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Relative abundance, size and age structure, and stock status of blue cod off Motunau in 2024

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PLAIN LANGUAGE SUMMARY

South Island recreational blue cod (*Parapercis colias*) fisheries are monitored by Fisheries New Zealand using potting surveys. This report describes the results of the blue cod potting survey carried out off Motunau in North Canterbury during January 2024 – as well as for three previous surveys (2012, 2016, 2020). Estimates are provided for population abundance, size structure from fish length, and age structure from otoliths (ear bones collected for ageing), as well as population sex ratio, total mortality, and fishing mortality. In 2024 the sex ratio was 74% male, and the estimated fishing mortality was nearly four times the target reference level indicating that overfishing is occurring. Survey mean catch rates showed a progressive decline over time, dropping by 66% between 2012 and 2024. The sex ratio over the four surveys was dominated by males with no trend (i.e., 72–76% male). Fishing pressure has been concentrated on just a few older ages, and was considerably higher than the target reference for all the previous surveys.

EXECUTIVE SUMMARY

Beentjes, M.P.[1]; Miller, A. (2024). Relative abundance, size and age structure, and stock status of blue cod off Motunau in 2024.

***New Zealand Fisheries Assessment Report 2024/79*. 54 p.**

This report describes the results of the random-site blue cod (*Parapercis colias*) potting survey carried out off Motunau in North Canterbury during January 2024. Estimates are provided for population abundance, size and age structure, sex ratio, total mortality (*Z*), and spawner biomass-per-recruit ratio. This is the fourth survey in the Motunau random-site survey time series, following those in 2012, 2016 and 2020.

Forty random sites (6 pots per site, producing 240 pot lifts) at depths of 4–36 m from three strata off Motunau were surveyed in January 2024 using the F.V. *Renegade*. Survey mean catch rate of blue cod (all sizes) was 1.02 kg pot^{-1} (coefficient of variation, CV 22 %) and 0.23 kg pot^{-1} (CV 35 %) for recruited blue cod (33 cm and over). Of the 240 pots, 53% had zero catch of blue cod. The overall weighted sex ratio was 74% male and mean lengths were 25.2 cm for males (range 12–46 cm) and 21.4 cm for females (range 13–33 cm). The survey length frequency distributions were unimodal and skewed to the right for both sexes. Mean age was 4.5 years for males (range 1–11 years) and 3.9 years (range 1–7 years) for females. The estimated population age distributions had strong modes at four and six years, and a weak mode for five-year-olds for both sexes.

The male Chapman Robson total mortality (*Z*) for age at recruitment of 7 years was 0.74 yr^{-1} (95% confidence interval of 0.42–1.19). Based on the default natural mortality (*M*) of 0.17, male estimated fishing mortality (*F*) in 2024 was 0.57 yr^{-1} (95% confidence interval 0.25–1.02).

There were no indications of spawning activity during the survey period, with virtually all fish either resting or maturing.

Time series analyses of the four random-site surveys indicate:

1) Mean catch rates for all blue cod and recruited fish showed a 66% decline between 2012 and 2024.
2) The scaled length frequency distributions varied among years because blue cod from Motunau are heavily exploited with high proportions of pre-recruited juvenile fish, and hence distributions are especially influenced by strong and weak recruitment of cohorts to the population.
3) Modal progression of strong age classes between surveys was apparent and supports the ageing methodology based on counts of annual growth rings.
4) The sex ratio of all blue cod was 72–76% male with no trend.
5) The proportion of pots with zero catch has more than doubled from 23% in 2012 to 53% in 2024, consistent with declining abundance
6) Male fishing mortality (*F)* estimates for all four surveys were well above the target reference point of *F*=0.15 (i.e., 0.87*M*) and the *F* in 2024 of 0.57 yr^{-1} was nearly four times that of the target reference *F*.

Motunau fixed-site surveys were carried out in 2005, 2008, 2012, and 2016; the latter two were conducted concurrently with random-site surveys. Notwithstanding the differences in catch rates that can be ascribed to the survey design (fixed- or random-site), there are strong indications that blue cod biomass has declined substantially between 2005 and 2024. The very high estimates of total and fishing mortality, truncated age composition, small size, and strongly skewed sex ratio towards males indicates that the blue cod population off Motunau has been, and continues to be, heavily overfished.

[1] National Institute of Water and Atmospheric Research Ltd.

1. INTRODUCTION

This report describes the results of the random-site blue cod (*Parapercis colias*) potting survey carried out off Motunau in North Canterbury during January 2024. Estimates are provided for population abundance, size and age structure, sex ratio, and total and fishing mortality (*Z* and *F*). This is the fourth survey in the Motunau random-site survey time series, following those in 2012, 2016, and 2020 (Beentjes & Sutton 2017, Carbines & Haist 2018d, Beentjes & Miller 2021). Fixed-site surveys were carried out in 2005, 2008, and concurrently with random-site surveys in 2012 and 2016 (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2012b, Beentjes & Sutton 2017), but have been now been replaced by solely random-site surveys. All Motunau blue cod surveys were funded by Fisheries New Zealand.

1.1 Status of the north Canterbury blue cod stocks

Blue cod has a wide depth range from a few metres depth to about 150 m in a range of habitats including reef edges, shingle/gravel, biogenic reefs, or sandy bottoms close to rocky outcrops. Blue cod is the third most common recreational species caught in New Zealand with a total catch of 223 t (413 000 fish) estimated from the 2022–23 panel survey involving face to face interviews with fishers, plus estimates from charter vessels and recreational take from commercial vessels (Heinemann et al. 2021, Fisheries New Zealand 2024).

Quota Management Area (QMA) BCO 3 extends from the Clarence River, north of Kaikōura, to Slope Point in Southland (Figure 1) and within this area, blue cod recreational catch in 2022–23 was 67 t, equating to 30% of the national total, the second highest of any QMA, behind BCO 5 at 42%. The equivalent BCO 3 estimates in 2011–12 and 2017–18 were 131 t and 109 t, respectively, indicating a declining recreational take over a 13-year period. Recreational boat ramp fishing surveys have consistently shown that the north Canterbury areas of Kaikōura and Motunau are important blue cod fisheries (Hart & Walker 2004, Kendrick et al. 2011, Kendrick & Hanley 2021). The most recent recreational survey of north Canterbury gave harvest estimates of about 21 t of blue cod (Maggs et al. 2023), all caught by line, accounting for almost 30% of the BCO 3 panel survey estimates of recreational catch.

The BCO 3 commercial catch had been stable for 20 years at about the level of the TACC (160 t) before a reduction in the TACC in 2021–22 to 130 t, with similar catches in the last two years (Fisheries New Zealand 2024). Most commercially landed blue cod in BCO 3 is caught by cod potting (67%) or bottom trawl (22%) (Holmes et al. 2022). The pot catch is taken predominantly from Statistical Area 024 off Oamaru, and to a lesser extent 026, and bottom trawl catch is spread throughout Statistical Areas 018, 020, 022, 024, and 026 (Figure 1).

Within the 'Kaikōura Marine Area' established in 2014, the minimum legal size (MLS) is 33 cm and the recreational daily bag limit (DBL) is six blue cod (Figure 2). For the rest of north Canterbury, from Conway River to Waimakariri River including Motunau, the MLS was 30 cm and the DBL ten blue cod until July 2020. On 1 July 2020, the MLS was increased to 33 cm for the entire South Island with different regional daily bag limits reflecting assumed stock status; from Clarence River to Hurunui River (Kaikoura Area), excluding the 'Kaikōura Marine Area' the DBL is currently 10 blue cod. The southern part of north Canterbury (Canterbury Area) from Hurunui River to Rakaia River that includes Motunau, was assigned a 'traffic light' colour of red by Fisheries New Zealand, indicating that the blue cod stocks in this area are considered to be overfished and the DBL was reduced to two blue cod per person.

1.2 Blue cod potting surveys

South Island recreational blue cod fisheries are monitored using potting surveys. These surveys take place predominantly in areas where blue cod recreational fishing is common, but, in some areas, there is substantial overlap between the commercial and recreational fishing grounds, e.g., Foveaux Strait. Surveys are generally carried out every four years and provide data that can be used to monitor local relative abundance, size, age, and sex structure of geographically separate blue cod populations. The surveys provide a measure of the response of populations to changes in fishing pressure and management intervention, such as changes to the daily bag limit, minimum legal size, and area closures. In addition to Motunau, there are currently eight other South Island areas located in key recreational fisheries that are routinely surveyed: Marlborough Sounds, Kaikōura, Banks Peninsula, north Otago, south Otago, Foveaux Strait, Paterson Inlet, and Dusky Sound (Appendix 1).

All South Island potting surveys except Foveaux Strait and south Otago originally used a fixed-site design (Appendix 1) with predetermined (fixed) locations randomly selected from a limited pool of such sites (Beentjes & Francis 2011, Beentjes 2019). Fixed sites represented 'good' fishing spots or locations where blue cod were known to be abundant. The South Island potting surveys were reviewed by an international expert panel in 2009 which recommended that blue cod would be more appropriately surveyed using random-site potting surveys (Stephenson et al. 2024). A random site is a location (single latitude and longitude) randomly generated within a stratum (Appendix 2). Following this recommendation, surveys transitioned to a fully random-site design with interim sampling of both fixed and random sites to allow comparison of catch rates, length and age composition, and sex ratios between the two survey designs. Random sites were used as the only site type in Foveaux Strait and all other surveys, except Dusky Sound, have now transitioned to a fully random survey design.

1.3 Previous Motunau blue cod potting surveys

Previous Motunau surveys were carried out in January 2005, 2008, 2012, 2016, and 2020 (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2012b, Beentjes & Sutton 2017, Carbines & Haist 2018d, Beentjes & Miller 2021). The first two surveys used only fixed sites, whereas in 2012 and 2016, concurrent fixed- and random-site surveys were carried out. The 2020 and 2024 surveys were solely random-site surveys.

1.4 Status of the Motunau blue cod stock

Previously, the standard method of assessing the stock status of blue cod around the South Island by Fisheries New Zealand was to estimate fishing mortality (F) and the associated spawner-biomass-per-recruit ratio (*SPR*), which was used as a proxy for F_{MSY} (maximum sustainable yield biomass) (Fisheries New Zealand 2024). Spawner-biomass-per-recruit is defined as the expected lifetime contribution to the spawning biomass for the average recruit to a fishery. The recommended Harvest Strategy Standard maximum sustainable yield reference point for blue cod (a low productivity stock) is $F_{45\%SPR}$ (Ministry of Fisheries 2011), i.e., target fishing mortality should be at or below a level that reduces the spawner biomass (the total weight of sexually mature fish in the stock) to 45% of that if there was no fishing.

The Fisheries New Zealand Stock Assessment Plenary meeting on 18 July 2022 agreed that the standard *SPR* was no longer appropriate as a target reference point for blue cod in Marlborough Sounds because few females currently grow large enough to recruit to the fishery and the standard spawner-per-recruit approach does not model blue cod sex change dynamics (Beentjes et al. 2022b, Fisheries New Zealand 2024). The Plenary meeting also recommended F=0.87M (natural mortality) as an alternative F_{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 were 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 2024 Motunau survey results to the Inshore Finfish Working Group (14 October 2024), and based on the same rationale applied to the 2021 Marlborough Sounds, the 2022 north Otago, the 2022 south Otago, and the 2023 Foveaux Strait surveys (Beentjes et al. 2022b, Beentjes

& Fenwick 2023a, 2023b, Beentjes & Miller 2024), the working group agreed that *SPR* is also no longer appropriate as a target reference point for Motunau blue cod. Hence *SPR* analyses for the 2024 Motunau 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 objectives of Fisheries New Zealand research project BCO2023-04 for Motunau. The Kaikōura blue cod survey is reported by Beentjes & Page (2024).

Overall Objective

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

Specific Objectives

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

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

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

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

5. Broader outcomes.

The Kaikoura blue cod survey is reported by Beentjes & Page (2024)

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

2. METHODS

2.1 Timing and consultation

A two-phase random stratified potting survey was carried off Motunau by the National Institute of Water & Atmospheric Research Ltd (NIWA) from 15 to 25 January 2024 (excluding mobilisation and demobilisation), consistent with the previous survey dates and coinciding with the known spawning times in this region. The Motunau survey was supported and endorsed by Ngai Tuahuriri and Motunau Marine Guardians.

2.2 Survey area

The survey area for the 2024 Motunau random-site survey was consistent with the previous surveys. The southern and northern boundaries were determined in 2004 based on discussions with local fishers, Fisheries New Zealand (formerly Ministry of Fisheries), and the South Recreational Advisory Committee (Carbines & Beentjes 2006a). Fishers were given charts of the area and asked to mark discrete locations where blue cod are most commonly caught within the survey areas. The survey area was divided into three contiguous inshore strata, from Double Corner to Sail Rock, using the approximate 30 m depth contour as the outer strata boundary (Figure 3). The total area (square kilometres) of each stratum was taken as a proxy for available habitat for blue cod.

2.3 Survey design

2.3.1 Allocation of sites

Simulations to determine the optimal allocation of random sites among the three strata were carried out using NIWA's Optimal Station Allocation Program (*allocate*) based on catch rate data from the 2012, 2016, and 2020 random-site Motunau surveys. Simulations were constrained to have a minimum of three sites per stratum and a CV (coefficient of variation) of no greater than 15%. The simulations indicated that 40 random sites were required to achieve the target CV.

A two-phase stratified random station design (Francis 1984) was used with 34 sites allocated to phase 1, and the remaining six available for allocation in phase 2, consistent with the proportion of phase 2 sites used in previous surveys (Table 1). Allocation of phase 2 stations was based on the mean pot catch rate (kg pot^{-1}) of all blue cod per stratum and optimised using the 'area mean squared' method of Francis (1984). In this way, stations were assigned iteratively to the stratum in which the expected gain is greatest, where expected gain is given by:

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

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

Random sites

A random site has a location (single latitude and longitude) generated randomly within a stratum (Beentjes 2019). Sufficient sites to cover both first and second phase stations were generated for each stratum using the NIWA random station generator program (*Rand_stn* v1.00-2014-07-21) with the constraint that sites were at least 800 m apart. 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 2019). Consistent with previous random-site surveys in Motunau, systematic pot placement was used where the position of each pot was arranged systematically with the first pot set 200 m to the north of the site location and remaining pots set in a hexagon pattern around the site, at about 200 m from the site position. Where sites were too close to shore to accommodate the hexagon configuration, pots were set either side of the site along the shore 100 m apart.

2.3.2 Vessels and gear

The 2024 Motunau survey was conducted from F.V. *Renegade* (Registration number 135918), a Motunau-based commercial vessel owned and skippered by Mr Geoff Basher, also used for the previous survey in 2020. Earlier surveys used either F.V. *Navigator* (2012 and 2016) or F.V. *Legacy* (2008) also owned and skippered by Geoff Basher. The F.V. *Renegade* is equipped to set and lift rock lobster and blue cod pots with specifications: 13.5 m length, 12 t weight, aluminium monohull, powered by twin 450 hp Yanmar Diesel Propulsion 292 jet units, with a maximum speed of 30 knots.

Six custom designed and built cod pots were used to conduct the survey (Pot Plan 2 given by Beentjes & Francis 2011). Pots were baited with 700 g of paua (*Haliotis iris*) viscera in 'snifter pottles'. Bait was topped up or replaced after every lift. The same pot design and bait type were used in all previous surveys.

A high-performance, 3-axis (3D) acoustic Doppler current profiler (Nortek Signature 500 kHz) was deployed at each site. The ADCP recorded current flow and direction in 1-m depth bins above the seafloor. A temperature sensor (Seabird SBE56 Temperature Logger) was also attached to the ADCP frame to record bottom water temperature during the set.

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

2.4 Sampling methods

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

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

At each site, six pots were set and left to fish (soak) for a target period of one hour during daylight hours. As each pot was placed, a record was made of sequential pot number (1 to 6), latitude and longitude from GPS, depth, and time of day. After each site was completed, the next closest site in the stratum was sampled. The ADCP was deployed at the centre of each site prior to the setting of pots and recovered after the last pot of each set was lifted. The order that strata were surveyed depended on the prevailing weather conditions, with the most distant strata and/or sites sampled in calm weather. Following pot placement, environmental data were recorded: wind direction, speed, and force; air temperature and pressure; water clarity using secchi disc, sea condition, and colour; swell height and direction; bottom type and contour; surface temperature. These variables and their units are defined in the potting manual (Beentjes 2019).

Pots were lifted aboard using the vessel's hydraulic pot lifter in the order they were set, and the time of each lift was recorded. The proportion of the bait remaining in the snifter pottle was recorded. Pots were then emptied and the contents sorted by species. Total catch weight per pot was recorded for each species to the nearest 10 g using 0–6/6–15 kg Marel motion compensating scales. The number of individuals of each species per pot was also recorded. Total length to the nearest centimetre below actual length, individual fish weight to the nearest 10 g, sex, and gonad maturity were recorded for all blue cod.

Both sagittal otoliths were removed from a representative length range of blue cod males and females over the available length range across all strata. To ensure that otolith collection was spread across the survey area and that larger and smaller fish were adequately sampled, the following collection schedule was used:

1. Collect three blue cod otolith pairs per one centimetre size class for each sex, in each stratum.
2. Collect all blue cod otoliths for males over 34 cm and below 16 cm.
3. Collect all blue cod otoliths for females over 25 cm and below 15 cm.

Sex and maturity were determined by dissection and macroscopic examination of the gonads (Carbines 1998, 2004).

Blue cod gonad staging was undertaken using the five stage Stock Monitoring (SM) method used on previous surveys. Gonads were recorded as follows: 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

2.5 Data storage

The 2024 Motunau survey trip code was REN2401. At the completion of the survey, trip, station, catch, and biological data were entered into the *trawl* and *age* databases in accordance with their business rules and the blue cod potting survey standards and specifications (Beentjes & Francis 2011, Beentjes 2019).

All analyses were carried out using data extracted from the *trawl* and *age* databases. Random sites were entered into attribute *stn_code*, prefixed with R (e.g., R1A, R2B, R3C). 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 in set one, 21 to 26 for set two, etc.). In the *age* database, the *sample_no* is equivalent to *station_no* in the *trawl* database.

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

2.6 Age estimates

Otolith preparation and reading

To assess reader competency in ageing before reading the 2024 survey otoliths, the two readers aged a subsample of 50 reference otolith preparations with the aim of achieving a score for Index of Average Percentage Error (IAPE) (Beamish & Fournier 1981) and mean coefficient of variation (CV) (Chang 1982) of below 1.50% and 2.12%, respectively (Walsh 2017).

Otolith preparation and reading

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

1. Blue cod otolith thin-section preparations were made as follows. Otoliths were individually marked on their distal faces with a dot in the centrum using a cold light source on low power to light the otolith from behind. Five otoliths (from five different fish) were then embedded in an epoxy resin mould and cured at 50 ºC. Thin sections were taken along the otolith dorso-ventral axis through the centrum of all five otoliths, using a Struers Accutom-50 digital sectioning machine, with a section thickness of approximately 350 µm. Resulting thin section wafers were cleaned and embedded on microscope slides using epoxy resin and covered with a coverslip. Finally, these slides were oven cured at 50 ºC.
2. Otolith sections were read against a black background using reflected light under a compound microscope at a magnification of 40–100 times. Under reflected light, opaque zones appear light and translucent zones appear dark. Translucent zones were counted (ageing of blue cod otolith thin sections prior to 2015 counted opaque zones to estimate age).
3. Two readers initially read all otoliths without reference to fish length, sex, or previous age estimates.
4. When interpreting blue cod zone counts, both ventral and dorsal sides of the otolith were read, mainly from the core toward the proximal surface close to the sulcus.
5. The forced margin method was used: ‘Wide’ (a moderate to wide translucent zone present on the margin), October–February; ‘Line’ (an opaque zone in the process of being laid down or fully formed on the margin), March–April; ‘Narrow’ (a narrow to moderate translucent zone present on the margin), May–September.
6. Where between-reader counts differed, the readers rechecked the count and conferred until agreement was reached, unless the section was a grade 5 (unreadable) or damaged (removed from the collection).
7. Between-reader ageing precision was assessed by the application of the methods and graphical techniques documented by Campana et al. (1995) and Campana (2001); including APE (average percent error) and coefficient of variation.

2.7 Data analyses

Analyses of catch rates, sex ratios, scaled length distribution, catch-at-age, and mortality estimates (Z and F), were carried out.

Analyses of catch rates and coefficients of variation, length-weight parameters, scaled length and age frequencies and CVs, sex ratios, mean length, and mean age were carried out using the equations documented in the blue cod potting survey standards and specifications (Beentjes & Francis 2011, Beentjes 2019). Fish length was recorded to the nearest millimetre on the survey, but, following standard protocol, all lengths were rounded down to the nearest centimetre for analyses of the scaled length distribution and mean length (i.e., using data extracted from t_lgth in the *trawl* database). Length was also rounded down when producing the age-length-keys for catch-at-age analyses, and for estimating von Bertalanffy parameters.

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, Beentjes 2019). Catch rates and 95% confidence intervals (± 1.96 standard error) were estimated for all blue cod and for recruited blue cod (33 cm and over). Catch rates of recruited blue cod were based on the sum of the weights of individual recruited fish. The stratum areas shown in Table 1 were used as the area of the stratum (A_t) when scaling catch rates (equations 3 and 5 given by Beentjes & Francis 2011). Catch rates are presented by stratum and overall.

2.7.2 Length-weight parameters

The length-weight parameters a_k, b_k from the 2024 Motunau survey were used in the following equation:

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

This calculates the expected weight (g) for a fish of sex k and length l (cm) in the survey catch. These parameters were calculated from the coefficients of sex-specific linear regressions of log(weight) on log(length) using all fish for which length, weight, and sex were recorded: b_k is the slope of the regression line, and log(a_k) is its y-intercept.

2.7.3 Growth parameters

von Bertalanffy growth models (von Bertalanffy 1938) for each sex were fitted to the 2024 Motunau survey length-age data as follows:

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

where L_t is the length (cm) at age t, L_∞ is the asymptotic mean maximum length, K is a constant (growth rate coefficient), and t_0 is hypothetical age (years) for a fish of zero length. Because there were so few fish older than seven years in the 2024 and previous random-site surveys, the resulting L_∞ growth parameters were highly variable. Hence, von Bertalanffy growth models were fitted to the combined length and age data from the last three Motunau surveys with valid ageing (i.e., 2016, 2020, and 2024) to provide more representative growth parameters for estimating selectivity of age to the fishery at the minimum legal size (33 cm in 2024, and 30 cm in 2016 and 2020). Growth was first compared for all three Motunau surveys to justify this approach.

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 (LF) data by the area of the stratum, number of sets in each stratum, and estimated catch weight determined from the length-weight relationship of individual fish. The latter scaling should be negligible or very close to one if all fish caught during the survey were measured (which they were) and if the actual weight of the catch is close to the estimated weight of the catch. The stratum area shown in Table 1 was taken as the area of the stratum (A_t), and the length-weight parameter estimates were from the 2024 Motunau survey data for males and females separately.

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

Bootstrap resampling (300 bootstraps) was used to calculate CVs for proportions- and numbers-at-length and -age using equation 12 of the manual (Beentjes & Francis 2011, Beentjes 2019). That is, simulated data sets were created by resampling (with replacement) sets from each stratum and fish from each set (for length and sex information).

Catch-at-age was estimated using a single age-length-key (ALK) (from 2024 Motunau age data) for each sex applied to the sex specific length data from the entire survey area. Scaled length and age frequency proportions are presented, together with CVs for each length and age class, and the mean weighted coefficients of variation (MWCVs).

2.7.5 Unsexed fish

All blue cod caught during the 2024 Motunau survey were sexed.

2.7.6 Sex ratios, and mean length and age

Sex ratios (expressed as percentage male) and mean lengths for the stratum and survey, were calculated using equations 10 and 11 of Beentjes & Francis (2011) from the stratum or survey scaled LFs. Mean ages were calculated analogously from the scaled age frequencies. Sex ratios were also estimated for recruited blue cod (33 cm and over), and overall survey 95% confidence intervals around sex ratios were generated from the 300 LF bootstraps. The proportion of fish of recruited size was estimated from the scaled LFs.

2.7.7 Total mortality (*Z*) and fishing mortality (*F*) estimates

Total mortality (*Z*) was estimated from catch-curve analysis using the Chapman-Robson estimator (CR) (Chapman & Robson 1960). Catch curve analyses measure the sequential decline of cohorts annually. The CR method was shown to be less biased than the simple regression catch curve analysis (Dunn et al. 2002). Catch curve analysis assumes that the right-hand descending part of the curve declines exponentially and that the slope is equivalent to the total mortality Z ($M + F$). This assumes that recruitment and mortality are constant, that all recruited fish are equally vulnerable to capture, and that there are no age estimation errors.

Estimates of CR total mortality, *Z*, were calculated for age-at-recruitment values of 5 to 9 years using the maximum-likelihood estimator (equation 13 of Beentjes & Francis 2011). Variance (95% confidence intervals) associated with *Z* was estimated under three different parameters of recruitment, ageing error, and *Z* estimate error (equations 14 to 18 of Beentjes & Francis 2011). Catch-at-age distributions were estimated separately for males and females and then combined, hence providing a single *Z* estimate for the population. Unlike previous analyses for the Motunau surveys, a second set of *Z* estimates was made using only ages of males. The male-only *Z* was estimated because there are often very few females larger than the MLS in heavily fished populations, particularly Motunau, and the fishing mortality of males is more informative. Fishing mortality was estimated from the results of the Chapman-Robson analyses and the current default estimate of *M* (i.e., $F = Z–M$) was assumed to be 0.17, revised from 0.14 in 2019 (Doonan 2020). Age-at-full recruitment (AgeR), was assumed to be equal to the average age at which males reached the MLS of 33 cm (selectivity based on the combined 2016, 2020, and 2024 surveys von Bertalanffy growth coefficients) plus one year (i.e., approximately 7 years of age in this case). Sensitivity analyses of *F* were carried out for *M* values 20% above and below the default (0.14 and 0.20).

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

2.7.8 Condition factor

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

$$K = 100w/l^3$$

where l is the total length (centimetres), w is the fish weight (grams).

2.7.9 Analyses of previous Motunau surveys

In the 2016 survey report (Beentjes & Sutton 2017), catch rates, scaled length frequencies, and sex ratios were estimated for the 2012 Motunau survey (carried out by Saltwater Research), consistent with the potting survey standards and specifications (Beentjes & Francis 2011, Beentjes 2019). At that time, the data for the 2012 survey had not been loaded into the Fisheries New Zealand *trawl* database, nor had the report been published, and hence analyses were carried out from raw data provided to NIWA on a spreadsheet. Catch rates of recruited blue cod were based on the sum of the weights of individual fish 30 cm and over. These were estimated from the 2015 Kaikōura survey length-weight coefficients because no individual fish weights were then available for the 2012 Motunau survey. The catch rates, scaled length frequencies, and sex ratios for the 2012 survey have not been re-estimated using data extracted from the *trawl* database. Although blue cod otoliths were collected and aged from the 2012 and previous surveys, the ageing is considered to be invalid because it was not carried out using the methods of the blue cod ADP (Walsh 2017).

As part of the 2024 survey analyses, catch rates and sex ratios for recruited fish were estimated for all Motunau fixed- and random-site surveys (2004 to 2020) using a length of 33 cm, the MLS that came into effect in July 2020, replacing the limit of 30 cm. In addition, male only total and fishing mortality (Z and *F*) was estimated for the random-site surveys with valid ageing (2016 and 2020).

3. RESULTS

3.1 Motunau 2024 random-site survey

Forty random sites (6 pots per site, producing 240 pot lifts) from three strata off Motunau were surveyed from 15 to 25 January 2024 (Table 1, Figure 4). Depths sampled were 4–36 m (mean = 21 m). Thirty-four sites were carried out in phase 1 and six in phase 2, in stratum 3. Random-site systematic pot placement configuration is shown for six sites in stratum 3 (Figure 5).

3.1.1 Blue cod catch rates, length and sex ratio

A total of 258.9 kg of blue cod (1107 fish) was taken from the three strata, comprising 86.5% by weight of the catch of all species on the survey (Table 2). Bycatch species included seven teleost fishes, as well as octopus. The three most abundant bycatch species, by number, were leatherjacket (*Meuschenia scaber*), spotty (*Notolabrus celidotus*), and scarlet wrasse (*Pseudolabrus miles*).

Mean catch rates (kg pot^{-1}) of blue cod (all blue cod, and 33 cm and over) are presented by stratum and overall (Table 3, Figure 6). Mean catch rates of blue cod (all sizes) by stratum were 0.87–1.53 kg pot^{-1} with highest catch rates in stratum 1 and lowest in stratum 2 (Table 3, Figure 6). The all-blue-cod survey catch rate was 1.02 kg pot^{-1} with a CV of 21.7%. Catch rates for recruited blue cod (33 cm and over) did not follow the same pattern among strata as for all blue cod with highest catch rates in stratum 3, and the recruited blue cod survey catch rate was 0.23 kg pot^{-1} (CV 35.0%) (Table 3, Figure 6). Of the 240 random-site pots, 128 (53%) had zero catch of blue cod.

The bubble plot catch rates of blue cod by site (kg site^{-1}) did not show any clear patterns offshore or alongshore (Figure 7). Of the 40 sites, 12 (30%) had zero catch in all six pots.

Of the 1107 blue cod caught, all were sexed, measured for length, and weighed (Table 4). The sex ratios were 68–76% male across the three strata and the overall area-weighted sex ratio was 74% male (Table 4). Length ranges were 12–46 cm for males and 13–33 cm for females, and the overall weighted mean length was 25.2 cm for males and 21.4 cm for females. The scaled length frequency distributions were generally similar for each sex among the three strata with few males and virtually no females of length 33 cm and over (Figure 8).

3.1.2 Age and growth

Otolith section ages from 145 males and 72 females collected from the 2024 survey across all three strata were used to estimate the population age structure (Table 5, Appendix 3).

The two readers achieved CV and IAPE scores below the targets when ageing 50 otoliths from the blue cod reference collection (Table 6). Between-reader comparisons of the 2024 Motunau survey otoliths are presented in Figure 9. The first counts of the two readers showed 95% agreement, and overall there was no bias between readers with a CV of 1.15% and an IAPE of 0.81%.

The length-age data for the 2024 survey are plotted and the von Bertalanffy model fits and growth parameters (K, t_0, and L_∞) are shown for males and females separately (Figure 10). There was a large range in length-at-age particularly for males; and males grew faster and were the largest and oldest fish. The 2016 and 2020 fitted von Bertalanffy (VB) curves were similar, but the L_∞ values were unlikely to be representative of the true growth because older fish, which can live to 30 years of age and which normally sit on the flat part of the curve, were absent (Figure 10). Comparison of the truncated VB growth curves for the three surveys indicate that growth, at least in the steeper part of the curves, was similar (Figure 11) and hence the age-length data were combined to generate a single set of VB parameters (Figure 12). These combined survey parameters were used to estimate the age at recruitment for males at minimum legal size at the time of each of the surveys (i.e., 30 cm in 2016 and 2020; and 33 cm in 2024).

The length-weight parameters from the 2024 Motunau survey were a = 0.007093 and b = 3.2146 for males (N = 804, range = 12–46 cm); a = 0.008316 and b = 3.1639 for females (N = 303, range = 13–33 cm); and a = 0.007307 and b = 3.2055 for males and females combined (N = 1104, range = 12–46 cm).

3.1.3 Condition

The mean condition factors (K) for the 2024 Motunau survey were 1.42 for males, and 1.38 for females (Table 7). The median condition and range by sex and stratum are shown in Figure 13. There were no clear differences in the mean or median condition factors for either sex, or among strata (Table 7, Figure 13).

3.1.4 Spawning activity

Gonad stages of blue cod sampled in January 2024 are presented by sex for the survey overall (Table 8). There was no indication of spawning activity during the survey period with virtually all fish either resting/immature or maturing.

3.1.5 Population length and age composition

The scaled length frequency and age distributions for the 2024 Motunau random-site survey are shown as histograms for all strata combined and as cumulative frequency line plots for males, females, and both sexes combined (Figure 14).

The scaled length frequency distribution for males was unimodal but skewed right, and the overall mean length was 25.2 cm. The female distribution was much narrower than males and was also unimodal with a slight right skew, and an overall mean length of 21.4 cm (Figure 14). The female cumulative distribution plots of length frequency were much steeper than for males, reflecting the virtual absence of females larger than 30 cm (Figure 14). Indeed, the proportions of all fish that were recruited (33 cm and over) were 10% for males and 0.5% for females by number. The mean weighted coefficients of variation (MWCVs) around the length distributions were 27% for males and 35% for females.

Age estimates ranged from 1–11 years for males and 1–7 years for females, but most males were aged between 2 and 6, and females between 3 and 6 (Figure 14). The estimated population age distributions indicated virtually knife-edge selectivity to the potting method at two to three years and show relatively strong modes at four and six years, and a weak mode for five-year-olds for both sexes. The cumulative distribution plots of age frequency were generally similar for both sexes with slight differences stemming from males having a higher proportion of older fish (Figure 14). Further, the mean age of females was less than that of males (4.5 for males and 3.9 years for females). The MWCVs around the age distributions were 23% for males and 29% for females, indicating a good representation of the overall population age structure.

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

The 2024 survey Chapman-Robson (CR) male-only total mortality estimates (*Z*) and 95% confidence intervals are given for a range of recruitment ages (5–9 years) in Table 9. Age-at-full recruitment (AgeR) was assumed to be equal to the age at which males reached the MLS of 33 cm plus one year, which is close to seven years (see growth curve in Figure 12). The male CR *Z* for AgeR of 7 years for Motunau in 2024 was 0.74 yr^{-1} (95% confidence interval of 0.42–1.19) (Table 9).

The traditional catch curve based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment is shown for diagnostic purposes (Figure 15). The age at full recruitment was taken as 7 years. The low numbers of fish and age classes older than the recruited age has influenced the slope of the regression line and probably the validity of *Z,* to some extent. However, the combined male and female plot seems plausible, reflecting very high total mortality.

The 2024 Motunau survey male mortality parameters (CR *Z* and *F*) at three values of *M* and age-at-full recruitment of 7 years are shown in Table 10. Based on the default *M* of 0.17, male estimated fishing mortality (*F*) in 2024 was 0.57 yr^{-1} (95% confidence intervals 0.25–1.02).

3.2 Motunau random-site survey time series (2012, 2016, 2020, and 2024)

There have been four random-site surveys in Motunau (2012, 2016, 2020, and 2024), which provide a time series that is becoming increasingly useful for identifying trends in the population status.

Mean catch rates (kg pot^{-1}) for all blue cod and recruited blue cod (33 cm and over) for each of the four random-site surveys are presented in Figure 16. Note, the MLS increased from 30 to 33 cm in July 2020, but for comparison, 33 cm is used as recruited length for all surveys. The relative differences in catch rates among strata were generally preserved over time, i.e., catch rates were consistently highest in stratum 1 and lowest in stratum 3. The all blue cod survey mean catch rates showed a progressive decline over time, dropping by 66% between 2012 and 2024 with no overlap of the confidence intervals (Figure 16). The recruited catch rates showed the same trend with a drop of 75% between 2012 and 2024, also with no overlap in the confidence intervals.

Catch rate bubble plots for each of the four random-site surveys were consistent with the strata and overall survey trends, showing declining catch rates over time (Figure 17). There were no strong spatial patterns in catch rates although the largest catch rates tended to be in stratum 1 in the north east of the survey area, except in 2024.

The scaled length frequency distributions varied among years, which is likely to be because blue cod from Motunau are heavily exploited with high proportions of pre-recruited juvenile fish, and hence distributions are especially influenced by strong and weak recruitment of cohorts to the population (Figure 18).

The mean recruited length of males or females showed no trend over the four random-site surveys, but there was a steady decline in the proportion of recruited males (33 cm and over), whereas for females, the proportion recruited was close to zero for all random-site surveys (i.e., 2012, 0.61%; 2016, 0.72%; 2020, 1.02%; and 2024, 0.46%) (Figure 19).

The sex ratio for all surveys was 72–76% male for all blue cod, and 97–99% male for recruited blue cod, with no trends (Figure 20). There were also no differences in the all blue cod sex ratio between strata, or trends within strata over time (Figure 20).

Age compositions could be validly compared for only the 2016, 2020, and 2024 random-site surveys (Figure 21) because blue cod ageing from the 2012 random-site survey was carried out before the new age determination protocol was developed. The 3-year-old age class in 2016 progressed through to a strong 7-year-old age class for both sexes in 2020. Similarly, the strong 5- and 6-year-old male age classes progressed to 9- and 10-year-old age classes in 2020, but for females these age classes were not present, which is likely to be a result of females changing sex at an elevated rate because of the high fishing mortality (Figure 21). The relatively weak 4-year-old age class in 2016 was not present in 2020. There was also clear modal progression apparent between 2020 and 2024 surveys with strong 2-, 5- and 7-year-old male age classes progressing through to strong age classes for 6-, 9-, and 11-year-olds; and the weak 6-year age class did not appear as 10-year-olds in 2024. Modal progression between 2020 and 2024 was less striking for females, which have fewer age classes in the population, but the strong 2-year-old age class progressed through to a strong 6-year-old age class in 2024.

The Chapman Robson male total mortality estimates (*Z*) for age of recruitment at 6 or 7 years of age have ranged from 0.68 yr^{-1} in 2020 to 0.79 yr^{-1} in 2016, and associated fishing mortality estimates followed the same pattern ranging from 0.51 to 0.62 yr^{-1} (Table 10, Figure 22). The wide confidence intervals around *F* indicated that these annual differences were not likely to be statistically significant. All male *F* estimates were well above the target reference point of F=0.15 (i.e., 0.87M) and the *F* in 2024 of 0.57 yr^{-1} was nearly four times that of the reference *F* (Figure 22). The slopes of the right-hand limbs of the catch curves can vary considerably depending on the number of recruited age classes (see Figures 15 and 21), and the strength of the first recruited age class. With so few age classes compared to virgin stocks, and highly variable recruitment, the slope can be strongly affected by one age class. A cautious approach should therefore be taken when interpreting *Z* and *F* estimates where so few age classes are included and recruitment is so variable, but clearly *Z* and *F* were very high relative to what would be expected from a virgin or lightly fished population.

The proportion of pots with zero catch for the four random-site surveys has more than doubled from 23% in 2012 to 53% in 2024, consistent with declining abundance (Figure 23).

The condition factors (*K*) for the 2020 and 2024 Motunau surveys are presented for each sex as density plots, scatter plots of condition on total length, and median box and whisker plots (Figure 24). The mean condition factors and standard errors for both surveys are shown in Table 7. Data from the previous Motunau surveys were not of sufficient quality or quantity to be included in these analyses. The condition analyses for the two surveys indicate: 1) condition was higher in 2020 than 2024 for both sexes; 2) condition was similar for both sexes within a year; and 3) condition improved with increasing length (Figure 24). Both surveys occurred at the same time of year and there were no fish in the mature or running-ripe spawning state on these surveys so annual differences do not appear to be associated with spawning condition. Regardless, it was legitimate to include all fish in the analyses, and not just the immature fish with undeveloped gonads, because all data sets had similar length ranges (Figure 24).

4. DISCUSSION

4.1 General

The 2024 Motunau random-site potting survey was the fourth in the time series of relative abundance and population structure of blue cod from this area, after previous random-site surveys in 2012, 2016, and 2020. Fixed-site surveys were carried out in 2005 and 2008 and then concurrently with the random-site surveys in 2012 and 2016. The fixed-site surveys were discontinued after the 2016 survey because the random-site design was deemed to be more accurate, statistically robust, and more likely to represent the entire blue cod population (Stephenson et al. 2024). Differences in catch rates between fixed- and random-site surveys, and the finding that the random-site surveys caught slightly larger blue cod (Beentjes & Sutton 2017), suggest that there is no suitable way of quantitatively linking the fixed-site with the random-site series. Notwithstanding the differences in catch rates that can be ascribed to the survey design (fixed or random), there are strong indications that blue cod biomass has declined substantially over the 19-year period from 2005 to 2024 (Figure 25).

4.2 Catch rates and survey precision

The target CV around relative abundance (catch rates) was not specified for the 2024 Motunau survey, but a CV of around 15% is generally targeted and simulations were carried out to estimate effort required to achieve this level of precision. The 22% CV achieved for the 2024 random-site survey was 6% above this nominal target, with previous CVs of 19%, 27%, and 19% for 2012, 2016, and 2020 surveys respectively. Effort was increased from 21 sites in 2012 and 2016, to 39 and 40 sites in 2020 and 2024 to reduce CVs. The achieved CV of 22% in 2024 indicates that the survey design and number of sites used is generally adequate, but the latter could be increased, especially if biomass continues to decline and catches by site become more variable and with more zero catches.

4.3 Age composition and cohort progression

Cohort progression of blue cod age classes off Motunau was apparent from 2016 to 2020 and 2020 to 2024, showing progression of both nominally strong and weak year classes (see Figure 21) and supports the ageing methodology based on counts of annual growth rings. It also indicates that these surveys were consistently sampling the same sub-population. The progression and relative strength of the 2012-year class (i.e., 3 years old in 2016 and 7 years old in 2020), suggests that this year class was strong. Growth estimates indicate that males would have been on average 5 years old and females 7 years old when they reached the previous MLS of 30 cm (increased to 33 cm on 1 July 2020) in this area (see growth curve in Figure 12). Hence, the 2012-year class faster growing males will have fully recruited to the fishery in 2018 and females in 2020. There were, however, no indications of a commensurate increase in all blue cod or recruited abundance in the 2020 survey, probably because, apart from two strong male cohorts (5- and 7-year-olds), other cohort strengths were comparatively weak and there were fewer older age classes. This suggests that for abundance to increase substantially, a number of strong recruitment pulses is required to offset those from the poor to average years, and that the population age structure needs time to rebuild by reducing fishing pressure on recruiting cohorts. Only 2% of female blue cod were over the previous 30 cm MLS in 2020, and in 2024, less than 1% of females were over the 33 cm MLS. The increase in MLS to 33 cm and reduction in the daily bag limit to two fish from July 2020 does not appear, at this stage, to have reduced the exploitation rate of this population, allowing the stock to rebuild, and the age structure in 2024 remains extremely truncated relative to the maximum blue cod age of around 30 years. However, this will become clearer after all recruited age classes have been exposed to the new mortality regime (i.e., increased MLS and decreased DBL) for the estimate of F to be reliable, as some of the older age classes would have been depleted before the regulation changes were introduced.

Comparison with other areas

The strong blue cod 2012 year class (3-year-olds) and the weak 2011 year class (4-year-olds) observed in Motunau in January 2016 (see Figure 21) were also present in the age compositions from Kaikōura in 2015, Banks Peninsula in 2016, and north and south Otago in 2018 (Beentjes & Fenwick 2017, Beentjes & Sutton 2017, Beentjes & Fenwick 2019a, 2019b, Beentjes 2021). The recruitment patterns for the Motunau surveys are most similar to those of nearby Kaikōura (Beentjes & Page 2024), including the most recent 2023 Kaikōura and 2024 Motunau surveys, indicating that the closer populations are to each other, the more similar are their patterns in recruitment strength. These consistent recruitment strength patterns suggest that spawning events and/or survival of subsequent life-history stages off the east coast of the South Island are somehow linked. Blue cod have a restricted home range (Rapson 1956, Mace & Johnston 1983, Mutch 1983, Carbines & McKenzie 2001, Govier 2001, Carbines & McKenzie 2004, Rodgers & Wing 2008) with only small numbers of blue cod travelling any distance from their tagging location. Blue cod off Kaikōura, Motunau, Banks Peninsula, and Otago are therefore likely to consist of largely independent sub-populations. Hence, the strong and weak year classes often common off the east coast South Island are more likely to be regulated by fisheries-independent environmentally driven events that act at the scale of the east coast of the South Island or wider, and impact localised spawning and survival of eggs, larvae, and juvenile fish (Beentjes 2021).

4.4 Sex change and sex ratio

In all four Motunau random-site surveys, sex ratio has strongly favoured males and ranged from 72 to 76% male (see Figure 20). Sex ratios of blue cod favouring females tend to be less common, particularly in exploited blue cod populations. Blue cod are sequential protogynous hermaphrodites with some (but not all) females changing into males as they grow (sex reversal) (Carbines 2004). Blue cod are a diandric species where males either develop directly from the undifferentiated state without sex inversion (primary males) or begin life as female and become male following sex inversion (secondary males) (Reinboth 1980, Beentjes 2021). In contrast , the monandric condition is where 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). The Motunau blue cod sex and size structure is consistent with this diandric reproductive strategy with both small males and large females present in the population. The sex ratio in Motunau has remained consistently strongly in favour of males on all four random-site surveys with no trend (see Figure 20).

Sex ratio of Motunau blue cod is more balanced at lengths below about 25 cm with the proportion male progressively increasing with length until virtually all blue cod are male after about 30 cm (Figure 26). Compared to Kaikōura and most other east coast areas, the dominance of males occurs at a very small size in Motunau, reflecting the lack of larger females in the population. For example, in Kaikōura, males are not fully dominant until about 45 cm and over (Beentjes & Page 2024). The steep increase in the proportion of males that occurs up to about 35 cm may be related to the elevated sex transition from female to male (Figure 26). Although females don’t grow as large as males, reasonable numbers of females as large as 40 cm are usually present in less exploited populations.

Plots of percent male versus age show similar trends to those versus length with the proportion of males increasing with age (Figure 27). Again, this pattern is unlike that from other populations where the oldest fish in the population are usually the slower growing females, and hence at older ages, the sex ratio favours females. These length and age sex ratio plots are likely to differ from those of most gonochoristic species, where the proportion of males would be close to one-to-one throughout and then decline for the largest and oldest fish, which are usually females.

In areas where fishing pressure is known to be high, such as Motunau, inshore Banks Peninsula, and the Marlborough Sounds, the sex ratios are strongly skewed towards males, which is contrary to an expected dominance of females resulting from selective removal of the larger male fish (Beentjes & Carbines 2003, 2006, Carbines & Beentjes 2006a, Beentjes & Carbines 2012, Beentjes & Sutton 2017, Beentjes & Miller 2021, Beentjes et al. 2022a). In contrast, in Foveaux Strait, offshore Banks Peninsula, and particularly Dusky Sound, ratios are more balanced and can even favour females, suggesting that fishing pressure is less intense (Beentjes & Carbines 2009, Carbines & Beentjes 2012, Beentjes & Page 2016, Beentjes & Miller 2024). Beentjes & Carbines (2005) suggest that the shift towards a higher proportion of males in more heavily fished blue cod populations may be caused by removal of the possible inhibitory effect of large males, resulting in a higher rate (and possibly earlier onset) of sex change by females. The reduced levels of behavioural interaction between males and females has been shown to lead to enhanced sex inversion in other protogynous fish species (Fishelson 1970, Robertson 1972, Warner 1984, Sato et al. 2018). Factors affecting sex change and sex ratios in blue cod are not well understood.

4.5 Stock status

The *Harvest Strategy Standard* specifies that a Harvest Strategy should include a fishery target reference point, and that this may be expressed in terms of biomass or fishing mortality (Ministry of Fisheries 2011). The most appropriate target reference point for blue cod is F_{MSY}, which is the amount of fishing mortality that results in the maximum sustainable yield. The recommended proxy for F_{MSY} is the level of spawner-per-recruit $F_{\%SPR}$ (Ministry of Fisheries 2011). Blue cod is categorised as an exploited species with low productivity (on account of complexities of sex change) and the recommended default proxy for F_{MSY} has been $F_{45\%SPR}$. As discussed in Section 1.4, the Inshore Finfish Working Group (14 October 2024) agreed that *SPR* is no longer appropriate as a target reference point for Motunau 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 sixth survey area, after Marlborough Sounds, Kaikōura, north Otago, south Otago, and Foveaux Strait for which Fisheries New Zealand has replaced *SPR* with F=0.87M as an overfishing threshold.

The 2024 Motunau random-site survey Z for males was 0.74 yr^{-1}, where M = 0.17 and age-at-full recruitment was 7 years of age, with a resulting F of 0.57 yr^{-1} (95% confidence intervals 0.25–1.02) (see Table 10, Figure 22). Relative to the target reference point of F=0.15 (F=0.87M), the estimated F in 2024 was nearly four times the target, indicating that overfishing is occurring. Similarly, the 2016 and 2020 F estimates were also very high at 0.62 and 0.51 yr^{-1}, respectively, much higher than the target of F=0.15, with no indications that fishing pressure has declined or that the stock is rebuilding (see Table 10, Figure 22). Indeed, the age distributions of blue cod from the three Motunau surveys are so truncated that growth could not be accurately modelled using the von Bertalanffy growth curve, which requires some larger and older fish to estimate a sensible length at infinity parameter (see Figure 12).

4.6 Reproductive condition

There were no indications of spawning in January 2024, consistent with all previous surveys all carried out at the same time of year (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2012b, Beentjes & Sutton 2017, Beentjes & Miller 2021) (Table 8). Given that some spawning activity is consistently observed in Kaikōura one month earlier, spawning may take place before January in Motunau. Alternatively, the absence of large females may preclude spawning activity in Motunau.

4.7 Fisheries management

In summary, blue cod abundance from potting surveys off Motunau has declined markedly over the nineteen years from 2005 to 2024, notwithstanding the differences that can be ascribed to the survey design (fixed or random). The very high estimates of fishing mortality, truncated age composition, small mean size, and strongly skewed sex ratio toward males indicate that the blue cod population off Motunau has been and continues to be heavily overfished. Further, given the small size of blue cod in this area, virtually all females and most males caught will be of sub-legal size (less than 33 cm), and this is likely to result in substantial mortality through catch and return of undersize fish.

There have been four recreational fishing surveys carried out in North Canterbury covering the years 2003, 2009, 2012–13, and most recently in 2021–22 (Hart & Walker 2004, Kendrick et al. 2011, Kendrick & Hanley 2021, Maggs et al. 2023). For the Motunau area, the harvest by private-vessel recreational fishers progressively increased with one and a half times as many blue cod harvested (retained) over the same period (January to April) in 2012–13 than in 2003, before a six-fold harvest decline in 2021–22 (Maggs et al. 2023) (Figure 28). Comparison over the full fishing year was possible only for the 2012–13 and 2021–22 surveys, and indicated that the Motunau harvest had also declined by six-fold over the nine-year period (Maggs et al. 2023). This trend of increasing recreational harvest occurred when the MLS was 30 cm and DBL was 10 blue cod, whereas the steep decline in harvest was observed following the increase in MLS to 33 m and a reduction in the DBL to 2 fish. It also seems likely that the small size and decline in blue cod catch rates off Motunau have discouraged fishing effort in this part of north Canterbury. The north Canterbury area that includes Motunau was assigned a 'traffic light' colour of red by Fisheries New Zealand in 2020 indicating that the blue cod stocks in this area were considered to be overfished. The increase in MLS and reduced DBL in July 2020 were introduced as a fisheries intervention to reduce fishing pressure and aid stock recovery, and this may have worked in the first instance.

Blue cod off Motunau have consistently been shown to be smaller, on average, by a few centimetres than those off Kaikōura in all four north Canterbury recreational surveys (Maggs et al. 2023). This was also observed in the potting surveys where mean length in Kaikoura has been consistently larger by about 4 cm (Beentjes & Page 2024). The size difference may be related to the higher fishing mortality in Motunau than in Kaikōura, although habitat quality may also be a contributing factor.

4.8 Broader outcomes

As required under Government Procurement rules[2], Fisheries New Zealand considered broader outcomes (secondary benefits such as environmental, social, economic or cultural benefits) that would be generated by this project. These surveys contribute to the knowledge around sustainability of the blue cod fishery off Motunau and are of benefit to a range of stakeholders including iwi (Ngai Tuahuriri), Motunau Marine Guardians, recreational and commercial fishers, environmental organisations and the wider New Zealand public.

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7. TABLES

Table 1: Effort and blue cod catch data for the 2024 Motunau random-site potting survey.

Stratum	Area (km²)	Site type	*N* sets (sites) Phase 1	Phase 2	*N* pots (stations)	Catch (blue cod) *N*	kg	Depth (m) Mean	Range
1	41.3	Random	10		60	492	91.6	28.3	7–36
2	66.9	Random	8		48	191	41.8	18.3	4–35
3	176.1	Random	16	6	132	424	125.5	19.0	4–30
Total	284.3	Random	34	6	240	1 107	258.9	21.2	4–36

Table 2: Total catch and numbers of blue cod and bycatch species caught on the 2024 Motunau random-site potting survey. Percent of the catch by weight is also shown.

Common name	Species	Code	Number	Catch (kg)	% catch
Blue cod	*Parapercis colias*	BCO	1 107	258.9	86.50
Common octopus	*Octopus Maorum*	OCT	10	14.3	4.78
Leatherjacket	*Meuschenia scaber*	LEA	28	11.6	3.88
Banded wrasse	*Notolabrus fucicola*	BPF	9	5.7	1.90
Scarlet wrasse	*Pseudolabrus miles*	SPF	11	4.5	1.50
Spotty	*Notolabrus celidotus*	STY	18	2.9	0.97
Sea perch	*Helicolenus percoides*	SPE	2	1.1	0.37
Tarakihi	*Nemadactylus macropterus*	NMP	2	0.2	0.07
Thornfish	*Bovichtus variegatus*	BVV	1	0.1	0.03
Totals			1 188	299.3	100

Table 3: Mean catch rates for all blue cod and recruited blue cod (33 cm and over) from the 2024 Motunau random-site potting survey. Catch rates are pot-based, and s.e. and CV are set-based. s.e., standard error; CV coefficient of variation.

Stratum	Site type	Pot lifts (N)	All blue cod Catch rate (kg pot^{-1})	s.e.	CV (%)	Recruited blue cod Catch rate (kg pot^{-1})	s.e.	CV (%)
1	Random	60	1.53	0.41	27.2	0.14	0.05	31.9
2	Random	48	0.87	0.49	56.2	0.19	0.13	68.2
3	Random	132	0.95	0.29	30.3	0.27	0.12	45.0
Overall	Random	240	1.02	0.22	21.7	0.23	0.08	35.0

Table 4: Descriptive statistics for blue cod caught on the 2024 Motunau random-site blue cod potting survey. Outputs are raw for each stratum and weighted for the survey overall. Sex ratio is also given for recruited blue cod (33 cm and over). m, male; f, female.

				Length (cm)			Percent male	
Stratum	Site type	Sex	No.	Mean	Minimum	Maximum	All blue cod	Recruited
1	Random	m	337	23.7	12.3	38.1	68.5	100
		f	155	21.0	15.6	29.2		
2	Random	m	143	24.7	16.2	39.6	74.7	92.2
		f	48	21.7	17.2	33.4		
3	Random	m	324	27.1	17.5	46.2	76.5	100
		f	100	22.7	13.2	32.2		
Overall	Random	m	804	25.2	12.3	46.2	73.8	98.4
		f	303	21.4	13.2	33.4		

Table 5: Otolith ageing data used in the catch-at-age and mortality estimates (Z and *F*) for the 2024 Motunau survey.

		Length of aged fish (cm)		Age (years)	
Survey	No. otoliths	Minimum	Maximum	Minimum	Maximum
Male	145	12	46	1	11
Female	72	13	33	1	7
Total	217	12	46	1	11

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

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

Table 7: Mean condition factor (*K*) of blue cod for the 2020 and 2024 Motunau random-site potting surveys. $K = wt*100/l^b$, where *wt* = weight (g), *l* =length (cm), and *b* = 3.

Survey	Sex	Mean condition (*K*)	Standard error	Number
2020	Males	1.546	0.004	1 600
	Females	1.510	0.007	548
	Both sexes	1.537	0.003	2 148
2024	Males	1.417	0.004	804
	Females	1.379	0.006	303
	Both sexes	1.407	0.003	1 107

Table 8: Gonad stages of all blue cod by sex from the Motunau survey in early January 2024. 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

	Gonad stage (%)					
Sex	1	2	3	4	5	*N*
Males	50.2	49.8	0	0	0	804
Females	97.4	2.6	0	0	0	303

Table 9: Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals (CI) for age at full recruitment (AgeR) values of 5 to 9 years for male blue cod from the 2024 Motunau random-site blue cod potting survey. Male *Z* estimates are also shown for previous surveys in 2016, and 2020.

			95% CIs	
Survey	AgeR	Male *Z*	Lower	Upper
2024	5	0.62	0.42	0.88
	6	1.04	0.63	1.56
	7	0.74	0.42	1.19
	8	0.66	0.34	1.10
	9	1.14	0.53	2.29
2020	5	0.71	0.46	0.98
	6	0.68	0.47	0.94
	7	2.20	1.24	3.37
	8	0.53	0.27	0.87
	9	1.19	0.48	1.95
2016	5	0.62	0.43	0.83
	6	0.82	0.53	1.13
	7	0.55	0.37	0.77
	8	0.77	0.48	1.11
	9	1.71	0.90	2.93

Table 10: Chapman Robson total (*Z*) and fishing (*F*) mortality point estimates at three values of natural mortality (*M*) for male blue cod from the Motunau random-site potting survey time series. *AgeR* is the age-at-recruitment at which males reach MLS (30 cm in 2016 and 2020; 33 cm in 2024) plus one year. The upper and lower 95% confidence intervals (CI) for *Z* and *F* estimates are also given for the default *M* (0.17)

Survey	AgeR	*M*	Male *Z*	Male *F*	Estimate type
2024	7	0.14	0.74	0.60	Point
	7	0.17	0.74	0.57	Point
	7	0.20	0.74	0.54	Point
	7	0.17	0.42	0.25	Lower CI
	7	0.17	1.19	1.02	Upper CI
2020	6	0.14	0.68	0.54	Point
	6	0.17	0.68	0.51	Point
	6	0.20	0.68	0.48	Point
	6	0.17	0.47	0.30	Lower CI
	6	0.17	0.94	0.77	Upper CI
2016	6	0.14	0.79	0.65	Point
	6	0.17	0.79	0.62	Point
	6	0.20	0.79	0.59	Point
	6	0.17	0.51	0.34	Lower CI
	6	0.17	1.13	0.96	Upper CI

8. FIGURES

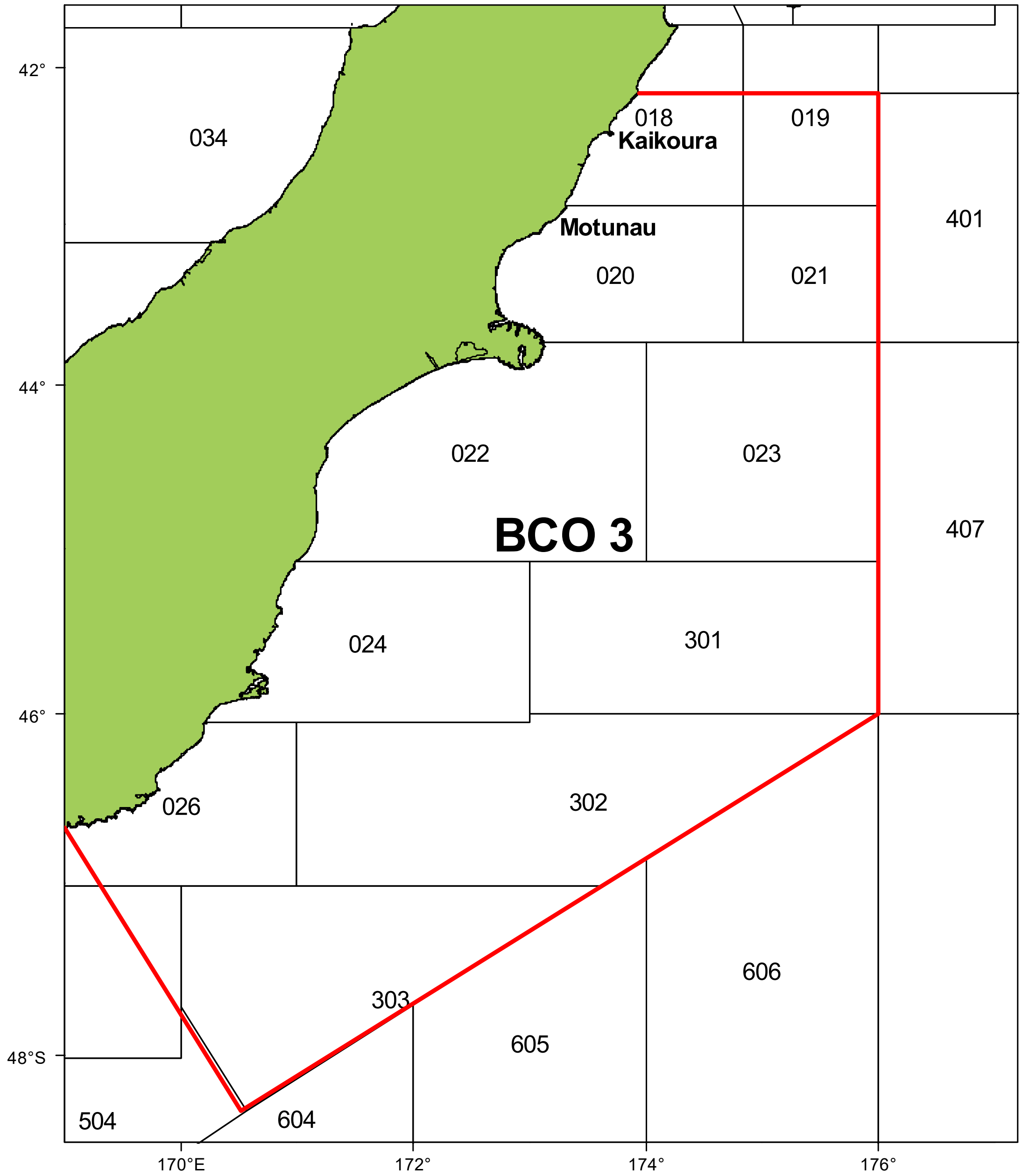

Figure 1: Blue cod Quota Management Area BCO 3 (red border) and statistical areas. The north Canterbury potting survey locations of Kaikōura and Motunau are shown.

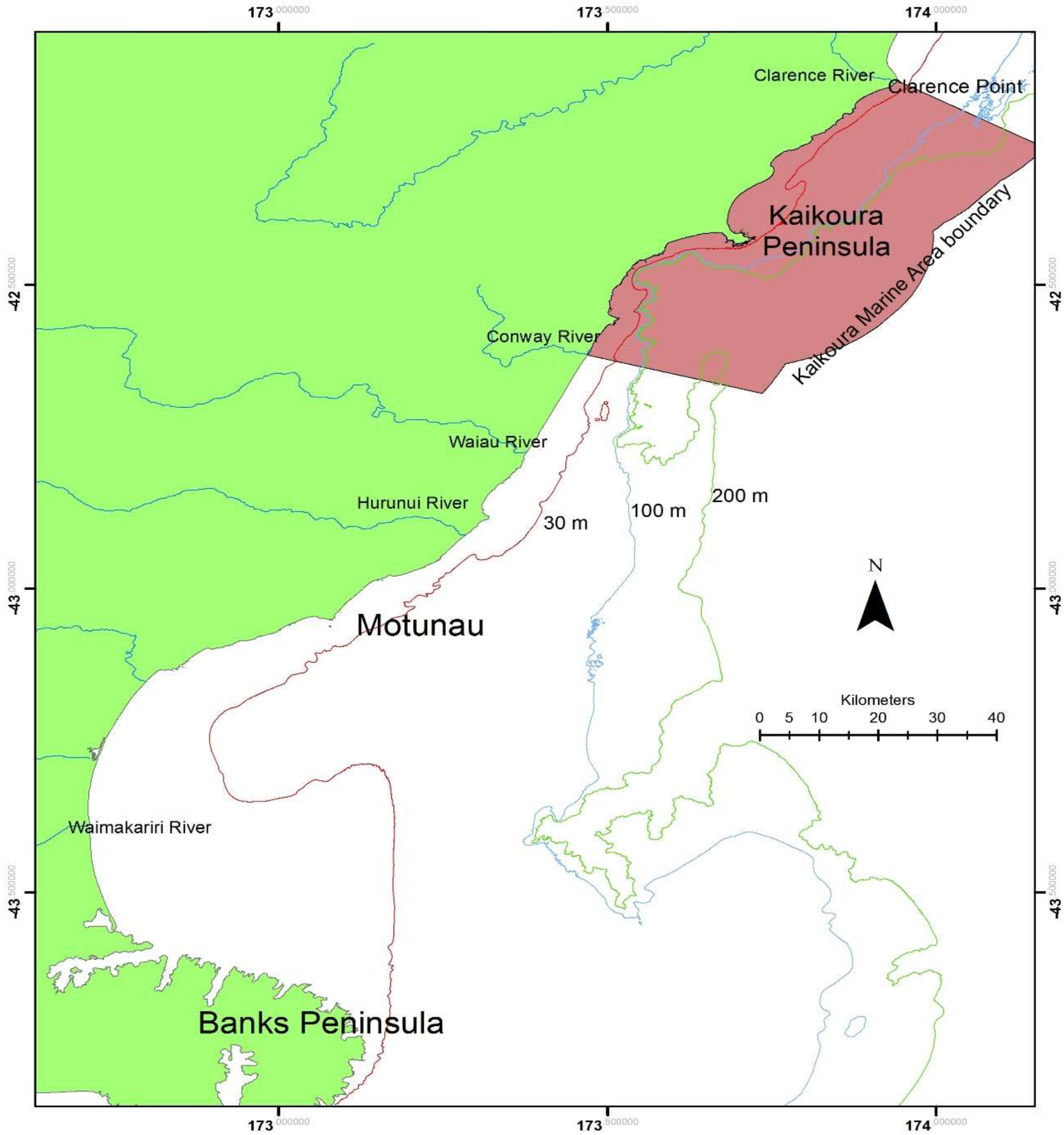

Figure 2: Map of north Canterbury coastline showing locations of Motunau and the Kaikōura Marine Area.

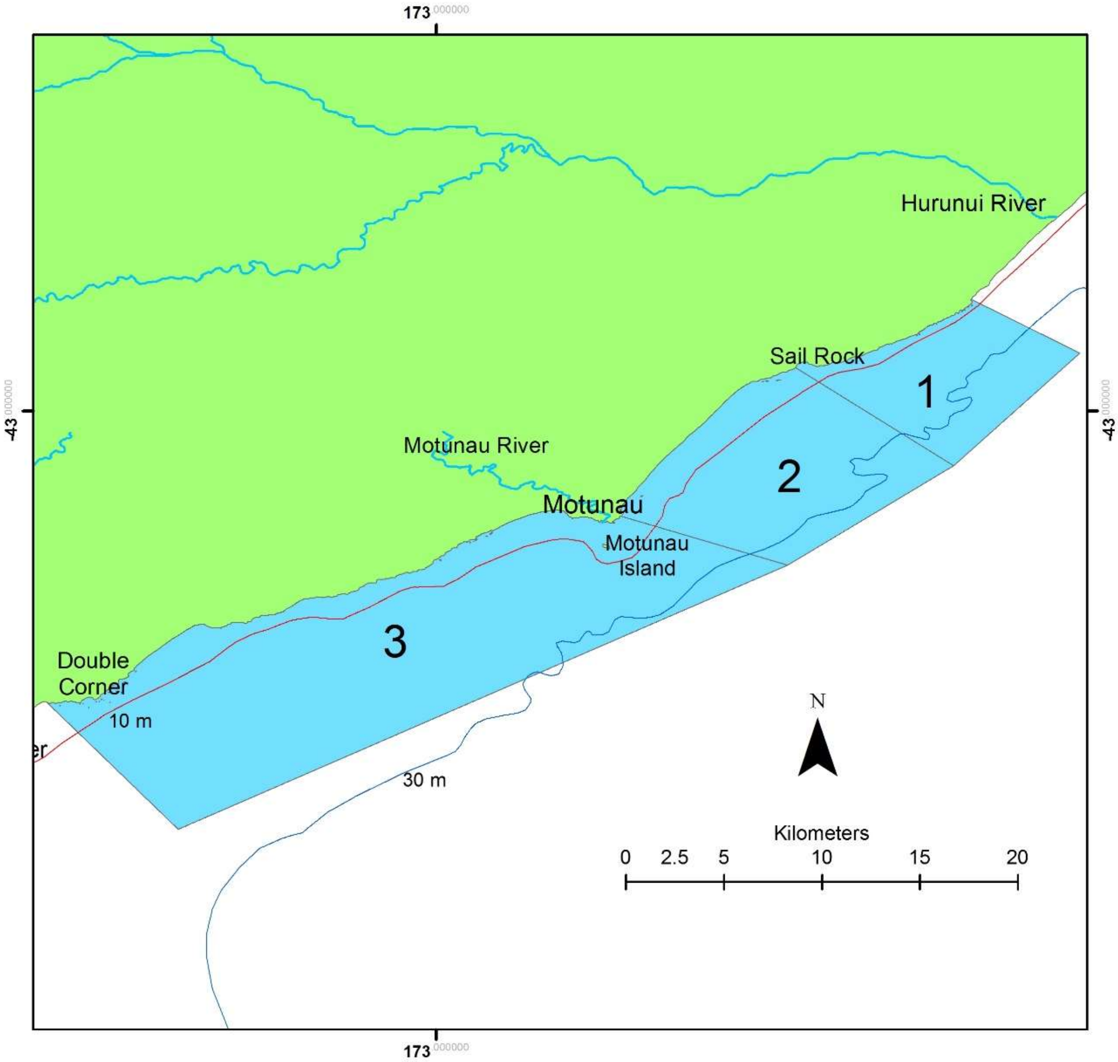

Figure 3: Map of Motunau blue cod potting survey strata (1, 2, and 3). The 10 m and 30 m depth contours are also shown.

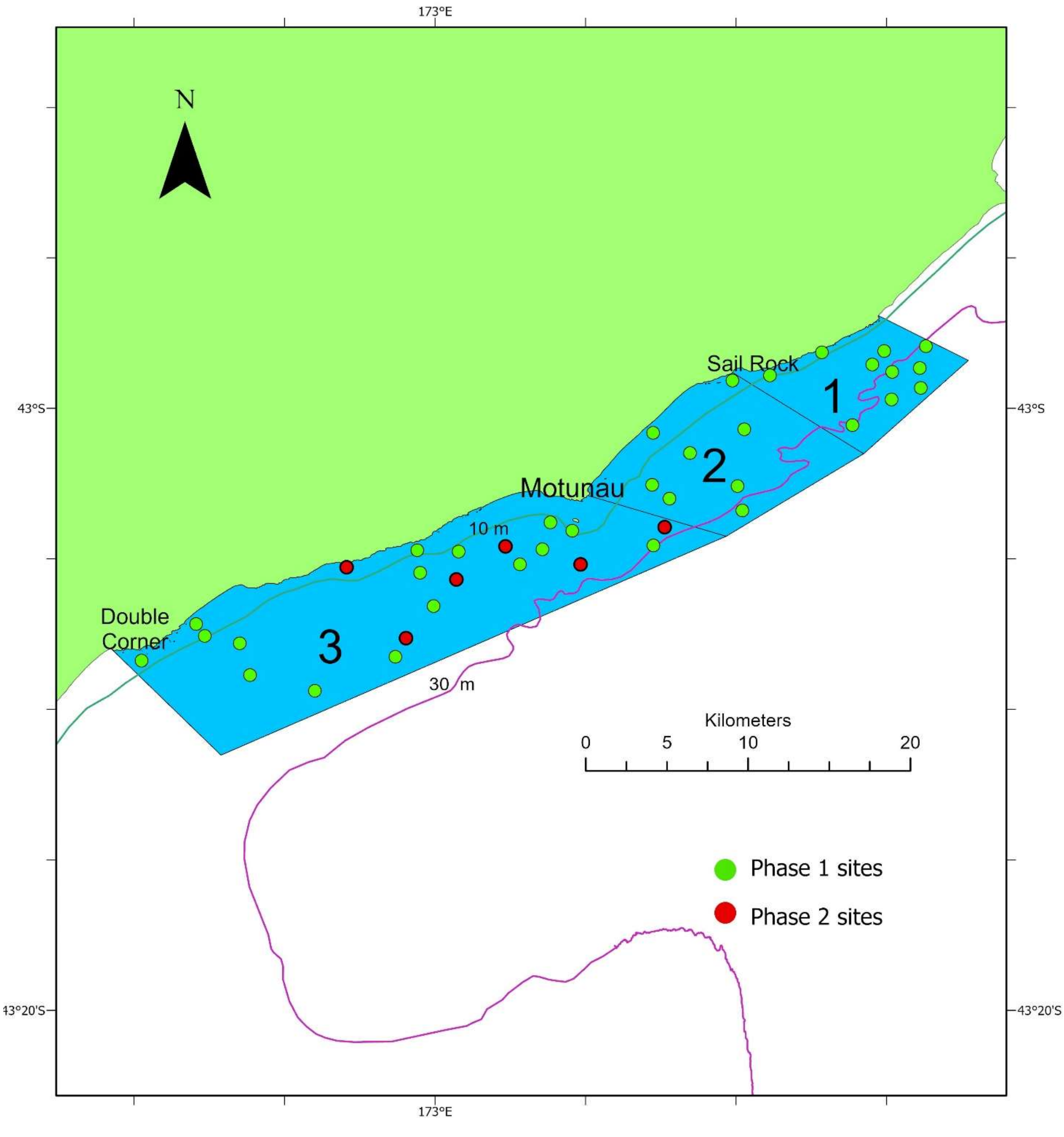

Figure 4: Map of Motunau strata showing phase 1 and phase 2 sites sampled during the 2024 blue cod random-site potting survey. The 10 m and 30 m depth contours are also shown.

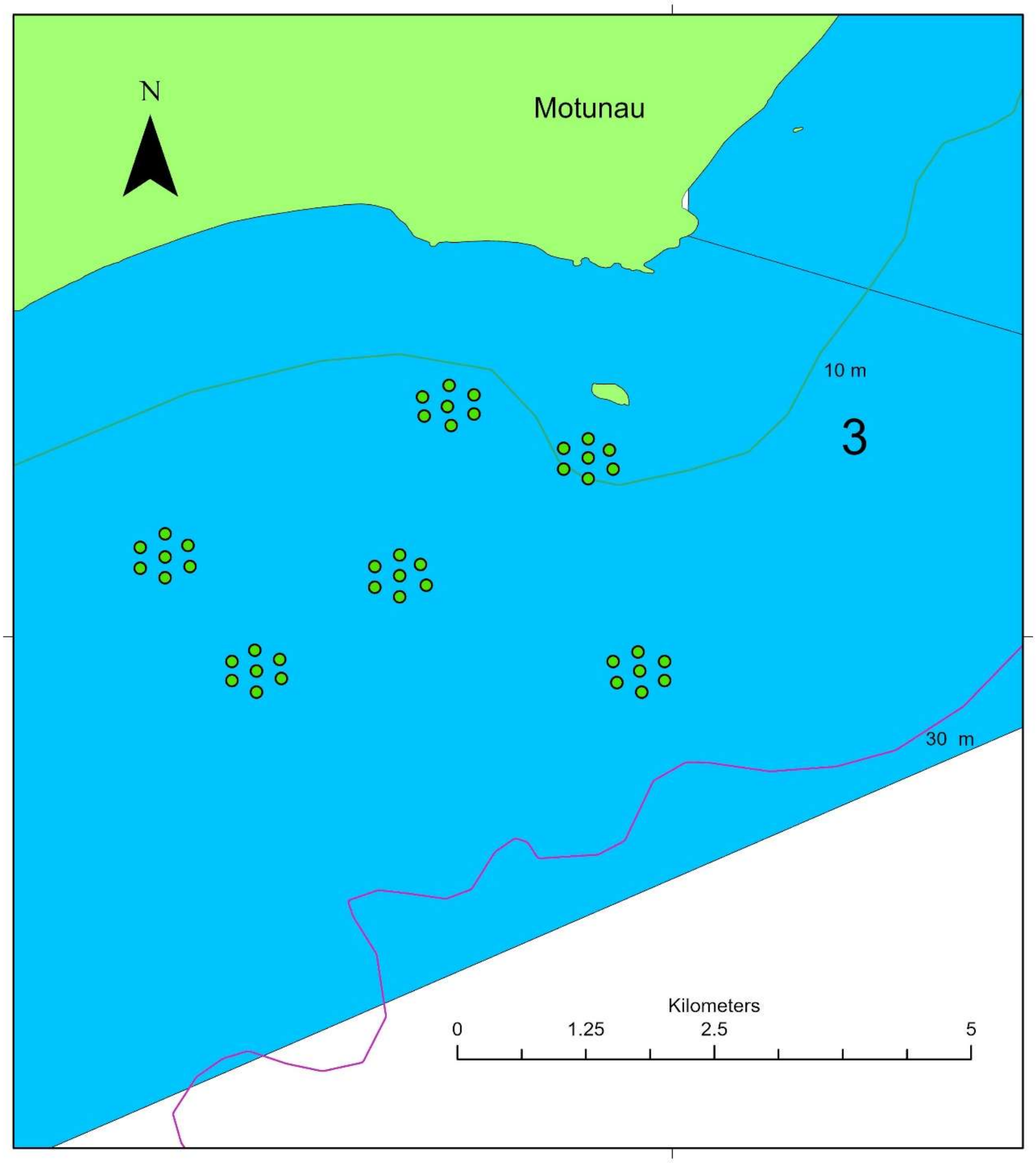

Figure 5: Random-site systematic pot placement configuration for six sites in stratum 3 for the 2024 survey. The position in the centre is the ADCP with the six pots set in a hexagon shape around the ADCP.

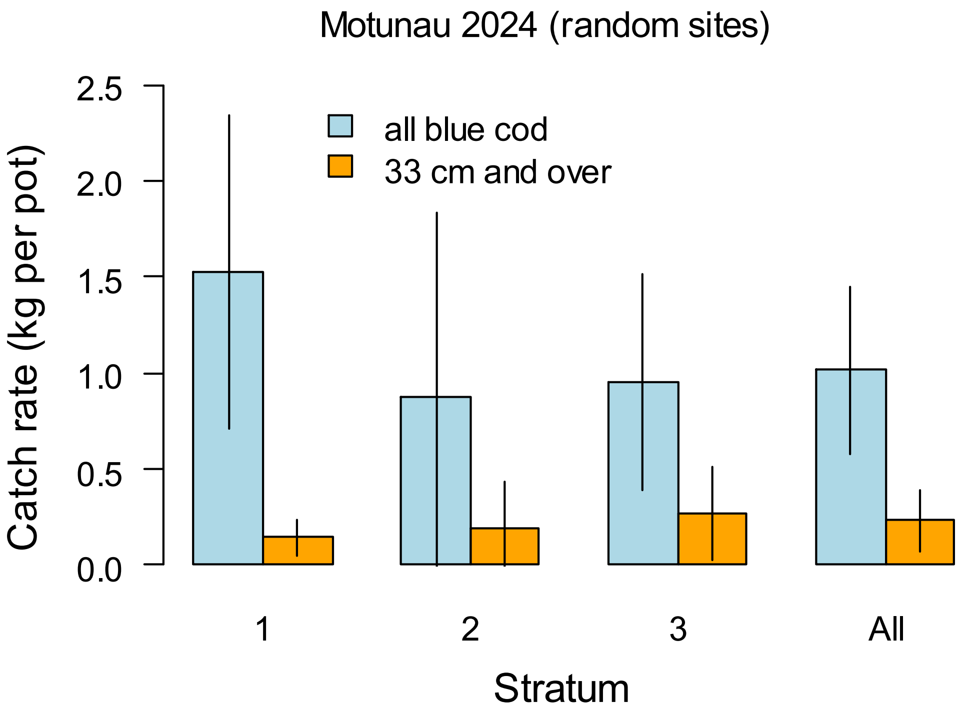

Figure 6: Catch rates (kg pot^{-1}) of all blue cod and recruited blue cod (33 cm and over) for the 2024 Motunau random-site potting survey. Error bars are 95% confidence intervals. See Figure 3 for location of strata.

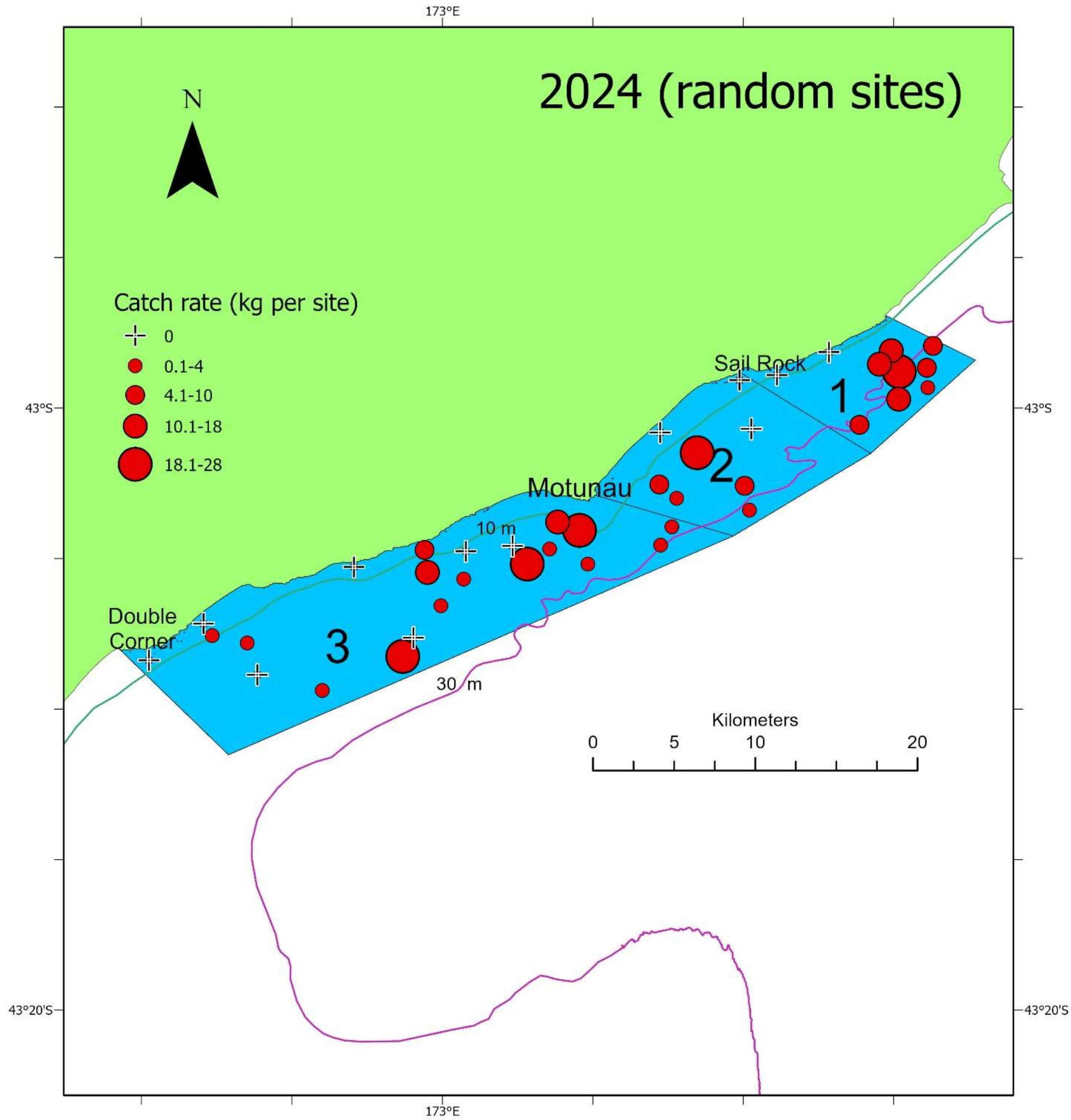

Figure 7: Strata and site positions showing relative blue cod catch rates (kg site^{-1}) for the 2024 Motunau random-site blue cod potting survey.

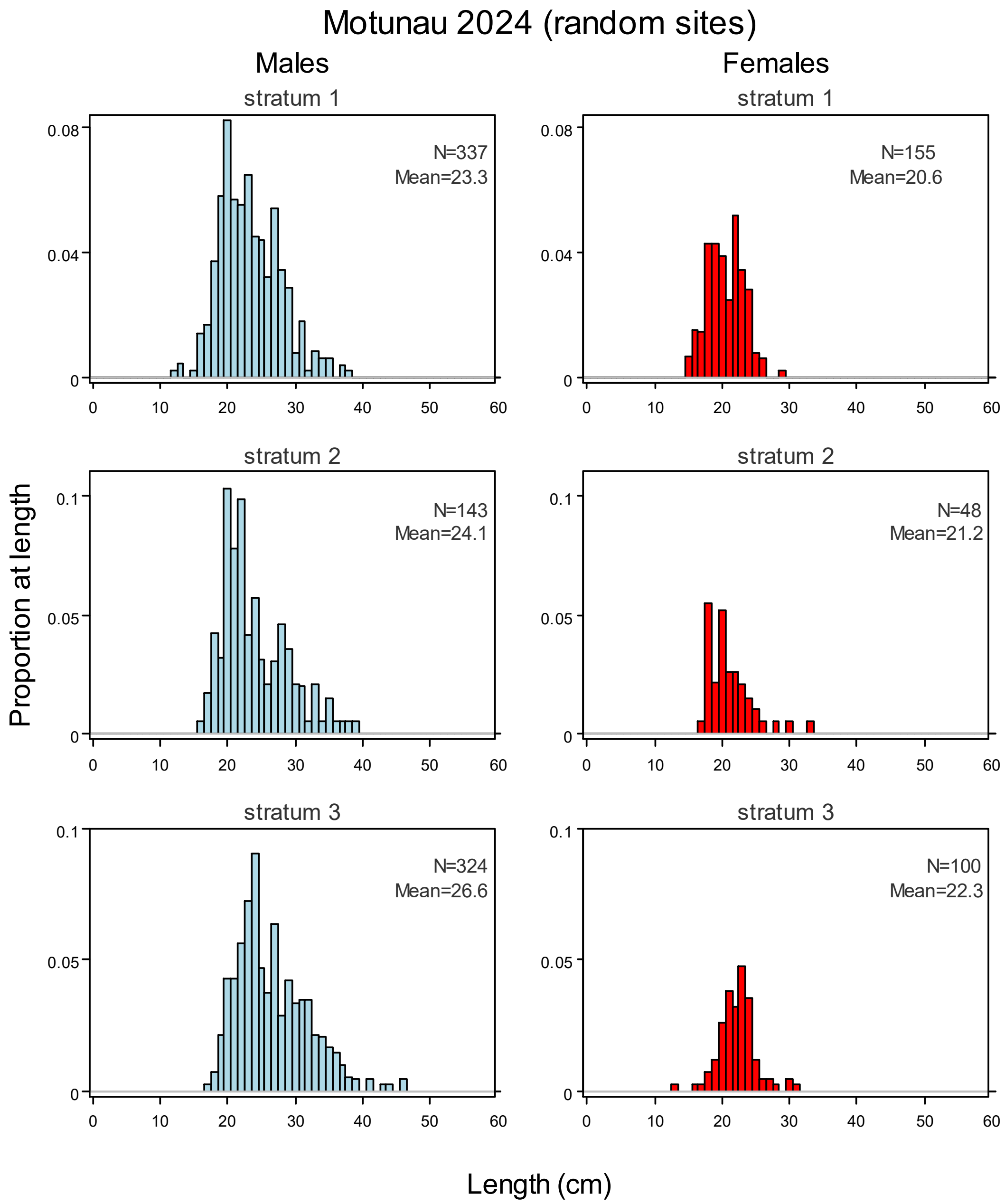

Figure 8: Scaled length frequency distributions by strata for the 2024 Motunau random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum.

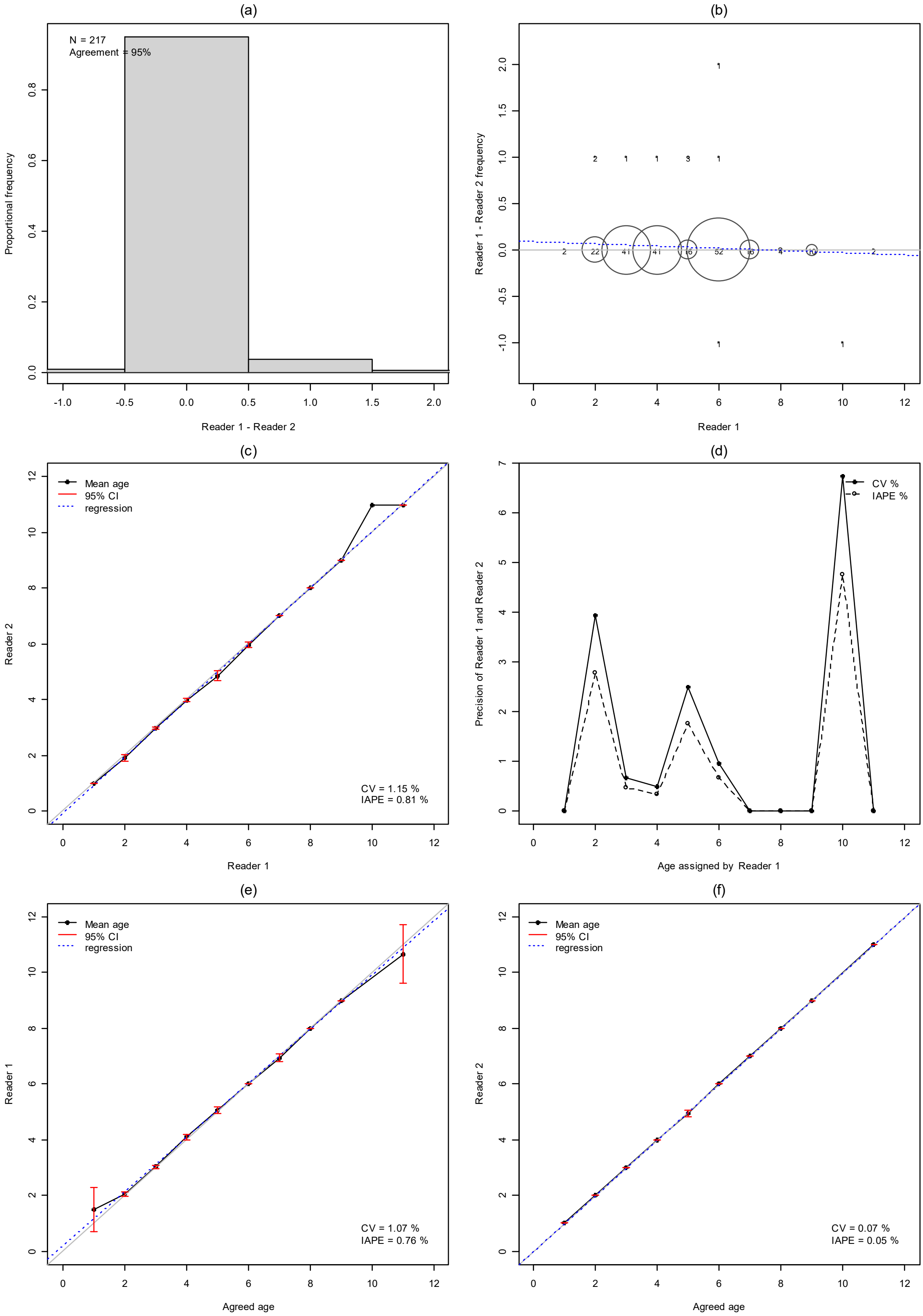

Figure 9: Blue cod age otolith reader comparison plots between reader 1 and reader 2 for the 2024 Motunau survey: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age bin 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 b, c, e, and f, solid lines show perfect agreement, dashed lines show the trend of a linear regression of the actual data.

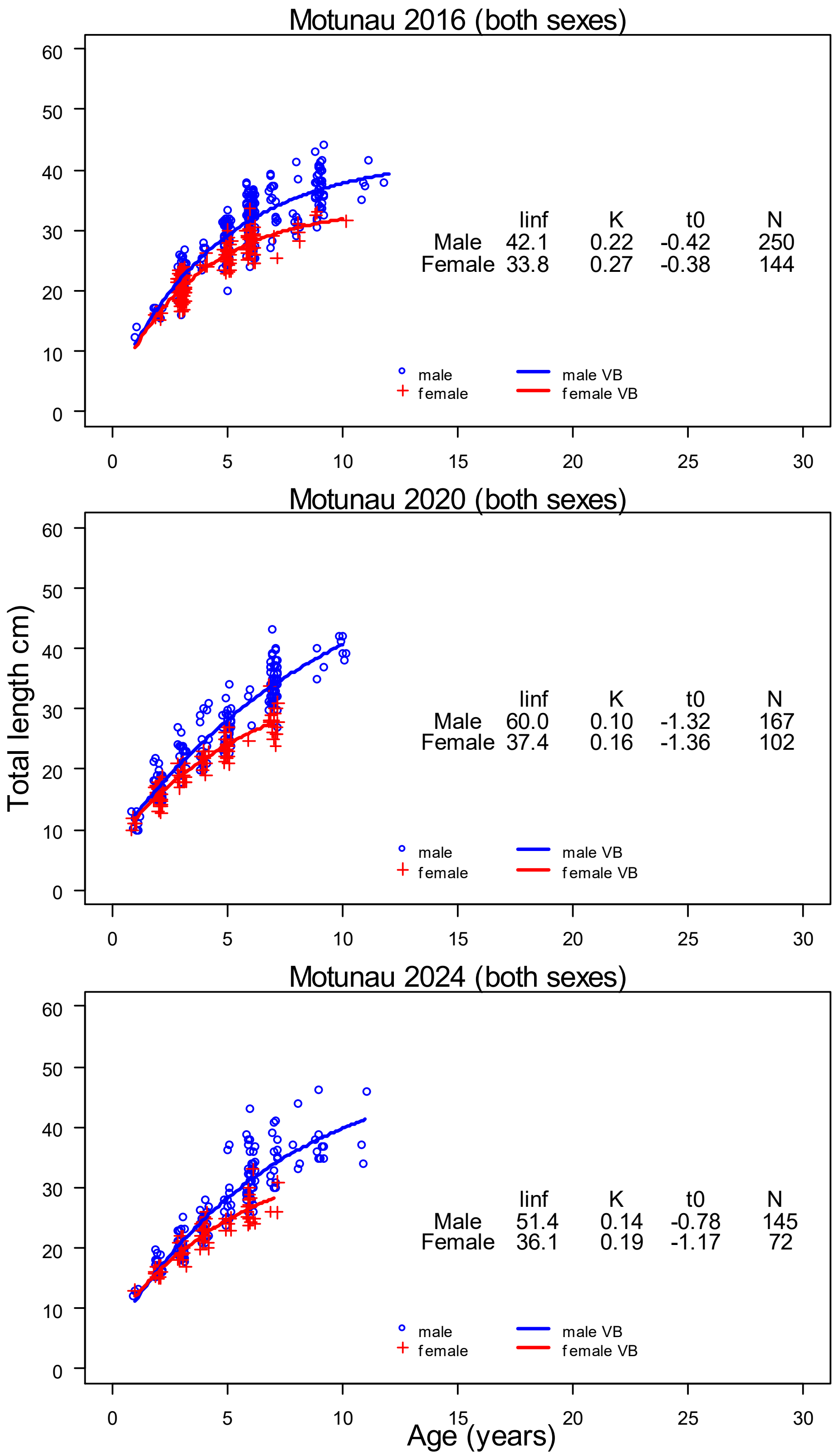

Figure 10: Observed blue cod age and length data by sex for the 2016, 2020, and 2024 Motunau blue cod potting surveys with von Bertalanffy (VB) growth models fitted to the data.

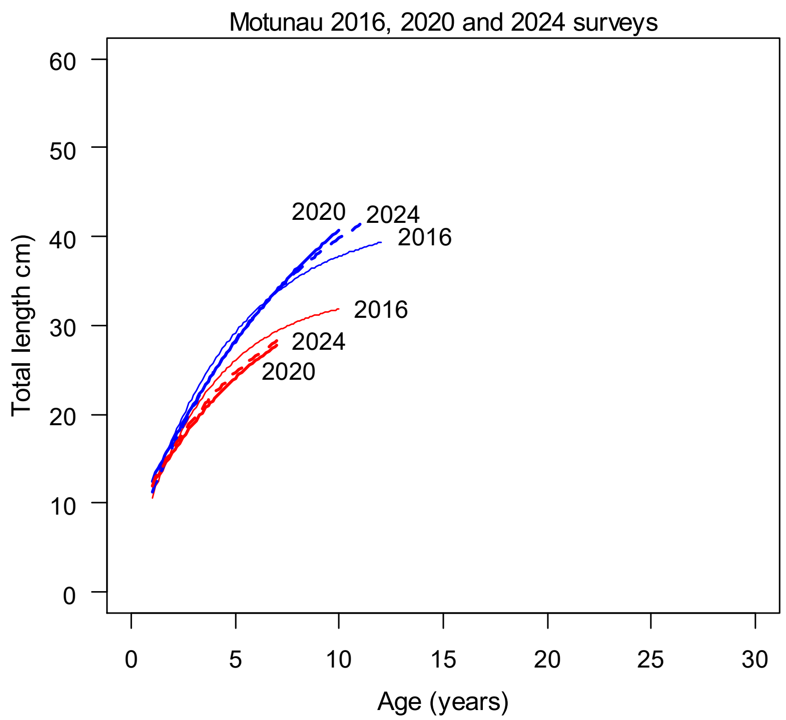

Figure 11: von Bertalanffy (VB) growth models fitted to the blue cod age and length data by sex for the 2016, 2020, and 2024 Motunau blue cod potting surveys.

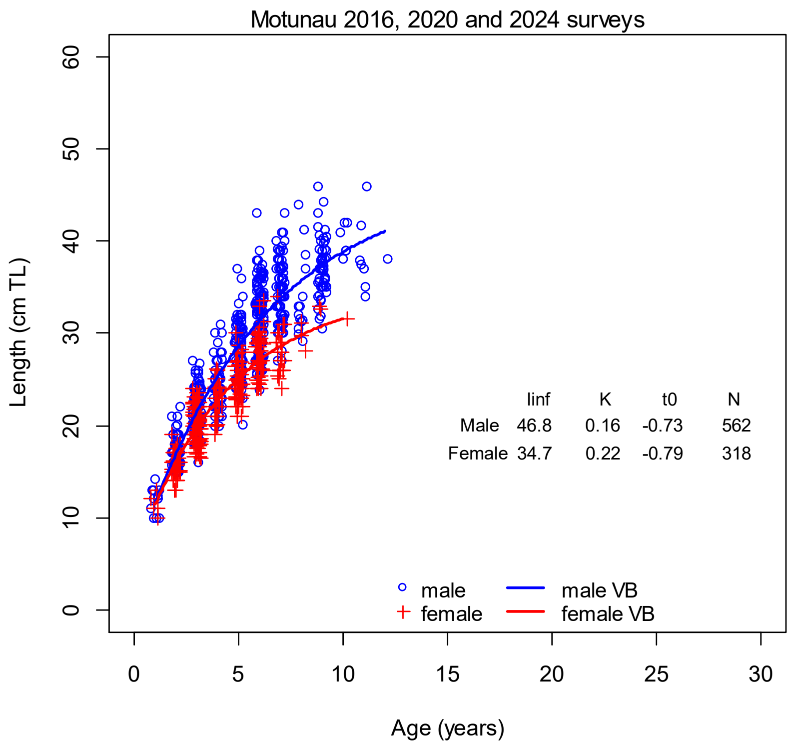

Figure 12: Observed length and age data, and von Bertalanffy (VB) growth models by sex for the combined 2016, 2020, and 2024 Motunau blue cod potting surveys. These VB parameters were used to determine male age at recruitment at the minimum legal size for each survey.

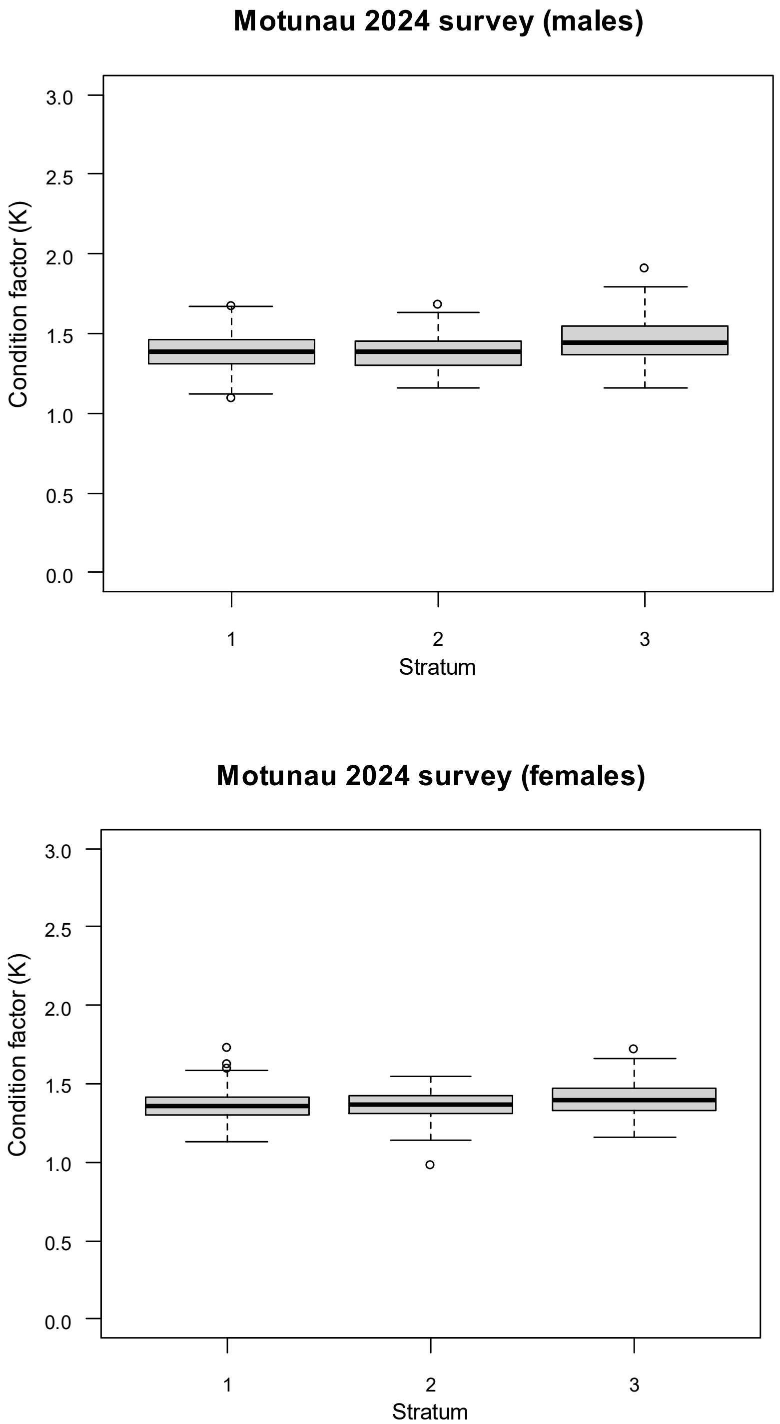

Figure 13: Median box and whisker plots of condition factor (*K*) of blue cod by stratum for males and females from the Motunau 2024 random-site potting survey. $K = wt \times 100/l^3$, where *wt* = weight (g), *l*=length (cm).

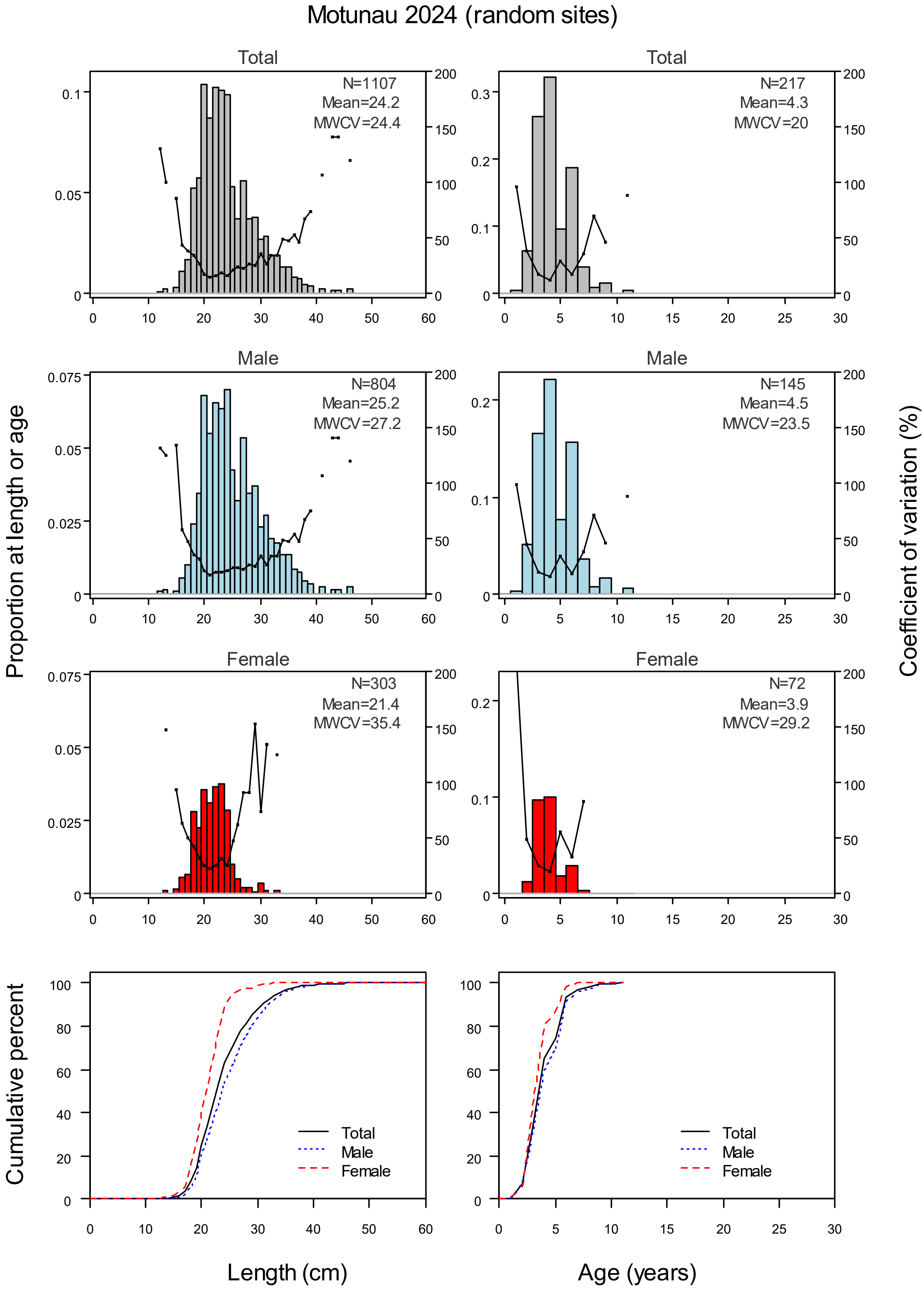

Figure 14: Scaled length and age frequency histograms, and cumulative distributions for total, male, and female blue cod for all strata in the 2024 Motunau random-site blue cod potting survey. The coefficients of variation are shown as lines plots for individual length and age. N, sample size; MWCV, mean weighted coefficient of variation (%).

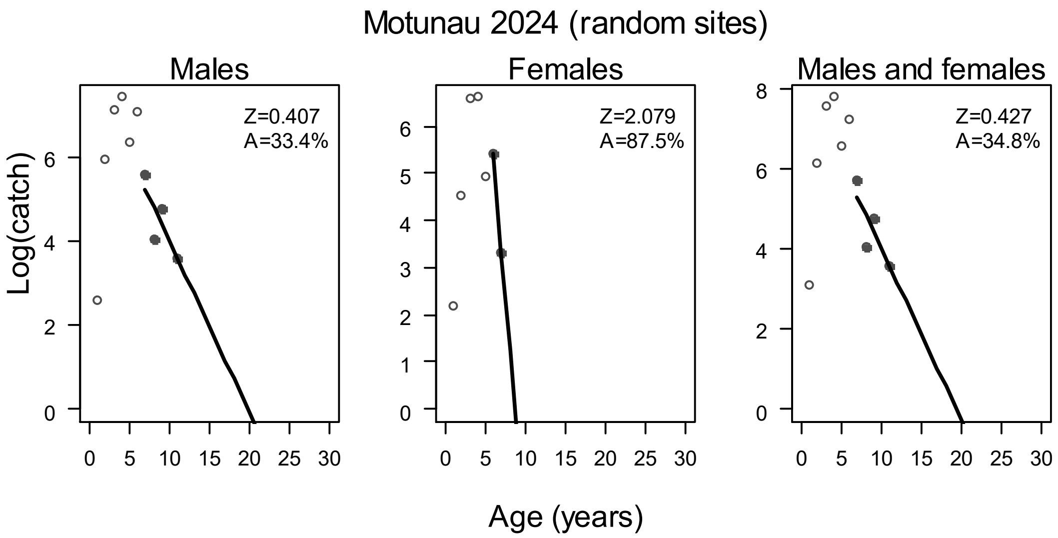

Figure 15: Motunau 2024 random-site blue cod potting survey catch curve (natural log of catch numbers versus age). The regression line is plotted from age at full recruitment of 7 years, (i.e., dark points on the graph). Z, instantaneous total mortality; A, the annual mortality rate or the proportion of the population that suffers mortality in a given year.

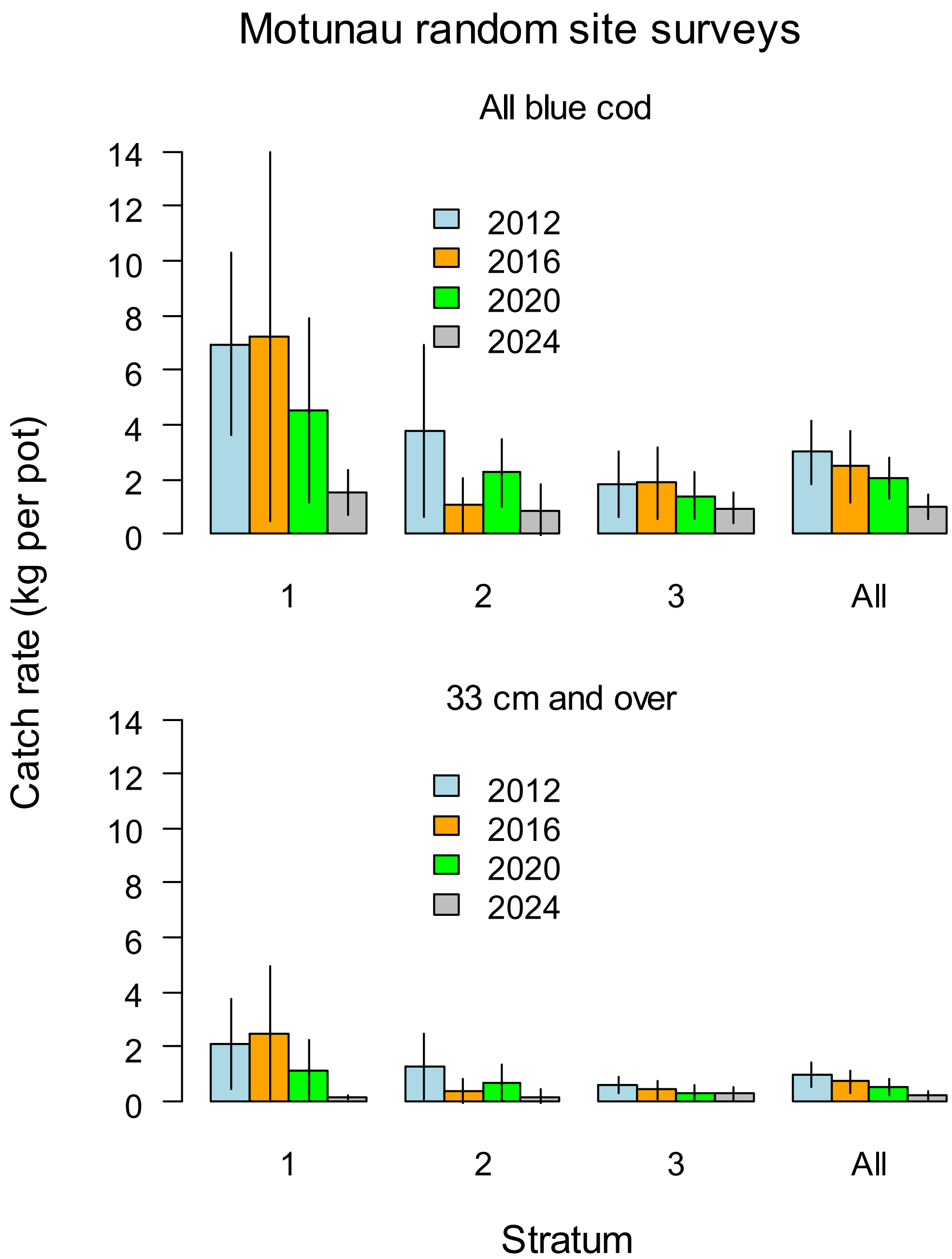

Figure 16: Catch rates (kg pot^{-1}) of all blue cod and for recruited blue cod (33 cm and over, i.e., the MLS as of July 2020) for the Motunau random-site potting surveys in 2012, 2016, 2020, and 2024. Error bars are 95% confidence intervals.

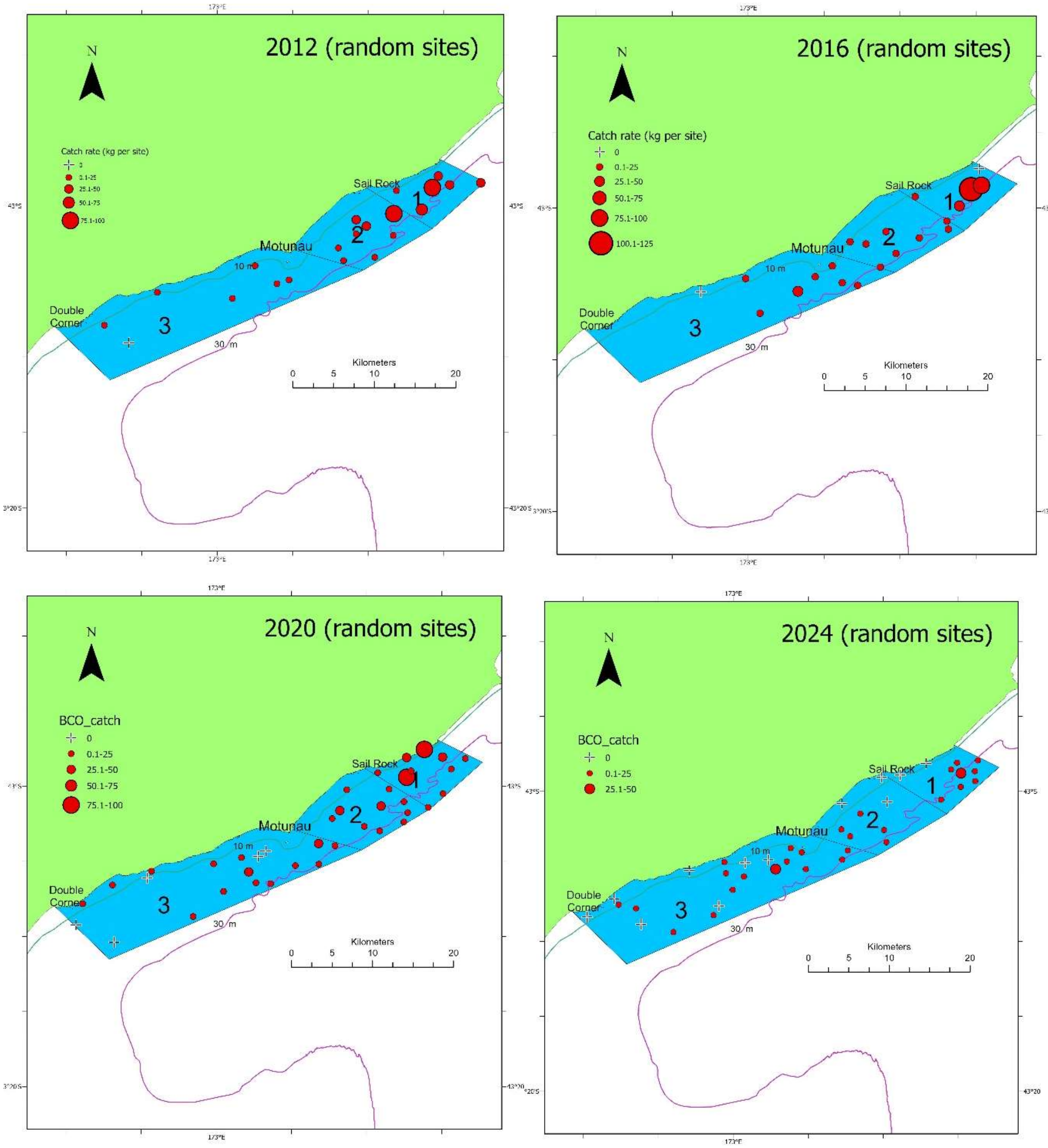

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Figure 17: Strata and site positions showing relative blue cod catch rates (kg site^{-1}) for the 2012, 2016, 2020, and 2024 Motunau random-site blue cod potting surveys.

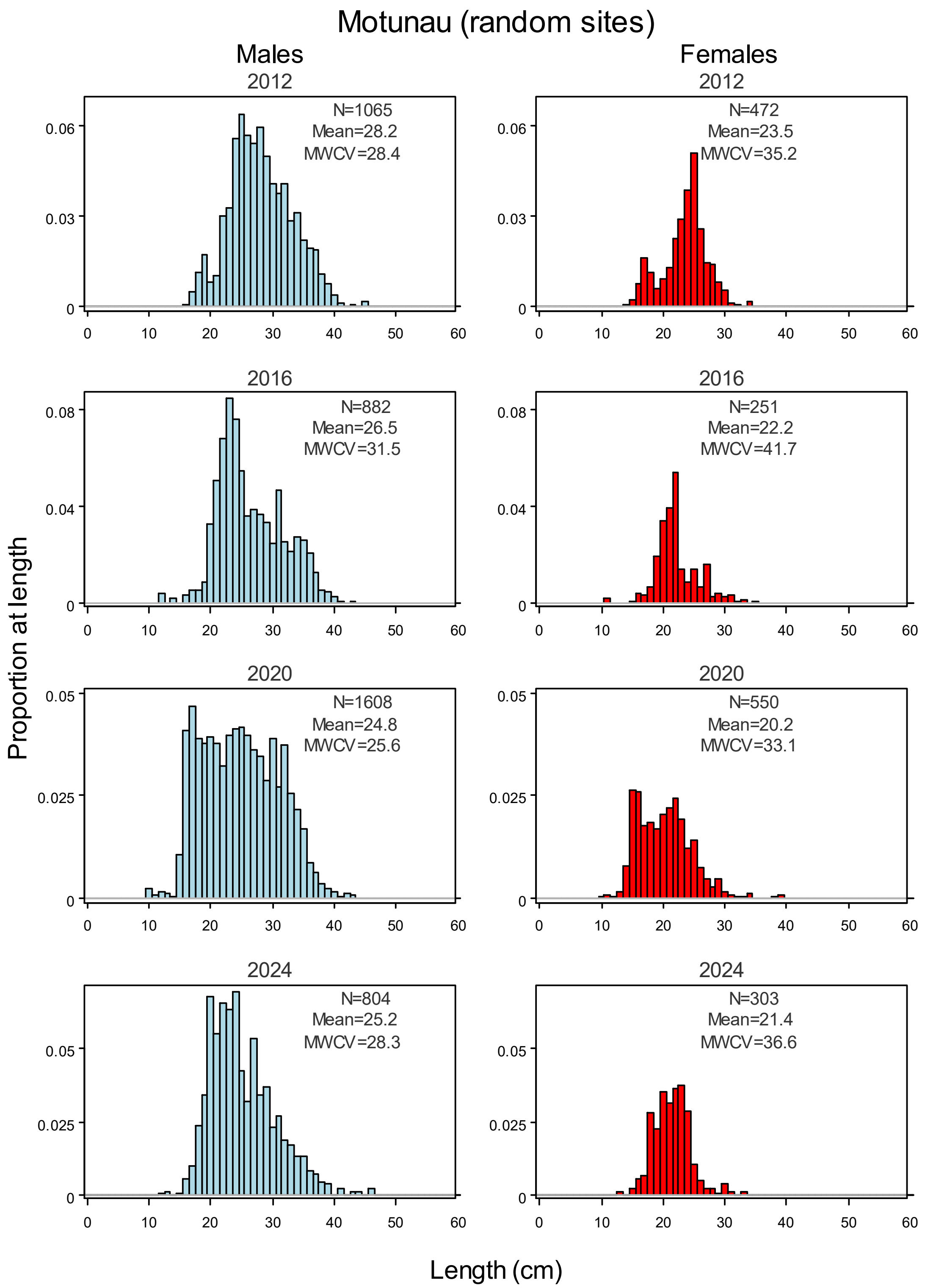

Figure 18: Scaled length frequencies for male and female blue cod from Motunau random-site blue cod potting surveys in 2012, 2016, 2020, and 2024.

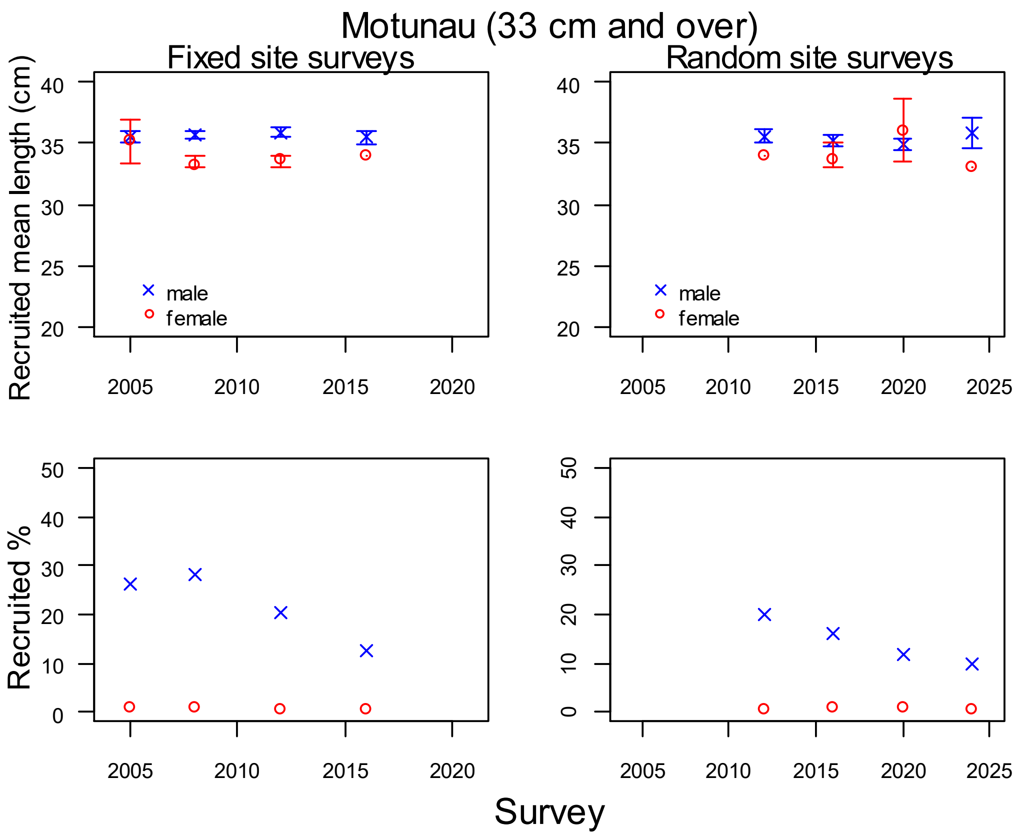

Figure 19: Mean length and 95% confidence intervals of recruited blue cod (33 cm and over) (top panels), and percent of fish that were recruited (bottom panels) for male and female blue cod from Motunau fixed-site and random-site blue cod potting surveys.

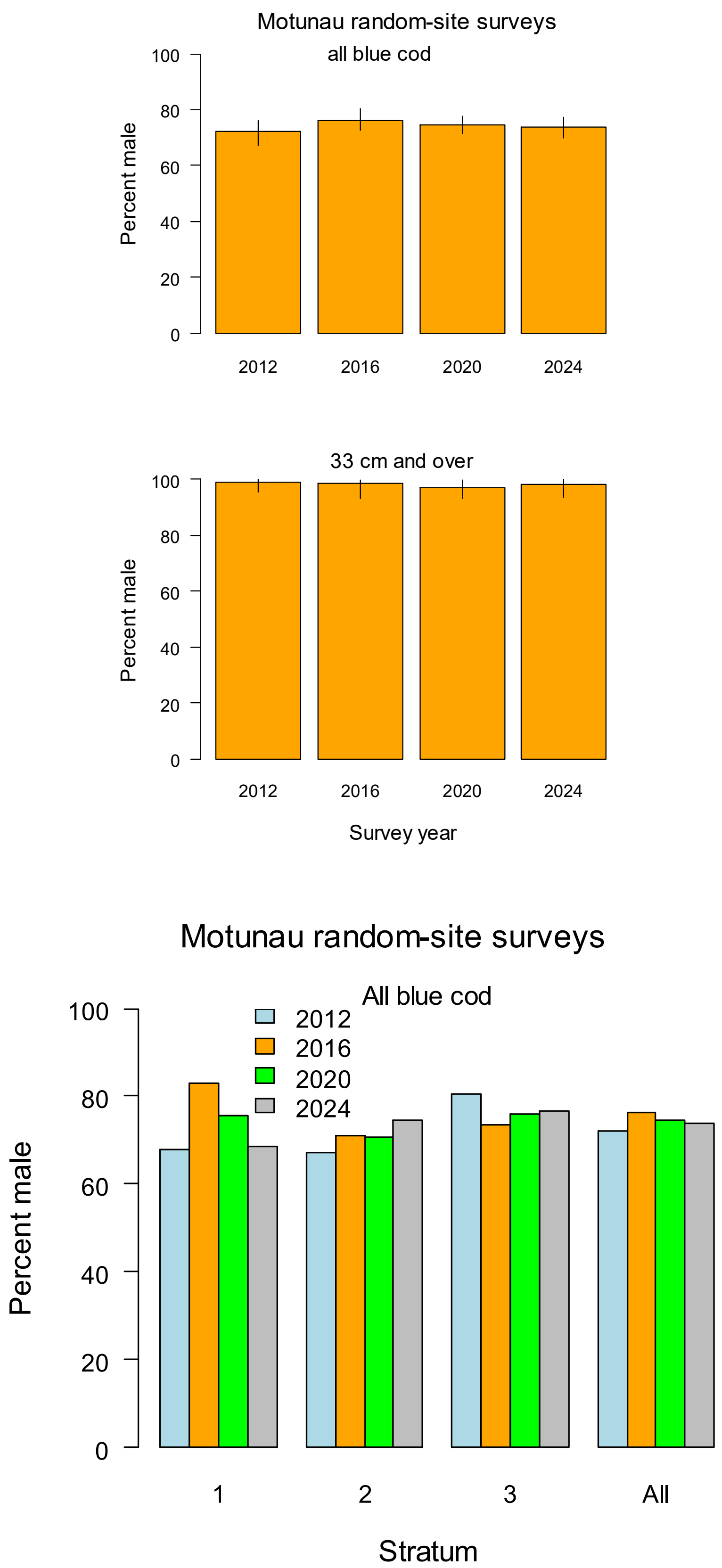

Figure 20: Sex ratio (percent male) and 95% confidence intervals of all blue cod and recruited blue cod (33 cm and over) by survey (top two panels), and for all blue cod by stratum and overall (bottom panel) for the Motunau random-site potting surveys in 2012, 2016, 2020, and 2024.

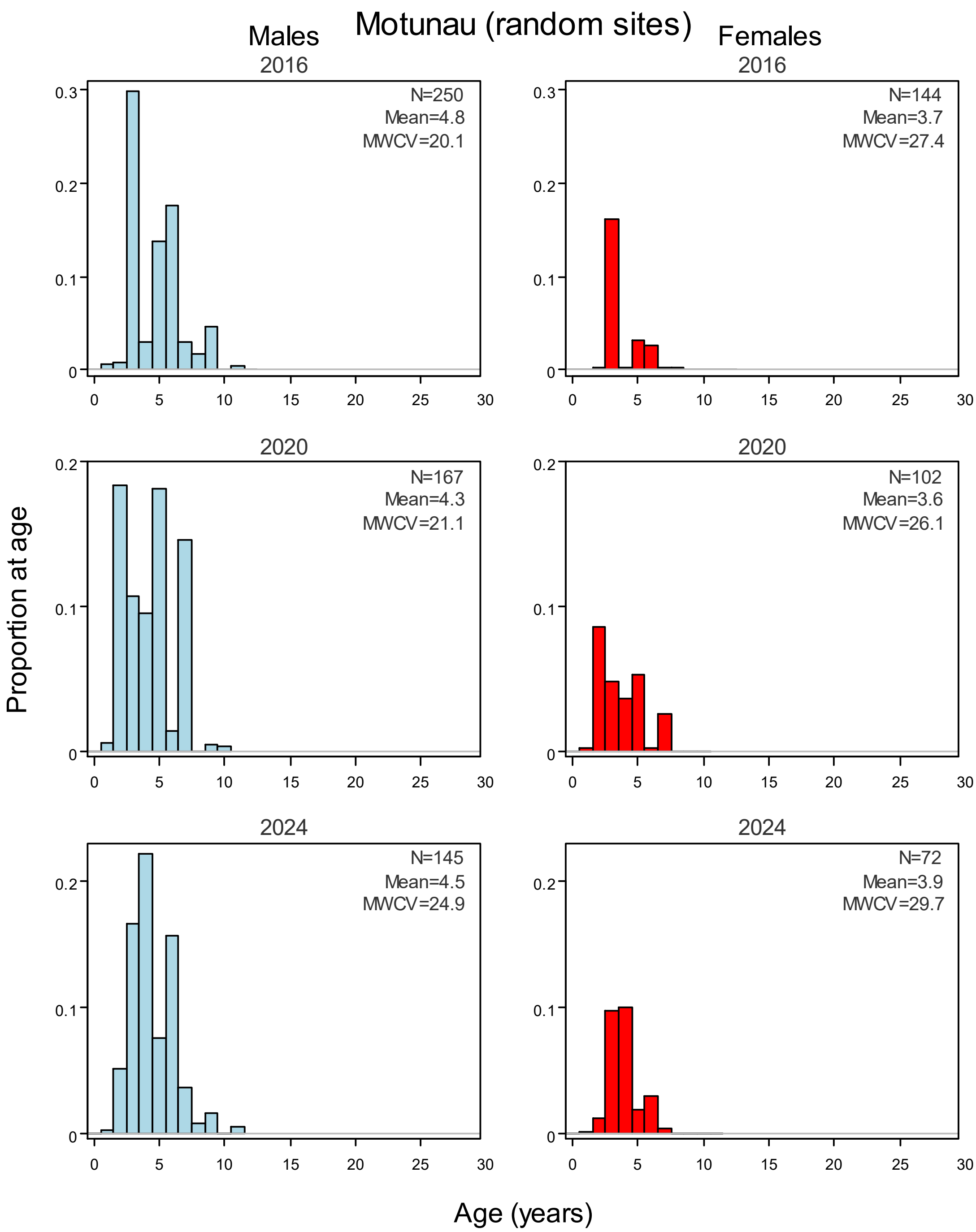

Figure 21: Scaled age frequency distributions for male and female blue cod in the 2016, 2020, and 2024 Motunau random-site blue cod potting surveys. N, sample size; no, population number; Mean, mean length (cm); MWCV, mean weighted coefficient of variation (%).

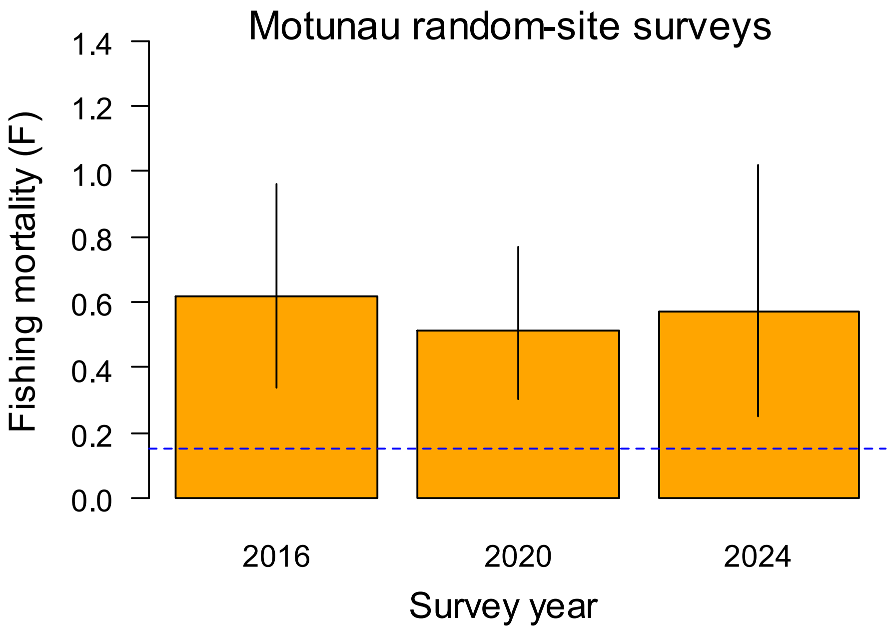

Figure 22: Fishing mortality (*F*) for male blue cod from the 2016, 2020, and 2024 Motunau random-site potting surveys with error bars representing 95% confidence intervals. Fishing mortality was estimated from Chapman Robson total mortality (*Z*), where natural mortality (*M*) was 0.17, and the age at recruitment was the age (plus one year) at which males reach the minimum legal size (30 cm and 6 years of age in 2016 and 2020; 33 cm and 7 years of age in 2024). The dashed blue horizontal line represents the *F* target reference point of 0.15. Plot data are also tabulated in Table 10.

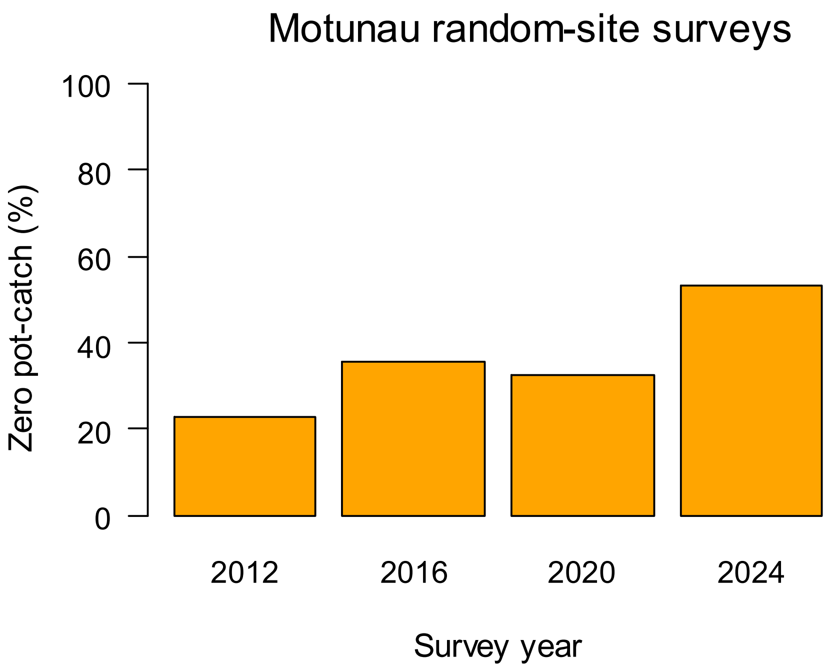

Figure 23: Proportion of pots with zero blue cod catch for the Motunau random-site potting surveys in 2012, 2016, 2020, and 2024. N= 126, 126, 234, and 240 pots for each survey, respectively.

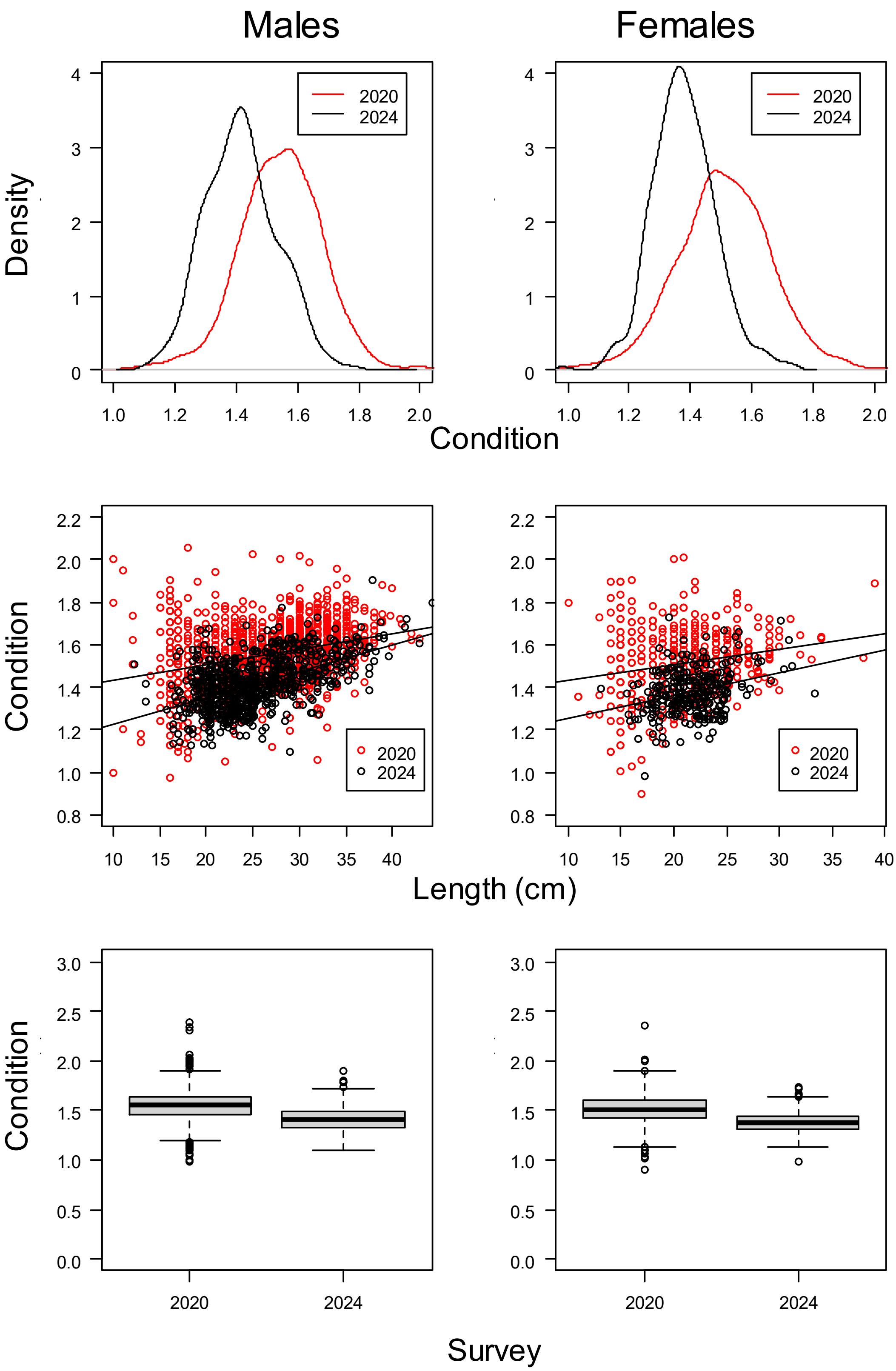

Figure 24: Condition factor (*K*) of blue cod by sex from the Motunau random-site potting surveys in 2020 and 2024, including density plots of condition (top), scatter plots of condition by length (centre), and median box and whisker plots of condition (bottom). $K = wt \times 100/l^3$, where *wt* = weight (g), *l*=length (cm). The lines passing through the scatter plots are linear regression fits to the data.

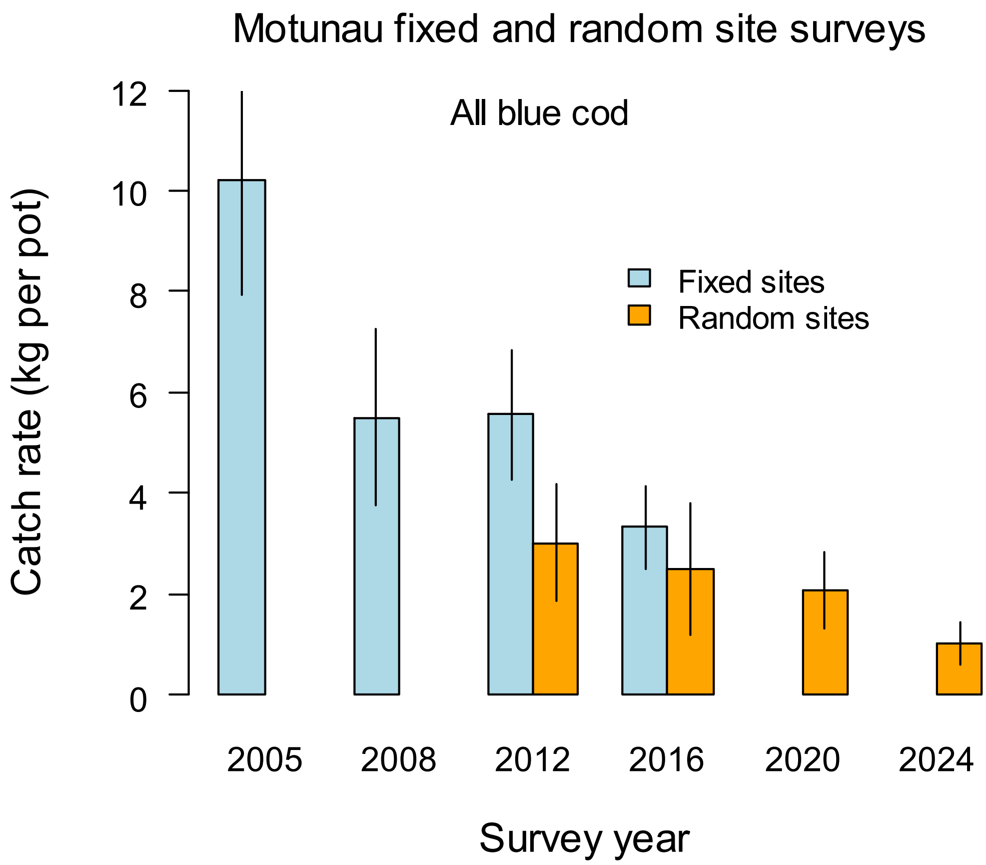

Figure 25: Catch rates (kg pot^{-1}) of all blue cod for the Motunau fixed-site potting surveys in 2005, 2008, 2012, and 2016; and random-site surveys in 2012, 2016, 2020, and 2024. Error bars are 95% confidence intervals.

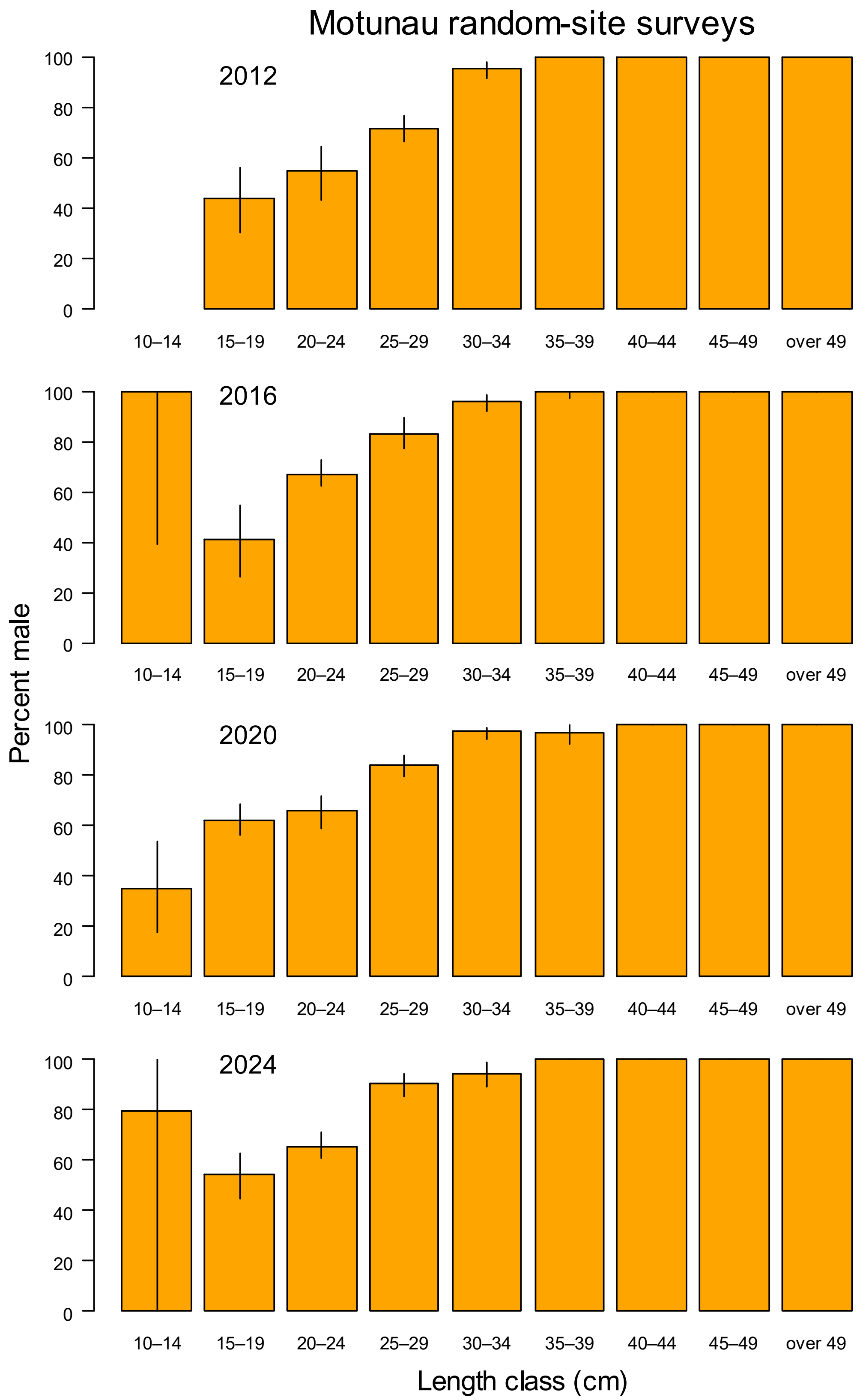

Figure 26: Blue cod sex ratio (percent male) by 5 cm length classes and over 49 cm, for the 2012, 2016, 2020, and 2024 Motunau random-site potting surveys. The errors bars are 95% confidence intervals.

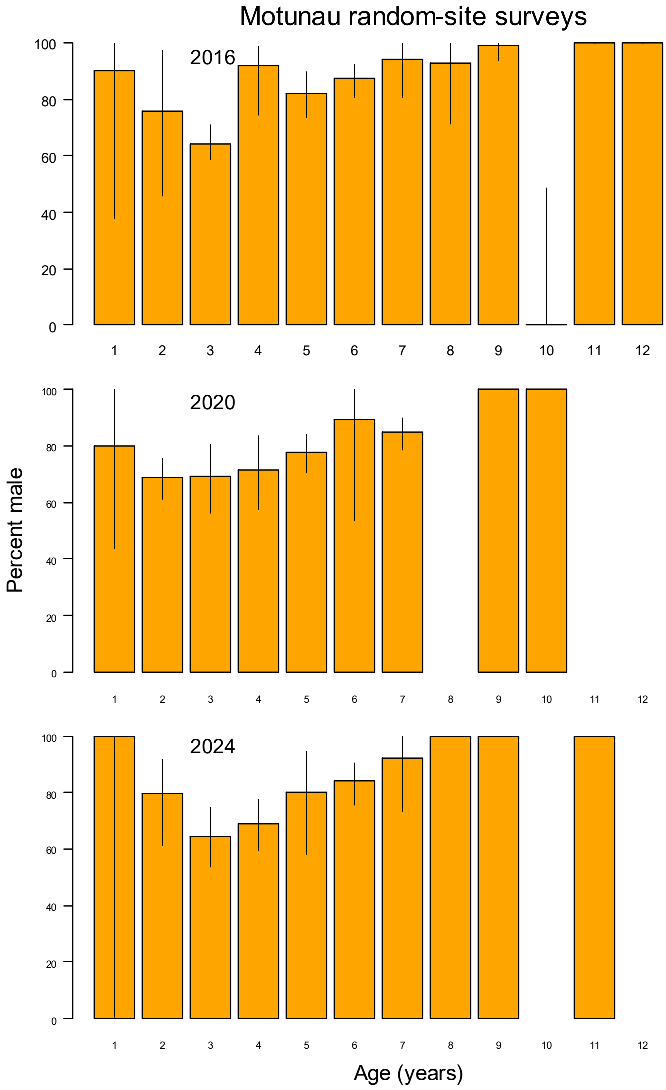

Figure 27: Blue cod sex ratio (percent male) by age class for the 2016, 2020, and 2024 Motunau random-site potting surveys. The errors bars are 95% confidence intervals.

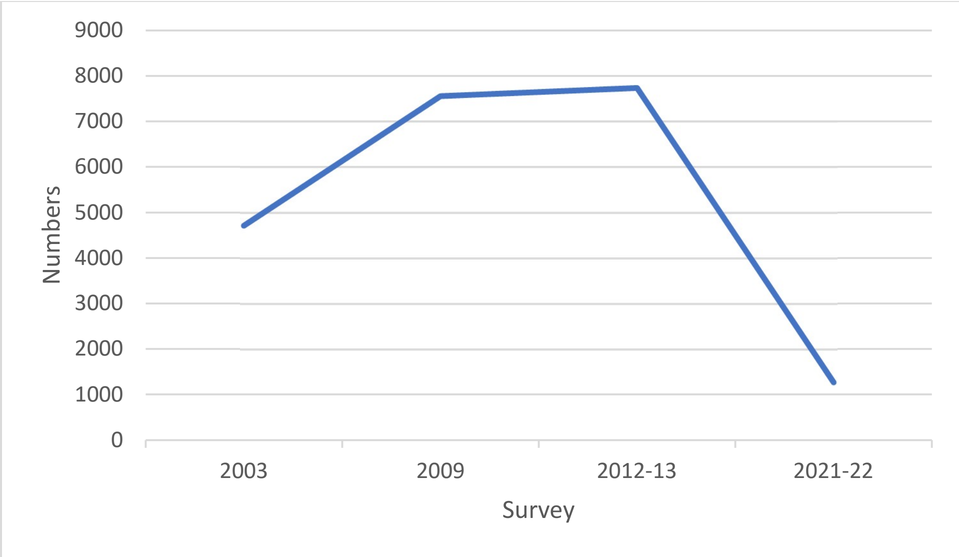

Figure 28: Recreational fishery survey blue cod harvest estimates in numbers by the Motunau private-vessels recreational fishery. Surveys were conducted in 2003, 2009, 2012–13 and 2021–22 (data from Maggs et al. 2023, restricted to January-April).

9. APPENDICES

Appendix 1: Blue cod potting surveys carried out for Fisheries New Zealand in 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 2012a, Beentjes & Page 2017)
	2017, 2019, 2023	Random-site	Systematic	(Beentjes & Page 2018, 2021, 2024)
Motunau	2005, 2008	Fixed-site	Directed	(Carbines & Beentjes 2006a, 2009)
	2012, 2016	Fixed- and random-site	Directed and systematic	(Carbines & Haist 2012a, Beentjes & Sutton 2017)
	2020, 2024	Random-site	Systematic	(Beentjes & Miller 2021), 2024 this report
Banks Peninsula	2002, 2005, 2008	Fixed-site	Directed	(Beentjes & Carbines 2003, 2006, 2009)
	2012	Fixed- and random-site	Directed and systematic	(Carbines & Haist 2017b)
	2016	Fixed- and random-site	Directed and systematic	(Beentjes & Fenwick 2017)
	2021	Random-site	Systematic	(Beentjes et al. 2022a)
North Otago	2005, 2009	Fixed-site	Directed	(Carbines & Beentjes 2006b, 2011b)
	2013, 2018	Fixed- and random-site	Directed and systematic	(Carbines & Haist 2018b, Beentjes & Fenwick 2019a)
	2022	Random-site	Systematic	(Beentjes & Fenwick 2023a)
South Otago	2010	Fixed- and random-site	Directed and systematic	(Beentjes & Carbines 2011)
	2013, 2018, 2022	Random-site	Systematic	(Carbines & Haist 2018c, Beentjes & Fenwick 2019b, 2023b)
Foveaux Strait	2010, 2014, 2018, 2023	Random-site	Systematic	(Carbines & Beentjes 2012, Carbines & Haist 2017a, Beentjes et al. 2019, Beentjes & Miller 2024)
Paterson Inlet	2006	Fixed-site	Directed	(Carbines 2007)
	2010, 2014	Fixed- and random-site	Directed and systematic	(Carbines & Haist 2014, 2018a)
	2018	Random-site	Systematic	(Beentjes & Miller 2020)
Dusky Sound	2002, 2008	Fixed-site	Directed	(Carbines & Beentjes 2003, 2011a)
	2014	Fixed- and random-site	Directed and systematic	(Beentjes & Page 2016)

Appendix 2: Glossary of terms used in this report. Modified from Beentjes & Francis (2011). See the potting survey standard and specifications for more details.

Fixed site	A site that has a fixed location (single latitude and longitude or the centre point location of a section of coastline) in a stratum and is available to be used repeatedly on subsequent surveys in that area. The fixed sites used in a particular 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 to 6 or 1 to 9) in the order they are placed during a set. In Motunau, six nine pots are 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 SONAR to locate a suitable area of reef/cobble or biogenic habitat. **Systematic**–the position of each pot is arranged systematically around the site or along the site for a section of coastline. For the former site, the position of 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 (see below). A site may be specified as a latitude and longitude or a section of coastline (for the latter, use the latitude and longitude at the centre of the section).
Site label	An alphanumeric label of no more than four characters, unique within a survey time series. A site label identifies each fixed site and also specifies which stratum it lies in. Site labels are constructed by concatenating the stratum code with an alpha label (A–Z) that is unique within that stratum. Thus, sites within stratum 2 could be labelled 2A, 2B, and sites in stratum 3 could be labelled 3A, 3B, etc. Site labels for random sites are constructed in the same way but prefixed with R (e.g., R4A, R4B, etc).
Station	The position (latitude and longitude) at which a single pot (or other fishing gear such as ADCP) is deployed at a site during a survey, i.e., it is unique for the trip.
Station number	A number which uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be *station_no* 234. This convention is important in enabling users of the *trawl* database to determine whether two pots are from the same set. Note that the set numbers for potting surveys are not recorded anywhere else in the *trawl* database.

Appendix 3: Numbers of otoliths collected during the 2024 Motunau survey. For males and females, by strata and length class.

	Stratum				Stratum			
Length (cm)	1	2	3	Male totals	1	2	3	Female totals
12	1			1				
13	2			2			1	1
14								
15	1			1	3			3
16	4			4	2		1	3
17	2	1		3	3		1	4
18	2	4	3	9	2	3		5
19	3	1	3	7	3		4	7
20		3	1	4	2	1	2	5
21	2	1	2	5	2	1	2	5
22		4	2	6	2	2	3	7
23	3	2	2	7	2	2	3	7
24		3	3	6		3	3	6
25	2	2	3	7	2	2	3	7
26		3	3	6	2		2	4
27		3	3	6			2	2
28		3	3	6		1	1	2
29		3	3	6	1			1
30		3	3	6			1	1
31		3	3	6			1	1
32		1	3	4				
33		3	3	6		1		1
34	1	1	3	5				
35		3	3	6				
36		1	5	6				
37	2	1	4	7				
38	1	1	2	4				
39		1	2	3				
40								
41			2	2				
42								
43			1	1				
44			1	1				
45								
46			2	2				
Totals	26	51	68	145	26	16	30	72