most of the fish over 10 years of age are males, but the oldest fish is a female at 29 years of age (Figure 9).

The 2022 north Otago survey von Bertalanffy growth parameters (L_∞, K, t_0) for males were 56.5 cm, 0.14 yr^{-1}, -0.89 yr^{-1} and 48.9 cm, 0.12 yr^{-1}, and -1.52 yr^{-1} for females. The von Bertalanffy curves for south Otago in 2018 and 2022 were similar for females, but deviated for males over 15 years of age, likely due to too fewer older fish in 2018 (Figure 10).

Between-reader comparisons showed 96% agreement between the first counts of the two readers, with a between-reader CV of 0.62% and index of average percent error (IAPE) of 0.44% (Figure 11). These results indicated high agreement between the two readers across all ages.

The length-weight parameters from the 2022 south Otago survey were a = 0.005613 and b = 3.2788 (N = 1392, range = 11–57 cm) for males and a = 0.005319 and b = 3.3006 (N = 565, range = 11–50 cm) for females. Eight outliers were not used.

3.1.5 Spawning activity

Gonad stages of blue cod sampled on the south Otago survey in late March to late April 2022 are presented for all fish combined (Table 7). There were few indications of spawning activity during the survey period with only a few fish in the mature and running ripe condition. However 20% of males were spent, suggesting that the survey occurred after the spawning peak.

3.1.6 Length and age composition

The scaled length frequency distributions for males and females were remarkably similar in shape, being bimodal with juvenile peaks at 13 and 12 cm, and larger but less defined peaks at about 27 cm and 23 cm, respectively (Figure 12). Both length distributions were strongly skewed to the right. The overall mean lengths were 26.6 cm for males and 23.1 cm for females (Figure 12). The cumulative distribution plots for length were similar in shape between the sexes, but the female plot was steeper and to the left, reflecting the smaller size overall, with few females over 35 cm length. The mean weighted coefficients of variation (MWCVs) around the length distributions were 28% for males and 39% for females.

Age of blue cod ranged from 1–25 years for males and 1–29 years for females, with most males and females being 1–4 years old. Few males were older than 10 years of age, and few females were older than seven years of age (Figure 12). There were strong modes at four, seven, and nine years for males, and four and seven years for females. The age distributions also exhibited weak modes for six- and eight-year-olds for males and six-year-olds for females. The cumulative distribution plots of age were almost identical for both sexes until age four and the mean ages were also similar (males 4.2 years, females 4.1 years) (Figure 12**Error! Reference source not found.**). The MWCVs around the age distributions were 19% for males and 28% for females, indicating a good representation of the overall population age structure, especially for males.

3.1.7 Total mortality estimates (*Z* and *F*)

Chapman-Robson total male mortality estimates (Z) and 95% confidence intervals for the 2022 random-site survey are given for a range of recruitment ages (5–10 yr) in Table 8. 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) (see growth curve in Figure 9). The male CR Z for AgeR of seven years for south Otago in 2022 was 0.45 yr^{-1} (95% confidence interval of 0.30–0.63) (Table 8).

The traditional fitted catch curve is shown for diagnostic purposes (Figure 13). The natural log of numbers-at-age did not display the traditional shape characterised by smooth ascending and descending limbs, but had an intermediate domed portion, suggesting that the assumption of constant recruitment had been sufficiently violated to detract from the results to some degree (Figure 13). Traditional catch curve Z estimates are invariably lower than those using the CR estimation method because the latter is less sensitive to age classes with few fish (Dunn et al. 2002). The very strong and weak recruited year classes will have introduced some error (and probably bias) into the *Z* estimate, which was reflected in the wide 95% confidence intervals around *Z* (Table 8).

Male mortality parameters (CR *Z* and *F*) at three values of *M* and age at full recruitment of seven years are shown in Table 9. Based on the default *M* of 0.17, male estimated fishing mortality (*F*) was 0.28 (95% confidence intervals 0.13–0.47).

3.2 South Otago random-site surveys time series (2010, 2013, 2018, and 2022)

Mean catch rates (kg pot^{-1}) for all blue cod and recruited blue cod by stratum for the four random-site surveys are presented in Figure 14. The 2010 survey included only three of the six strata (1, 3, and 6). The pattern of catch rates in 2010 and 2013 amongst the three strata in common (1, 3, and 6) were similar, with the highest catch rates in stratum 6 and the lowest in stratum 1 (see Figure 4 for strata locations). The catch rate pattern in 2018 and 2022 changed from that in 2013, but for both surveys highest catch rates were in stratum 6. Overall, whether comparing survey catch rates from the three common strata (1, 2 and 6) or for all strata (1–6) combined, blue cod abundance (all and recruited) increased in 2013 followed by a four-fold decline in 2018 and little difference in 2022 (Figures 14 and 15). The decline was statistically significant (t-test, p = 0.001) between 2013 and 2018 random site surveys, and not significant between 2018 and 2022 (t-test, p=0.44).

To determine whether the random sites from the 2010 survey (strata 1, 3, and 6) should be compared with later surveys, the scaled length frequency distributions were compared across two groups (A, strata 1, 3, and 6; B, strata 2, 4, and 5) (Figure 16). Group B strata tended to have a higher proportion of small juvenile fish than group A strata and this was most evident in 2013. This indicates that the 2010 survey length frequency distributions should not be compared with those from subsequent random surveys without considering this spatial difference. The 2010 fixed-site survey also caught larger fish overall than the random-site survey in 2010, in the same strata (Figure 16).

The random-site scaled length frequency distribution time series from 2013 onward, when all strata were surveyed, showed broadly similar distributions across the three years, especially for females, although the 2013 survey had proportionately more large recruited fish and a very strong pre-recruit mode (Figure 17). The cumulative distribution indicates that size was smaller overall in 2022 than in earlier surveys (Figure 17). Similarly, recruited mean length was significantly larger in 2013 than 2018 for males, with no overlap in confidence intervals (Figure 18). Recruited mean length can be expected to vary between surveys depending on the strength of pre-recruited cohorts.

The sex ratio for the four random-site surveys was 57–70% male for all blue cod and 75–88% male for recruited blue cod, with no clear trend (Figure 19). The lower male sex ratio in 2013 was driven by the strong pre-recruit female cohort (see Figure 17).

The proportion of pots with zero catch for the three random-site surveys ranged from 34 to 56%, peaking in 2018, but with no long-term trend (Figure 20).

Only the 2018 and 2022 survey had valid age estimates based on the ADP. The differences in age composition and cohort progression are discussed in Section 4.4.

Condition factor (*K*) for the 2018 and 2022 south Otago random-site surveys is presented as density plots, median box and whisker plots, and scatter plots of condition on total length for each sex (Figure 21). Data from 2010 and 2013 surveys were not of sufficient quality or quantity to be included in these analyses. The 2018 and 2022 exploratory plots indicated that there were sex differences in condition and therefore sex-specific (not combined) analyses were more appropriate. Condition was more variable at smaller sizes (Figure 21), probably due to the accuracy of the scales (± 10 g), which had a relatively greater impact on small fish, but was negligible for fish over about 20 cm. The mean condition factors and standard errors are shown in Table 10. There were highly statistically significant differences (t-test $p<0.0001$) in mean condition between males and females within the surveys, and between surveys. Females had overall better condition in 2018, while males were in better condition in 2022 (Figure 21, Table 10). Condition is likely to vary depending on season with fish weighing more for a given length during the active spawning period. The 2018 and 2022 surveys occurred at the same time of year and there were negligible numbers of fish in maturing or running ripe spawning states (see Table 7), so differences cannot be ascribed to survey spawning condition.

Comparison of the 2010 fixed- and random-site surveys are summarised in Appendix 4.

4. DISCUSSION

4.1 General

The 2022 south Otago random-site potting survey was the fourth survey in the time series of relative abundance and population structure of blue cod from this area, with previous surveys in 2010, 2013, and 2018. The 2010 survey was a dual random-site and fixed-site experimental survey in only three of the current six strata, whereas the three subsequent surveys were solely random-site surveys in all six strata.

Differences in catch rates for equivalent strata between the 2010 fixed- and random-site survey suggest that there is no suitable way of quantitatively linking the fixed-site survey with the random-site time series. The random-site surveys are becoming more informative with each successive survey, particularly with the improvement in ageing following adherence to the ADP. There remains the option of re-ageing the 2013 survey, which may be informative given the strong juvenile cohort and large numbers of larger fish on this survey. The reduced strata catch-rate analyses using the 2010 strata (1, 3, and 6) and the full strata analyses both indexed the marked decline in abundance that occurred from 2013 to 2018, which was also reflected in the progressive increase in the proportion of empty pots over time (see Figures 15 and 20).

4.2 Blue cod habitat and abundance

Sediment samples (n = 30 000 stations) collected predominantly on the New Zealand continental shelf have been used to build sediment distribution maps that are now freely available online in the New Zealand Oceanographic Data Network (see Figure 3) (Bostock et al. 2019). The sediment maps of south Otago show how sand, mud, gravel, and rock are distributed within and around the six strata. Within the survey strata, substrates are patchy, with rock dominating the inshore strata (1 and 2) and a mix of sand and gravel with some rock occurring offshore (strata 4–6). The deep stratum 3 in 100–200 m is mostly sand with some gravel between Saunders Canyon and Papanui Canyon (see Figure 3).

South Otago offers substantial and varied blue cod habitat, both inshore, offshore on the mid shelf (30 to 75 m), and also in deep water out to 200 m at the head of the Saunders Canyon. The area off the south Otago coast is a highly dynamic oceanic environment with a narrow continental shelf incised with many canyons and complex water current and water mass regimes that include inshore neritic water, the fast flowing, warm, saline Southland Current, bounded offshore by cooler and less saline sub-Antarctic water (Carter et al. 1985, Chiswell 1996). The seafloor is rugged and characterised by large areas of foul ground that provide substantial and varied blue cod habitat. The stratum boundaries were originally based, to a large extent, on where blue cod were thought to be most abundant and where they were targeted. Stratum 3 is the deepest of any area surveyed for blue cod in any of the South Island surveys and demonstrates the wide depth distribution of blue cod from near shore out to 200 m.

The spatial distribution of blue cod relative catch across the 2013, 2018, and 2022 survey is similar in terms of areas of high and low catches, notwithstanding that catch rates overall were higher in 2013 and that site positions are randomly allocated within strata. Most of the largest set catches were offshore, in the south (strata 5 and 6), while sets with zero catch were mostly confined to the inshore strata or shallow parts of the offshore strata (Figure 22). ERS data show that there is a good overlap between commercial fishing effort in Statistical Areas 026 and the survey strata and the highest commercial catches are also taken in strata 5 and 6 (pers. comm., Tony Brett, Fisheries New Zealand).

The catch rate distributions in the three surveys show no clear association between habitat type and abundance (Figure 22, see Figure 3). The sediment maps, however, are only approximations based on extrapolations from the nearest historical sediment sampling stations and most likely do not fully reflect the dynamic nature of sediment shifts. A more detailed analysis of habitat type by pot location in real time is required to determine if a relationship exists between habitat type and blue cod abundance. For example, underwater video at selected sites during the 2013 south Otago potting survey showed some preference by small and large fish for specific habitats (Carbines & Haist 2018c). It is clear, however, that off the south Otago coast, blue cod occupy a broad variety of seafloor types from rock through to sand, across a wide depth range.

4.3 Survey precision

A target survey CV around relative abundance estimates (catch rates) was not specified in the project objectives for the 2022 south Otago survey, but a CV of around 15–20% is generally targeted in blue cod surveys. The achieved CV of 17% in 2022 (from 46 sites) was within the desired range indicating that the survey design and applied effort were appropriate. Previous random-site surveys achieved CVs of 20% (2013 from 40 sites) and 28% (2018 from 43 sites). The high CV in 2018 may have been reduced if a phase 2 component had been carried out, but more likely this was because of the lower abundance of blue cod in 2018 than 2013 and the increase in zero catches. As a result, the 2022 survey simulation indicated that more sites were required in 2022, resulting in a much lower CV.

4.4 Age composition and cohort progression

The 2018 and 2022 age distributions both display evidence of highly variable recruitment, with intermittent strong and weak year classes moving through the fishery over time, typical of blue cod from all areas where surveys have been conducted (Figure 23). Further, the strong and weak male year classes in 2018 have progressed through to 2022, retaining the same relative cohort strengths, i.e., strong 3- and 5-year-old cohorts have grown to strong 7- and 9-year-old age classes. Similarly, weak male 2-, 4-, and 7-year-old cohorts have grown to weak 6-, 8-, and 11-year-old age classes (Figure 23). For females, progression is similar, but there are fewer older fish and only the progression of the strong 3-year-old and weak 2-year-old cohorts are clearly apparent (Figure 23). This reinforces the confidence in the blue cod ageing methodology and the consistency achieved by the two readers over time. It also suggests that the same sub-populations of blue cod off south Otago have been sampled in subsequent surveys and that these surveys are likely monitoring the age composition effectively.

Growth estimates indicate that males are, on average, nearly 6-years-old and females nearly 8-years-old when they reach the current MLS of 33 cm in south Otago, although this was about a year younger before July 2020, when the MLS was 30 cm. The relatively high age at recruitment, combined with the truncated nature of these age compositions with few fish older than 10 years of age, for a species that has a maximum age of 31 years, concentrate the fishing pressure on just a few cohorts, some of which are poorly represented. In 2018, the fishery was largely reliant on the 5-, 6-, and 8-year-old males, and 5- and 8-year-old female age classes, whereas, in 2022, it was the 7- and 9-year-old males and 7- to 9-year-old females. Lightly fished populations, such as those offshore from Banks Peninsula, have a much broader age structure, with a better representation of older age classes that contribute to the fishery (Beentjes et al. 2022a). Comparison of age compositions from blue cod potting surveys off the east coast South Island, from Kaikōura to south Otago, have comparable age structures, with the same intermittent strong and weak year classes present (Beentjes 2021). The age compositions of north and south Otago were remarkably similar in both 2018 and 2022, as they are in neighbouring Kaikōura and Motunau surveys, indicating that the closer sub-populations are geographically, the more similar the age compositions.

Tagging studies have consistently shown that blue cod have a restricted home range (Rapson 1956, Mace & Johnston 1983, Mutch 1983, Carbines & McKenzie 2001, Carbines & McKenzie 2004). For example, in Dusky Sound and Foveaux Strait, most blue cod were recaptured close to the tagging location, but a few were recaptured several to many kilometres away (Carbines & McKenzie 2001, Carbines & McKenzie 2004). Similarly, a recent tagging study of blue cod at Kaikōura showed that most returns were from locations close to the site of release, but one tag was reportedly recaptured off Kapiti Island eight months after release (Emma Kearney, University of Otago, pers. comm.). Despite having limited movement, there is no evidence that blue cod are genetically distinct around the New Zealand mainland (Gebbie 2014), suggesting that mixing is occurring on a wider geographical scale than within the mainly restricted home range indicated by tagging studies. Mechanisms for genetic mixing are unknown but may be facilitated by the few longer-distance movements and dispersal of eggs and larvae, both of which are pelagic for about five days. The temporally related strong and weak year classes, characteristic of east coast South Island sub-populations, are likely to be regulated by fisheries-independent environmentally driven events acting at the scale of the east coast of the South Island or wider (Beentjes 2021). These events will have impacted localised productivity as spawning and survival of eggs, larvae, and juvenile fish.

4.5 Sex change and sex ratio

The 2022 south Otago blue cod survey sex ratio was 70% male (see Table 4) and, for recruited fish 33 cm and over, it is closer to 90% male, values reasonably consistent across all three random-site surveys (see Figure 19). The proportion male tends to increase with length until there are only males, with females often dominating at lengths below about 20 cm to 30 cm (Figure 24). Analogous plots of percent male versus age shows almost the opposite trends because the oldest fish are usually the slower growing females (Figure 25). These plots will likely differ from those of most gonochoristic species where the proportion male would be close to one-to-one throughout and then decline for the largest and oldest fish, which are usually females.

Blue cod are sequential protogynous hermaphrodites with some (but not all) females changing into males as they grow (sex change) (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). The monandric condition is where life always begins as female and males develop only through sex inversion; this occurs in six Australian reef species of the same genus as blue cod (*Parapercis* spp.) (Stroud 1982).

South Otago blue cod population sex and size structure is consistent with diandric reproductive strategy, with both small males and large females present in the population. In areas where fishing pressure is known to be especially high, such as Motunau, Marlborough Sounds, and inshore Banks Peninsula, 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, Beentjes et al. 2022a). In contrast, in Foveaux Strait, Dusky Sound, and offshore Banks Peninsula, sex ratios tend to be more balanced (Beentjes & Page 2016, Beentjes et al. 2019, Beentjes et al. 2022a), suggesting that fishing pressure is less intense in these areas. The shift towards a higher proportion of males in more heavily fished blue cod populations may be enhanced by removing large males that would otherwise moderate or inhibit sex inversion, resulting in a higher rate (and possibly earlier onset) of sex change by females (Beentjes & Carbines 2005, Beentjes 2021). The reduced levels of behavioural interaction and tactile stimulation 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). Factors affecting sex change and sex ratios in blue cod are not well understood; nevertheless, high fishing pressure appears to result in fewer and smaller females in the population, which will have a large impact on egg production. The male-dominated sex ratio in south Otago indicates that this population is heavily fished, consistent with high estimates of fishing mortality (see below).

4.6 Reproductive condition

The 2013, 2018, and 2022 south Otago random-site blue cod surveys were carried out between March and May, and the 2010 survey went into early June, so reproductive status is temporally comparable among surveys. There were no indications of spawning activity for either sex on any of the four surveys. Blue cod are 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 spawn multiple times (Pankhurst & Conroy 1987) and it seems likely they will transition between the mature and running-ripe conditions during this period. Often there are higher proportions of females than males in the combined mature/running-ripe conditions, possibly related to the reproductive strategy where a large male will hold a territory, attracting multiple females. The virtual absence of mature or running-ripe fish in any of the south Otago surveys suggests that these surveys in March to early June took place after the spawning season.

4.7 Stock status and management implications

The *Harvest Strategy Standard* specifies that a Harvest Strategy should include a fishery target reference point and that this may be expressed in terms of biomass or fishing mortality (Ministry of Fisheries 2011). The most appropriate target reference point for blue cod is F_{MSY}, which is the amount of fishing mortality that results in the maximum sustainable yield. The recommended proxy for F_{MSY} is the level of spawner-per-recruit $F_{\%SPR}$ (Ministry of Fisheries 2011). Blue cod is categorised as an exploited species with low productivity (on account of complexities of sex change) and the recommended proxy for F_{MSY} is $F_{45\%SPR}$. As discussed in Section 1.4, the Inshore Finfish Working Group (17 April 2022) agreed that *SPR* is not appropriate as a target reference point for south Otago blue cod and, instead, recommended F=0.87M 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 third survey area, after Marlborough Sounds and north Otago, for which Fisheries New Zealand has replaced *SPR* with F=0.87M as an overfishing threshold.

The 2022 south Otago random-site survey Z for males, where M = 0.17 and age at full recruitment is 7 years of age, was 0.45, with a resulting F of 0.28 (95% confidence intervals 0.13–0.47) (see Table 9). Relative to the target reference point of F=0.15 (F=0.87M), the estimated F of 0.28 in 2022 was nearly two times higher than this target, indicating that overfishing is occurring.

The 2018 estimates of Z and F for males were 0.40 and 0.23 (95% confidence intervals 0.10–0.37), respectively (Table 9). The lower Z and F than in 2022, to some extent, are because of the lower age at recruitment in 2018, when the MLS was 30 cm, compared with 33 cm in 2022. The estimated F of 0.23 was 53% higher than this target, indicating that overfishing was occurring in 2018, but less so than in 2022. Stock status before 2018 cannot be determined because there is no valid ageing for the 2010 and 2013 surveys.

The finding that blue cod were over-exploited in 2018 and 2022 using the target reference point F=0.87M, is consistent with the large decline in abundance in 2018 abundance and a peak in pots with zero catch (see Figures 15 and 20).

The high historical catch rates, MLS of 30 cm, and a bag limit of 30 fish (or blue cod) until July 2020 had made north and south Otago attractive to blue cod fishers and there is strong anecdotal evidence of a large increase in effort at Moeraki in recent years, from both recreational and charter vessels. South Otago may have become even more popular as the current daily bag limit is 15 blue cod, compared with 10 in north Otago. Displacement of recreational fishing effort from Canterbury to north and south Otago is likely to have occurred in recent years because of low catch rates around inshore Banks Peninsula combined with lower daily bags limits at Motunau and Kaikōura. Without information on recreational fishing effort at finer scale than BCO 3, however, it is difficult to gauge impacts on the stock status. For example, the 2018 and 2022 low abundance in south Otago may be a result of sustained poor recruitment over several years, although there are no reliable ageing data before 2018 to verify this. Otoliths from the 2013 survey could be re-aged using the age determination protocol for blue cod (Walsh 2017).

5. POTENTIAL RESEARCH

Research is needed into understanding the factors that control sex change in blue cod, to better interpret survey sex ratios and trends.

Re-ageing the 2013 south Otago survey otoliths adhering to the ADP methodology will be useful for looking at the age composition in 2013 when abundance was high, relative to subsequent surveys in 2018 and 2022. This was recommended by the Inshore Working Group (17 April 2023).

A multivariate analysis could be used to routinely standardise blue cod potting survey abundance indices and potentially allow linkage between fixed- and random-site surveys. Predictor variables could include survey design (fixed or random), ADCP outputs (current strength and direction, bottom temperature), strata, depth, bottom contour, bottom type, sediment type, water clarity, multibeam seafloor descriptive variables, surface water temperature, tide state, and bycatch.

While not strictly a research priority, the ADCP data collected on blue cod potting surveys do not have an appropriate database where they can be archived and easily extracted. Data are currently archived in proprietary software files (.cnv, .ad2cp) and in a customised version in Matlab format with corrections made for magnetic declination to the compass data. Resources are required to investigate and extract the most appropriate ADCP summary metrics (for example, mean bottom water temperature, mean current direction and speed) that can be archived appropriately (for example, in the *trawl* database) and assigned to each pot and/or site from potting surveys.

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7. REFERENCES

Batson, P.B. (2000). The Otago shelf bryozoan thickets: aspects of their distribution, ecology and sedimentology. (Unpublished MSc thesis, University of Otago, New Zealand.) 166p.

Batson, P.B.; Probert, P.K. (2000). Bryozoan thickets off Otago Peninsula. *New Zealand Fisheries Assessment Report 2000/46*. 31 p.

Beentjes, M.P. (2019). Blue cod potting surveys: standards and specifications: Version 2. *New Zealand Fisheries Assessment Report 2019/21*. 62 p.

Beentjes, M.P. (2021). Age structure, recruitment variation, and sex ratio in blue cod (*Parapercis colias*) subpopulations in New Zealand. *New Zealand Journal of Marine and Freshwater Research 55(4)*: 524–549. *DOI: 10.1080/00288330.2020.1825000 55*

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

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

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

Beentjes, M.P.; Carbines, G.D. (2009). Abundance, size and age composition, and mortality of blue cod off Banks Peninsula in 2008. *New Zealand Fisheries Assessment Report 2009/25*. 46 p.
Beentjes, M.P.; Carbines, G.D. (2011). Relative abundance, size and age structure, and stock status of blue cod off south Otago in 2010. *New Zealand Fisheries Assessment Report 2011/42*. 60 p.
Beentjes, M.P.; Carbines, G.D. (2012). Relative abundance, size and age structure, and stock status of blue cod from the 2010 survey in Marlborough Sounds, and review of historical surveys. *New Zealand Fisheries Assessment Report 2012/43*. 137 p.
Beentjes, M.P.; Fenwick, M. (2017). Relative abundance, size and age structure, and stock status of blue cod off Banks Peninsula in 2016. *New Zealand Fisheries Assessment Report 2017/30*. 81 p.
Beentjes, M.P.; Fenwick, M. (2019a). Relative abundance, size and age structure, and stock status of blue cod off north Otago in 2018. *New Zealand Fisheries Assessment Report 2019/07*. 55 p.
Beentjes, M.P.; Fenwick, M. (2019b). Relative abundance, size and age structure, and stock status of blue cod off south Otago in 2018. *New Zealand Fisheries Assessment Report 2019/14*. 47 p.
Beentjes, M.P.; Fenwick, M. (2023). Relative abundance, size and age structure, and stock status of blue cod (*Parapercis colias*) off north Otago in 2022. *New Zealand Fisheries Assessment Report 2023/21*. 51 p.
Beentjes, M.P.; Fenwick, M.; Miller, A. (2022a). Relative abundance, size and age structure, and stock status of blue cod off Banks Peninsula in 2021. *New Zealand Fisheries Assessment Report 2022/29*. 65 p.
Beentjes, M.P.; Francis, R.I.C.C. (2011). Blue cod potting surveys: standards and specifications. Version 1. *New Zealand Fisheries Assessment Report 2011/29*. 47 p.
Beentjes, M.P.; Michael, K.; Pallentin, A.; Parker, S.; Hart, A. (2017). Blue cod relative abundance, size and age structure, and habitat surveys of Marlborough Sounds in 2013. *New Zealand Fisheries Assessment Report 2017/61*. 110 p.
Beentjes, M.P.; Miller, A. (2020). Relative abundance, size and age structure, and stock status of blue cod in Paterson Inlet in 2018. *New Zealand Fisheries Assessment Report 2020/12*. 52 p.
Beentjes, M.P.; Miller, A. (2021). Relative abundance, size and age structure, and stock status of blue cod off Motunau in 2020. *New Zealand Fisheries Assessment Report 2021/28*. 44 p.
Beentjes, M.P.; Miller, A.; Kater, D. (2019). Relative abundance, size and age structure, and stock status of blue cod in Foveaux Strait in 2018. *New Zealand Fisheries Assessment Report 2019/13*. 52 p.
Beentjes, M.P.; Page, M. (2016). Relative abundance, size and age structure, and stock status of blue cod in Dusky Sound in 2014. *New Zealand Fisheries Assessment Report 2016/42*. 51 p.
Beentjes, M.P.; Page, M. (2017). Relative abundance, size and age structure, and stock status of blue cod off Kaikōura in 2015. *New Zealand Fisheries Assessment Report 2017/16*. 54 p.
Beentjes, M.P.; Page, M. (2018). Relative abundance, size and age structure, and stock status of blue cod off Kaikōura in 2017. *New Zealand Fisheries Assessment Report 2018/37*. 44 p.
Beentjes, M.P.; Page, M. (2021). Relative abundance, size and age structure, and stock status of blue cod off Kaikōura in 2019. *New Zealand Fisheries Assessment Report 2021/27*. 46 p.
Beentjes, M.P.; Page, M.; Hamill, J. (2022b). Relative abundance, size and age structure, and stock status of blue cod from the 2021 survey in Marlborough Sounds. *New Zealand Fisheries Assessment Report 2022/39*. 79 p.
Beentjes, M.P.; Page, M.; Sutton, C.; Olsen, L. (2018). Relative abundance, size and age structure, and stock status of blue cod from the 2017 survey in Marlborough Sounds, and review of historical surveys. *New Zealand Fisheries Assessment Report 2018/33*. 103 p.
Beentjes, M.P.; Sutton, C. (2017). Relative abundance, size and age structure, and stock status of blue cod off Motunau in 2016. *New Zealand Fisheries Assessment Report 2017/17*. 54 p.
Beer, N.A.; Wing, S.R.; Carbines, G. (2013). First estimates of batch fecundity for *Parapercis colias*, a commercially important temperate reef fish. *New Zealand Journal of Marine and Freshwater Research 47*: 587–594.
Blackwell, R.G. (1997). Abundance, size composition, and sex ratio of blue cod in the Marlborough Sounds, September 1995. *NIWA Technical Report 88*. 52 p.
Blackwell, R.G. (1998). Abundance, size and age composition, and yield-per-recruit of blue cod in the Marlborough Sounds, September 1996. *NIWA Technical Report 30*. 47 p.

Blackwell, R.G. (2002). Abundance, size and age composition of recruited blue cod in the Marlborough Sounds, September 2001. Final Research Report for Ministry of Fisheries Research Project BCO2001/01. (Unpublished report held by Fisheries New Zealand, Wellington.)

Blackwell, R.G. (2005). Abundance and size composition of recruited blue cod in the Marlborough Sounds, September 2005. Final Research Report for the Ministry of Fisheries Research Project BCO2003/01. (Unpublished report held by Fisheries New Zealand, Wellington.)

Blackwell, R.G. (2008). Abundance and size composition of recruited blue cod in the Marlborough Sounds, September 2007. Final Research Report for Ministry of Fisheries Research Project BCO2006/01 24 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Bolger, T.; Connolly, P.L. (1989). The selection of suitable indices for the measurement and analysis of fish condition. *The Fisheries Society of the British Isles 34*: 171–182.

Bostock, H.; Jenkins, C.; Mackay, K.; Carter, L.; Nodder, S.; Orpin, A.; Pallentin, A.; Wysoczanski, R. (2019). Distribution of surficial sediments in the ocean around New Zealand/Aotearoa. Part B: continental shelf. *New Zealand Journal of Geology and Geophysics 62(1)*: 24–45. DOI: 10.1080/00288306.2018.1523199.

Bull, B.; Dunn, A. (2002). Catch-at-age: User Manual v1.06.2002/09/12. NIWA Internal Report 114. 23 p. (Unpublished report held by NIWA Library, Wellington.)

Campana, S.E. (2001). Accuracy, precision, and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology 59*: 197–242.

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

Carbines, G.; Haist, V. (2012). Relative abundance, size structure, and stock status of blue cod off Banks Peninsula in 2012. Presentation to the SINS WG. SIN-WG-2012/23. (Unpublished report held by Fisheries New Zealand, Wellington.)

Carbines, G.; Haist, V. (2014a). Relative abundance, size and age structure, and stock status of blue cod in Paterson Inlet of BCO 5 in 2010. *New Zealand Fisheries Assessment Report 2014/14*. 49 p.

Carbines, G.; Haist, V. (2014b). Relative abundance, size structure, and stock status of blue cod off South Otago in 2013. Presentation to the SINS WG. SIN-WG-2014/31. (Unpublished report held by the Ministry for Primary Industries, Wellington.)

Carbines, G.; Haist, V. (2017a). Relative abundance, population structure, and stock status of blue cod in the Foveaux Strait in 2014. Experimental evaluation of pot catchability and size selectivity. *New Zealand Fisheries Assessment Report 2017/63*. 61 p.

Carbines, G.; Haist, V. (2017b). Relative abundance, size and age structure, and stock status of blue cod off Banks Peninsula in 2012. *New Zealand Fisheries Assessment Report 2017/37*. 126 p.

Carbines, G.; Haist, V. (2018a). Relative abundance, population structure, and stock status of blue cod in Paterson Inlet in 2014. Concurrent fixed and random site potting surveys. *New Zealand Fisheries Assessment Report 2018/09*. 59 p.

Carbines, G.; Haist, V. (2018b). Relative abundance, population structure, and stock status of blue cod off north Otago in 2013. Concurrent fixed and random site potting surveys. *New Zealand Fisheries Assessment Report 2018/07*. 58 p.

Carbines, G.; Haist, V. (2018c). Relative abundance, population structure, and stock status of blue cod off south Otago in 2013. Estimates of pot catchability and size selectivity. *New Zealand Fisheries Assessment Report 2018/08*. 69 p.

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

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

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

Carbines, G.D.; Beentjes, M.P. (2003). Relative abundance of blue cod in Dusky Sound in 2002. *New Zealand Fisheries Assessment Report 2003/37*. 25 p.
Carbines, G.D.; Beentjes, M.P. (2006a). Relative abundance of blue cod off north Canterbury in 2004–2005. *New Zealand Fisheries Assessment Report 2006/30*. 26 p.
Carbines, G.D.; Beentjes, M.P. (2006b). Relative abundance of blue cod off North Otago in 2005. *New Zealand Fisheries Assessment Report 2006/29*. 20 p.
Carbines, G.D.; Beentjes, M.P. (2009). Relative abundance, size and age structure, and mortality of blue cod off north Canterbury (BCO 3) in 2007–08. *New Zealand Fisheries Assessment Report 2009/37*. 56 p.
Carbines, G.D.; Beentjes, M.P. (2011a). Relative abundance, size and age structure, and stock status of blue cod in Dusky Sound, Fiordland, in 2008. *New Zealand Fisheries Assessment Report 2011/35*. 56 p.
Carbines, G.D.; Beentjes, M.P. (2011b). Relative abundance, size and age structure, and stock status of blue cod off north Otago in 2009. *New Zealand Fisheries Assessment Report 2011/36*. 57 p.
Carbines, G.D.; Beentjes, M.P. (2012). Relative abundance, size and age structure, and stock status of blue cod in Foveaux Strait in 2010. *New Zealand Fisheries Assessment Report 2012/39*. 66 p.
Carbines, G.D.; McKenzie, J (2001). Movement patterns and stock mixing of blue cod in Southland (BCO 5). Final Research Report for Ministry of Fisheries Research Project BCO9702. 16 p. (Unpublished report held by Fisheries New Zealand, Wellington.)
Carbines, G.D.; McKenzie, J. (2004). Movement patterns and stock mixing of blue cod in Dusky Sound in 2002. *New Zealand Fisheries Assessment Report 2004/36*. 28 p.
Carter, L.; Carter, R.M.; Williams, J.J.; Landis, C.A (1985). Modern and relict sedimentation on the south Otago continental shelf, New Zealand. *New Zealand Oceanographic Memoir 93.* 43 p.
Chapman, D.G.; Robson, D.S. (1960). The analysis of a catch curve. *Biometrics 16*: 354–368.
Chiswell, S.M. (1996). Variability in the Southland current, New Zealand. *New Zealand Journal of Marine and Freshwater Research 30*: 1–17.
Doonan, I. (2020). Stock assessment of blue cod (*Parapercis colias*) in BCO 5 using data to 2019. *New Zealand Fisheries Assessment Report 2020/14*. 48 p.
Dunn, A.; Francis, R.I.C.C.; Doonan, I.J. (2002). Comparison of the Chapman-Robson and regression estimators of Z from catch-curve data when non-sampling stochastic error is present. *Fisheries Research 59*: 149–159.
Fishelson, L. (1970). Protogynous sex reversal in the fish *Anthias squamipinni*s (Teleostei, Anthiidae) regulated by presence or absence of male fish. *Nature 227*: 90–91.
Fisheries New Zealand (2022). Fisheries Assessment Plenary, May 2022: stock assessments and stock status. Compiled by the Fisheries Science Team, Fisheries New Zealand, Wellington, New Zealand. 1886 p.
Francis, R.I.C.C. (2006). Optimum allocation of stations to strata in trawl surveys. *New Zealand Fisheries Assessment Report 2006/23*. 50 p.
Francis, R.I.C.C. (1984). An adaptive strategy for stratified random trawl surveys. *New Zealand Journal of Marine and Freshwater Research 18*: 59–71.
Gebbie, C.L. (2014). Population genetic structure of New Zealand blue cod *(Parapercis colias*) based on mitochondrial and microsatellite DNA markers. 89 p. (MSc. thesis, Victoria University of Wellington.)
Holmes, S.J.; Large, K.; Bian, R.; Datta, S.; Beentjes, M. (2022). Characterisation of the blue cod (*Parapercis colias*) commercial fishery in BCO 3 and an update of the standardised CPUE to the 2017–18 fishing year. *New Zealand Fisheries Assessment Report 2022/25*. 44 p.
Mace, J.T.; Johnston, A.D. (1983). Tagging experiments on blue cod (*Parapercis colias*) in the Marlborough Sounds, New Zealand. *New Zealand Journal of Marine and Freshwater Research 17*: 207–211.
Ministry of Fisheries (2011). Operational guidelines for New Zealand's harvest strategy standard (Revision 1). 78 p. (Unpublished report held by Fisheries New Zealand, Wellington.)
Mutch, P.G. (1983). Factors influencing the density and distribution of the blue cod (*Parapercis colias*) (Pisces: Mugilodae). Unpublished M.Sc. thesis, University of Auckland, New Zealand. 76 p.

Nash, R.D.M.; Valencia, A.H.; Geffen, A.J. (2006). The origin of Fulton's condition factor–setting the record straight. *Fisheries 31*: 236–238.

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

Rapson, A.M. (1956). Biology of the blue cod (*Parapercis colias* Forster) of New Zealand. (Unpublished Ph.D. Thesis, Victoria University, Wellington, New Zealand.) 53 p.

Reinboth, R. (1980). Can sex inversion be environmentally induced? *Biology of Reproduction 22*: 49–59.

Robertson, D.R. (1972). Social Control of Sex Reversal in a Coral-Reef Fish. *Science 177*: 1007–1009.

Sato, T.; Kobayashi, M.; Takebe, T. et al. (2018). Induction of female-to-male sex change in a large protogynous fish, *Choerodon schoenleinii*. *Marine Ecology 39*: e12484.

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

Stroud, G.J. (1982). The taxonomy and biology of fishes of the genus *Parapercis* (Teleostei: Mugiloididae) in Great Barrier Reef waters. 428 p. (Ph.D. thesis, James Cook University, Australia.)

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

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

Warner, R.R (1984). Mating behavior and hermaphroditism in coral reef fishes. *American Scientist 72*: 128–136.

Wynne-Jones, J.; Gray, A; Heinemann, A.; Hill, L.; Walton, L. (2019). National Panel Survey of Marine Recreational Fishers 2017–18. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.

Zhou, S.; Yin, S.; Thorson, J.T.; Smith, A.D.M.; Fuller, M. (2012). Linking fishing mortality reference points to life history traits: an empirical study. *Canadian Journal of Fisheries and Aquatic Sciences 69*: 1292–1301.

8. TABLES AND FIGURES

Table 1: Details of the four south Otago blue cod potting surveys.

Year	Strata	Survey design	Vessel	Skipper	Research provider	Timing
2010	1, 3, 6	Fixed- and random-site	F.V. *Trident*	Neil McDonald	NIWA	21 April–5 June
2013	1–6	Random-site	F.V. *Trident*	Neil McDonald	Saltwater Research	5 April–17 May
2018	1–6	Random-site	F.V. *Trident*/ F.V. *Chivalair*	Neil McDonald/ John Pile	NIWA	4 April–5 May
2022	1–6	Random-site	F.V. *Chivalair*	John Pile	NIWA	24 March–27 April

Table 2: Effort and catch data for the 2022 south Otago random-site blue cod potting survey. *N* indicates number.

			N sets (sites)			Catch (blue cod)		Depth (m)	
Stratum	Area (km^2)	Site type	Phase 1	Phase 2	*N* pots (stations)	kg	*N*	Mean	Range
1	154.9	Random	5		30	29.5	61	24	10–41
2	245.4	Random	3		18			25	15–37
3	177.9	Random	4		24	35.0	50	120	101–136
4	426.2	Random	13		78	38.6	317	51	37–60
5	196.6	Random	5	5	60	241.8	700	54	42–66
6	251.3	Random	11		66	366.7	842	60	46–76
Total	1 452.3	Random	41	5	276	711.6	1 970	55	10–136

Table 3: Total catch and numbers of blue cod and bycatch species caught on the 2022 south Otago random-site blue cod potting survey. Percent of the catch by weight is also shown.

Common name	Species	Code	Number	Catch (kg)	% catch
Blue cod	*Parapercis colias*	BCO	1 970	711.6	91.54
Brittle star	Ophiroidea	OPH	1 139	27.3	3.51
Tarakihi	*Nemadactylus macropterus*	NMP	83	13.6	1.75
Ling	*Genypterus blacodes*	LIN	2	9.9	1.27
Common octopus	Octopod	OCP	5	4.8	0.62
Red cod	*Pseudophycis bachus*	RCO	2	3.0	0.39
Scarlet wrasse	*Pseudolabrus miles*	SPF	9	2.4	0.31
Starfish	Asteroidea	ASR	11	1.3	0.17
Hermit crab	Paguridae	PAG	2	1.2	0.15
Blue moki	*Latridopsis ciliaris*	MOK	1	1.0	0.13
Sea perch	*Helicolenus percoides*	SPE	1	0.5	0.06
Leatherjacket	*Meuschenia scaber*	LEA	2	0.3	0.04
Decorator crab	*Notomithrax peronii*	NTP	2	0.2	0.03
Masking crab	*Leptomithrax* spp.	LMI	1	0.1	0.01
Smooth red swimming crab	*Nectocarcinus bennetti*	NCB	1	0.1	0.01
Trumpeter	*Latris lineata*	TRU	1	0.1	0.01
Totals			3 232	777.4	100

Table 4: Mean catch rates for all blue cod and recruited blue cod (33 cm and over) from the 2022 south Otago random-site blue cod potting survey. Catch rates are pot-based, while s.e. and CV are set-based. s.e., standard error; CV coefficient of variation; –, not applicable.

			All blue cod			Recruited blue cod (≥ 33 cm)		
Stratum	Sites (N)	Pot lifts (N)	Catch rate (kg pot^{-1})	s.e.	CV (%)	Catch rate (kg pot^{-1})	s.e.	CV (%)
1	5	30	0.98	0.65	66.3	0.55	0.41	75.1
2	3	18	0.00	0.00	–	0.00	0.00	–
3	4	24	1.46	1.43	97.7	1.14	1.11	97.7
4	13	78	0.49	0.23	46.0	0.02	0.02	67.9
5	10	60	4.03	1.38	34.2	1.84	1.17	63.9
6	11	66	5.56	1.03	18.5	3.44	1.11	32.4
Overall	46	276	1.94	0.33	16.8	1.05	0.29	27.5

Table 5: Descriptive statistics for blue cod caught on the 2022 south Otago random-site blue cod potting survey. Mean lengths are raw for each stratum, and weighted (scaled) overall. Sex ratio is given for all blue cod and recruited blue cod (33 cm and over). – indicates no data.

			Length (cm)			Percent male	
Stratum	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited blue cod
1	Male	51	30.3	20.5	49.1	83.6	100
	Female	10	23.9	19.5	30.2		
	Unsexed	0	–	–	–		
2	Male	0	–	–	–	–	–
	Female	0	–	–	–		
	Unsexed	0	–	–	–		
3	Male	18	36.4	11.6	50.9	35.5	44.3
	Female	32	33.0	24.9	42.2		
	Unsexed		–	–	–		
4	Male	211	19.7	10.6	41.1	67.4	100
	Female	101	18.3	10.9	31		
	Unsexed	5	11.5	10.0	12.1		
5	Male	510	27.5	11.0	55.1	72.9	94.3
	Female	190	23.6	11.3	49.9		
	Unsexed	0	–	–	–		
6	Male	608	30.0	12.1	57.4	72.2	93.7
	Female	234	24.6	13.1	48.7		
	Unsexed	0	–	–	–		
Overall	Male	1 398	26.6	10.6	57.4	70.1	87.7
	Female	567	23.1	10.9	49.9		
	Unsexed	5	11.5	10.0	12.1		

Table 6: Otolith ageing data used in the catch-at-age and total mortality (*Z*) estimates for the 2022 south Otago random-site blue cod potting survey.

		Length of aged fish (cm)		Age (years)	
Survey	No. otoliths	Minimum	Maximum	Minimum	Maximum
Male	478	11	57	1	25
Female	256	11	49	1	29
Total	734	11	57	1	29

Table 7: Percentages of blue cod (by sex) at each gonad maturity stage from the 2022 south Otago random-site blue cod potting survey. 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

	Gonad maturity stage (%)					
Sex	1	2	3	4	5	*N*
Males	67.5	12.6	0.1	0.1	19.8	1 398
Females	89.8	8.5	0.5	0.0	1.2	567

Table 8: Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals for male blue cod from the 2018 and 2022 south Otago random-site blue cod potting surveys. *AgeR*, age at full recruitment.

				95% CIs	
Survey	Site type	*AgeR*	*Z*	Lower	Upper
2022	Random	5	0.31	0.21	0.42
	Random	6	0.34	0.23	0.47
	Random	7	0.45	0.30	0.63
	Random	8	0.44	0.27	0.64
	Random	9	0.58	0.35	0.87
	Random	10	0.45	0.25	0.75
2018	Random	5	0.49	0.34	0.65
	Random	6	0.4	0.27	0.54
	Random	7	0.4	0.26	0.55
	Random	8	0.53	0.35	0.76
	Random	9	0.42	0.25	0.63
	Random	10	0.61	0.34	0.99

Table 9: Chapman Robson total mortality (*Z*), and fishing mortality (*F*) point estimates at three values of natural mortality (*M*) for male blue cod from the 2018 and 2022 south Otago random-site potting surveys. In 2022 *AgeR* = 7, the age at which males reach MLS of 33 cm, plus one year; in 2018 *AgeR* = 6, age at which males reach MLS of 30 cm, plus one year. *F* values are also given for the default *M* (0.17) and the 95% confidence interval *Z* values. *AgeR*, age at full recruitment; *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality; CI indicates 95% confidence interval.

Survey	Site type	*M*	*Z*	*F*	Estimate type
2022	Random	0.14	0.45	0.31	Point
		0.17	0.45	0.28	Point
		0.20	0.45	0.25	Point
		0.17	0.30	0.13	Lower CI
		0.17	0.64	0.47	Upper CI
2018	Random	0.14	0.40	0.26	Point
		0.17	0.40	0.23	Point
		0.20	0.40	0.20	Point
		0.17	0.27	0.10	Lower CI
		0.17	0.54	0.37	Upper CI

Table 10: Mean condition factor (*K*) of blue cod for the 2018 and 2022 south Otago random-site surveys. $K = wt*100/l^b$, where *wt* = weight (g), *l* =length (cm), and *b* = survey sex-specific growth coefficient.

Survey	Sex	Mean condition (*K*)	Standard error	Number
2018	Males	0.477	0.002	702
	Females	0.554	0.004	335
	Both sexes	0.502	0.002	1 037
2022	Males	0.563	0.001	1 392
	Females	0.534	0.002	565
	Both sexes	0.555	0.001	1 957

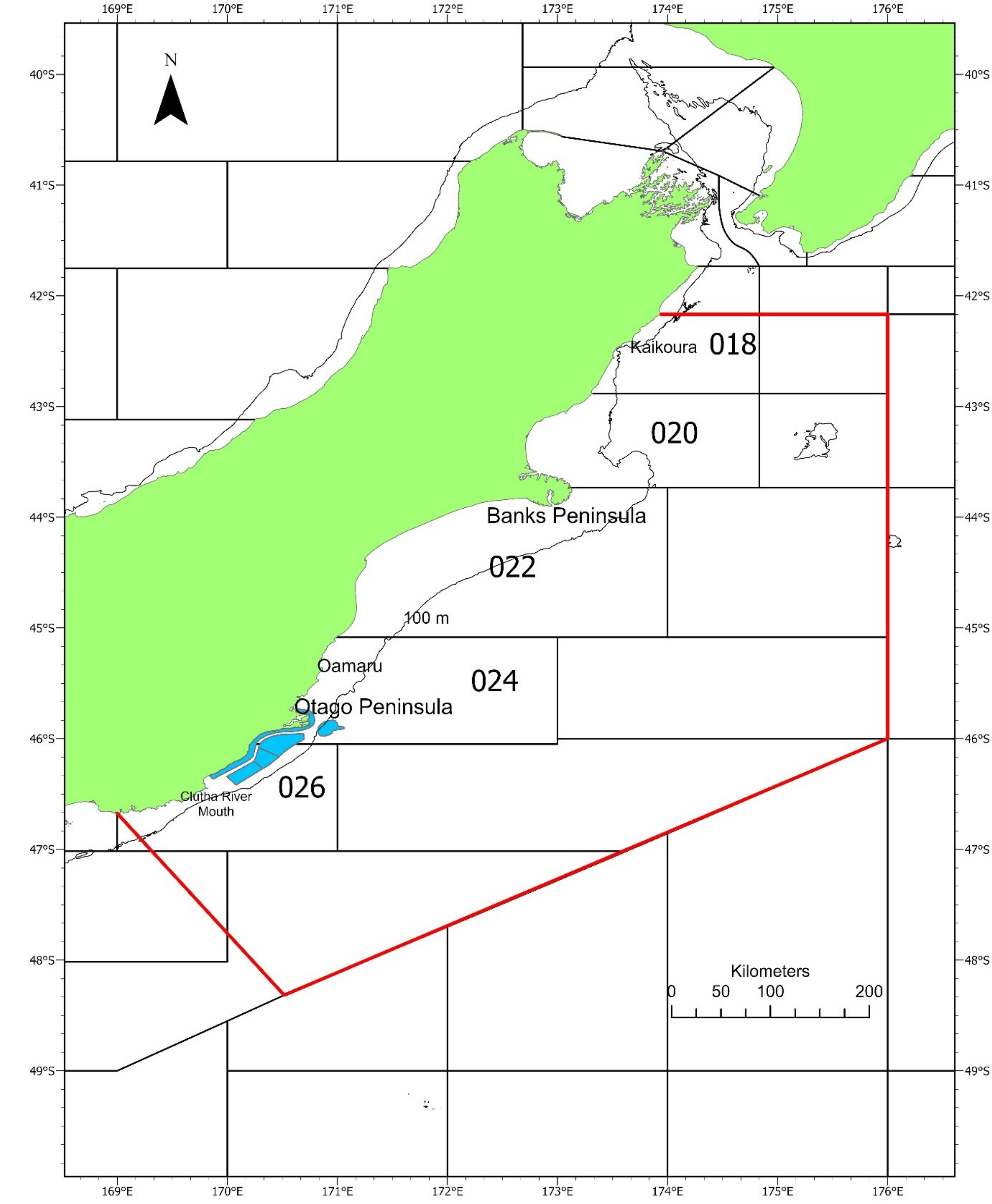

Figure 1: Blue cod Quota Management Area BCO 3 (red border) and coastal Statistical Areas (018, 020, 022, 024, 026). The six survey strata of the south Otago survey, from Otago Peninsula to Clutha River Mouth, are shaded in blue. The 100 m depth contour is shown.

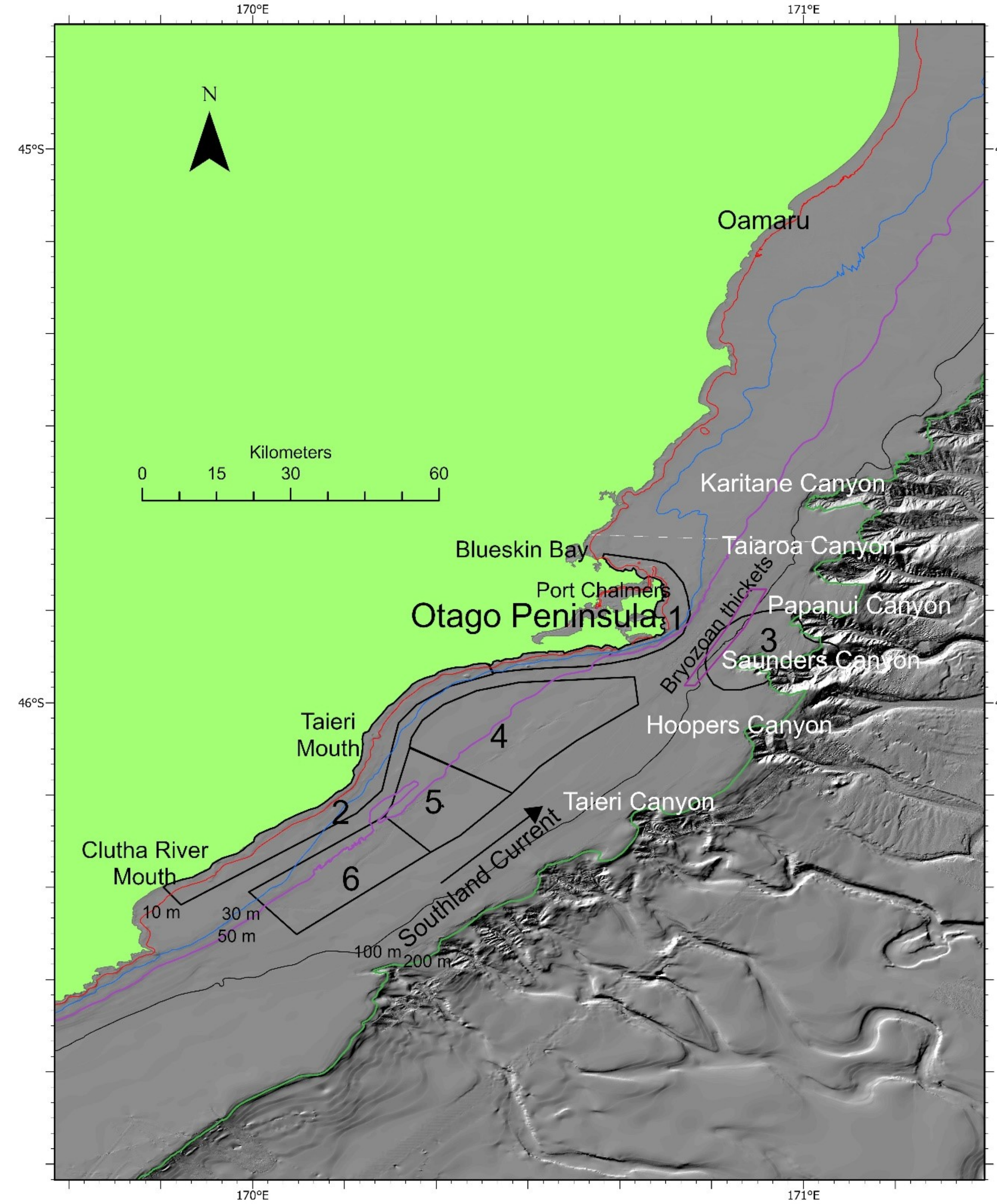

Figure 2: South Otago blue cod survey strata, bathymetry contours, and hillshade view of the seafloor based on the NIWA Digital Terrain Model (DEM) of the 25-m gridded data set (3× vertical exaggeration).

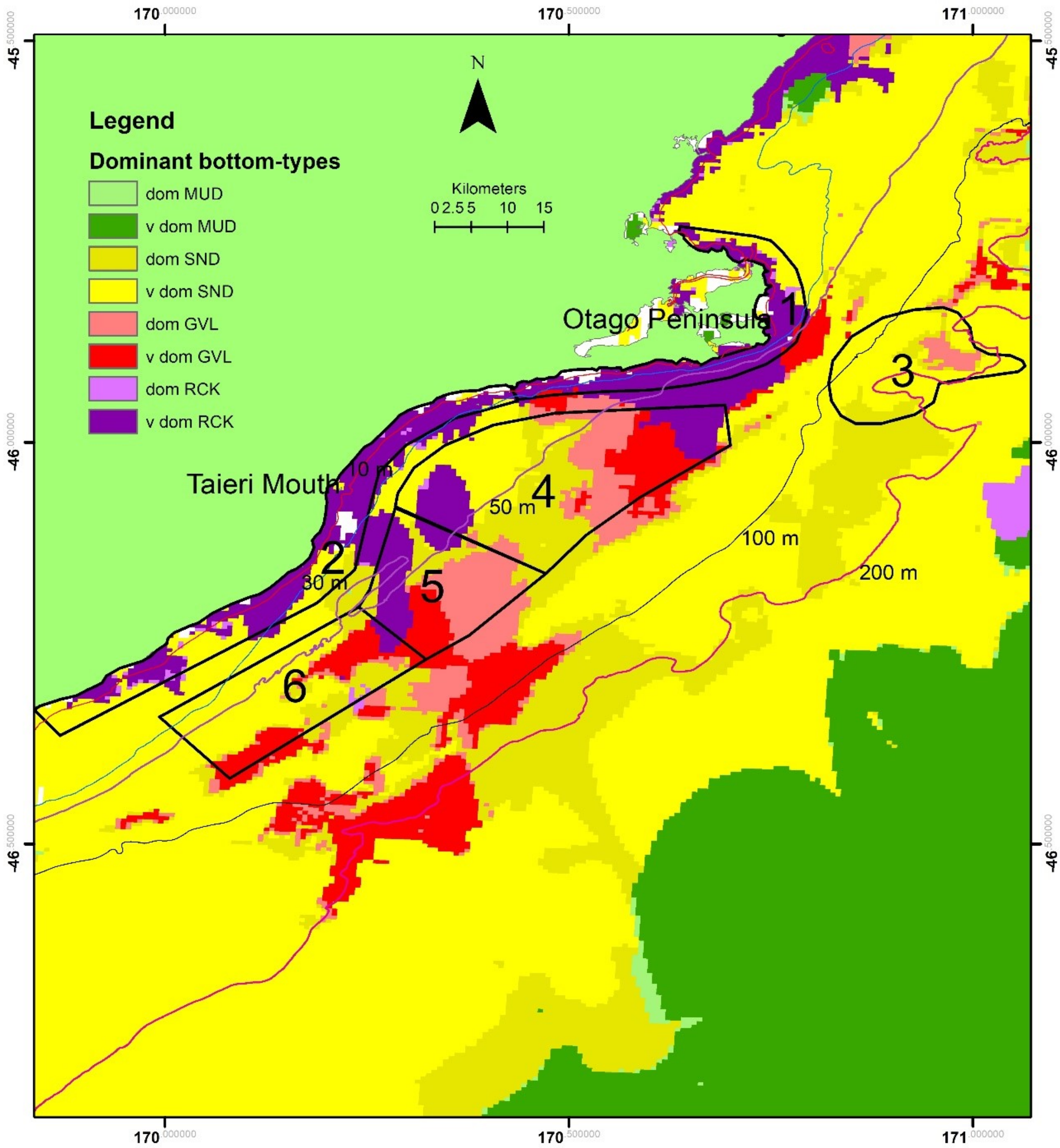

Figure 3: Dominant seafloor substrate types in the South Otago blue cod, including bathymetry contours and blue cod survey strata (data from Bostock et al. 2019). Key: dom, dominant; v dom, very dominant; MUD, mud; SND, sand; GVL, gravel; RCK, rock.

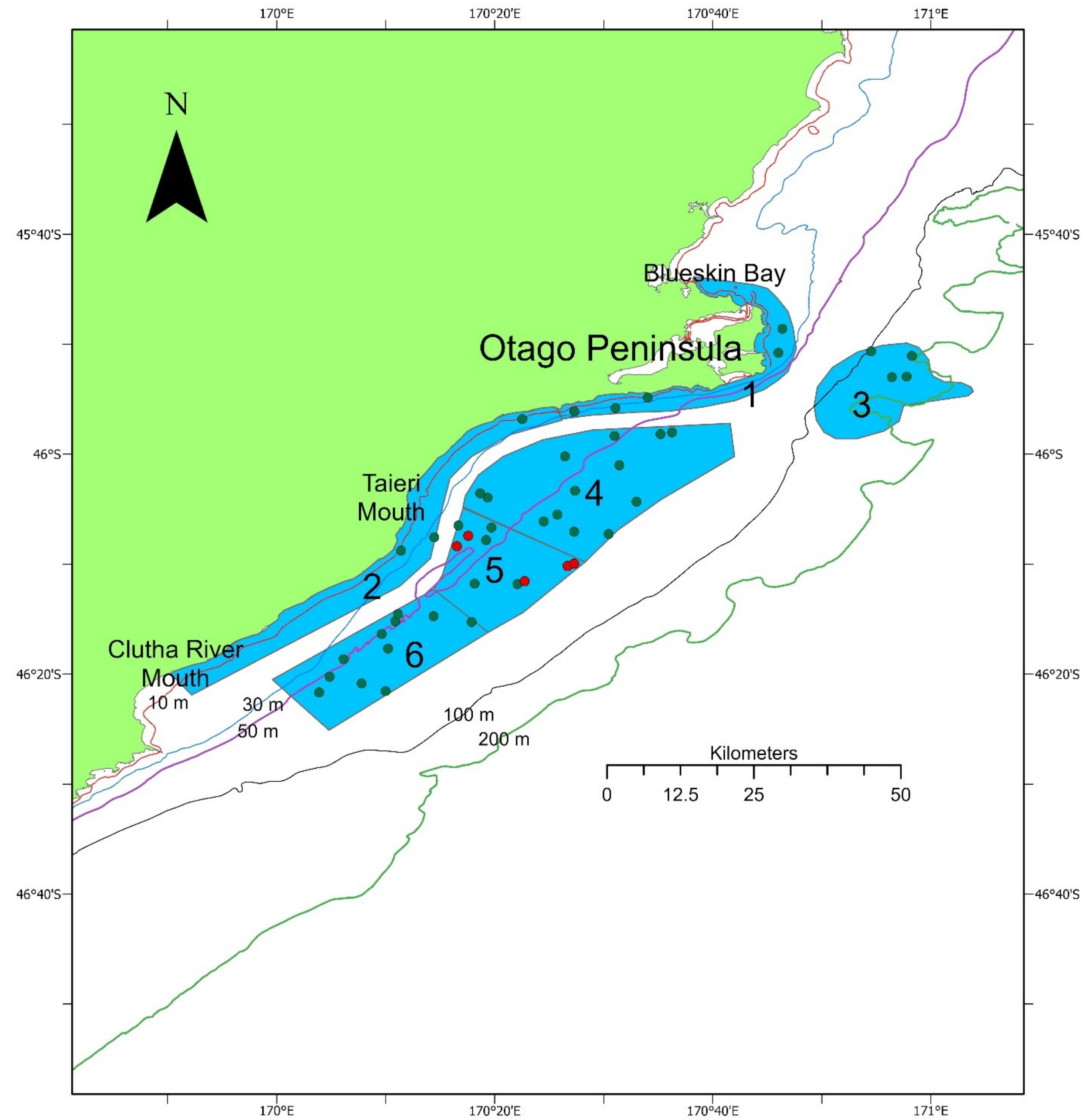

Figure 4: Stratum and site positions for the 2022 south Otago random-site blue cod potting survey. Green circles are phase 1 sites and red circles are phase 2 sites.

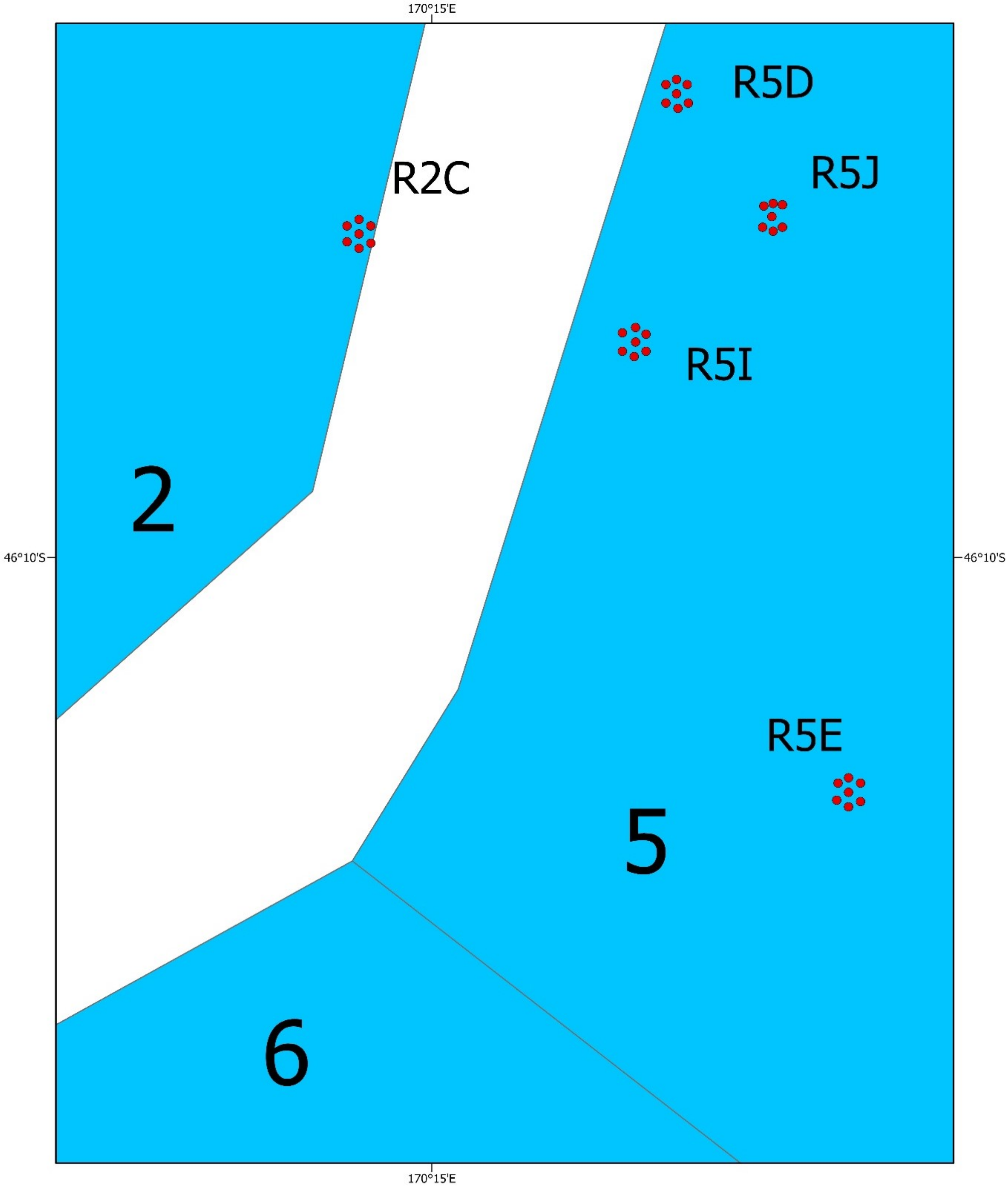

Figure 5: Site and pot position for the 2022 south Otago random-site blue cod potting survey in parts of strata 2 and 5, demonstrating how the six pots were placed around the sites, i.e., systematic pot placement. The centre position in each cluster is where the ADCP (Acoustic Doppler Current Profiler) was deployed.

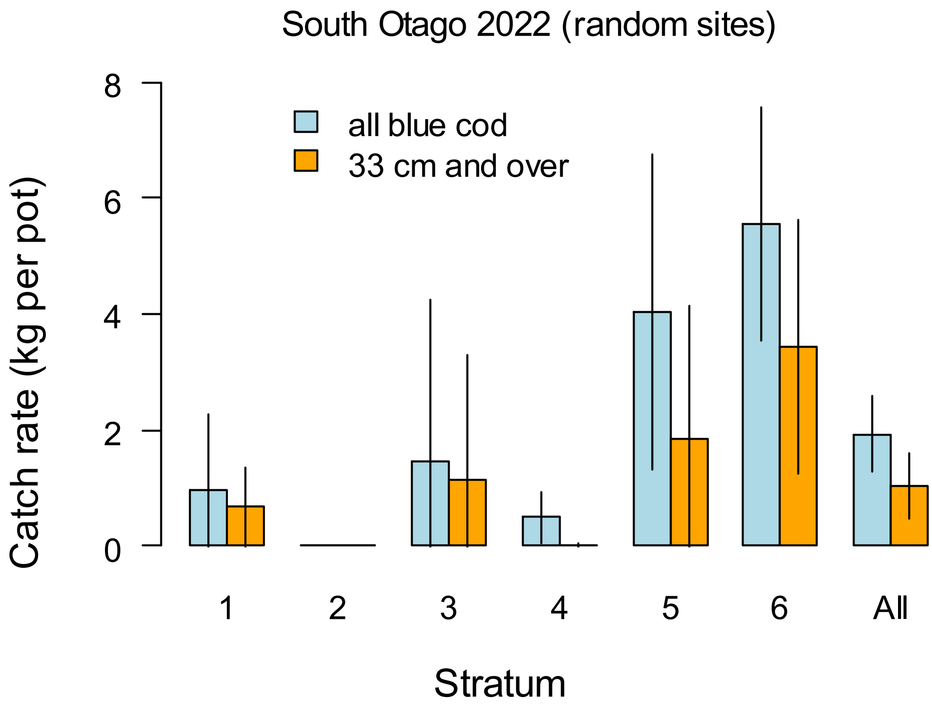

Figure 6: Catch rates (kg pot^{-1}) of all blue cod and recruited blue cod (33 cm and over) by strata and overall for the 2022 south Otago random site survey. Error bars are 95% confidence intervals.

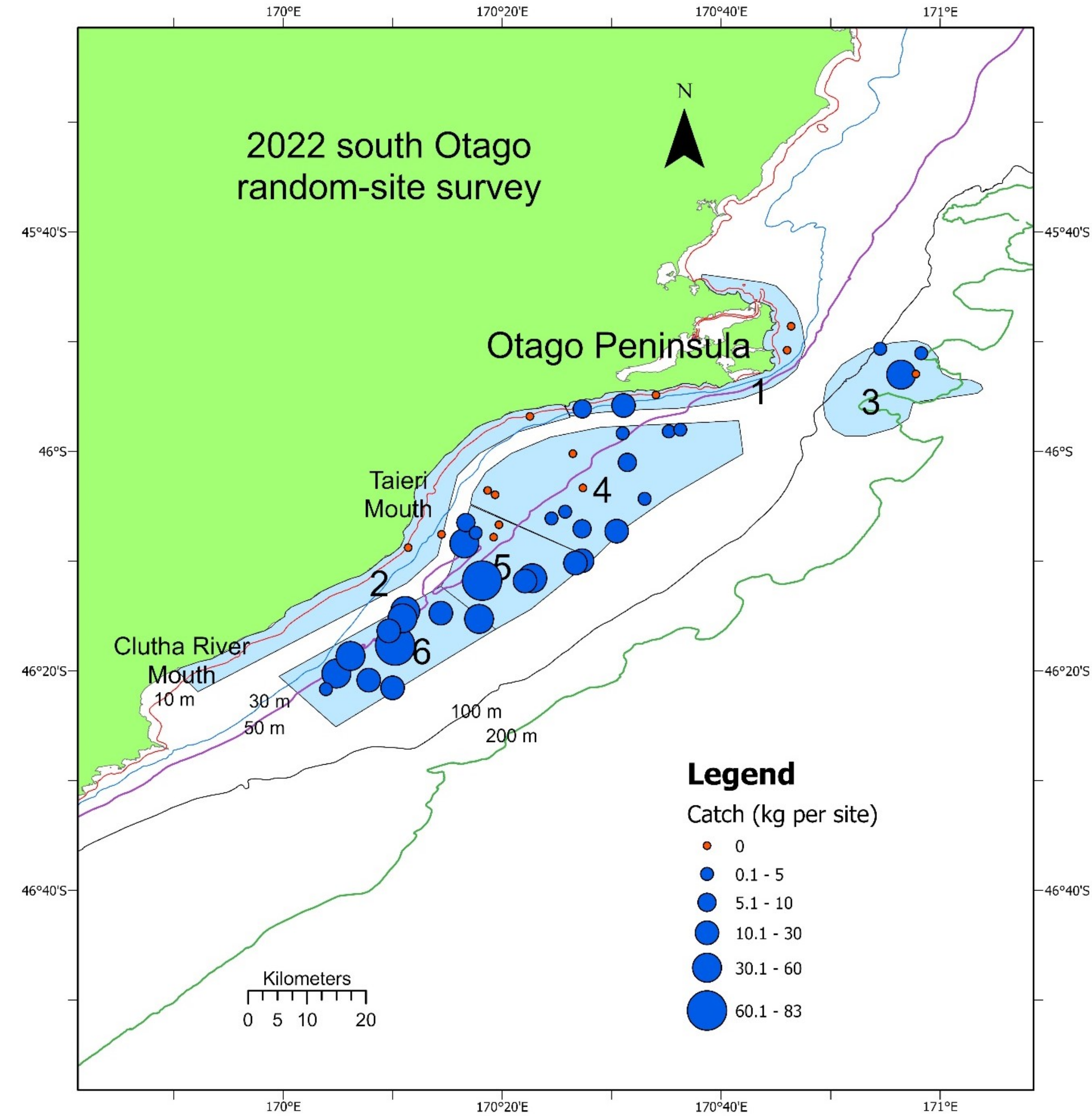

Figure 1: Strata and site positions showing relative blue cod catch rates (kg site^{-1}) for the south Otago 2022 random-site blue cod potting survey.

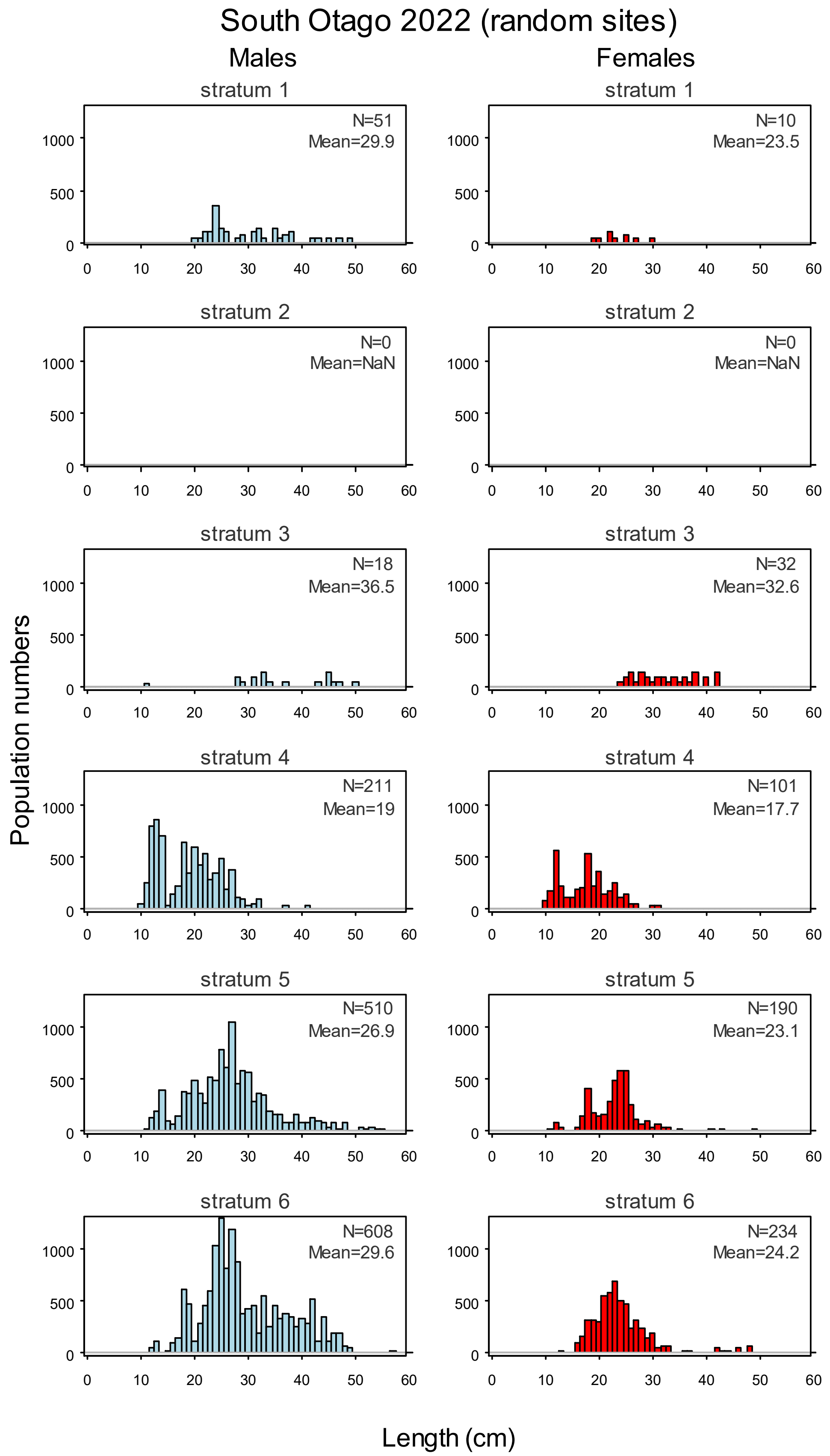

Figure 8: Scaled length frequency distributions by stratum and sex for the 2022 south Otago random-site potting survey. N, sample numbers; Mean, mean length (cm). Not shown are 5 unsexed fish in stratum 4 in the length range 10–12 cm.

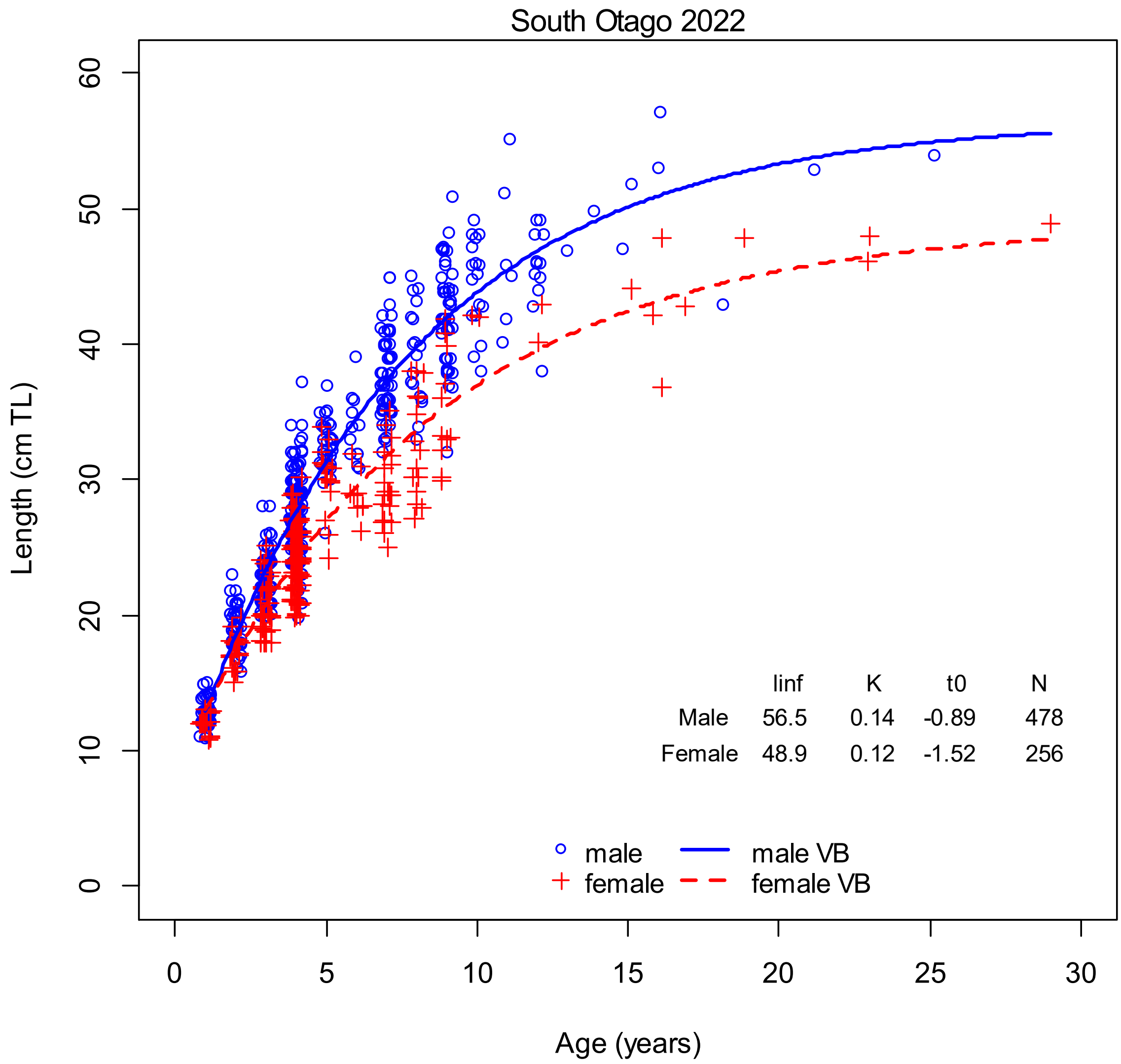

Figure 9: Observed blue cod age and length data by sex for the 2022 south Otago survey with von Bertalanffy (VB) growth models fitted to the data. l_{inf}, average size at the maximum age (cm); *K*, Brody growth coefficient (yr^{-1}); t_0, age when the average size is zero.

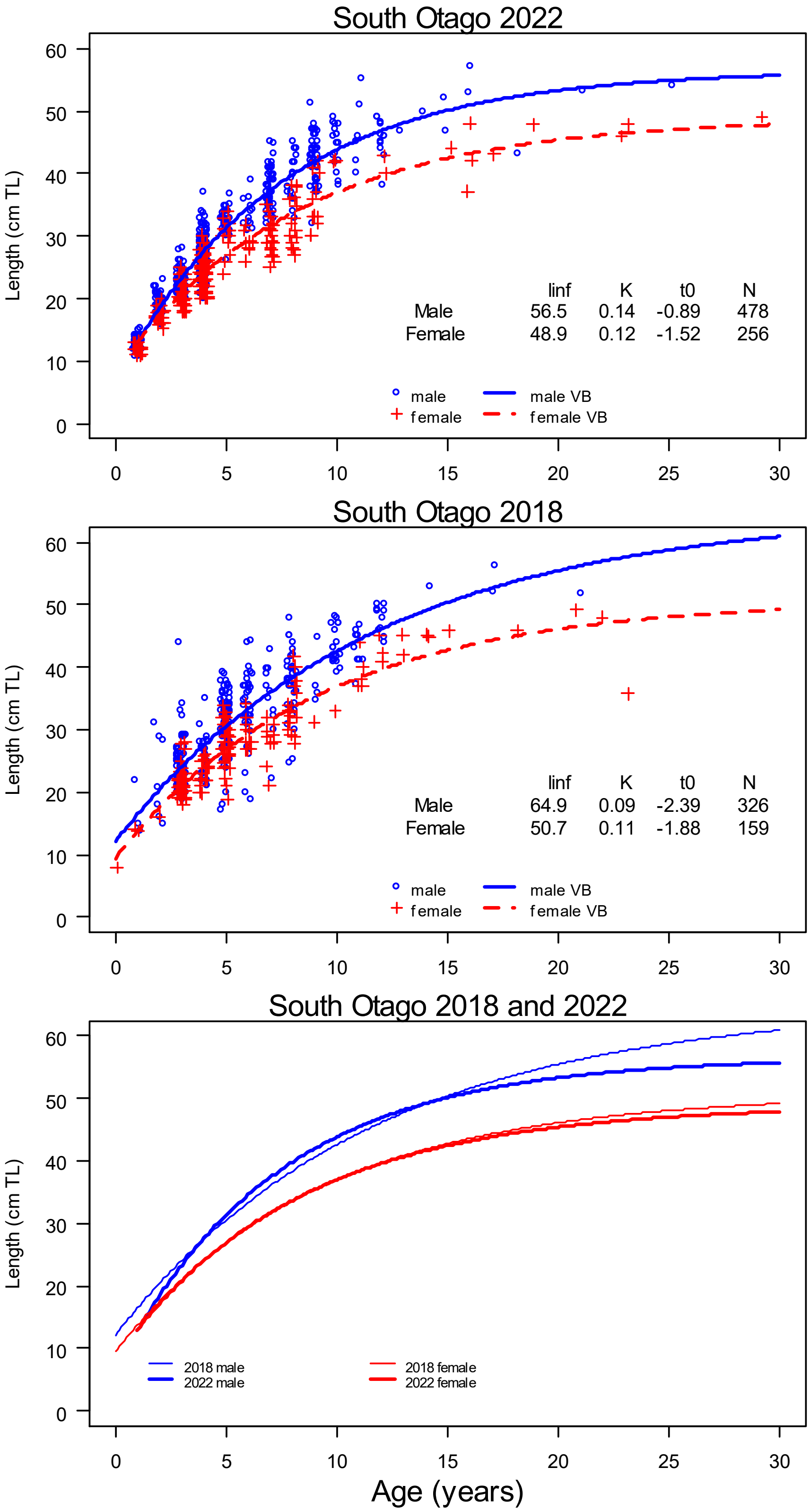

Figure 10: Observed blue cod age and length data by sex for the 2018 and 2022 south Otago surveys with von Bertalanffy (VB) growth models fitted to the data (top two panels). The bottom figure shows only the fitted VB growth models for both surveys. l_{inf}, average size at the maximum age (cm); *K*, Brody growth coefficient (yr^{-1}); t_0, age when the average size is zero; N, number of fish.

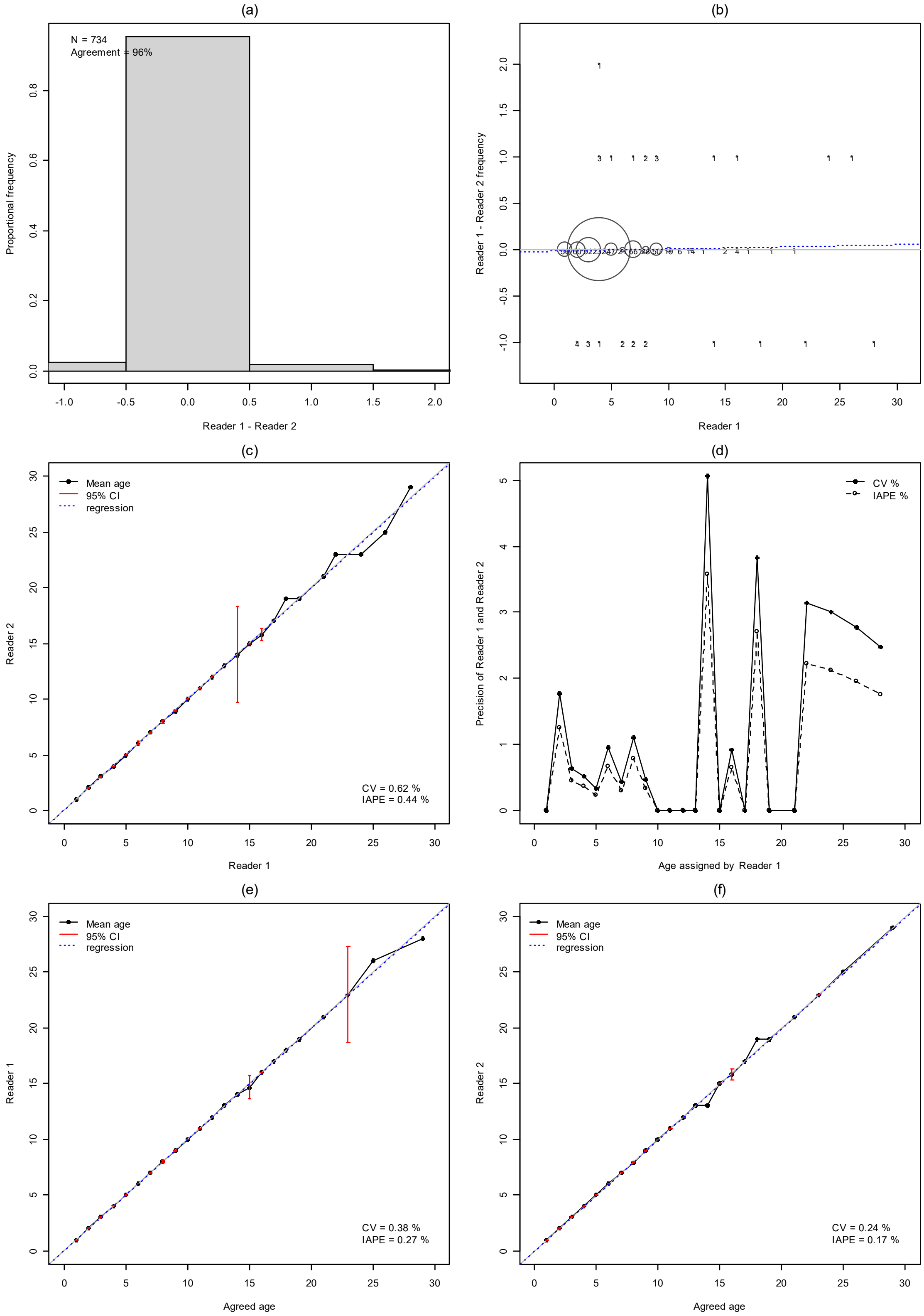

Figure 11: Otolith reader comparison plots between reader 1 and reader 2 for blue cod from the 2022 south Otago survey. (a) Histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age 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.

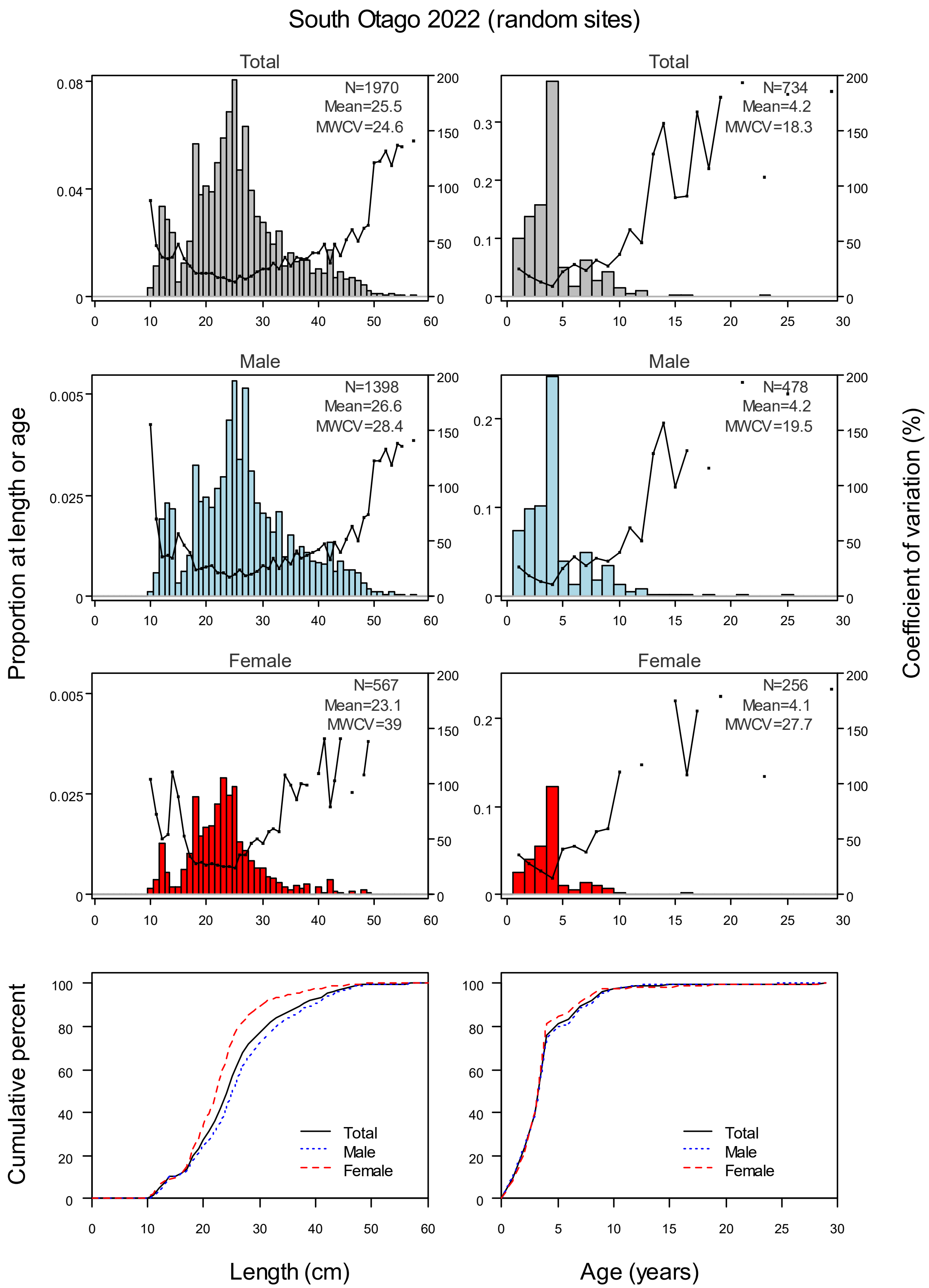

Figure 12: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2022 south Otago random-site blue cod potting survey. N, sample size; mean, mean length and mean age; MWCV, % mean weighted coefficient of variation.

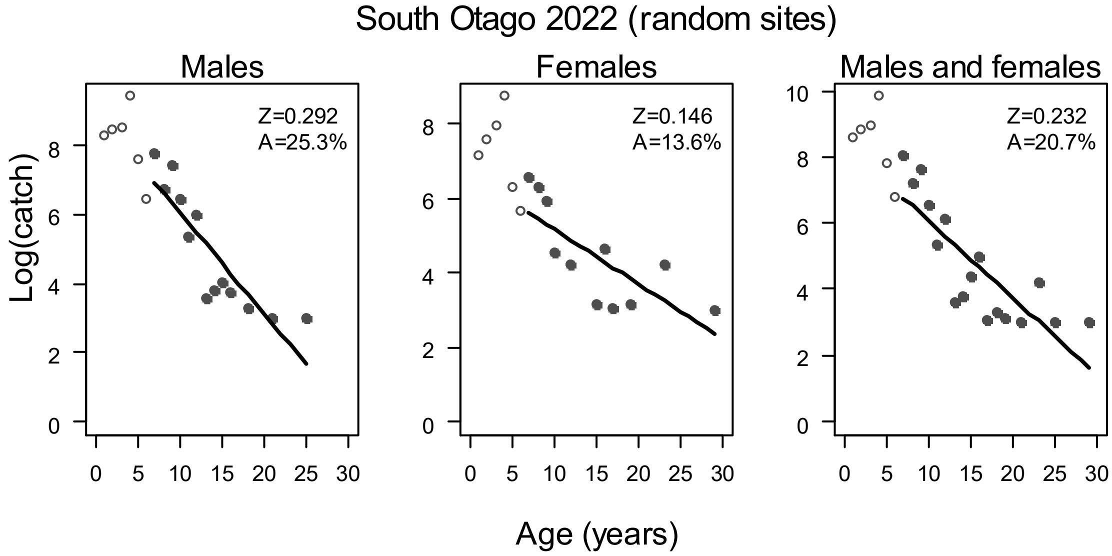

Figure 13: Catch curves (natural log transformed catch number versus age) for the 2022 south Otago random-site survey. The regression line is plotted from age at full recruitment of 7 years i.e., the age of males at MLS (33 cm) plus 1 year (dark points on the graph). *Z*, instantaneous total mortality; *A*, the annual mortality rate or the proportion of the population that suffers mortality in a given year.

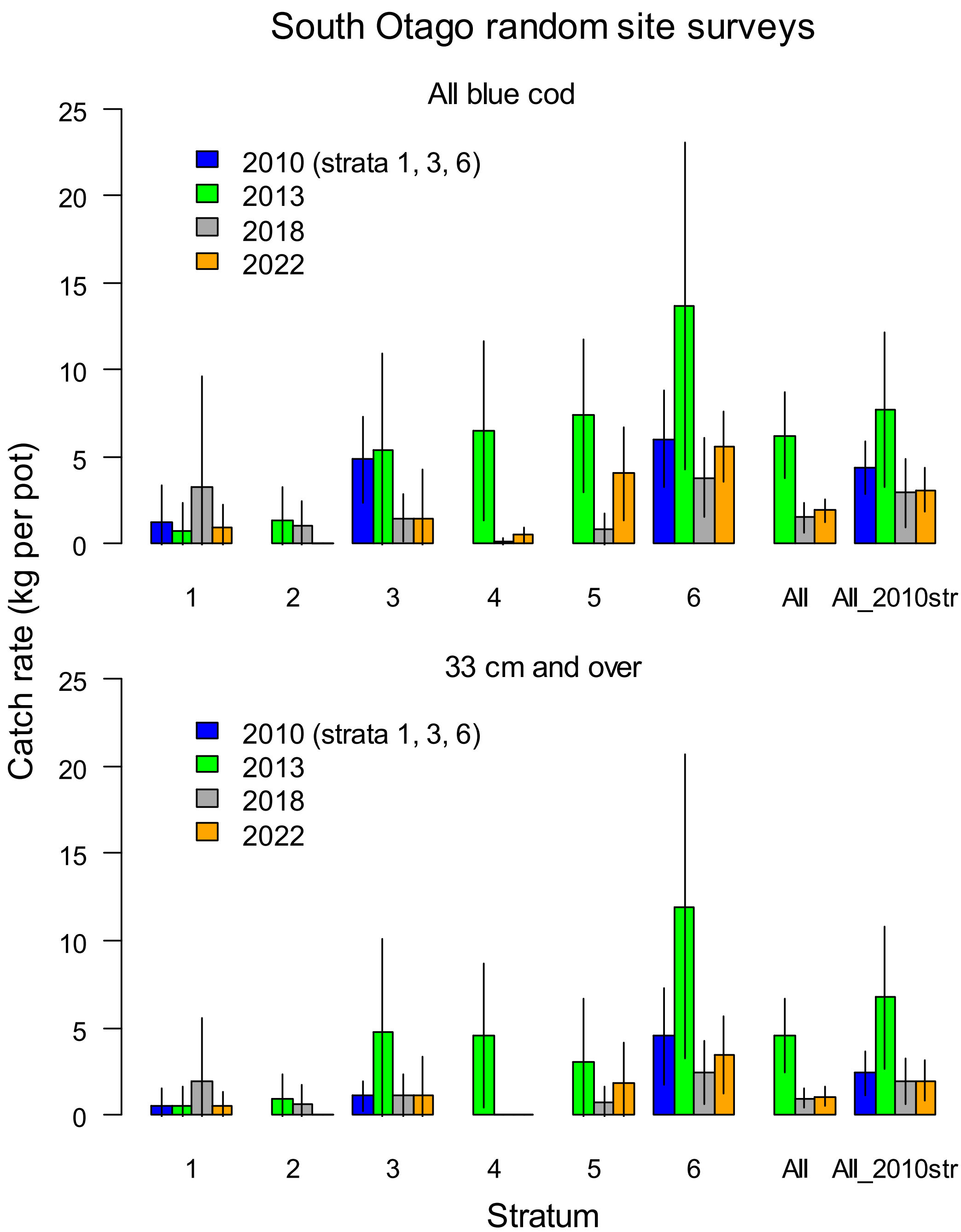

Figure 14: Catch rates (kg pot^{-1}) of all blue cod and for recruited blue cod (33 cm and over) for the south Otago random-site potting surveys in 2010, 2013, 2018, and 2022. Catch rates are shown by strata and for all strata combined (All). Catch rates are also shown for strata 1, 3, and 6 combined (All_2010str) to compare with 2010 when only these three strata were surveyed. Error bars are 95% confidence intervals.

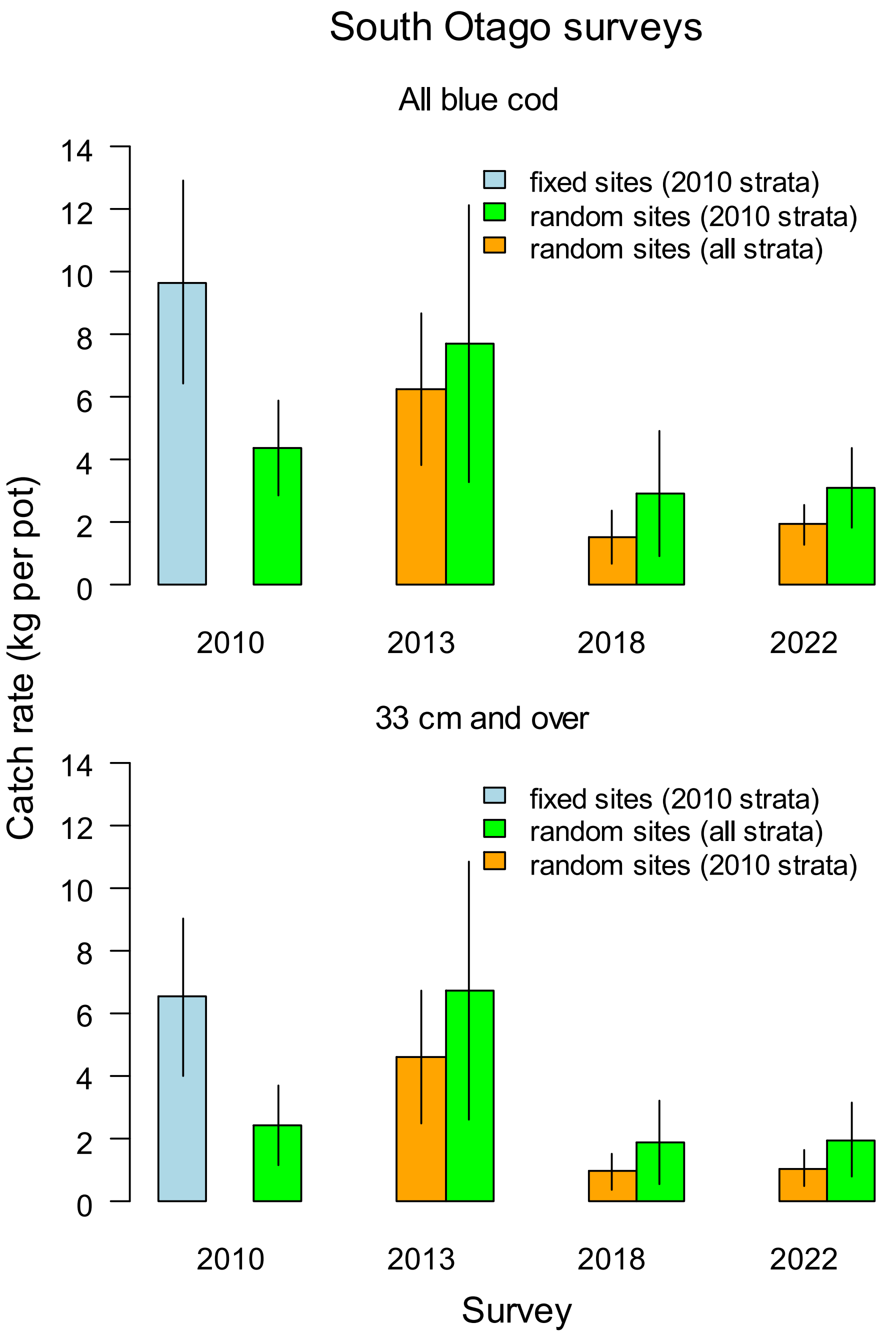

Figure 15: Catch rates (kg pot^{-1}) of all blue cod (top) and for recruited blue cod (33 cm and over) (bottom) for the south Otago 2010 fixed- and random-site potting surveys, and the random-site potting surveys in 2013, 2018, and 2022. Random-site survey catch rates are shown for all strata combined (all strata) and for the 2010 strata 1, 3, and 6 combined (2010 strata). Error bars are 95% confidence intervals.

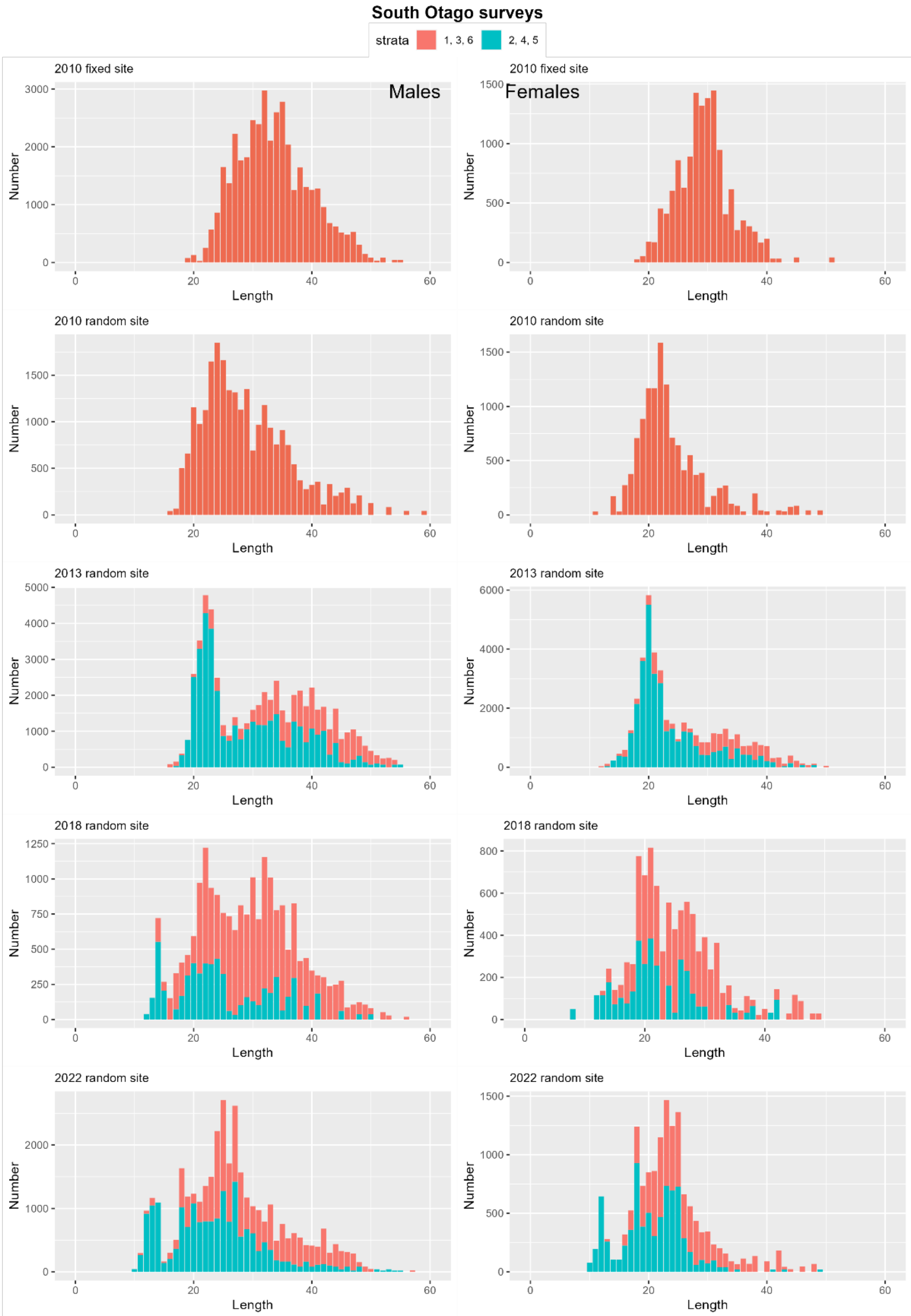

Figure 16: Scaled length frequency distributions for male and female blue cod for the south Otago 2010 fixed- and random-site potting surveys, and the random-site potting surveys in 2013, 2018, and 2022. Length frequencies were split by strata groups (1, 3, 6; and 2, 4, 5), to allow comparison between the 2010 survey strata (1, 3, and 6) and strata 2, 4 and 5 that were also surveyed in the 2013 to 2022 surveys. Distributions in 2013 to 2022 are stacked not overlaid.

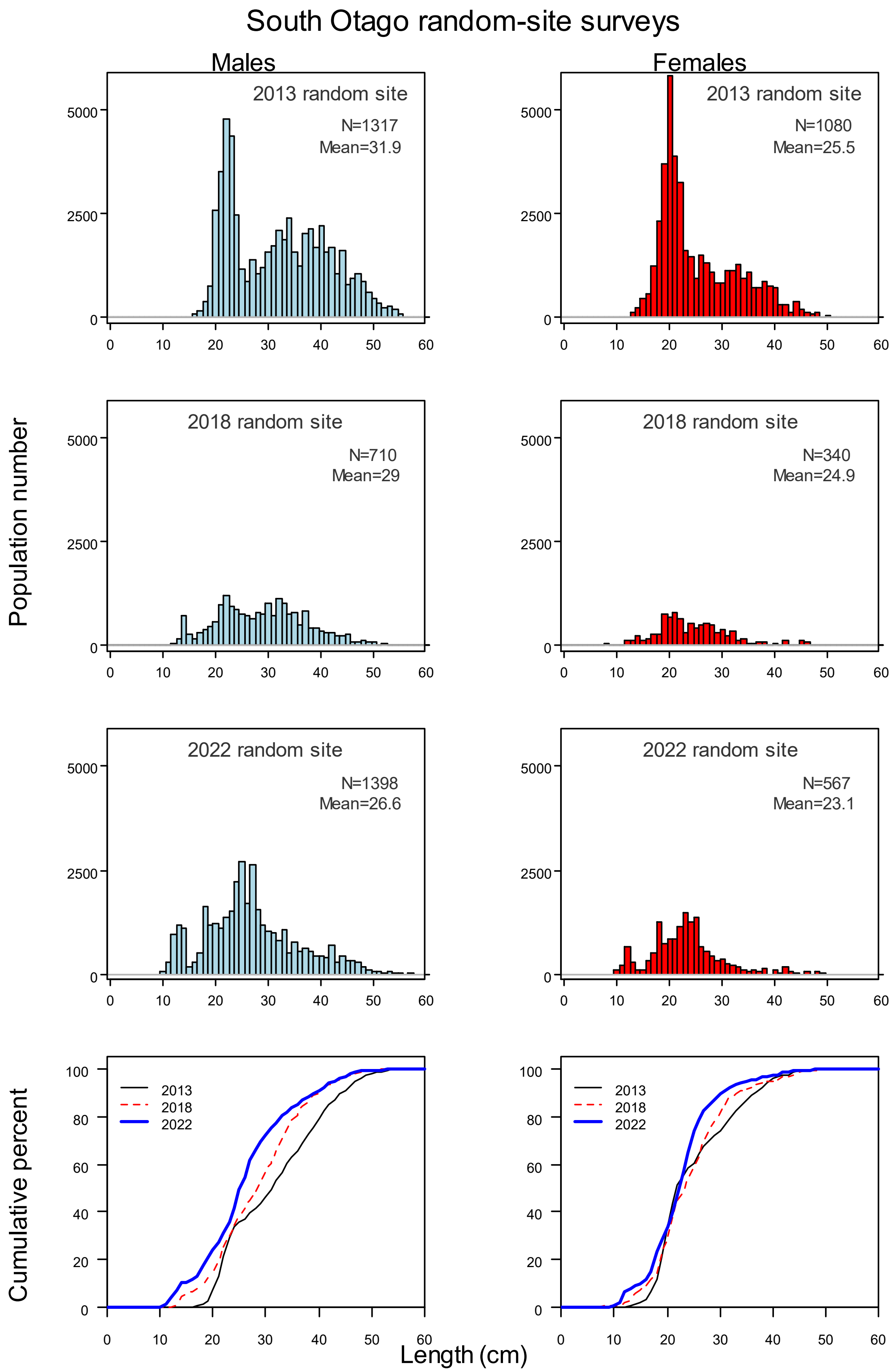

Figure 17: Scaled length frequency and cumulative distributions for male and female blue cod from the south Otago random-site potting surveys in 2013, 2018, and 2022, when all six strata were surveyed. N, sample numbers; Mean, mean length (cm).

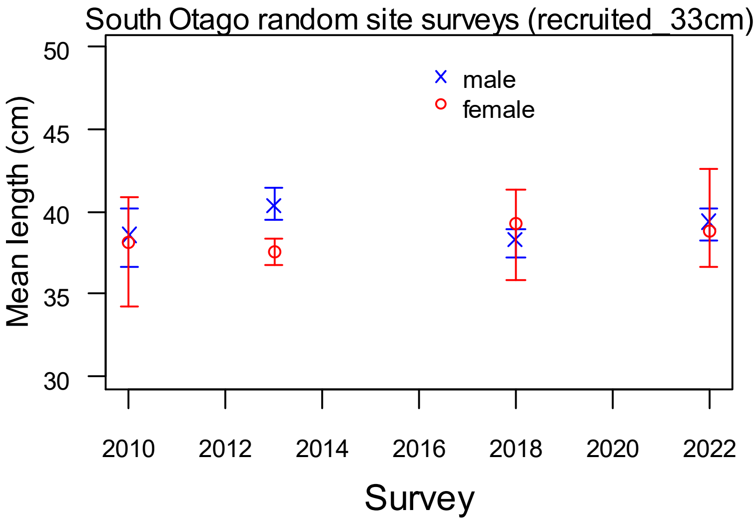

Figure 18: Mean length and 95% confidence intervals for male and female recruited blue cod (33 cm and over) from the south Otago random-site survey in 2010, 2013, 2018, and 2022. The 2010 random-site survey included only three of the six strata (1, 3, and 6).

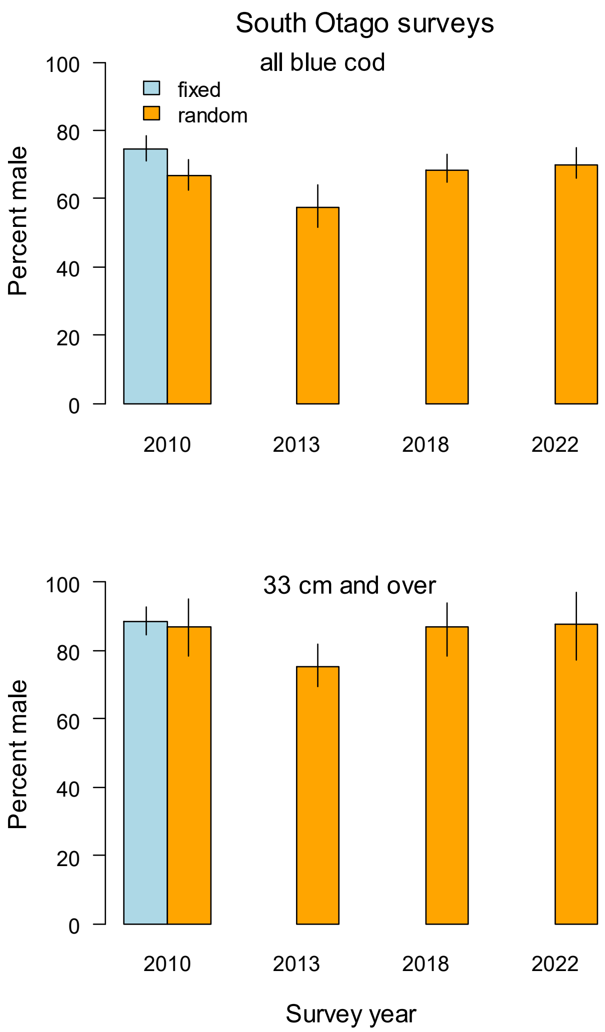

Figure 19: Proportion of males in the south Otago fixed-site potting survey in 2010, and random-site potting surveys in 2010, 2013, 2018, and 2022. The 2010 surveys included only three of the six strata (1, 3, and 6).

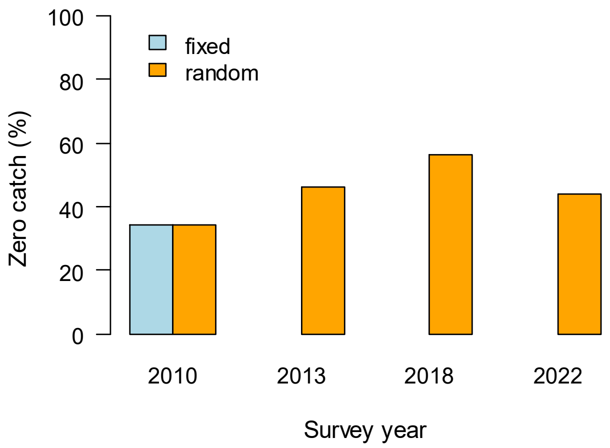

Figure 20: Proportion of pots with zero blue cod catch for the south Otago fixed-site potting survey in 2010, and random-site potting surveys in 2010, 2013, 2018, and 2022. The 2010 surveys included only three of the six strata (1, 3, and 6).

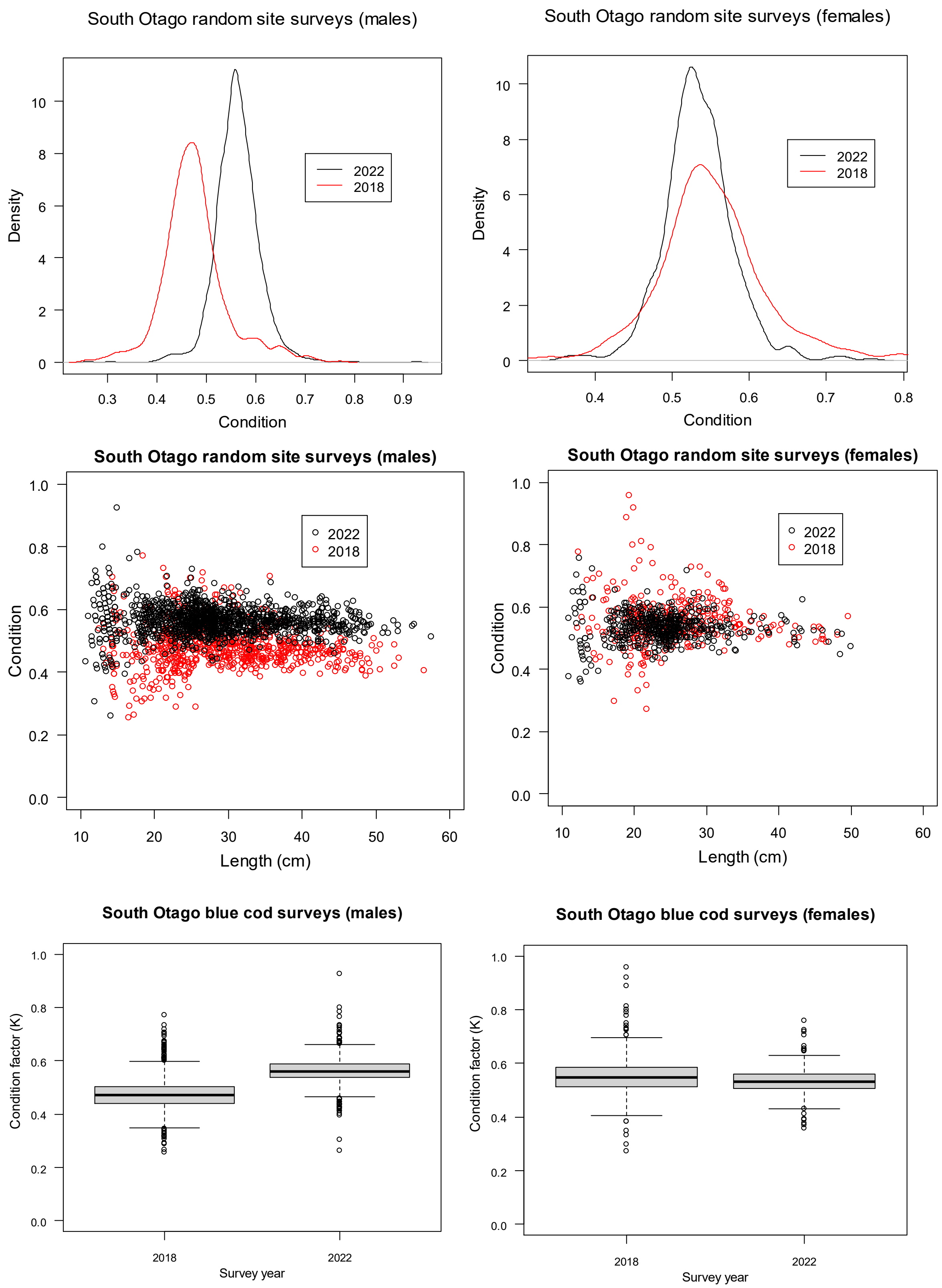

Figure 21: Condition factor (*K*) of blue cod by sex from the random-site potting surveys in 2018 and 2022, including density plots of condition (top); scatter plots of condition by length (centre); median box and whisker plots of condition (bottom). $K = wt*100/l^b$, where *wt* = weight (g), *l*=length (cm), and *b* = survey sex specific growth coefficient.

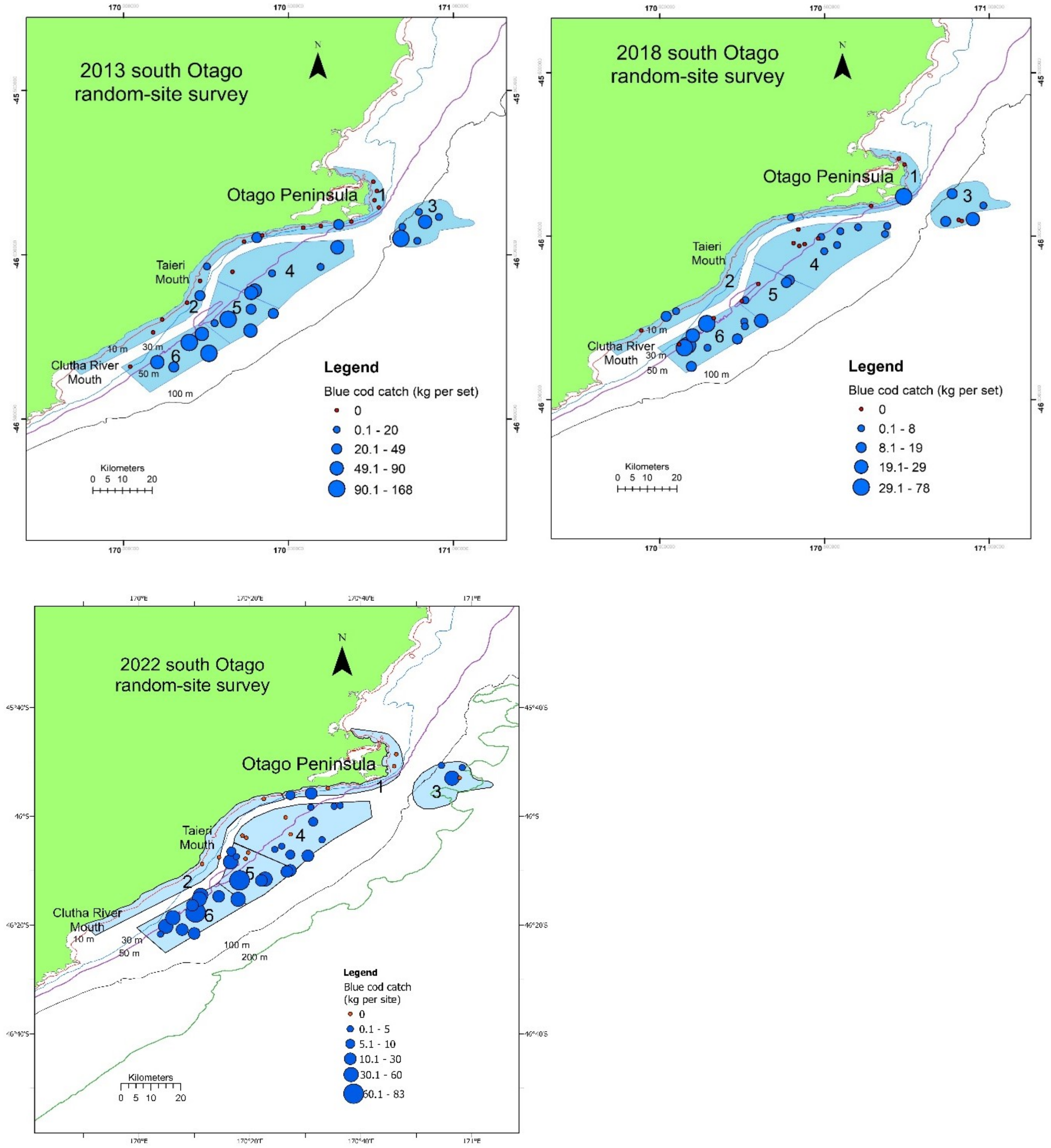

Figure 22: Blue cod catch rates (kg set^{-1}) for the 2013, 2018, and 2022 south Otago random-site blue cod potting surveys. Catch was summed for the six pots in each set. *N* = 40, 43, and 46 sites surveyed, respectively. Note that the scales differ for each plot.

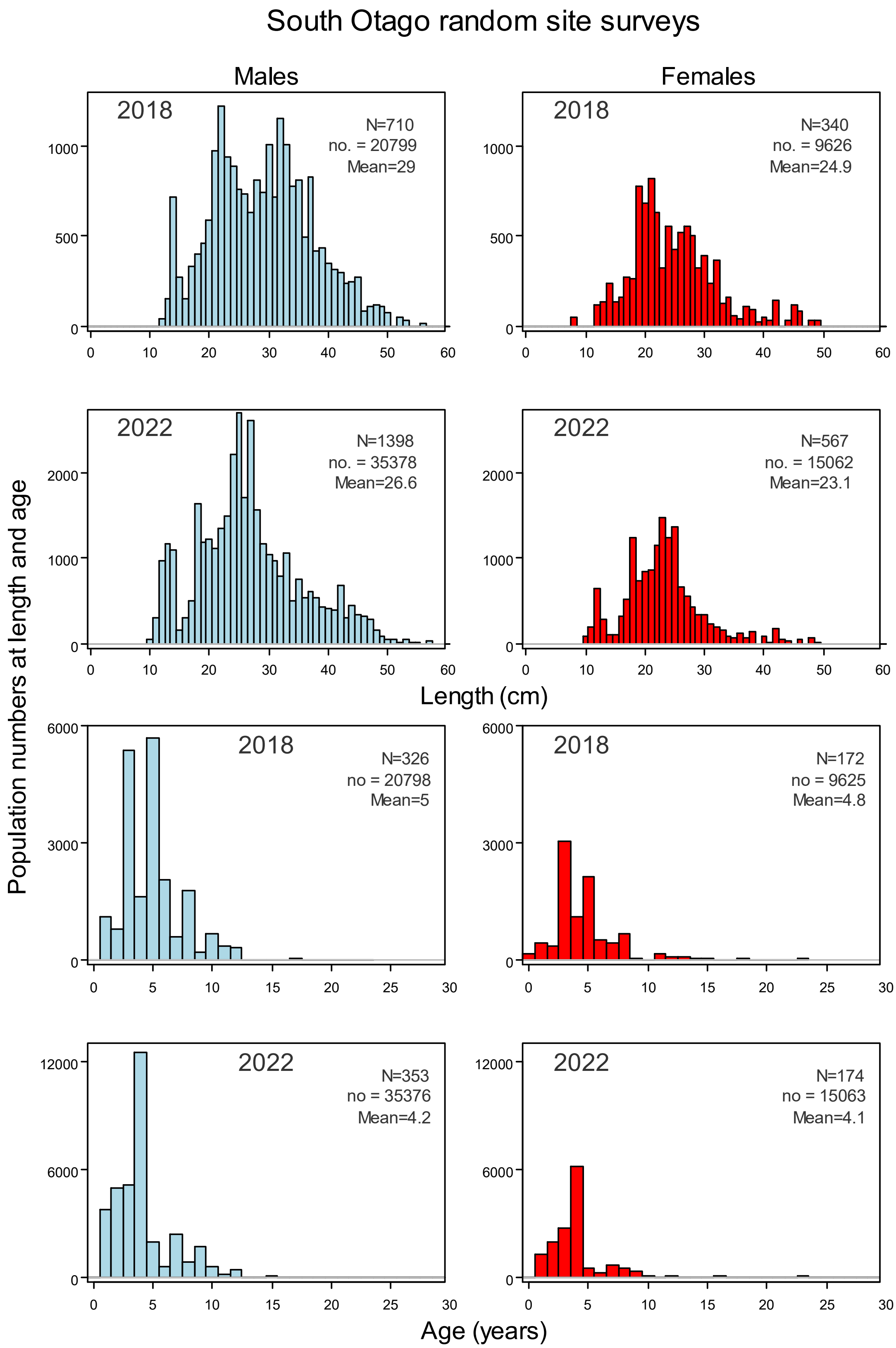

Figure 23: Scaled length and age frequency distributions for male and female blue cod for the 2018 and 2022 south Otago random-site blue cod potting surveys. Scaled numbers are relative, but non-informative. N, sample size; no, population number; Mean, mean length (cm).

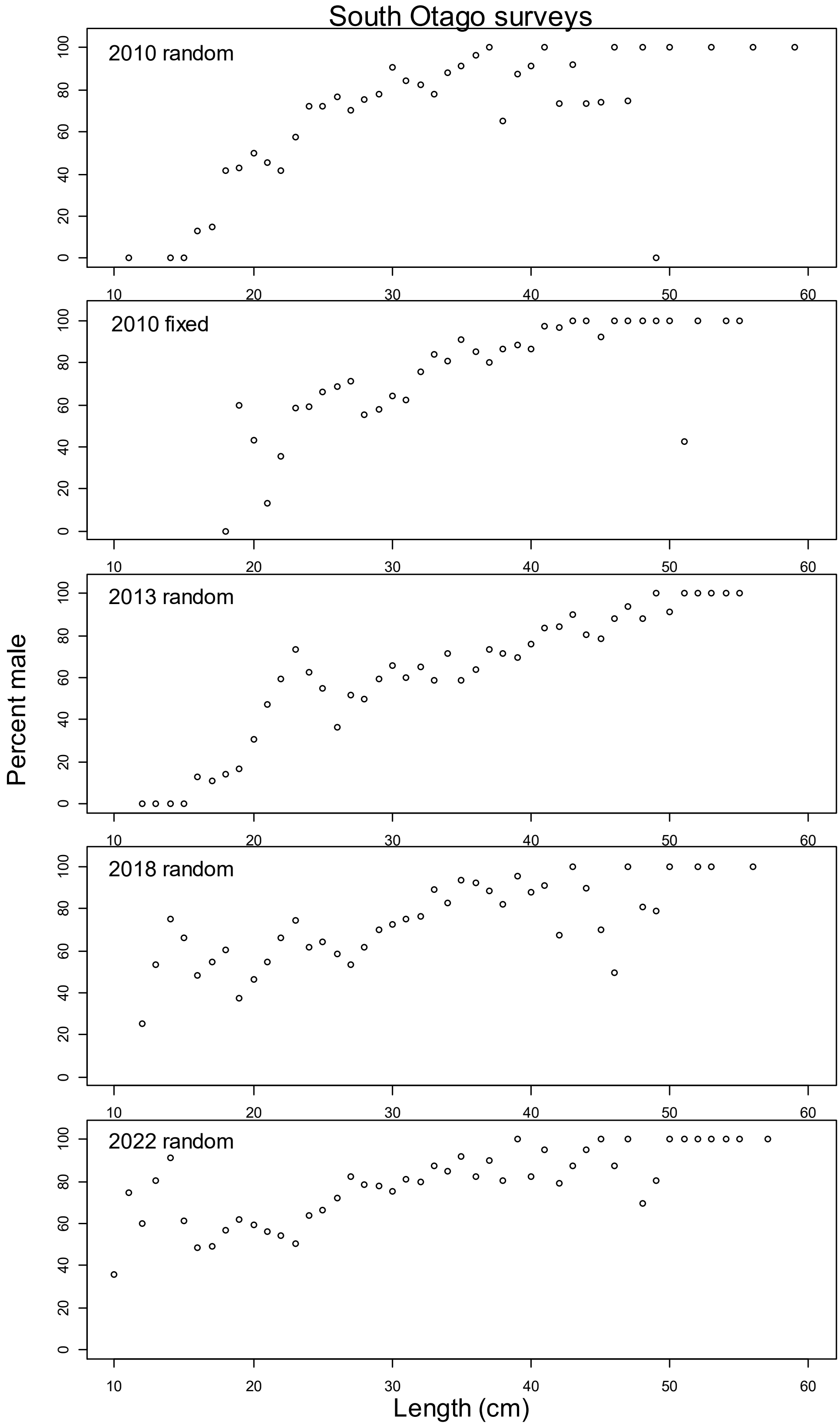

Figure 24: Blue cod percent male by length for the 2010 fixed- and random-site surveys, and the 2013, 2018, and 2022 random-site blue cod potting surveys off south Otago. The 2010 surveys included only three of the six strata (1, 3, and 6).

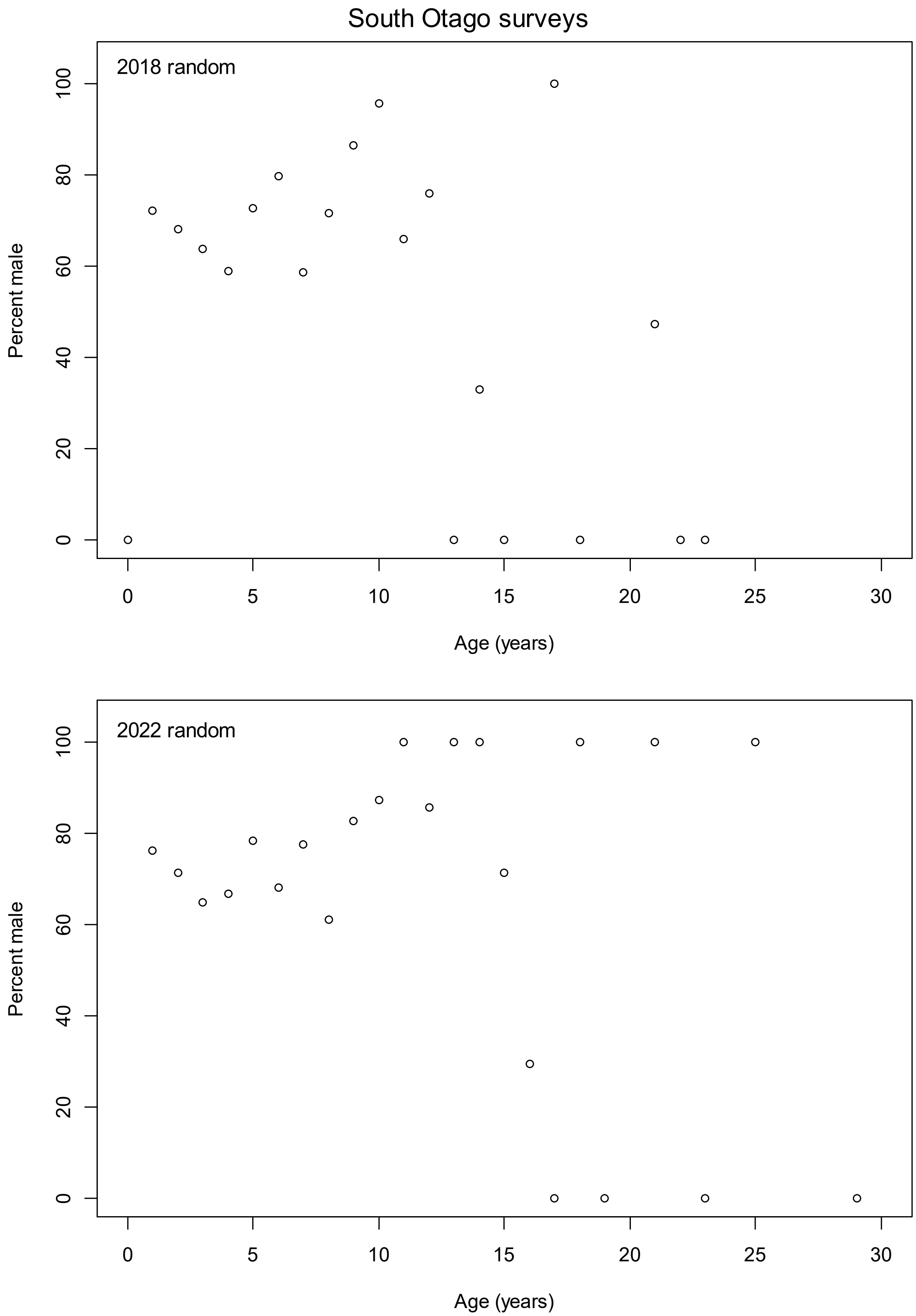

Figure 25: Blue cod percent male by age for the 2018 and 2022 random-site blue cod potting surveys off south Otago. There are no valid age estimates for the 2010 and 2013 surveys.

9. APPENDICES

Appendix 1: Blue cod potting survey details

Table 1-1: 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	Random-site	Systematic	(Beentjes & Page 2018)
	2019	Random-site	Systematic	(Beentjes & Page 2021)
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	Random-site	Systematic	(Beentjes & Miller 2021)
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 2023)
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), 2022 survey this report
Foveaux Strait	2010, 2014, 2018, 2023	Random-site	Systematic	(Carbines & Beentjes 2012, Carbines & Haist 2017a, Beentjes et al. 2019), 2023 survey report pending.
Paterson Inlet	2006	Fixed-site	Directed	(Carbines 2007)
	2010, 2014	Fixed- and random-site	Directed and systematic	(Carbines & Haist 2014a, 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

The following terms are from the blue cod potting survey manual (Beentjes & Francis 2011).

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 south Otago 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, 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 specifies the stratum in which it lies. 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 e.g., 2A, 2B, and sites in stratum 3 could be labelled e.g., 3A, 3B. 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 number 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 2022 south Otago survey for blue cod.

Table 3-1: Number of otoliths collected by sex, strata, and length class during the 2022 survey.

	Males							Females						
	Strata							Strata						
Length (cm)	1	2	3	4	5	6	Totals	1	2	3	4	5	6	Totals
10														
11			1	1	1		3				2	1		3
12				6	4	1	11				6	3		9
13				4	5	3	12				1	2		3
14				5	7		12							
15					3		3				1			1
16						2	2				1	1	2	4
17				1	2		3					2	3	5
18				3	3	4	10				1	6	5	12
19					4	6	10	1			1	3	2	7
20	1			5	5	3	14				6	5	5	16
21				6	3	6	15				4	5	5	14
22	3			5	5	5	18	2			4	5	5	16
23	3			4	6	5	18	1			5	6	5	17
24	10			6	5	5	26				2	9	5	16
25	4			7	8	5	24	2		2	3	8	5	20
26	3			5	6	4	18			3	1	7	7	18
27				5	7	5	17	1		1	1	6	5	14
28	2		2	2	6	5	17			3		3	6	12
29	2		1	3	7	5	18			2		5	5	12
30	1				8	5	14	1		1	1	2	5	10
31	3		2	1	5	5	16			2	1	3	2	8
32	4			3	5	5	17			1		2	3	6
33	2		2		6	4	14			1		2	3	6
34			1		6	6	13			2				2
35	3				4	4	11			1		1		2
36	1				5	5	11			2			1	3
37	3		1		4	5	13			1			1	2
38	3				3	6	12			3				3
39	1				5	4	10							
40					4	5	9			2				2
41				1	4	5	10					1		1
42	1				5	5	11			2			2	4
43	1		1		5	4	11					1	1	2
44	1				4	5	10						1	1
45	2		2		2	4	10							
46			1		4	4	9						1	1
47	2		1		1	4	8							
48					4	2	6						3	3
49	2					1	3					1		1
50			1				1							
51					2		2							
52					1		1							
53					2		2							
54					1		1							
55					1		1							
56														
57						1	1							
Totals	58	0	16	73	178	153	478	8	0	29	41	90	88	256

Appendix 4: Comparison of the 2010 fixed-site and random-site surveys

In 2010, the catch rates of all blue cod from fixed sites were more than double catches from random sites, with no overlap in confidence intervals (see Figure 15). The CVs were similar at 17% and 18%, for fixed- and random-site surveys, respectively, and the highest catch rates in both surveys were in stratum 6.

The length frequency distributions in 2010 were different between fixed and random sites with fixed sites having a higher proportion of larger fish and fewer smaller fish (see Figure 16).

Sex ratios were much the same between survey types in 2010 with 74% and 67% male for fixed- and random-site surveys, respectively (see Figure 19).

The proportion of pots with zero catch was identical (34%) for fixed and random site surveys in 2010 (see Figure 20).

The 2010 survey also compared pot placement (directed and systematic) and found no meaningful differences in catch rates, regardless of pot placement, for either fixed- or random-site surveys (Beentjes & Carbines 2011).