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Relative abundance, size and age structure, and stock status of blue cod off Kaikoura in 2015

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EXECUTIVE SUMMARY

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This report describes the results of blue cod (*Parapercis colias*) fixed and random site potting surveys carried out concurrently off Kaikoura in December 2015. Estimates are provided for population abundance, size and age structure, sex ratio, total mortality (Z), and spawner-per-recruit. This is the fourth survey in the Kaikoura fixed site survey time series, following surveys in 2004, 2007, and 2011; and the second random site survey with the previous survey in 2011.

2015 fixed site survey

Twenty-five fixed sites (6 pots per site, 150 pot lifts) at depths of 3–137 m from four strata off Kaikoura were surveyed in December 2015.

Mean catch rates of blue cod (all sizes) by stratum were about 2–5 kg.pot^{-1} with the lowest catch rates in stratum 2 (inshore from South Bay to Haumuri Bluffs), and the highest in stratum 4, (offshore of Kaikoura Peninsula at 100–200 m). The survey mean blue cod catch rate was 2.2 kg.pot^{-1} with a CV of 20%. Mean catch rates for recruited blue cod 30 cm and over (minimum legal size up to 2014), and 33 cm and over (minimum legal size after 2014), followed the same pattern among strata as all blue cod catch rates, but were lower; the survey mean recruited blue cod catch rates were 1.26 kg.pot^{-1} (CV 18%) and 0.74 kg.pot^{-1} (CV 17%), for 30 cm and 33 cm respectively. The strata sex ratio was 15–77% male and the survey weighted sex ratio was 66% male. The survey weighted mean length for males was 25.9 cm (range 16–54 cm) and 27.0 cm for females (range 16–45 cm).

Otolith thin section ages from 229 males and 146 females were used to estimate the population age structure with separate age-length keys for males and females. 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 1.6% and 1.2%, respectively. Von Bertalanffy growth parameters (L_{∞}, K, t_0) for males were 52.3 cm, 0.17 yr $^{-1}$, -0.26 yr; and 40.7 cm, 0.17 yr $^{-1}$, and -1.23 yr for females.

Scaled length frequency distributions for both males and females were bimodal with a strong juvenile mode at about 22 cm, more prominent in males. Age of blue cod ranged from 2–25 years for males and 3–29 years for females, but most males and females were 3–6 years old. The estimated population age distributions indicate knife-edge selectivity to the potting method at three years and shows strong modes at three and five years for both sexes, but particularly for males, and weak modes for four year olds, reflecting the paucity of fish around 25 cm in length. Mean age was 4.1 years for males and 6.1 years for females.

Total mortality estimates (Z) for age-at-full recruitment of eight years were 0.25. Based on the default M of 0.14, estimated fishing mortality (F) was 0.11 and the associated spawner biomass per recruit ratio was 53.1%.

There was a clear indication of spawning activity during the survey period with about 20% of males and 27% of females maturing or running ripe, indicating that spawning had not peaked (applies to fixed and random sites).

2015 random site survey

Twenty-five random sites (6 pots per site, producing 150 pot lifts) at depths of 6–147 m from four strata off Kaikoura were surveyed in December 2015.

Mean catch rates of blue cod (all sizes) by stratum were 0.5–9 kg.pot^{-1} with the lowest catch rates in stratum 2, and the highest in stratum 4. The survey mean blue cod catch rate was 2.2 kg.pot^{-1} with a CV of 19%. Mean catch rates for recruited blue cod 30 cm and over, and 33 cm and over, followed the same pattern among strata as all blue cod catch rates, but were lower; the survey mean recruited blue cod catch rates were 1.66 kg.pot^{-1} (CV 18%), and 1.14 kg.pot^{-1} (CV 17%), for 30 cm and 33 cm respectively. The sex ratio ranged from 16 to 75% male across the four strata and the overall weighted sex ratio was 52% male. The overall weighted mean length for males was 29 cm (range 18–52 cm) and 30 cm for females (range 16–46 cm).

Scaled length frequency distributions for both males and females were bimodal with a juvenile mode at about 22 cm, particularly for males. The same age-length-keys (one each for males and females) were used to estimate the age composition of blue cod at both fixed and random sites. Age ranged from 3–25 years for males and 3–18 years for females, but most males and females were between three and six years old. The estimated population age distributions indicate knife-edge selectivity to the potting method at three years and shows strong modes at three and five years for both sexes, but particularly for males. The age distribution also shows a corresponding weak mode for four year olds, reflecting the paucity of fish around 25 cm in length. Mean age was 5 years for males and 7.9 years for females.

Total mortality estimates (Z) for age-at-full recruitment of eight years were 0.23. Based on the default M of 0.14, estimated fishing mortality (F) was 0.09 and the associated spawner biomass per recruit ratio was 57.9%.

Fixed and random site comparison (2015 survey)

The survey mean catch rates and CVs were similar for fixed and random surveys in 2015. Length distributions were also similar within each of the four strata, but overall blue cod were larger for both males and females in random sites. The strong, predominantly male, juvenile mode, was less pronounced at random sites and the largest males were also from random sites. Sex ratios for fixed and random sites showed a similar pattern among strata, i.e., skewed towards males in all strata except the deepest stratum (stratum 4 offshore of Kaikoura Peninsula in 100–200 m) which strongly favoured females.

Time series trends

Overall catch rates from fixed sites increased nearly two-fold from 2004 to 2007, and then declined in both 2011 and 2015, with catch rates from the last the lowest of all four surveys. The sex ratio for all blue cod was close to parity for all fixed site surveys, with the exception of the 2015 fixed site survey where two-thirds of the blue cod were male, a result of the strong juvenile cohort which was dominated by males.

There was no trend in random site catch rates and sex ratios for the 2011 and 2015 surveys.

For the two concurrent surveys in 2011 and 2015, there was a higher percentage of males at fixed compared to random sites.

1. INTRODUCTION

This report describes the Ministry for Primary Industries (MPI) potting surveys of relative abundance, population length/age structure and stock status of blue cod (*Parapercis colias*) off Kaikoura in November/December 2015. This is the fourth in the time series with previous surveys in 2004, 2007, and 2011 (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2012).

1.1 Status of the north Canterbury blue cod stocks

Blue cod is a target species most frequently landed by recreational fishers off the South Island (Ministry for Primary Industries 2016). The Quota Management Area 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 during 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) with average daily catches of over 13 blue cod taken by 17% of respondents, and the most common method by far was by rod and line. There are no reliable data to determine how the recreational blue cod catch is distributed within BCO 3, but Kaikoura and Motunau are important blue cod fisheries in north Canterbury (Hart & Walker 2004).

The commercial catch in BCO 3 is about 40–50% higher than the recreational catch with between 166–183 t caught annually in the last five years up to 2014–15 (Ministry for Primary Industries 2016). Nearly all commercially landed blue cod in BCO 3 are caught by potting, and the bulk of this was from Statistical Area 024 off Oamaru (Figure 1).

The 'Kaikoura Marine Area' was established in 2014 by the Department of Conservation (DOC) with consultation from Kaikōura Marine Guardians, and extends from Clarence Point south to Conway River out to the territorial sea boundary (12 n. miles) (Figure 2). Within this area the minimum legal size is 33 cm and the daily bag limit is six blue cod. Before 2014, and for the rest of north Canterbury from Conway River to Waimakariri River including Motunau, the minimum legal size is 30 cm, and the daily bag limit is 10 blue cod. In 2014 the 10 ha. Hikurangi Marine Reserve was also established between Goose and South Bays extending out 24 km over the Kaikoura Canyon (Figure 2).

In north Canterbury the two key recreational fishing areas for blue cod and many other species are Kaikoura and Motunau which are about 90 km apart (Figure 3). Kaikoura offers substantial and varied blue cod habitat with a wide range of depths and a narrow continental shelf, whereas the coastline around Motunau is a relatively shallow wide shelf with less areas of foul. A recreational survey of private fishers and charter boats off Kaikoura and Motunau from January to April 2003 indicated that blue cod was the most common species caught at Motunau, and at Kaikoura it was the most common species caught by charter vessels, but third behind sea perch and rock lobster for private fishers (Hart & Walker 2004). Blue cod were smaller at Motunau (mean 38 cm) than Kaikoura (mean 43.1 cm), and the proportion undersize that were released was also higher at Motunau (57% compared to 39% released, respectively). Catch rates were higher at Motunau, but because more under size fish were released the overall estimated recreational catch over the four month period was similar at about 3 t for both Kaikoura and Motunau (Hart & Walker 2004). The finding that blue cod at Motunau were smaller on average than at Kaikoura is consistent with length data from the potting surveys of Motunau and Kaikoura in 2004–05 and 2007–08 (Carbines & Beentjes 2006a, 2009).

1.2 Blue cod potting surveys

South Island recreational blue cod stocks are monitored using Ministry for Primary Industries (MPI) potting surveys. These surveys take place predominantly in areas where recreational fishing is common, but in some areas there is substantial overlap between the commercial and recreational fishing grounds, including parts of north Canterbury. Surveys are generally carried out every four years providing data that can be used to monitor local relative abundance as well as size, age, and sex structure of geographically separate blue cod populations. The surveys provide a means to evaluate the response of populations to changes in fishing pressure and to management initiatives such as changes to the daily bag limit, minimum legal size, and/or 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 reference point for blue cod (a low productivity stock) is $F_{45\%SPR}$ (Ministry of Fisheries 2011).

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

1.3 Previous North Canterbury blue cod potting surveys

All potting surveys (except Foveaux Strait) originally used a fixed site design, in which sites with predetermined locations (fixed sites) were randomly drawn 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). Random sites have now been used as the only site type in Foveaux Strait, or in conjunction with fixed sites in all other South Island blue cod surveys. It is the intention of MPI to transition to a fully random survey design and the sampling of both fixed and random sites allows comparison of catch rates, length and age composition, and sex ratios between the site type survey designs.

MPI blue cod potting surveys were carried out in north Canterbury separately for the Kaikoura and Motunau recreational fishing areas under the same project code, and before now both surveys were documented in a single report (north Canterbury surveys). In this report the results of the Kaikoura surveys are presented, and the Motunau survey is dealt with separately (Beentjes & Sutton 2017). Previous Kaikoura surveys were carried out in October of 2004, 2007 and 2011 (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2012). The first two Kaikoura potting surveys used only fixed sites, whereas the 2011 survey also included a concurrent random site survey. The first two fixed site surveys were reanalysed in 2012, updating catch-at-age, sex ratios, total mortality (Z), and spawner-per-recruit (SPR) estimates as prescribed by the potting survey standards and specifications (Beentjes 2012).

1.4 Objectives

Overall Objective

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

Specific objectives

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

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

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

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

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

The Motunau blue cod survey is reported in Beentjes & Sutton (2017).

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

2. METHODS

2.1 Timing

The Kaikoura blue cod potting survey was carried out by NIWA between 29 November and 11 December 2015, consistent with the previous survey dates and coinciding with the known spawning times in this region.

2.2 Consultation with tangata whenua

The Kaikoura Marine Guardians (Te Korowai) and local iwi were consulted before the commencement of the Kaikoura survey and both groups gave their support and endorsement.

2.3 Survey areas

The survey area for the 2015 Kaikoura fixed site survey was consistent with the previous surveys. The southern and northern boundaries of the two survey areas were based on discussions with local fishers, the Dunedin Ministry for Primary Industries, and the South Recreational Advisory Committee in 2004 (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. From this information, the survey area off Kaikoura was subdivided into three contiguous strata from Kaikoura Peninsula to Haumuri Bluffs; two inshore strata out to 100 m depth and one offshore stratum from 100 to 200 m depth. In addition, the survey area includes one discrete offshore stratum about 10 km south of Haumuri Bluffs, which is broken into two substrata (Conway Rocks and Bushett Shoal) (Figure 4). The random site survey strata are the same as those used in 2011 and identical to the fixed sites strata, except that the rectangles that delineate random survey strata 1a and 1b are larger by about three fold (9.6 km^2 for fixed compared to 24.6 km^2 for random) (Figure 4). The Hikurangi Marine Reserve, established in 2014 after the first three surveys, overlaps with stratum 2. This small overlapping area was still included in the survey area for both fixed and random site surveys in 2015, but no sites were allocated within the reserve (Figure 4). Each stratum was assumed to contain roughly random distributions of blue cod habitat and the total area (km^2) within each stratum was taken as a proxy for available habitat for blue cod.

2.4 Survey design

2.4.1 Allocation of sites

Full fixed site and full random site surveys were carried out concurrently in Kaikoura in 2015 (Table 1).

Simulations to determine the optimal allocation of fixed sites among the four strata were carried out using catch rate data from the 2004, 2007, and 2011 fixed site surveys using NIWA's Optimal Station Allocation Program (*allocate*). Simulations were first carried out for fixed sites and constrained to have a minimum of three sites per stratum and a CV (coefficient of variation) of no greater than 10%. Because there were no random sites surveyed in 2004 and 2007, random site allocation was based on data from the 2011 survey constrained to have a minimum of three sites per strata and a CV of no greater than 15%. The target CV for random sites was 5% higher than for fixed sites because random site surveys tend to have higher CVs than fixed site surveys. The simulations indicated that 27 fixed sites and 31 random sites were required to meet the target CVs. In the final design agreed by the Southern Inshore Working Group (SINSWG-2015-42), the number of sites was prorated down to 25 for both surveys

The surveys used a two-phase stratified random station design (Francis 1984). For the fixed site survey 20 fixed sites were allocated to phase 1, with the remaining five available for phase 2, consistent with the proportion of phase 2 sites used in previous surveys (Table 1). Similarly, for the random site survey 22 random sites were allocated to phase 1, with the remaining three available for phase 2. 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*.

Fixed sites

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 2015 Kaikoura survey, the 25 allocated fixed sites were randomly selected from the full and larger list of 41 possible fixed sites

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 sonar 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, with the constraint that they were not closer than 400 m to an allocated fixed site (Table 1). If the random site was too close to a fixed site, a new fixed site from the list was selected to avoid biasing random site location which takes priority as the future survey design.

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

2.4.2 Vessels and gear

As for the first three surveys, the Kaikoura survey was conducted from F.V. *Mystique II* (Registration number 901093), a Kaikoura-based commercial vessel equipped to set and lift rock lobster and blue cod pots. As for previous surveys the vessel was skippered by the owner Mr Paul Reinke, or Mr Robert McHerron**.** The vessel specifications are: 13.6 m length, aluminium monohull, powered by two Yanmar 500 hp diesel engines with twin jets.

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 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 (SonTek/YSI ADP; Acoustic Doppler Profiler, 500 kHz, ADCP) was deployed at each site. The ADCP recorded current flow and direction in 5 m depth bins.

2.4.3 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) and the pot identification code (PP2A to PP2F), latitude and longitude from GPS, depth, and time of day. After each site was completed, the next closest site (either random or fixed) 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 then emptied and the contents sorted by species. Total catch weight per pot was recorded for each species to the nearest 10 g using 0–6/6–15 kg Marel motion compensating scales. The number of individuals of each species per pot was also recorded. Total length to the nearest centimetre below actual length, individual fish weight to the nearest 10 g, sex and gonad maturity were recorded for all blue cod. Sagittal otoliths were removed from a representative length range of blue cod males and females over the available length range across all strata. To ensure that otolith collection was spread across the survey area, the following collection schedule was used: Kaikoura – collect three otoliths per 1 cm size class for each sex in strata 1 and 2 combined, and strata 3 and 4 combined (Appendix 2). Sex and maturity were determined by dissection and macroscopic examination of the gonads (Carbines 1998, Carbines 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.

2.4.4 Data storage

The Kaikoura survey trip code was MYS1501. At the completion of the survey, trip, station, catch, and biological data were entered into the Ministry for Primary Industries (MPI) *trawl* and *age* databases in accordance with the business rules and the blue cod potting survey standards and specifications (Beentjes & Francis 2011). All analyses were carried out from data extracted from the *trawl* database. Fixed sites were entered into *trawl* table *t_station* in attribute *stn_code* (concatenating stratum number and site label, e.g., 1A, 2B etc.). Similarly, random sites were entered into attribute *stn_code*, but were 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.) with no distinction between fixed and random sites. In the *age* database the *sample_no* is equivalent to *station_no* in the *trawl* database. The complete list of all possible Kaikoura fixed sites were archived in the trawl database in table *t_site* after this survey as this had not been carried out hitherto.

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

2.4.5 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 centre 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.
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).

2.4.6 Data analyses

Analyses of catch rates, sex ratios, scaled length distribution, catch-at-age, Z estimates, and spawner-per-recruit were carried out and presented separately for 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).

2.4.6.1 Catch rates

The catch rate (kg.pot^{-1}) estimates are pot-based and the CV estimates are 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, and 33 cm and over). Catch rates of recruited blue cod are based on the sum of the weights of individual recruited fish. 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 for fixed and random sites surveys. Catch rates were estimated for individual strata and for all strata combined.

2.4.6.2 Length-weight parameters

The length-weight parameters a_k, b_k from the 2015 Kaikoura survey were used in the following equation:

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

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

2.4.6.3 Growth parameters

Separate von Bertalanffy growth models (von Bertalanffy 1938) were fitted to the 2015 Kaikoura 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.

2.4.6.4 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 area (km^2) shown in Table 1 was taken as the area of the stratum (A_t), and the length-weight parameter estimates are from the 2015 Kaikoura 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.

For each survey, 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, and the same ALK was 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).

2.4.6.5 Unsexed fish

All but two fish were sexed during the Kaikoura survey. The unsexed fish were not used in ageing or to estimate total mortality (*Z*), but are used to show the total scaled length frequency and corresponding total scaled age compositions.

2.4.6.6 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 of two sizes: the MLS before 2014 of 30 cm and over, and post 2014 of 33 cm and over, and overall survey 95% confidence intervals around sex ratios were generated from the 300 LF bootstraps. The proportion of fish of recruited size was estimated from the scaled LFs.

2.4.6.7 Total mortality estimates

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

Estimates of CR total mortality, *Z*, were calculated for age-at-recruitment values of 5 to 10 y using the maximum-likelihood estimator (equation 13 of Beentjes & Francis (2011). Variance (95% confidence intervals) associated with *Z* was estimated under three different parameters of recruitment, ageing error, and *Z* estimate error (equations 14 to 18 of Beentjes & Francis (2011)). Catch-at-age distributions were estimated separately for males and females and then combined, hence providing a single *Z* estimate for the population.

A traditional catch curve was also plotted from 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.

2.4.6.8 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*, in a population with deterministic recruitment, 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:

Parameter	Males	Females
K (yr^{-1})	0.1711	0.1736
t_0 (yr)	-0.2662	-1.1273
L_∞ (cm)	52.3	40.7
a	0.007506	0.007812
b	3.22040	3.21160

Natural mortality — default assumed to be 0.14. Sensitivity runs 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 2015 Kaikoura survey von Bertalanffy models. The Kaikoura recreational MLS is 33 cm and selectivity was 5.6 years for males and 8.5 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.

Because this was a 'per-recruit' analysis, it does not matter what stock-recruit relationship was assumed. However, the calculations are simpler, and the simulated population reaches equilibrium faster, if recruitment is treated as independent of spawning biomass (i.e., has a steepness of 1).

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

The SPR estimates are based on age at recruitment equal to the MLS for females, in this case 8 years.

2.4.6.9 Analyses of 2011 Kaikoura survey

Catch rates, scaled length frequencies, and sex ratios were estimated for the 2011 Kaikoura surveys, consistent with the potting survey standards and specifications (Beentjes & Francis 2011). At the time of writing, this survey was not on the MPI *trawl* database or published and analyses were carried out from raw data provided to NIWA on a spreadsheet. Catch rates of recruited blue cod are based on the sum of the weights of individual fish 30 cm and over, and 33 cm and over. These were estimated from the 2015 Kaikoura survey length-weight coefficients because no individual fish weight data were available for the 2011 survey.

3. RESULTS

3.1 2015 Kaikoura fixed site survey

3.1.1 Fixed sites surveyed

Twenty five fixed sites (6 pots per site, 150 pot lifts) from four strata off Kaikoura were fished (Table 1, Figure 5). Depths sampled were 3–137 m (mean = 58 m). Twenty sites were fished in phase 1 and five in phase 2.

3.1.2 Catch (fixed sites)

A total of 448.9 kg of blue cod (1136 fish) was taken comprising 77% by weight of the catch of all species on the survey (Table 2). Bycatch species included 13 teleost fishes, as well as one species of octopus. The three most abundant bycatch species, by number, were banded wrasse (*Notolabrus fucicola*), scarlet wrasse (*Pseudolabrus miles*), and spotty (*Notolabrus celidotus*).

3.1.3 Catch rates (fixed sites)

Mean catch rates ($kg.pot^{-1}$) of blue cod (all blue cod, 30 cm and over, 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 2–5 $kg.pot^{-1}$ with the lowest catch rates in stratum 2 (inshore from South Bay to Haumuri Bluffs), and the highest in stratum 4, offshore of Kaikoura Peninsula (Table 3, Figure 6). The survey all blue cod catch rate was 2.2 $kg.pot^{-1}$ with a CV of 20%. Catch rates for recruited blue cod 30 cm and over, and 33 cm and over, followed the same pattern among strata as for all blue cod and overall were 1.26 $kg.pot^{-1}$ (CV 18%), and 0.74 $kg.pot^{-1}$ (CV 17%) (Table 3, Figure 6). Of the 150 site pots, 31 (21%) had zero catch of blue cod.

3.1.4 Biological and length frequency data (fixed sites)

Of the 1136 blue cod caught, all but two were sexed, and all were measured for length and weighed (Table 4). The sex ratios were 15–77% male across the four strata and the overall weighted sex ratio was 66% male (Table 4). Length was 16–54 cm for males and 16–45 cm for females, although this range varied among strata. The overall weighted mean length was 25.9 cm for males and 27.0 cm for females. The scaled length frequency distributions are generally similar among strata 1 to 3, with males dominating, and a strong mode around 22 cm. By contrast, in stratum 4 the 22 cm mode was absent, fish tended to be larger, and females were over five-fold more abundant than males (Figure 7).

3.1.5 Age and growth

Otolith section ages from 229 males and 146 females collected from fixed and random sites were used to estimate the population age structure from Kaikoura in 2015 (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 for both sexes and males grow faster and larger than females. 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 1.6% and average percent error (APE) of 1.2%.

3.1.6 Spawning activity

Gonad stages of blue cod sampled in the early December 2015 Kaikoura survey are presented for all fish from fixed and random sites combined (Table 6). There was a clear indication of spawning activity during the survey period with about 20% of males and 27% of females maturing or running ripe, indicating that the spawning had not peaked.

3.1.7 Population length and age composition (fixed sites)

The scaled length frequency and age distributions for the 2015 Kaikoura 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).

Scaled length frequency distributions for both males and females were bimodal with a strong juvenile mode at about 22 cm, and overall mean lengths of 25.9 cm and 27.0 cm respectively (Figure 10). The cumulative distribution plots of length frequency are similar between sexes with the only real difference resulting from the stronger smaller mode in the males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 30.5% for males and 39.7% for females. Recruited fish comprised 29% of males and 37% of females (30 cm and over), and 13% of males and 19% of females (33 cm and over).

Age estimates of blue cod were 2–25 years for males and 3–29 years for females, but most males and females were 3–6 years old (Figure 10). The estimated population age distributions indicate knife-edge selectivity to the potting method at three years and shows strong modes at three and five years for both sexes, but particularly for males. The age distribution also shows a corresponding weak mode for four year olds, reflecting the paucity of fish around 25 cm in length. The cumulative distribution plots of age frequency show clearly that females had a much higher proportion of older fish than males, driven largely by the strong male three and five year old cohorts (Figure 10). Further, the mean age of females was greater than that of males (4.1 for males and 6.1 years for females). The MWCVs around the age distributions were 19% for males and 37% for females, the latter higher than desired to provide a good representation of the overall population age structure.

3.1.8 Total mortality estimates (*Z*) and spawner-per-recruit (SPR) (fixed sites)

Chapman Robson total mortality estimates (Z) and 95% confidence intervals are given for a range of recruitment ages (5–10 years) in Table 7. Age-at-full recruitment (AgeR) was assumed to be eight years, equal to the age at which females reach the MLS of 33 cm. The CR Z for AgeR of eight years is 0.25 (95% confidence interval of 0.17–0.35).

The traditional catch curve, based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment of eight years, is shown in Figure 11. There were few blue cod aged between 19 and 29 years of age which will have influenced the slope of the regression line and hence Z. Further, numbers-at-age do not follow a classic catch curve shape characterised by smooth ascending and descending limbs, and an intermediate domed portion. The departure from a traditional catch curve is largely due to a wide scatter of numbers at age and may be a result of variable recruitment. This is exemplified by the low numbers of 4 year old fish relative to 3 year olds, and as such is a violation of the catch curve assumption that recruitment is constant. This will have introduced error into the Z estimate which is reflected in the 95% confidence intervals around Z (see Table 7).

Mortality parameters (CR Z and F, and M) and spawner-per-recruit ($F_{\mathbf{SPR\%}}$) estimates at three values of M and age at full recruitment of eight years are shown in Table 8. Based on the default M of 0.14, estimated fishing mortality (F) was 0.11 and spawner-per-recruit was $F_{53.1\%SPR}$ (Figure 12). This indicates that at the 2015 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 53% of the contribution in the absence of fishing.

Stratum 1 is mostly outside the Kaikoura Marine Area (see Figure 4) and hence within stratum 1 the MLS is 30 cm, not 33 cm. The selectivity to the fishery in the spawner-per-recruit model is the age at 33 cm for males and females (see Section 2.4.7.8), and hence the resulting spawner-per-recruit estimate may not be as representative of blue cod in stratum 1. The length distributions and mean size of blue cod from stratum 1, however, are not different from those in the adjacent stratum 2 (see Figure 7).

3.2 2015 Kaikoura random site survey

3.2.1 Random sites surveyed

Twenty five random sites (5 pots per site, producing 150 pot lifts) from four strata off Kaikoura were fished (Table 1, Figure 5). Depths sampled were 6–147 m (mean = 58 m). Twenty-two sites were carried out in phase 1 and three in phase 2.

3.2.2 Catch (random sites)

A total of 507.9 kg of blue cod (1047 fish) was taken, comprising 91% by weight of the catch of all species on the survey (Table 2). Bycatch species included eight teleost fishes, as well as one species of octopus. The three most abundant bycatch species for random site surveys, by number, were scarlet wrasse (*Pseudolabrus miles*), girdled wrasse (*Notolabrus cinctus*), and octopus.

3.2.3 Catch rates (random sites)

Mean catch rates (kg.pot^{-1}) of blue cod (all blue cod, 30 cm and over, 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 0.5–9 kg.pot^{-1} with the lowest catch rates in stratum 2 (inshore from South Bay to Haumuri Bluffs), and the highest in stratum 4, offshore of Kaikoura Peninsula (Table 3, Figure 6). The survey all blue cod catch rate was 2.2 kg.pot^{-1} with a CV of 19%. Catch rates for recruited blue cod 30 cm and over, and 33 cm and over (minimum legal size up to 2014, and after 2014), followed the same pattern among strata as for all blue cod and overall were 1.66 kg.pot^{-1} (CV 18%), and 1.14 kg.pot^{-1} (CV 17%) (Table 3, Figure 6). Of the 150 random site pots, 56 (37%) had zero catch of blue cod.

3.2.4 Biological and length frequency data (random sites)

Of the 1047 blue cod caught, all were sexed, measured for length, and weighed (Table 4). The sex ratios were 16–75% male across the four strata and the overall weighted sex ratio was 52% male (Table 4). Length was 18–52 cm for males and 16–46 cm for females, although this range varied among strata and the overall weighted mean length was 29.0 cm for males and 30.0 cm for females. The scaled length frequency distributions are generally similar among strata 1–3, but there were low sample sizes for females, and males were dominant, with a strong mode around 22 cm (Figure 13). By contrast, in stratum 4, the 22 cm mode was absent, fish tended to be larger, and females were five-fold more abundant than males.

3.2.5 Age and growth

See Section 3.1.5 for the age and growth description which applies to both fixed and random site surveys.

3.2.6 Spawning activity

See Section 3.1.6 for the spawning activity description which applies to both fixed and random site surveys.

3.2.7 Population length and age composition (random sites)

The scaled length frequency and age distributions for the 2015 Kaikoura 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 14).

The scaled length frequency distribution for males was bimodal with a small juvenile mode at about 24 cm, and an overall mean length of 29 cm. The small mode is less apparent in the female distribution, and the overall mean length is 30 cm (Figure 14). The cumulative distribution plots of length frequency are similar between sexes with the only real difference resulting from the stronger smaller mode in the males and the higher proportion of larger males over 40 cm. The mean weighted coefficients of variation (MWCVs) around the length distributions are 39.4% for males and 36.2% for females. Recruited fish (33 cm and over) comprised 30% of males and 36% of females.

Age ranged from 3–25 years for males and 3–18 years for females, but most males and females were 3–6 years old (Figure 14). The estimated population age distributions indicate knife-edge selectivity to the potting method at three years with strong modes at three and five years for both sexes, but particularly for males. The age distribution also shows a corresponding weak mode for four year olds, reflecting the paucity of fish around 25 cm in length. The cumulative distribution plots of age frequency show clearly that females had a much higher proportion of older fish than males, driven largely by the strong male three and five year old cohorts (Figure 14). Further, the mean age of females was greater than that of males (5 for males and 7.9 years for females). The MWCVs around the age distributions were 24% for males and 46% for females, the latter higher than desired to provide a good representation of the overall population age structure.

3.2.8 Total mortality estimates (*Z*) and spawner-per-recruit (SPR) (random sites)

Random site CR total mortality estimates (*Z*) and 95% confidence intervals are given for a range of recruitment ages (5–10 y) in Table 7. Age-at-full recruitment (AgeR) is assumed to be eight years, equal to the age at which females reach the MLS of 33 cm. The CR Z for AgeR of eight years is 0.23 (95% confidence interval of 0.16–0.32).

The traditional catch curve, based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment of eight years, is shown in Figure 11. There were few blue cod aged between 18 and 25 years of age which will have influenced the slope of the regression line and hence Z. Further, numbers-at-age do not follow a classic catch curve shape characterised by smooth ascending and descending limbs, and an intermediate domed portion. The departure from a traditional catch curve is largely due to a wide scatter of numbers at age and may be a result of variable recruitment. This exemplified by the low numbers of 4 year old fish relative to 3 year olds, and as such is a violation of the catch curve assumption that recruitment is constant. This will have introduced error into the Z estimate which is reflected in the 95% confidence intervals around Z (see Table 7).

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 eight years are shown in Table 8. Based on the default *M* of 0.14, estimated fishing mortality (*F*) was 0.09 and associated spawner-per-recruit was 57.9% (see Figure 12). This indicates that at the 2015 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 58% of the contribution in the absence of fishing.

As described for the fixed site survey, stratum 1 is mostly outside the Kaikoura Marine Area (see Figure 4) and within stratum 1 the MLS is 30 cm, not 33 cm. Hence, the resulting spawner-per-recruit estimate may not be as representative of blue cod in stratum 1.

3.3 Comparison of fixed site and random site surveys in 2015

Mean catch rates of all blue cod were similar for the two surveys in strata 1 and 3, but were considerably higher for random sites in stratum 4, and lower in stratum 2 (Table 3, Figure 15). Given the magnitude of confidence intervals around these catch rate estimates these observed differences are not likely to be significant. The survey mean catch rate, was almost the same in fixed and random sites. The recruited fish (30 cm and over, and 33 cm and over) catch rates exhibited the same pattern among strata as all blue cod, although recruited catch rates from random sites were slightly higher, because fish were larger than those from fixed sites (Table 3, Figure 15).

The length distributions from the four strata showed similar patterns between fixed and random sites (compare Figures 7 and 13), but the random site blue cod were larger for both males and females (Figure 16). The strong juvenile mode, prominent in the fixed sites, was less pronounced in the random sites and the largest males were from random sites (Figures 7, 13, and 16). The length distribution differences are reflected in the age structure with older blue cod from random sites (Figure 16).

Sex ratios for fixed and random sites are similar with strata 1–3 favouring males and stratum 4 strongly favouring females (i.e., 15% and 16% male, respectively) (Table 4). The survey sex ratios were 66% male for fixed sites and 52% male for random sites. Recruited sex ratios showed similar patterns among strata, but the overall proportion male was less (Table 4).

Total mortality and SPR estimates were similar for fixed and random site surveys with Z estimates of 0.25 and 0.23, and spawner biomass per recruit ratios of 53% and 58%, respectively, for age at recruitment of 8 years and M of 0.14 (see Table 8, Figure 12).

3.4 Kaikoura survey time series

3.4.1 Catch rates

Fixed sites – Mean catch rates (kg.pot^{-1}) for all blue cod and recruited blue cod (30 cm and over, and 33 cm and over) from fixed sites are presented for each of the four surveys in the time series (Figure 17). Survey catch rates increased nearly two-fold from 2004 to 2007, and then declined in both 2011 and 2015, with the latter the lowest of all four surveys. The confidence intervals indicate that the catch rate increased in 2007, and that the decline between 2007 and 2015 is highly significant. Catch rates in Kaikoura Peninsula strata 3 and 4, follow the same pattern as survey catch rates. Catch rates in stratum 2 are consistently the lowest of the four surveys. Catch rates for recruited blue cod display the same patterns among strata as all blue cod (Figure 17).

Random sites – Mean catch rates (kg.pot^{-1}) for all blue cod from random sites are presented for the 2011 and 2015 surveys (Figure 18). The decline in survey catch rates between 2011 and 2015, observed for fixed sites, is absent for random site surveys, largely because of the high catch rates in stratum 4 in 2015.

Comparison of the survey blue catch rates between fixed and random sites over the time series is shown in Figure 19. The catch rates of all blue cod for the overlapping surveys in 2011 and 2015 are not likely to be significantly different.

3.4.2 Length distributions

Because blue cod ageing from the previous three surveys was carried out before the age determination protocol was developed, age compositions, total mortality (Z) and SPR estimates from these surveys cannot be compared with those from the 2015 survey. Scaled length, however, can be validly compared for the four fixed site and two random site surveys across years.

Fixed sites – scaled length frequency distributions and mean length from fixed sites were similar for the 2004 and 2007 surveys. Mean overall length declined by 2 cm in 2011, and by a further 2 cm in 2015. This is partly a result of the strong recruitment of juvenile blue cod, especially in 2015, and to a decline in large fish over time, particularly males (Figure 20).

Random sites – scaled length frequency distributions and mean length from random sites were similar for the 2011 and 2015 surveys with any difference due to the stronger recruitment of mainly juvenile male blue cod in 2015 (Figure 21).

In 2011 the random and fixed sites length distributions were similar in shape and size, but in 2015 fixed sites lacked the large males present from random sites and had a stronger juvenile mode (compare Figures 20 and 21).

3.4.3 Sex ratios

The sex ratio for the fixed site surveys for all blue cod was around 50% male for the first three surveys but increased to 66% male in 2015 (Figure 22). For recruited blue cod in fixed sites, the percent male was higher than for all blue cod (except for 2015), and stable across all four surveys. For the two random site surveys, in both years, and across all sizes the percent male was less than in fixed sites, at about 50% male, with no differences for recruited blue cod (Figure 22).

4. DISCUSSION

4.1 General

The 2015 Kaikoura potting survey provides the fourth fixed site and the second random site in the time series of relative abundance and population structure of blue cod from this area. After reviewing the results of the 2015 Kaikoura survey in December 2016, the Southern Inshore Working Group (SINSWG-2016/38) recommended moving to solely random sites in the next survey round with a target CV of 15%. Suggested design modifications to be investigated included increasing the number of random sites to improve the power to detect change, and subdividing existing strata.

The abundance estimates, and length and age distributions are weighted (scaled) by the area of each stratum in this survey. Scaling by area assumes that the size of each stratum is directly proportional to the amount of blue cod habitat (i.e., it is assumed to be a proxy for habitat), however, this is probably not always the case given the discrete nature of areas of foul and biogenic habitat.

Target CVs around relative abundance (catch rates) were not specified for the 2015 Kaikoura survey. The achieved CVs of 20% for the fixed site and 19% for random site surveys were similar to CVs obtained for other blue cod surveys (Ministry for Primary Industries 2016). Previous fixed site surveys achieved slightly lower CVs of 11%, 13%, and 13% for 2004, 2007, and 2011 respectively. The one previous random site survey in 2011 achieved a CV of 17%, slightly less than in 2015. The achieved CVs for both surveys over time indicate that the survey design and number of sites used are appropriate for fixed site surveys, but more sites may be required for random site surveys.

4.2 Kaikoura 2015 fixed site versus random site surveys

The overall catch rates and CVs were similar for fixed and random surveys (see Table 3), and the length distributions were also similar within each of the four strata, but blue cod were larger for both males and females from random sites (see Figure 16). Further, the fixed site length distribution was characterised by a strong predominantly male juvenile mode, less pronounced in random sites and the largest males were also from random sites. The strong juvenile mode appears in the age composition as three year old fish indicating good spawning and /or survival in spring/summer of 2012 (see Figure 10). Previous fixed site Kaikoura surveys show no indications of strong recruitment into the population suggesting that this pulse may be unusual (see Figure 20). This is the first Kaikoura survey for which ageing was carried out using the blue cod age determination protocol and therefore it is not strictly valid to compare age estimates from previous surveys. The 2014 Dusky Sound survey for which ageing was carried out using the ADP, indicates that the strongest age modes are 4 and 5 years old, with a weak left hand tail comprising 3 and 2 year olds (Beentjes & Page 2016). This suggests that full selectivity to the potting method is not reached until 4 to 5 years old in Dusky Sound. The finding that 3 year old blue cod are the dominant cohort off Kaikoura in 2015 suggests that the 2012 year class is exceptionally strong and can be expected to enhance the fishery in the next few years as it recruits fully to the recreational and commercial fisheries. Conversely, the weak 4 year old cohort may have the opposite effect. The reason that this 3 year old cohort is weaker from random sites may be related to the location of fixed sites near known fishing 'hot spots' where blue cod spawning and recruitment of juveniles may be more concentrated than from random sites. Similarly, the result that the largest blue cod are from random sites may be due to less fishing intensity compared to the fixed site 'hot spots'.

The sex ratios from fixed and random sites showed a similar pattern among strata, but the survey sex ratio favoured males from fixed sites (see Table 4). The sex ratio in the deeper stratum 4 (offshore of Kaikoura Peninsula in 100–200m) strongly favoured females, but in other strata the sex ratio was skewed towards males. This is partly explained by the absence of the strong 3 year old male dominated mode in stratum 4 (see Figures 7 and 13).

CR total mortality (Z) and SPR estimates were similar for fixed and random site surveys with slightly lower Z estimates for random sites due to the presence of larger fish (see Table 8).

4.3 Stock status

The MPI *Harvest Strategy Standard* specifies that a Fishery Plan 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). Based on this and recommendations from the Southern Inshore Working Group, blue cod is categorised as an exploited species with low productivity and the recommended default proxy for F_{MSY} is $F_{45\%SPR}$.

Random site surveys are considered to be superior to fixed sites surveys in design and precision (Stephenson et al. 2009), so estimates of Z and SPR from random site surveys are likely to be more representative of the population. The 2015 random site survey SPR estimate, for the default M value of 0.14, and age at full recruitment of 8 years (based on age to reach MLS for females), was $F_{58\%SPR}$, indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit was reduced to 58% of the contribution in the absence of fishing (see Figure 12). The level of exploitation (F) of Kaikoura blue cod stocks is therefore below the F_{MSY} target reference point of $F_{45\%SPR}$, i.e., it is under exploited. The estimate of Z and hence F determine the value of the Spawner per Recruit ratio. Total mortality (Z) is a product of the slope of the right hand descending curve of age versus population numbers. In this case Z was relatively low which dictates that F is low and therefore the SPR value is high. The wide scatter of numbers at age and the absence of a clear dome on the catch curve, however, may be a result of variable recruitment, and hence violate the catch curve assumption that recruitment is constant (see Figure 11). Point estimates of *Z*, *F* and SPR should therefore be treated with caution and the all Z estimates that fall within the 95% confidence intervals may be plausible.

4.4 Reproductive condition

All four surveys were carried out in October, so reproductive status is comparable. During the 2004 survey most blue cod had mature or maturing gonads, with small numbers of running ripe indicating that spawning had only just begun (Carbines & Beentjes 2006a). Gonad stages observed in 2007 were more developed than those in the 2004 survey, with about one quarter of male blue cod in the running ripe condition (Carbines & Beentjes 2009). The higher proportion of blue cod with gonads in the mature and running ripe phases in 2007 suggests that spawning began earlier than in 2004. In comparison, only 2–12% of gonads were in running ripe condition in 2015, more in line with the spawning cycle of 2004 (see Table 6).

4.5 Time series trends from Kaikoura surveys

There are now four fixed site surveys in the time series, allowing a cautious attempt to identify and offer explanations for trends. The MPI Southern Inshore Working Group noted, however, that the fixed site time series may not be valid given that fixed sites may be 'hyperstable' by virtue of their locations on fishing hot spots and that the meaningful time series should be based on random site surveys (SINSWG-2016/26). Also, because ageing of blue cod from the 2004, 2007, and 2011 surveys was carried out before the age determination protocol was agreed upon, age compositions, total mortality (Z) and SPRs cannot be compared among the surveys.

4.5.1 Trends in catch rates

Overall catch rates from fixed sites increased nearly two-fold from 2004 to 2007, and then declined in both 2011 and 2015, with catch rates from the latter the lowest of all four surveys (see Figure 19). While the difference in overall abundance between the 2015 and the previous survey in 2011 is unlikely to be significant, this is not the case for recruited blue cod with no overlap of the 95% confidence intervals (see Figure 19). The catch rate pattern in stratum 4 is closely mirrored by the survey catch rates because blue cod are consistently the most abundant in this stratum (see Figure 17). The proportion of pots with no blue cod (i.e., blue cod catch is zero) does not follow the catch rate pattern and has varied from 15 to 21% (Figure 23).

Random site catch rates for the 2011 and 2015 surveys are almost the same (see Figure 19).

The increase in MLS from 30 cm to 33 cm and the reduction in bag limit from 10 to 6 blue cod within the Kaikoura Marine Area took place in March 2014, about 21 months before the December 2015 survey. There are no clear indications that these regulations have had an effect on blue cod catch rates or size as both have declined since 2011. Displacement of recreational fishing effort from the Marlborough Sounds to Kaikoura and Motunau is likely to have occurred in recent years with the restrictions on blue cod fishing in the Marlborough Sounds[1]. Without information on recreational fishing effort, however, it is difficult to gauge the impacts of the increase in MLS and reduction in MDL within the Kaikoura Marine Area. For example, it may be that the benefits of these measures were diminished or offset by increased fishing effort.

[1] Closure of the inner Marlborough Sound to all blue cod fishing in October 2008; a slot limit of 30 to 35 cm and a MDL of 2 blue cod in April 2011; and from 20 December 2015, a MLS of 33 cm and MDL of 2 blue cod within the period 20 December to 31 August.

4.5.2 Trends in length and sex ratio

Overall blue cod mean length (see Figure 20), and catch rates of blue cod 30 cm and over from fixed sites declined in 2011 and again in 2015 (Figure 19). Mean length is not always a good indicator of whether population size is increasing or decreasing because it can be biased by strong recruitment events, such as occurred in 2015. It is clear, however, that numbers of large fish are declining over time, especially males. Random site surveys show no real change in size between 2011 and 2015, and as described for trends in catch rates, this may be a result of less fishing intensity compared to the fixed site 'hot spots'.

The sex ratio for all blue cod was close to parity for all surveys, with the exception of the 2015 fixed site survey where two-thirds of the blue cod were male (see Figure 22). The higher proportion of males in 2015 is a result of the strong juvenile cohort which was dominated by males. There was no trend in sex ratio of the recruited blue cod which slightly favours males since the largest blue cod tend to be male. Blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow (Carbines 2004); the Kaikoura blue cod population sex and size structure is consistent with this reproductive strategy.

In areas where fishing pressure is known to be high, such as Motunau, inshore Banks Peninsula, and the Marlborough Sounds, the sex ratios are 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, females are dominant suggesting that fishing pressure is less intense (Beentjes & Carbines 2009, Carbines & Beentjes 2012, Beentjes & Page 2016). Beentjes & Carbines (2005) suggested 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. While the sex ratio is close to parity for Kaikoura for all surveys, this is strongly influenced by stratum 4 (offshore of Kaikoura Peninsula in 100–200 m) where consistently abundance is highest and the proportion male has always been low, i.e., in 2015 it was 15% and 16% for fixed and random sites respectively (see Table 4). For the other strata, the sex ratio tends to favour males, especially in stratum 2 (inshore south Bay to Haumuri Bluffs) which also has the lowest abundance and the smallest fish.

4.5.3 Concluding remarks

The strong blue cod 3 year old cohort and the weak 4 year old cohort observed in Kaikoura in December 2015, were also present in the age compositions in Motunau in January 2016, and Banks Peninsula in April 2016 (Beentjes & Fenwick 2017, Beentjes & Sutton 2017). This consistent pattern suggests that the 2012 spawning event was better than average and/or that natural mortality was low on this cohort on the north east coast of the 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, and Banks Peninsula stocks of this species are likely to consist of largely independent sub-populations. However, blue cod are not genetically distinct around the New Zealand mainland (Gebbie 2014) indicating that mixing is occurring on a wider geographical scale than within the restricted home range indicated by tagging studies. It is possible that wider mixing is facilitated by egg and larval drift more than movements by juveniles or adults. Hence the strong 2012 year class, across the north east South Island, may have at least two possible explanations: 1) favourable environmental conditions in one area enhanced spawning and resulted in the source of abundant eggs and larvae that drifted to the other areas, or 2) favourable environmental conditions existed in all areas enhancing localised spawning and survival of eggs and larvae.

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Table 1: Effort and catch data for the 2015 Kaikoura blue cod potting survey.

Stratum	Area (km^2)	Site type	*N* sets (sites) Phase 1	Phase 2	*N* pots (stations)	Catch (blue cod) *N*	kg	Depth (m) Mean	Range
1	9.6	Fixed	3		18	153	41.9	41.7	27–64
2	96.0	Fixed	6	3	54	328	85.5	15.1	3–32
3	24.8	Fixed	5	1	36	313	108.6	67.1	32–93
4	15.7	Fixed	6	1	42	342	212.9	113.8	100–137
Total	146.1	Fixed	20	5	150	1 136	448.9	58.4	3–137

Stratum	Area (km^2)	Site type	*N* sets (sites) Phase 1	Phase 2	*N* pots (stations)	Catch (blue cod) *N*	kg	Depth (m) Mean	Range
1	26.4	Random	3		18	111	48.2	34.1	21–43
2	96.0	Random	7	2	54	82	26.1	24.9	6–64
3	24.8	Random	8	1	54	492	207.8	71.6	34–101
4	15.7	Random	4		24	362	225.8	118.1	105–147
Total	146.1	Random	22	3	150	1 047	507.9	57.7	6–147

Table 2: Total catch and numbers of blue cod and bycatch species caught on the 2015 Kaikoura fixed site and random site 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	1 136	448.9	77.3
Banded Wrasse	*Notolabrus fucicola*	BPF	114	62.1	10.7
Common octopus	*Macroctopus maorum*	OCT	12	27.5	4.7
Scarlet wrasse	*Pseudolabrus miles*	SPF	50	16.8	2.9
Southern bastard cod	*Pseudophycis barbata*	SBR	5	8.6	1.5
Girdled wrasse	*Notolabrus cinctus*	GPF	30	5.6	1.0
Spotty	*Notolabrus celidotus*	STY	46	4.1	0.7
Tarakihi	*Nemadactylus macropterus*	NMP	6	2.7	0.5
Sea perch	*Helicolenus percoides*	SPE	10	2.2	0.4
Blue moki	*Latridopsis ciliaris*	MOK	1	1.2	0.2
Dwarf scorpion fish	*Scorpaena papillosa*	RSC	5	0.6	0.1
Triplefin	Tripterygiidae	TRP	3	0.2	0.0
Butterfly perch	*Caesioperca lepidoptera*	BPE	1	0.2	0.0
Butterfish	*Odax pullus*	BUT	1	0.2	0.0
Red cod	*Pseudophycis bachus*	RCO	1	0.2	0.0
Totals			1 421	581.1	

		Random sites			
Common name	Species	Code	Number	Catch (kg)	% catch
Blue cod	*Parapercis colias*	BCO	1 047	507.9	90.8
Common octopus	*Macroctopus maorum*	OCT	9	25.7	4.6
Southern conger	*Conger verreauxi*	CVR	1	10.0	1.8
Scarlet wrasse	*Pseudolabrus miles*	SPF	19	7.0	1.3
Girdled wrasse	*Notolabrus cinctus*	GPF	16	3.3	0.6
Banded Wrasse	*Notolabrus fucicola*	BPF	3	1.8	0.3
Dwarf scorpion fish	*Scorpaena papillosa*	RSC	7	1.6	0.3
Tarakihi	*Nemadactylus macropterus*	NMP	4	1.1	0.2
Sea perch	*Helicolenus percoides*	SPE	3	0.9	0.2
Red cod	*Pseudophycis bachus*	RCO	1	0.3	0.1
Totals			1 110	559.6	

Table 3: Mean catch rates for all blue cod, and recruited blue cod (30 cm and over; 33 cm and over) from the 2015 Kaikoura fixed site and random site potting surveys. Catch rates are pot-based, and s.e. and CV are set-based. s.e., standard error; CV coefficient of variation.

Fixed sites survey

			All blue cod			Recruited blue cod (30 cm and over)			Recruited blue cod (33 cm and over)		
Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)
1	Fixed	18	2.33	1.30	56.1	1.03	0.62	60.1	0.73	0.44	60.9
2	Fixed	54	1.58	0.64	40.1	0.68	0.29	43.2	0.34	0.15	45.1
3	Fixed	36	3.02	0.69	22.7	1.53	0.26	17.2	0.84	0.15	18.3
4	Fixed	42	5.07	1.04	20.5	4.56	1.01	22.1	3.04	0.64	21.0
Overall	Fixed	150	2.25	0.46	20.2	1.26	0.23	18.1	0.74	0.13	17.3

Random sites survey

			All blue cod			Recruited blue cod (30 cm and over)			Recruited blue cod (33 cm and over)		
Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)
1	Random	18	2.68	1.50	56.1	1.82	0.90	49.4	1.28	0.54	42.0
2	Random	54	0.48	0.32	67.0	0.29	0.18	62.9	0.17	0.12	70.0
3	Random	54	3.85	1.25	32.6	2.42	0.83	34.5	1.47	0.46	31.0
4	Random	24	9.41	2.16	22.9	8.59	2.04	23.8	6.28	1.40	22.3
Overall	Random	150	2.21	0.42	18.9	1.66	0.30	17.8	1.14	0.19	16.6

Table 4: Weighted mean lengths for the 2015 Kaikoura fixed site and random site potting surveys for all blue cod. Weighted sex ratio (percent male) is given for all blue cod and recruited blue cod (33 cm and over and 30 cm and over). m, male; f, female; u, unsexed. –, no data.

Fixed site survey

				Length (cm)			Percent male		
Stratum	Site type	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited >=30 cm	Recruited >=33 cm
1	Fixed	m	104	25.7	16	40.5	68.1	85.2	94.9
		f	49	23.2	16	34.0			
		u	0	–	–	–			
2	Fixed	m	253	25.1	16.2	39.9	77.1	89.8	96.1
		f	75	23.5	17.5	34.0			
		u	0	–	–	–			
3	Fixed	m	207	27.1	19.4	41.7	66.1	70.5	69.6
		f	106	26.8	18.2	43.0			
		u	0	–	–	–			
4	Fixed	m	52	36.7	23.8	53.9	15.3	14.8	19.7
		f	288	32.5	24.4	45.0			
		u	2	26.4	33.5	38.2			
Overall	Fixed	m	616	25.9	16.0	53.9	66.3	60.3	58.2
		f	518	27.0	16.0	45.0			
		u	2	26.4	33.5	38.2			

Random site survey

				Length (cm)			Percent male		
Stratum	Site type	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited >=30 cm	Recruited >=33 cm
1	Random	m	83	28.9	18.6	45.9	74.6	83.5	96.5
		f	28	26.0	18.3	32.6			
		u	0	–	–	–			
2	Random	m	61	27.3	19.8	40.0	74.5	91.9	100
		f	21	21.7	16.2	31.0			
		u	0	–	–	–			
3	Random	m	271	28.7	18.1	49.5	55.5	54.5	60.5
		f	221	29.0	18.1	41.0			
		u	0	–	–	–			
4	Random	m	60	35.2	20.2	51.6	16.5	15.5	16.6
		f	303	33.0	23.8	46.0			
		u	0	–	–	–			
Overall	Random	m	475	29.0	18.1	51.6	51.7	45.1	46.6
		f	572	30.0	16.2	46.0			
		u	0	–	–	–			

Table 5: Otolith ageing data used in the catch-at-age, Z estimates and SPR analyses for the 2015 Kaikoura survey.

		Length of aged fish (cm)		Age (years)	
Survey	No. otos	Minimum	Maximum	Minimum	Maximum
Total	375	16	53	2	29
Male	229	16	53	2	25
Female	146	16	46	3	29

Table 6: Gonad stages of blue cod from Kaikoura in early December 2015 for all blue cod. 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	44.2	29.1	18.3	2.4	6.0	1 091
Females	39.3	29.1	15.5	12.2	3.9	1 090

Table 7: Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals of blue cod for the fixed and random site 2015 Kaikoura potting surveys. AgeR, age at full recruitment.

		Fixed site survey	
		95% CIs	
AgeR	*Z*	Lower	Upper
5	0.44	0.29	0.6
6	0.33	0.23	0.45
7	0.23	0.15	0.32
8	0.25	0.17	0.35
9	0.30	0.19	0.42
10	0.27	0.18	0.38

		Random site survey	
		95% CIs	
AgeR	*Z*	Lower	Upper
5	0.31	0.22	0.43
6	0.27	0.19	0.37
7	0.21	0.14	0.28
8	0.23	0.16	0.32
9	0.27	0.18	0.38
10	0.27	0.18	0.4

Table 8: Mortality parameters (CR *Z* and *F*, and *M*) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* for age at full recruitment (AgeR) of 8 years for blue cod from the 2015 Kaikoura fixed and random site potting surveys. AgeR is the age at which females reach MLS of 33 cm. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality.

				Fixed site survey
AgeR	*M*	*Z*	*F*	$F_{\%SPR}$
8	0.11	0.25	0.14	$F_{40.4\%}$
8	0.14	0.25	0.11	$F_{53.1\%}$
8	0.17	0.25	0.08	$F_{66.0\%}$

				Random site survey
AgeR	*M*	*Z*	*F*	$F_{\%SPR}$
8	0.11	0.23	0.12	$F_{44.1\%}$
8	0.14	0.23	0.09	$F_{57.9\%}$
8	0.17	0.23	0.06	$F_{72.0\%}$

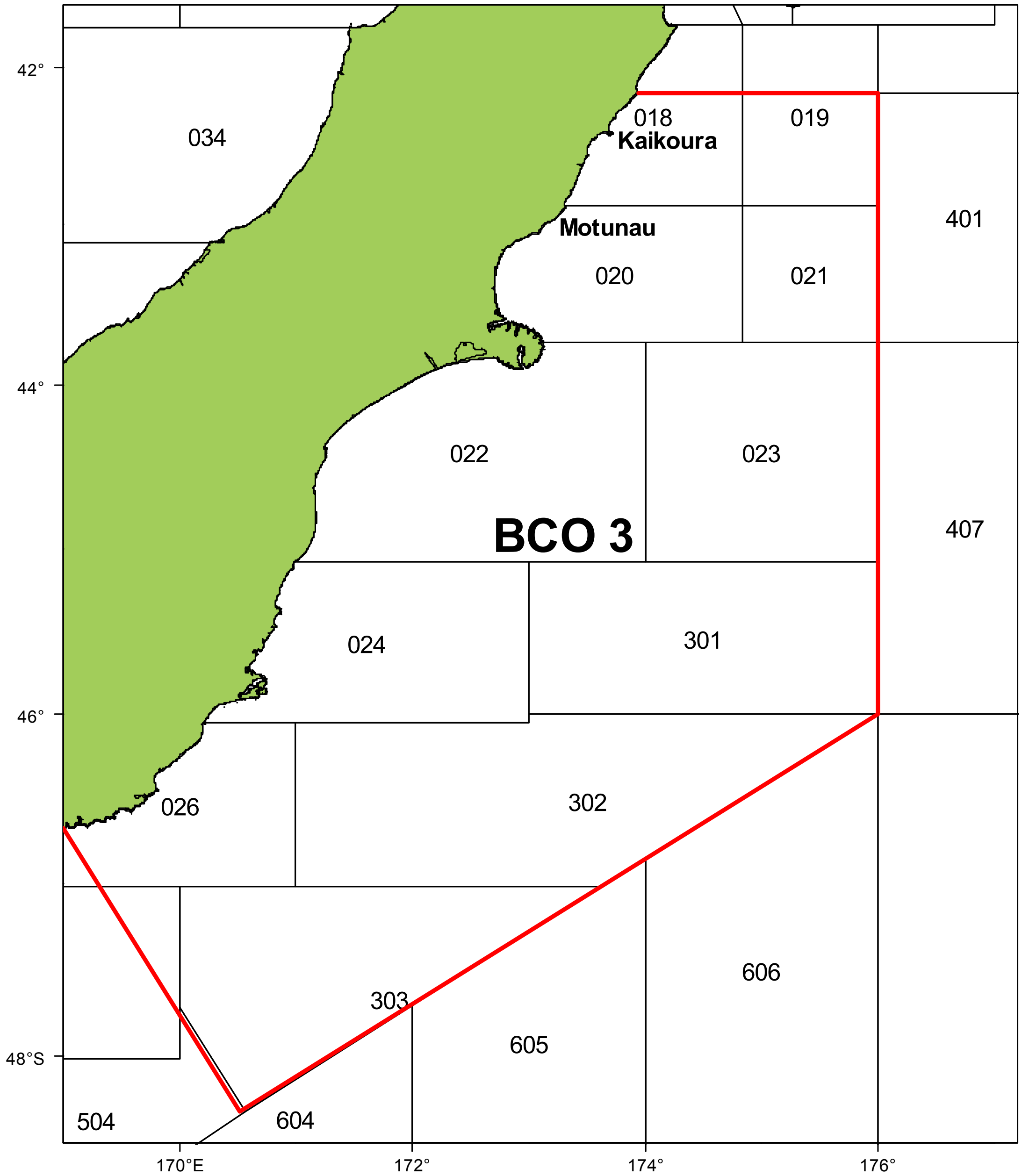

Figure 1: Blue cod Quota Management Area BCO 3 (red border) and statistical areas. The north Canterbury potting survey locations of Kaikoura and Motunau are shown.

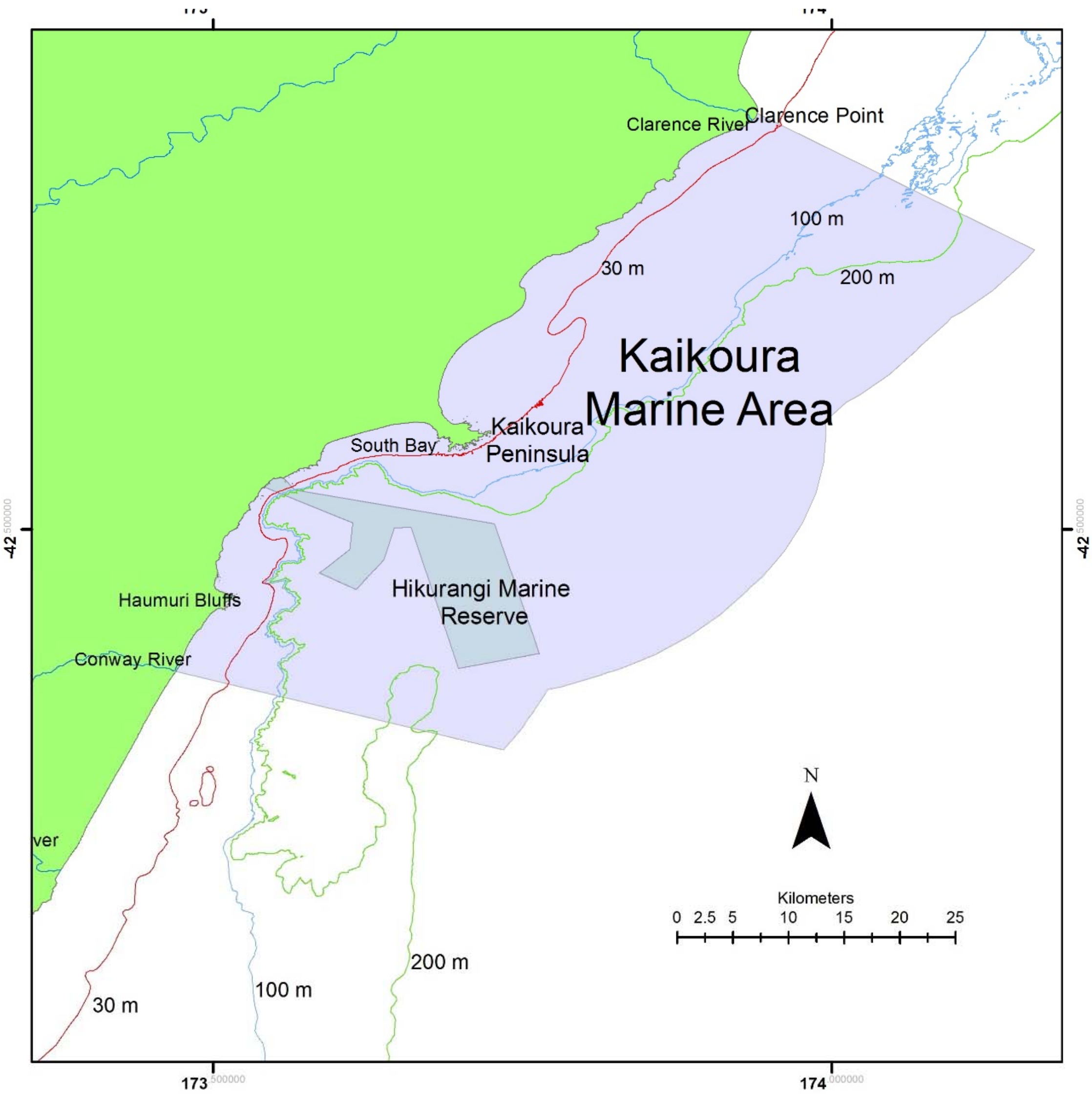

Figure 2: Map of north Canterbury region showing the Kaikoura Marine Area and Hikurangi Marine Reserve, both established in 2014. Within the Kaikoura Marine Area the recreational blue cod minimum legal size is 33 cm, and daily bag limit is six. Elsewhere in north Canterbury it is 30 cm and 10 blue cod.

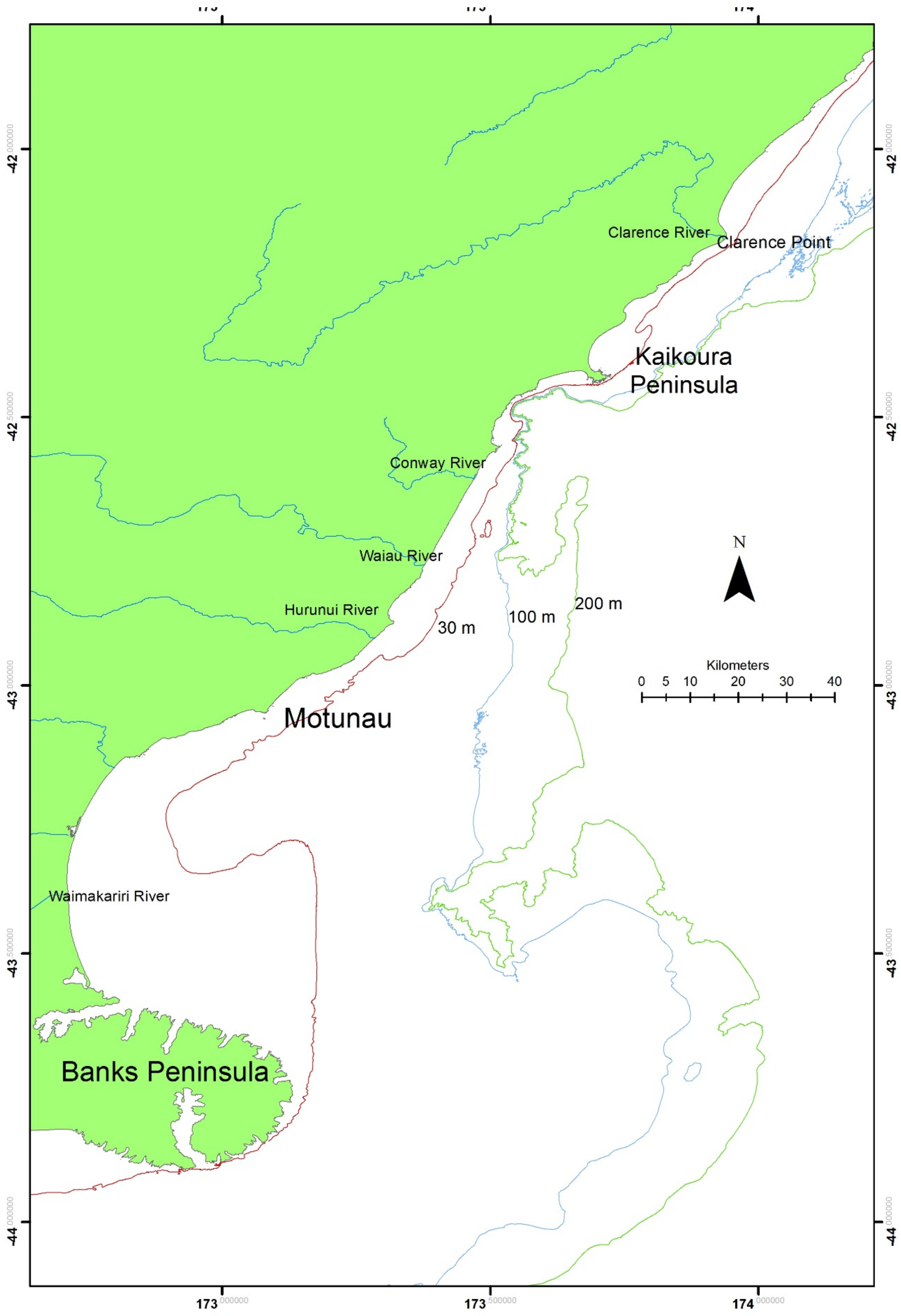

Figure 3: Map of north Canterbury region showing the potting survey areas Kaikoura and Motunau.

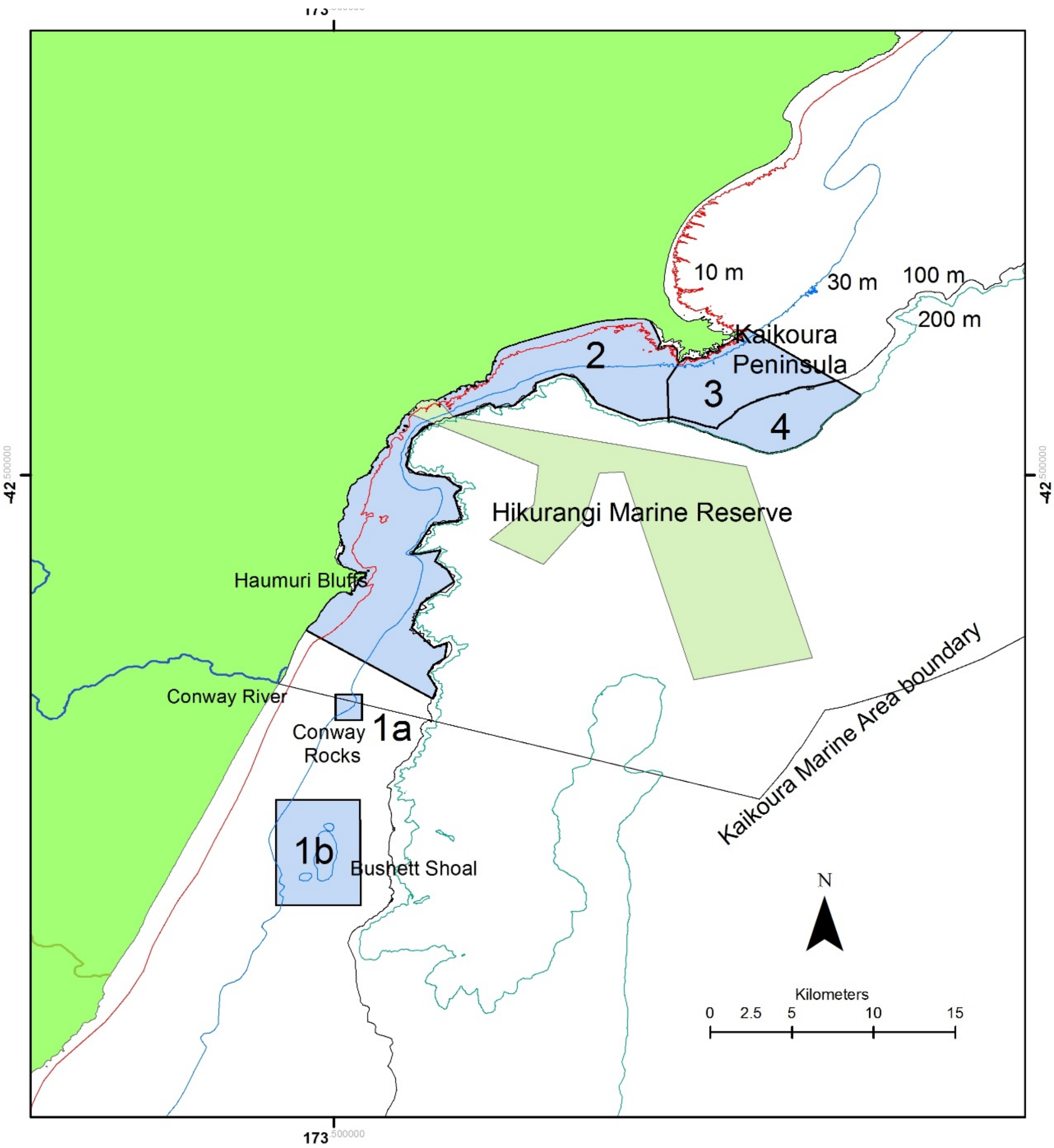

Figure 4: Map of Kaikoura potting survey strata (1a, 1b, 2, 3, 4) for random site surveys. Fixed sites survey strata are identical except that the rectangles around strata 1a and 1b are about one third the area (9.6 km^2 compared with the 24.6 km^2 shown). The Hikurangi Marine Reserve and Kaikoura Marine Area are also shown.

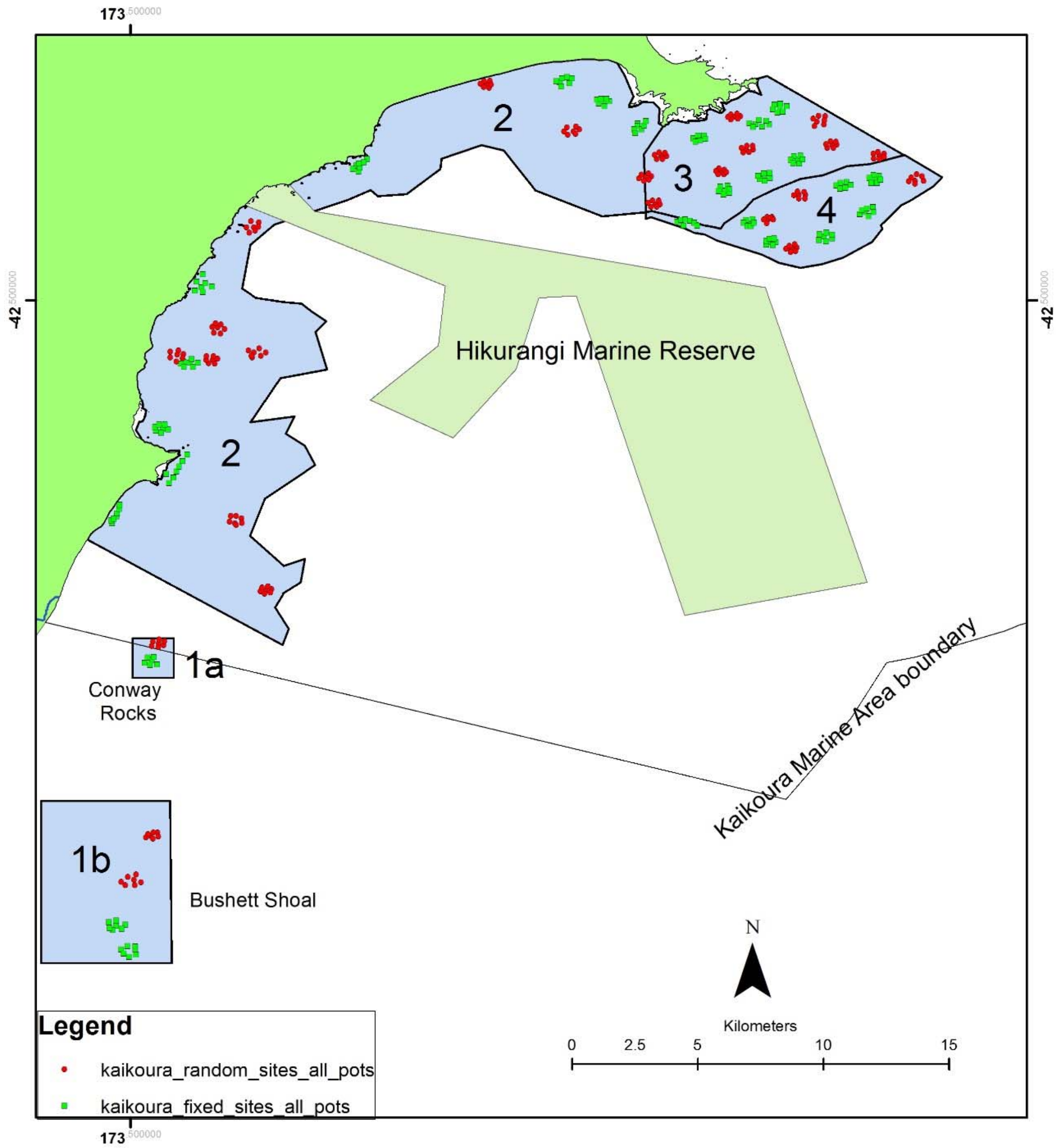

Figure 5: Kaikoura strata and pot locations for the fixed and random sites survey in 2015.

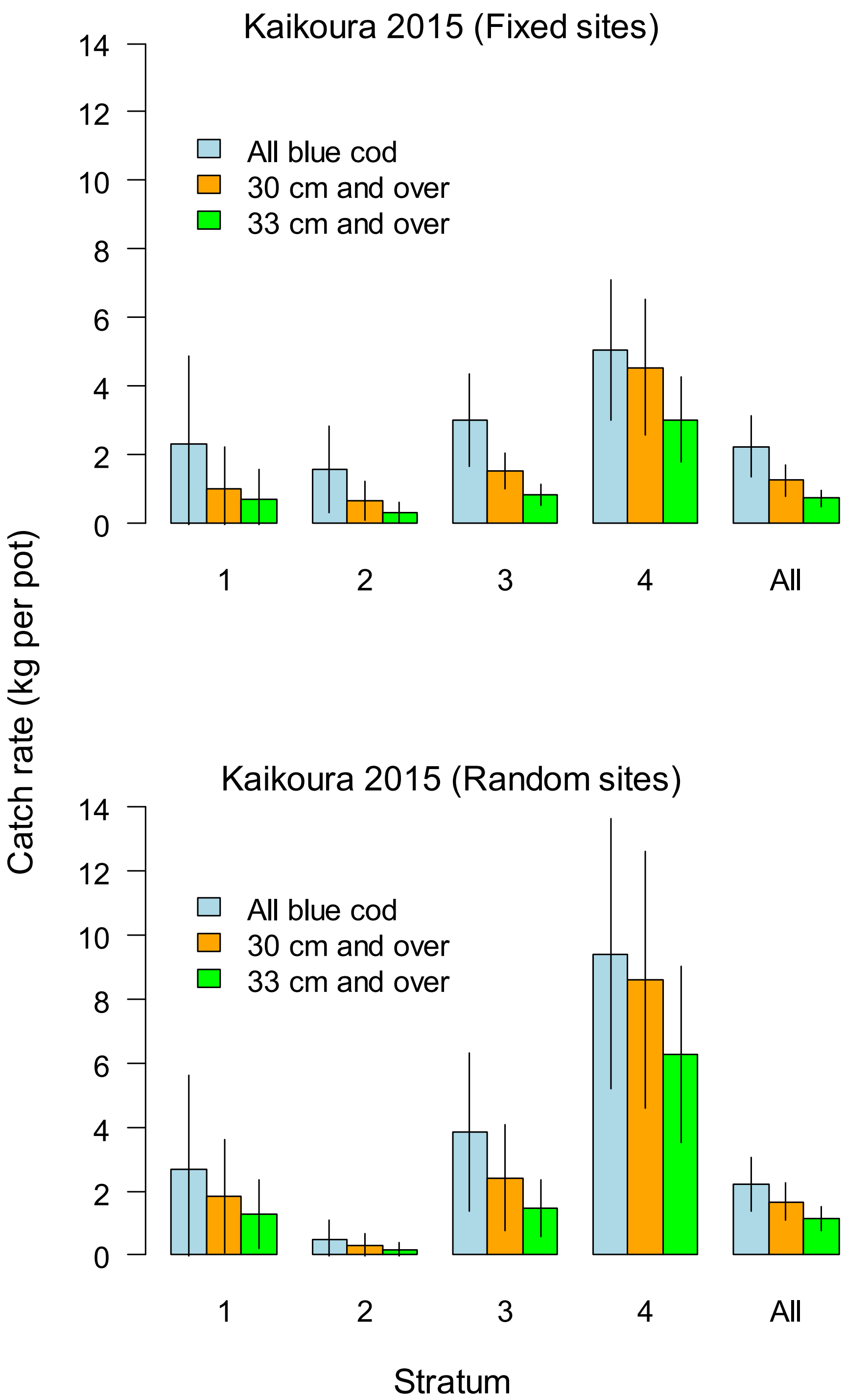

Figure 6: Catch rates (kg.pot^{-1}) of all blue cod and recruited blue cod (30 cm and over, and 33 cm and over) for the 2015 Kaikoura fixed site (top panel) and random site (bottom panel) surveys. Error bars are 95% confidence intervals. The y-axis scales are different for fixed and random sites graphs.

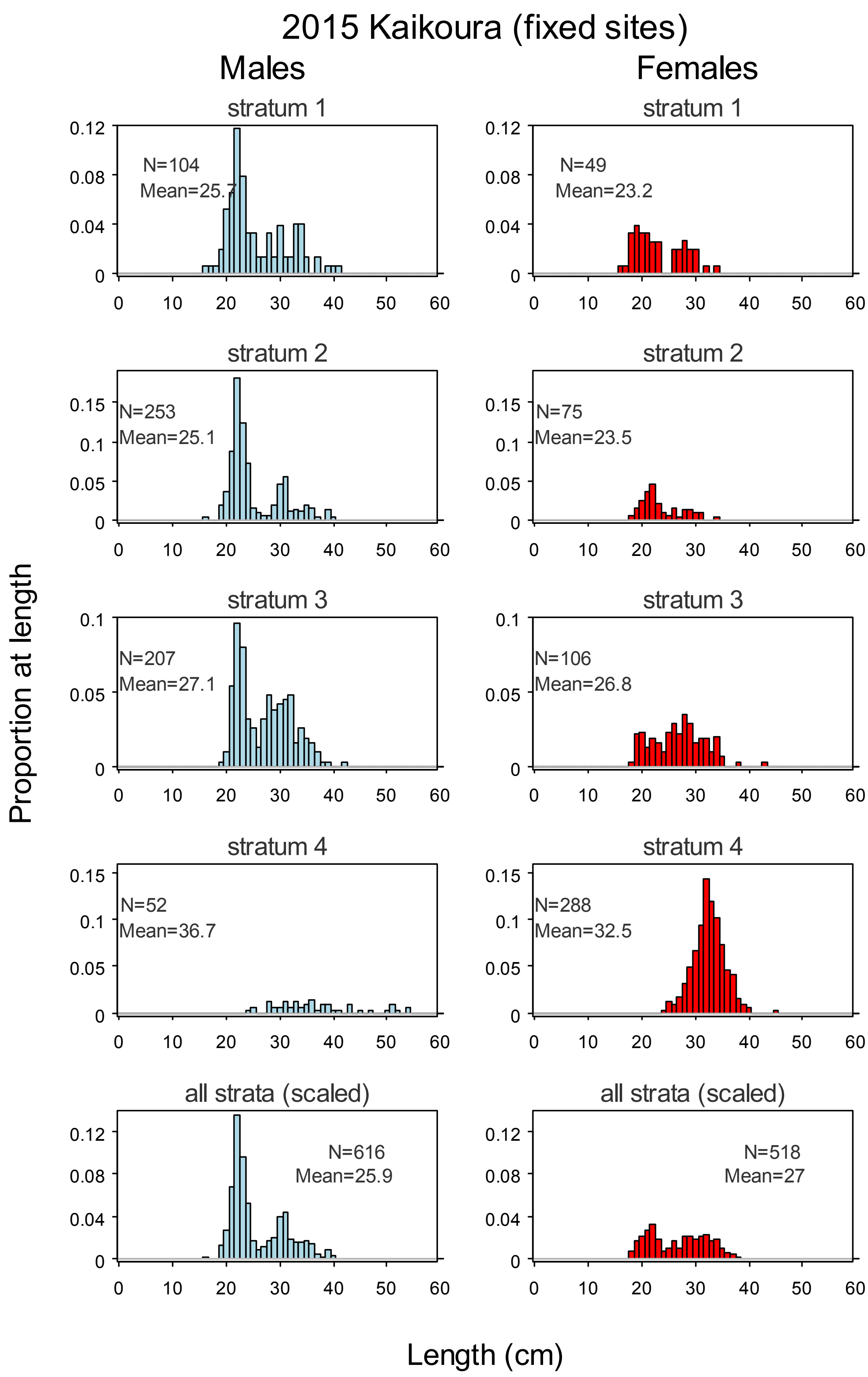

Figure 7: Scaled length frequency distributions by strata and overall for the 2015 Kaikoura fixed site potting survey. Two unsexed fish in stratum 4 are not shown (33.5 cm and 38.2 cm). N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum.

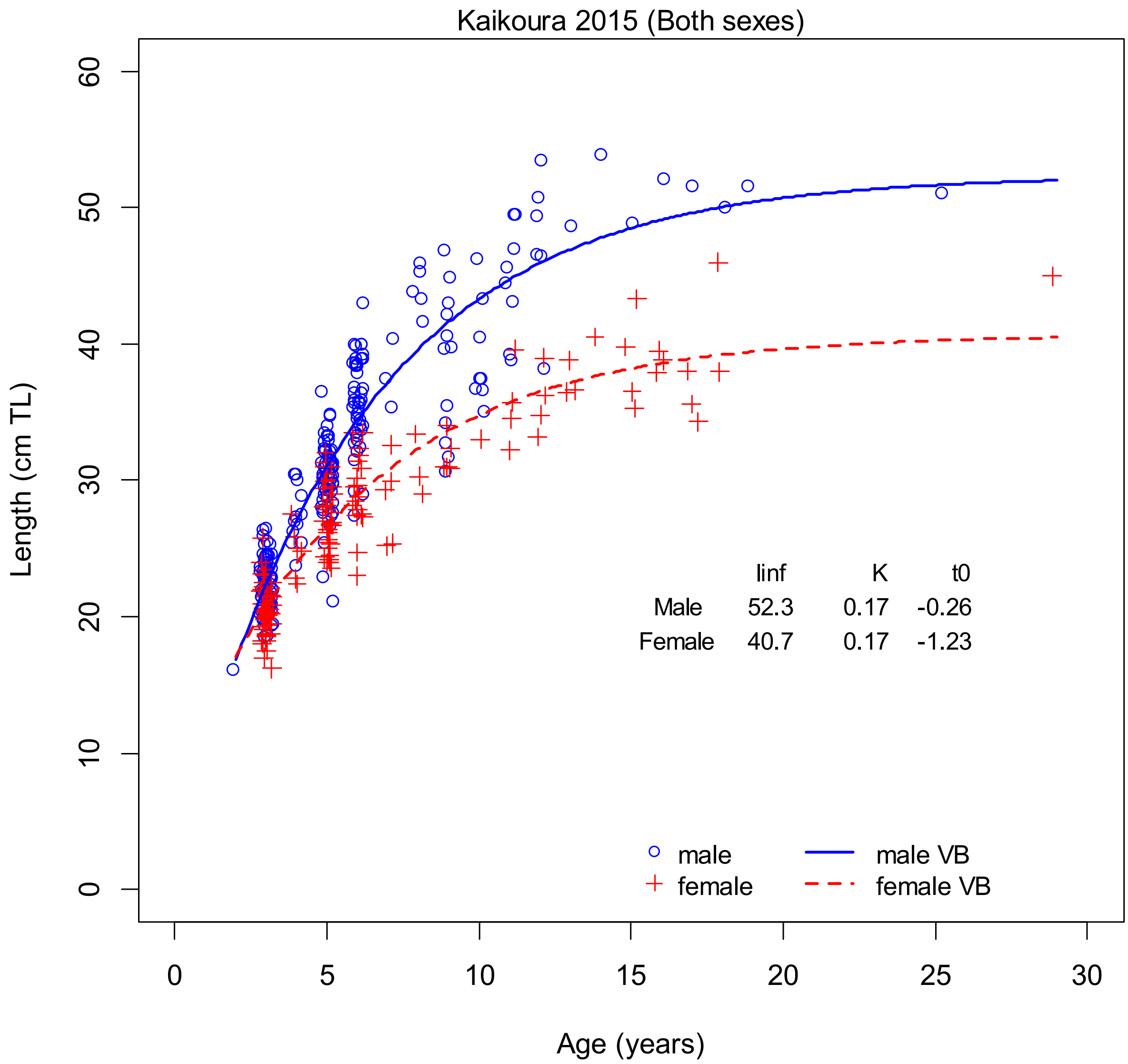

Figure 8: Observed blue cod age and length data by sex for the 2015 Kaikoura survey with von Bertalanffy (VB) growth models fitted to the data. N= 229 males and 146 females.

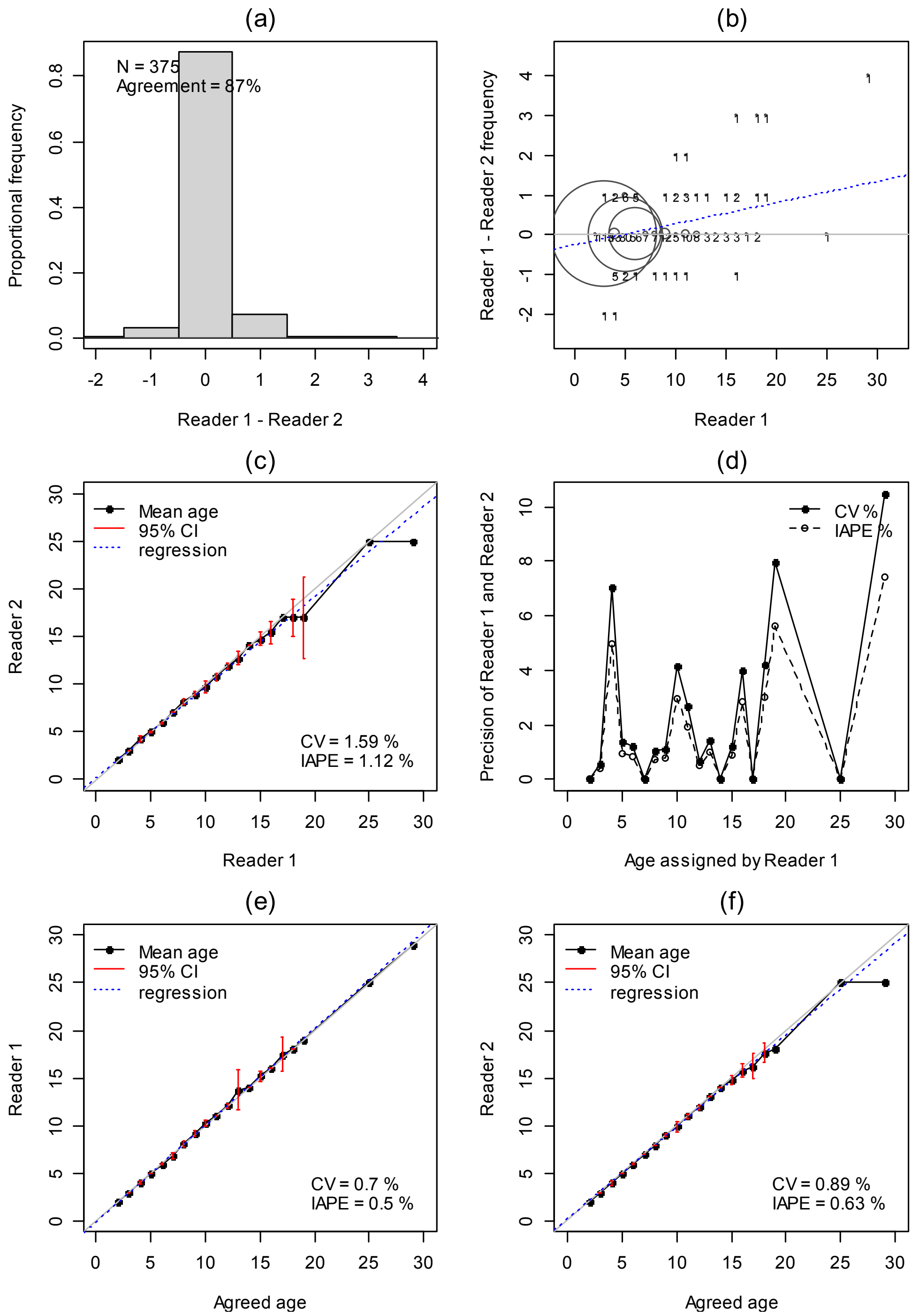

Figure 9: Blue cod age otolith reader comparison plots between reader 1 and reader 2 for the 2015 Kaikoura survey: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age bin 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.

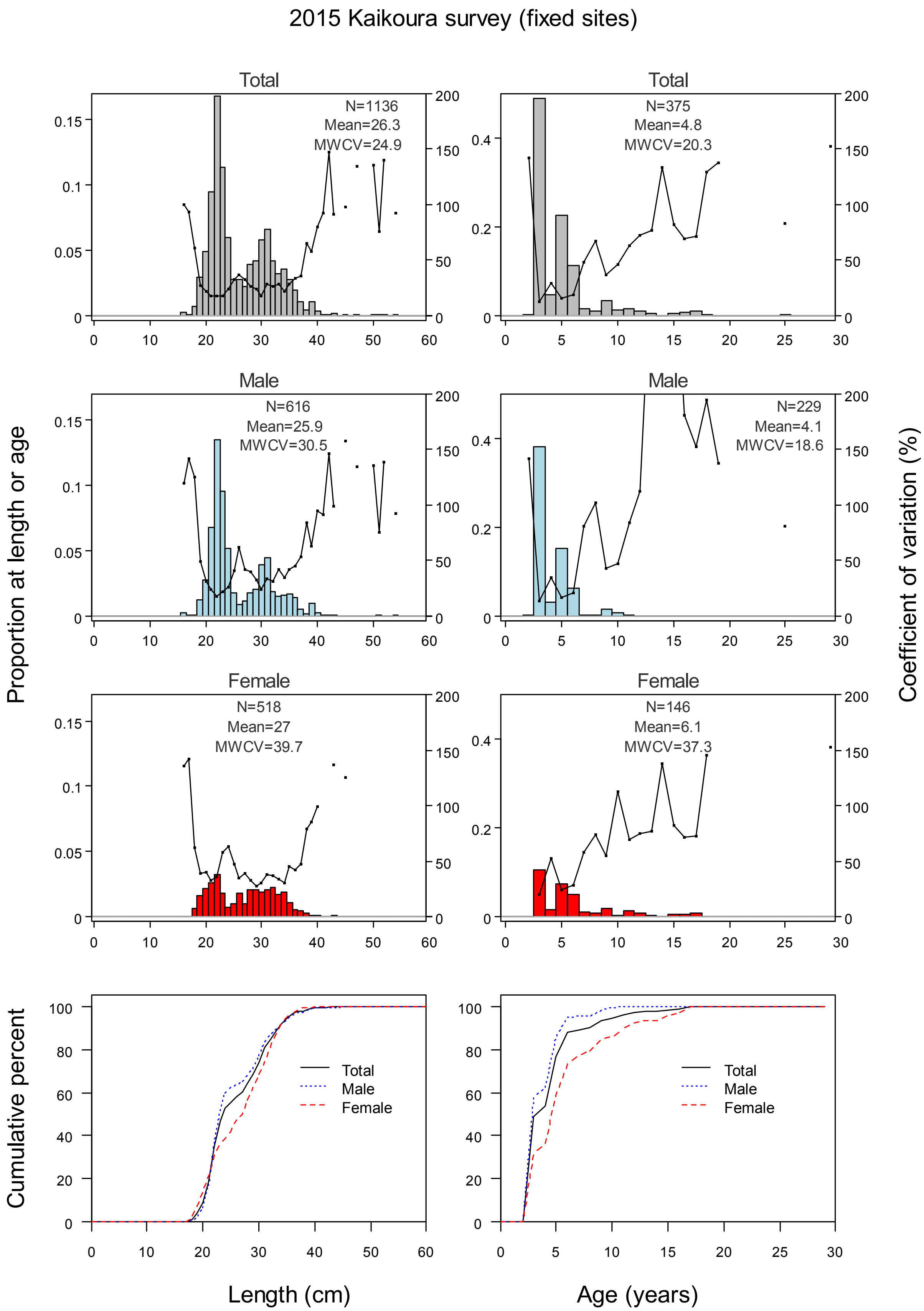

Figure 10: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2015 Kaikoura fixed site blue cod potting survey (N, sample size; MWCV, mean weighted coefficient of variation.

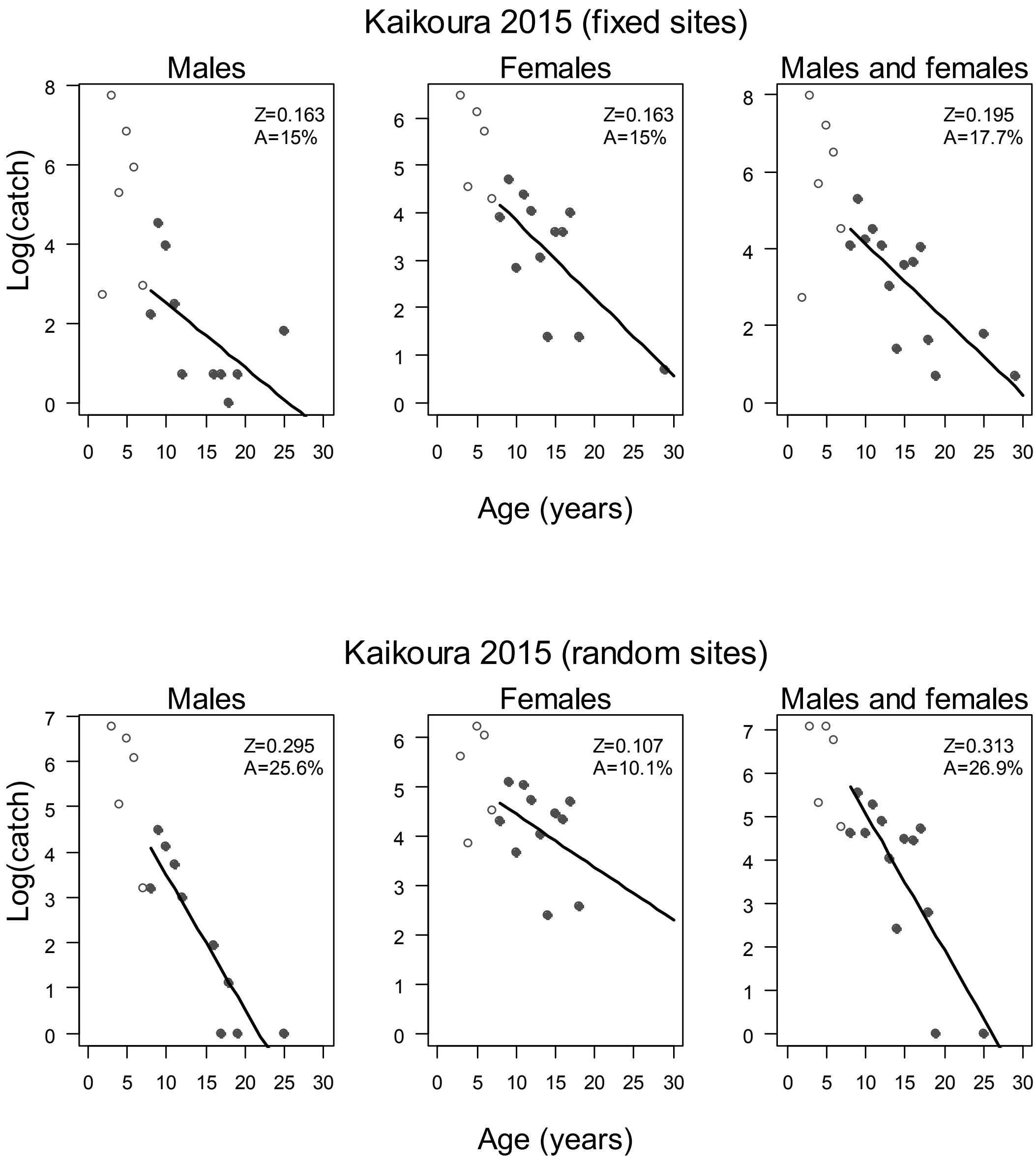

Figure 11: Kaikoura 2015 fixed site (top panel) and random site (bottom panel) survey catch curves (natural log of catch numbers versus age). The regression line is plotted from age at full recruitment of 8 years (i.e., dark points on the graph). Z, instantaneous total mortality; A, the annual mortality rate or the proportion of the population that suffers mortality in a given year.

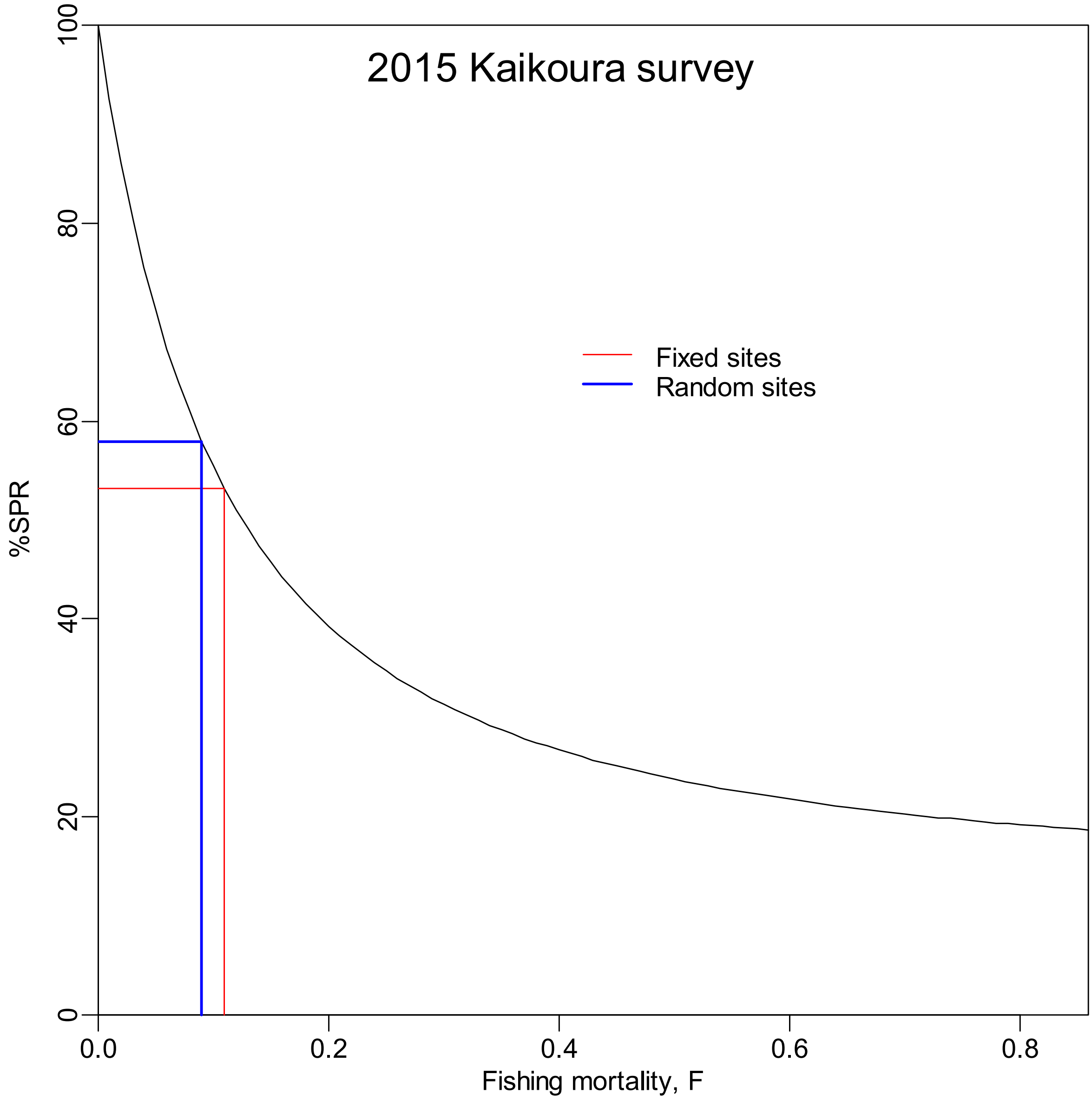

Figure 12: Spawner-per-recruit (SPR) as a function of fishing mortality (*F*) for 2015 Kaikoura fixed and random site surveys. The %SPR is 53.1% corresponding to the *F* value of 0.11 for fixed sites, and 57.9% and 0.09 for random sites, respectively. In this plot *M* = 0.14, and *F* value is for age of full recruitment equal to 8 years for females.

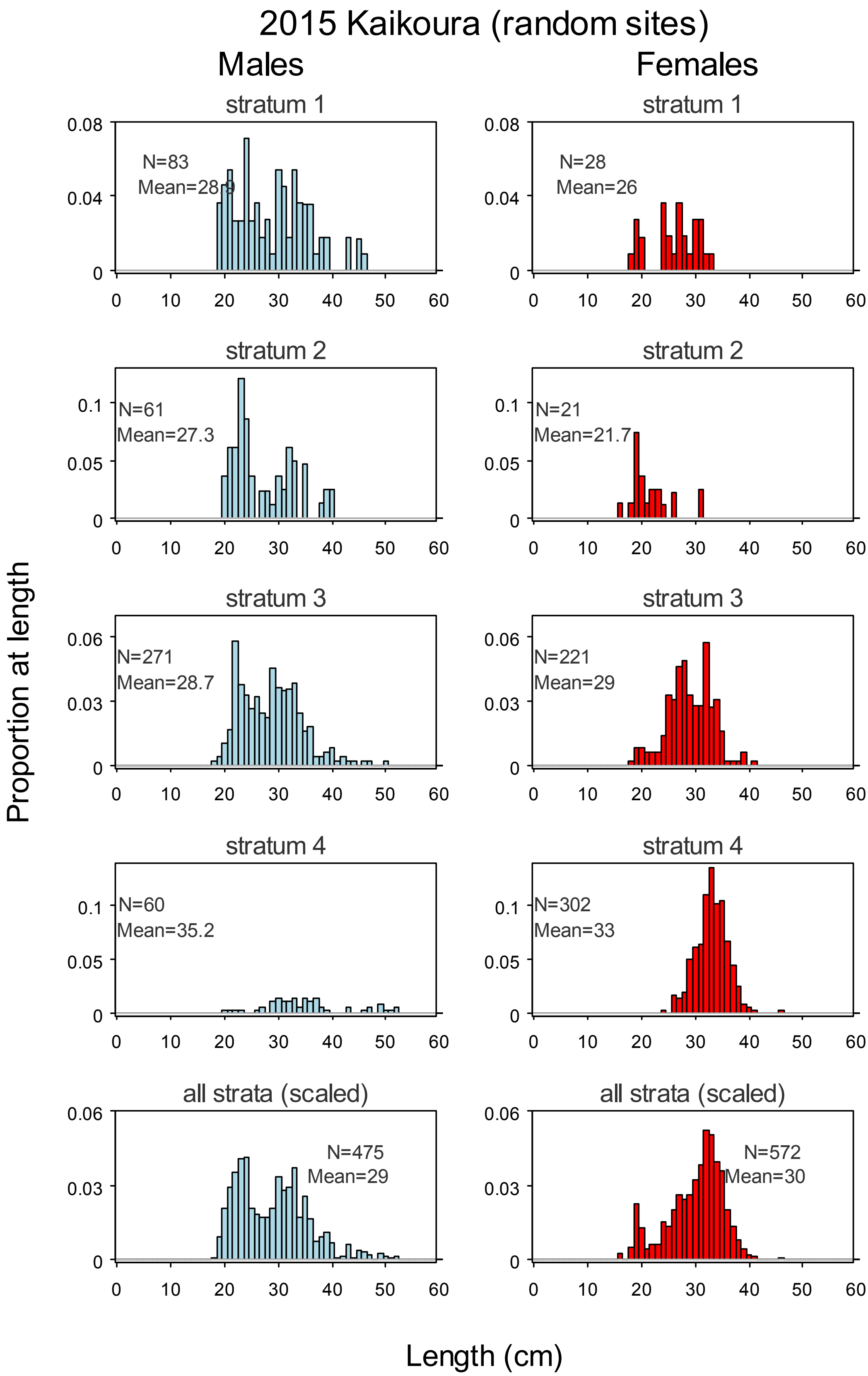

Figure 13: Scaled length frequency distributions by strata and overall for the 2015 Kaikoura random site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum.

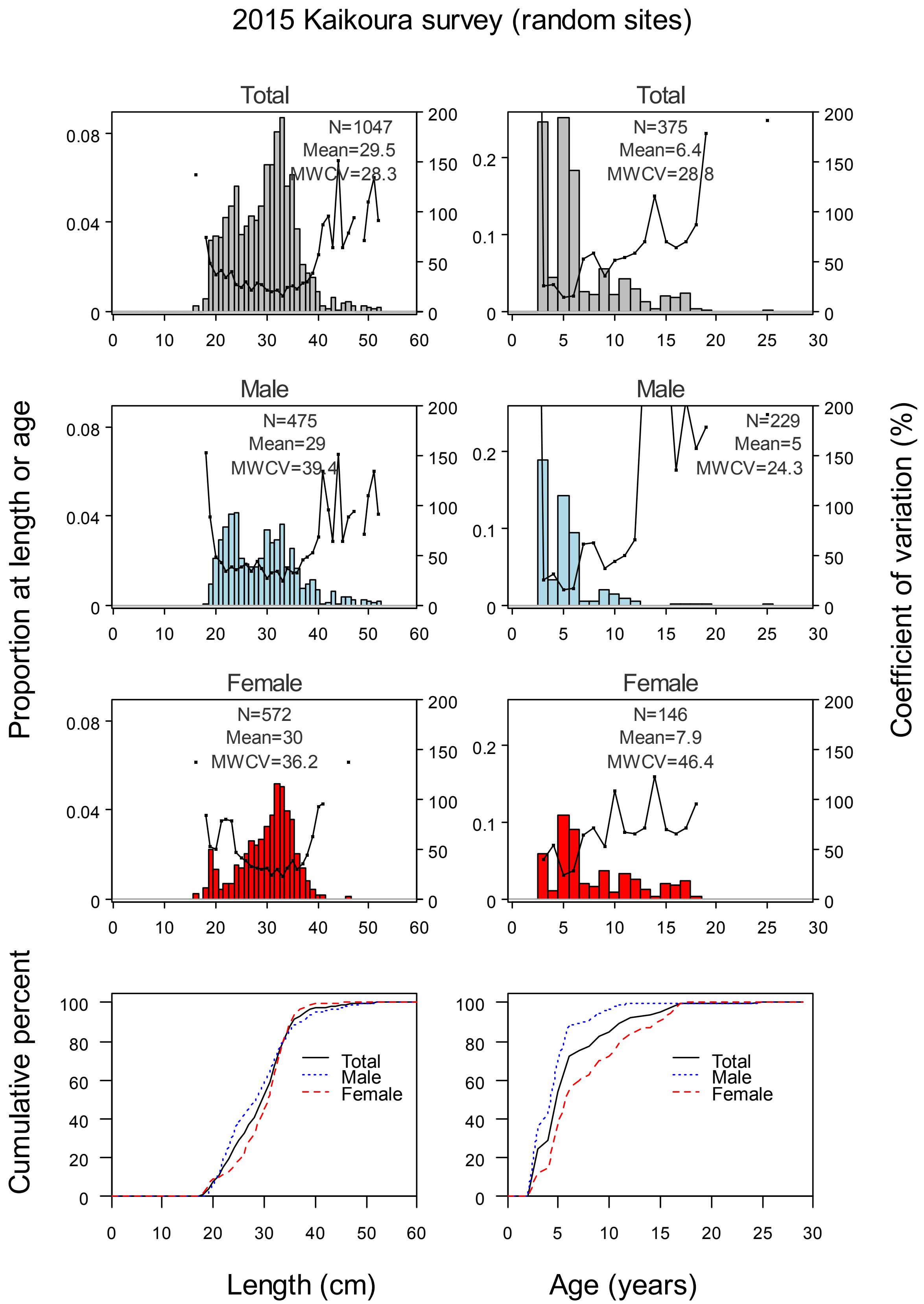

Figure 14: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2015 Kaikoura random site blue cod potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

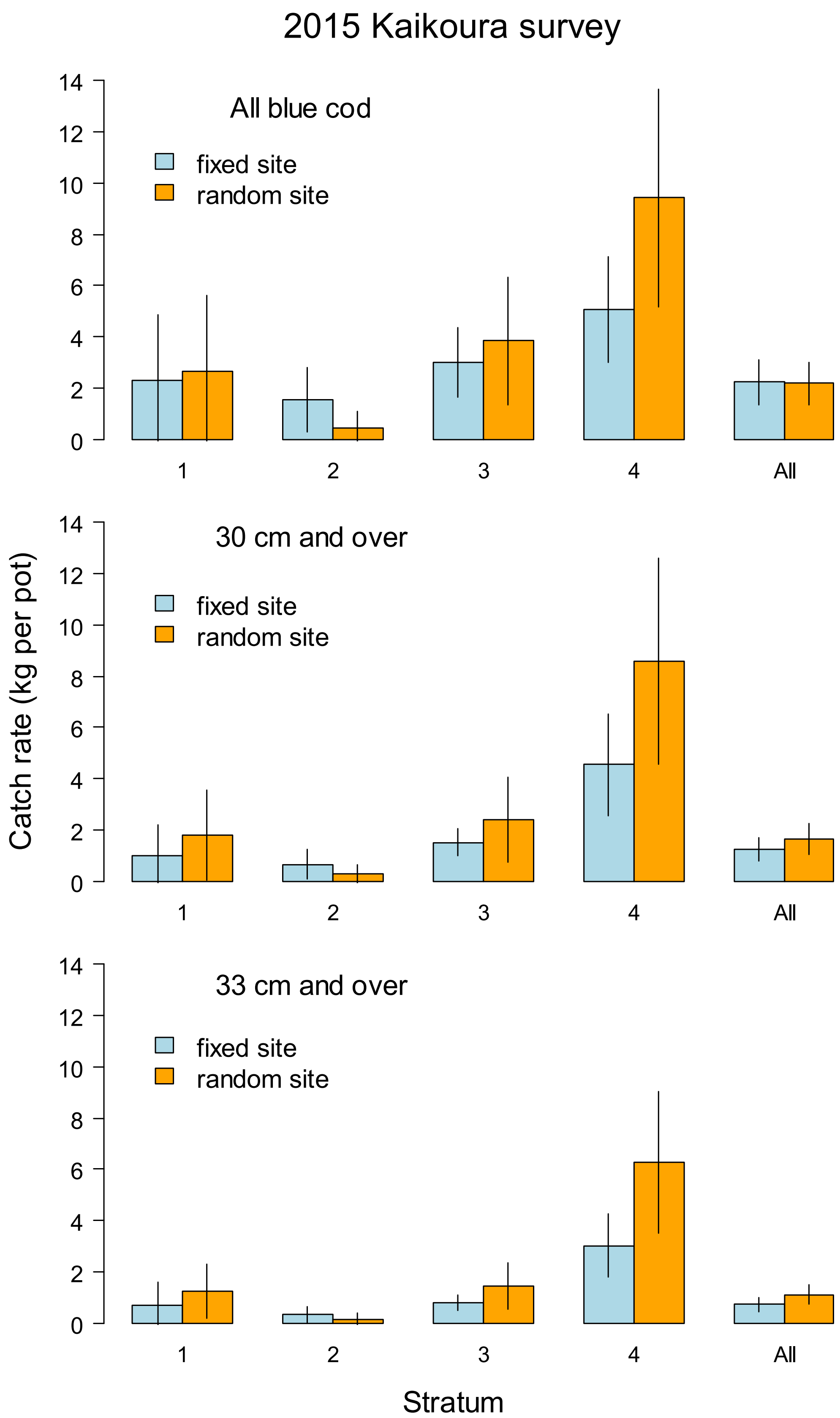

Figure 15: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and recruited (30 cm and over, middle panel; 33 cm and over, bottom panel) for the 2015 Kaikoura fixed and random site surveys. Error bars are 95% confidence intervals.

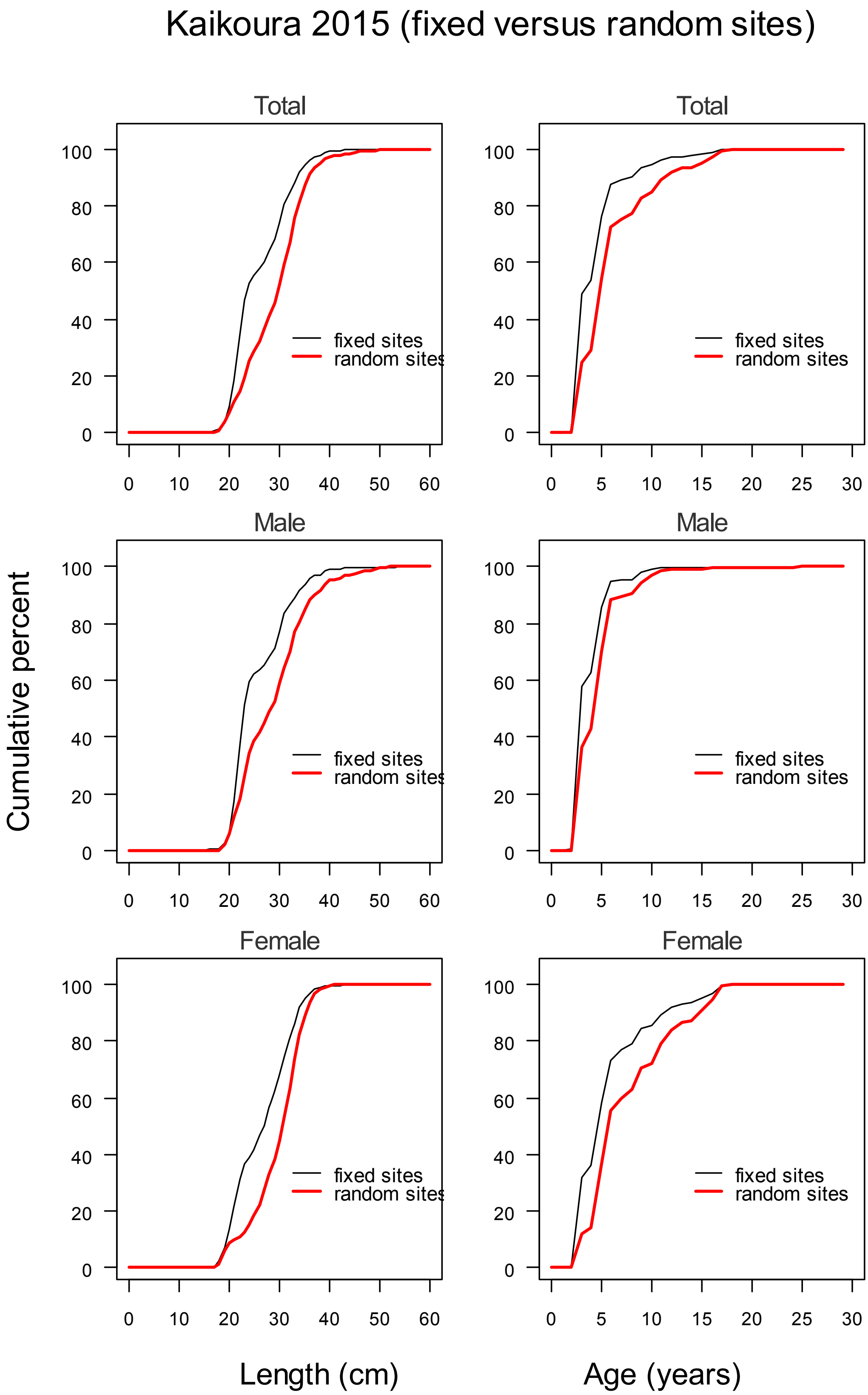

Figure 16: Cumulative distributions of scaled length and age frequencies for total, male, female, and unsexed blue cod from the 2015 Kaikoura blue cod fixed site and random site potting surveys.

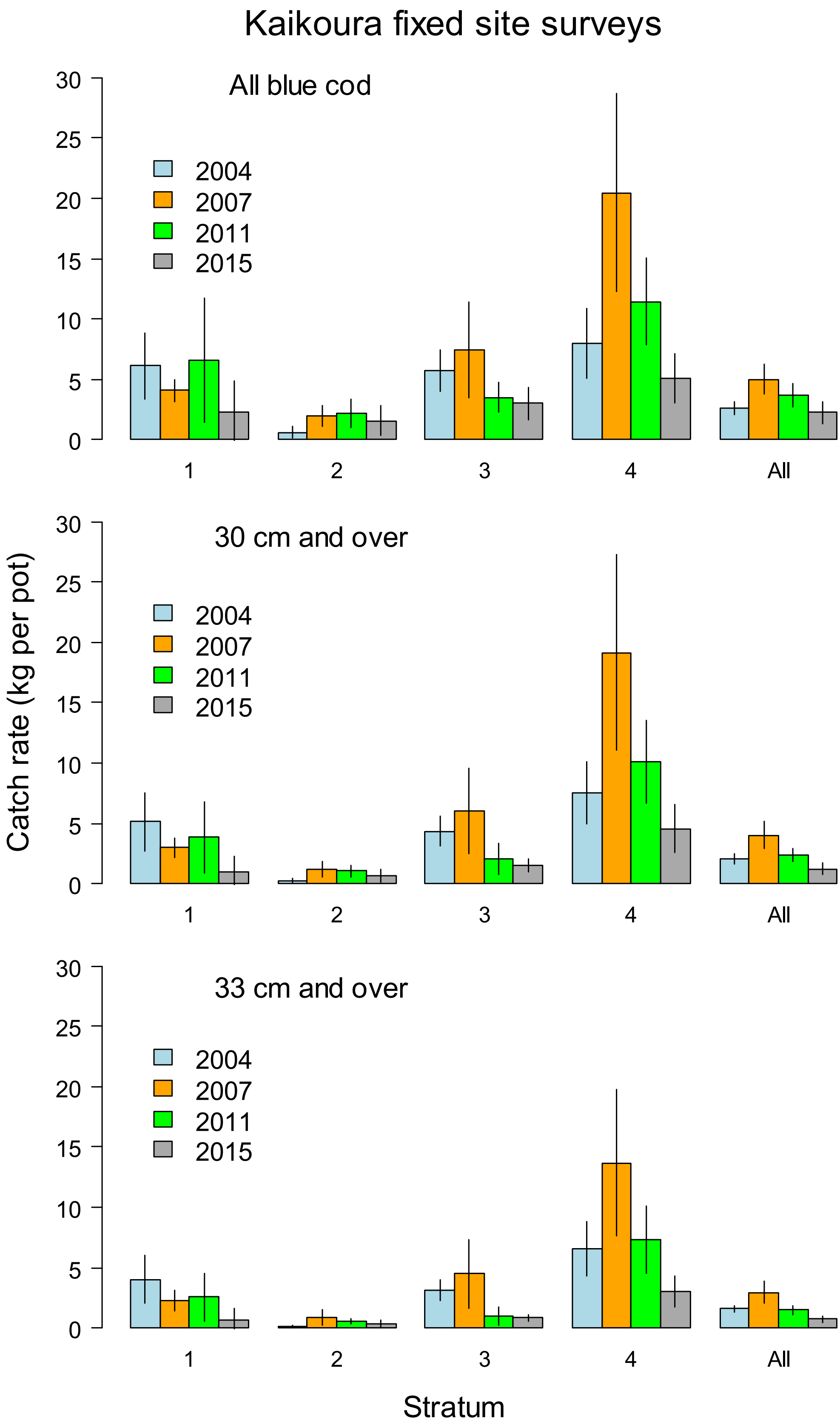

Figure 17: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and for recruited blue cod (30 cm and over, middle panel; 33 cm and over, bottom panel) for the Kaikoura fixed site potting surveys in 2004, 2007, 2011, and 2015. Error bars are 95% confidence intervals.

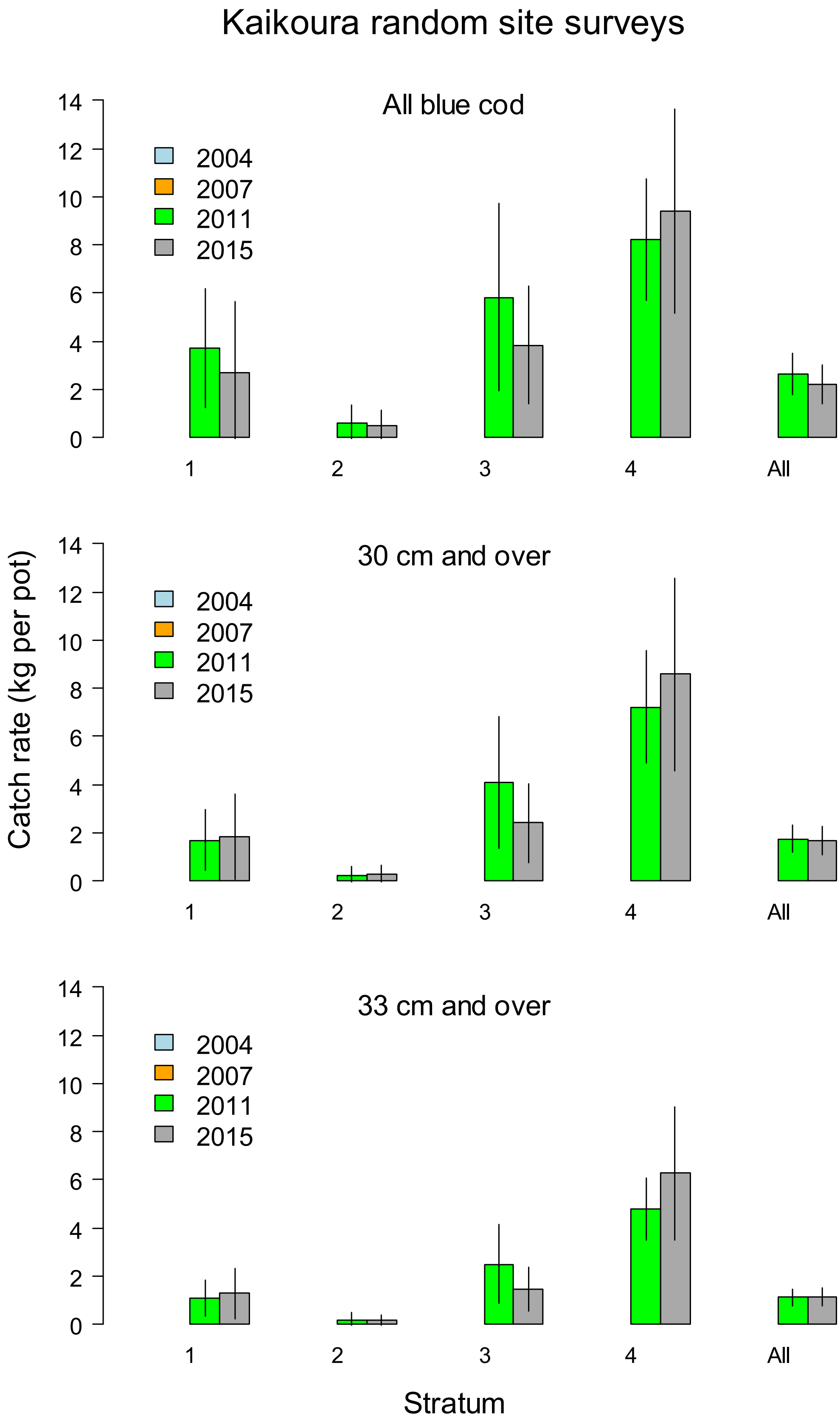

Figure 18: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and for recruited blue cod (30 cm and over, middle panel; 33 cm and over, bottom panel) for the Kaikoura fixed site potting surveys in 2011 and 2015. There were no random site surveys in 2004 and 2007. Error bars are 95% confidence intervals.

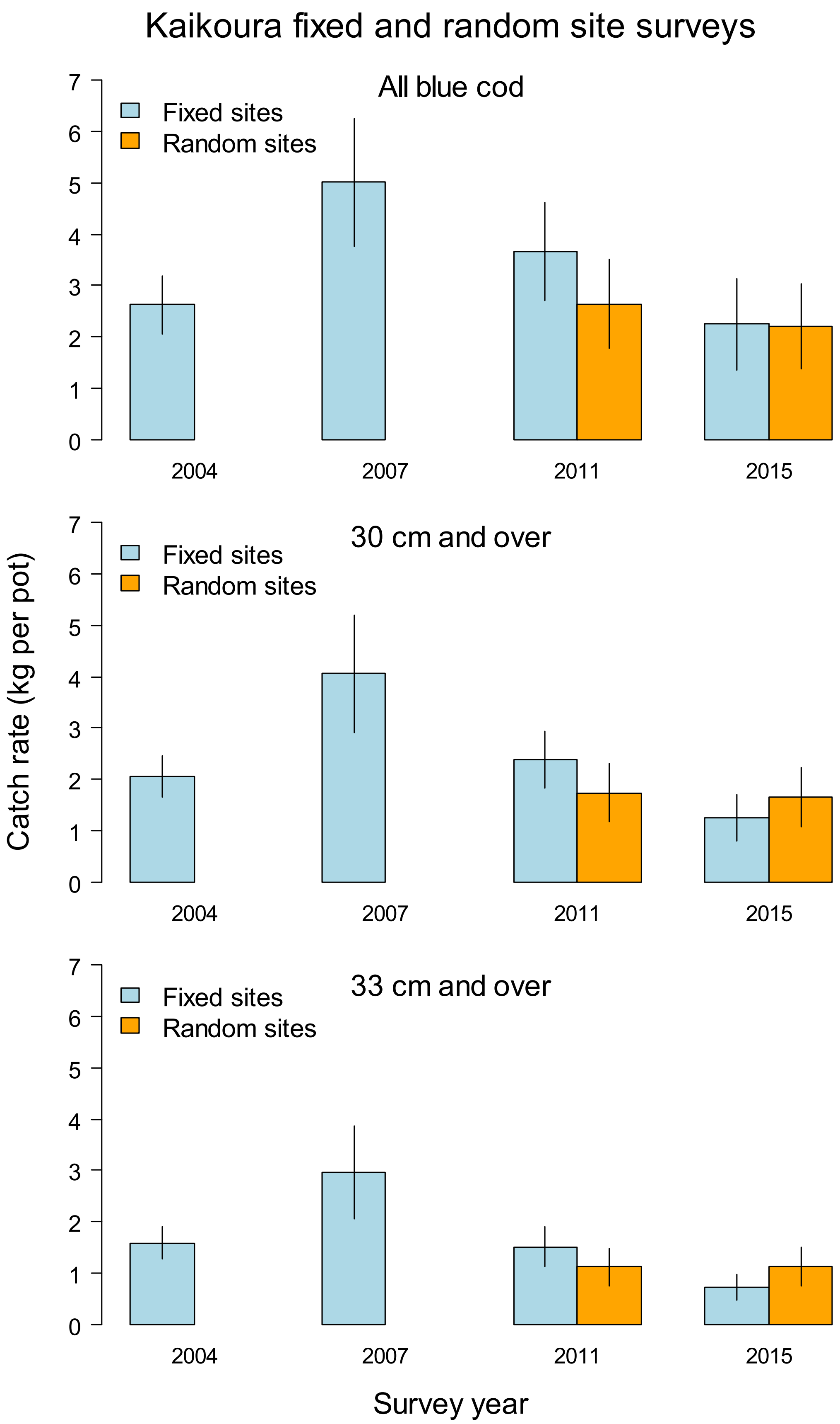

Figure 19: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and for recruited (30 cm and over, middle panel; 33 cm and over, bottom panel) for the Kaikoura fixed site potting surveys in 2004, 2007, 2011, and 2015; and random site surveys in 2011 and 2015. Error bars are 95% confidence intervals

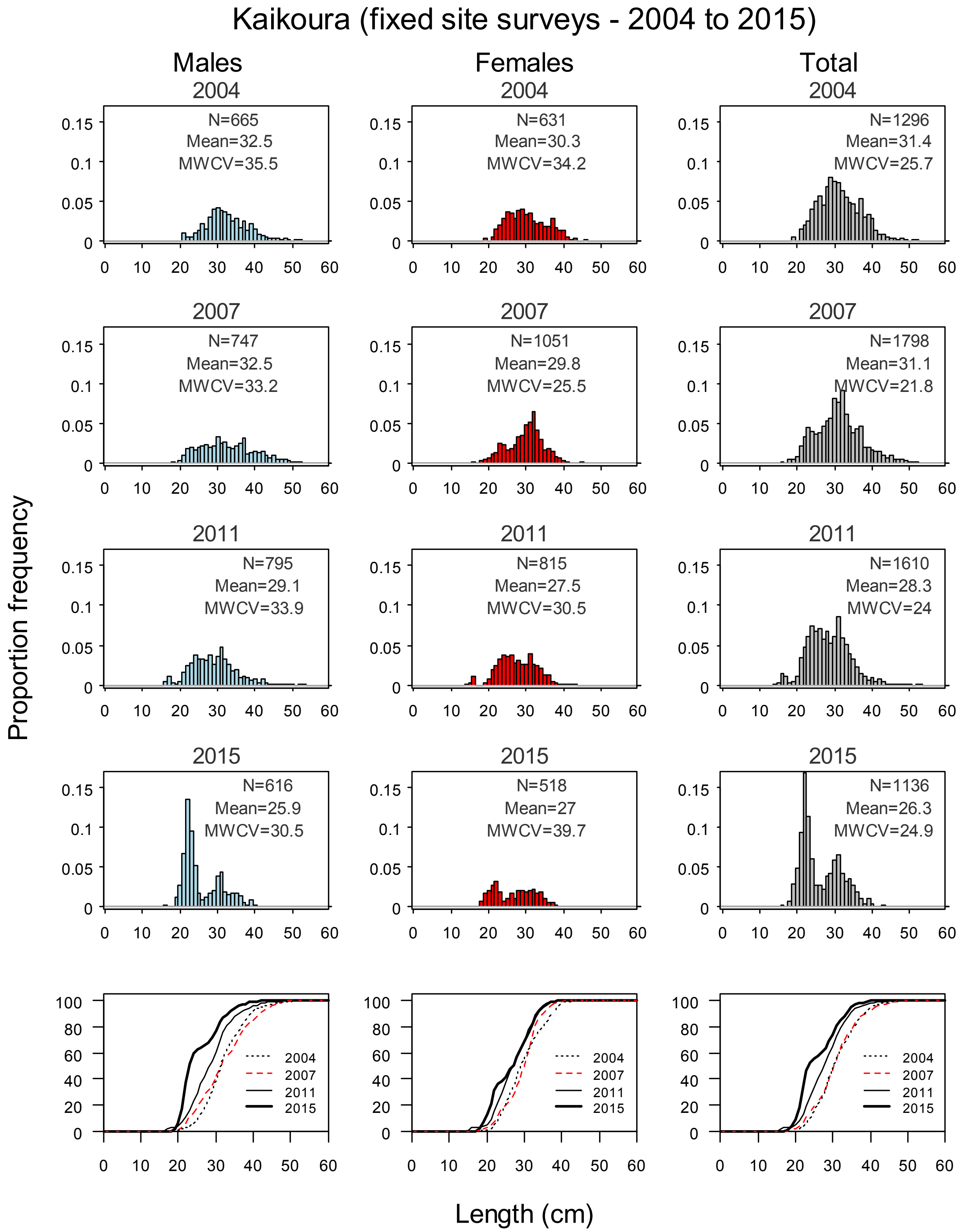

Figure 20: Scaled length frequency and cumulative distributions of scaled length frequencies for total, male, and female blue cod from Kaikoura fixed site blue cod potting surveys in 2004, 2007, 2011, and 2015. N, sample numbers; Mean, mean length (cm).

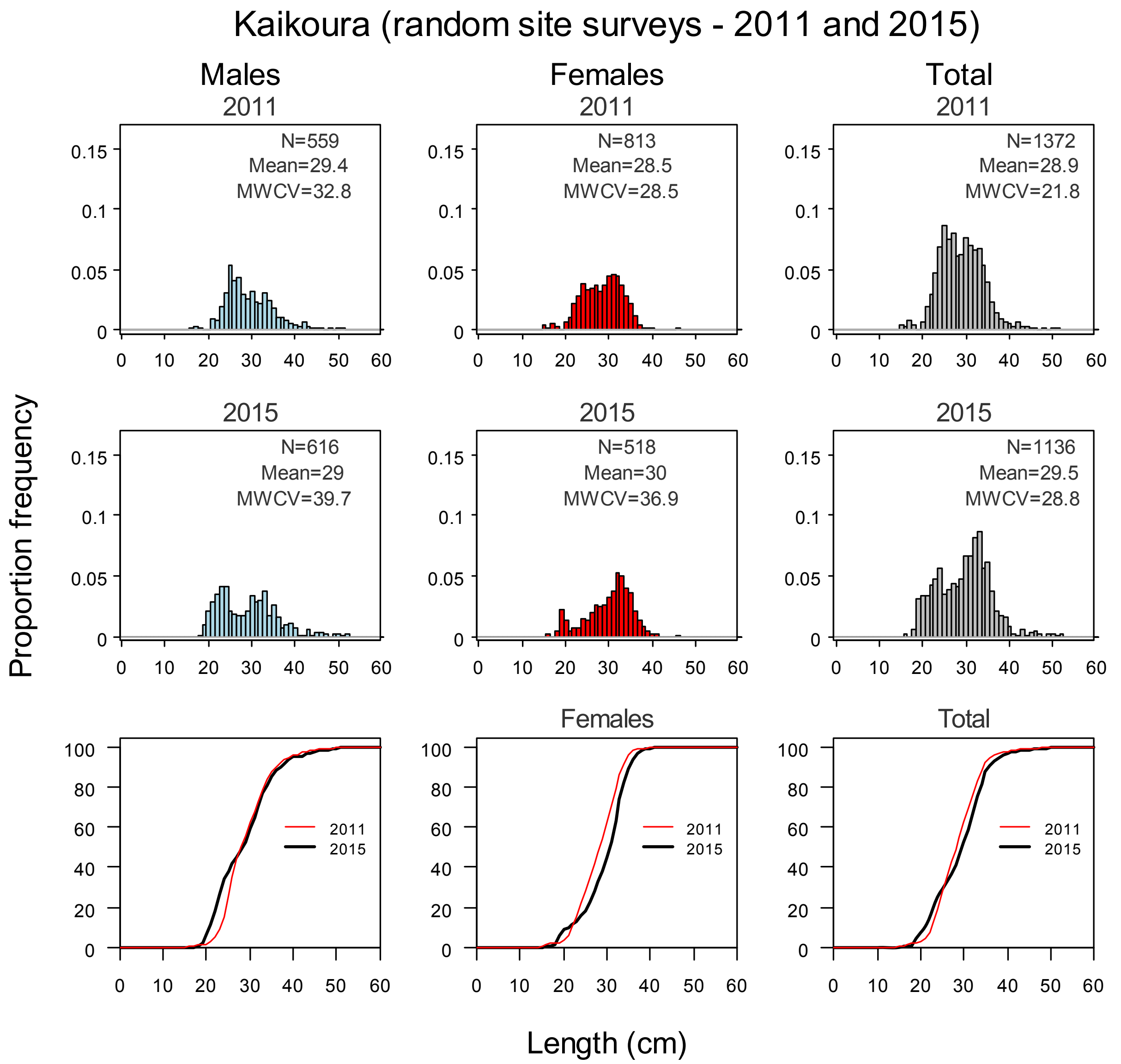

Figure 21: Scaled length frequency and cumulative distributions of scaled length frequencies for total, male, and female blue cod from Kaikoura random site blue cod potting surveys in 2011 and 2015. N, sample numbers; Mean, mean length (cm).

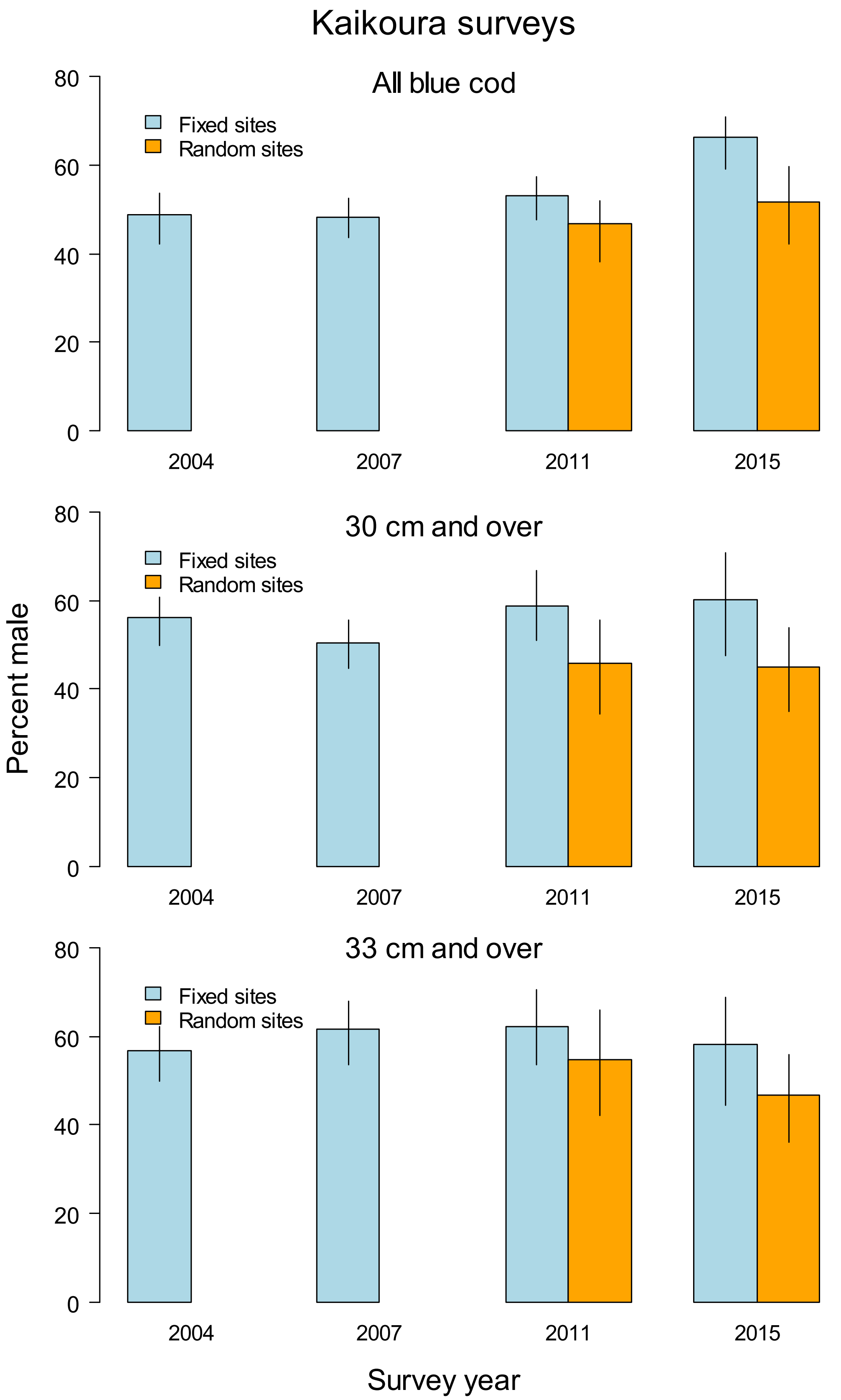

Figure 22: Sex ratio (percent male) of scaled length frequencies of all blue cod (top panel) and recruited blue cod (30 cm and over, middle panel; 33 cm and over, bottom panel) for the Kaikoura fixed site potting surveys in 2004, 2007, 2011, and 2015; and random site potting surveys in 2011 and 2015. Error bars are 95% confidence intervals.

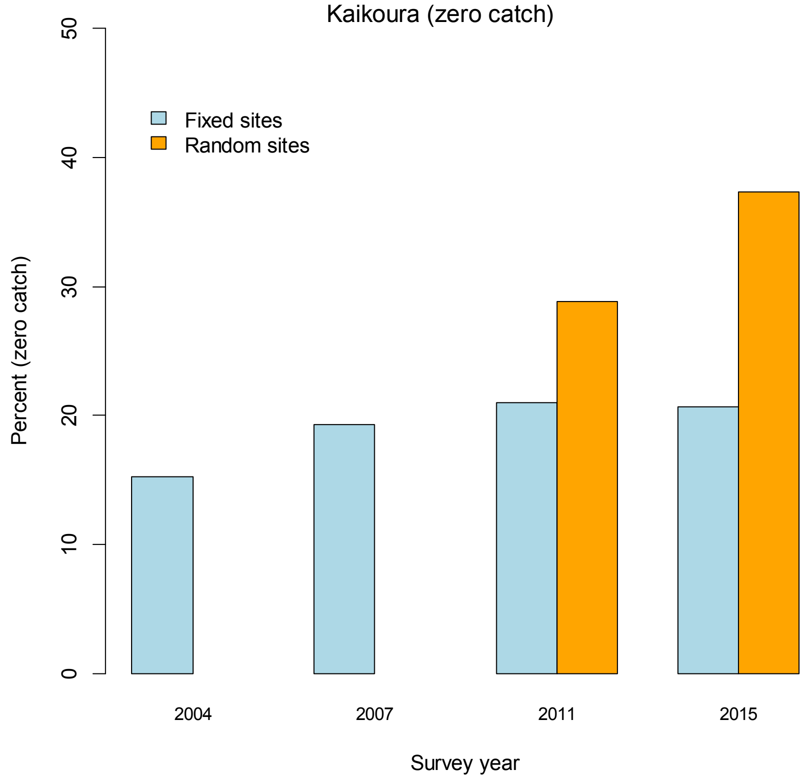

Figure 23: Proportion of pots with no blue cod catch for the Kaikoura fixed site potting surveys in 2004, 2007, 2011, and 2015; and random site potting surveys in 2011 and 2015. N= 150 pots for each survey.

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 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 the Marlborough Sounds 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 300 m to the north of the site location and remaining pots are set in a hexagon pattern around the site, at about 300 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 2. Numbers of otoliths collected during the 2015 Kaikoura survey for males and females, by strata and length class. Lgth, length.

	Males					Females				
	Strata					Strata				
Lgth (cm)	1	2	3	4	Male totals	1	2	3	4	Female totals
16		1			1		1			1
17						1	1			2
18		2			2		5	2		7
19	2	3			5		4	2		6
20		2	5	1	8	2	10	5		17
21	1	8	3	2	14		4	3		7
22	1	7	1	1	10	2	2	2		6
23	2	6	5	1	14		3	2		5
24	1	4	4		9	2	2	2	2	8
25		3	2	1	6	2	4	3		9
26	2	1	3		6	1	1	4	1	7
27		3	4	1	8	1	2	3	2	8
28	1	4	2		7	1	2	3		6
29	1	3	4	2	10	2	2	2	2	8
30	2	7	2	1	12		4	3		7
31		10	3	1	14	2	3	1	1	7
32	1	4	4	1	10	2		2	1	5
33	1	4	3		8	1	1	2	2	6
34	2	4	2	1	9				4	4
35		5	5	2	12				3	3
36	3	1	1	2	7				4	4
37	1		2	1	4				1	1
38	2	4		2	8				4	4
39		4	2	2	8				4	4
40	2	2	1	1	6				1	1
41			1		1					
42			1		1					
43	2		1	3	6			1		1
44	1			1	2					
45	2			1	3				1	1
46			2	2	4				1	1
47				1	1					
48				2	2					
49			1	2	3					
50				2	2					
51				3	3					
52				1	1					
53				2	2					
Totals	30	92	64	43	229	19	51	42	34	146