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Relative abundance, size and age structure, and stock status of blue cod off north Otago in 2018

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EXECUTIVE SUMMARY

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This report describes the results of the fixed-site and random-site blue cod (*Parapercis colias*) potting surveys carried out concurrently off north Otago in January 2018. Estimates are provided for population relative abundance, size and age structure, sex ratio, total mortality (*Z*), and spawner biomass-per-recruit ratio. This is the fourth survey in the north Otago fixed site survey time series, following those in 2005, 2009 and 2013; and the second random-site survey, with the first survey in 2013.

Otolith thin section ages from 227 males and 172 females collected from fixed and random sites were used to estimate the population age structure. The initial counts from each of the two otolith readers achieved 87% agreement, there was minimal bias between readers, and CV and average percent error were 1.3% and 0.9%, respectively. Von Bertalanffy growth parameters (L_∞, K, t_0) were 53.9 cm, 0.14 yr^{-1}, -0.74 yr for males; and 42.3 cm, 0.16 yr^{-1}, and -0.80 yr for females. Sexed based age-length-keys (the same ALK for both surveys) were used to estimate the population age composition for fixed and random-site surveys.

There were indications of spawning activity during the survey period with about 8% of males and 10% of females maturing or running ripe, and over 40% of males were spent suggesting that spawning had peaked prior to the survey dates.

2018 fixed-site survey

Twenty-seven fixed sites (6 pots per site, producing 162 pot lifts) at depths of 14–43 m from six strata off north Otago, were surveyed in January 2018. Mean catch rates of blue cod (all sizes) by stratum were 2.2–5.3 $kg.pot^{-1}$. The survey mean catch rate was 3.55 $kg.pot^{-1}$ with a CV of 18%. Catch rates for recruited blue cod (30 cm and over) followed the same pattern among strata as for all blue cod and overall was 2.4 $kg.pot^{-1}$ (CV 18%). Of the 162 fixed-site pots, 47 (29%) had zero catch of blue cod. The sex ratios were 61–79% male across the six strata and the overall weighted sex ratio was 73% male. The overall weighted mean length for males was 30.4 cm (range 17–50 cm) and 26.3 cm for females (range 17–49 cm). The scaled length frequency distributions for both males and females were unimodal, skewed to the right, with strong peaks at about 27 cm for males and 25 cm for females. Age ranged from 2–20 years for both males and females, but most blue cod were 3–8 years old. The estimated population age distributions indicate knife-edge selectivity to the potting method at three years with strong modes at three, five and eight years for both sexes, but particularly for males. The age distribution also shows a corresponding weak mode for four and seven-year-olds. Mean age was 5.6 years for both males and females. Total mortality (*Z*) for age-at-full recruitment of seven years was estimated at 0.48 (95% confidence interval 0.33–0.65). Based on the default *M* of 0.14, estimated fishing mortality (*F*) was 0.34 and the associated spawner biomass-per-recruit ratio was 23.5% (95% confidence interval 18–35%).

2018 random-site survey

Forty random sites (6 pots per site, producing 240 pot lifts) at depths of 6–47 m from six strata off north Otago, were surveyed in January 2018. Mean catch rates of blue cod (all sizes) by stratum were 0.33–4.14 $kg.pot^{-1}$. The survey blue cod mean catch rate was 2.35 $kg.pot^{-1}$ with a CV of 14%. Catch rates for recruited blue cod (30 cm and over) followed the same pattern among strata as for all blue cod and overall was 1.62 $kg.pot^{-1}$ (CV 15%). Of the 240 random-site pots, 103 (43%) had zero catch of blue cod. The sex ratios were 62–80% male across the six strata and the overall weighted sex ratio was 75% male. The overall weighted mean length for males was 30.2 cm (range 13–53 cm) and 26.7 cm for females (range 16–41 cm). The scaled length frequency distributions for both males and females were unimodal, skewed to the right, with strong peaks at about 27 cm for males and 25 cm for females. Age ranged from 1–15 years for males and 2–16 for females, but most blue cod were 3–8 years old. The estimated

population age distributions indicate almost knife-edge selectivity to the potting method at three years with strong modes at three, five and eight years for both sexes, but particularly for males. The age distributions also show a corresponding weak mode for four-and seven-year-olds. The cumulative distribution plots of age frequency are almost identical for males and females and the mean ages were similar (males 5.5 years, females 5.8 years). Total mortality (Z) for age-at-full recruitment of seven years was estimated at 0.48 (95% confidence interval 0.34–0.64). Based on the default M of 0.14, estimated fishing mortality (F) was 0.34 and the associated spawner biomass-per-recruit ratio was 23.5% (95% confidence interval 19–35%).

Fixed versus random-site surveys

Where valid comparisons can be made between the 2013 and 2018 surveys, the catch rates from fixed sites are generally higher across strata and slightly higher overall than for random-sites, but with overlapping confidence intervals. The catch rate CVs and associated confidence intervals were not noticeably different between survey types. There were no real differences in the length distributions or sex ratios in 2013 and 2018 between fixed and random site surveys. The proportions of pots with zero catch were markedly higher for random site surveys. Valid age data are currently available only for the 2018 survey and age distributions were similar for the 2018 fixed and random-site surveys resulting in identical estimates of total mortality, fishing mortality and spawner-biomass-per-recruit ratios.

Time series (fixed sites)

Catch rates among strata were similar in 2005 and 2009, but in 2013 and again in 2018 the pattern changed among strata. There was a marked decline in the abundance in 2013 with no overlap in the confidence intervals, and abundance remained low in 2018. The scaled length frequency distributions shapes were similar for 2005 and 2009, but changed in 2013 and again in 2018 with the latter having relatively fewer larger fish than earlier surveys. Although mean length of all blue cod declined over time, for recruited blue cod (30 cm and over) there was no trend. The sex ratio showed no trend. The proportion of pots with zero catch for all fixed site surveys increased steeply on each survey from 2% in 2005 to 29% in 2018.

Time series (random sites)

There are two random site surveys in the time series. The survey abundance declines between 2013 and 2018, with no overlap in the confidence intervals. The length frequency distributions were much the same but overall blue cod were slightly smaller in 2018, although mean length of all blue cod and recruited blue cod showed no change. The proportion of pots with zero catch increased from 34% in 2013 to 43% 2018.

1. INTRODUCTION

This report describes the fixed and random-site potting surveys of blue cod (*Parapercis colias*) relative abundance, population length/age structure and stock status off north Otago in January 2018. This is the fourth in the fixed site time series with previous surveys in 2005, 2009 and 2013, and the second random site survey with the previous survey in 2013 (Carbines & Beentjes 2006b, 2011, Carbines & Haist 2018b).

1.1 Status of the north Otago blue cod stocks

In the South Island, blue cod is the finfish species most frequently targeted and landed by recreational fishers (Ministry for Primary Industries 2017) and is caught from small vessels fishing over reef edges on shingle/gravel, biogenic substrata, or sandy bottoms close to rocky outcrops. The Quota Management Area (QMA) BCO 3 extends from the Clarence River, north of Kaikoura, to Slope Point in Southland (Figure 1). In BCO 3, recreational annual take was estimated at 119 t by a 2011–2012 panel survey involving face to face interviews with fishers (Wynne-Jones et al. 2014). Further, blue cod recreational catch in BCO 3 was the highest of any QMA (36% of total national recreational blue cod catch) with average daily catches of over 13 blue cod taken by 17% of respondents, and the most common method by far was rod and line. This was supported by the National Blue Cod Strategy Report by MPI in 2017 (Ministry for Primary Industries 2017) where recreational blue cod fishers were surveyed on-line nationally to gauge perceptions of the status of the New Zealand wide blue cod fishery. Results from that survey ranked BCO 3 as the most important Quota Management Area in New Zealand, in line with the 2011– 2012 panel survey. Perceptions by respondents from Oamaru and Moeraki (Figure 1) ranked recreational bag limits as the major management issue, followed by localised depletion and fishing charter vessels, respectively. There are no reliable data to determine how the recreational blue cod catch was distributed within BCO 3, however north Otago is becoming increasingly popular with recreational fishers as it offers relatively high catches, a bag limit of 30 blue cod (combined daily bag limit), and a minimum legal size of 30 cm.

The commercial catch from BCO 3 was about 40–50% higher than the estimated recreational catch with 166–183 t caught annually in the last seven years up to 2016–17 (Fisheries New Zealand 2018). Nearly all commercially landed blue cod in BCO 3 was caught by potting, and the bulk of this was from Oamaru (Statistical Area 024), with much smaller amounts from Taieri Mouth (Statistical Area 026) and until the late 1990s from Kaikoura Statistical Area 018 (Fisheries New Zealand 2018) (Figure 1).

1.2 North Otago bathymetry and substrate

In north Otago the two key recreational fishing areas for blue cod and many other species are Oamaru and Moeraki which are about 30 km apart and provide access from boat ramps (Figure 3). North Otago has substantial blue cod habitat such as biogenic reefs, both inshore and offshore, across a relatively flat sloping shelf. The survey area lies on the inner continental shelf, which slopes gently away to the east, terminating in the continental slope. The slope is characterised by a series of canyons forming part of Otago Canyon Complex extending from Oamaru to the Otago Peninsula (Figure 2). The sediments off north Otago have considerable areas of predominantly rock and gravel inshore, and sand and gravel offshore, providing ideal blue cod habitat (Figure 3).

1.3 Blue cod potting surveys

South Island recreational blue cod fisheries are monitored using potting surveys. These surveys take place predominantly in areas where blue cod recreational fishing is common, but in some areas there is substantial overlap between the commercial and recreational fishing grounds, including parts of north

Otago. Surveys are generally carried out every four years and provide data that can be used to monitor local relative abundance, size, age, and sex structure of geographically separate blue cod populations. The surveys provide a measure of the response of populations to changes in fishing pressure and management initiatives such as changes to the daily bag limit, minimum legal size, and area closures. One method to investigate the status of blue cod stocks is to estimate fishing mortality, the associated spawner-per-recruit ratio (SPR) and the Maximum Sustainable Yield (MSY) related proxy. The recommended Harvest Strategy Standard target reference point for blue cod (a low productivity stock in which fishing induces changes in sex ratio) is $F_{45\%SPR}$ (Ministry of Fisheries 2011) — i.e., target fishing mortality should be at or below a level that reduces the spawner biomass to 45% of what it would be if there was no fishing.

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

1.4 Previous north Otago blue cod potting surveys

All South Island potting surveys (except Foveaux Strait) originally used a fixed site design, with predetermined (fixed) locations randomly selected from a limited pool of such sites (Beentjes & Francis 2011). The South Island potting surveys were reviewed by an international expert panel in 2009, which recommended that blue cod would be more appropriately surveyed using random-site potting surveys (Stephenson et al. 2009). A random-site is any location (single latitude and longitude) generated randomly from within a stratum (Beentjes & Francis 2011). Following this recommendation, the surveys are in transition to a fully random survey design and the interim sampling of both fixed and random sites allows comparison of catch rates, length and age composition, and sex ratios between the survey designs. Random sites were used as the only site type in Foveaux Strait, and surveys have changed to solely random-site surveys in south Otago (2013 survey), Kaikoura (2017 survey), and Paterson Inlet (2018 survey). For other areas, including north Otago, the most recent surveys included both fixed and random sites.

Previous north Otago surveys in 2005 and 2009 were carried out in January, and the 2013 survey in January through to mid-February (Carbines & Beentjes 2006b, 2011, Carbines & Haist 2018b). The first two surveys used only fixed sites, whereas the 2013 and the current 2018 surveys included concurrent fixed and random-site surveys.

1.5 Objectives

Overall Objective

To estimate relative abundance, maturity state, sex ratio, and age structure of blue cod (*Parapercis colias*) between Oamaru and Shag Point.

Specific objectives

1. To undertake a potting survey between Oamaru and Cornish Head (BCO 3) to estimate relative abundance, size- and age-at-maturity, sex ratio and 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.

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

2. METHODS

2.1 Timing and survey area

A potting survey off north Otago was carried out by NIWA from 7–29 January 2018, consistent with previous surveys.

The original 2005 survey area was defined after discussions with local fishers, Ministry of Fisheries, and the South Recreational Advisory Committee (Carbines & Beentjes 2006b). Fishers were given charts of the area and asked to mark discrete locations around north Otago where blue cod are commonly caught. The survey area was divided arbitrarily into three inshore and two offshore strata between Oamaru and Bobbys Head (Figure 2). The outer boundaries of the inshore and offshore strata were defined approximately by the 30 m and 50 m depth contours, respectively. In subsequent surveys the same five strata used in 2005 were surveyed as well as an additional inshore stratum to the south (Bobbys Head to Cornish Head) (Figure 2). 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 Survey design

2.2.1 Allocation of sites

Fixed site survey

A fixed site 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 (Beentjes & Francis 2011). The fixed sites used in a particular survey are randomly selected from the list of all available fixed sites in each stratum. For the 2018 north Otago survey, the 27 allocated fixed sites were randomly selected from the full and larger list of 62 possible fixed sites.

Simulations to determine the optimal allocation of fixed sites among the six strata were carried out using catch rate data from the 2005, 2009 and 2013 fixed-site surveys and NIWA's Optimal Station Allocation Program (*allocate*). Simulations were constrained to have a minimum of three sites per stratum and a CV (coefficient of variation) of no greater than 15%. The simulations informed the allocation within strata and indicated that about 27 fixed sites were required to achieve a CV of between 10 and 15%, the same number of sites used in 2013.

The 2018 fixed-site survey used a two-phase stratified random station design (Francis 1984) with 24 sites allocated to phase 1, and the remaining three available for phase 2, consistent with the proportion of phase 2 sites used in previous surveys (Table 1). Allocation of phase 2 stations was based on the mean pot catch rate (kg.pot.$^{-1}$) of all blue cod per stratum and optimised using the "area mean squared" method of Francis (1984). In this way, stations were assigned iteratively to the stratum in which the expected gain is greatest, where expected gain is given by:

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

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

Pot configuration and placement for fixed sites is defined in the blue cod potting manual (Beentjes & Francis 2011). Six pots (pot plan 2) were set in a cluster, no further than 0.5 km from the site position, but separated by at least 100 m. Pot placement for fixed sites was 'directed' with placement of each pot around the site determined by the skipper using local knowledge and the vessel echo sounder to locate a suitable area of reef/cobble or biogenic habitat.

Random sites

A random site has a location (single latitude and longitude) generated randomly within a stratum (Beentjes & Francis 2011). Sufficient sites to cover both first and second phase stations were generated for each stratum using the NIWA random station generator program (*Rand_stn* v1.00-2014-07-21) with the constraint that sites were at least 800 m apart. From this list, the allocated number of random sites per stratum to be surveyed was selected in the order they were generated.

Simulations to determine the optimal allocation of random sites among the six strata were carried out using catch rate data from the 2013 random-site survey and NIWA's Optimal Station Allocation Program (*allocate*). Simulations were constrained to have a minimum of three sites per stratum and a CV (coefficient of variation) of no greater than 15%. The simulations informed the allocation within strata and indicated that about 31 random sites were required to achieve a CV of between 15%, however forty sites were used, consistent with 2013.

The 2018 random-site survey used a two-phase stratified random station design (Francis 1984) with 36 sites allocated to phase 1, and the remaining four available for phase 2, consistent with the proportion of phase 2 sites used in 2013 (Table 1). Phase 2 sites were calculated as described above for fixed sites.

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

2.2.2 Vessels and gear

The Otakou based fishing vessel F.V. *Triton* (registration number 7515) skippered by Mr Neil McDonald, was used on the 2018 north Otago survey. The *Triton* is a 12.6 m length wood/fibreglass monohull with a length of 13.9 m, and powered by a Ford diesel 120 hp engine with propeller propulsion. The same vessel and skipper were used on the 2013 survey.

As in all previous surveys, six custom designed and built cod pots were used to conduct the survey (Pot Plan 2 in Beentjes & Francis 2011). Pots were baited with paua viscera in "snifter pottles". Bait was replaced after every lift.

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

2.2.3 Sampling methods

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

At each site, six pots were set and left to fish (soak) for a target period of one hour during daylight hours. As each pot was placed, a record was made of sequential pot number (1 to 6), latitude and longitude from GPS, depth, and time of day. After each site was completed, the next closest site in the stratum was sampled. The ADCP was deployed at the centre of each site prior to the setting of pots and recovered after the last pot of each set was lifted. The order that strata were surveyed depended on the prevailing weather conditions, with the most distant strata and/or sites sampled in calm weather.

Pots were lifted aboard using the vessel's hydraulic pot lifter in the order they were set, and the time of each lift was recorded. Pots were 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. For blue cod, total length to the nearest centimetre below actual length, individual fish weight to the nearest 10 g, sex and gonad maturity were recorded. 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, three otoliths per 1 cm size class for each sex were targeted in strata 1, 2 and 3 combined, and the same for strata 4, 5 and 6 combined (Appendix 2). Sex and maturity were determined by dissection and macroscopic examination of the gonads (Carbines 1998, 2004).

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

2.2.4 Data storage

The 2018 north Otago survey trip code was TRI1801. 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 & Francis 2011). All catch rate, length and sex based analyses were from data extracted from the *trawl* database. Catch-at-age analyses were based on the ageing results provided by the otolith readers, and 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). Random-site locations were also entered into *trawl* table *t_site*. Pot locations were entered in table *t_station* in attribute *station_no* (concatenating set number and pot number e.g., 11 to 16, or 31 to 36 etc.). In the *age* database the *sample_no* is equivalent to *station_no* in the *trawl* database.

ADCP data were sent to the Research Database Manager in spreadsheet format.

2.2.5 Age estimates

Otolith preparation and reading

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

1. Blue cod otolith thin-section preparations were made as follows: otoliths were individually marked on their distal faces with a dot in the centrum using a cold light source on low power to light the otolith from behind. Five otoliths (from five different fish) were then embedded in an epoxy resin mould and cured at 50 ºC. Thin sections were taken along the otolith dorso-ventral axis through the centrum of all five otoliths, using a Struers Accutom-50 digital sectioning machine, with a section thickness of approximately 350 µm. Resulting thin section wafers were cleaned and embedded on microscope slides using epoxy resin and covered with a coverslip. Finally, these slides were oven cured at 50ºC.

2. Otolith sections were read against a black background using reflected light under a compound microscope at a magnification of 40–100 times. Under reflected light opaque zones appear light and translucent zones dark. Translucent zones were counted (ageing of blue cod otolith thin sections prior to 2015 counted opaque zones to estimate age).
3. Two readers read all otoliths without reference to fish length, after having first read the blue cod reference collection.
4. When interpreting blue cod zone counts, both ventral and dorsal sides of the otolith were read, mainly from the core toward the proximal surface close to the sulcus.
5. The forced margin method was used: 'Wide' (a moderate to wide translucent zone present on the margin), October–February; 'Line' (an opaque zone in the process of being laid down or fully formed on the margin), March–April; 'Narrow' (a narrow to moderate translucent zone present on the margin), May–September.
6. Where between-reader counts differed, the readers rechecked the count and conferred until agreement was reached, unless the section was a grade 5 (unreadable) or damaged (removed from the collection).
7. Between-reader ageing precision was assessed by the application of the methods and graphical techniques documented in Campana et al. (1995) and Campana (2001); including APE (average percent error) and coefficient of variation (CV).

2.2.6 Data analyses

Analyses of catch rates, sex ratios, scaled length distribution, catch-at-age, Z estimates, and spawner-per-recruit were carried out and are presented for the 2018 fixed and random-site surveys.

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

2.2.6.1 Catch rates

The catch rate (kg.pot^{-1}) estimates were pot-based and the CV estimates were set-based (Beentjes & Francis 2011). Catch rates and 95% confidence intervals (± 1.96 standard error) were estimated for all blue cod and for recruited blue cod (30 cm and over). Catch rates of recruited blue cod were based on the sum of the weights of individual recruited fish which were all weighed on the survey. The stratum areas (km^2) shown in Table 1 were used as the area of the stratum (A_t) when scaling catch rates (equations 3 and 5 in Beentjes & Francis 2011). Catch rates are presented by stratum and overall. Catch rates were estimated for individual strata and for all strata combined.

2.2.6.2 Length-weight parameters

The length-weight parameters a_k, b_k from the 2018 north Otago fixed and random-site surveys combined 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. 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.

2.2.6.3 Growth parameters

Separate von Bertalanffy growth models (von Bertalanffy 1938) were fitted to the 2018 North Otago survey length-age data by sex as follows:

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

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

2.2.6.4 Scaled length and age frequencies

Length and age compositions were estimated using the NIWA program Catch-at-Age (Bull & Dunn 2002). The program scales the length frequency data by the area of the stratum, number of sets in each stratum, and estimated catch weight determined from the length-weight relationship of individual fish. The latter scaling should be negligible or very close to one if all fish caught during the survey were measured (which they were) and if the actual weight of the catch is close to the estimated weight of the catch. The stratum areas (km^2) are shown in Table 1, and the length-weight parameter estimates are from the 2018 north Otago survey data for males and females separately.

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

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

Catch-at-age was estimated using a single age-length-key (ALK) for each sex applied to the length data from the entire survey area. The same ALKs were used for both random and fixed sites. Scaled length frequency and age frequency proportions are presented, together with CVs for each length and age class, and the mean weighted coefficients of variation (MWCV).

2.2.6.5 Sex ratios, and mean length and age

Sex ratios (expressed as percentage male) and mean lengths, for the stratum and survey, were calculated using equations 10 and 11 of Beentjes & Francis (2011) from the stratum or survey scaled length frequencies. Mean ages were calculated analogously from the scaled age frequencies. Sex ratios were also estimated for recruited blue cod (30 cm and over), and overall survey 95% confidence intervals around sex ratios were generated from the 300 length frequency bootstraps.

2.2.6.6 Total mortality estimates

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

Estimates of CR total mortality, *Z*, were calculated for age-at-recruitment values of 5 to 10 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.

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

2.2.6.7 Spawner-per-recruit estimates

A spawner-per-recruit analysis was conducted using CASAL (Bull et al. 2005). The calculations involved simulating fishing with constant fishing mortality (*F*), and estimating the equilibrium spawning biomass per recruit (SPR) associated with that value of *F* (Beentjes & Francis 2011). The %SPR for that *F* is then simply that SPR, expressed as a percentage of the equilibrium SPR when there is no fishing (i.e., when $F = 0$, and %SPR = 100%).

Input parameters used in SPR analyses

Growth parameters — von Bertalanffy growth parameters and length-weight coefficients from the 2018 surveys:

Parameter	Males	Females
$K\ (yr^{-1})$	0.1410	0.1645
$t_0\ (yr)$	-0.7386	-0.7971
$L_\infty\ (cm)$	53.95	42.29
a	0.005968	0.005992
b	3.2721	3.2756

Natural mortality — default assumed to be 0.14. Sensitivity analyses were carried out for *M* values 20% above and below the default (0.11 and 0.17).

Maturity — the following maturity ogive was used: 0, 0, 0, 0.1, 0.4, 0.7, and 1; where 10% of blue cod are mature at 4 years old and all are mature at 7 years.

Selectivity — selectivity to the fishery (recreational/commercial) is described as knife-edge equal to age-at-MLS calculated from the 2018 north Otago survey von Bertalanffy models. The north Otago recreational MLS is 30 cm and selectivity was 5.05 years for males and 6.72 years for females.

Fishing mortality (*F*) — fishing mortality was estimated from the results of the Chapman-Robson analyses and the assumed estimate of *M* (i.e., $F = Z–M$). The *Z* value was for age-at-full recruitment (8 years for females).

Maximum age — assumed to be 31 years.

To estimate SPR the CASAL model uses the Baranov catch equation which assumes that *M* and *F* are occurring continuously throughout the fishing year. i.e., instantaneous natural and fishing mortality.

The SPR estimates are based on age at recruitment equal to the MLS for females, in this case 7 years.

2.2.6.8 Analyses of previous north Otago surveys

For previous surveys in 2005, 2009, and 2013, catch rates, scaled length composition and sex ratios were analysed using the methods described above to ensure comparability with earlier analyses and/or research providers. No ageing analyses of the three previous surveys were carried out because although blue cod were aged from these surveys, ageing was not compliant with the ADP for blue cod and therefore ages cannot be assumed to be accurate.

3. RESULTS

3.1 2018 fixed-site survey

Twenty-seven fixed sites (6 pots per site, producing 162 pot lifts) from six strata off north Otago were surveyed from 7–29 January 2018 (Table 1, Figure 4). Depths sampled were 14–43 m (mean = 28 m). Twenty-four sites were sampled in phase-one and three in phase-two. An example of the fisher directed pot placement configuration for fixed sites is shown in Figure 5.

3.1.1 Catch and catch rates

A total of 590.2 kg of blue cod (1293 fish) was taken, comprising 91.0% by weight of the catch of all species on the fixed-site survey (Table 2). Bycatch species included eight teleost fishes, as well as octopus, carpet shark, and brittle star. The most abundant teleost by-catch species, by number, were leatherjacket (*Meuschenia scaber*) and scarlet wrasse (*Pseudolabrus miles*).

Mean catch rates ($kg.pot^{-1}$) of blue cod (all blue cod, and 30 cm and over) are presented by stratum and overall for the fixed-site survey (Table 3, Figure 6). Mean catch rates of blue cod (all sizes) by stratum were 2.24–5.30 $kg.pot^{-1}$ with the lowest in stratum 3 (offshore between Moeraki and Oamaru), and the highest in stratum 4 (inshore between Moeraki and Bobby's Head) (Table 3, Figure 6). The all-blue-cod survey catch rate was 3.55 $kg.pot^{-1}$ with a CV of 17.7%. Catch rates for recruited blue cod (30 cm and over) generally followed the same pattern among strata as for all blue cod and was 2.43 $kg.pot^{-1}$ (CV 18.4%) (Table 3, Figure 6). Of the 162 fixed-site pots, 47 (29%) had zero catch of blue cod.

3.1.2 Biological and length frequency data

All 1293 blue cod caught from fixed sites were sexed, measured for length, and weighed (Table 4). The sex ratios were 61–79% male across the six strata and the overall weighted sex ratio was 73% male (Table 4). Length was 17–50 cm for males and 17–49 cm for females, although this range varied among strata and the overall weighted mean length was 30.4 cm for males and 26.3 cm for females. The scaled length frequency distributions were variable among the strata, but males and females tended to show similar shapes within strata (Figure 7). Males were dominant in all strata.

3.1.3 Age and growth

Otolith thin-section ages from 227 males and 172 females collected from the 2018 fixed and random-site surveys were used to estimate the population age structure from north Otago in 2018 (Table 5). The length-age data are plotted and the von Bertalanffy model fits and growth parameters (K, t_0 and L_∞) are shown for males and females separately (Figure 8). There is a large range in length-at-age particularly for males; males generally grow faster and comprise most of the largest fish.

Between-reader comparisons are presented in Figure 9. The first counts of the two readers showed 87% agreement, and overall there was no bias between readers with a CV of 1.3% and average percent error (APE) of 0.92%.

3.1.4 Spawning activity

Gonad stages of blue cod from fixed and random sites sampled in February 2018 from north Otago are presented for all fish combined and by stratum (Table 6a and 6b). There were indications of spawning activity during the survey period with about 8% of males and 10% of females maturing or running ripe, and over 40% of males were spent suggesting that spawning had peaked prior to the survey. Gonad stage by stratum results indicated that nearly all spawning activity occurred in the northern strata 1–3.

3.1.5 Population length and age composition

The scaled length frequency and age distributions for the 2018 north Otago fixed-site survey are shown for all strata combined, as histograms, and as cumulative frequency line plots for males, females, and both sexes combined (Figure 10).

The scaled length frequency distribution for males was unimodal, skewed to the right, with a strong peak at about 27 cm and an overall mean length of 30 cm. The female distribution was also unimodal, skewed to the right, with a strong peak at about 25 cm and an overall mean length of 26 cm (Figure 10). The cumulative distribution plots of length frequency are similar in shape between sexes, but the female plot is steeper and to the left, reflecting the smaller size overall with few fish over 35 cm length. The mean weighted coefficients of variation (MWCVs) around the length distributions were 30% for males and 26% for females.

Age estimates were 2–20 years for both males and females, but most males and females were 3–8 years old (Figure 10). The fixed site estimated population age distributions indicate almost knife-edge selectivity to the potting method at three years with strong modes at three, five and eight years for both sexes, but particularly for males. The age distributions also exhibit weak modes for four-and seven-year-olds. The cumulative distribution plots of age frequency are almost identical for males and females and the mean ages were the same at 5.6 years (Figure 10). The MWCVs around the age distributions were 21% for males and 29% for females, indicating a good representation of the overall population age structure.

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

Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals for the fixed-site survey are given for a range of recruitment ages (5–10 y) in Table 7. Age-at-full recruitment (AgeR) is assumed to be seven years, equal to the age at which females reach the MLS of 30 cm. The CR *Z* for AgeR of seven years is 0.48 (95% confidence interval of 0.33–0.65).

The traditional catch curve, based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment of seven years, is shown for diagnostic purposes (Figure 11). The natural log of numbers-at-age does not follow the ideal straight line descending limb, suggesting that the assumption of constant recruitment had been sufficiently violated to detract from the results to a small degree (Figure 11). Although the CR estimation is less sensitive to age classes with few fish, some very weak recruited year classes will have introduced some error (and probably bias) into the *Z* estimate, which is reflected in the wide 95% confidence intervals around *Z* (see Table 7).

Fixed-site survey mortality parameters (CR *Z* and *F*, and *M*) and spawner-per-recruit (SPR) estimates at three values of *M* and age at full recruitment of seven years are shown in Table 8. Based on the default

M of 0.14, estimated fishing mortality (*F*) was 0.34 and the associated spawner-per-recruit ratio was 23.5% (Figure 12). At the 2018 levels of fishing mortality, the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 23% of the contribution in the absence of fishing. The 95% confidence intervals around the SPR ratios were 18–35% (Table 8).

3.2 2018 Random-site survey

Forty random sites (6 pots per site, producing 240 pot lifts) from six strata off north Otago were surveyed from 7–29 January 2018 (Table 1, Figure 4). Depths sampled were 6–47 m (mean = 25 m). Thirty-six sites were sampled in phase-one and four in phase-two. An example of the systematic pot placement configuration for random sites is shown in Figure 5.

3.2.1 Catch and catch rates

A total of 694.9 kg of blue cod (1497 fish) was taken, comprising 94.0% by weight of the catch of all species on the random-site survey (Table 2). Bycatch species included seven teleost fishes, as well as octopus, brittle star, hagfish, and sea cucumber. The most abundant teleost bycatch species, by number, were leatherjacket (*Meuschenia scaber*), scarlet wrasse (*Pseudolabrus miles*), and tarakihi (*Nemadactylus macropterus*).

Mean catch rates ($kg.pot^{-1}$) of blue cod (all blue cod, and 30 cm and over) are presented by stratum and overall for the random-site survey (Table 3, Figure 13). Mean catch rates of blue cod (all sizes) by stratum were 0.33–4.12 $kg.pot^{-1}$ with the lowest in stratum 2 (inshore south of Oamaru), and the highest in stratum 4 (inshore between Moeraki and Bobby's Head) (Table 3, Figure13). The all-blue-cod survey catch rate was 2.35 $kg.pot^{-1}$ with a CV of 14.3%. Catch rates for recruited blue cod (30 cm and over) generally followed the same pattern among strata as for all blue cod and overall was 1.62 $kg.pot^{-1}$ (CV 15.3%) (Table 3, Figure 13). Of the 240 random-site pots, 103 (43%) had zero catch of blue cod.

3.2.2 Biological and length frequency data

All 1497 blue cod caught from random sites were sexed, measured for length, and weighed (Table 4). The sex ratios were 62–80% male across the six strata and the overall weighted sex ratio was 75% male (Table 4). Length was 13–53 cm for males and 16–41 cm for females, although this range varied among strata and the overall weighted mean length was 30.2 cm for males and 26.7 cm for females. The scaled length frequency distributions were variable among the strata, but males and females tended to show similar shapes within strata (Figure 14). Males were dominant in all strata.

3.2.3 Age and growth

See Section 3.1.3 for age and growth description which applies to fixed and random-site surveys.

3.2.4 Spawning activity

See Section 3.1.4 for spawning activity description which applies to fixed and random-site surveys.

3.2.5 Population length and age composition

The scaled length frequency and age distributions for the 2018 north Otago random-site survey are shown for all strata combined, as histograms, and as cumulative frequency line plots for males, females,

and both sexes combined (Figure 15). The scaled length frequency distribution for males was unimodal, slightly skewed to the right, with a strong peak at about 27 cm and an overall mean length of 30 cm (Figure 15). The female distribution was also unimodal, skewed to the right, with a strong peak at about 25 cm and an overall mean length of 27 cm (Figure 15). The cumulative distribution plots of length frequency are similar in shape between sexes, but the female plot is steeper and to the left, reflecting the smaller size overall with few fish over 35 cm length. The mean weighted coefficients of variation (MWCVs) around the length distributions were 23% for males and 35% for females.

Age estimates were 1–15 years for males and 2–16 years for females, but most males and females were 3–8 years old (Figure 15). The estimated random site population age distributions indicate almost knife-edge selectivity to the potting method at three years with strong modes at three, five and eight years for both sexes, but particularly for males. The age distributions also exhibit weak modes for four-and seven-year-olds. The cumulative distribution plots of age frequency are almost identical for males and females and the mean ages were similar (males 5.5 years, females 5.8 years) (Figure 15). The MWCVs around the age distributions were 19% for males and 26% for females, indicating a good representation of the overall population age structure.

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

Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals for the random-site survey are given for a range of recruitment ages (5–10 y) in Table 7. Age-at-full recruitment (AgeR) is assumed to be seven years, equal to the age at which females reach the MLS of 30 cm. The CR *Z* for AgeR of seven years is 0.48 (95% confidence interval of 0.34–0.64).

The traditional catch curve, based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment of seven years, is shown for diagnostic purposes (Figure 11). The natural log of numbers-at-age does not follow the ideal straight line descending limb, suggesting that the assumption of constant recruitment had been sufficiently violated to detract from the results to a small degree (Figure 11). Although the CR estimation is less sensitive to age classes with few fish, some very weak recruited year classes will have introduced some error (and probably bias) into the *Z* estimate, which is reflected in the wide 95% confidence intervals around *Z* (see Table 7).

Random-site survey mortality parameters (CR *Z* and *F*, and *M*) and spawner-per-recruit (SPR) estimates at three values of *M* and age at full recruitment of seven years are shown in Table 8. Based on the default *M* of 0.14, estimated fishing mortality (*F*) was 0.34 and associated spawner-per-recruit was 23.5% (Figure 12). At the 2018 levels of fishing mortality, the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 23% of the contribution in the absence of fishing. The 95% confidence intervals around the SPR ratios were 19–35% (Table 8).

3.3 Comparison of fixed and random-site surveys

Where valid comparisons can be made between the 2013 and 2018 surveys, the catch rates from fixed sites are generally higher across strata and slightly higher overall than for random sites, but with overlapping confidence intervals. (Figure 16). The CVs and associated confidence intervals are not noticeably different between survey types with 2013 CVs of 13% and 14%, and 2018 CVs of 18% and 14% for fixed and random sites, respectively. The patterns of catch rates across strata are also similar for both survey types in 2013 and 2018.

There were only slight differences in the length distributions in 2013 and 2018 between fixed and random sites (Figure 17).

Sex ratios are largely the same between survey types with proportions of male in 2013 of 76% and 68%, and in 2018 of 73% and 75% for fixed and random sites, respectively.

The proportion of pots with zero catch are markedly higher for random-site surveys with proportions of 22% and 34% in 2013, and 29% and 43% in 2018 for fixed and random sites, respectively.

Valid age data are currently available only for the 2018 survey because on previous surveys, ageing was not carried out in accordance with the blue cod ADP. Age distributions were similar for the 2018 fixed and random-site surveys (Figure 18) to the extent that total mortality, fishing mortality and spawner-biomass-per-recruit ratios were identical for age at recruitment of seven years and *M* of 0.14 (Table 8, Figure 12).

3.4 North Otago survey time series

Fixed sites (2005, 2009, 2013, and 2018)

Mean catch rates ($kg.pot^{-1}$) scaled by stratum area for all blue cod and recruited blue cod for the four fixed-site surveys are presented in Figure 19. The addition of stratum 6 to the surveys from 2009 onward has made little difference to the survey overall catch rates estimated including or excluding stratum 6, and hence 2005 can be included in the time series (All) despite not including stratum 6 (Figure 19). Catch rates among strata were similar in 2005 and 2009 when abundance was similar, however in 2013 and 2018 the pattern changes among strata and is also not consistent between these two years. For north Otago there was a clear and marked decline in the survey abundance between 2009 and 2013 with no overlap in the confidence intervals, and abundance remained low in 2018 (Figure 19).

The scaled length frequency distribution shapes were similar for the 2005 and 2009, but changed in 2013 and again in 2018 with the latter having relatively fewer larger fish than earlier surveys (Figure 20). Although mean length of all blue cod declined over time, for recruited blue cod (30 cm and over) there was no trend (Figure 21).

The sex ratio for all fixed site surveys was 72–76% male for all blue cod, and 85–86% male for recruited blue cod, with no trends (Figure 22).

The proportion of pots with zero catch for all fixed site surveys increased steeply on each survey from 2% in 2005 to 29% in 2018 (Figure 23).

Random sites (2013 and 2018)

There are only two random site surveys in the time series. The survey abundance shows a decline between 2013 and 2018 with no overlap in the confidence intervals (Figure 24). The length frequency distributions were much the same, but overall blue cod were slightly smaller in 2018 (Figure 25), although mean length showed no significant change (see Figure 21). The proportion of pots with zero catch from random sites, although higher than from fixed sites, also increased steeply from 2013 to 2018 (see Figure 23).

4. DISCUSSION

4.1 General

The 2018 north Otago potting survey was the fourth fixed-site survey in the time series of relative abundance and population structure of blue cod from this area, after previous surveys in 2005, 2009 and 2013. Random-site surveys were carried out in 2013 and 2018 concurrently with the fixed-site surveys. The Fisheries New Zealand Southern Inshore Working Group (SINSWG-2018-36) agreed that future surveys off north Otago will use only a random-site design which is considered to be more accurate, statistically robust and more likely to represent the entire blue cod population (Stephenson et al. 2009). Differences in catch rate trends for equivalent strata between the 2013 and 2018 fixed and random surveys, suggest that there is no suitable way of quantitatively linking the fixed-site series with the

random-site series. Accordingly, the random site surveys provide a separate time-series that will become more informative with each successive survey. The four fixed-site surveys have nevertheless indexed the decline in abundance that occurred after 2009, also reflected in the progressive increase in the proportion of empty pots over time (see Figures 19 and 23).

Although length and age structures, and sex ratios were similar between the overlapping fixed and random-site north Otago surveys in 2013 and 2018, the differences in these survey designs are shown in the generally lower abundance indices and the higher proportion of empty pots for random sites. Although size distributions can sometimes vary, catch rates tend to be higher in fixed than random-site surveys throughout the South Island, such as in Marlborough Sounds, Kaikoura, Motunau, Banks Peninsula and south Otago (Beentjes & Fenwick 2017, Beentjes & Sutton 2017, Beentjes & Page 2018, Beentjes et al. 2018, Beentjes & Fenwick in prep). The likely reason for this is that fixed sites were selected as locations where blue cod were known to be abundant, whereas random sites can fall anywhere within a stratum, including on marginal habitat.

4.2 Blue cod habitat

Sediment sampling stations (n = 30 000) 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. 2018). The sediment maps of north Otago show how sand, mud, and rock are distributed within the six north Otago strata and may be useful for re-stratifying future surveys. The north Otago coastline and inner shelf occupied by the strata are characterised by rock inshore, transitioning into gravel, and sand outside 30 m (Figure 3). There is little mud, with the exception of a small patch in stratum 6. Highest catch rates were in stratum 4 dominated by rock and gravel, and stratum 5 dominated by sand. A multivariate analysis may determine if sediment type is related to catch rates, but this could be limited by the paucity of sediment sampling sites used to build the sediment distribution maps in this area. A high resolution multibeam seabed survey, similar to that carried out off Kaikoura in 2017 (Neil et al. 2018), would provide additional information on seabed structure that may be related to blue cod localised abundance. The north Otago survey abundance estimates, length and age distributions, and sex ratio were weighted (scaled) by the area of each stratum. Scaling by strata area assumes that the size of each stratum is directly proportional to the amount of blue cod habitat, although it is likely that some strata (and parts thereof) will have more habitat suited to blue cod than others.

4.3 Survey precision

The survey CV around relative abundance (catch rates) was not specified in the project objectives for the 2018 north Otago survey, but a CV of around 15% is generally targeted. The achieved CV of 18% for the fixed-site survey was higher than those from previous fixed-site surveys (8% for 2005, 6% for 2009 and 13% for 2013), most likely a result of declining catch rates and the increase in zero catches. Random-site CVs were similar for 2013 (13.9%) and 2018 (14.3%), although both surveys took place following the large decline in abundance after 2009. The random-site CV in 2018 indicates that the survey design and number of sites used (40 sites) are appropriate for north Otago random-site surveys, assuming abundance does not decline any further.

4.4 Cohort strength and recruitment

Growth estimates indicate that males are on average 5-years-old, and females nearly 8-years-old when they reach the current MLS of 30 cm in north Otago (see Figure 8). Hence the dominant 5-year-old mode (5+) in 2018 suggests that the north Otago 2012 year-class was exceptional and can be expected to provide a strong pulse of recruitment to the fishery over the next few years (see Figure 18). Blue cod are not fully selected to the potting method until at least 4 to 5 years old, a finding supported by the age

composition in other areas surveyed, most recently Kaikoura (Beentjes & Page 2018). Despite this, the 2015 (3+) year class appears to be relatively strong when compared with that in 2016 (4+) and most likely will result in another strong pulse of recruitment to the fishery in a few years' time. The north Otago fishery is currently dominated by the 2009 year-class (8+) (Figure 18).

The age structure off north Otago in 2018 is similar to that observed in Kaikoura two months earlier where modal progression of strong and weak year classes were observed between the 2015 and 2017 surveys (Beentjes & Page 2017, 2018). Further, the strong 2012 year-class (3-year-olds) and the weak 2011 year-class (4-year-olds) observed in Kaikoura in December 2015, were also present in the age compositions from Motunau in January 2016, and Banks Peninsula in April 2016 (Beentjes & Fenwick 2017, Beentjes & Sutton 2017). These findings indicate that blue cod populations exhibit variable recruitment with intermittent pulses of strong and weak year classes. Further, the consistent age pattern on the northeast and southeast coast of the South Island suggests that the 2012 spawning event was more successful than average and/or that natural mortality was low, possibly as a result of favourable environmental conditions along the east coast South Island. Blue cod have a restricted home range (Rapson 1956, Mace & Johnston 1983, Mutch 1983, Carbines & McKenzie 2001, Carbines & McKenzie 2004) and the Kaikoura, Motunau, Banks Peninsula, and north Otago stocks of this species are likely to consist of largely independent sub-populations. However, there is no evidence that blue cod are genetically distinct around the New Zealand mainland (Gebbie 2014) suggesting that mixing is occurring on a wider geographical scale than within the restricted home range indicated by tagging studies. Mechanisms for genetic mixing are unknown.

4.5 Sex change and sex ratio

The 2018 north Otago sex ratio for both survey types and across all strata favours males at a ratio of about three to one (see Table 4). This finding was consistent across the previous fixed and random-site north Otago surveys (see Figure 22). Sex ratios tend to favour males in heavily exploited blue cod populations, and despite the north Otago random site survey abundance declining by one-half between 2013 and 2018, the sex ratio has remained male dominated, but stable.

Blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow (Carbines 2004); the north Otago blue cod population sex and size structure is consistent with this reproductive strategy. In areas where fishing pressure was known to be high, such as Motunau, inshore Banks Peninsula, and the Marlborough Sounds, the sex ratios were strongly skewed towards males which is contrary to an expected dominance of females resulting from selective removal of the larger final phase male fish (Beentjes & Carbines 2003, 2006, Carbines & Beentjes 2006a, Beentjes & Carbines 2012, Beentjes & Sutton 2017). In contrast, in Foveaux Strait, offshore Banks Peninsula, and particularly Dusky Sound, where fishing mortality is lower, females are dominant (Beentjes & Page 2016, Beentjes & Fenwick 2017, Beentjes et al. In prep). Beentjes & Carbines (2005) suggest that the shift towards a higher proportion of males in heavily fished blue cod populations may be caused by removal of the possible inhibitory effect of large males, resulting in a higher rate (and possibly earlier onset) of sex change by primary females. The male dominated sex ratio in north Otago indicates that this population is heavily fished, thereby confirming high estimates of fishing mortality and low spawner biomass per recruit ratio (see below).

4.6 Stock status

The *Harvest Strategy Standard* specifies that a Harvest Strategy should include a fishery target reference point, and that this may be expressed in terms of biomass or fishing mortality (Ministry of Fisheries 2011). The most appropriate target reference point for blue cod is F_{MSY}, which is the amount of fishing mortality that results in the maximum sustainable yield. The recommended proxy for F_{MSY} is the level of spawner-per-recruit $F_{\%SPR}$ (Ministry of Fisheries 2011). Blue cod is categorised as an exploited

species with low productivity (on account of complexities of sex change) and the recommended proxy for F_{MSY} is $F_{45\%SPR}$.

Given that random site surveys are considered to be more statistically robust and will be used in future, the discussion is confined to the random-site survey mortality and spawner per recruit results. The 2018 random-site survey Z was 0.48, F was 0.34 and the SPR estimate, (M value of 0.14, and age at full recruitment of 7 years) was $F_{23.5\%SPR}$ ($F_{19\%}$–$F_{34\%}$, 95% CIs), indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit was reduced to 23% of the contribution in the absence of fishing (see Figure 12). These results suggest that the level of exploitation (F) of north Otago blue cod stocks was above the F_{MSY} target reference point of $F_{45\%SPR}$, in 2018 (over-exploited).

The finding that blue cod are over-exploited in 2018 is consistent with a trend of declining abundance and an increase in pots with zero catch (see Figures 19, 23 and 24).

4.7 Reproductive condition

All north Otago blue cod surveys (fixed and random) were carried out in January, with the exception of 2013, which went into mid-February, so reproductive status is temporally comparable. All four surveys show indications of spawning activity for both sexes, with a variable but declining trend in the proportions in the ripe and running-ripe conditions. 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 ripe and running-ripe conditions during this period. Often there are higher proportions of females than males in the combined ripe/running-ripe conditions, possibly related to the reproductive strategy where a large male will hold a territory, attracting multiple females. This is not the case for north Otago where proportions are similar. The north Otago surveys occurred during the known protracted spawning period, and the high proportions of males in the spent condition suggests that spawning had passed its peak, with spawning largely restricted to the northern strata off Oamaru (see Table 6b).

4.8 Management implications

The high historic catch rates, MLS of 30 cm and a bag limit of 30 fish (or blue cod) has made north Otago attractive to blue cod fishers and there is strong anecdotal evidence of a large increase in effort at Moeraki in recent years, both from recreational and charter vessels. Displacement of recreational fishing effort from Canterbury to north Otago is likely to have occurred in recent years because of low catch rates around inshore Banks Peninsula combined with lower daily bags limits and larger MLS at Motunau and Kaikoura. Without information on recreational fishing effort, however, it is difficult to gauge impacts on the stock status. For example, the 2013 and 2018 low abundance may be a result of sustained poor recruitment over several years. Before 2013, blue cod were more abundant in north Otago than in any other area surveyed, with fixed-site catch rates in 2005 and 2009 of 9–10 kg.pot^{-1}. The 2018 north Otago catch rates (fixed 3.55 kg.pot^{-1}; random 2.35 kg.pot^{-1}) are similar to Dusky Sound (2.6 kg.pot^{-1}, random in 2014), and below those from Foveaux Strait (5.6 kg.pot^{-1}, random in 2017) which now has the highest blue cod abundance (Beentjes & Page 2016, Beentjes et al. In prep).

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7. TABLES AND FIGURES

Table 1: Effort and catch data for the 2018 north Otago fixed and random-site blue cod potting surveys.

	Area		*N* sets (sites)			Catch (blue cod)		Depth (m)	
Stratum	(km^2)	Site type	Phase 1	Phase 2	*N* pots (stations)	*N*	kg	Mean	Range
1	153.1	Fixed	4		24	124	75.0	23.0	14–31
2	243.5	Fixed	4	1	30	201	67.2	19.7	14–27
3	149.9	Fixed	4		24	125	68.9	39.3	36–42
4	115.9	Fixed	4		24	314	127.1	20.9	14–29
5	200.1	Fixed	4	2	36	306	185.7	38.2	33–43
6	54.3	Fixed	4		24	223	66.3	24.8	20–29
Total	916.8		24	3	162	1293	590.2	27.7	14–43

	Area		*N* sets (sites)			Catch (blue cod)		Depth (m)	
Stratum	(km^2)	Site type	Phase 1	Phase 2	*N* pots (stations)	*N*	kg	Mean	Range
1	153.1	Random	8	2	60	386	216.2	17.2	6–29
2	243.5	Random	4		24	24	7.8	17.3	12–23
3	149.9	Random	7		42	114	53.9	36.8	29–47
4	115.9	Random	5	1	36	377	148.4	19.1	7–31
5	200.1	Random	8	1	54	326	173.4	37.3	29–47
6	54.3	Random	4		24	270	95.2	20.0	8–34
Total	916.8		36	4	240	1497	694.9	24.6	6–47

Table 2: Total catch and numbers of blue cod and bycatch species caught on the 2018 north Otago fixed and random-site blue cod potting surveys. Percent of the catch by weight is also shown.

				Fixed sites	
Common name	Species	Code	Number	Catch (kg)	% catch
Blue cod	*Parapercis colias*	BCO	1293	590.2	91.18
Common octopus	*Octopus maorum*	OCT	7	17.8	2.75
Scarlet wrasse	*Pseudolabrus miles*	SPF	20	16.1	2.49
Leatherjacket	*Meuschenia scaber*	LEA	25	8.7	1.34
Southern conger	*Conger verreauxi*	CVR	1	4.0	0.62
Carpet shark	*Cephaloscyllium isabella*	CAR	1	3.3	0.51
Sea perch	*Helicolenus percoides*	SPE	4	2.7	0.42
Tarakihi	*Nemadactylus macropterus*	NMP	5	2.0	0.31
Brittle star	Ophiuroid	OPH	12	1.4	0.22
Blue moki	*Latridopsis ciliaris*	MOK	4	0.8	0.12
Spotty	*Notolabrus celidotus*	STY	3	0.2	0.03
Blue warehou	*Seriolella brama*	WAR	1	0.1	0.02
Totals			1376	647.3	100

				Random sites	
Common name	Species	Code	Number	Catch (kg)	% catch
Blue cod	*Parapercis colias*	BCO	1497	694.9	94.50
Leatherjacket	*Meuschenia scaber*	LEA	44	15.6	2.12
Southern conger	*Conger verreauxi*	CVR	1	7.0	0.95
Banded Wrasse	*Notolabrus fucicola*	BPF	4	4.1	0.56
Brittle star	Ophiuroid	OPH	41	3.6	0.49
Common octopus	*Octopus maorum*	OCT	2	3.2	0.44
Scarlet wrasse	*Pseudolabrus miles*	SPF	10	2.5	0.34
Tarakihi	*Nemadactylus macropterus*	NMP	10	2.1	0.29
Hagfish	*Eptatretus cirrhatus*	HAG	1	1.0	0.14
Girdled wrasse	*Notolabrus cinctus*	GPF	2	0.8	0.11
Starfish	Asteroidea & Ophiuroidea	SFI	2	0.3	0.04
Sea cucumber	Holothurian	HTH	1	0.2	0.03
Blue moki	*Latridopsis ciliaris*	MOK	1	0.1	0.01
Totals			1616	735.4	100

Table 3: Mean catch rates for all blue cod and recruited blue cod (30 cm and over) from the 2018 north Otago fixed and random-site blue cod potting surveys. Catch rates are pot-based, and s.e. and CV are set-based. s.e., standard error; CV coefficient of variation; NA, not applicable.

			All blue cod			Recruited blue cod ≥ 30 cm		
Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
1	Fixed	24	3.13	1.49	47.6	2.68	1.33	49.7
2	Fixed	30	2.24	0.99	44.1	1.28	0.54	41.8
3	Fixed	24	2.87	1.05	36.6	2.17	0.79	36.4
4	Fixed	24	5.30	2.44	46.2	2.89	1.62	56.0
5	Fixed	36	5.16	1.69	32.8	3.90	1.22	31.2
6	Fixed	24	2.76	0.76	27.3	1.21	0.39	32.7
Overall		162	3.55	0.63	17.7	2.43	0.45	18.4

			All blue cod			Recruited blue cod ≥ 30 cm		
Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
1	Random	60	3.60	0.89	24.8	2.88	0.73	25.2
2	Random	24	0.33	0.17	53.4	0.18	0.10	52.1
3	Random	42	1.28	0.67	52.1	0.95	0.46	48.3
4	Random	36	4.12	1.24	30.0	2.37	0.76	32.2
5	Random	54	3.21	0.98	30.4	2.33	0.77	32.9
6	Random	24	3.97	1.48	37.4	2.07	0.83	40.3
Overall		240	2.35	0.34	14.3	1.62	0.25	15.3

Table 4: Descriptive statistics for blue cod caught on the 2018 north Otago fixed and random-site blue cod potting surveys. Outputs are raw for each stratum and weighted overall. Sex ratio is also given for recruited blue cod (30 cm and over). m, male; f, female; u, unsexed. –, no data.

Fixed site survey

			Length (cm)			Percent male	
Stratum	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited ≥ 30 cm
1	m	86	33.3	20.2	47.1	69.2	69.7
	f	38	31.1	19.9	37.8		
2	m	123	28.8	19.6	43.5	61.2	78.2
	f	78	24.8	17.5	33.8		
3	m	99	32.0	20.4	46.7	79.3	88.2
	f	26	28.2	20.2	40.7		
4	m	245	29.6	19.6	42.2	78.0	92.8
	f	69	25.5	18.8	32.6		
5	m	239	32.9	19.9	49.9	78.3	89.4
	f	67	29.1	21	49.3		
6	m	148	26.9	18.5	41.5	66.6	95.1
	f	75	23.1	18.2	31.5		
Overall	m	940	30.4	18.5	49.9	72.6	84.9
	f	353	26.3	17.5	49.3		

Random site survey

			Length (cm)			Percent male	
Stratum	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited ≥ 30 cm
1	m	276	33.0	20.1	47.3	71.5	82.2
	f	110	29.3	19.1	41.4		
2	m	17	28.1	22	35.7	70.5	78.1
	f	7	28.4	23.5	34.1		
3	m	70	29.5	13.2	48.2	62.4	54.3
	f	44	29.4	19.1	39.8		
4	m	301	29.6	18.4	41.2	79.8	96.3
	f	76	25.0	15.9	32.2		
5	m	260	31.5	16.8	53.5	80.0	93.0
	f	66	26.8	18.6	37.5		
6	m	195	28.7	16.6	41.9	72.2	95.6
	f	75	24.7	17.6	33.6		
Overall	m	1119	30.2	13.2	53.5	75.2	87.0
	f	378	26.7	15.9	41.4		

Table 5: Otolith ageing data used in the catch-at-age, *Z* estimates and SPR analyses for the 2018 Otago fixed and random-site blue cod potting surveys.

		Length of aged fish (cm)		Age (years)	
Survey	No. otoliths	Minimum	Maximum	Minimum	Maximum
Male	227	13.2	53.5	1	20
Female	172	15.9	47.1	2	19
Total	399	13.2	53.5	1	20

Table 6a: Gonad stages (%) of all blue cod from the north Otago fixed and random-site blue cod potting survey in January 2018 for all blue cod by sex. 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

	Gonad stage (%)					
Sex	1	2	3	4	5	*N*
Males	25.3	25.3	2.8	4.3	42.4	2059
Females	74.0	11.5	10.0	0.3	4.2	731

Table 6b: Gonad stages (%) of all blue cod from north Otago fixed and random-site blue cod potting surveys in January 2018, by stratum and sex.

	Male gonad stage (%)						
Stratum	1	2	3	4	5	Stratum totals (%)	Stratum totals (*N*)
1	16.9	21.5	4.7	5.5	51.4	100	362
2	4.3	18.6	20.7	35.7	20.7	100	140
3	26.0	23.1	0.0	1.2	49.7	100	169
4	28.2	22.7	0.4	0.7	48.0	100	546
5	25.1	37.3	1.6	2.4	33.7	100	499
6	38.2	19.5	0.3	0.0	42.0	100	343
Gonad totals (*N*)	521	520	57	88	873		2059

	Female gonad stage (%)						
Stratum	1	2	3	4	5	Stratum totals (%)	Stratum totals (*N*)
1	45.3	27.7	22.3	0.0	4.7	100	148
2	32.9	29.4	16.5	1.2	20.0	100	85
3	57.1	11.4	30.0	0.0	1.4	100	70
4	96.6	2.1	0.0	0.0	1.4	100	145
5	88.7	4.5	3.8	0.8	2.3	100	133
6	98.7	0.7	0.0	0.0	0.7	100	150
Gonad totals (*N*)	541	84	73	2	31		731

Table 7: Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals of blue cod for the 2018 north Otago fixed and random-site blue cod potting surveys. AgeR, age at full recruitment.

			95% CIs	
Site type	AgeR	*Z*	Lower	Upper
Fixed	5	0.50	0.35	0.67
Fixed	6	0.42	0.29	0.57
Fixed	7	0.48	0.33	0.65
Fixed	8	0.83	0.56	1.16
Fixed	9	0.4	0.27	0.57
Fixed	10	0.45	0.28	0.65
Random	5	0.53	0.36	0.74
Random	6	0.43	0.30	0.58
Random	7	0.48	0.34	0.64
Random	8	0.85	0.60	1.16
Random	9	0.44	0.30	0.61
Random	10	0.53	0.35	0.75

Table 8: Mortality parameters (Chapman Robson *Z*, *F* and *M*) and spawner-per-recruit ($F_{SPR\%}$) point-estimates at three values of *M* for blue cod from the 2018 north Otago fixed and random-site blue cod potting surveys. The mortality parameters and spawner-per-recruit estimates are also given for the default *M* (0.14) and the 95% confidence interval values of *Z*. AgeR = 7, where AgeR is the age at which females reach MLS of 30 cm. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality; LowerCI, lower 95% confidence interval; UpperCI, Upper 95% confidence interval.

Site type	*M*	*Z*	*F*	$F_{\%SPR}$	Estimate
Fixed	0.11	0.48	0.37	$F_{17.2\%}$	Point
Fixed	0.14	0.48	0.34	$F_{23.5\%}$	Point
Fixed	0.17	0.48	0.31	$F_{30.1\%}$	Point
Fixed	0.14	0.33	0.19	$F_{35.0\%}$	LowerCI
Fixed	0.14	0.65	0.51	$F_{17.8\%}$	UpperCI
Site type	*M*	*Z*	*F*	$F_{\%SPR}$	Estimate
Random	0.11	0.48	0.37	$F_{17.2\%}$	Point
Random	0.14	0.48	0.34	$F_{23.5\%}$	Point
Random	0.17	0.48	0.31	$F_{30.1\%}$	Point
Random	0.14	0.34	0.20	$F_{33.8\%}$	LowerCI
Random	0.14	0.64	0.50	$F_{18.8\%}$	UpperCI

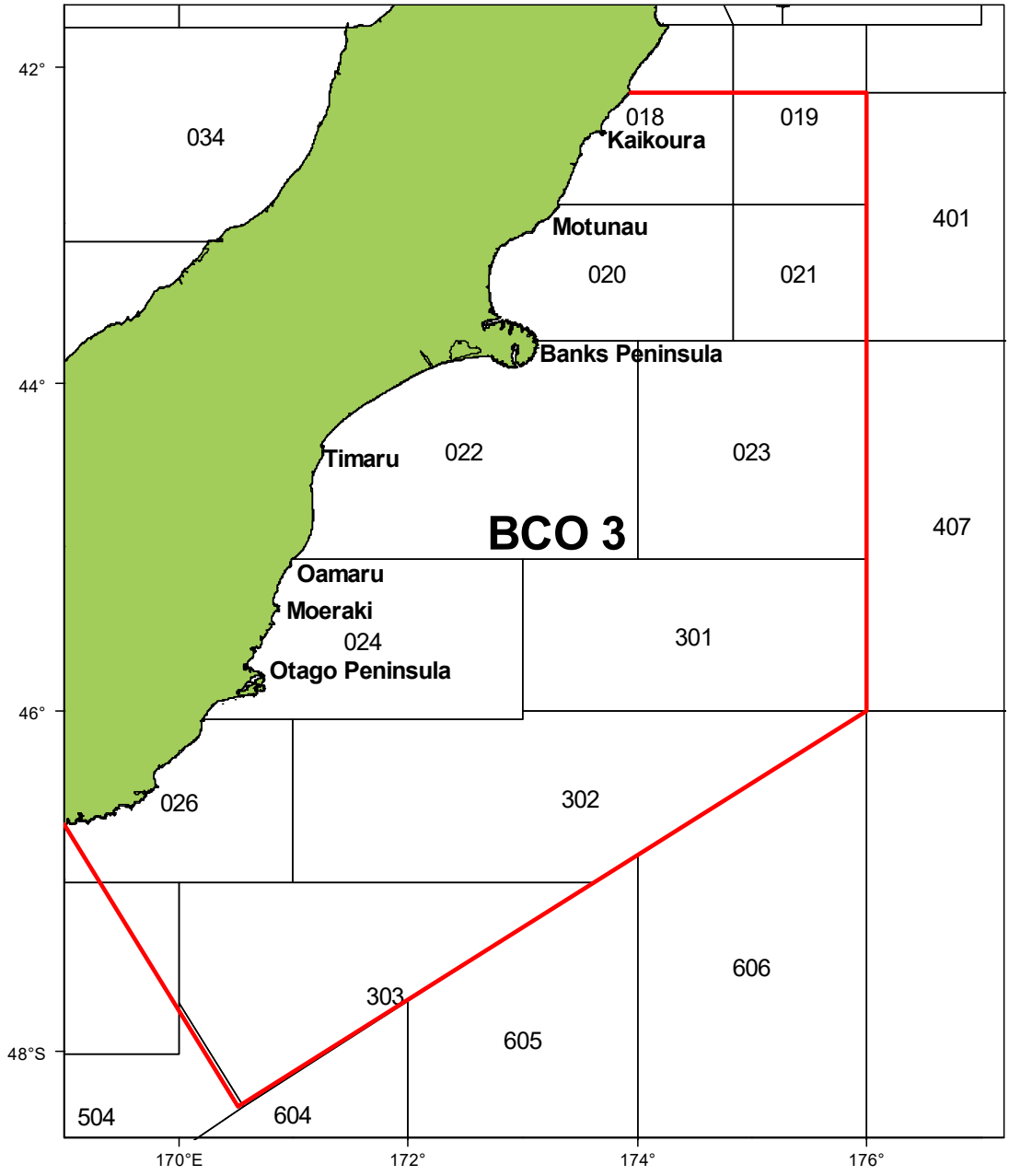

Figure 1: Blue cod Quota Management Area BCO 3 (red border) and statistical areas. The north Otago potting survey takes place off Oamaru and Moeraki.

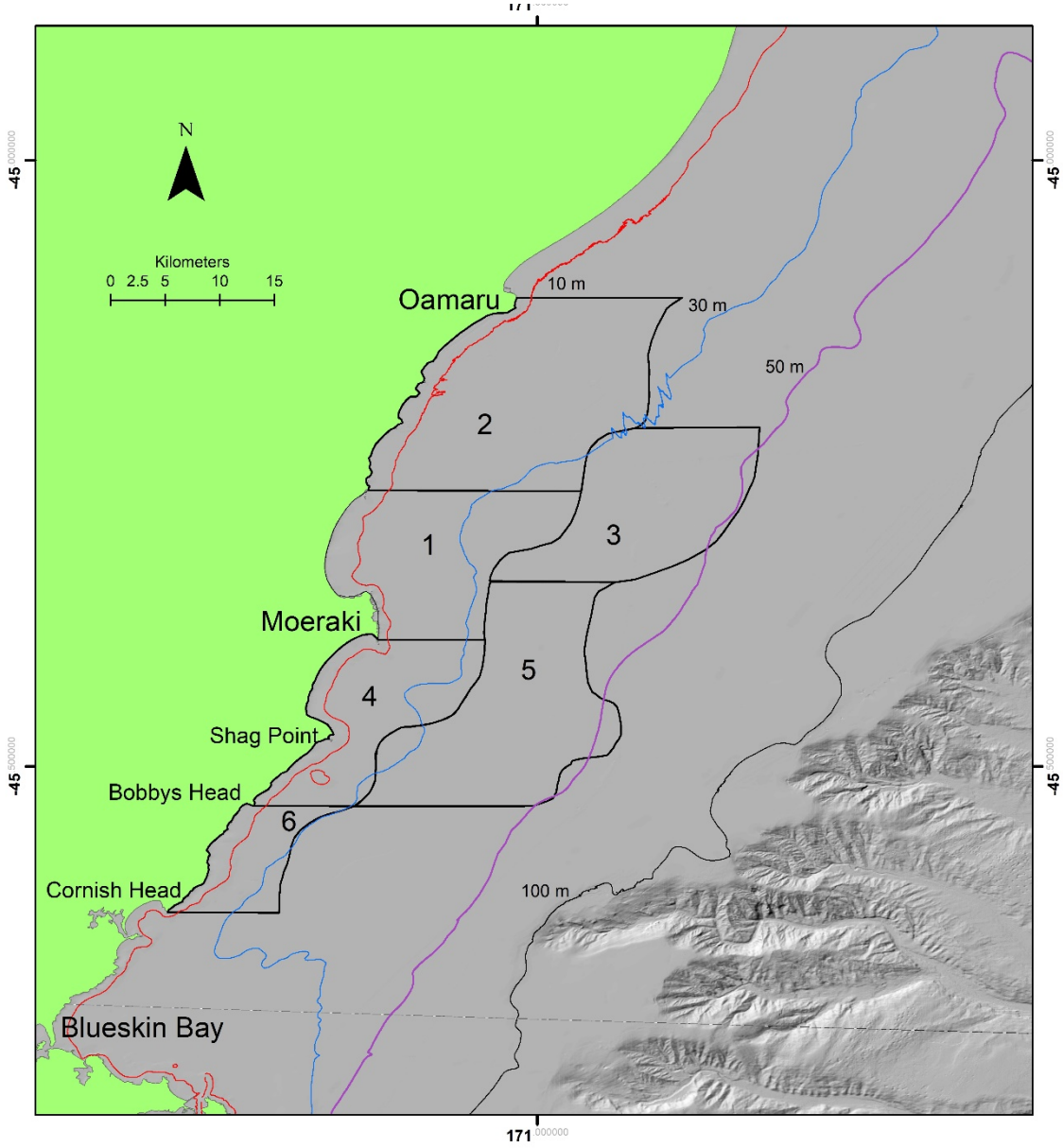

Figure 2: North Otago blue cod survey strata, bathymetry contours, and hillshade view of the seafloor based on the NIWA Digital Terrain Model (DEM) of the 25 m gridded data-set (3x vertical exaggeration).

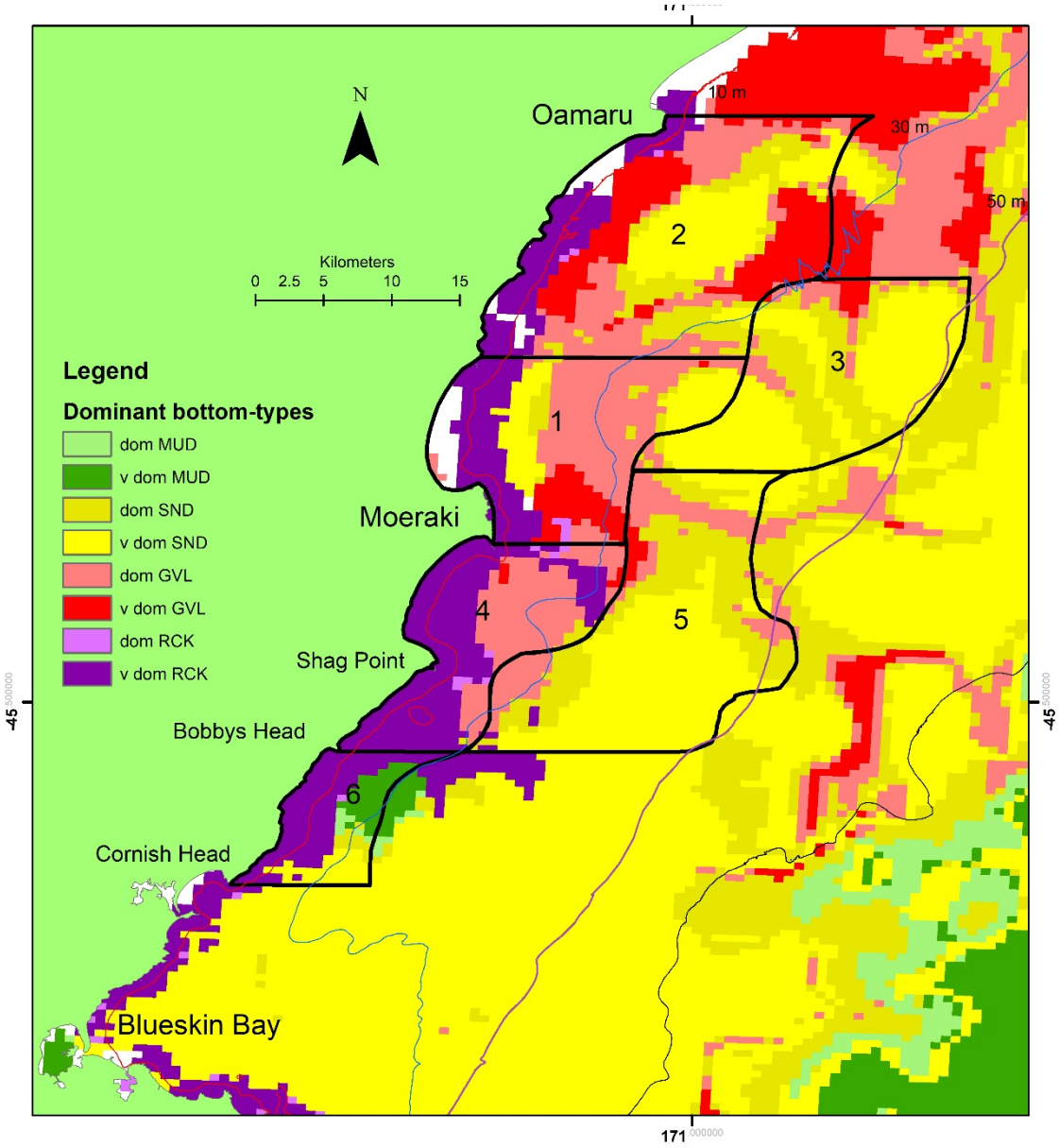

Figure 3: North Otago blue cod survey strata, bathymetry contours, and dominant sea floor substrate types (data from Bostock et al. 2018). Dom, dominant; v dom, very dominant; MUD, mud; SND, sand; GVL, gravel; RCK, rock.

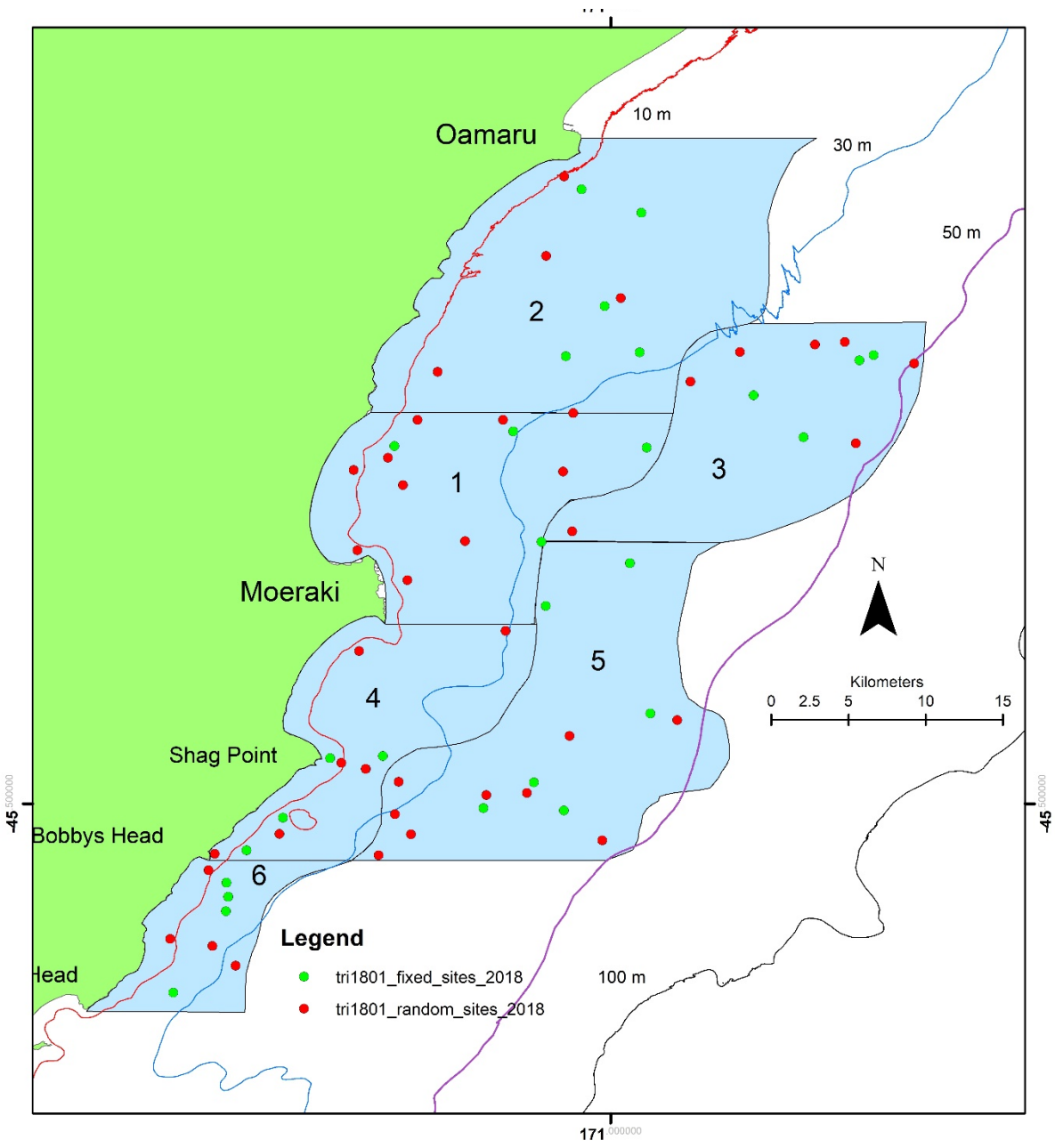

Figure 4: Strata and site positions for the 2018 North Otago fixed-site and random-site blue cod potting surveys.

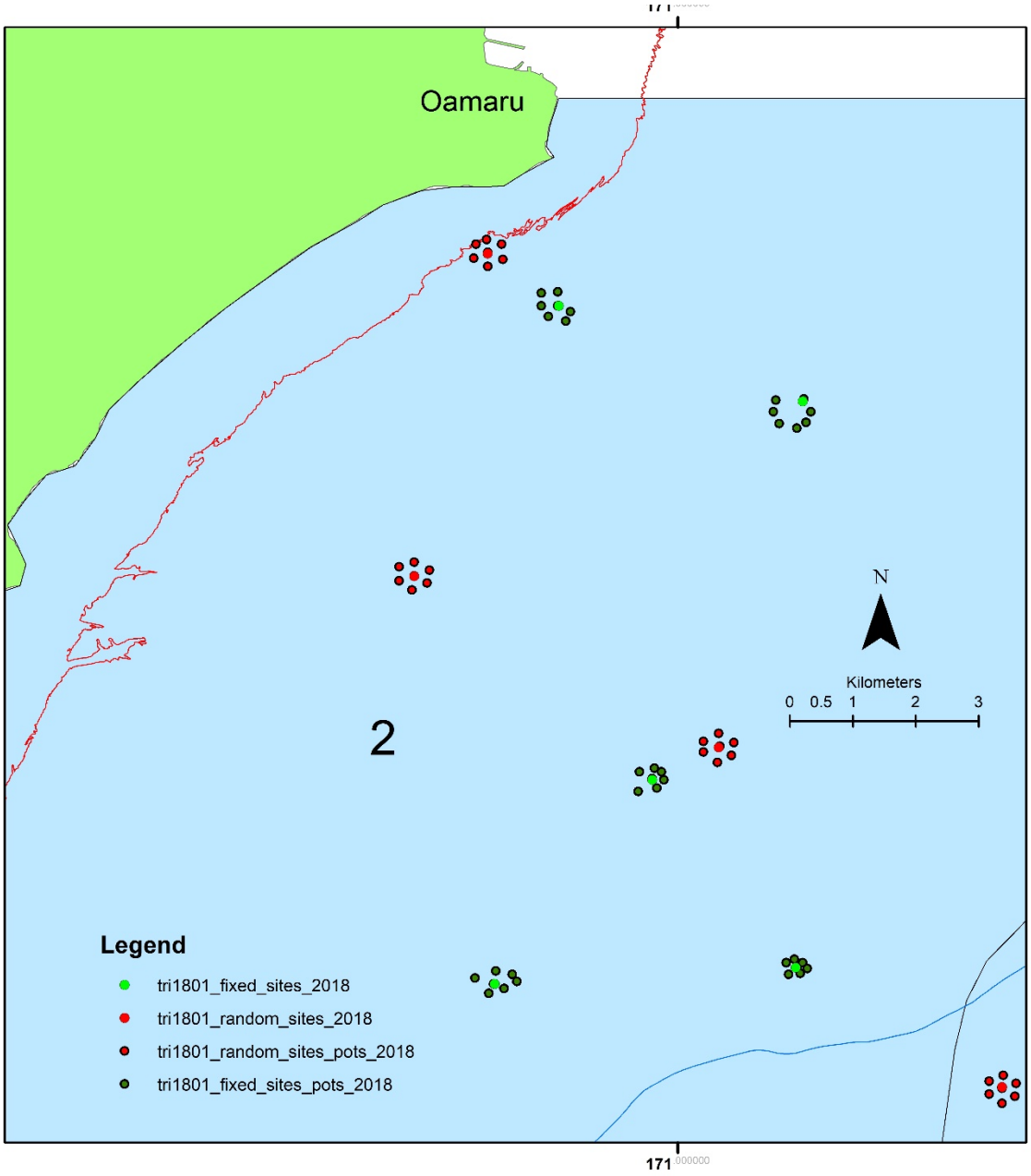

Figure 5: Site and pot positions for the 2018 north Otago fixed-site and random-site blue cod potting surveys in stratum 2, shown to demonstrate how pots were placed around the sites.

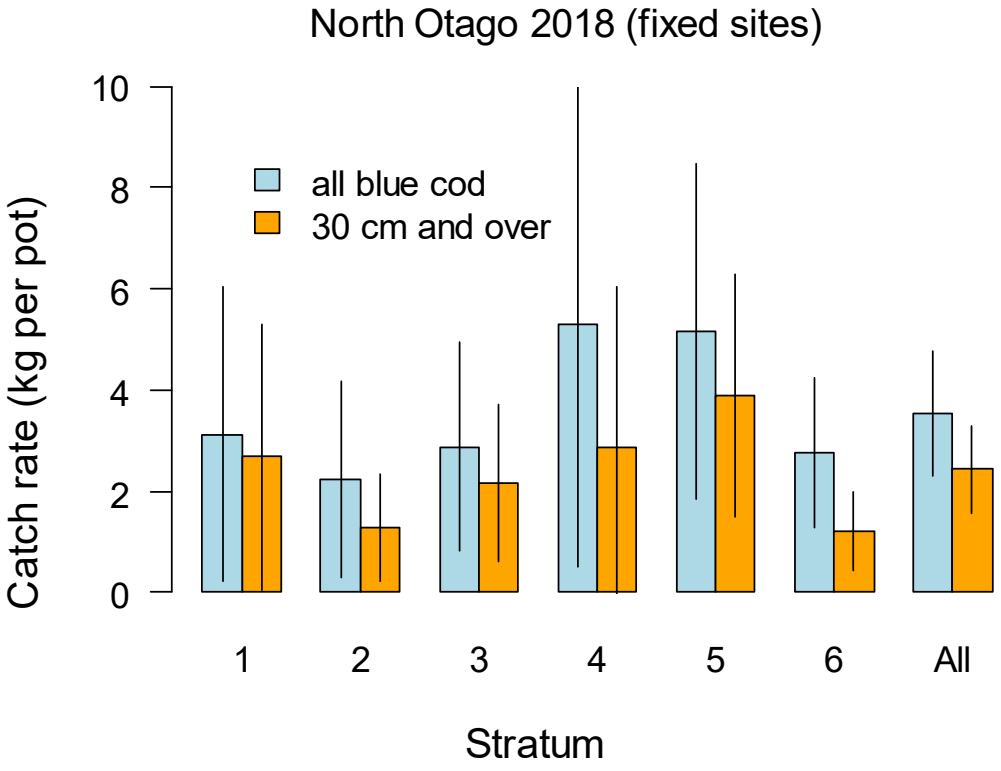

Figure 6: Catch rates (kg.pot^{-1}) of all blue cod and recruited blue cod (30 cm and over) by strata, and overall for the 2018 north Otago fixed-site survey. Error bars are 95% confidence intervals.

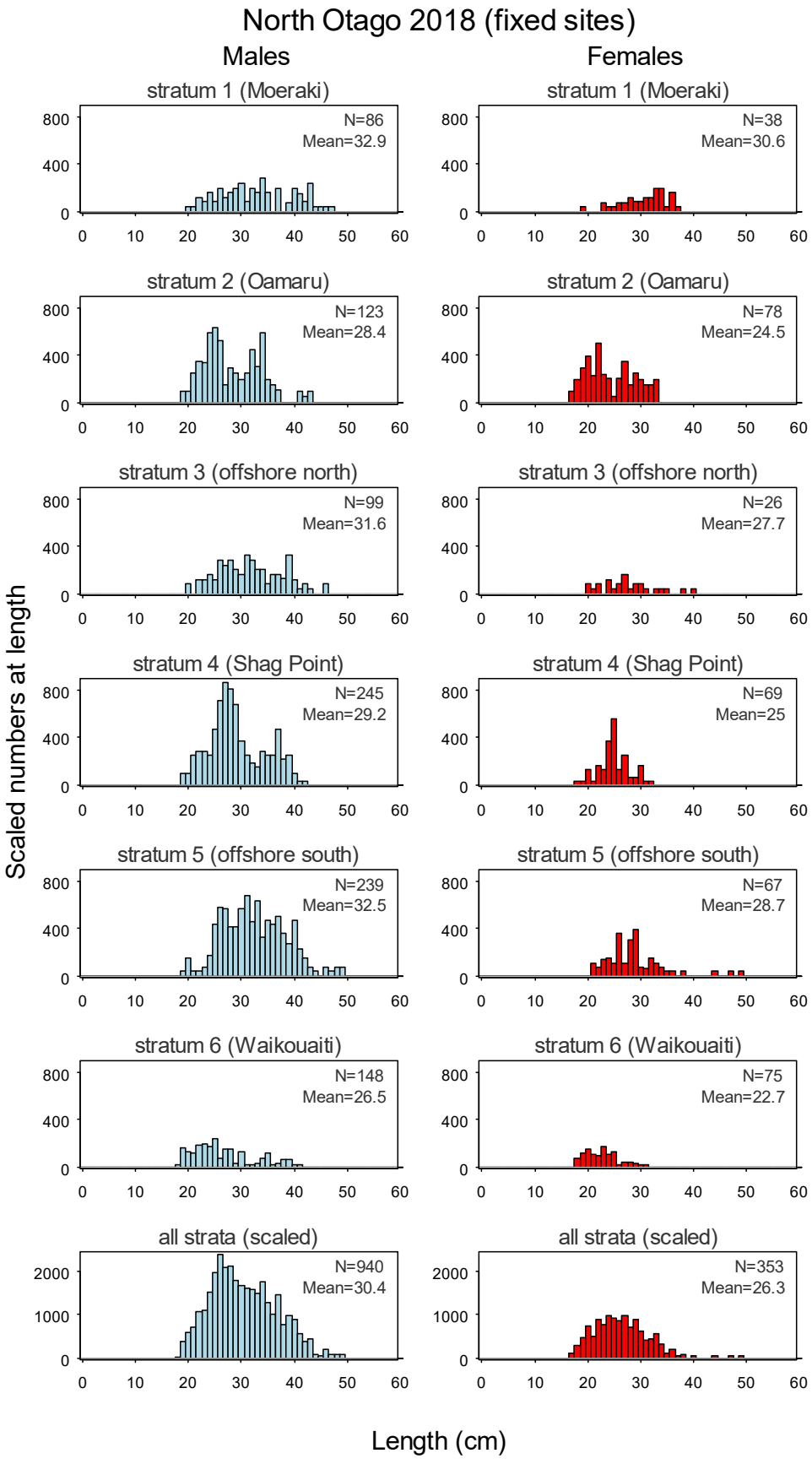

Figure 7: Scaled length frequency distributions of blue cod by strata and overall for the 2018 north Otago fixed-site potting survey. N, sample numbers; Mean, mean length (cm). Scaled numbers are relative, but non-informative.

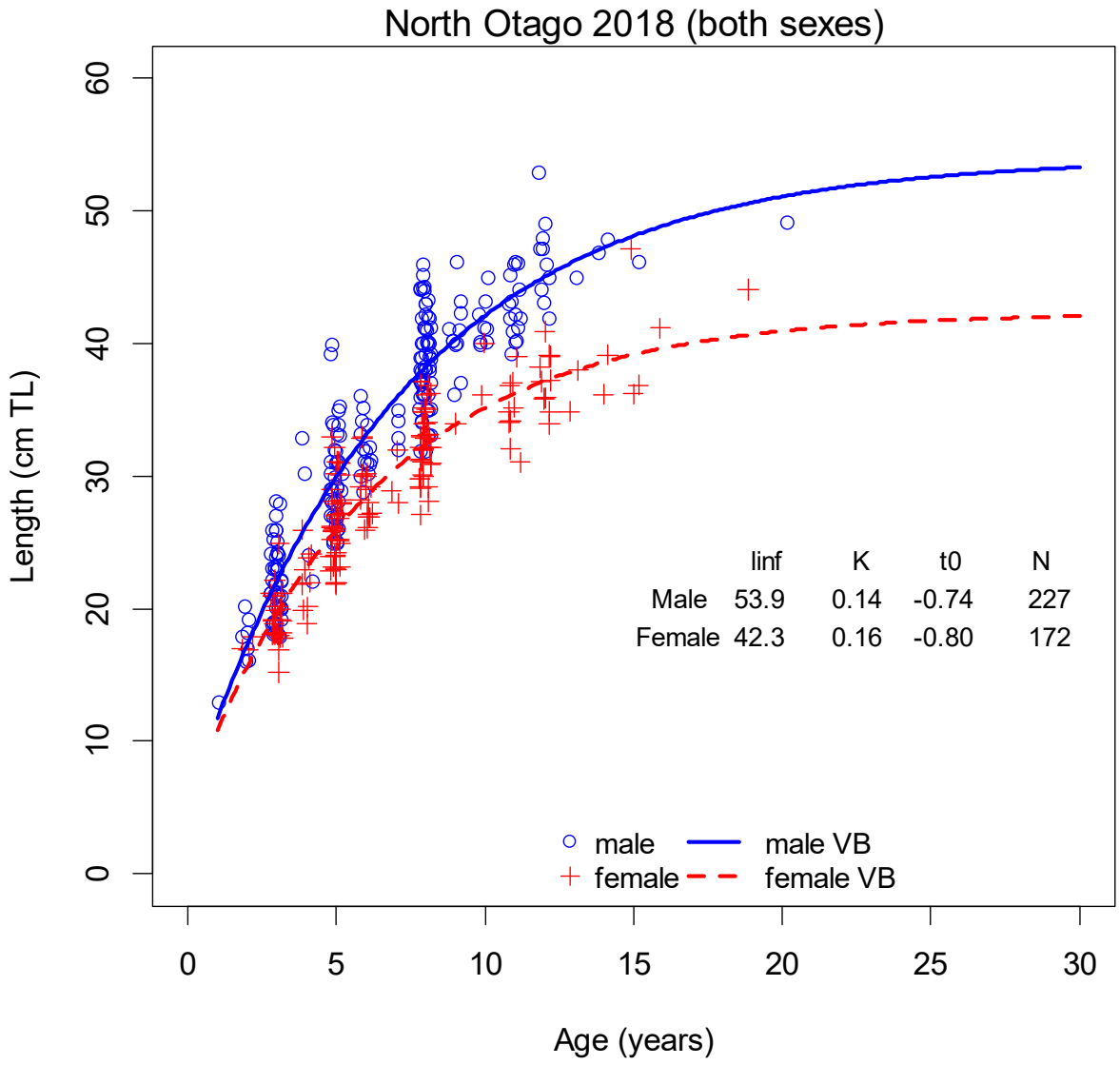

Figure 8: Observed blue cod age-length data by sex for the 2018 north Otago fixed and random-site surveys, with von Bertalanffy (VB) growth models fitted to the data. Linf, average size at the maximum age (cm); K, Brody growth coefficient (yr^{-1}); t0, age when the average size is zero.

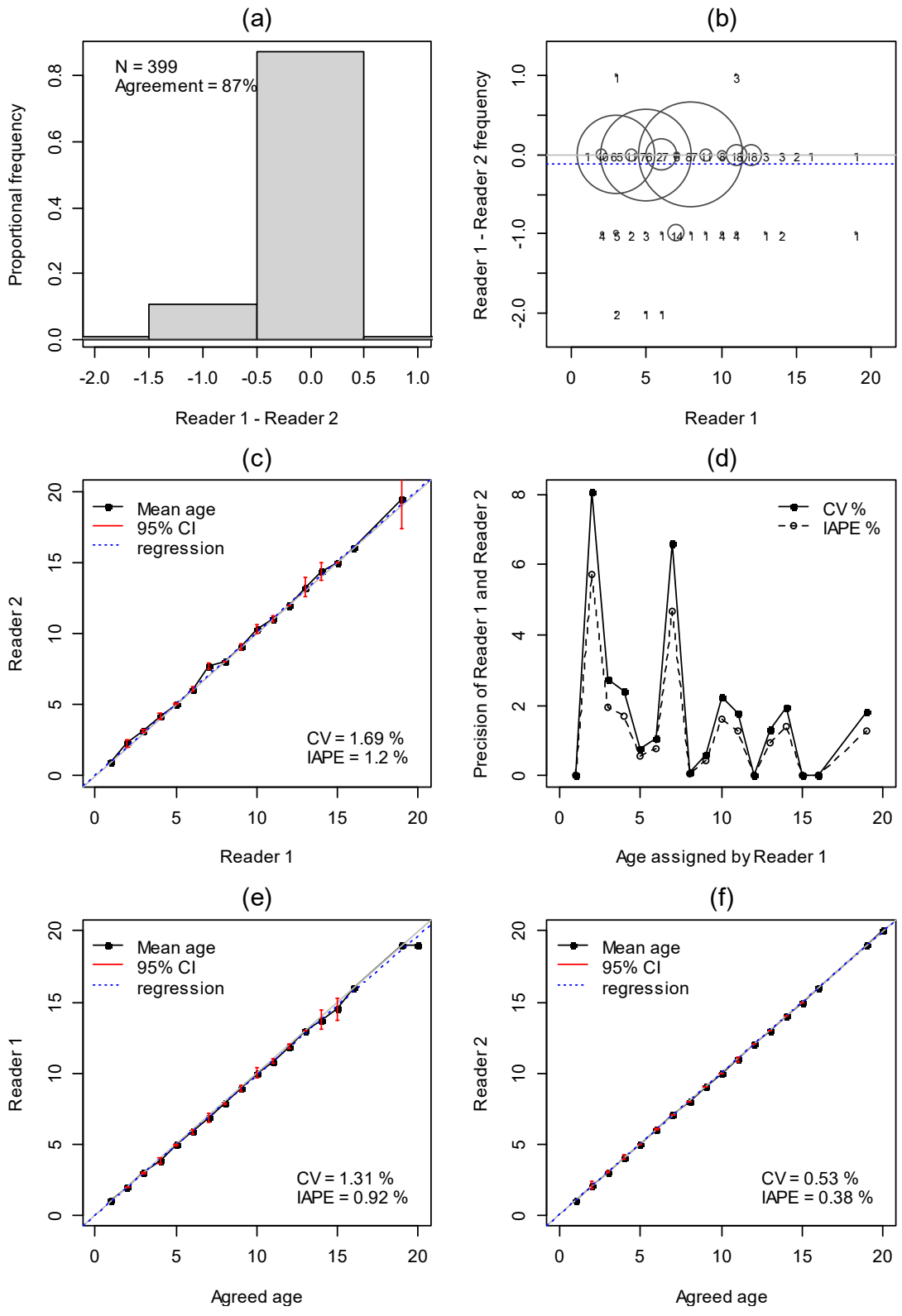

Figure 9: Blue cod age otolith reader comparison plots between reader 1 and reader 2 for the 2018 north Otago survey: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age 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, dashed lines show the trend of a linear regression of the actual data.

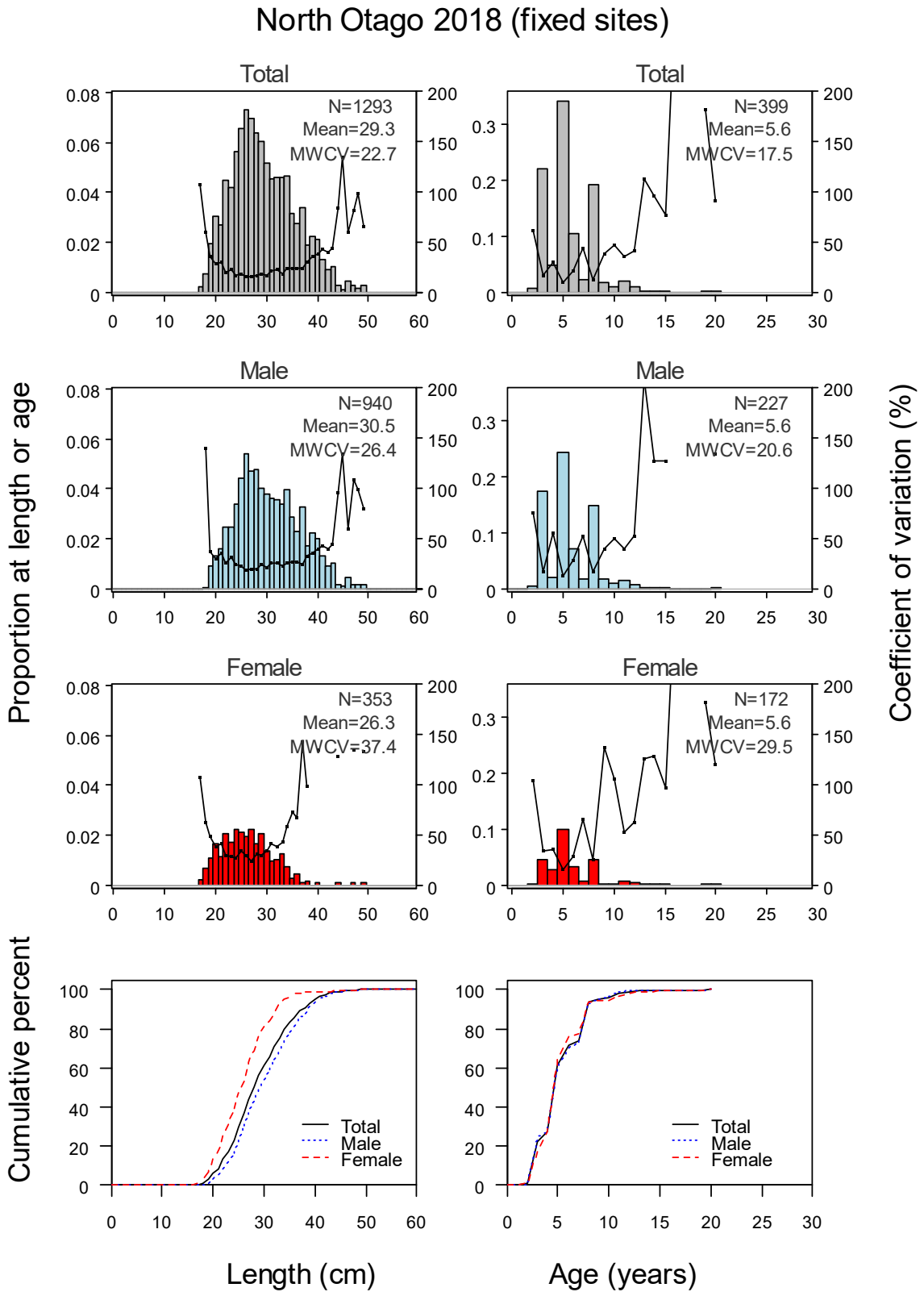

Figure 10: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2018 north Otago fixed-site blue cod potting survey (N, sample size; MWCV, mean weighted coefficient of variation, %).

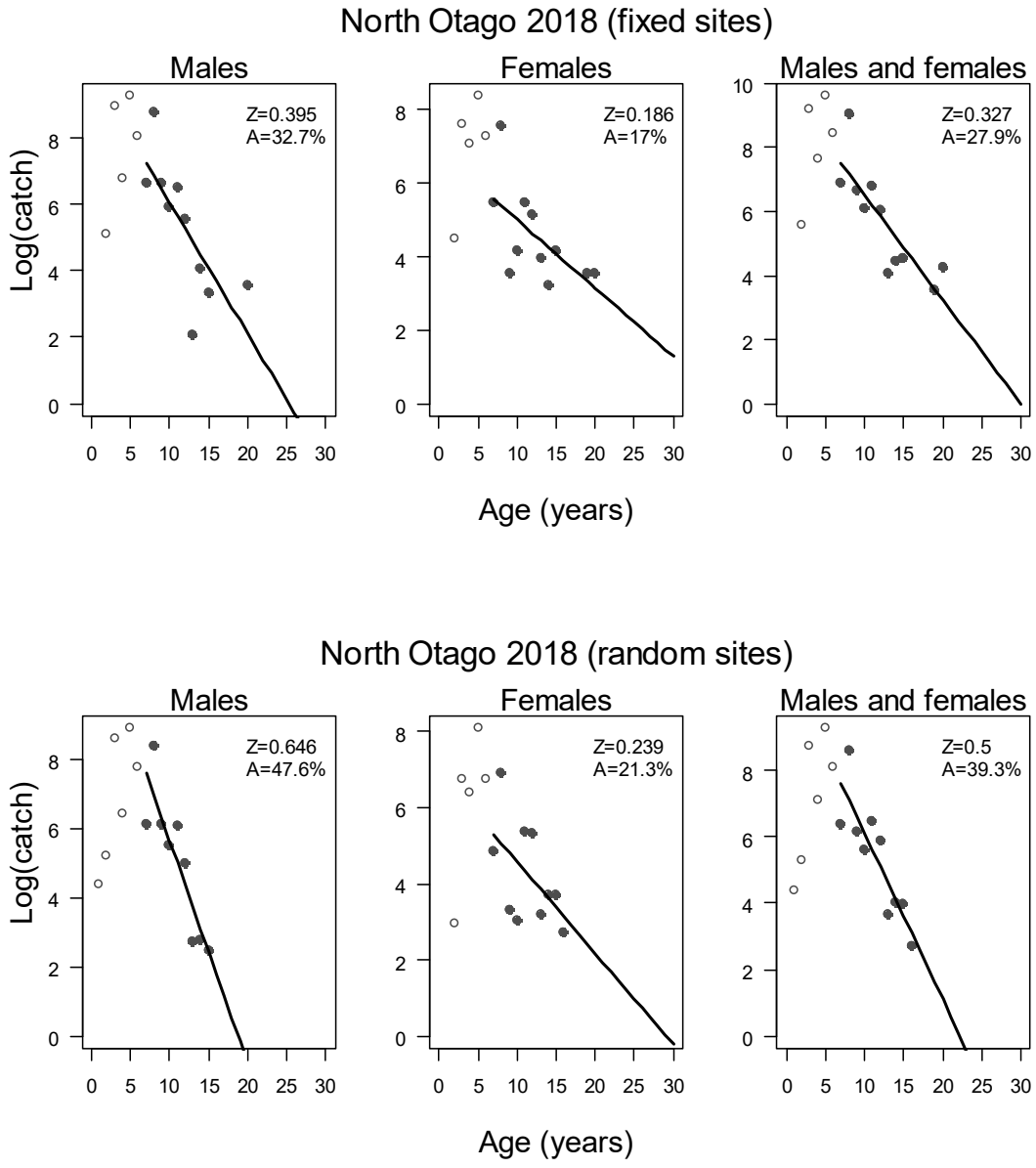

Figure 11: Catch curves (natural log of catch numbers versus age) for the 2018 north Otago fixed and random-site surveys. The regression line is plotted from age at full recruitment of 7 years (i.e., dark points on the graph). Z, instantaneous total mortality; A, the annual mortality rate or the proportion of the population that suffers mortality in a given year.

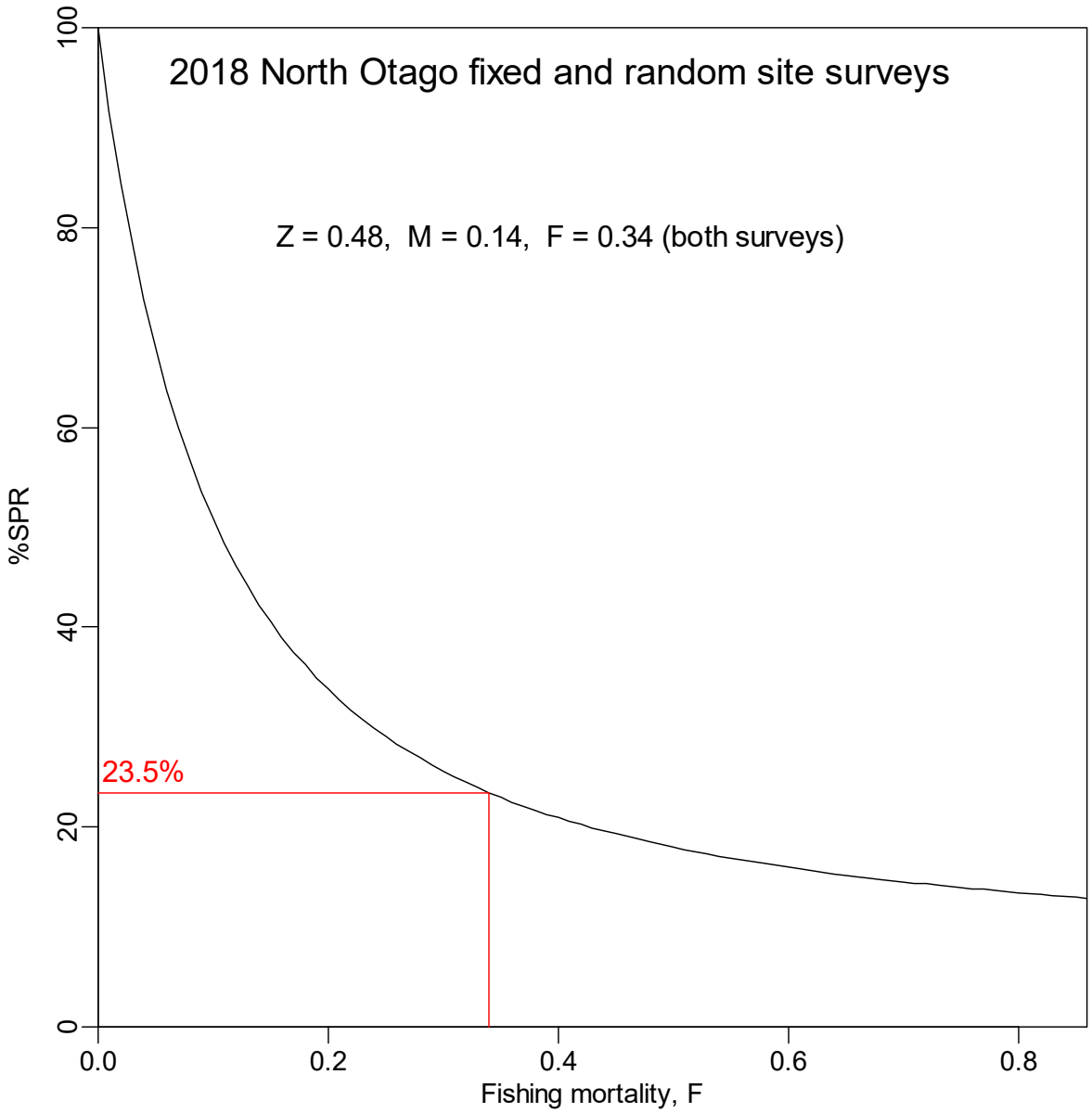

Figure 12: Spawner-per-recruit (SPR) as a function of fishing mortality (*F*) for the 2018 north Otago fixed and random-site surveys. The values of *Z*, *F* and SPR were the same for fixed and random-site surveys. In this plot *M* = 0.14, and the *F* value is for age of full recruitment equal to 7 years for females.

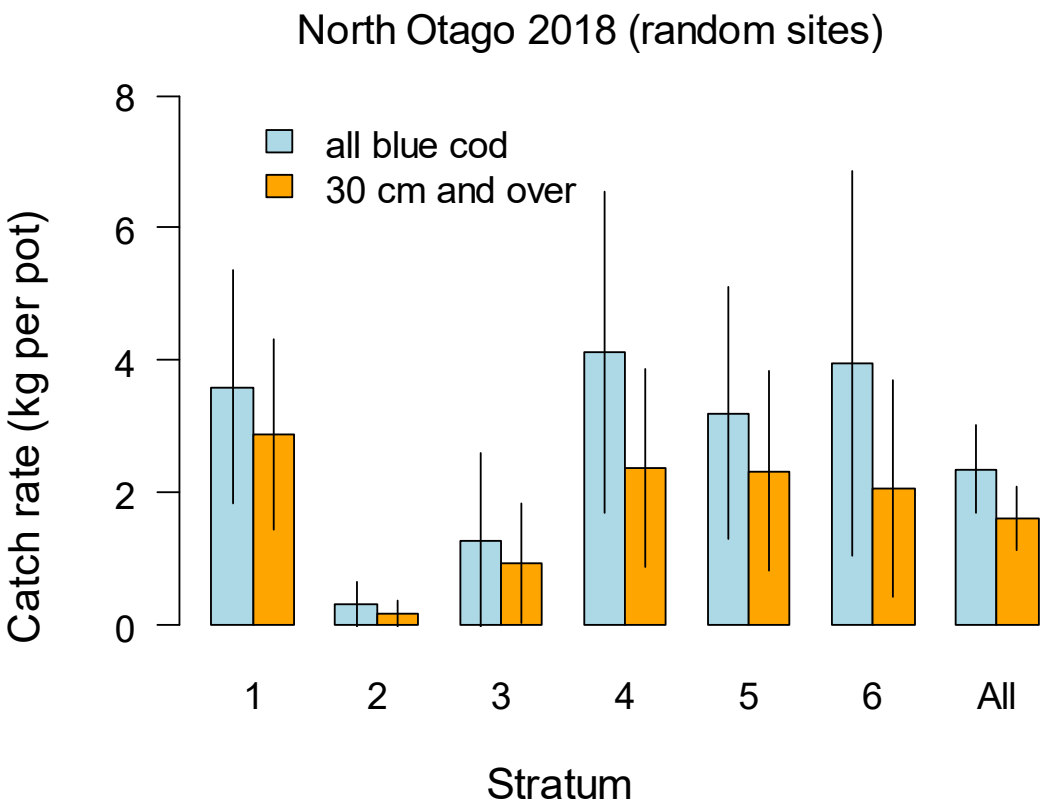

Figure 13: Catch rates (kg.pot^{-1}) of all blue cod and recruited blue cod (30 cm and over) by strata, and overall for the 2018 north Otago random-site survey. Error bars are 95% confidence intervals.

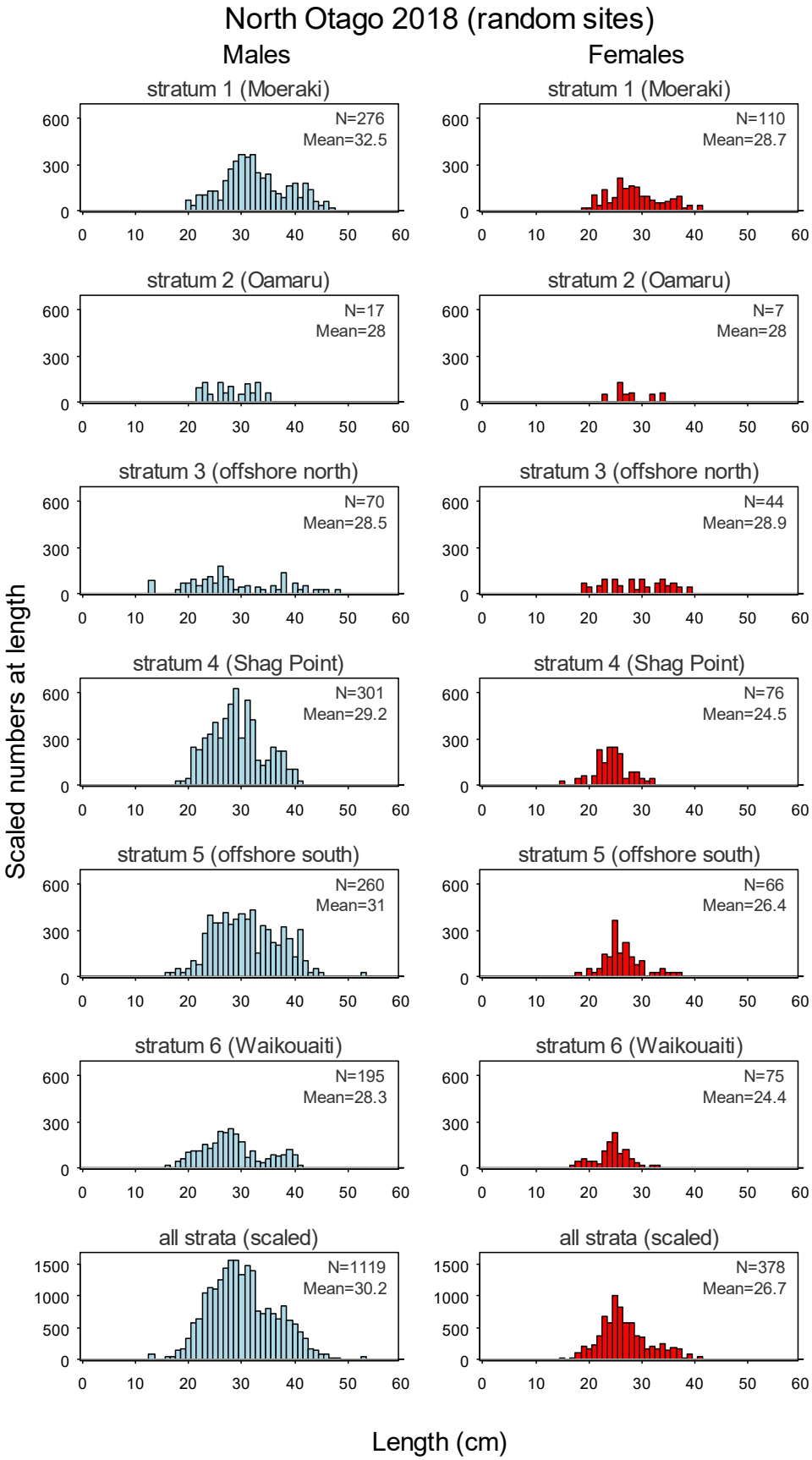

Figure 14: Scaled length frequency distributions of blue cod by strata and overall for the 2018 north Otago random-site potting survey. N, sample numbers; Mean, mean length (cm). Scaled numbers are relative, but non-informative.

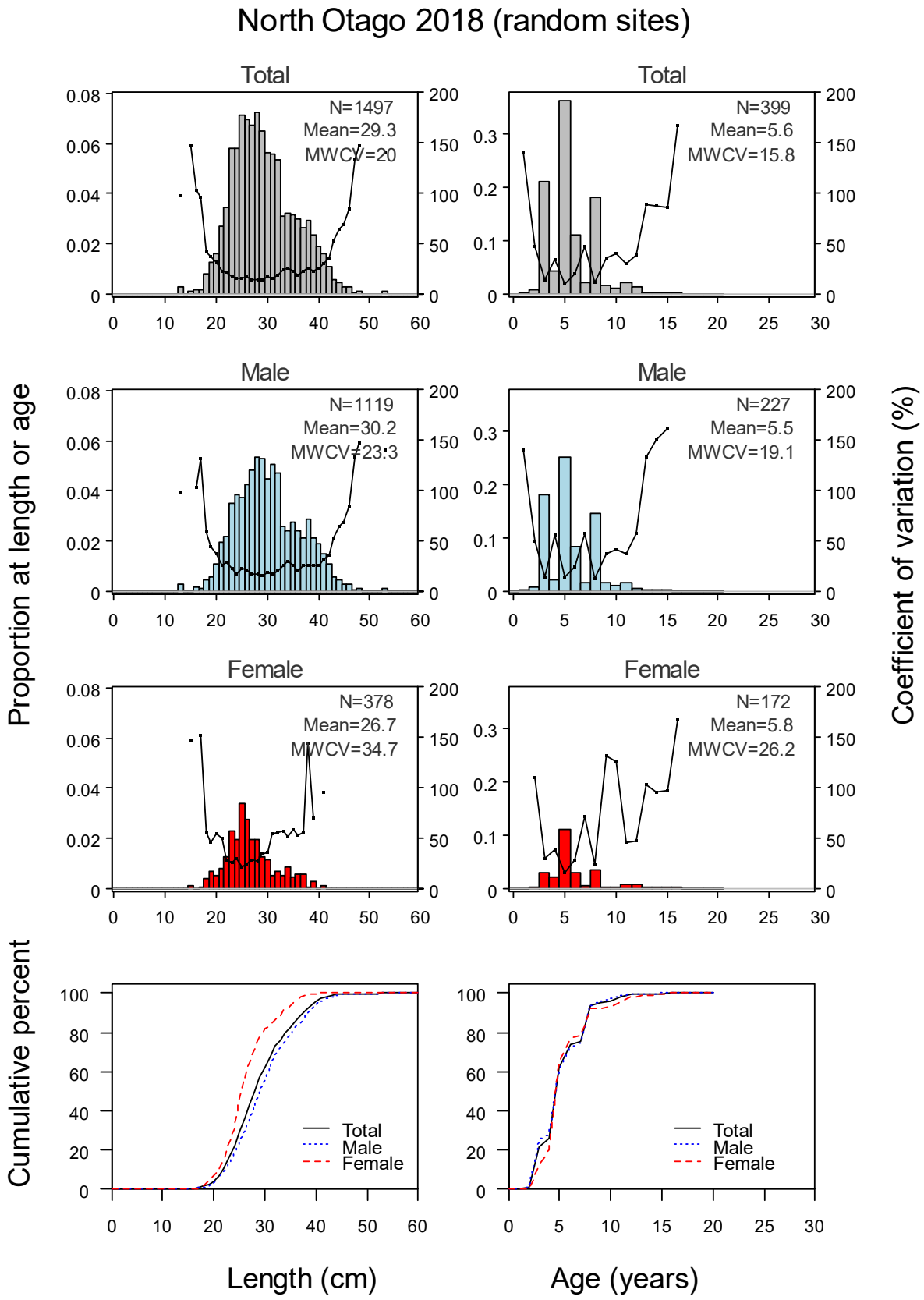

Figure 15: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2018 north Otago fixed-site blue cod potting survey (N, sample size; MWCV, mean weighted coefficient of variation, %).

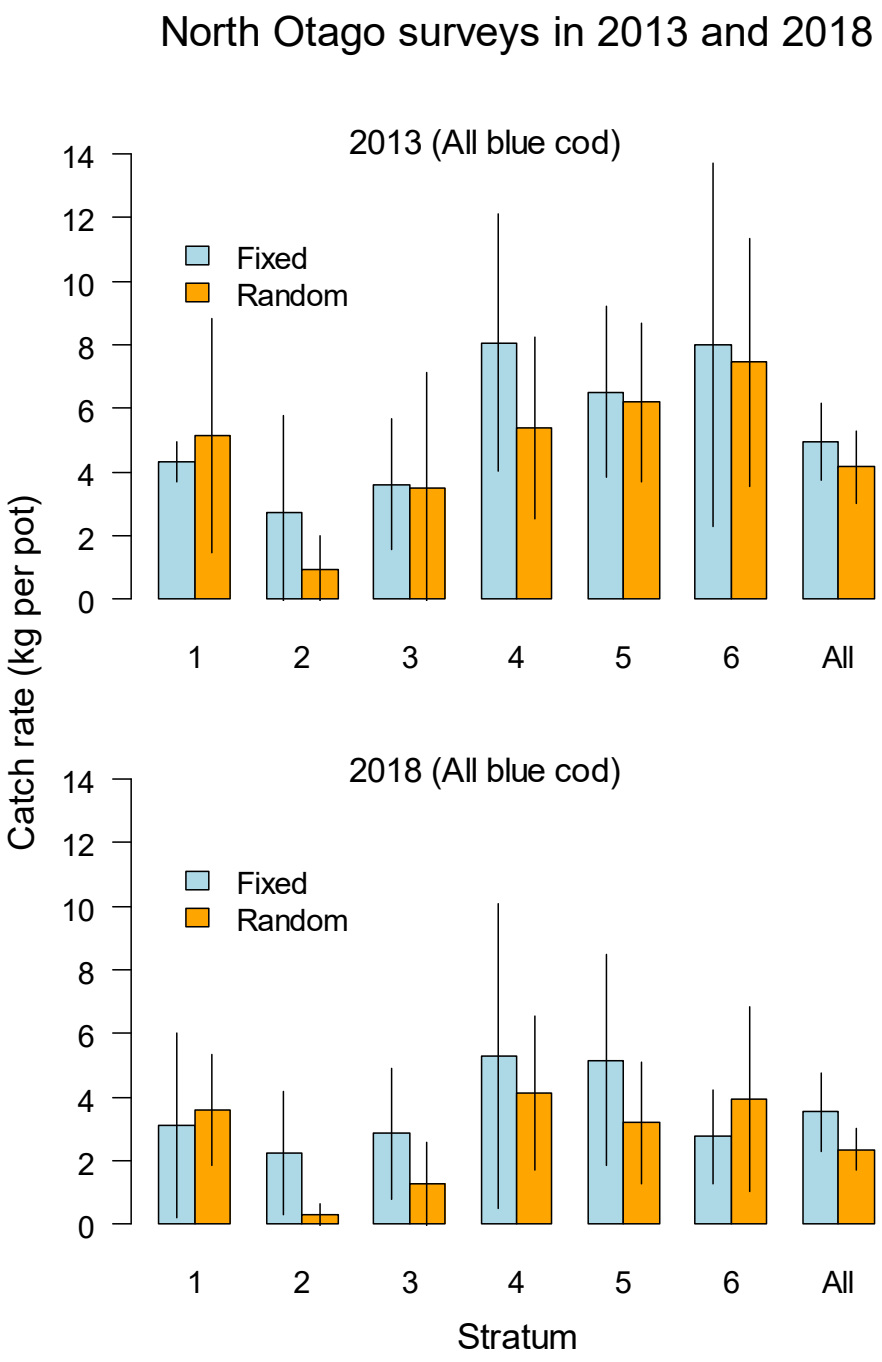

Figure 16: Catch rates (kg.pot^{-1}) of all blue cod for the north Otago concurrent fixed and random-site potting surveys in 2013 and 2018. Error bars are 95% confidence intervals.

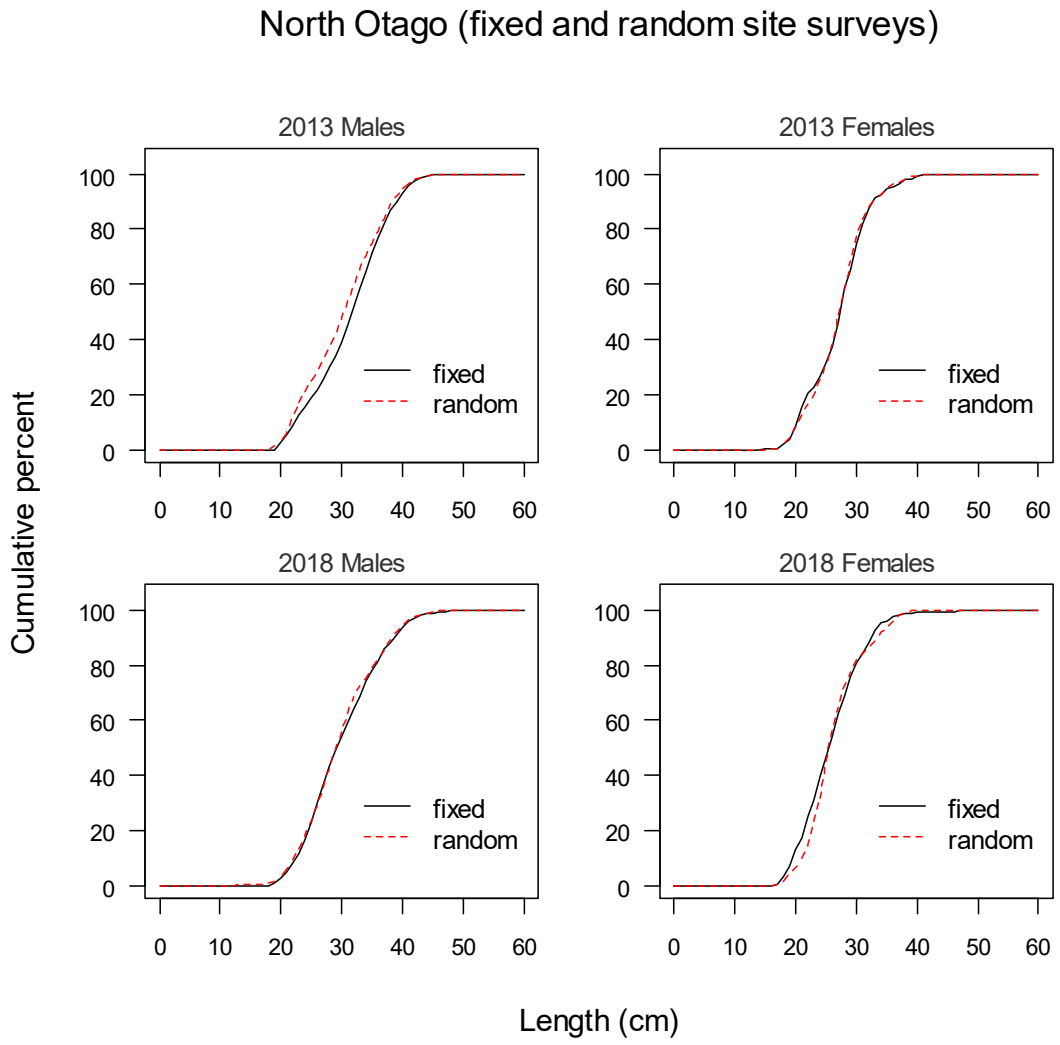

Figure 17: Cumulative distributions of scaled male and female length of all blue cod for the north Otago concurrent fixed and random-site potting surveys in 2013 and 2018.

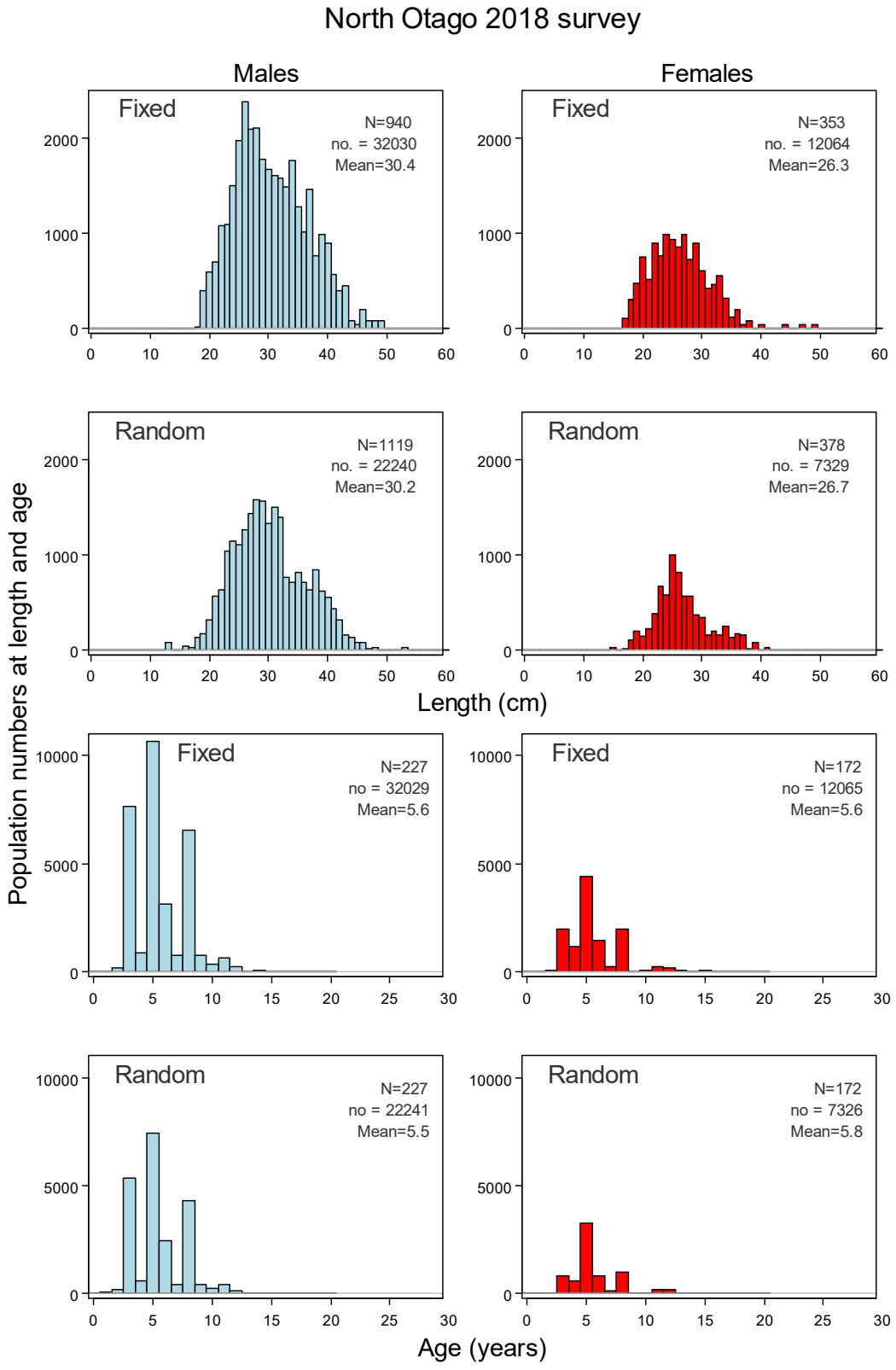

Figure 18: Scaled length frequency and age frequency distributions for male and female blue cod for the 2018 fixed and random-site blue cod potting surveys. N, sample size; no, population number; Mean, mean length (cm). Scaled numbers are relative, but non-informative.

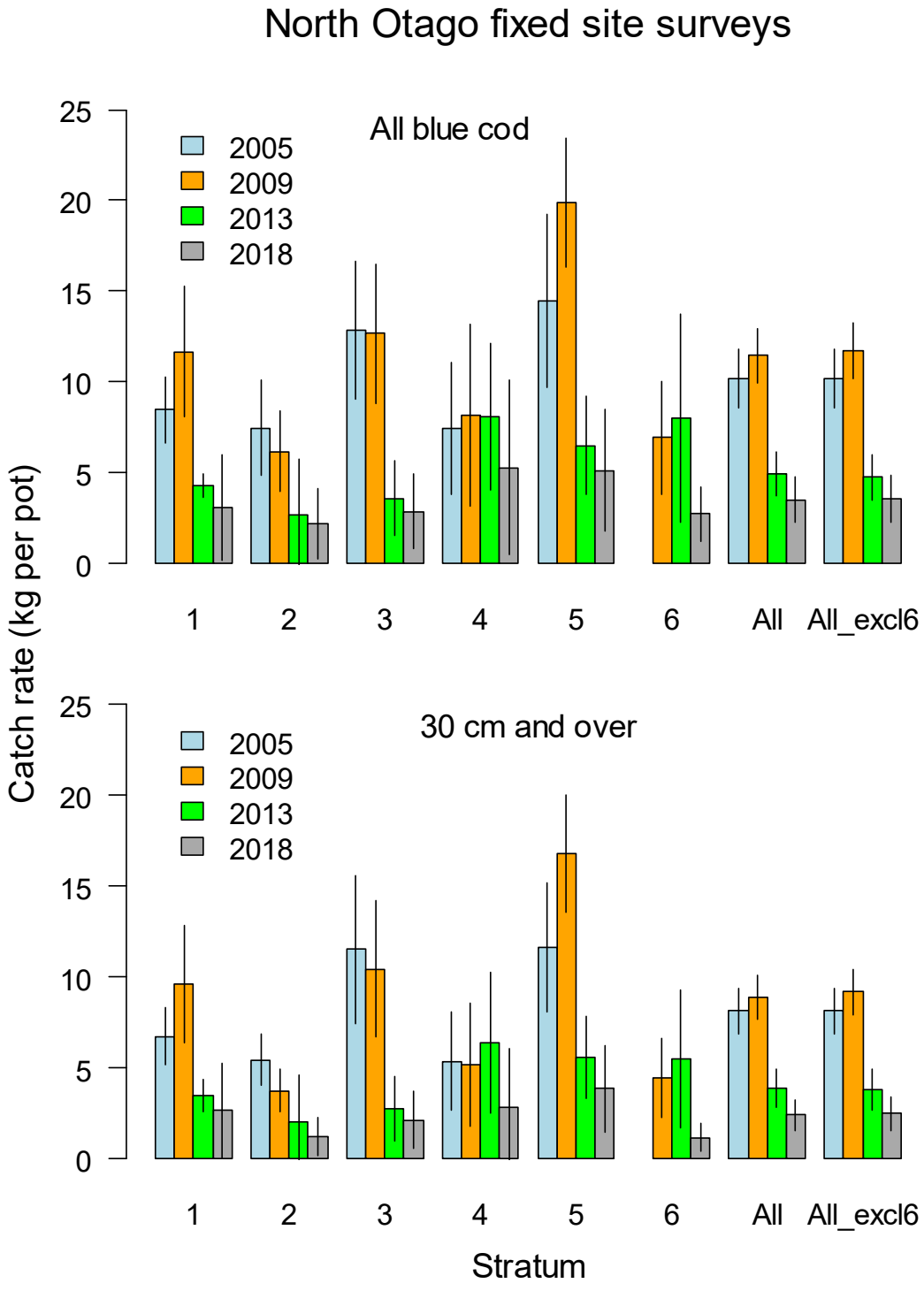

Figure 19: Catch rates (kg.pot^{-1}) of all blue cod and for recruited blue cod (30 cm and over) for the north Otago fixed-site potting surveys in 2005, 2009, 2013 and 2018. Error bars are 95% confidence intervals. Stratum 6 was added in 2009.

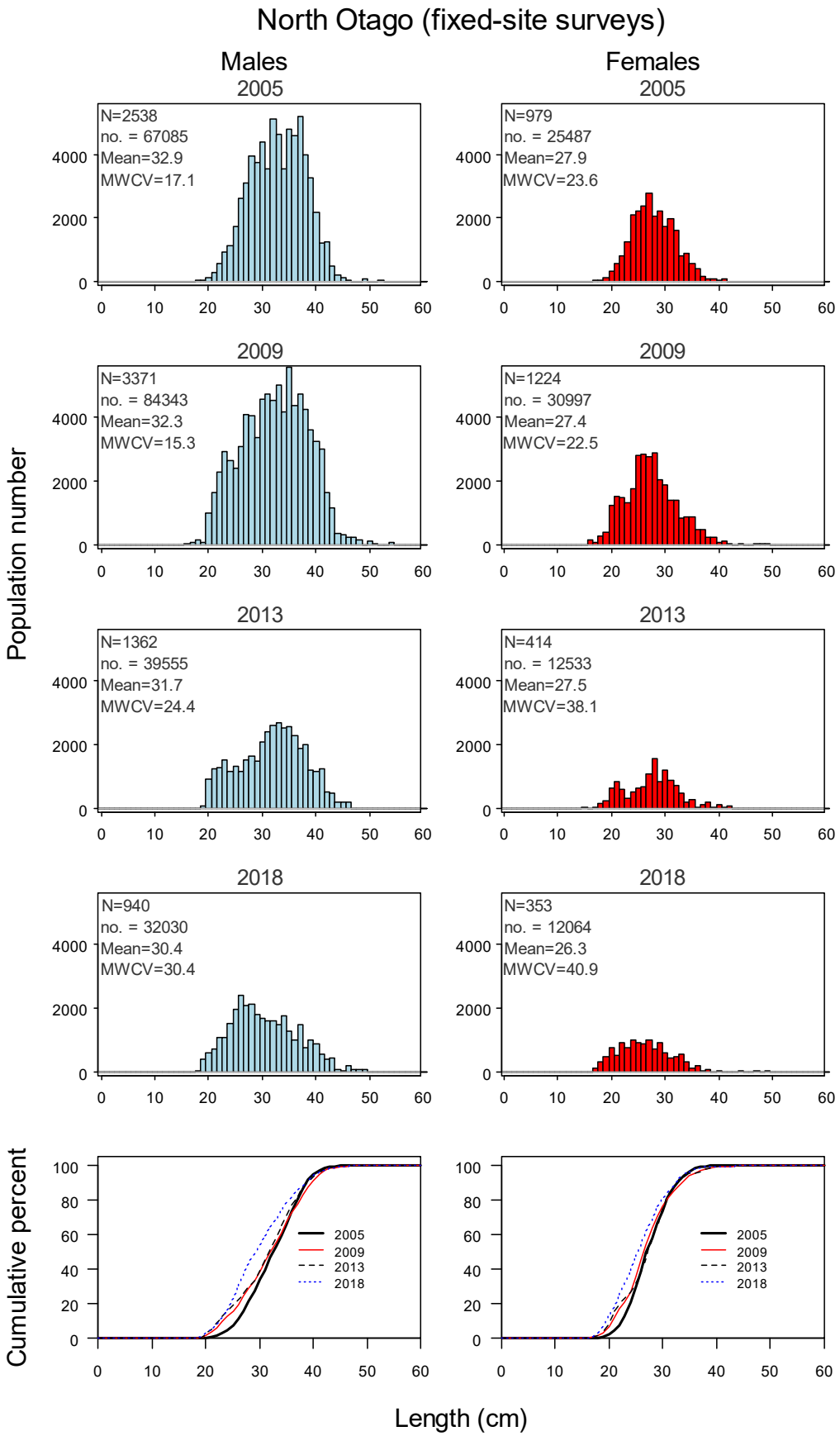

Figure 20: Scaled length frequency and cumulative distributions for male and female blue cod from north Otago fixed-site blue cod potting surveys in 2005, 2009, 2013 and 2018. N, sample numbers; no, population number; Mean, mean length (cm); MWCV, mean weighted coefficient of variation (%). Scaled numbers are relative, but non-informative.

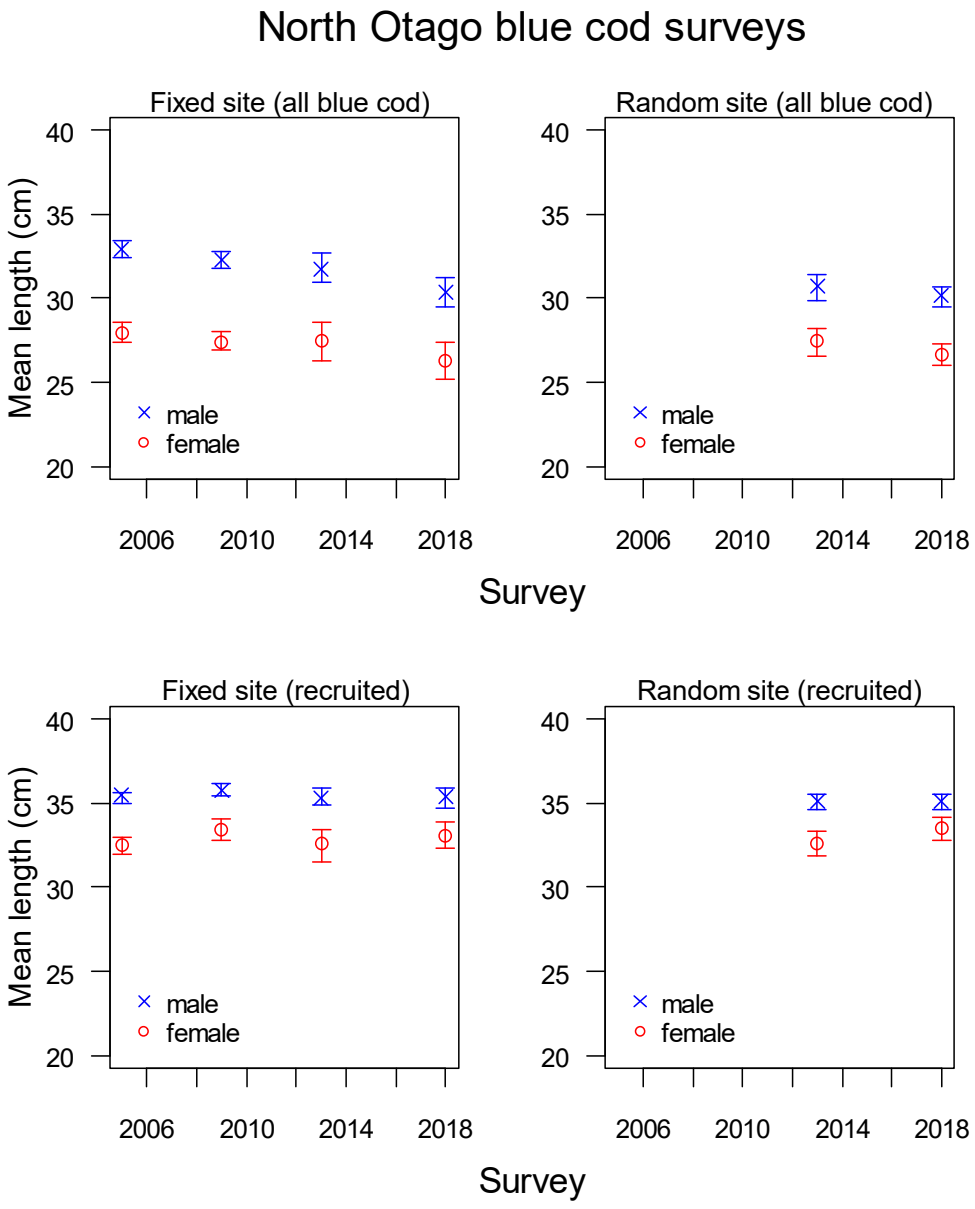

Figure 21: Mean length and 95% confidence intervals for male and female all blue cod (top panels) and recruited blue cod (bottom panels) from north Otago fixed-site potting surveys in 2005, 2009, 2013 and 2018; and random-site potting surveys 2013 and 2018. Surveys from 2009 onward include stratum 6.

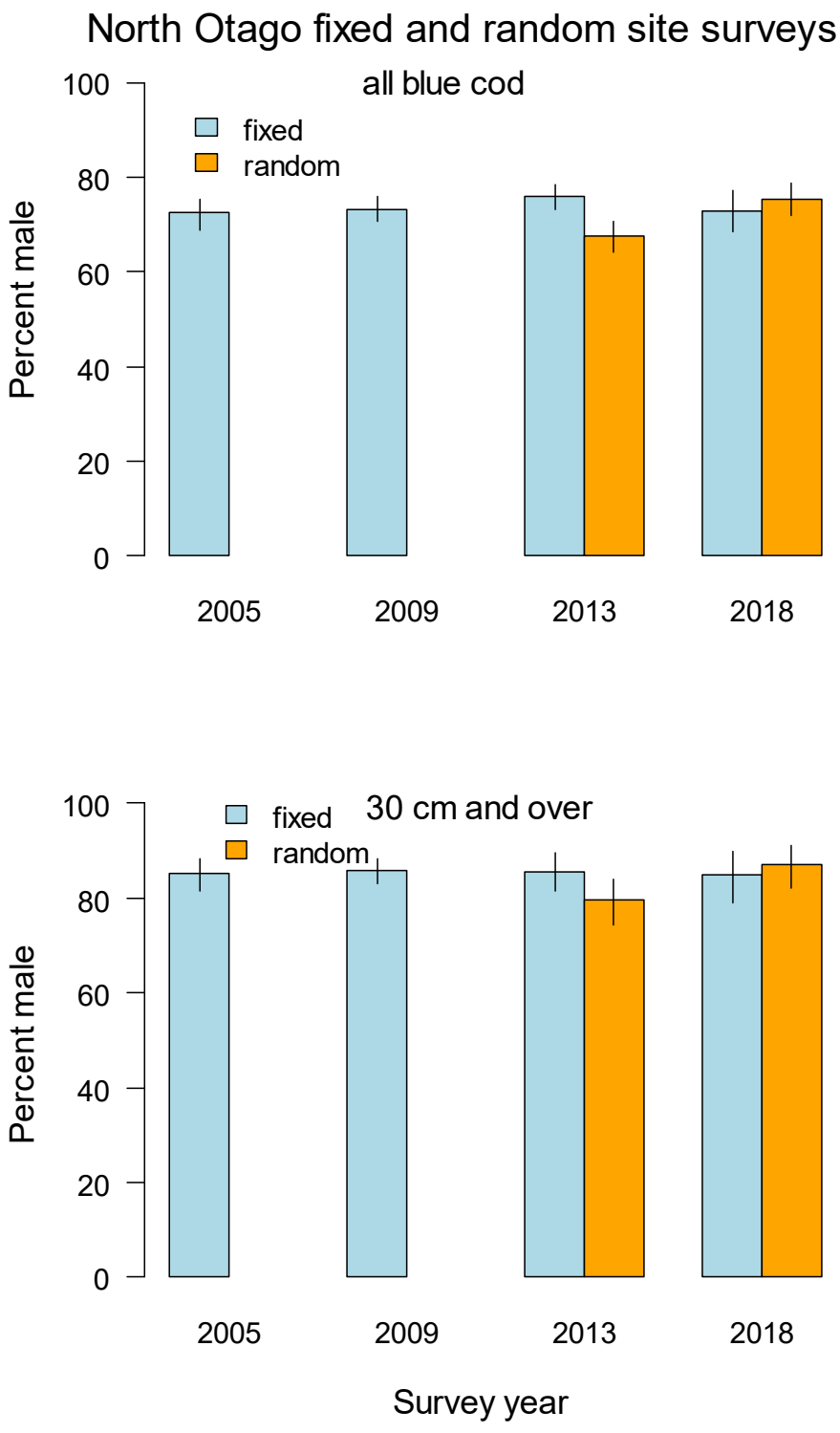

Figure 22: Proportion of males in the north Otago fixed-site potting surveys in 2005, 2009, 2013 and 2018; and random-site potting surveys 2013 and 2018. Surveys from 2009 onward include stratum 6.

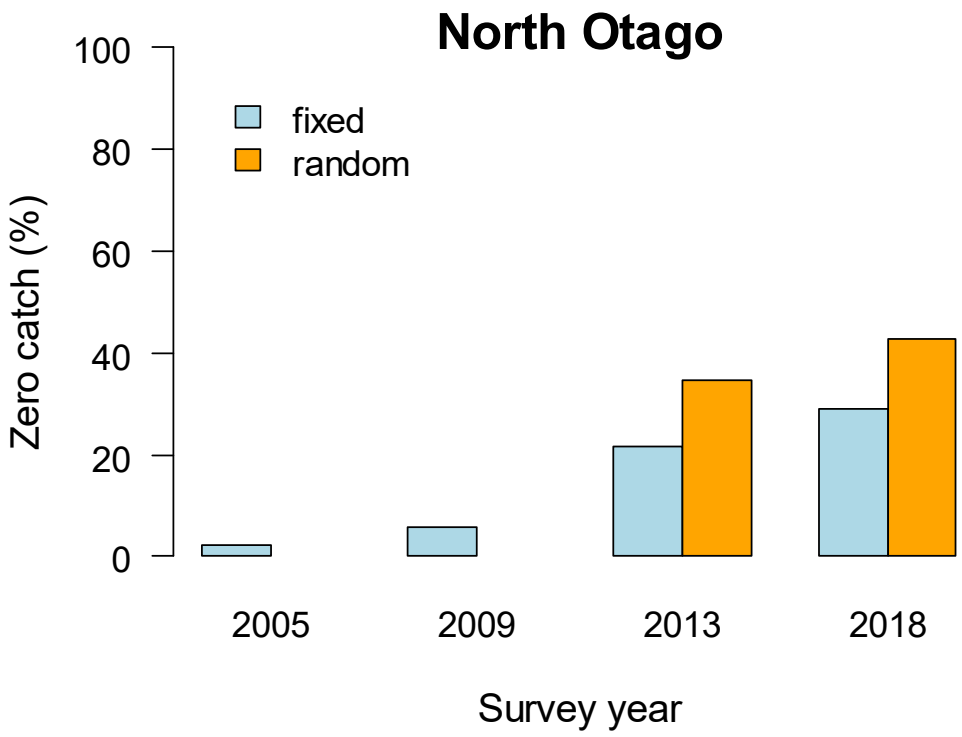

Figure 23: Percent of pots with zero catch of blue cod for the north Otago fixed-site surveys in 2005, 2009, 2013 and 2018; and random site surveys in 2013 and 2018. Surveys from 2009 onward include stratum 6.

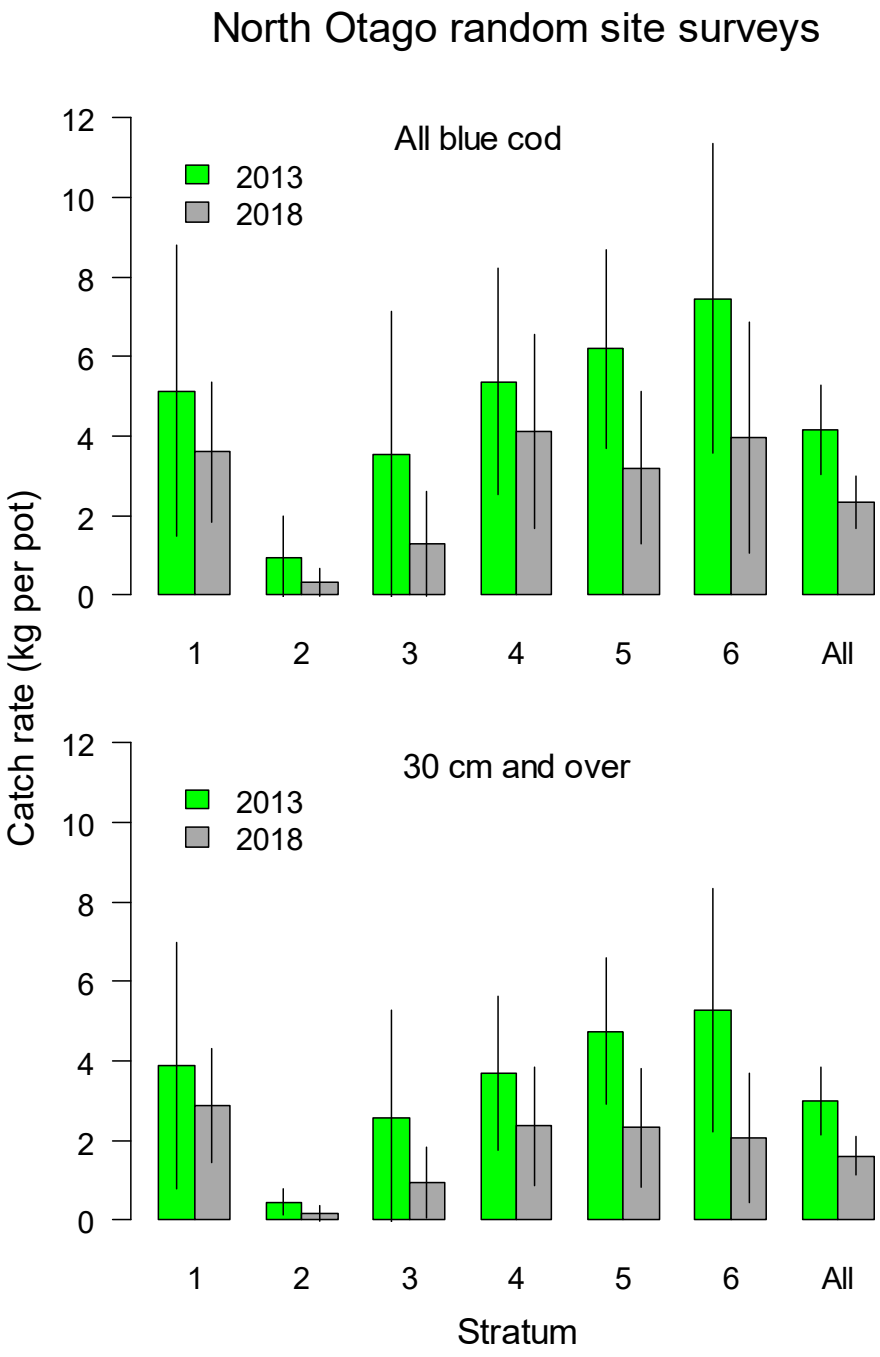

Figure 24: Catch rates (kg.pot^{-1}) of all blue cod and for recruited blue cod (30 cm and over) for the north Otago random-site potting surveys in 2013 and 2018. Error bars are 95% confidence intervals.

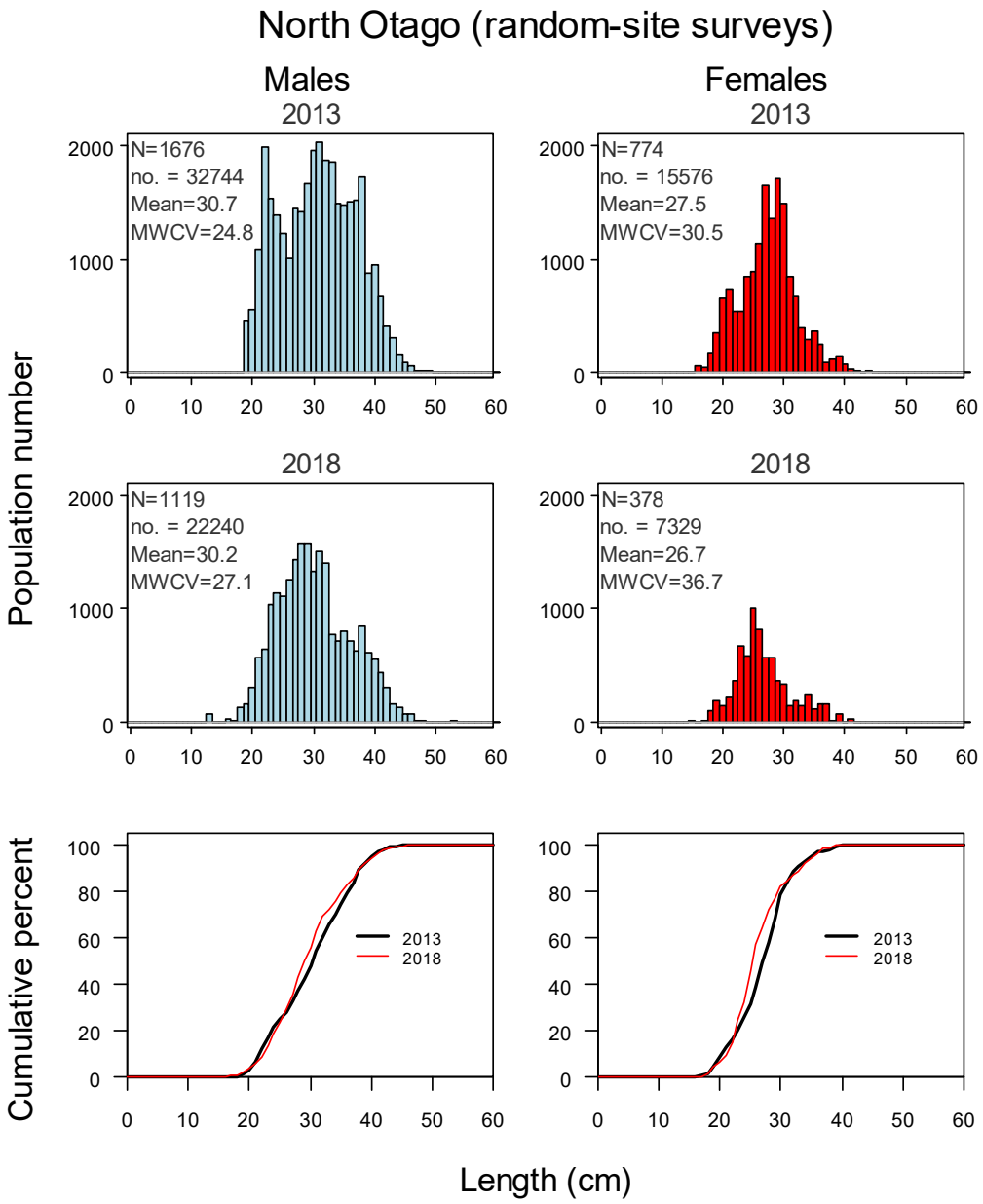

Figure 25: Scaled length frequency and cumulative distributions for male and female blue cod from north Otago random-site blue cod potting surveys in 2013 and 2018. N, sample numbers; no, population number; Mean, mean length (cm); MWCV, mean weighted coefficient of variation (%). Scaled numbers are relative, but non-informative.

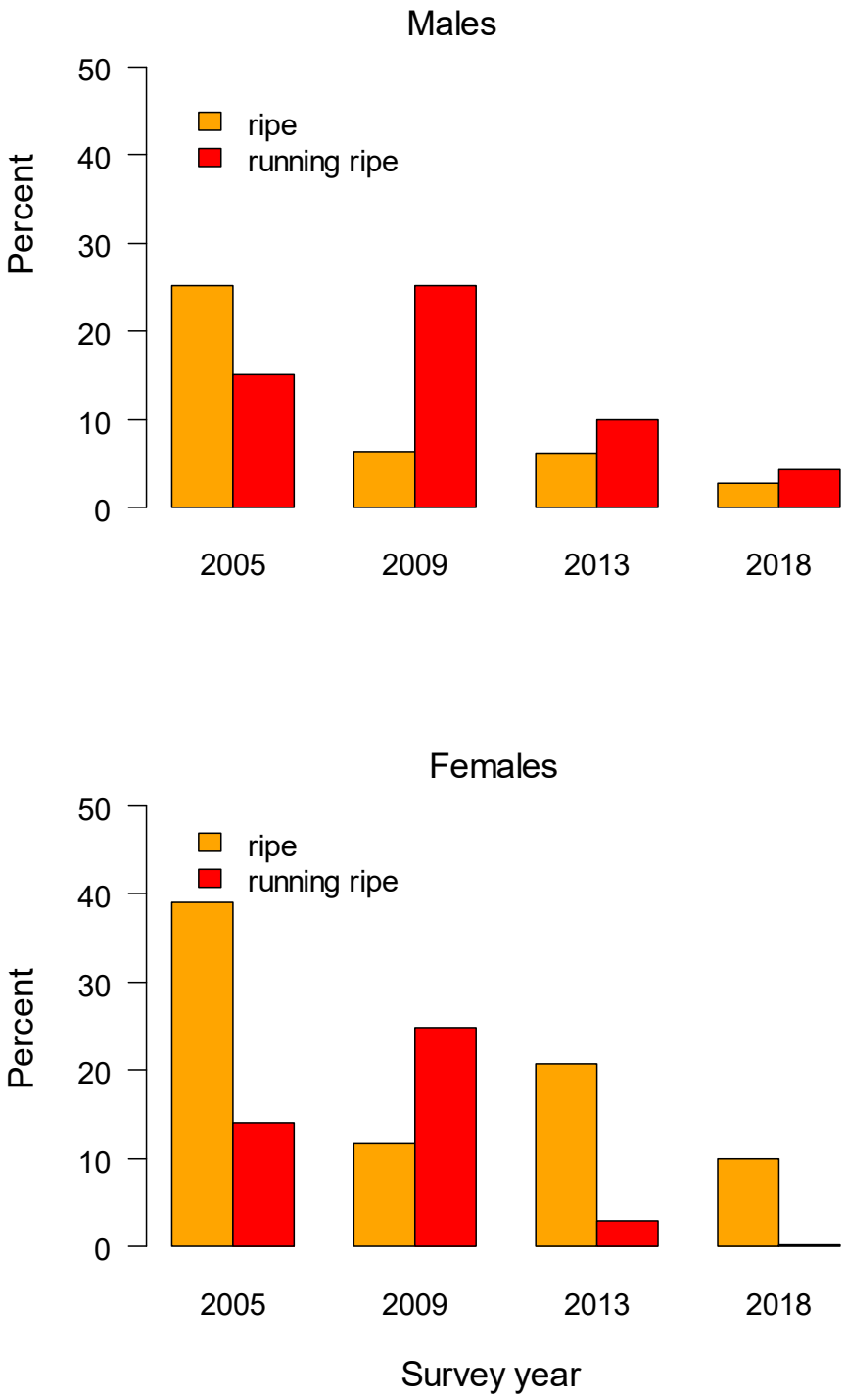

Figure 26: Percent of male and female blue cod in the ripe or running ripe reproductive condition from North Otago blue cod potting surveys (all data combined for fixed and random-site surveys).

8. APPENDICES

Appendix 1: Glossary of terms used in this report (modified from Beentjes & Francis 2011). See the potting survey standard and specifications for more details.

Fixed site	A site that has a fixed location (single latitude and longitude or the centre point location of a section of coastline) in a stratum and is available to be used repeatedly on subsequent surveys in that area. The fixed sites used in a survey are randomly selected from the list of all available fixed sites in each stratum. Fixed sites are sometimes referred to as index sites or fisher-defined sites and were defined at the start of the survey time series (using information from recreational and commercial fishers)
Pot number	Pots are numbered sequentially (1–6 or 1–9) in the order they are placed during a set. In the north 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 site, the first pot is set 200 m to the north of the site location and remaining pots are set in a hexagon pattern around the site, at about 200 m from the site position.
Random site	A site that has the location (single latitude and longitude) generated randomly within a stratum, given the constraints of proximity to other selected sites for a specific survey.
Site	A geographical location near to which sampling may take place during a survey. A site may be either fixed or random. A site may be specified as a latitude and longitude or a section of coastline (for the latter, the latitude and longitude at the centre of the section is used).
Site label	An alphanumeric label of no more than four characters, unique within a survey time series. A site label identifies each fixed site and also specifies which stratum it lies in. Site labels are constructed by concatenating the stratum code with an alpha label (A–Z) that is unique within that stratum. Thus, sites within stratum 2 could be labelled 2A, 2B, and sites in stratum 3 could be labelled 3A, 3B etc. Site labels for random sites are constructed in the same way but prefixed with R (e.g., R4A, R4B etc).
Station	The position (latitude and longitude) at which a single pot (or other fishing gear such as ADCP) is deployed at a site during a survey, i.e., it is unique for the trip.
Station number	A number which uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be *station_no* 234. This convention is important in enabling users of the *trawl* database to determine whether two pots are from the same set. Note that the set numbers for potting surveys are not recorded anywhere else in the *trawl* database.

Appendix 2. Numbers of otoliths collected during the 2018 north Otago blue cod survey for males and females, by stratum and length class.

	Males							Females						
	Strata							Strata						
Length (cm)	1	2	3	4	5	6	Male totals	1	2	3	4	5	6	Female totals
13			1				1							
14														
15											1			1
16					1	1	2							
17					1		1		2				1	3
18			1	1	2	3	7		4		2	1	4	11
19		1	1	1	2	1	6	1	1	1	1		2	6
20	1	1		2		2	6		2	2		1	1	6
21	2		1	2		1	6		2	1	2		1	6
22	1	1		2	1	1	6		3			2	1	6
23		1	2	1	1	1	6			2	1	1	2	6
24	1	4		1			6			1	1	2	2	6
25	1	2	1		2		6				2	2	2	6
26	2	2	2				6	1	1	2	2	1	2	9
27	3	1		2			6	3	3	1	1	1		9
28	1	3	1	1			6	2	1	1	1	2	2	9
29	1	1	2	1		1	6	2		1	1	1	3	8
30	1	1	1		1	2	6	1	1	3	1	2	1	9
31	1		2	3	2		8	2	3	1	2		1	9
32	1	2	2	1		2	8	1	3		2	2	1	9
33		2	1	3	2		8	2	2	1		4		9
34	2	4		1		1	8	3		2		4		9
35	2	2		2	1	1	8	3		3		2		8
36		1	1	1	3	2	8	4		2		2		8
37		2	2	1	1	2	8	5		2		1		8
38	2		1	2	3		8	1		1				2
39	2		1	2	1	2	8	2		2				4
40	3		3	3	4	3	16			1				1
41	2		2	2	3	2	11	2						2
42	3		3	1	3		10							
43	3	2	1		2		8							
44	3		1		3		7					1		1
45	3		1		1		5							
46	3		3		1		7							
47	2				1		3					1		1
48			1		1		2							
49					2		2							
50														
51														
52														
53					1		1							
Totals							227							172