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Relative abundance, size and age structure, and stock status of blue cod off Banks Peninsula in 2016

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M.P. Beentjes
M. Fenwick

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Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

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EXECUTIVE SUMMARY

Beentjes, M.P.; Fenwick, M. (2017). Relative abundance, size and age structure, and stock status of blue cod off Banks Peninsula in 2016.

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This report describes the results of blue cod (*Parapercis colias*) fixed and random site potting surveys carried out concurrently off Banks Peninsula in April 2016. Surveys were split into separate inshore and offshore areas. Estimates are provided for population abundance, size and age structure, sex ratio, total mortality (*Z*), and spawner-per-recruit. This is the fifth survey in the fixed site survey time series following surveys in 2002, 2005, 2008, and 2012; and the second random site survey, with the previous survey carried out in 2012.

Otolith thin section ages from 207 males and 97 females (inshore), and 256 males and 197 females (offshore) were used to estimate the population age structure with separate age-length keys for males and females, and inshore and offshore. Two readers achieved agreement on 83% of read otoliths, and overall there was no bias between readers with a CV of 1.9% and average percent error (APE) of 1.3%. Low maximum ages (8 years for males and 6 years for females) for inshore strata gave improbable von Bertalanffy (VB) parameters, especially L_∞, so the combined inshore and offshore VB parameters were used in estimating spawner-per-recruit ratios.

There was no clear indication of spawning activity during the survey period (fixed and random sites).

2016 fixed site survey

Forty fixed sites (6 pots per site, 240 pot lifts) at depths of 8–90 m from five inshore and two offshore strata off Banks Peninsula were surveyed in April 2016.

Inshore–mean catch rates of blue cod (all sizes) by stratum were 0.6–2.1 kg.pot^{-1} and the survey mean catch rate for all blue cod was 1.26 kg.pot^{-1} with a CV of 12%. Mean catch rates for recruited blue cod (30 cm and over) followed the same pattern among strata as for all blue cod, and overall was 0.4 kg.pot^{-1} (CV 26%). The sex ratios were 65–72% male across the five strata and the overall weighted sex ratio was 67% male. The overall weighted mean length for males was 26.5 cm (range 14–43 cm) and 23.3 cm for females (range 14–50 cm). Scaled length frequency distributions for both males and females were unimodal with strong juvenile modes at about 25 and 23 cm respectively, and skewed to the right. Age estimates were 1–8 years for males and 1–6 years for females, but 82% of fish were three years old. The estimated population age distributions indicate virtual knife-edge selectivity to the pot method at three years with mean age 3.3 years for males and 3.2 years for females. Total mortality estimate (*Z*) for age-at-full recruitment of six years was 1.87. Based on the default *M* of 0.14, estimated fishing mortality (*F*) was 1.73 and associated spawner biomass per recruit ratio was 4.7%.

Offshore–mean catch rates of blue cod (all sizes) by stratum were 5.1–6.1 kg.pot^{-1} and the survey mean catch rate for all blue cod was 5.6 kg.pot^{-1} with a CV of 14%. Mean catch rates for recruited blue cod (30 cm and over) followed the same pattern among strata as for all blue cod, and overall was 5.2 kg.pot^{--1} (CV 15%). The sex ratios were 61–69% male across the two strata and the overall weighted sex ratio was 65% male. The overall weighted mean length for males was 36.8 cm (range 20–55 cm) and 33.6 cm for females (range 19–50 cm). Scaled length frequency distributions for both males and females showed no clear modes, with a wide size range. Age estimates were 3–27 years for males and 3–29 years for females, but most fish were less than eleven years old. The estimated population age distributions indicate virtual knife-edge selectivity to the pot method at three years with mean age 7.6 years for males and 9.2 years for females. The total mortality estimate (*Z*) for age-at-full recruitment of six years was 0.26. Based on the default *M* of 0.14, estimated fishing mortality (*F*) was 0.12 and associated spawner biomass per recruit ratio was 40.7%.

2016 random site survey

Forty random sites (6 pots per site, 240 pot lifts) at depths of 5–93 m from five inshore and two offshore strata off Banks Peninsula were surveyed in April 2016.

Inshore–mean catch rates of blue cod (all sizes) by stratum were 0.09–0.94 kg.pot^{-1} and the survey mean catch rate for all blue cod was 0.53 kg.pot^{-1} with a CV of 22%. Mean catch rates for recruited blue cod (30 cm and over) followed the same pattern among strata as for all blue cod, and overall was 0.11 kg.pot^{-1} (CV 37%). The sex ratio was 42–88% male across the five strata and the overall weighted sex ratio was 81% male. The overall weighted mean length for males was 26.1 cm (range 14–41 cm) and 23.8 cm for females (range 14–30 cm). The scaled length frequency distributions were similar among strata with males dominating, and a mode around 25 cm. Age estimates were 1–8 years for males and 1–6 years for females, but 83% of fish were three years old. The estimated population age distributions indicate virtual knife-edge selectivity to the pot method at three years with mean age 3.3 years for males and 3.2 years for females. Total mortality estimate (Z) for age-at-full recruitment of six years was 2.24. Based on the default M of 0.14, estimated fishing mortality (F) was 2.10 and associated spawner biomass per recruit ratio was 4.3%.

Offshore–mean catch rates of blue cod (all sizes) by stratum were 4.5–5.2 kg.pot^{-1} and the survey mean catch rate for all blue cod was 5.1 kg.pot^{-1} with a CV of 19%. Catch rates for recruited blue cod (30 cm and over) followed the same pattern among strata as for all blue cod and overall was 4.9 kg.pot^{-1} (CV 19%). The weighted sex ratio was 42–60% male across the two strata and the overall weighted sex ratio was 57% male. The overall weighted mean length for males was 41.3 cm (range 20–57 cm) and 36.1 cm for females (range 21–49 cm). The scaled length frequency distributions had a wide size range and with a male mode of about 25 cm. Age estimates were 3–27 years for males and 3–29 years for females, but most fish were less than eleven years old. The estimated population age distributions indicate virtual knife-edge selectivity to the pot method at three years with mean age 10.6 years for males and 9.6 years for females. Total mortality estimate (Z) for age-at-full recruitment of six years was 0.19. Based on the default M of 0.14, estimated fishing mortality (F) was 0.05 and associated spawner biomass per recruit ratio was 64.2%.

Comparison of fixed versus random site surveys

Catch rates of all blue cod from the 2016 random site inshore survey were considerably lower across all five strata and the survey catch rate was less than half that of fixed sites, with no overlap of confidence intervals. The CVs and associated confidence intervals were considerably larger for random sites from all strata and for the survey. The length and age distributions among the five inshore strata showed no differences. Sex ratios for fixed and random sites showed a similar pattern among strata, but the proportions of male were higher in random sites and for the survey (67% male for fixed sites and 81% for random sites).

Catch rates of all blue cod were similar for fixed and random site offshore surveys, between strata and surveys, with overlapping confidence intervals. The length distributions showed different patterns between fixed and random sites and blue cod males and females were larger and older from random sites. The all blue cod proportions male for the two strata and for the survey were higher for fixed sites (65% for fixed sites and 57% for random sites).

Summary

The very high estimate of total mortality, truncated age composition, and strongly skewed sex ratio toward males, indicates that the Banks Peninsula inshore blue cod population is over exploited and heavily depleted. Further, as nearly all females and most males caught will be of sub-legal size (less than 30 cm), there is also likely to be substantial mortality through catch and return of undersize fish.

The offshore blue cod population in contrast to inshore had high catch rates, a wide size range of both males and females, a more balanced sex ratio, and are under-exploited relative to MPIs Bmsy proxy target.

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 Banks Peninsula in April 2016. These are the fifth in the time series with previous surveys in 2002, 2005, 2008, and 2012 (Beentjes & Carbines 2003, 2006, 2009, Carbines & Haist 2017a)

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 in the northern part of BCO 3 Kaikoura and Motunau are important blue cod fisheries (Hart & Walker 2004) along with Banks Peninsula (Bell 1997). Further south, important recreational blue cod fisheries include Moeraki and Taieri Mouth.

The commercial catch in BCO 3 is 40–50% higher than the recreational catch with between 166 and 183 t caught 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 recreational minimum legal size (MLS) and maximum daily bag limit (MDL) varies geographically within BCO 3. Within the 'Kaikoura Marine Area' established in 2014 (extends from Clarence Point south to Conway River out to the territorial sea boundary, 12 n. miles), the MLS is 33 cm and the MDL is six blue cod. From Conway River to Waimakariri River, including Motunau, the MLS is 30 cm, and the MDL is 10 blue cod. For the rest of BCO 3, including Banks Peninsula but excluding the Akaroa Taiapure, the MLS is 30 cm and the MDL is 30 blue cod. Within the Akaroa Taiapure the MLS was 30 cm and the MDL 30 blue cod when it was established in 2006, but in 2009 the MDL was reduced to 3 blue cod.

There are two Department of Conservation marine reserves (MR) within the inshore survey area. Pohatu MR in Flea Bay established in 1999, and Akaroa MR established in 2014 (Figure 2). Pohatu MR was never included in the Ministry for Primary Industries (MPI) blue cod potting surveys which began in 2002, however, the area that is now Akaroa MR was included in all four surveys before 2016 within stratum 2.

1.2 Blue cod potting surveys

South Island recreational blue cod stocks are monitored using 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 off Banks Peninsula. 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 Bmsy 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 Banks Peninsula, there are currently seven other South Island areas surveyed, located in key recreational fisheries: North Canterbury including Kaikoura and Motunau (Carbines & Beentjes 2006a, 2009, Beentjes & Page 2017, Beentjes & Sutton 2017, Carbines & Haist 2017b), 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 Banks Peninsula 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 were 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 conducting both fixed and random site surveys allows comparison of catch rates, length and age composition, and sex ratios between the site type survey designs in the interim.

Banks Peninsula surveys were carried out in 2002, 2005, 2008, and 2012 (Beentjes & Carbines 2003, 2006, 2009, Carbines & Haist 2017a). The first three surveys used only fixed sites, whereas the 2012 survey also included concurrent random site surveys. The first three fixed site surveys were reanalysed in 2012 with catch-at-age, sex ratios, total mortality (Z), and spawner-per-recruit (SPR) estimates updated according to methods prescribed by the potting survey standards and specifications (Beentjes 2012).

1.4 Objectives

Overall Objective

To estimate relative abundance, sex ratio, and age structure of blue cod (*Parapercis colias*) around Banks Peninsula.

Specific objectives

1. To undertake a potting survey around Banks Peninsula 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 determine stock status of blue cod populations in this area, and compare this with other previous surveys in this area and other survey areas
4. To determine F_{MSY} proxies for Banks Peninsula blue cod.

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 blue cod potting survey off Banks Peninsula was carried out by the National Institute of Water & Atmospheric Research Ltd (NIWA) from 6 April to 1 May 2016, consistent with the previous survey dates.

2.2 Survey area

Fixed sites

The survey area for the 2016 fixed site survey was with the same as the previous surveys except that the Akaroa MR was excluded from stratum 2. The southern and northern boundaries of the survey area off Banks Peninsula were based on discussions with a commercial blue cod fisher in Akaroa and several charter boat operators that regularly fished in this area. Before the first survey in 2002 these fishers were given charts and asked to mark discrete locations around Banks Peninsula where blue cod are most commonly caught. The survey area selected was between Snuffle Nose in the south and Le Bon's Bay in the north, because outside this area water clarity is often poor and considered to reduce catches. The survey area adjacent to the coast was arbitrarily divided into five strata of similar size with boundaries often determined by headlands or bays (Figure 2). Discussions with fishers also indicated considerable recreational catch of blue cod was taken offshore in two large, but discrete areas of foul: Pompey's Rocks (20 km southeast of Pompey's Pillar), and Le Bon's Rocks (36 km east of Le Bon's Bay) (Figure 2).

The blue cod habitat adjacent to Banks Peninsula comprises a narrow band of foul extending out from the cliff faces and exposed headland reefs. It was assumed that this habitat band was reasonably constant in width and that the length of the coastline was proportional to the amount of blue cod habitat. Thus, the areas of the inshore strata were defined by the length of coastline (km). The areas of the two offshore strata (Le Bon's Rocks and Pompey's Rocks), however, could not be quantified in the same manner because they were discrete areas of foul (smaller than shown in Figure 2) (Beentjes & Carbines 2009). To make inshore and offshore strata comparable, the boundaries of both offshore strata were defined by rectangles (roughly equivalent to the size of the area of foul as estimated in 2002), each subdivided into 12 smaller rectangles (3 wide and 4 long) within which fixed sites were determined by the skipper during the first survey in 2002. The effective area of each offshore stratum was taken as three times the length of the longest side of each stratum. In this way, the foul was artificially divided into bands analogous to those of inshore strata and was also expressed in kilometres.

Each fixed site stratum was assumed to contain roughly random distributions of blue cod habitat and the total area (km) within each stratum was taken as a proxy for available habitat for blue cod.

Random sites

Inshore random site strata are polygons with the coastal boundary the same as the fixed site strata coastline and the offshore boundary about 500 m from shore, joined perpendicular to the shore where the strata meet, or at the ends of strata 1 and 5 (Figure 2). Similar polygons were used in the 2012 survey, but at the time these were not digitised, and Akaroa MR was included in stratum 2 (Carbines & Haist 2017a). As part of the 2016 survey design the random site strata polygons were formally digitised and converted into shape files. Offshore random site strata were mapped before the 2012 survey using sonar to identify more accurately the extent of the foul around Le Bon's and Pompey's Rocks (Carbines & Haist 2017a). Using this information, offshore random site strata polygons were drawn which differed in shape and were larger than the fixed site rectangle polygons used for all fixed site surveys (Carbines & Haist 2017a) (Figure 2). These offshore strata were also digitised and converted to shape files during the design phase of the 2016 survey.

Each random site 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.

2.3 Survey design

2.3.1 Allocation of sites

Full fixed site and full random site surveys were carried out concurrently off Banks Peninsula in 2016 (Table 1).

Simulations to determine the optimal allocation of fixed sites among the five inshore and two offshore strata were carried out with catch rate data from the 2002, 2005, 2008, and 2012 fixed site surveys using NIWA's Optimal Station Allocation Program (*allocate*). During the optimisation the inshore and offshore strata were treated as separate surveys. Simulations were first carried out for fixed sites and constrained to have a minimum of three sites per stratum and a CV of no greater than 15%. Because there were no random sites surveyed in 2002, 2005 and 2008, random site allocation was based on data from the 2012 survey constrained to have a minimum of three sites per stratum and a CV of no greater than 25%. In the final design approved by the Southern Inshore Working Group (SINSWG-2015-42), the number of sites was set at 40 for both fixed and random site surveys allocated across the seven strata consistent with the optimum station allocation.

The survey used a two-phase stratified random station design (Francis 1984). For both the fixed and random site surveys 35 sites were allocated to phase 1, with the remaining five available for phase 2, consistent with the proportion of sites allocated to phase 2 in previous surveys (Table 1). Allocation of phase 2 stations was based on the mean pot catch rate ($kg.pot.^{-1}$) of all blue cod per stratum and optimised using the "area mean squared" method of Francis (1984). In this way, stations were assigned iteratively to the stratum in which the expected gain is greatest, where expected gain is given by:

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

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

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 were randomly selected from the list of all available fixed sites in each stratum. For the 2016 Banks Peninsula survey, the 40 allocated fixed sites were randomly selected from the full and larger list of 66 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 or along the coastline, 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 500 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.

2.3.2 Vessel and gear

The Banks Peninsula survey was conducted from F.V. *CherilynJ* (Registration number 63139), an Akaroa-based commercial vessel owned and skippered by Mr John Wright. The *CherilynJ* (including skipper John Wright) was used on all four previous surveys. The vessel is equipped to set and lift rock lobster and blue cod pots with specifications: 10.5 m length, 3.5 t aluminium monohull, propeller powered by two Volvo Penta 230 hp diesel engines.

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 north Canterbury blue cod potting 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.

2.3.3 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 in which 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. Separate otolith collections were made for the inshore (strata 1–5) and the offshore strata (strata 6–7). A target of five otoliths per 1 cm size class, for each sex was aimed for ensuring that the otolith collection was spread across the inshore and offshore strata (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 and 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.

2.3.4 Data storage

The survey trip code was CHJ1601 for the 2016 Banks Peninsula survey. At the completion of the survey, trip, station, catch, and biological data were entered into the 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 Banks Peninsula fixed sites was 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.

2.3.5 Age estimates

Otolith preparation and reading

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

1. Blue cod otolith thin-section preparations were made as follows: otoliths were individually marked on their distal faces with a dot in the centrum using a cold light source on low power to light the otolith from behind. Five otoliths (from five different fish) were then embedded in an epoxy resin mould and cured at 50 ºC. Thin sections were taken along the otolith dorso-ventral axis through the centrum of all five otoliths, using a Struers Accutom-50 digital sectioning machine, with a section thickness of approximately 350 µm. Resulting thin section wafers were cleaned and embedded on microscope slides using epoxy resin and covered with a coverslip. Finally, these slides were oven cured at 50ºC.
2. Otolith sections were read against a black background using reflected light under a compound microscope at a magnification of 40–100 times. Under reflected light opaque zones appear light and translucent zones dark. Translucent zones were counted (ageing of blue cod otolith thin sections prior to 2015 counted opaque zones to estimate age).
3. Two readers read all otoliths without reference to fish length.
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).

2.3.6 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 inshore and offshore strata, for both 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).

2.3.6.1 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). Catch rates of recruited blue cod are based on the sum of the weights of individual fish 30 cm and over. The strata areas (km for fixed sites and km^2 for random sites) 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 for the fixed and random sites surveys for individual strata, for inshore strata combined, and for offshore strata combined.

2.3.6.2 Length-weight parameters

The length-weight parameters a_k, b_k from the 2016 Banks Peninsula 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.

2.3.6.3 Growth parameters

von Bertalanffy growth models (von Bertalanffy 1938) were fitted to the 2016 Banks Peninsula combined surveys 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.

2.3.6.4 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 (shown in Table 1 was taken as the area of the stratum (A_t in km or km^2), and

the length-weight parameter estimates are from the 2016 Banks Peninsula 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 keys.

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

2.3.6.5 Unsexed fish

All blue cod from the 2016 surveys were sexed except two very small fish from random sites, where it was not possible with any certainty to assign sex. These 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.

2.3.6.6 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 (30 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.

2.3.6.7 Total mortality estimates

Total mortality (Z) was estimated from catch-curve analysis using the Chapman-Robson estimator (CR) (Chapman & Robson 1960). 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 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.

2.3.6.8 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})	0.1304	0.1162
t_0 (yr)	-1.2099	-2.0712
L_∞ (cm)	58.72	50.22
A	0.006673	0.006190
B	3.2469	3.2767

The 2016 Banks Peninsula survey von Bertalanffy growth parameters and length-weight parameters from all strata combined (inshore and offshore) were used to model the relationship between the spawner-per-recruit ratio and fishing mortality. The combined inshore and offshore von Bertalanffy growth model was used because there were few fish older than 7 years inshore, and conversely no fish younger than three years old offshore. Combing length-age data from all strata resulted in a growth curve with ages well represented across the full age range.

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 2016 Banks survey von Bertalanffy combined model. Banks Peninsula recreational MLS is 30 cm and selectivity was 4.3 years for males and 5.8 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 (6 years for females), calculated from the 2016 Banks Peninsula survey female combined von Bertalanffy model.

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 6 years as estimated from the combined von Bertalanffy growth curve.

2.3.6.9 Analyses of the 2012 Banks Peninsula survey

Catch rates, scaled length frequencies, and sex ratios were estimated for the 2012 Banks Peninsula survey, 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. These were estimated from the 2016 Banks Peninsula survey length-weight coefficients because no individual fish weights were available for the 2012 survey.

3. RESULTS

3.1 2016 fixed site survey

3.1.1 Fixed sites surveyed

Forty fixed sites (6 pots per site, 240 pot lifts) from seven strata off Banks Peninsula were fished (Table 1, Figures 3 and 4). Depths sampled were 8–90 m (mean = 42.5 m). Thirty five sites were fished in phase 1 and five in phase 2.

3.1.2 Catch (fixed sites)

A total of 665 kg of blue cod (1264 fish) was taken comprising 78% by weight of the catch of all species on the survey (Table 2). Bycatch species included eleven teleost fishes, one species of octopus, unidentified starfish, and carpet shark. The three most abundant bycatch species, by number, were banded wrasse (*Notolabrus fucicola*), spotty (*Notolabrus celidotus*) and scarlet wrasse (*Pseudolabrus miles*).

3.1.3 Catch rates (fixed sites)

Mean catch rates (kg.pot^{-1}) of blue cod (all blue cod, 30 cm and over) are presented by stratum (Table 3, Figure 5). The catch rates from inshore strata (1–5) are all substantially lower than those from the offshore strata (6–7).

Inshore–mean catch rates of blue cod (all sizes) were 0.6–2.1 kg.pot^{-1} with the lowest catch rates in stratum 1 and the highest in stratum 3 (Table 3, Figure 6). The survey all blue cod catch rate was 1.26 kg.pot^{-1} with a CV of 12%. Catch rates for recruited blue cod 30 cm and over, followed the same pattern among strata as for all blue cod, and overall was 0.4 kg.pot^{-1} (CV 26%), i.e., low or high catch rate estimates for all fish was generally mirrored by low or high values for recruited fish (Table 3, Figure 6). All 26 inshore fixed sites had some blue cod catch, but of the 156 pots, 45 (29%) had zero catch of blue cod.

Offshore–mean catch rates of blue cod (all sizes) were 5.1–6.1 kg.pot^{-1} with the lowest catch rates in stratum 7 and the highest in stratum 6 (Table 3, Figure 7). The survey all blue cod catch rate was 5.6 kg.pot^{-1} with a CV of 14%. Catch rates for recruited blue cod 30 cm and over, followed the same pattern among strata as for all blue cod, and overall was 5.2 kg.pot^{-1} (CV 15%) (Table 3, Figure 7). All 14 offshore fixed sites had some blue cod catch, but of the 84 pots, 13 (15%) had zero catch of blue cod.

3.1.4 Biological and length frequency data (fixed sites)

Of the 1264 blue cod caught in fixed sites, all were sexed and measured for length and weighed (Table 4). The sex ratio was 61–72% male across the seven strata (Table 4).

Inshore strata (1–5)

Length was 14–43 cm for males and 14–50 cm for females, although this range varied among strata and the overall weighted mean lengths were 26.5 cm for males and 23.3 cm for females (Table 4). The sex ratios were 65–72% male across the five strata and overall weighted sex ratio was 67% male. The scaled length frequency distributions are generally similar among strata with males dominating, and a strong mode around 25 cm (Figure 8). There were few females over 30 cm length and in strata 1 and 2 there were none.

Offshore strata (6–7)

Length was 20–55 cm for males and 19–50 cm for females, similar between the two strata, and the overall weighted mean length was 36.8 cm for males and 33.6 cm for females (Table 4). The sex ratios were 61 and 69% male in stratum 6 and 7 respectively, and overall weighted sex ratio was 65% male. The scaled length frequency distributions differ between strata with those in stratum 6 displaying possible modes around 25 and 35 cm, whereas stratum 7 was unimodal (Figure 9).

Contrast inshore and offshore

Compared to offshore, blue cod were much smaller inshore with relatively few fish over 30 cm, especially females (Figure 10). In contrast offshore strata had the full length range observed inshore but had equal numbers of fish over 30 cm and also attained a larger size overall (Figure 10).

3.1.5 Age and growth

Inshore strata (1–5)

Otolith section ages from 207 males and 97 females collected from fixed and random sites were used to estimate the population age structure from Banks Peninsula inshore strata in 2016 (Table 5). The length-age data are plotted and the von Bertalanffy model fits and the growth parameters (K, t_0 and L_∞) are shown for males and females separately (Figure 11). There is a large range in length at age for both sexes and males grow faster and larger than females. The low maximum ages (8 years for males and 6 years for females) has resulted in improbable von Bertalanffy parameters, especially L_∞.

Offshore strata (6–7)

Otolith section ages from 256 males and 197 females collected from fixed and random sites were used to estimate the population age structure from Banks Peninsula offshore strata in 2016 (Table 5). The length-age data are plotted and the von Bertalanffy model fits and the growth parameters (K, t_0 and L_∞) are shown for males and females separately (Figure 12). There is a large range in age-at-length for both sexes and males grow faster and larger than females.

Combined strata (1–7)

As well as for inshore and offshore strata separately, the length-age data are plotted and the von Bertalanffy model fits and the growth parameters (K, t_0 and L_∞) are shown for all age data combined (Figure 13). These combined growth parameters were used in the spawner-per-recruit estimates (see Section 2.3.6.8)

For all ageing between-reader comparisons are presented in Figure 14. The first counts of the two readers showed 83% agreement, and overall there was no bias between readers with a CV of 1.9% and average percent error (APE) of 1.3%.

3.1.6 Spawning activity

Gonad stages of blue cod sampled in the April 2016 Banks survey are presented for all fish from fixed and random sites combined for inshore and offshore strata (Table 6). There was no indication of spawning activity inshore during the survey period for either males or females, with virtually all fish either resting or maturing. Offshore, however, about 5% of males and females were either mature or running ripe, but about half of all fish were spent, indicating that the main spawning period may have taken place in recent months.

3.1.7 Population length and age composition (fixed sites)

Inshore strata (1–5)

The scaled length frequency and age distributions for the 2016 Banks Peninsula fixed site inshore survey are shown for all five strata combined, as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Figure 15).

Scaled length frequency distributions for both males and females were unimodal with strong juvenile modes at about 25 and 23 cm respectively, but skewed to the right with overall mean lengths of 28.5 cm and 23.3 cm, respectively (Figure 15). The cumulative distribution plots of length frequency are similar in shape between sexes, but overall females were smaller with few fish over 30 cm. The mean weighted coefficients of variation (MWCVs) for the length distributions are 29% for males and 34% for females. Recruited fish (30 cm and over), comprised 14% of males and 3% of females.

Age of blue cod was 1–8 years for males and 1–6 years for females, but 82% blue cod were three years old (Figure 15). The estimated population age distributions indicate virtually knife-edge selectivity to the potting method at three years. For both sexes, and especially females, there are very few fish over three years of age and this is represented in the cumulative distribution plots of age frequency (Figure 15). The mean ages were 3.2 years for females and 3.3 years for males. The MWCVs around the age distributions were 12% for males and 17% for females, indicating a good representation of the overall population age structure.

Offshore strata (6–7)

The scaled length frequency and age distributions for the 2016 Banks Peninsula fixed site offshore survey are shown for both strata combined, as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Figure 16).

Scaled length frequency distributions for both males and females showed no clear modes with a wide size range and overall mean lengths of 36.8 cm and 33.6 cm, respectively (Figure 16). The cumulative distribution plots of length frequency are similar in shape between sexes, but overall females were smaller. The mean weighted coefficients of variation (MWCVs) for the length distributions are 37% for males and 34% for females. Recruited fish (30 cm and over), comprised 75% of males and 64% of females.

Age of blue cod was 3–27 years for males and 3–29 years for females, but most blue cod were less than 11 years old (Figure 16). The estimated population age distributions indicate knife-edge selectivity to the potting method at three years. Strong age classes are present for three, six and nine year old males, but there were few four year olds. Similarly, six and nine year old age classes were strong for females. These strong and weak age classes are apparent in the cumulative distribution plots of age frequency (Figure 16). The mean ages were 9.2 years for females and 7.6 years for males. The MWCVs for the age distributions were 29% for males and 40% for females.

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

Inshore strata (1–5)

Inshore fixed site CR 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 six years, equal to the age at which females reach the MLS of 30 cm. The CR *Z* for AgeR of six years was 1.87 (95% confidence interval of 0.96–2.58).

The traditional catch curve for inshore strata, based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment of six years, is shown in Figure 17. There were no blue cod aged over 6 years for females and 8 years for males and this resulted in a very steep slope of the regression line for males and a nonsensical plot for females with only one recruited age class. 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 a result of having a severely truncated age distribution and variable recruitment 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. These factors 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 ($F_{SPR\%}$) estimates at three values of *M* and age at full recruitment of six years are shown for inshore strata in Table 8. Based on the default *M* of 0.14, estimated fishing mortality (*F*) was 1.73 and associated spawner-per-recruit ratio was 4.7% (Figure 18). This indicates that at the 2016 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 5% of the contribution in the absence of fishing.

Offshore strata (6–7)

Offshore fixed site CR 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 six years, equal to the age at which females reach the MLS of 30 cm. The CR *Z* for AgeR of six years was 0.26 (95% confidence interval of 0.19–0.34).

The traditional catch curve for offshore strata, with age-at-full recruitment of six years, is shown in Figure 17. 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 for males, 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 ($F_{SPR\%}$) estimates at three values of *M* and age at full recruitment of six years are shown for inshore strata in Table 8. Based on the default *M* of 0.14, estimated fishing mortality (*F*) was 0.12 and associated spawner-per-recruit ratio was 40.7% (Figure 18). This indicates that at the 2016 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 41% of the contribution in the absence of fishing.

3.2 2016 random site survey

3.2.1 Random sites surveyed

Forty random sites (6 pots per site, 240 pot lifts) from seven strata off Banks Peninsula were fished (Table 1, Figures 3 and 4). Depths sampled were 5–93 m (mean = 50.2 m). Thirty five sites were fished in phase 1 and five in phase 2.

3.2.2 Catch (random sites)

A total of 670 kg of blue cod (691 fish) was taken comprising 93% by weight of the catch of all species on the survey (Table 2). Bycatch species included seven teleost fishes, and an unidentified crab. The four most abundant bycatch species, by number, were crab, spotty (*Notolabrus celidotus*), banded wrasse (*Notolabrus fucicola*), and scarlet wrasse (*Pseudolabrus miles*).

3.2.3 Catch rates (random sites)

Mean catch rates (kg.pot^{-1}) of blue cod (all blue cod, 30 cm and over) are presented by stratum (Table 3, Figure 5). The catch rates from inshore strata (1–5) are all substantially less than those from the offshore strata (6–7).

Inshore–mean catch rates of blue cod (all sizes) were 0.09–0.94 kg.pot^{-1} with the lowest catch rates in stratum 5 and the highest in stratum 2 (Table 3, Figure 6). The survey all blue cod catch rate was 0.53 kg.pot^{-1} with a CV of 22.2%. Catch rates for recruited blue cod 30 cm and over, followed the same pattern among strata as for all blue cod, and overall was 0.11 kg.pot^{-1} (CV 37%) (Table 3, Figure 6). Of the 20 inshore random sites, 7 had no blue cod, and of the 120 pots, 93 (77.5%) had zero catch of blue cod.

Offshore–mean catch rates of blue cod (all sizes) were 4.5–5.2 kg.pot^{-1} with the lowest catch rates in stratum 6 and the highest in stratum 7 (Table 3, Figure 7). The survey all blue cod catch rate was 5.1 kg.pot^{-1} with a CV of 19.5%. Catch rates for recruited blue cod 30 cm and over, followed the same pattern among strata as for all blue cod, and overall was 4.9 kg.pot^{-1} (CV 19.5%) (Table 3, Figure 7). Of the 20 offshore random sites, 4 had no blue cod, and of the 120 pots, 62 (52%) had zero catch of blue cod.

3.2.4 Biological and length frequency data (random sites)

Of the 1264 blue cod caught in random sites, all but two very small fish were sexed and measured for length and weighed (Table 4). The weighted sex ratio was 42–60% male across the seven strata (Table 4).

Inshore strata (1–5)

Length was 14–41 cm for males and 14–30 cm for females, although this range varied among strata and the overall weighted mean length was 26.1 cm for males and 23.8 cm for females (Table 4). The sex ratios were 42–88% male across the five strata and overall weighted sex ratio was 81% male. The scaled length frequency distributions are generally similar among strata with males dominating, and a mode around 25 cm (Figure 19). There were no females over 30 cm length except in stratum 3.

Offshore strata (6–7)

Length was 20–57 cm for males and 21–49 cm for females, similar between the two strata, and the overall weighted mean length was 41.3 cm for males and 36.1 cm for females (Table 4). The sex ratios were 42 and 60% male in stratum 6 and 7 respectively, and overall weighted sex ratio was 57% male. The scaled length frequency distributions in stratum 7 display possible male modes around 23 and 35 cm, whereas stratum 6 has insufficient sampled fished to compare (Figure 20).

Contrast inshore and offshore

Compared to offshore, blue cod were much smaller inshore with relatively few fish over 30 cm, especially females (Figure 21). In contrast offshore strata had the full length range observed inshore,

with the exception of a few very small fish, but had large numbers of fish over 30 cm, and also attained a larger size overall (Figure 21).

3.2.5 Age and growth

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

3.2.6 Spawning activity

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

3.2.7 Population length and age composition (random sites)

Inshore strata (1–5)

The scaled length frequency and age distributions for the 2016 Banks Peninsula random site inshore survey are shown for all five strata combined, as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Figure 22).

Scaled length frequency distributions for both males and females were unimodal with strong juvenile modes at about 25 and 23 cm respectively, but skewed to the right with overall mean lengths of 26.1 cm and 23.8 cm, respectively (Figure 22). The cumulative distribution plots of length frequency are similar in shape between sexes, but overall females were smaller with few fish over 30 cm. The mean weighted coefficients of variation (MWCVs) around the length distributions were 49% for males and 71% for females. Recruited fish (30 cm and over), comprised 10% of males and 2% of females.

Age of blue cod was 1–8 years for males and 1–6 years for females, but 83% of blue cod were three years old (Figure 22). The estimated population age distributions indicate virtually knife-edge selectivity to the potting method at three years. For both sexes, and especially females, there are very few fish over three years of age and this is represented in the cumulative distribution plots of age frequency (Figure 22). The mean ages were 3.2 years for females and 3.3 years for males. The MWCVs around the age distributions were 19% for males and 36% for females.

Offshore strata (6–7)

The scaled length frequency and age distributions for the 2016 Banks Peninsula random site offshore survey are shown for both strata combined, as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Figure 23).

Scaled length frequency distributions for both males and females had a wide size range and overall mean lengths of 41.3 cm and 36.1 cm, respectively (Figure 23). There are indications of a juvenile male mode at about 25 cm. The cumulative distribution plots of length frequency are similar in shape between sexes, but overall females were smaller. The mean weighted coefficients of variation (MWCVs) around the length distributions were 50% for males and 54% for females. Recruited fish (30 cm and over), comprised 86% of males and 74% of females.

Age of blue cod was 3–27 years for males and 3–29 years for females, but most blue cod were less than 11 years old (Figure 23). The estimated population age distributions indicate knife-edge selectivity to the potting method at three years. Strong age classes are present for three, six and nine year old males, but there were few four year olds. Similarly, six and nine year old age classes were strong for females. These strong and weak age classes are apparent in the cumulative distribution plots of age frequency (Figure 23). The mean ages were 9.6 years for females and 10.6 years for males. The MWCVs around the age distributions were 37% for males and 48% for females.

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

Inshore strata (1–5)

Inshore random site CR 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 six years, equal to the age at which females reach the MLS of 30 cm (based on the fitted VB growth curve). The CR *Z* for AgeR of six years was 2.24 (95% confidence interval of 1.05–2.61).

The traditional catch curve for inshore strata, based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment of six years, is shown in Figure 24. There were no blue cod aged over 6 years for females and 8 years for males and this resulted in a very steep slope of the regression line for males and a nonsensical plot for females with only one recruited age class. 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 a result of having a severely truncated age distribution and variable recruitment 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. These factors 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 ($F_{SPR\%}$) estimates at three values of *M* and age at full recruitment of six years are shown for inshore strata in Table 8. Based on the default *M* of 0.14, estimated fishing mortality (*F*) was 2.1 and associated spawner-per-recruit ratio was 4.3% (Figure 18). This indicates that at the 2016 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 4% of the contribution in the absence of fishing.

Offshore strata (6–7)

Offshore random site CR 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 six years, equal to the age at which females reach the MLS of 30 cm. The CR *Z* for AgeR of six years was 0.19 (95% confidence interval of 0.14–0.24).

The traditional catch curve for offshore strata, with age-at-full recruitment of six years, is shown in Figure 24. 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 for males, 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). Residuals were nevertheless evenly distributed around the fitted straight line, suggesting that variable year class strength had not introduced substantial bias.

Mortality parameters (CR *Z* and *F*, and *M*) and spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* and age at full recruitment of six years are shown for inshore strata in Table 8. Based on the default *M* of 0.14, estimated fishing mortality (*F*) was 0.05 associated spawner-per-recruit ratio was 64.2% (Figure 18). This indicates that at the 2016 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 64% of the contribution in the absence of fishing.

3.3 Comparison of fixed and random site 2016 surveys

Inshore strata (1–5)

Catch rates of all blue cod from the 2016 random site inshore strata surveys are considerably lower across all five strata and the survey catch rate is less than half that of fixed sites, with no overlap of confidence intervals (Table 3, Figure 25). The CVs and associated confidence intervals are considerably larger for random sites in each stratum and for the survey. The recruited fish (30 cm and over) catch rates exhibited the same pattern among strata as all blue cod, and the random site survey recruited catch rate is less than one-third that of fixed sites, with no overlap of confidence intervals (Table 3, Figure 25). Random site strata 4 and 5 had no recruited blue cod over 30 cm and over.

The length distributions among the five inshore strata showed similar patterns between fixed and random sites (compare Figures 8 and 19), and overall there was no difference in the survey length and age distributions for male or females (Figure 26).

Sex ratios for fixed and random sites showed a similar pattern among strata, but the proportions of males were higher for random sites in each stratum and for the survey (67% male for fixed sites and 81% for random sites) (Table 4). Recruited sex ratios showed similar patterns among strata, but the proportions male were much greater with few females over 30 cm and some stratum catches were 100% male (Table 4).

Total mortality was higher for random than fixed sites (1.87 versus 2.24), but spawner-biomass-per-recruit ratios were similar (43% and 47%, respectively), for age at recruitment of 6 years and M of 0.14 (see Table 8, Figure 18).

Offshore strata (6–7)

Catch rates of all blue cod and recruited blue cod were similar for fixed and random site offshore surveys, between strata and surveys, with overlapping confidence intervals (Table 3, Figure 27).

The length distributions for the two offshore strata showed different patterns between fixed and random sites (compare Figures 9 and 20), and blue cod males and females were larger and older from random sites (Figure 28).

The all blue cod proportions male for the two strata and for the survey were higher for fixed sites (65% for fixed sites and 57% for random sites) (Table 4). Recruited sex ratios showed similar patterns and the proportions male were only slightly higher than for all blue cod (Table 4).

Total mortality was lower for random than fixed sites (Z = 0.19 and 0.26, respectively), resulting in a higher spawner-biomass-per-recruit ratio for the random site survey ($F_{64.2\%SPR}$ and $F_{40.7\%SPR}$, respectively), for age at recruitment of 6 years and M of 0.14 (see Table 8, Figure 18).

3.4 Inshore 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) from fixed sites are presented by stratum and survey for each of the five inshore surveys in the time series (Figure 29). Stratum catch rates displayed high variability between years, in some cases, by several fold. Apart from the high survey catch rate in 2005, there was no trend in the all blue cod catch rate across surveys. Catch rates for recruited blue cod displayed similar patterns among strata, and although survey recruited catch rates also showed no trend, the 2016 catch rate was the lowest (Figure 29).

Random sites – Mean catch rates (kg.pot^{-1}) for all blue cod and recruited blue cod (30 cm and over) from random sites are presented by strata and survey for the two inshore surveys in the time series (Figure

30). Stratum catch rates displayed high variability between years by several fold, particularly in strata 4 and 5 where they declined substantially. The survey catch rate more than halved in 2016 with no overlap of confidence intervals. Catch rates for recruited blue cod showed similar patterns among strata and the survey catch rate declined by 6-fold in 2016.

Comparison of the all blue cod survey catch rates between fixed and random sites inshore strata over the time series is shown in Figure 31.

3.4.2 Length distributions

Because blue cod ageing from the previous four 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 2016 survey. Scaled length, however, can be compared among the five fixed site and two random site inshore surveys.

Fixed sites – scaled length frequency distributions of inshore blue cod are most similar between 2002 and 2016 and are characterised by a strong recruitment pulse with modes at about 25 cm total length, whereas the 2012 and 2016 surveys had low numbers of fish over 40 cm compared to earlier surveys (Figure 32). Mean length was the lowest in 2016, due to the strong juvenile mode at 25 cm and a decline in the numbers of fish over 40 cm (Figure 32).

Random sites – scaled length frequency distributions of inshore blue cod from random sites differed between 2012 and 2016 surveys, with 2016 characterised by a strong mode at about 25 cm length, and few fish over 30 cm (Figure 33). The 2012 survey also had a juvenile mode at about 18 cm, largely absent in 2016.

In both 2012 and 2016, the random and fixed sites inshore length distributions were similar in shape and size range (compare Figures 32 and 33).

3.4.3 Sex ratios and zero catch

The sex ratio among fixed site inshore surveys for all blue cod and recruited blue cod was consistently around 70% and 90% male, respectively, with no trends (Figure 34). For both random site surveys, sex ratios were almost the same as those in fixed sites for recruited blue cod, but in 2016 all blue cod had about 10% more males with no overlap in confidence intervals (Figure 34).

The proportion of pots that had no blue cod in fixed sites ranged from 23%–52% with no trend (Figure 35). In the two random site surveys the proportions of pots with no blue cod was higher, particularly in 2016 when it was 77% compared to 29% in fixed sites (Figure 35).

3.5 Offshore survey time series

3.5.1 Catch rates

Fixed sites – Mean catch rates ($kg.pot^{-1}$) for all blue cod and recruited blue cod (30 cm and over) from fixed sites are presented by strata and survey for each of the two offshore surveys in the time series (Figure 36). Stratum catch rates displayed high variability between years, in some cases, by several fold. Apart from the high survey catch rate in 2005, there was no trend in the all blue cod catch rate, although 2002 was the lowest and 2016 the highest. Catch rates for recruited blue cod had similar catch rates and displayed almost identical patterns among strata (Figure 36).

Random sites – Mean catch rates (kg.pot^{-1}) for all blue cod and recruited blue cod (30 cm and over) from random sites are presented by stratum and survey for the two offshore surveys in the time series (Figure 37). Given the large confidence intervals, there were no differences in all blue cod or recruited blue cod strata catch rates or survey catch rates.

Comparison of the all blue cod survey catch rates between fixed and random sites offshore strata over the time series is shown in Figure 38.

3.5.2 Length distributions

Because blue cod ageing from the previous four 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 2016 survey. Scaled length, however, can be compared among the two fixed site and two random site offshore surveys.

Fixed sites – scaled length frequency distributions of offshore blue cod were generally similar among the five fixed site surveys, and characterised by a wide length distribution from about 20 to 59 cm with no obvious modes or trends (Figure 39). The differences in the cumulative distribution curves are a result of varying contributions of small or large fish among the surveys, e.g., 2005 had relatively few small fish while 2008 had larger fish.

Random sites – scaled length frequency distributions of offshore blue cod were generally similar between 2012 and 2016 random sites surveys, and were characterised by a wide length distribution from about 13 to 58 cm with no obvious modes or trends (Figure 40).

In 2012 the random and fixed sites inshore length distributions were similar in shape and size, but in 2016 overall blue cod were larger from random sites (Figure 41).

3.5.3 Sex ratios and zero catch

The sex ratio among fixed site offshore surveys for all blue cod favoured females in 2002 when about 40% of fish were males, but in 2016 65% of fish were male, with no overlap in confidence intervals (Figure 42). Recruited fish showed a similar trend. For both random site surveys, sex ratios were almost the same as those in fixed sites (Figure 42).

The proportion of pots that had no blue cod in fixed sites ranged from 5%–31% with no trend (Figure 35). In the two random site surveys the proportion of pots with no blue cod was higher, particularly in 2016 when it was 52% compared to 15% in fixed sites (Figure 43).

4. DISCUSSION

4.1 General

The 2016 Banks Peninsula potting survey provides the fifth fixed site and the second random site survey in the time series of relative abundance and population structure of blue cod from this area. The split between inshore and offshore provided independent outputs on population status in recognition of the geographic separation of these populations in distance from each other and from the coast. After reviewing the results of the 2016 Banks Peninsula 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 for estimates of relative abundance (catch rates) were not specified for the 2016 Banks Peninsula survey. The 12% and 14% CVs achieved for the fixed site survey inshore and offshore surveys, respectively, were acceptable and comparable to previous surveys (see Table 3). For random site surveys the CVs of 22% for inshore and 19% for offshore were higher than desired given that most fixed site surveys achieve CVs considerably less than 20% (Ministry for Primary Industries 2016). In comparison, the 2012 random site surveys achieved CVs of 17% (inshore) and 36% (offshore). The achieved CVs indicate that the survey design and number of sites used are appropriate for fixed, but may require more sites for random surveys. The number of pots with zero catch is considerably higher for random compared to fixed site surveys (Figure 43). In 2016, eleven random sites had no blue cod all, while all fixed sites had some catch, and this contributed to the higher CVs for the random site survey.

4.2 2016 fixed site versus random site surveys

Inshore (strata 1–5)

Catch rates of all blue cod from the 2016 random site inshore strata surveys were considerably lower across all five strata and the survey catch rate was less than half that of fixed sites, with no overlap of confidence intervals (see Figure 25). The length distributions, however were similar within each of the five inshore strata for the fixed and random site surveys (see Figure 26). In both surveys the length distributions are characterised by a strong predominantly male juvenile mode, skewed to the right, and the largest fish were males. The strong juvenile mode appears in the age composition of both fixed and random site surveys as three year old fish indicating good recruitment in spring/summer of 2012 (see Figures 15 and 22).

This is the first Banks Peninsula survey for which ageing was carried out using the blue cod age determination protocol (ADP) and therefore is the only survey in the time series for which age composition is considered to be valid. The 2014 Dusky Sound survey, for which ageing was carried 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 inshore cohort off Banks in 2016 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 relatively weak 4 year old cohort for males, may well have the opposite effect (see Figures 15 and 22).

Sex ratios for fixed and random sites in 2016 both strongly favour males, but the proportion male was higher in random sites (67% male for fixed sites and 81% for random sites) (see Figure 34). Both inshore surveys indicated that there were very few females of recruited size (30 cm and over) and hence the recreational fishery is based almost exclusively on males. This is possibly the result of females changing sex early as there are no large dominant males to suppress sex change.

Chapman-Robson total mortality and SPR estimates were similar for fixed and random sites surveys (see Table 8) and together with results on size and age, indicate that the two survey types sampled the same population of blue cod (or had similar selectivity).

Offshore (strata 6–7)

Offshore catch rates were similar for fixed and random sites in 2016, but blue cod were larger from random sites, possibly a result of less fishing intensity compared to the fixed site 'hot spots' (see Figures 27 and 28). The juvenile mode, which dominated the inshore length distributions was less apparent and although the three year old cohort was still strong for males, the six and nine year old cohorts were also

visible (see Figures 16 and 23). The high proportion of three year old males offshore, may be the result of males growing faster than females (see Figure 12), and therefore recruiting earlier to the survey catch. Sex ratios slightly favoured males in 2016, with little difference between fixed and random sites (see Figure 42). The larger size of blue cod from random sites resulted in a lower estimate of total mortality than from fixed sites (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.

Inshore (strata 1–5)

The 2016 random site inshore survey SPR estimate, for the default M value of 0.14, and age at full recruitment of 6 years (based on age to reach MLS for females), was $F_{4\%SPR}$, indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit was reduced to 4% of the contribution in the absence of fishing (see Figure 18). The level of exploitation (F) of Banks Peninsula inshore blue cod stocks therefore greatly exceeds the F_{MSY} target reference point of $F_{45\%SPR}$. The estimate of Z and hence *F* are the parameters that determine the value of spawner-per-recruit ratio. Total mortality (*Z*) is a product of the slope of the right hand descending curve of age versus population numbers. The oldest males and females were only 8 and 6 years old respectively, hence the estimate of *Z* is based on only a few age classes. The age distribution of blue cod from the 2016 inshore survey is so truncated that growth cannot be accurately modelled using the von Bertalanffy growth model which requires some larger and older fish to estimate a sensible length at infinity parameter (see Figure 24). Given the low number of fully recruited year classes, and the fact that year class strength is shown to vary considerably from one year to the next, estimates of *Z*, *F* and SPR should be treated with caution and the Z estimates that fall within the 95% confidence intervals may be plausible.

Offshore (strata 6–7)

The 2016 random site offshore survey SPR estimate, for the default M value of 0.14, and age at full recruitment of 6 years (based on age to reach MLS for females), was $F_{64\%SPR}$, indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit was reduced to 64% of the contribution in the absence of fishing (see Figure 18). The level of exploitation (F) of Banks Peninsula offshore blue cod stocks therefore is less than the F_{MSY} target reference point of $F_{45\%SPR}$. The catch curve analyses for offshore strata indicates that Z is better estimated than for inshore stocks, as there are a good number of recruited year classes and even though recruitment strength does vary from year to year, the residuals are evenly distributed around the catch curve, suggesting that good years are balanced by bad years, leading to a reasonable estimate of Z.

4.4 Reproductive condition

All five Banks surveys, except 2002[1], were carried out in April, so reproductive status is comparable only from the last four surveys. During the 2005 and 2008 surveys there was little indication of

[1] The 2002 survey was carried out in two stages because of bad weather. Stage one from 4–10 January 2002, and stage 2 from 18–23 April 2002.

spawning, whereas in 2012 a high proportion of blue cod were maturing or running ripe, indicative of spawning activity overlapping with the survey. In 2016 there was again little indication of spawning activity during the survey period (see Table 6), suggesting that the peak spawning period is not fixed and that timing may change between years.

4.5 Time series trends

There are now five fixed site inshore and offshore 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 2002, 2005, 2008, and 2012 surveys were 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 Inshore surveys

All blue cod and recruited catch rates from inshore fixed sites showed high variability among and within strata, but apart from the large catch rate in 2005, there is no trend in survey abundance over time (see Figure 29). The proportion of pots with no blue cod catch in 2005 is also the lowest, indicating that blue cod were more wide spread and abundant than in other years (see Figure 35). The 2002 survey had a strong juvenile mode of fish 3–4 years old, which probably contributed to the very high catch rate in 2005 (see Figure 31). The 2016 juvenile mode is larger than in 2002 and can be expected to contribute to increased abundance in about three years when they recruit to the fishery.

Random site inshore catch rates of all blue cod for the 2016 survey were less than half that in 2012, with no overlap in confidence intervals, and the decline was even greater for recruited fish (see Figure 30). The decline was consistent with the proportion of random site pots with zero catch which was more than double that of fixed sites in 2016, reflecting the positioning of some sites in less than optimum blue cod habitat (see Figure 35).

Catch rates of blue cod from the inshore coast around Banks Peninsula were low compared to all areas for which surveys are carried out except the inner Marlborough Sounds and Motunau in 2016 where they are comparable (Ministry for Primary Industries 2016, Beentjes & Sutton 2017). Restrictions on blue cod fishing in the Marlborough Sounds[2] are likely to have displaced recreational fishing effort to Kaikoura and Motunau in recent years. Further, the establishment of the Kaikoura Marine Area[3] in 2014, and a bag limit of 30 blue cod south of the Waimakariri River compared to 10 for Motunau, may also have shifted effort further south, including to Banks Peninsula. There are anecdotal reports of increasing recreational fishing effort off Moeraki where blue cod are larger and more abundant than the inshore fisheries further north. Surveys of the Pohatu Marine Reserve (Flea Bay) in 2008 and particularly 2012 (see location in Figure 3) showed that blue cod were more abundant and generally larger in the reserve than adjacent fished areas (Carbines 2017)). This suggests that inshore observations of blue cod are not the result of fish moving offshore as they grow older and larger.

There were no trends in the fixed site inshore length distributions or mean length, but in 2016 there were few females over the MLS, consistent with the low catch rate of recruited fish in 2016 (see Figure 32). The sex ratio for all blue cod strongly favoured males on all fixed site inshore surveys with about 70% of fish male, and no trend (see Figure 34). There was also no trend in sex ratio of the recruited blue cod

[2] Closure of the inner Marlborough Sounds 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.
[3] MLS of 33 cm, MDL of 6 blue cod

which greatly favoured males (about 90%). Blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow (Carbines 2004). The Banks blue cod inshore population sex and size structure observed in the 2016 survey 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 is 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. In the Banks Peninsula inshore fishery, the heavily skewed sex ratio towards males is similar to the populations in Motunau, and Marlborough Sounds which are all characterised by small mean size, low catch rates, and high total mortality.

Size and sex ratios from random site inshore surveys were similar to those of the 2012 and 2016 fixed site surveys.

4.5.2 Offshore surveys

All blue cod and recruited catch rates from offshore fixed sites showed high variability among and within the two strata, but there was no trend in survey abundance over time (see Figure 36). The highest catch rate was in 2005, in which the proportion of pots with no blue cod catch was also the lowest, indicating that blue cod were more wide spread and abundant than in other years (see Figure 43).

There was also no trend in random site offshore catch rates of all blue cod between 2012 and 2016 which were similar to those from fixed sites, but with larger confidence intervals (see Figure 38). The proportion of random sites with zero catch in 2016 was three times that of fixed sites, reflecting the positioning of some sites in less than optimum blue cod habitat (see Figure 43). The less precise estimates of abundance for random sites is partly the result of catching no blue cod from four sites.

Fixed site catch rates of blue cod from offshore are more than four times higher than those from inshore, and comparable to those from the most recent surveys of Otago, Foveaux Strait, and Dusky Sound (Ministry for Primary Industries 2016). The distance from Akaroa and Lyttelton limit recreational fishing effort and has probably contributed to the stability of the offshore stocks.

There were no trends in the fixed site or random site offshore length distributions or mean length, but in 2016 blue cod were larger in random sites resulting in a lower estimate of total mortality and hence a spawner-per-recruit ratio that indicated a lower exploitation rate than from fixed sites. The sex ratios for both fixed and random sites were close to parity, with indications of a slight trend towards more males (see Figure 42). As discussed above, blue cod are protogynous hermaphrodites and the offshore blue cod population sex and size structure is consistent with this reproductive strategy in which low fishing pressure favours a more balanced sex ratio.

4.5.3 Concluding remarks

The very high estimate of total mortality, truncated age composition, and strongly skewed sex ratio toward males, indicates that the Banks Peninsula inshore blue cod population is depleted and over-exploited. Further, as nearly all females and most males caught will be of sub-legal size (less than 30 cm), there is also likely to be substantial mortality through catch and return of undersize fish.

The strong blue cod 3 year old cohort and the weak 4 year old cohort observed inshore in April 2016, were also present in the age compositions in Kaikoura in December 2015, and Motunau in January 2016 (Beentjes & Page 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 Motunau, Kaikoura and Banks Peninsula inshore 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.

The offshore blue population, in contrast to inshore, have high catch rates, a wide size range of both males and females, balanced sex ratio, and are under-exploited relative to MPI's Fmsy target.

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Table 1: Effort and catch data for the 2016 Banks Peninsula fixed and random site blue cod potting surveys.

Stratum	Area (km)	Site type	*N* sets (sites) Phase 1	*N* sets (sites) Phase 2	*N* pots (stations)	Catch (blue cod) *N*	Catch (blue cod) kg	Depth (m) Mean	Depth (m) Range
1	7.96	Fixed	4		24	51	14	22.9	16–31
2	9.44	Fixed	6		36	185	49	30.3	17–40
3	7.96	Fixed	4		24	180	51	23.0	16–30
4	7.78	Fixed	7		42	166	51	18.8	8–40
5	8.15	Fixed	5		30	154	31	14.9	8–30
6	16.67	Fixed	3	4	42	244	256	84.3	80–90
7	16.67	Fixed	6	1	42	284	214	76.7	72–82
Total	**74.63**	**Fixed**	**35**	**5**	**240**	**1 264**	**665**	**42.5**	**8–90**

Stratum	Area (km^2)	Site type	*N* sets (sites) Phase 1	*N* sets (sites) Phase 2	*N* pots (stations)	Catch (blue cod) *N*	Catch (blue cod) kg	Depth (m) Mean	Depth (m) Range
1	6.57	Random	4		24	18	11	21.2	13–30
2	5.26	Random	4		24	64	23	31.9	12–40
3	5.68	Random	4		24	62	22	24.0	20–29
4	4.39	Random	4		24	13	3	16.3	9–22
5	4.69	Random	4		24	10	2	13.2	5–17
6	8.32	Random	4		24	83	109	87.5	82–93
7	35.07	Random	11	5	96	441	500	76.9	70–80
Total	**69.98**	**Random**	**35**	**5**	**240**	**691**	**670**	**50.2**	**5–93**

Table 2: Total catch and numbers of blue cod and bycatch species caught on the 2016 Banks Peninsula 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	1264	665	77.9
Banded Wrasse	*Notolabrus fucicola*	BPF	209	111.4	13.1
Scarlet wrasse	*Pseudolabrus miles*	SPF	88	29.2	3.4
Spotty	*Notolabrus celidotus*	STY	137	15.8	1.9
Common octopus	*Octopus maorum*	OCP	4	8.1	0.9
Sea perch	*Helicolenus percoides*	SPE	13	5.3	0.6
Girdled wrasse	*Notolabrus cinctus*	GPF	15	4.1	0.5
Southern conger	*Conger verreauxi*	CVR	1	4	0.5
Starfish	Asteroid	ASR	4	3.1	0.4
Carpet shark	*Cephaloscyllium isabella*	CAR	1	2.5	0.3
Blue moki	*Latridopsis ciliaris*	MOK	5	2.3	0.3
Maori chief	*Paranotothenia augustata*	MCH	1	1.2	0.1
Trumpeter	*Latris lineata*	TRU	2	1	0.1
Leatherjacket	*Meuschenia scaber*	LEA	1	0.3	0.0
Southern bastard cod	*Pseudophycis barbata*	SBR	1	0.3	0.0
Totals			1 746	853.6	

				Random sites	
Common name	Species	Code	Number	Catch (kg)	% catch
Blue cod	*Parapercis colias*	BCO	691	670.1	93.0
Banded Wrasse	*Notolabrus fucicola*	BPF	21	27.6	3.8
Scarlet wrasse	*Pseudolabrus miles*	SPF	21	7.5	1.0
Sea perch	*Helicolenus percoides*	SPE	5	4.1	0.6
Spotty	*Notolabrus celidotus*	STY	24	3.4	0.5
Tarakihi	*Nemadactylus macropterus*	NMP	19	3.1	0.4
Girdled wrasse	*Notolabrus cinctus*	GPF	7	2.8	0.4
Crab		CRB	97	1.1	0.2
Red cod	*Pseudophycis bachus*	RCO	5	0.5	0.1
Totals			890	720.2	

Table 3: Mean catch rates for all blue cod, and recruited blue cod (30 cm and over) from the 2016 Banks 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		
Stratum	Area	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
1	Inshore	Fixed	24	0.57	0.15	26.5	0.09	0.05	60.6
2	Inshore	Fixed	36	1.35	0.38	28.2	0.22	0.07	33.8
3	Inshore	Fixed	24	2.12	0.41	19.3	0.82	0.45	54.4
4	Inshore	Fixed	42	1.22	0.28	23.4	0.46	0.17	36.2
5	Inshore	Fixed	30	1.03	0.35	33.7	0.33	0.11	33.5
Overall	**Inshore**	**Fixed**	**156**	**1.26**	**0.15**	**11.8**	**0.38**	**0.10**	**25.6**
6	Offshore	Fixed	42	6.10	1.09	17.8	5.89	1.11	18.9
7	Offshore	Fixed	42	5.09	1.14	22.5	4.49	1.16	25.8
Overall	**Offshore**	**Fixed**	**84**	**5.60**	**0.79**	**14.1**	**5.19**	**0.80**	**15.5**

									Random sites survey
				All blue cod			Recruited blue cod		
Stratum		Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
1	Inshore	Random	24	0.45	0.23	50.1	0.09	0.09	100
2	Inshore	Random	24	0.94	0.33	34.8	0.16	0.09	53.5
3	Inshore	Random	24	0.92	0.36	39.3	0.28	0.14	52.0
4	Inshore	Random	24	0.13	0.13	100.0	0.00	0.00	NA
5	Inshore	Random	24	0.09	0.07	82.1	0.00	0.00	NA
Overall	**Inshore**	**Random**	**120**	**0.53**	**0.12**	**22.2**	**0.11**	**0.04**	**36.6**
6	Offshore	Random	24	4.54	1.80	39.7	4.49	1.81	40.4
7	Offshore	Random	96	5.21	1.15	22.1	4.99	1.10	22.1
Overall	**Offshore**	**Random**	**120**	**5.08**	**0.99**	**19.5**	**4.90**	**0.96**	**19.5**

Table 4: Weighted mean lengths for the 2016 Banks Peninsula 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 (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
1	Fixed	m	37	26.3	14.5	40.8	72.5	100
		f	14	23.8	14.2	27.4		
		u	0	–				
2	Fixed	m	123	26.6	16.1	41.1	66.5	100
		f	62	23.2	17.5	28.4		
		u	0	–				
3	Fixed	m	121	26.5	15.1	43.5	67.3	88.0
		f	59	23.1	18.8	31.5		
		u	0	–				
4	Fixed	m	116	27.0	15.9	43.3	69.9	83.3
		f	50	23.8	15.5	40.0		
		u	0	–				
5	Fixed	m	100	25.9	14.8	41.6	64.7	89.0
		f	54	23.2	17.8	35.0		
		u	0	–				
6	Fixed	m	148	38.7	20.4	55.2	60.6	60.1
		f	96	36.2	20.4	50.4		
		u	0	–				
7	Fixed	m	196	35.4	21.1	51.8	69.0	76.8
		f	88	30.9	18.6	46.1		
		u	0	–				
Inshore (1–5)	Fixed	m	497	26.5	14.5	43.5	67.5	89.5
		f	239	23.3	14.2	50.4		
		u	0	–				
Offshore (6–7)	Fixed	m	344	36.8	20.4	55.2	65.3	68.8
		f	184	33.6	18.6	50.4		
		u	0	–				
Overall (1–7)	Fixed	m	841	31.8	14.5	55.2	66.3	71.3
		f	423	28.8	14.2	50.4		
		u	0	–				

Table 4 – *continued*

				Random site survey				
				Length (cm)			Percent male	
Stratum	Site type	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited
1	Random	m	13	24.8	14.5	40.5	88.5	100
		f	5	22.0	19.5	23.8		
		u	0	–				
2	Random	m	50	26.5	14.1	40.9	78.7	100
		f	14	24.3	14.1	28.1		
		u	0					
3	Random	m	50	26.8	21.7	37.9	83.6	91.3
		f	12	24.4	21.5	30.2		
		u	0					
4	Random	m	10	25.8	23.9	29.6	76.9	100
		f	3	22.7	22.2	23.4		
		u	0					
5	Random	m	4	25.2	23.0	27.8	42.3	NA
		f	6	23.3	19.5	27.9		
		u	0					
6	Random	m	35	44.3	24.1	56.4	42.1	43.2
		f	48	39.1	20.6	49.4		
		u	0					
7	Random	m	264	41.0	20.0	57.2	60.2	64.7
		f	175	35.3	21.1	49		
		u	2	–	11.5	14.1		
Inshore (1–5)	Random	m	127	26.1	14.1	40.9	81.3	95.1
		f	40	23.8	14.1	30.2		
		u	0					
Offshore (6–7)	Random	m	299	41.3	20	57.2	57.5	61.2
		f	223	36.1	20.6	49.4		
		u	2	–	11.5	14.1		
Overall (1–7)	Random	m	426	37.1	14.1	57.2	62.6	62.2
		f	263	34.7	14.1	49.4		
		u	2	–	11.5	14.1		

Table 5: Otolith ageing data used in the catch-at-age, Z estimates and SPR analyses for the 2016 Banks Peninsula survey. Data presented for inshore and offshore strata.

			Length of aged fish (cm)		Age (years)	
Survey strata	Sex	No. otoliths	Minimum	Maximum	Minimum	Maximum
Inshore (1–5)	Male	207	14.1	43.5	1	8
	Female	97	14.1	40.0	1	6
	Total	304	14.1	43.5	1	8
Offshore (6–7)						
	Male	256	20	57.2	3	27
	Female	197	18.6	50.4	3	29
	Total	453	18.6	57.2	3	29

Table 6: Gonad stages of blue cod from Banks Peninsula in April 2016 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*
Inshore	Males	84.0	12.7	0.0	0.0	3.4	624
	Females	67.4	32.3	0.0	0.0	0.4	279
Offshore	Males	35.0	2.8	0.6	3.6	57.9	642
	Females	37.1	11.5	5.2	0.0	46.2	407

Table 7: Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals of blue cod for the fixed and random site 2016 Banks Peninsula inshore and offshore potting surveys. AgeR, age at full recruitment (years).

		Fixed site survey (Inshore)	
		95% CIs	
AgeR	*Z*	Lower	Upper
5	1.02	0.58	1.66
6	1.87	0.96	2.58
7	1.14	0.42	1.62
8	NA	NA	NA
9	NA	NA	NA
10	NA	NA	NA

		Random site survey (Inshore)	
		95% CIs	
AgeR	*Z*	Lower	Upper
5	1.05	0.52	1.89
6	2.24	1.05	2.61
7	NA	NA	NA
8	NA	NA	NA
9	NA	NA	NA
10	NA	NA	NA

		Fixed site survey (Offshore)	
		95% CIs	
AgeR	*Z*	Lower	Upper
5	0.22	0.17	0.29
6	0.26	0.19	0.34
7	0.21	0.16	0.28
8	0.26	0.19	0.33
9	0.30	0.22	0.4
10	0.23	0.17	0.3

		Random site survey (Offshore)	
		95% CIs	
AgeR	*Z*	Lower	Upper
5	0.17	0.12	0.21
6	0.19	0.14	0.24
7	0.17	0.13	0.21
8	0.20	0.15	0.26
9	0.22	0.16	0.29
10	0.19	0.14	0.24

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 6 years for blue cod from the 2016 Banks Peninsula fixed and random site inshore and offshore potting surveys. AgeR is the age at which females reach MLS of 30 cm. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality.

			Fixed site survey (Inshore)	
AgeR	*M*	*Z*	*F*	$F_{\%SPR}$
6	0.11	1.87	1.76	$F_{3.3\%}$
6	0.14	1.87	1.73	$F_{4.7\%}$
6	0.17	1.87	1.70	$F_{6.2\%}$

			Random site survey (Inshore)	
AgeR	*M*	*Z*	*F*	$F_{\%SPR}$
6	0.11	2.24	2.13	$F_{3.0\%}$
6	0.14	2.24	2.10	$F_{4.3\%}$
6	0.17	2.24	2.07	$F_{5.7\%}$

			Fixed site survey (offshore)	
AgeR	*M*	*Z*	*F*	$F_{\%SPR}$
6	0.11	0.26	0.15	$F_{28.8\%}$
6	0.14	0.26	0.12	$F_{40.7\%}$
6	0.17	0.26	0.09	$F_{53.9\%}$

			Random site survey (Offshore)	
AgeR	*M*	*Z*	*F*	$F_{\%SPR}$
6	0.11	0.19	0.08	$F_{45.5\%}$
6	0.14	0.19	0.05	$F_{64.2\%}$
6	0.17	0.19	0.02	$F_{85.5\%}$

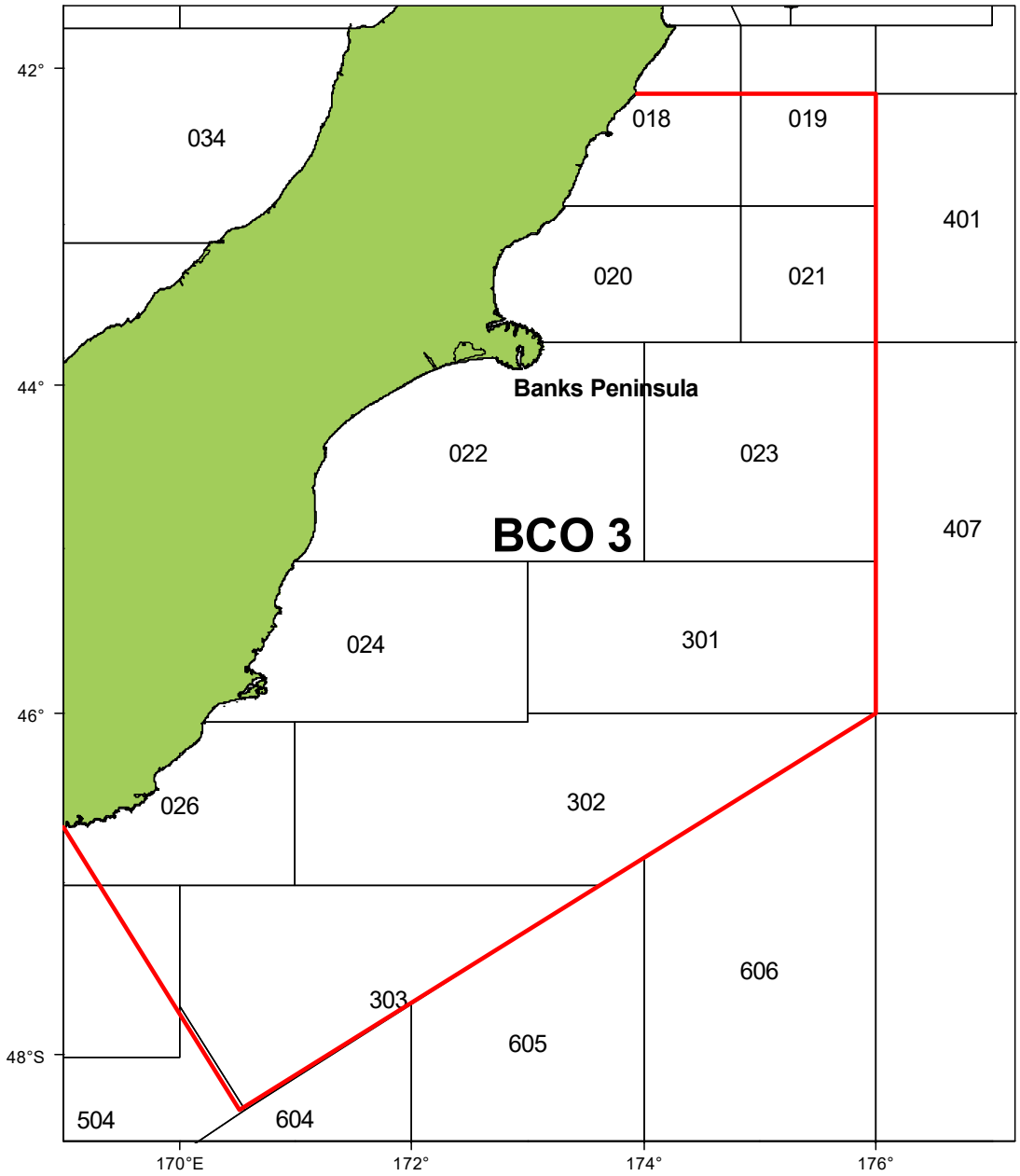

Figure 1: Blue cod Quota Management Area BCO 3 (red border) and statistical areas.

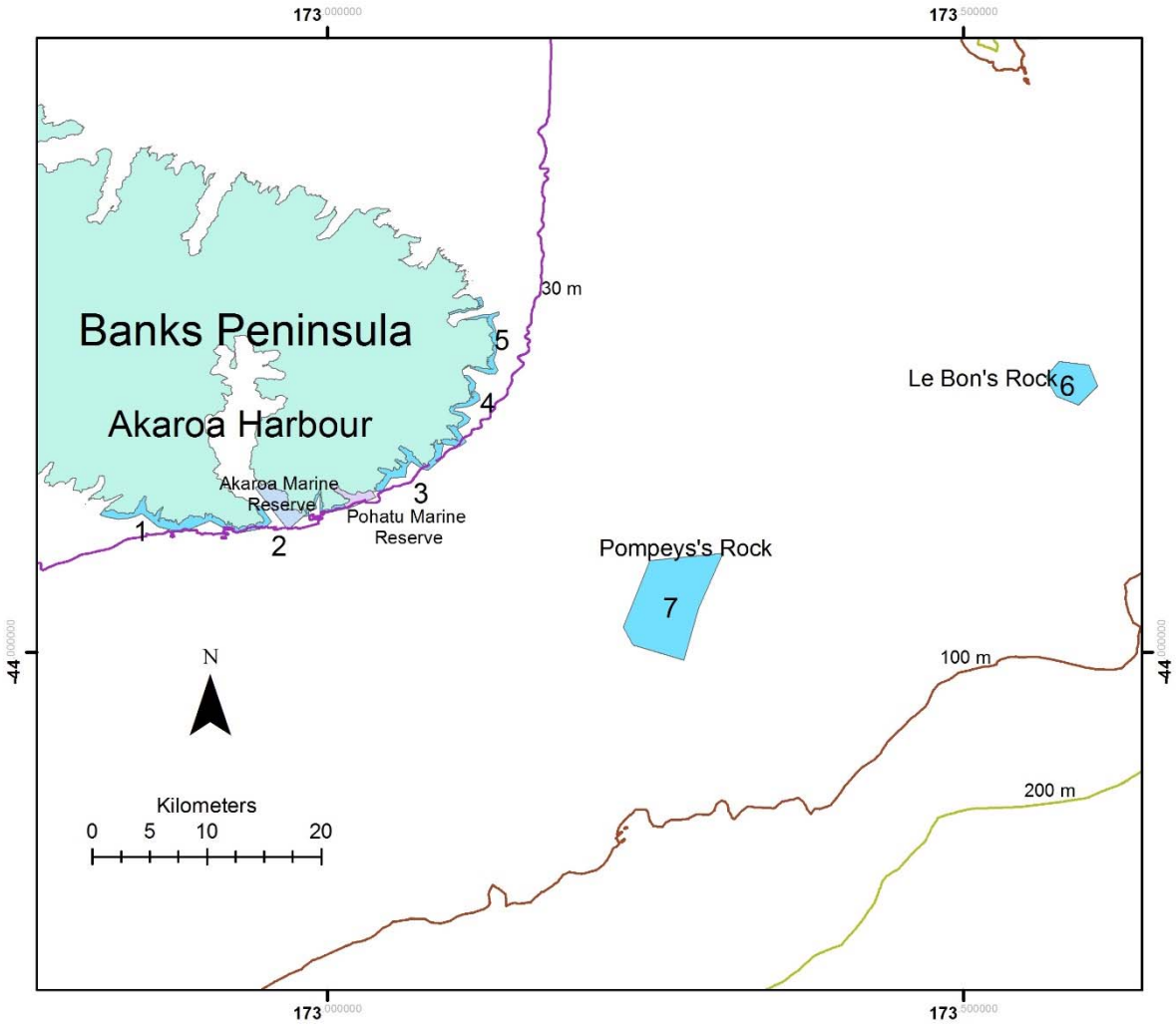

Figure 2: Map of Banks Peninsula potting survey of inshore strata (1–5) and offshore strata (6 and 7). Fixed site survey areas are the length (km) of coastline within each inshore stratum, and three times the length of the longest side of each stratum for offshore strata (fixed site polygons for offshore strata are smaller than shown). Random site survey areas are the areas (km^2) within the strata polygons.

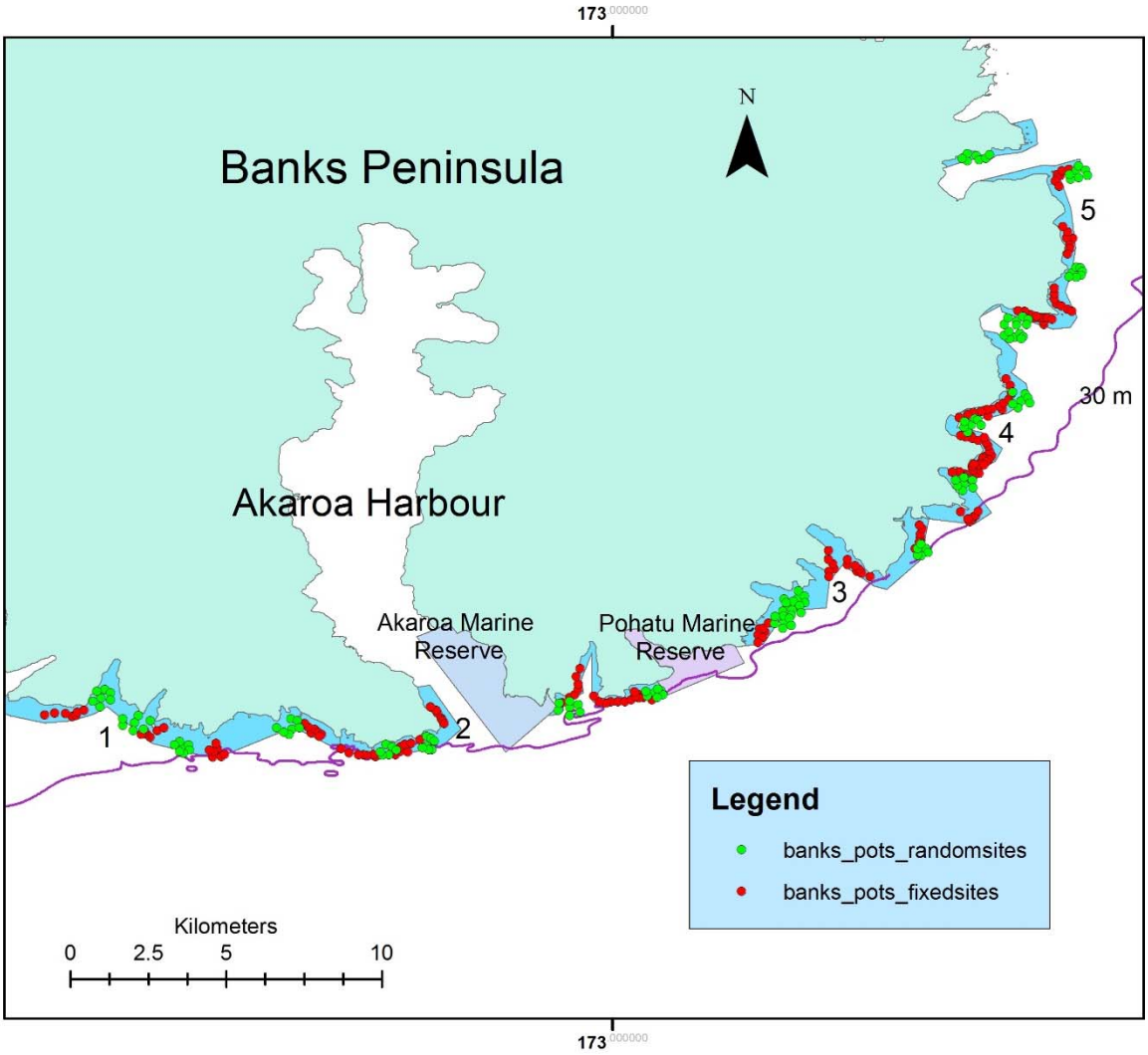

Figure 3: Map of Banks Peninsula inshore strata (1–5), and pot locations for the fixed and random sites surveyed in 2016.

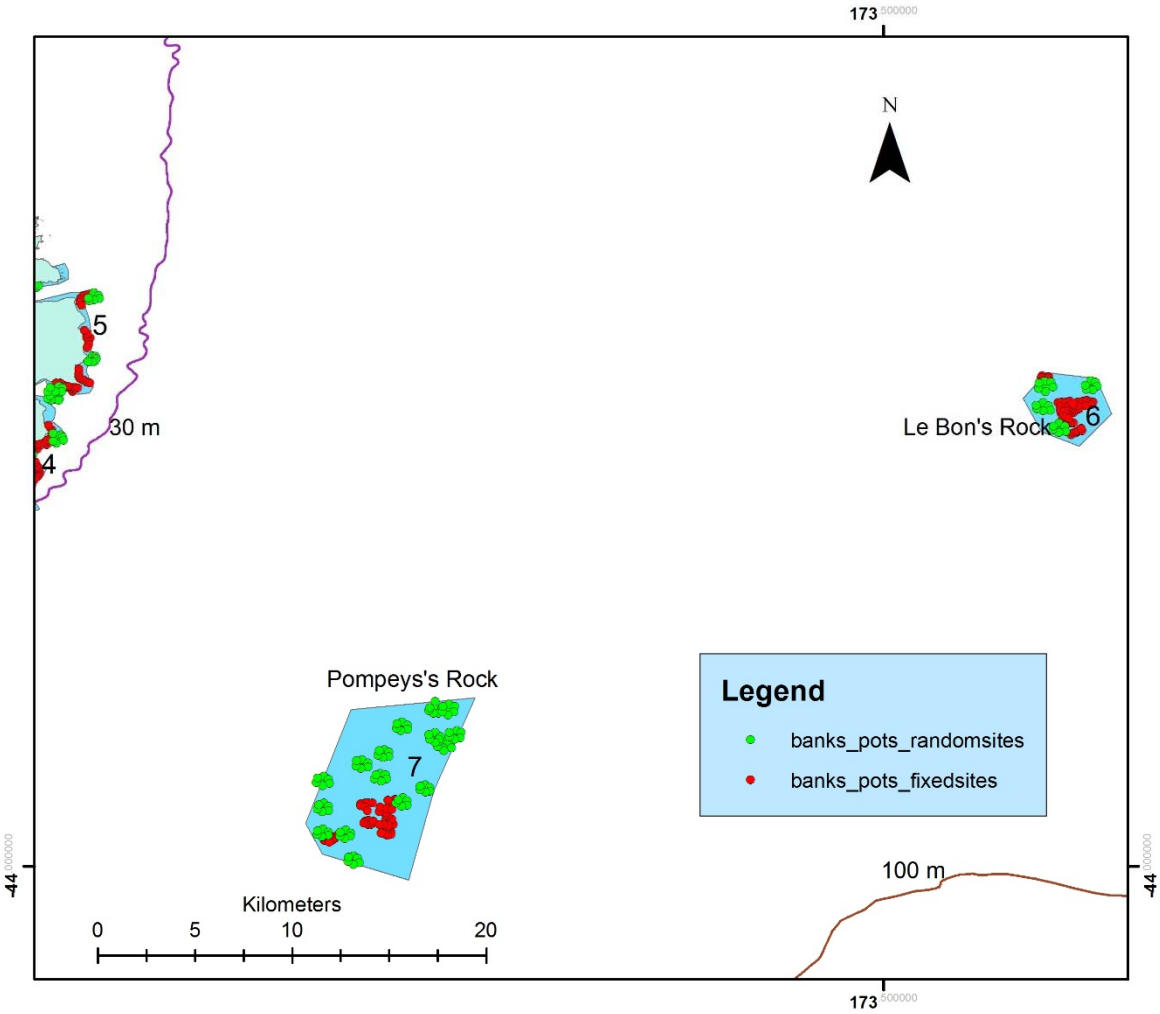

Figure 4: Map of Banks Peninsula offshore strata (6–7), and pot locations for the fixed and random sites surveyed in 2016.

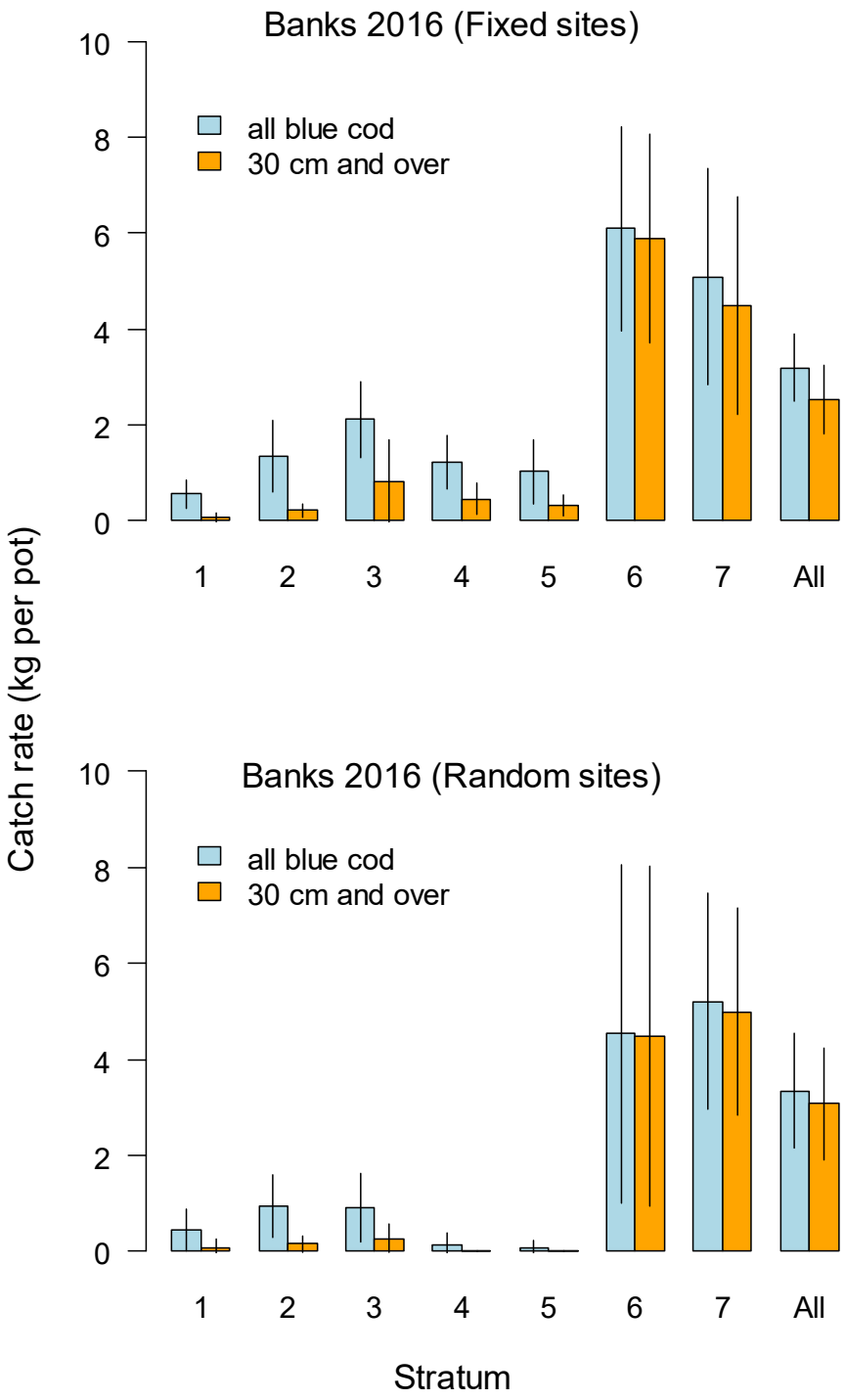

Figure 5: Catch rates (kg.pot^{-1}) of all blue cod and recruited blue cod (30 cm and over) for the 2016 Banks Peninsula fixed site (top panel) and random site (bottom panel) surveys for all strata (inshore and offshore). Error bars are 95% confidence intervals. See Figure 2 for location of strata.

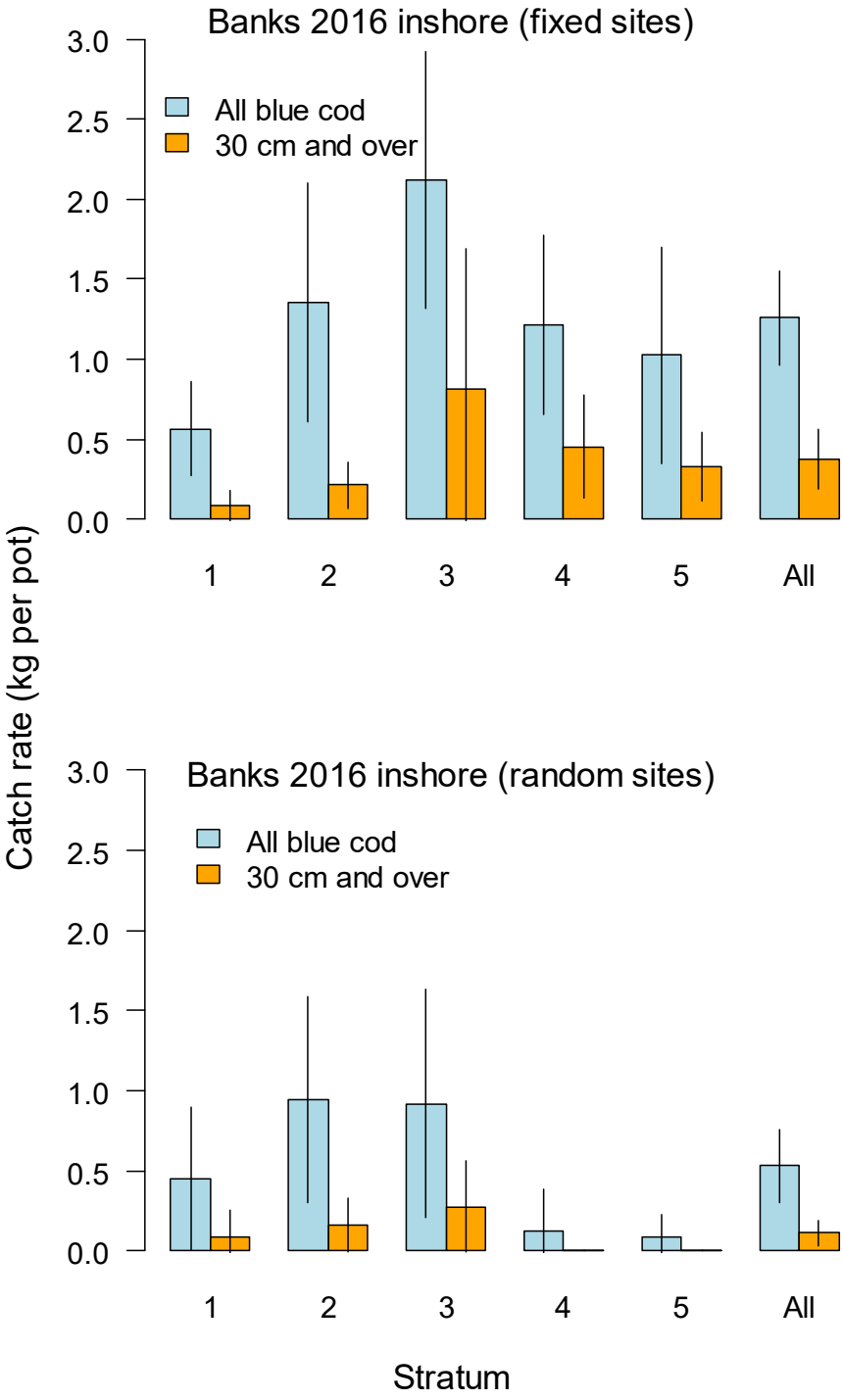

Figure 6: Catch rates (kg.pot^{-1}) of all blue cod and recruited blue cod (30 cm and over) for the 2016 Banks Peninsula inshore fixed site (top panel) and inshore random site (bottom panel) surveys. Error bars are 95% confidence intervals. See Figure 2 for location of strata.

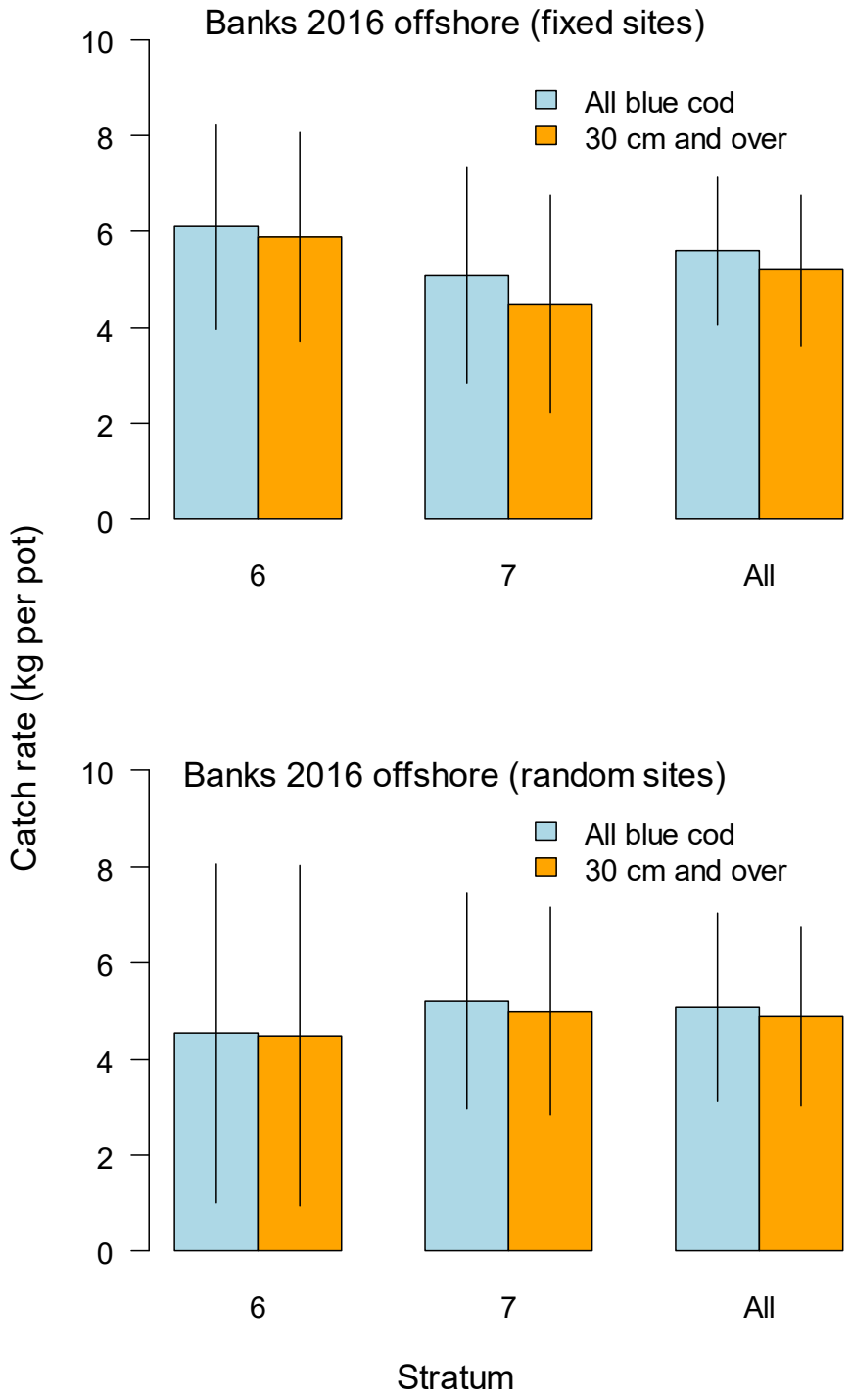

Figure 7: Catch rates (kg.pot^{-1}) of all blue cod and recruited blue cod (30 cm and over) for the 2016 Banks Peninsula offshore fixed site (top panel) and offshore random site (bottom panel) surveys. Error bars are 95% confidence intervals. See Figure 2 for location of strata.

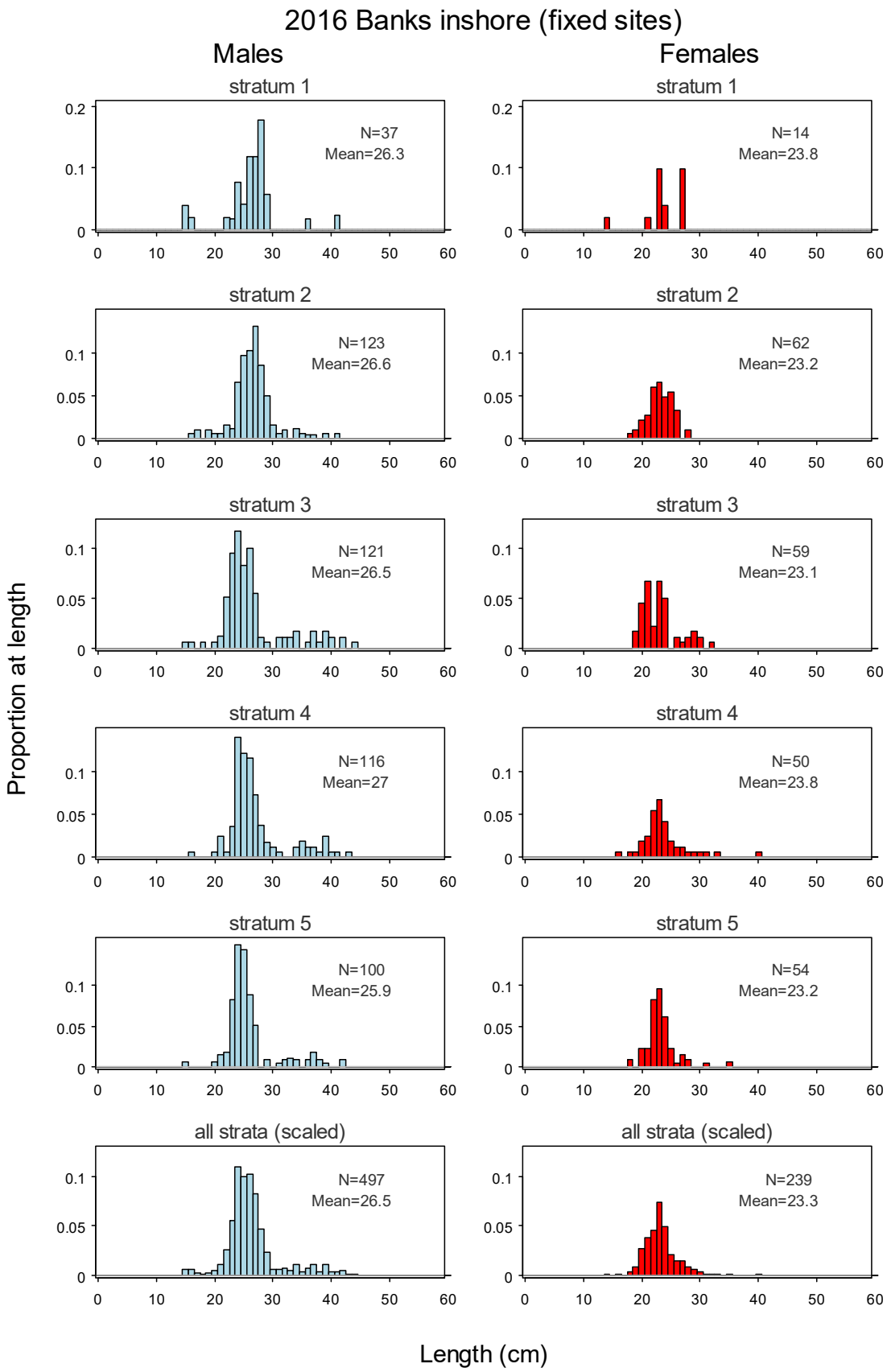

Figure 8: Scaled length frequency distributions by strata and overall for the 2016 Banks Peninsula inshore (1 –5) fixed site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum.

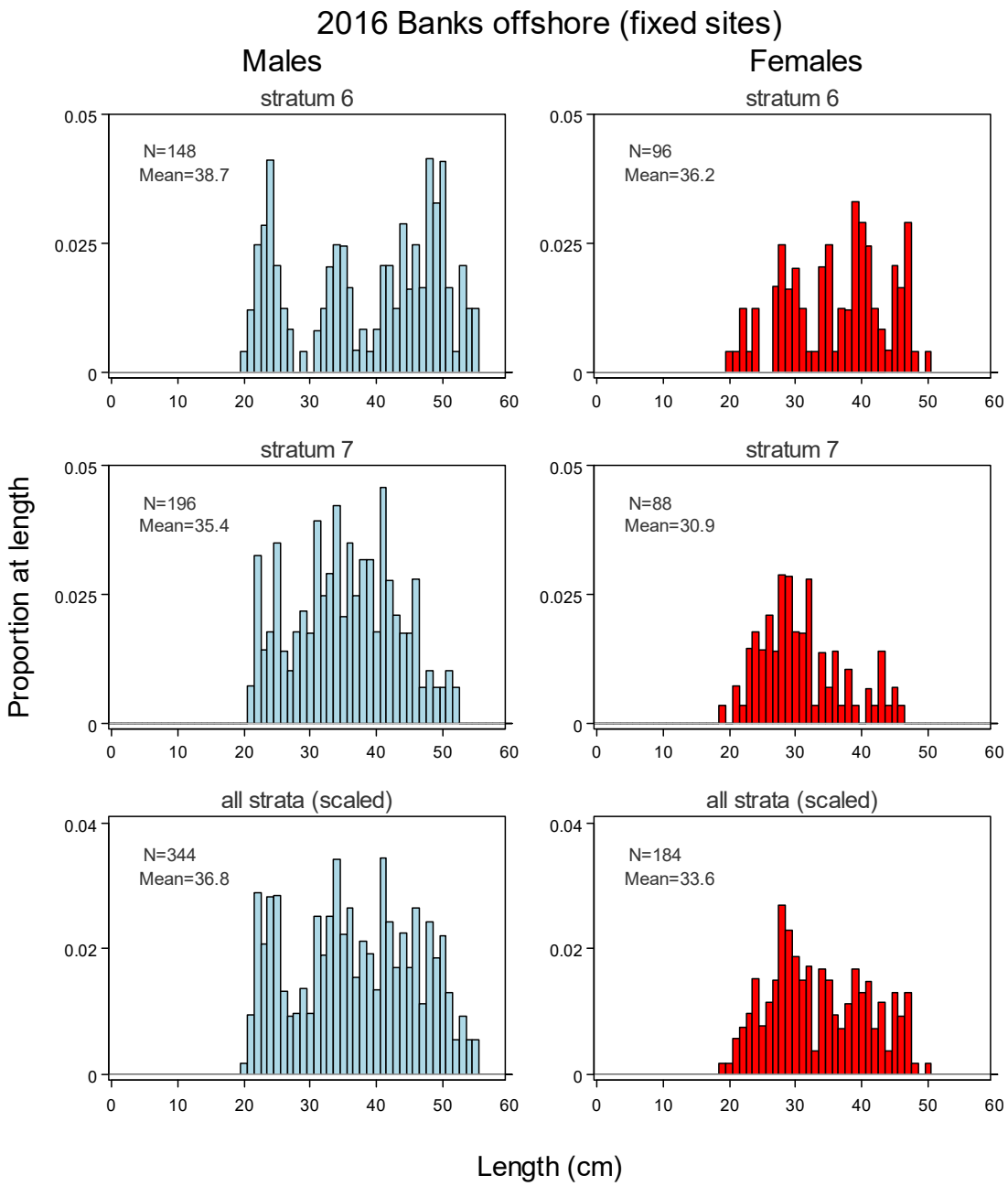

Figure 9: Scaled length frequency distributions by strata and overall for the 2016 Banks Peninsula offshore (6 –7) fixed site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum.

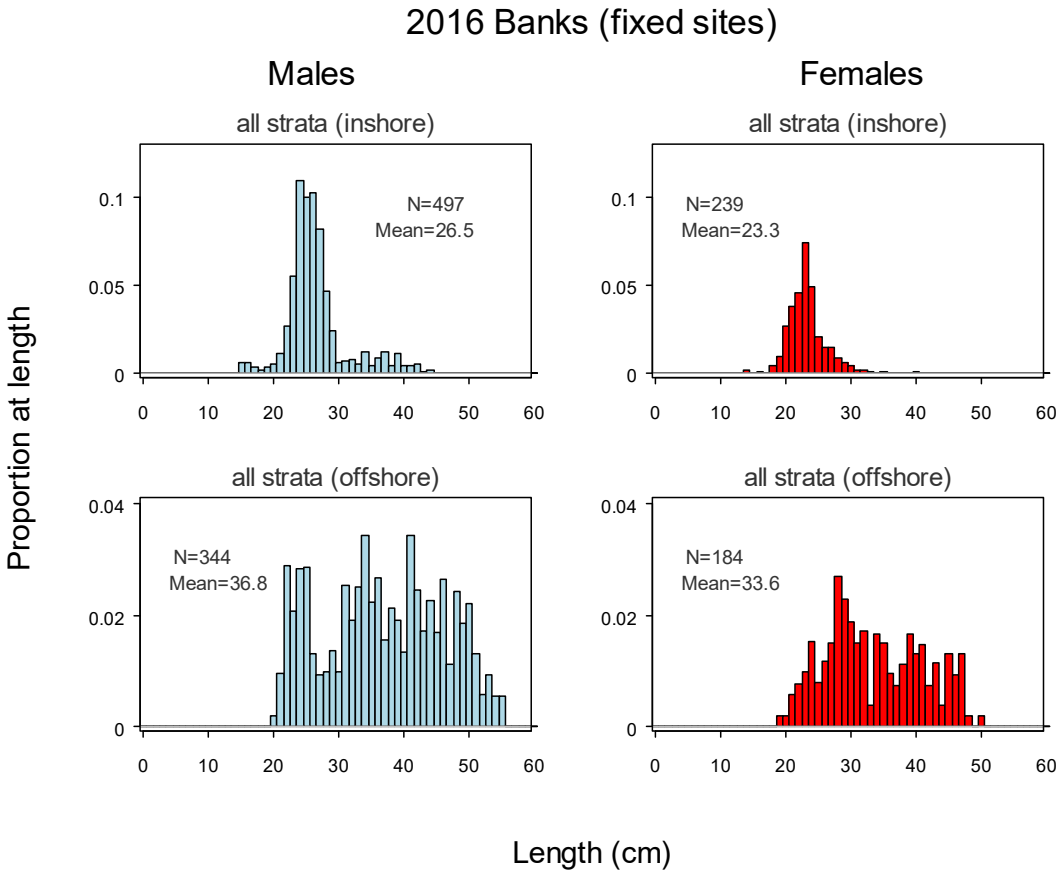

Figure 10: Scaled length frequency distributions overall for the 2016 Banks Peninsula inshore strata (1–5) and offshore strata (6 –7) fixed site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum.

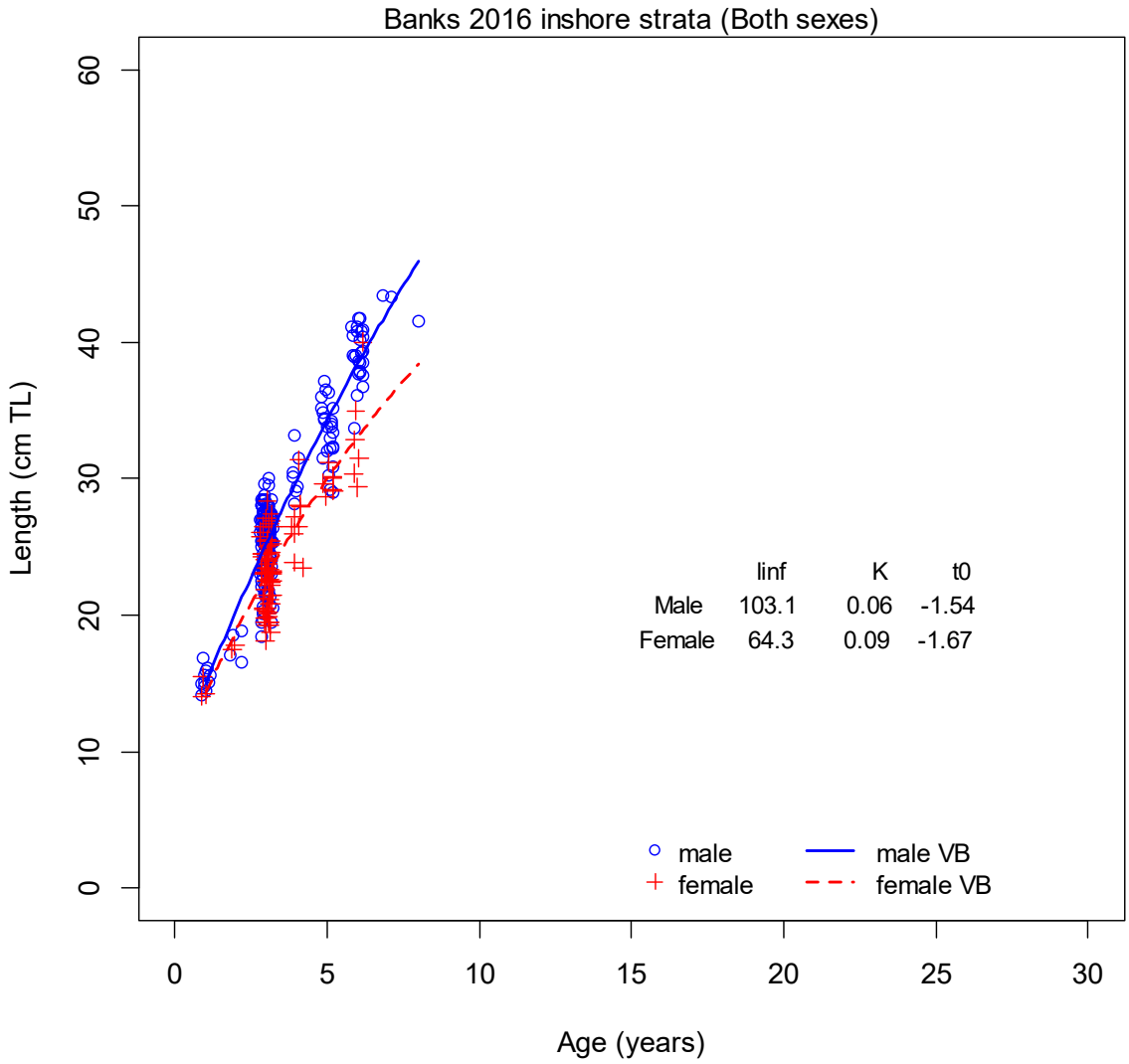

Figure 11: Observed blue cod age and length data by sex for the 2016 Banks Peninsula inshore (strata 1 –5) potting survey with von Bertalanffy (VB) growth models fitted to the data. N= 207 males and 97 females.

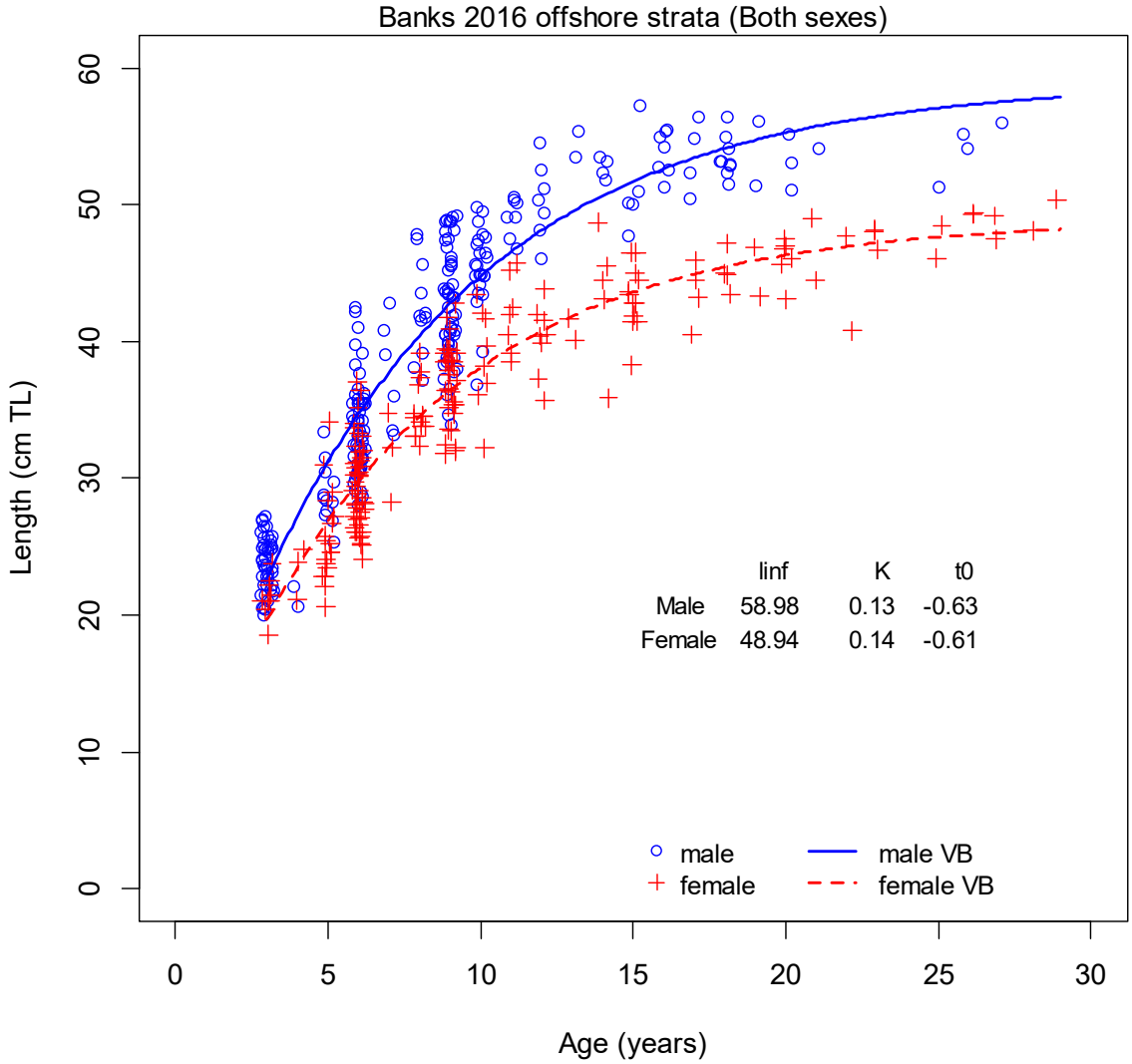

Figure 12: Observed blue cod age and length data by sex for the 2016 Banks Peninsula offshore (strata 6–7) potting survey with von Bertalanffy (VB) growth models fitted to the data. N= 256 males and 197 females.

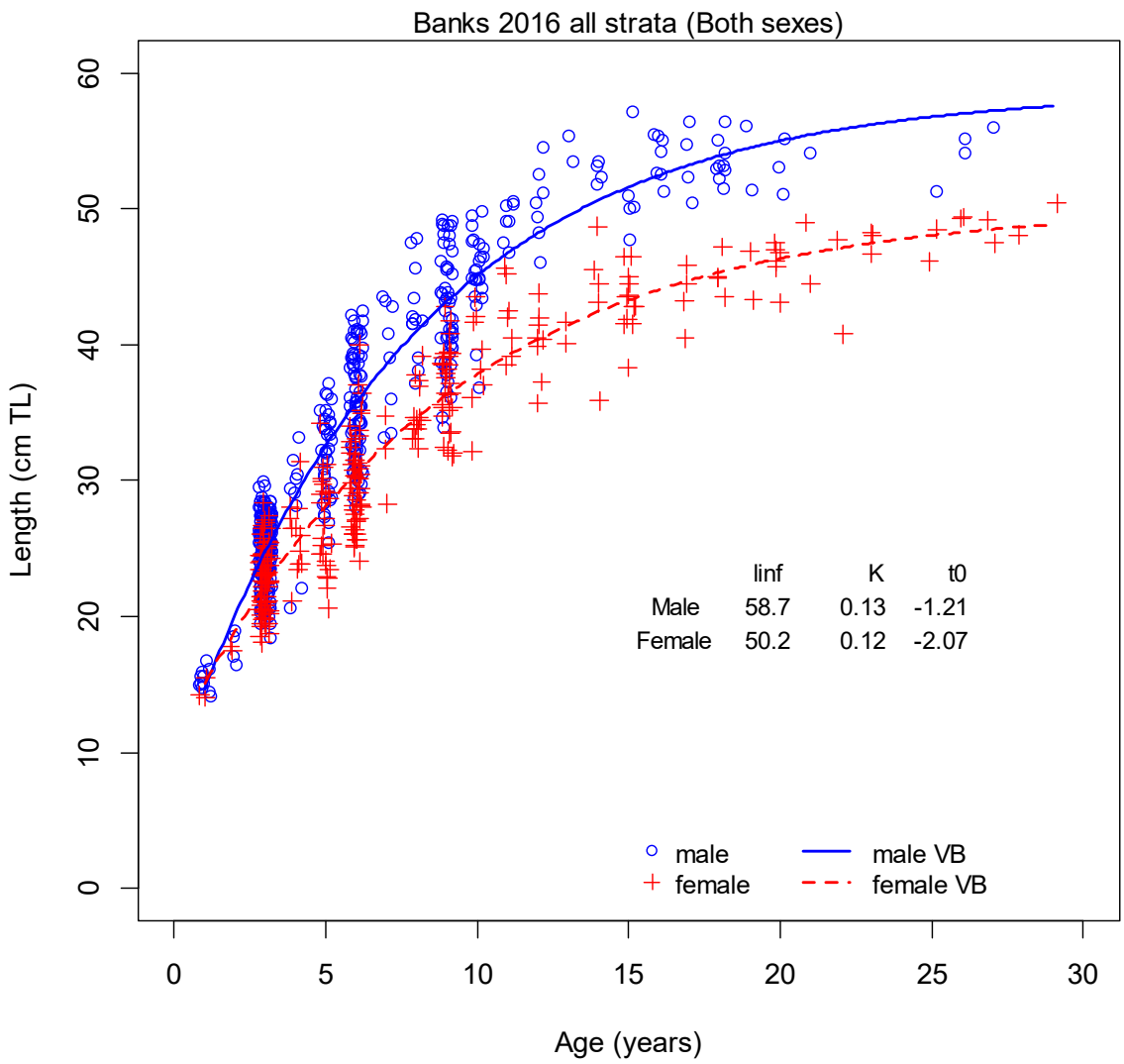

Figure 13: Observed blue cod age and length data by sex for the 2016 Banks Peninsula inshore and offshore (strata 1 –7) potting survey with von Bertalanffy (VB) growth models fitted to the data. N= 463 males and 294 females.

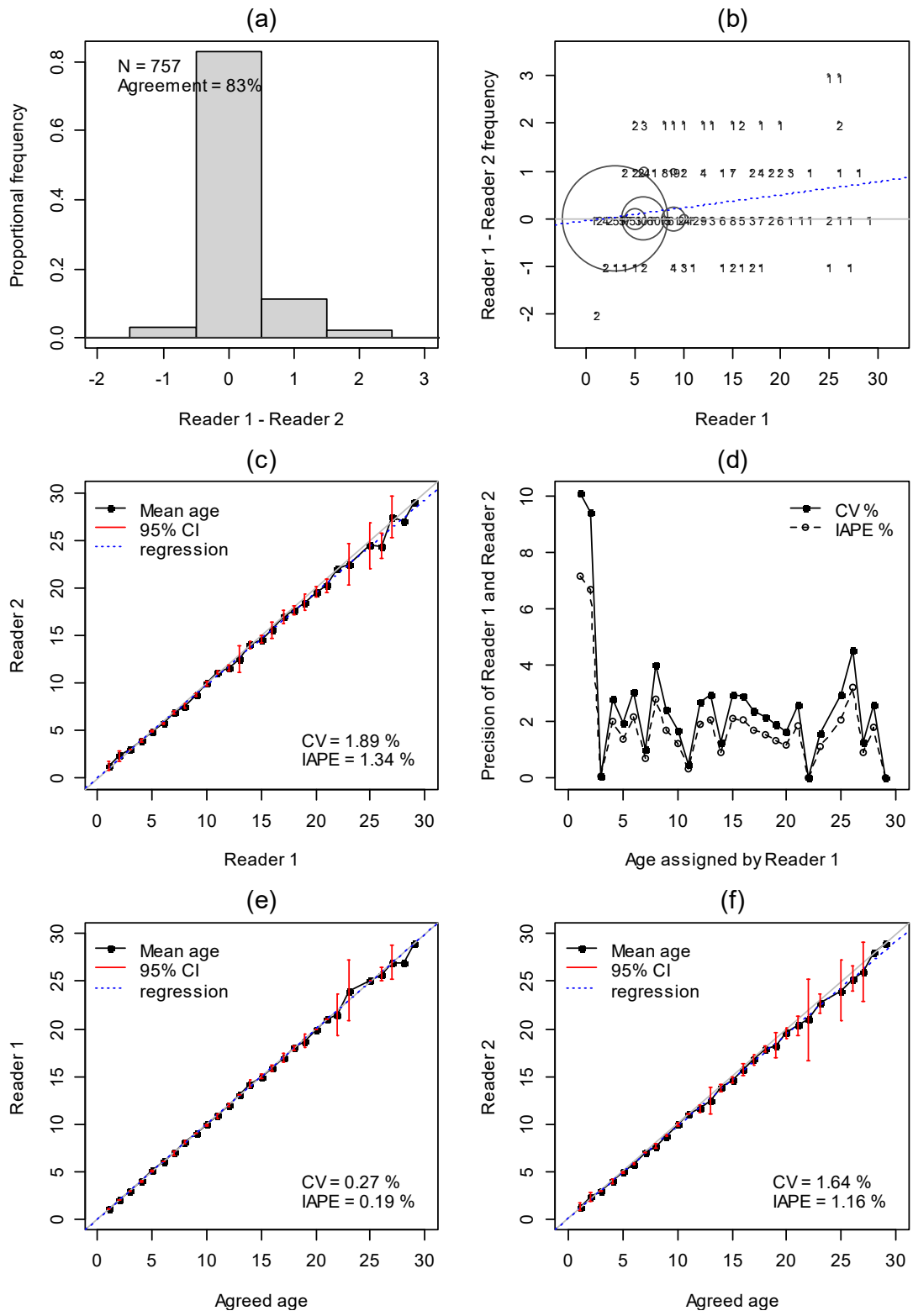

Figure 14: Blue cod age otolith reader comparison plots between reader 1 and reader 2 for the 2016 Banks Peninsula survey (inshore and offshore): (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the 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.

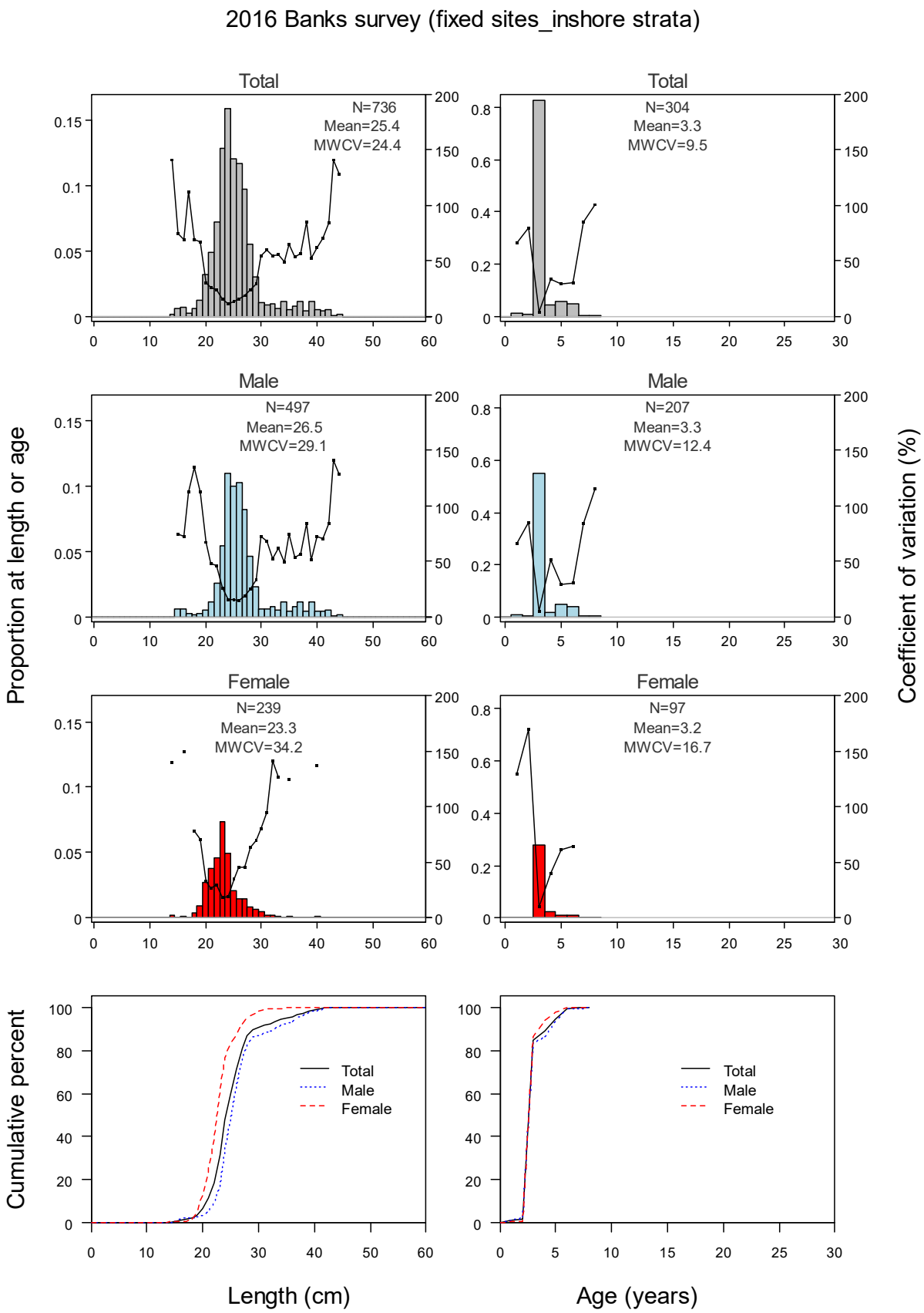

Figure 15: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2016 Banks Peninsula fixed site inshore (strata 1–5) blue cod potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

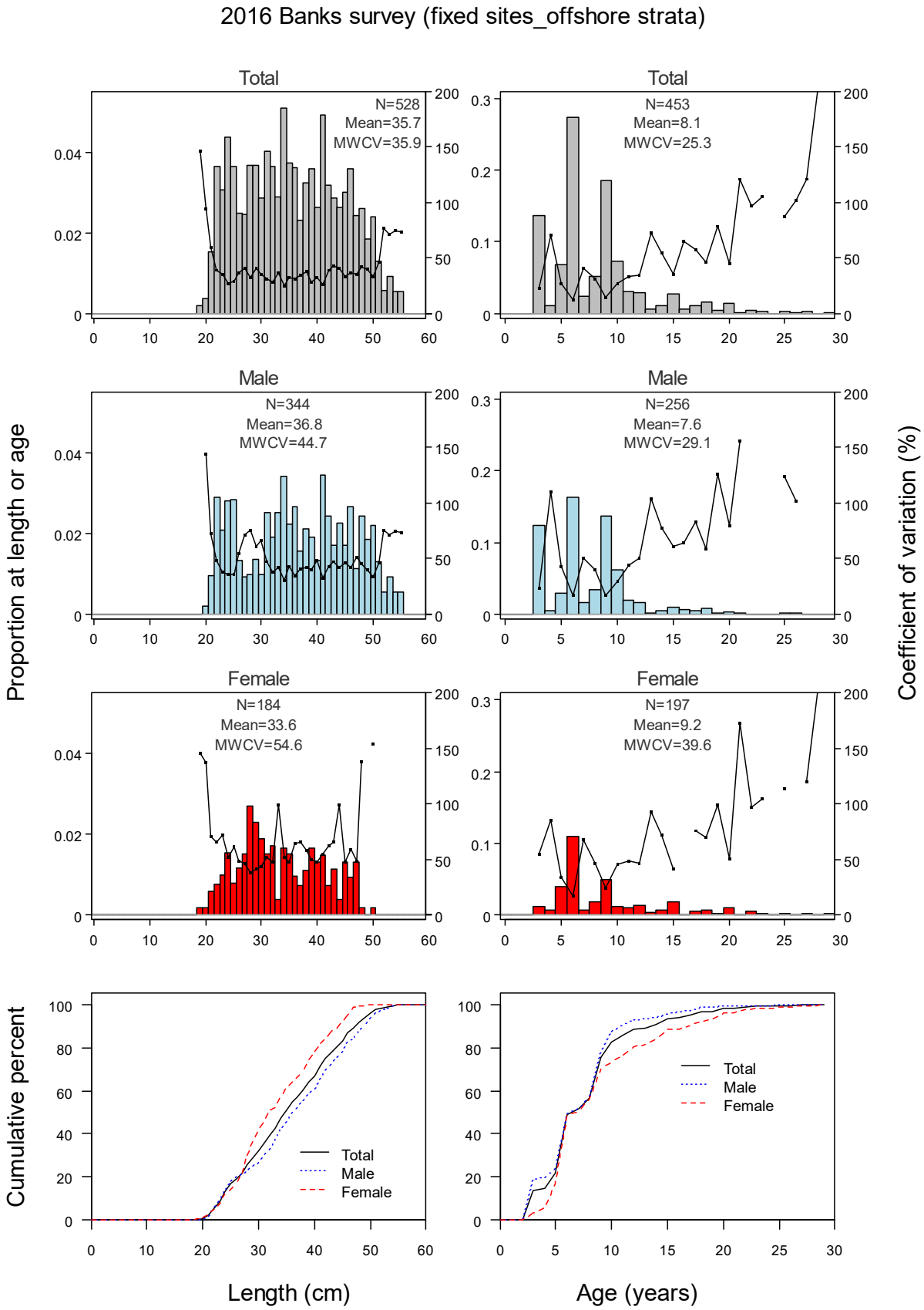

Figure 16: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2016 Banks Peninsula fixed site offshore (strata 6–7) blue cod potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

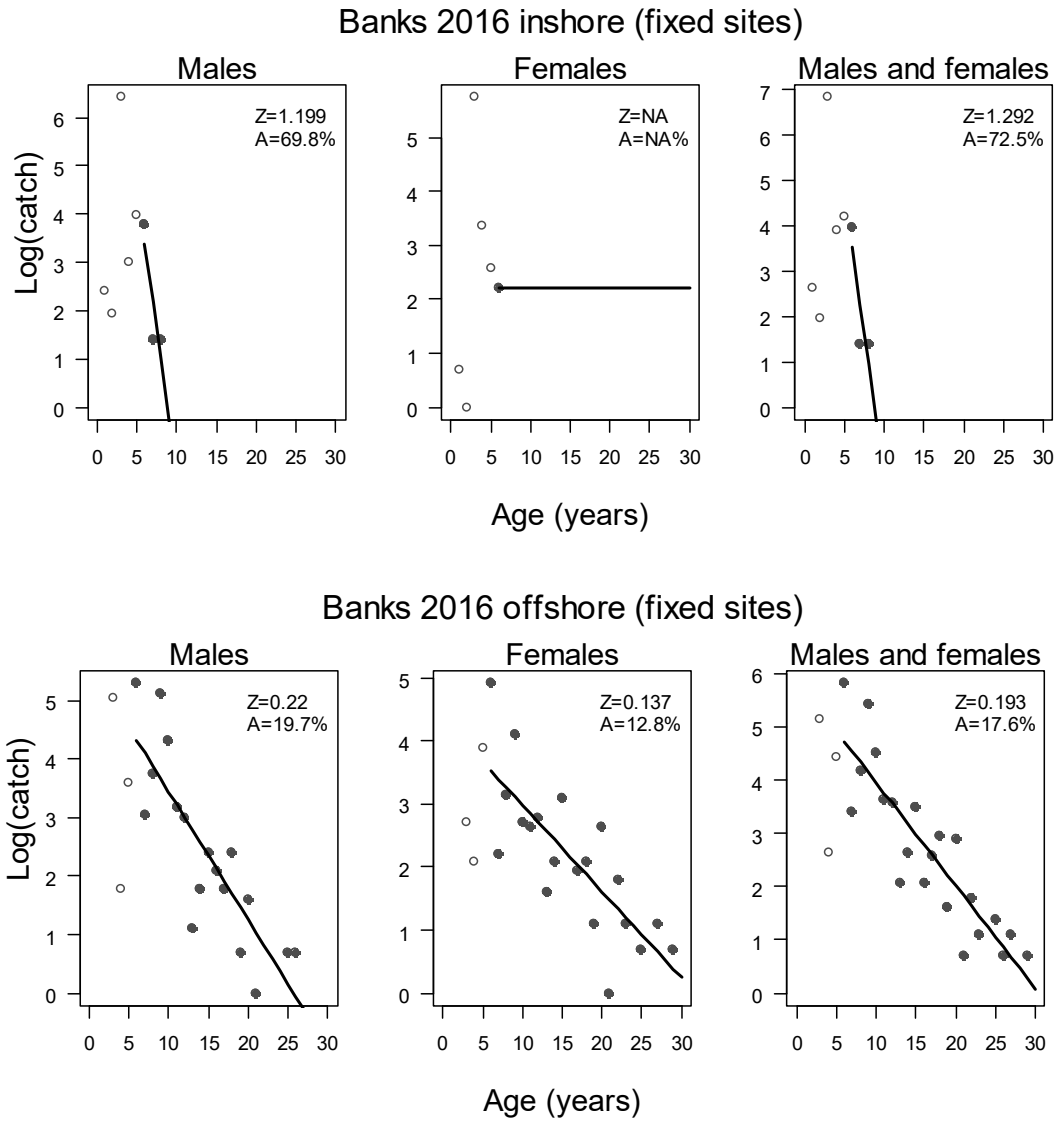

Figure 17: Banks Peninsula 2016 fixed site inshore (top panel) and offshore (bottom panel) survey catch curves (natural log of catch numbers versus age). The regression line is plotted from age at full recruitment of 6 years (i.e., dark points on the graph). Z, instantaneous total mortality; A, the annual mortality rate or the proportion of the population that suffers mortality in a given year.

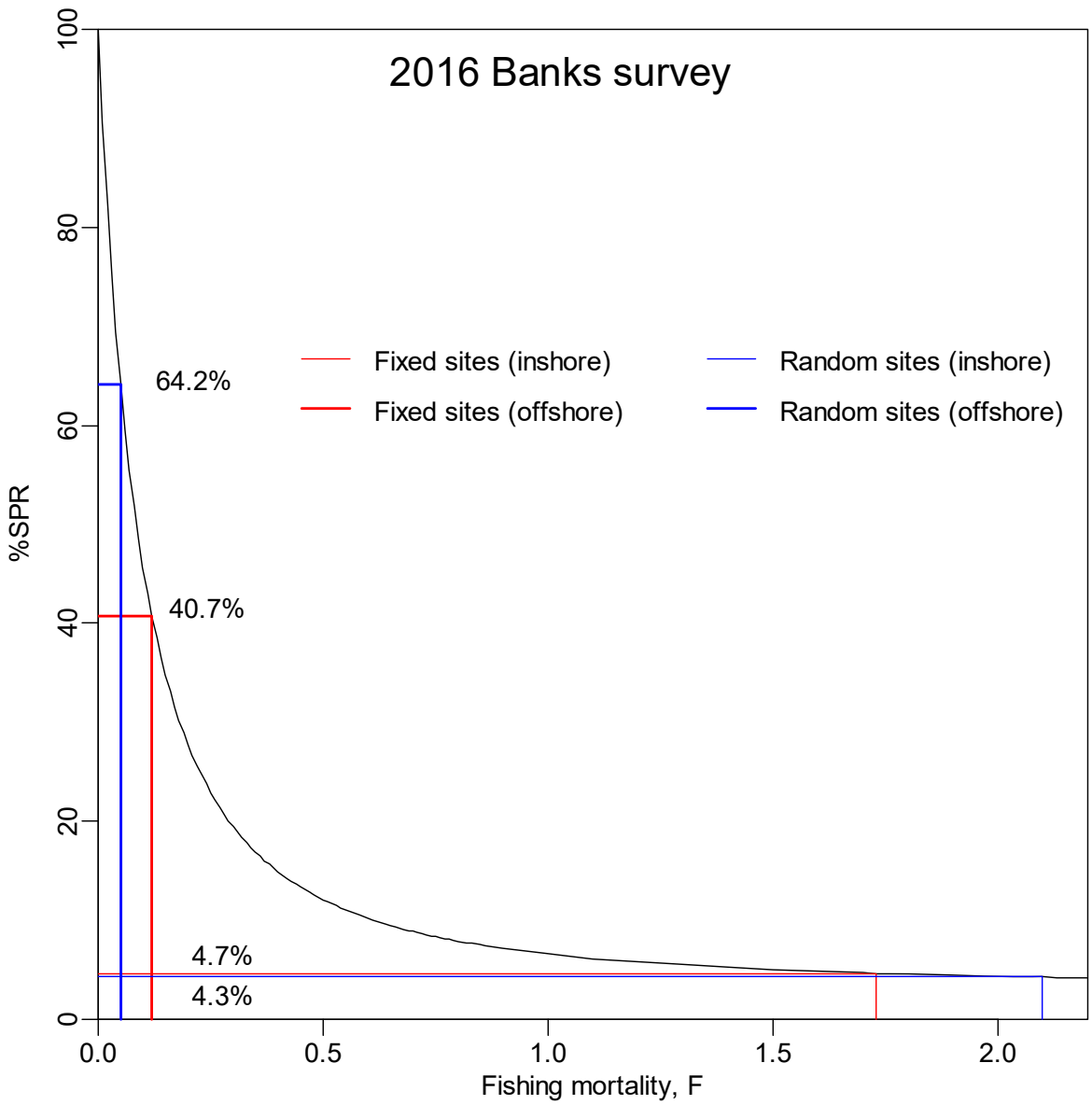

Figure 18: Spawner-per-recruit (SPR) as a function of fishing mortality (*F*) for 2016 Banks Peninsula fixed and random site surveys for inshore and offshore strata. The %SPR values corresponding to the *F* values are annotated on the plot. In this plot *M* = 0.14, and *F* value is for age of full recruitment equal to 6 years for females.

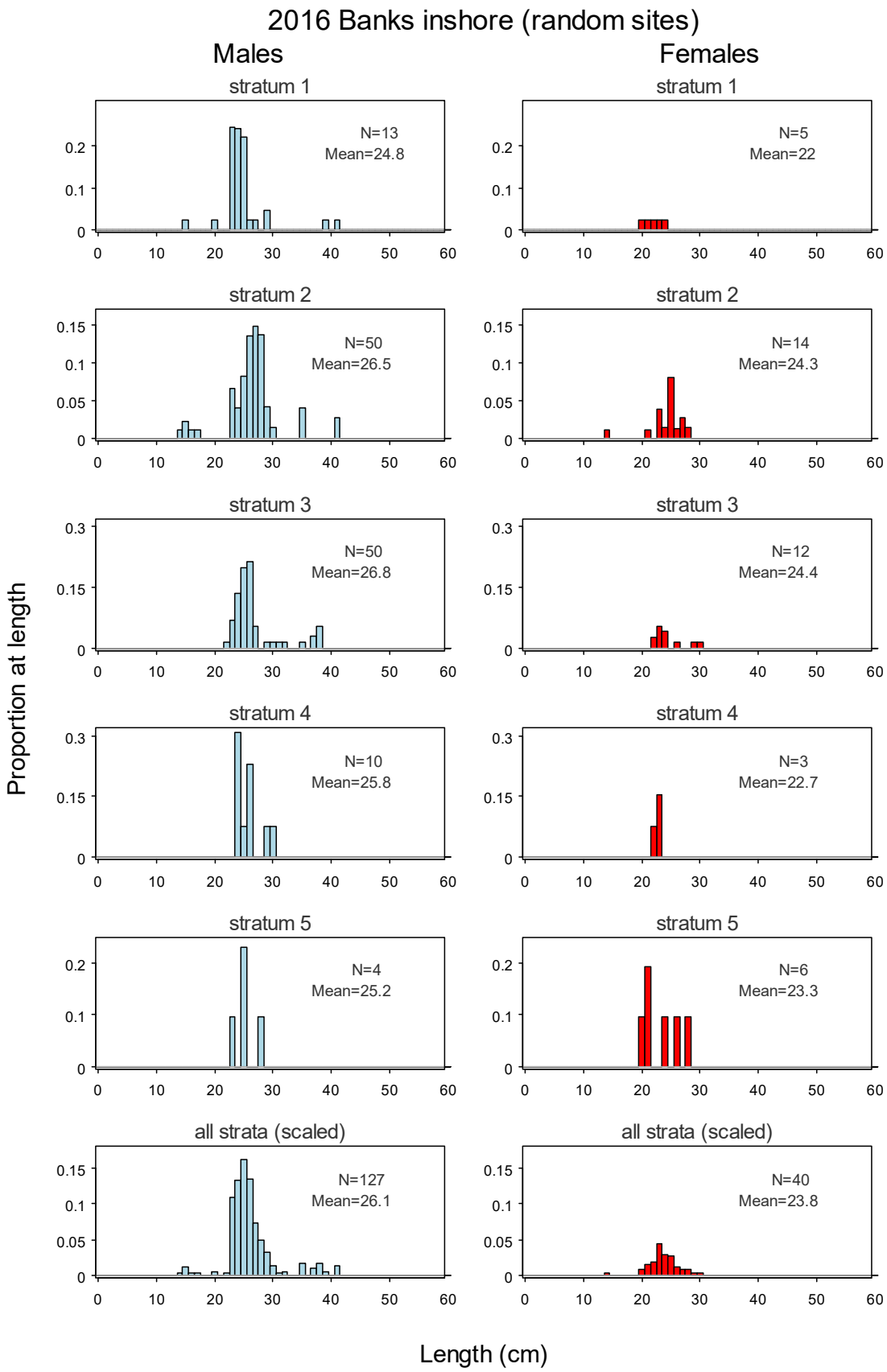

Figure 19: Scaled length frequency distributions by strata and overall for the 2016 Banks Peninsula inshore (strata 1–5) random site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum.

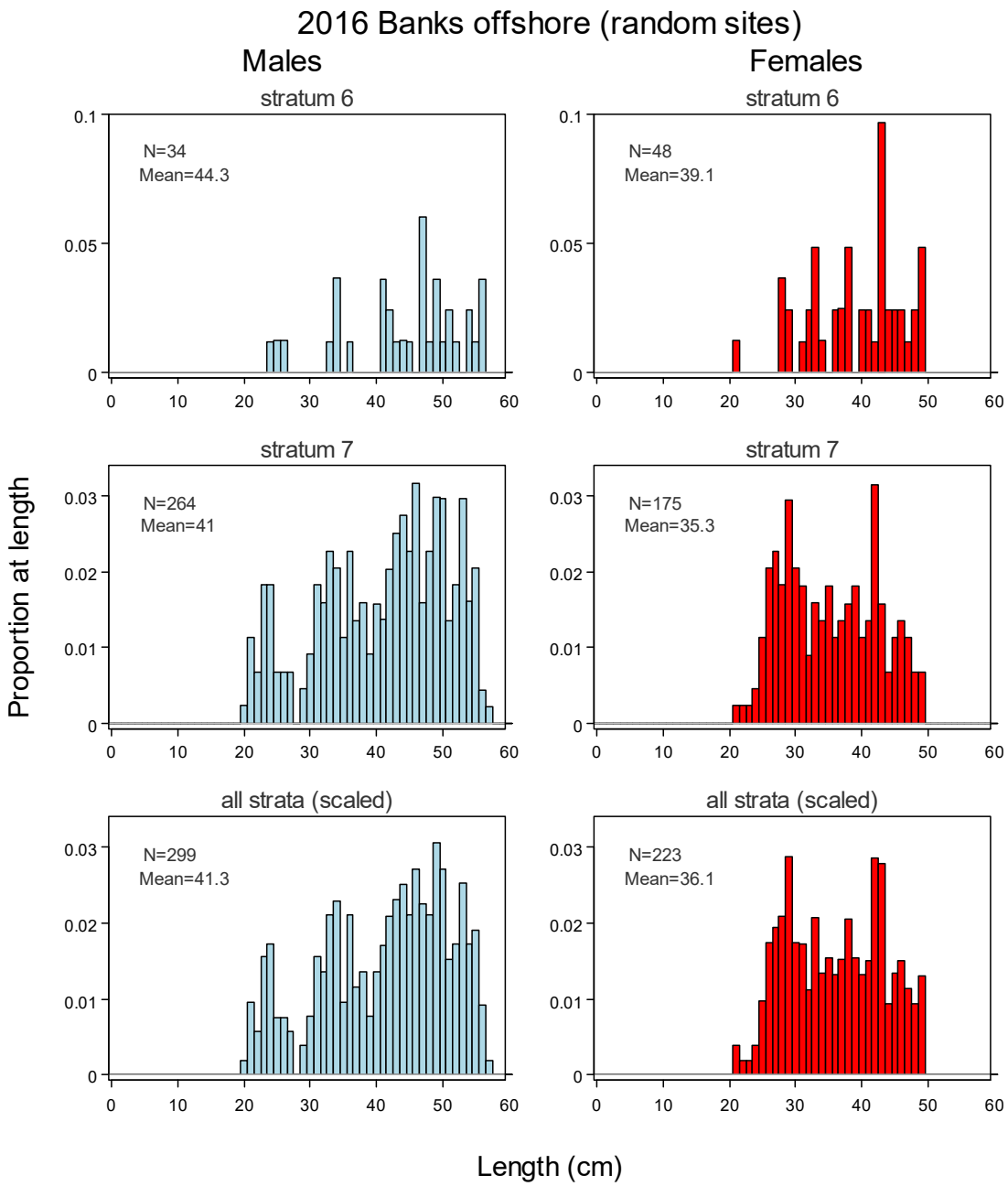

Figure 20: Scaled length frequency distributions by strata and overall for the 2016 Banks Peninsula offshore (strata 6–7) random site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum.

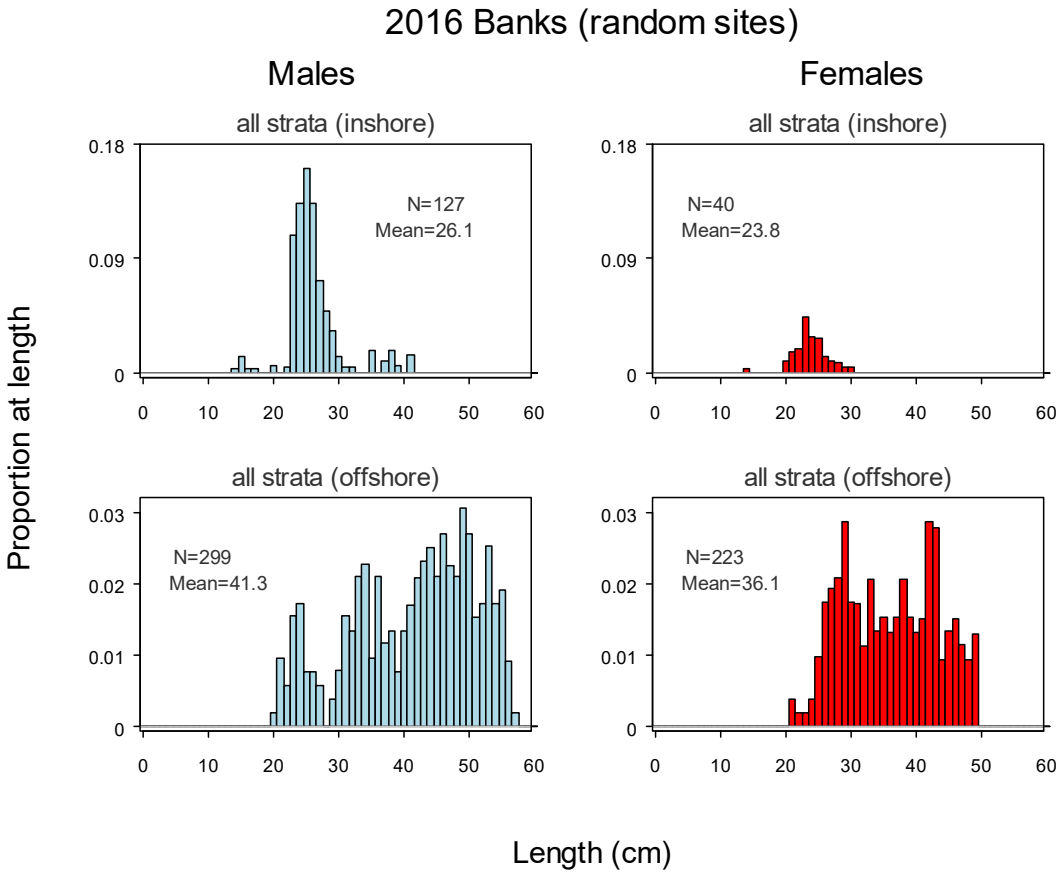

Figure 21: Scaled length frequency distributions overall for the 2016 Banks Peninsula inshore strata (1–5) and offshore strata (6 –7) random site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum.

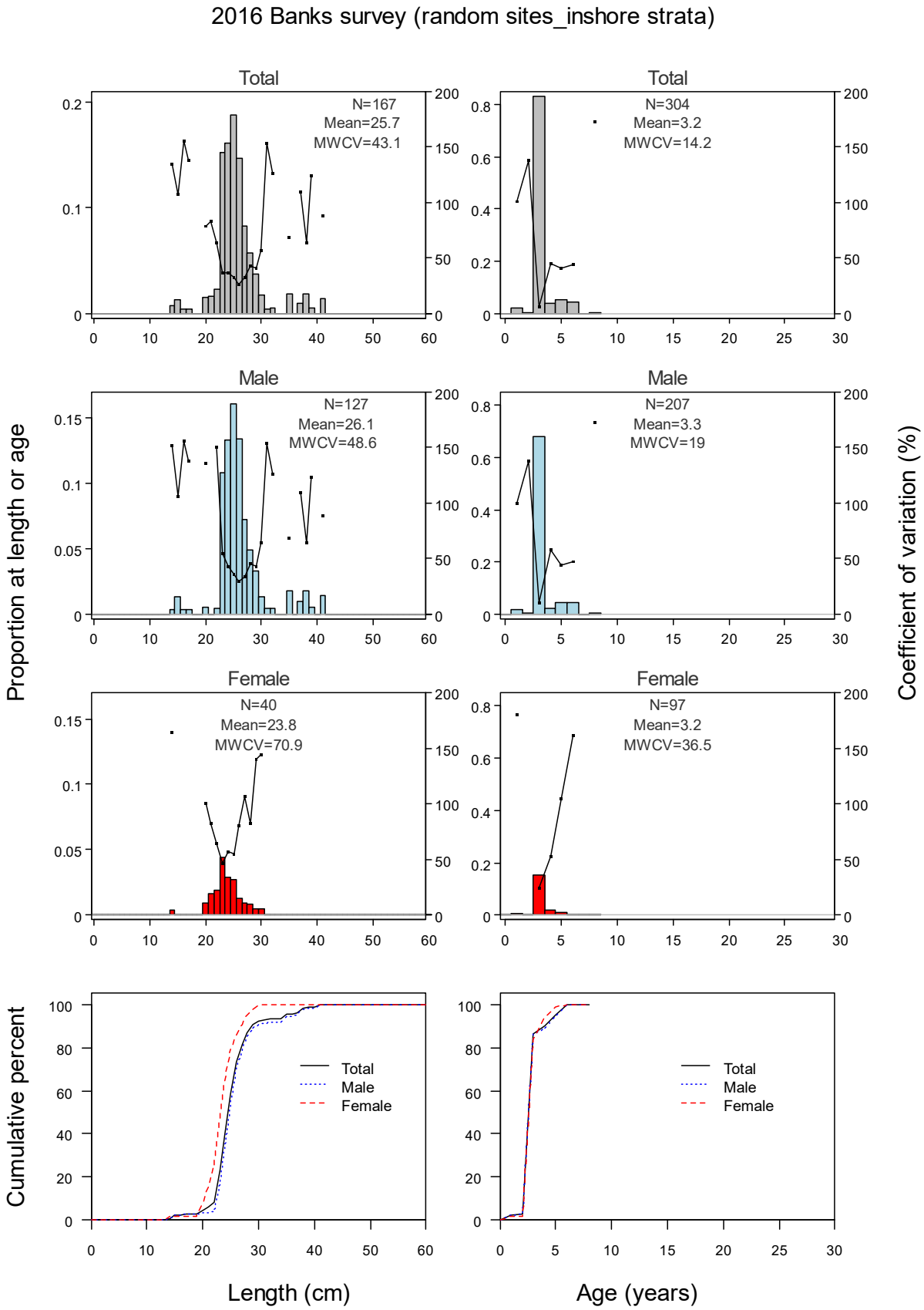

Figure 22: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2016 Banks Peninsula inshore (strata 1–5) random site blue cod potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

S

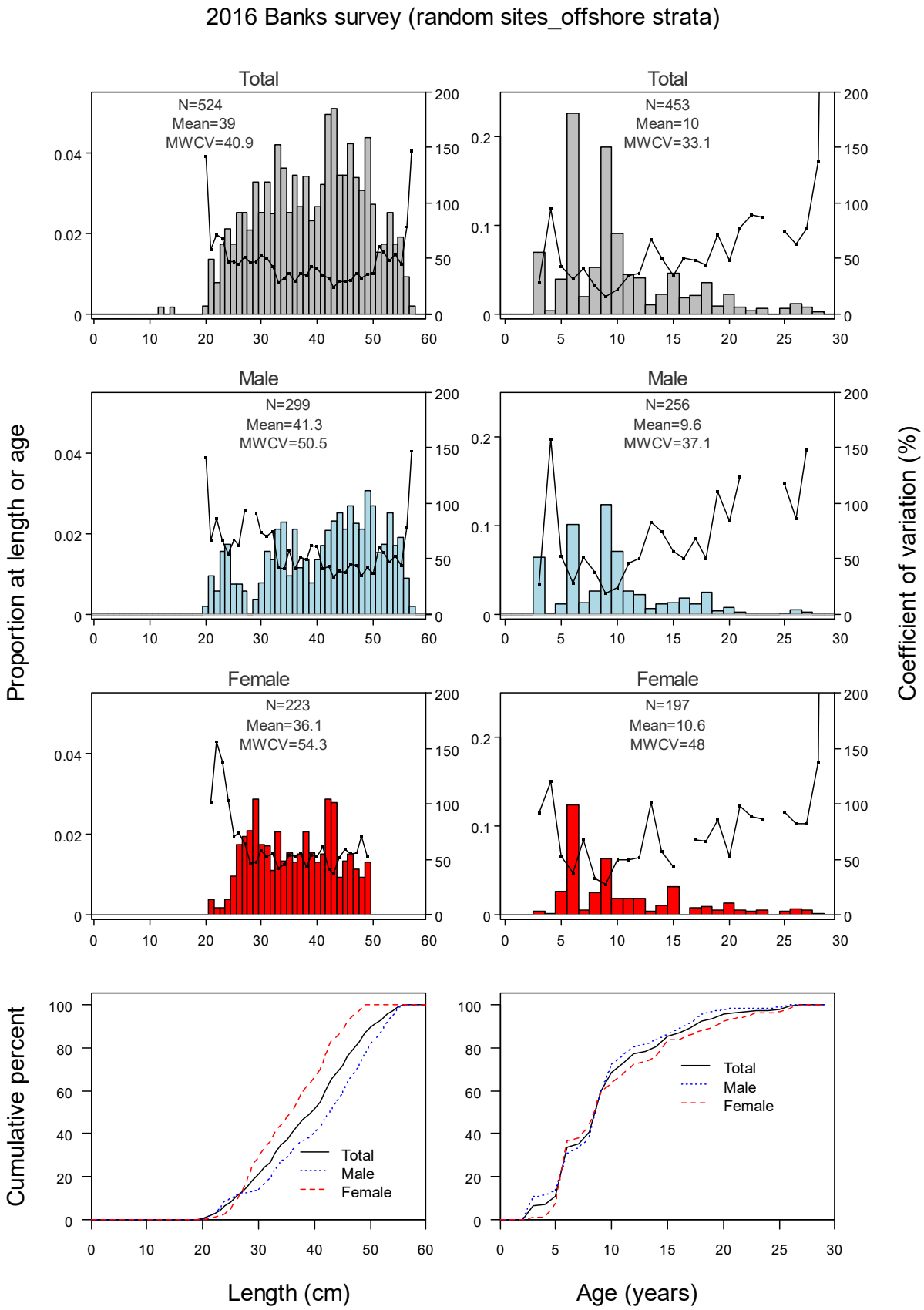

Figure 23: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2016 Banks Peninsula offshore (strata 6–7) random site blue cod potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

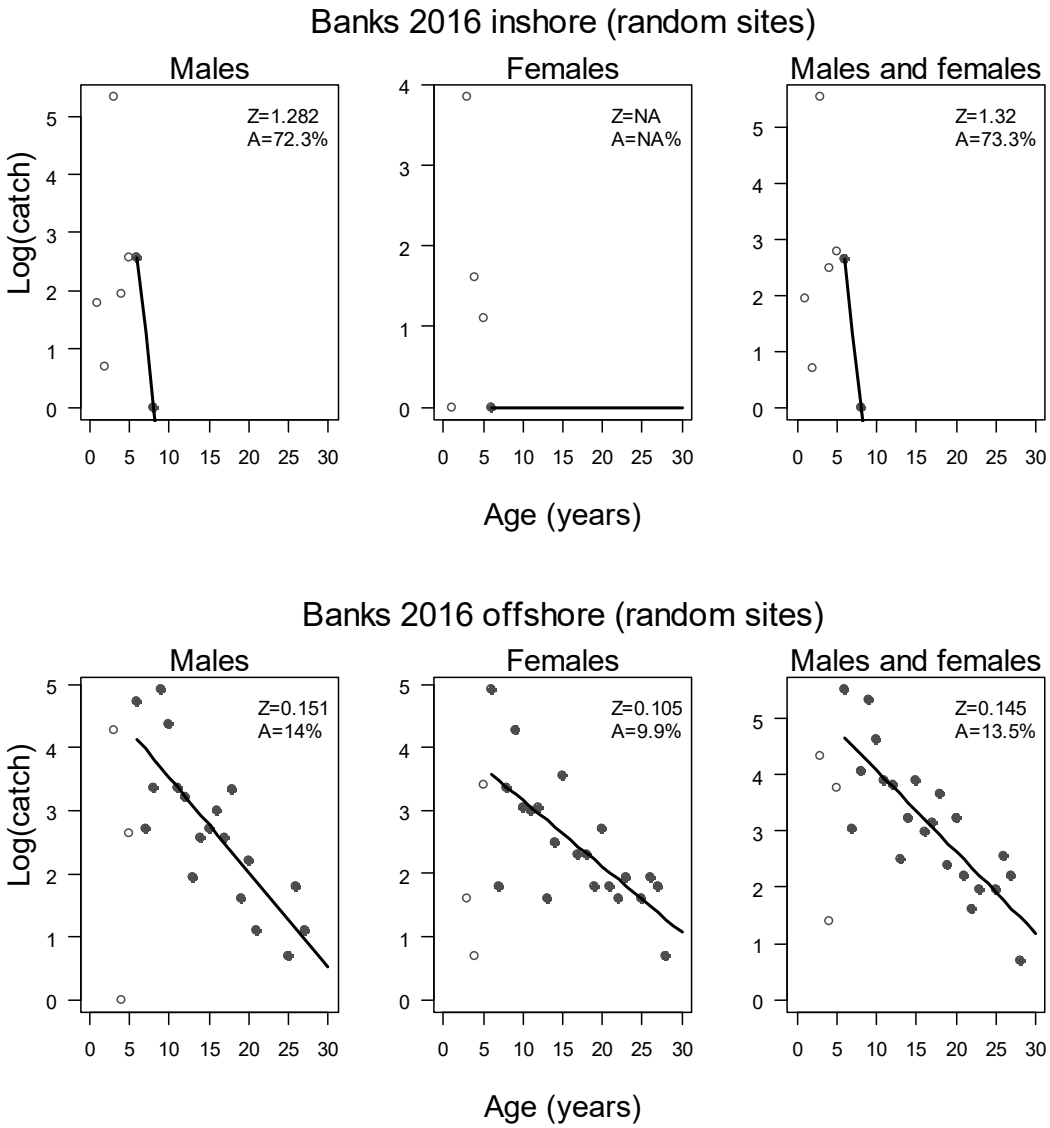

Figure 24: Banks Peninsula 2016 random site inshore (top panel) and offshore (bottom panel) survey catch curves (natural log of catch numbers versus age). The regression line is plotted from age at full recruitment of 6 years (i.e., dark points on the graph). Z, instantaneous total mortality; A, the annual mortality rate or the proportion of the population that suffers mortality in a given year.

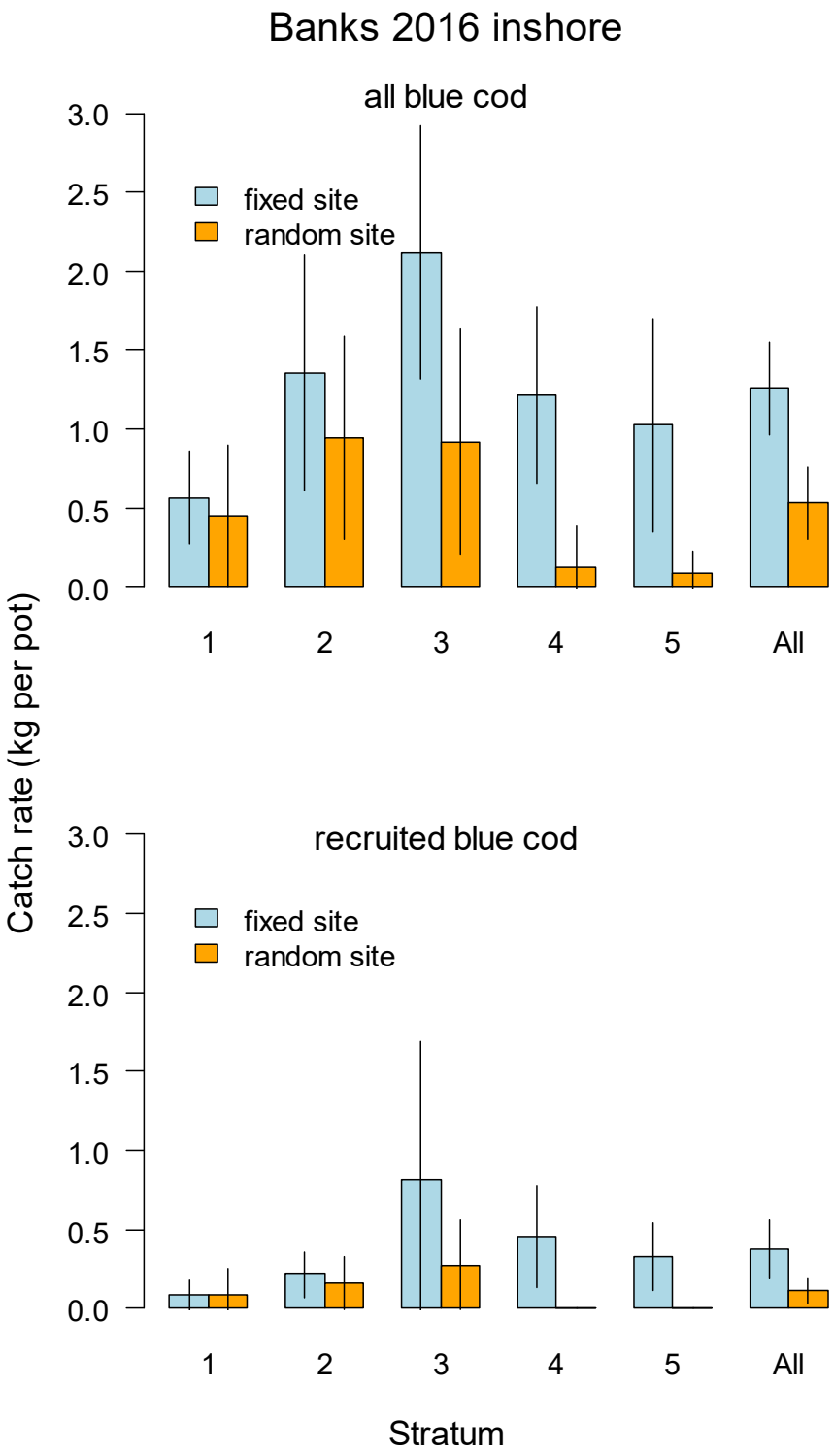

Figure 25: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and recruited (30 cm and over, bottom panel) for the 2016 Banks Peninsula fixed and random site surveys from inshore strata (1–5). Error bars are 95% confidence intervals.

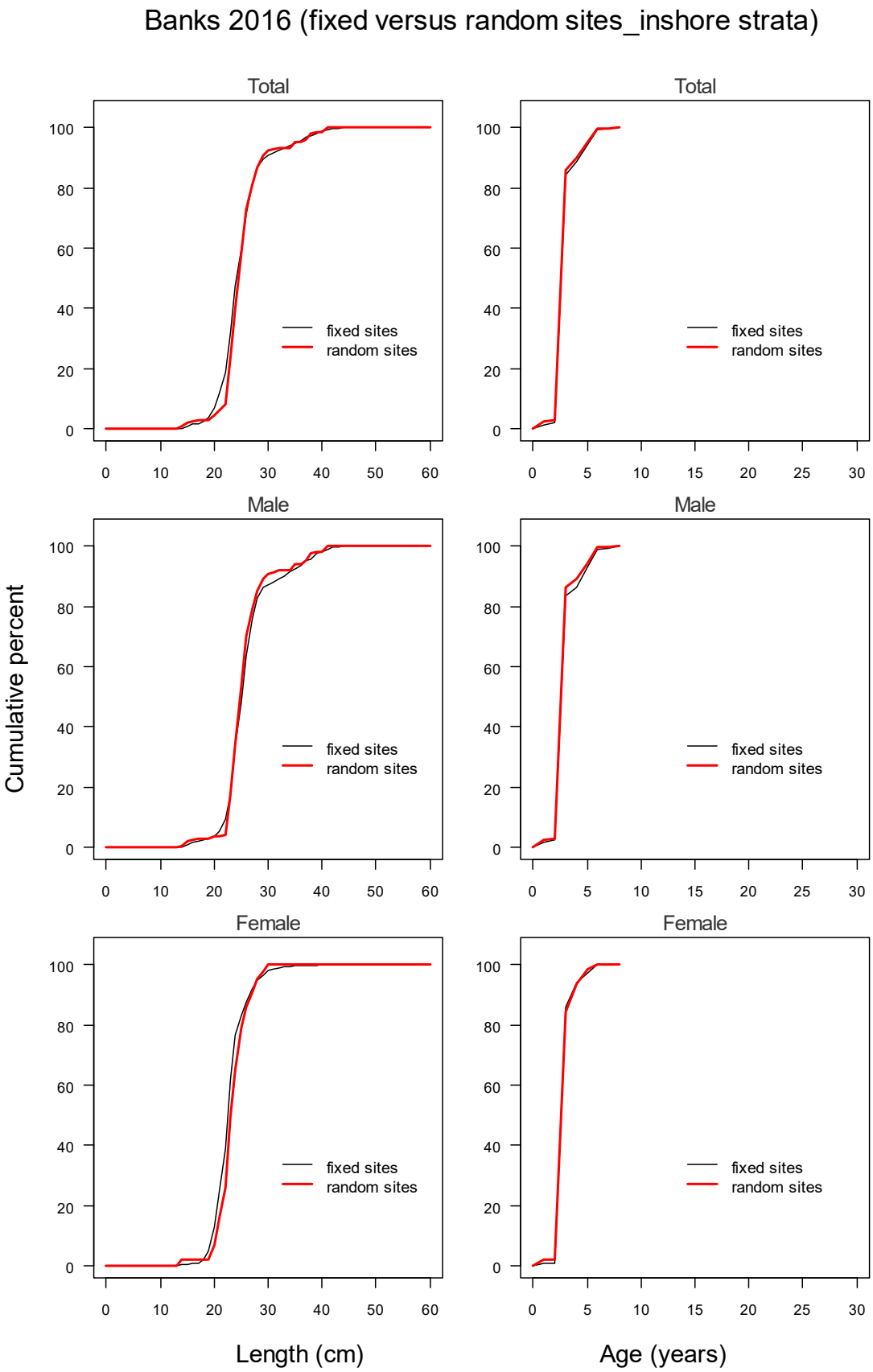

Figure 26: Cumulative distributions of scaled length and age frequencies for total, male, female, and unsexed blue cod from the 2016 Banks Peninsula blue cod fixed site and random site inshore strata (1–5) potting surveys.

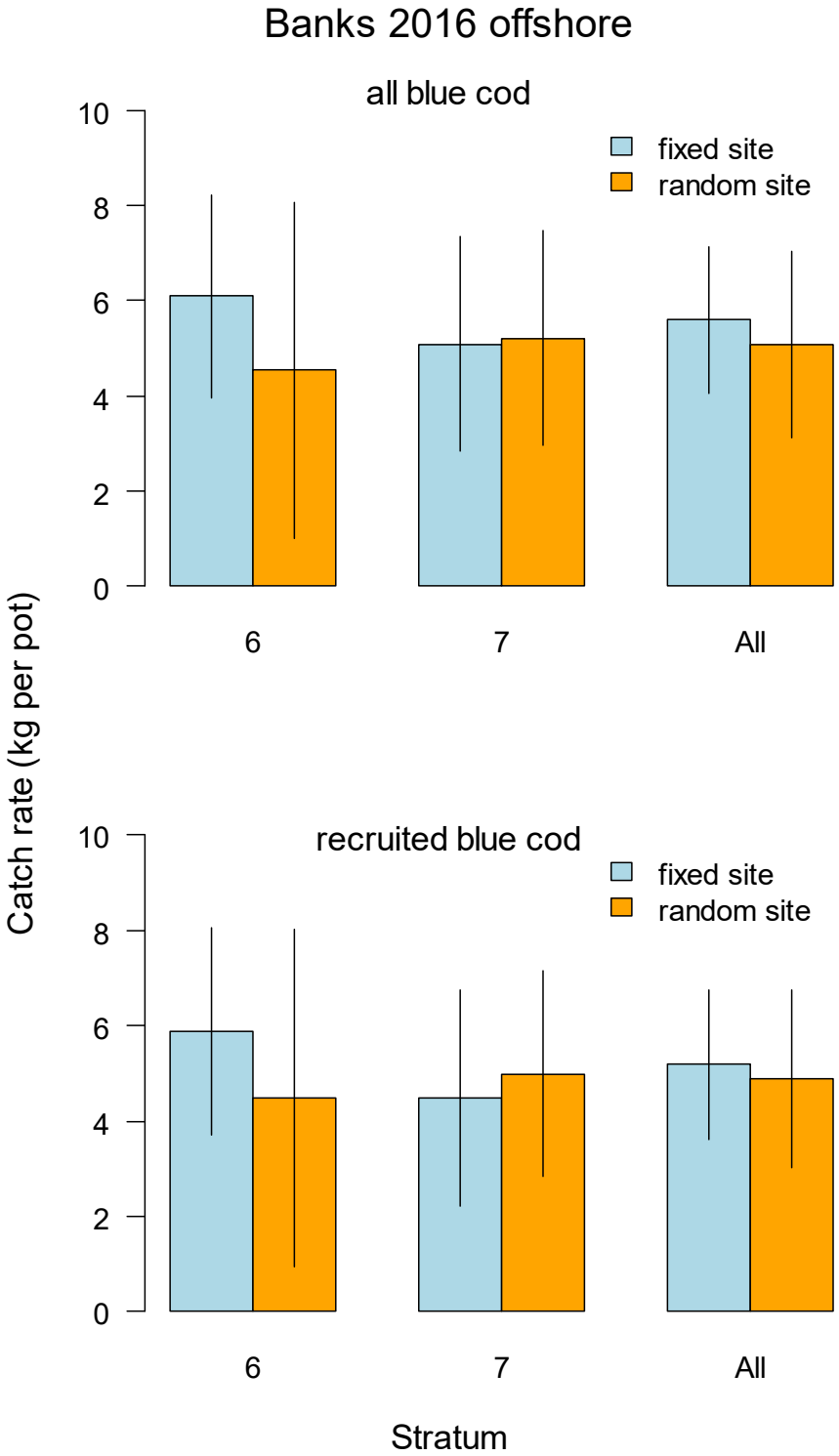

Figure 27: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and recruited (30 cm and over, bottom panel) for the 2016 Banks Peninsula fixed and random site surveys from offshore strata (6–7). Error bars are 95% confidence intervals.

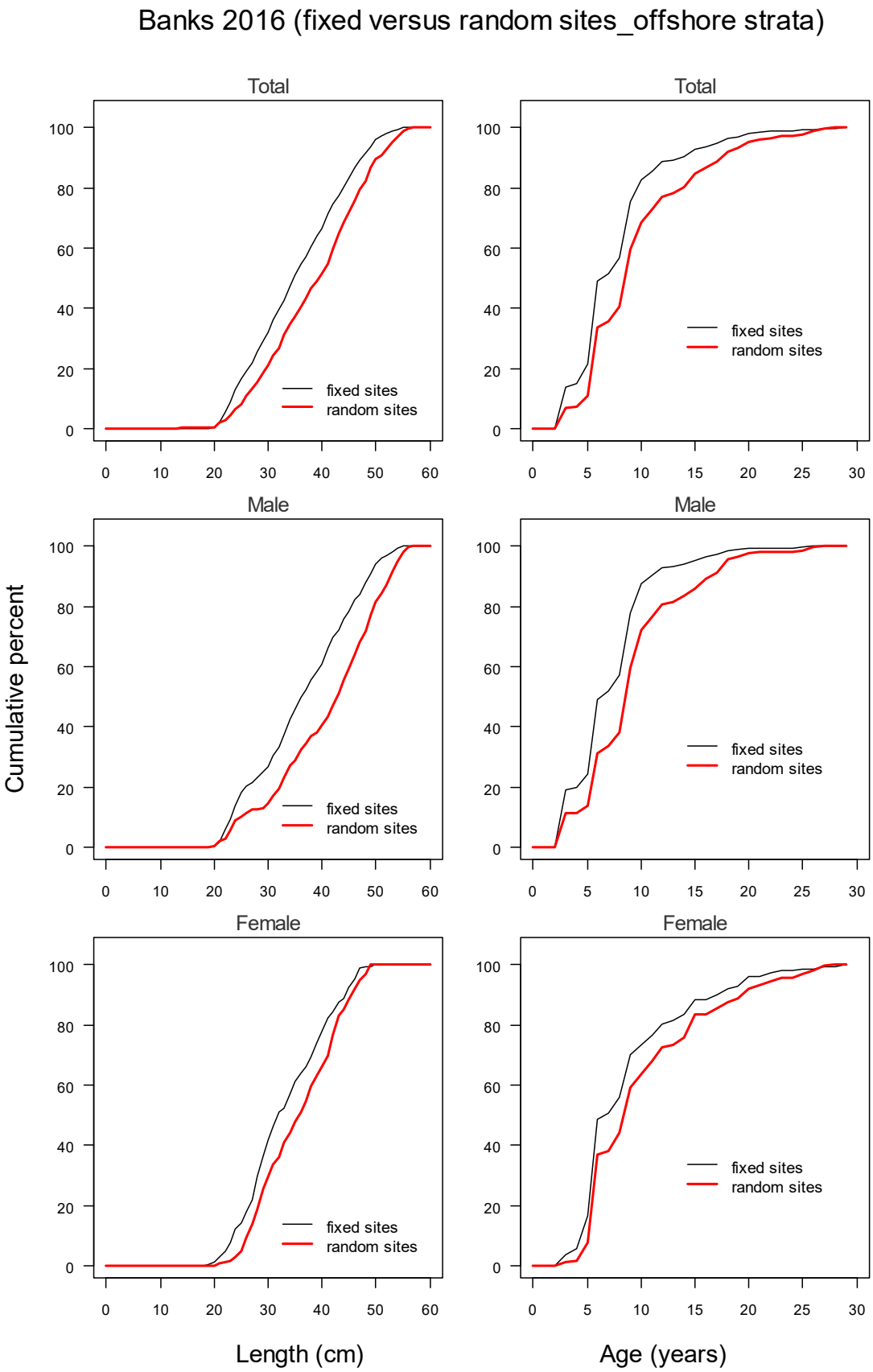

Figure 28: Cumulative distributions of scaled length and age frequencies for total, male, female, and unsexed blue cod from the 2016 Banks Peninsula blue cod fixed site and random site offshore strata (6–7) potting surveys.

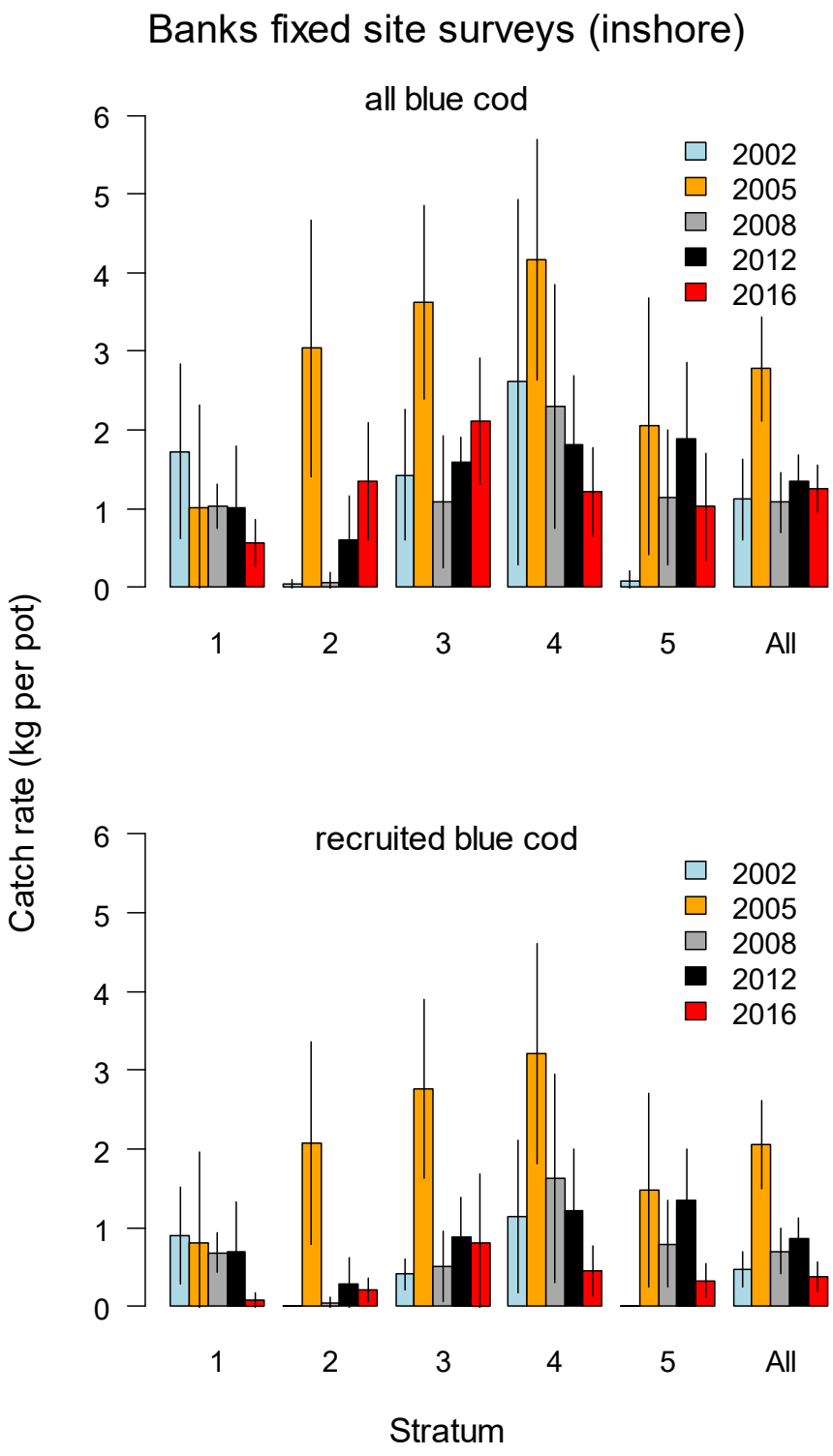

Figure 29: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and recruited blue cod (30 cm and over, bottom panel) for the Banks Peninsula fixed site inshore potting surveys in 2002, 2005, 2008, 2012, and 2016. Error bars are 95% confidence intervals.

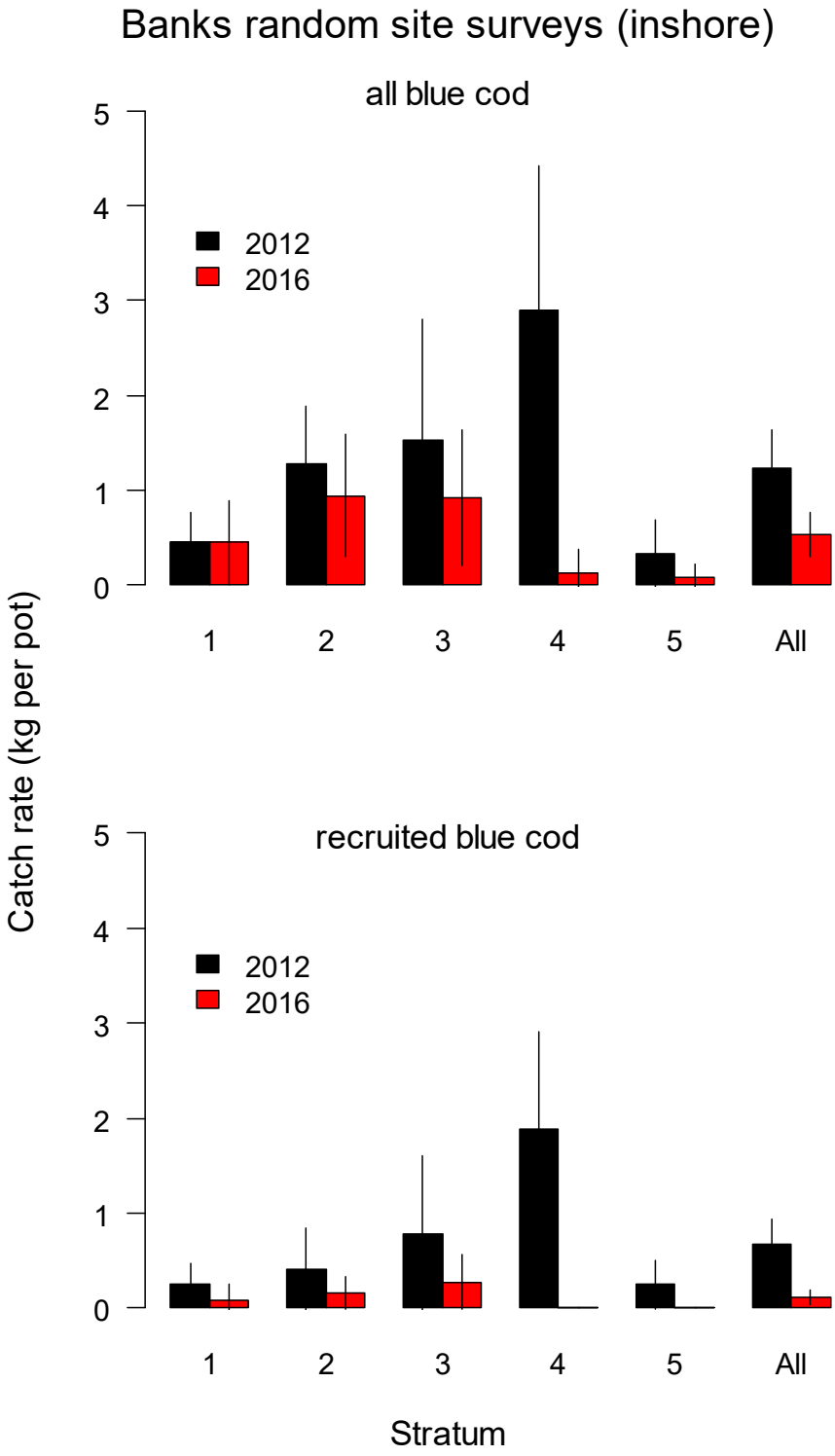

Figure 30: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and for recruited blue cod (30 cm and over, bottom panel) for the Banks Peninsula random site inshore potting surveys in 2012 and 2016. There were no random site surveys in 2002, 2005, and 2008. Error bars are 95% confidence intervals.

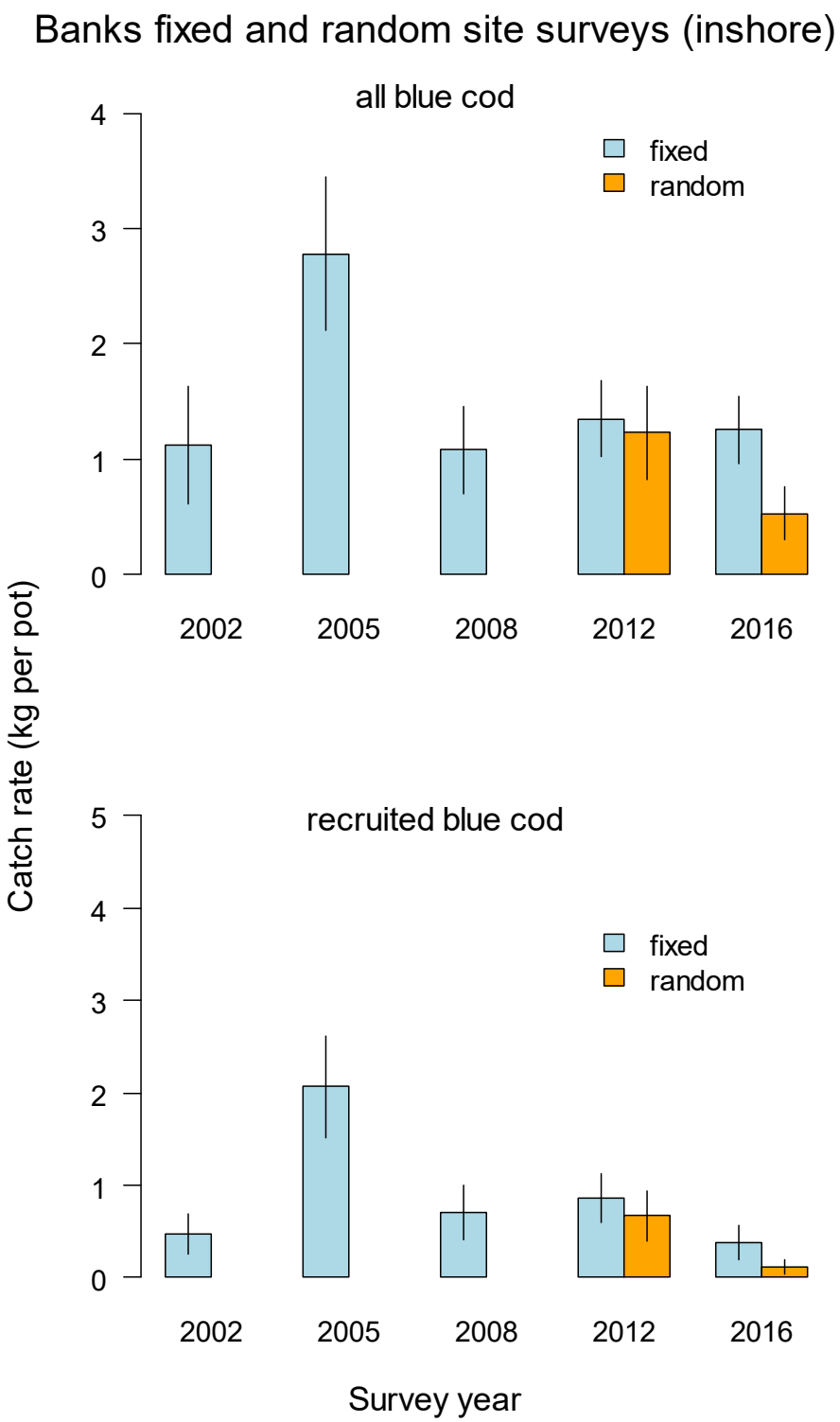

Figure 31: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and for recruited (30 cm and over, bottom panel) for the Banks Peninsula fixed site inshore potting surveys in 2002, 2005, 2008, 2012, and 2016; and random site surveys in 2012 and 2016. Error bars are 95% confidence intervals.

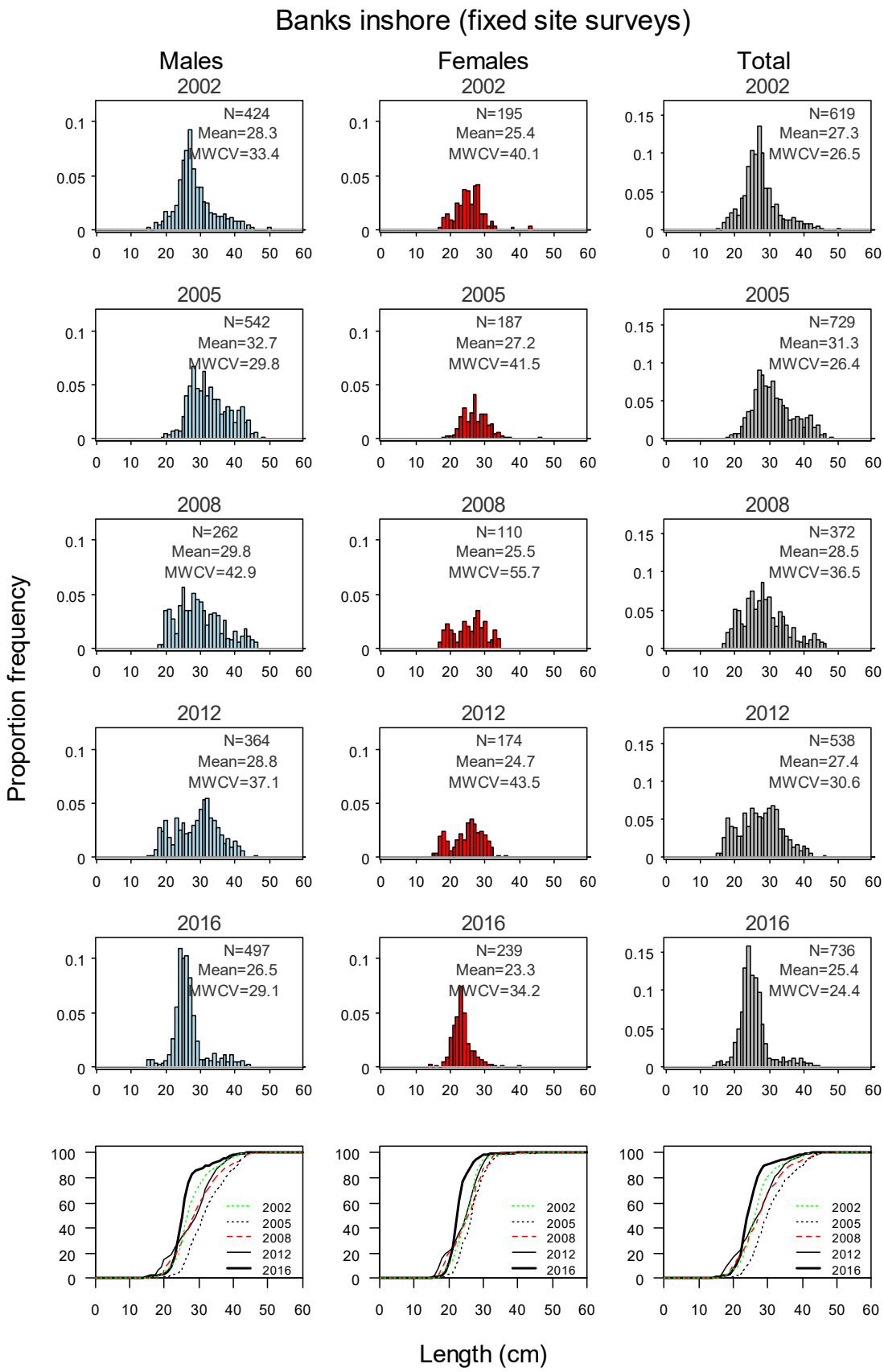

Figure 32: Scaled length frequency and cumulative distributions of scaled length frequencies for total, male, and female blue cod from Banks Peninsula fixed site inshore blue cod potting surveys in 2002, 2005, 2008, 2012, and 2016.

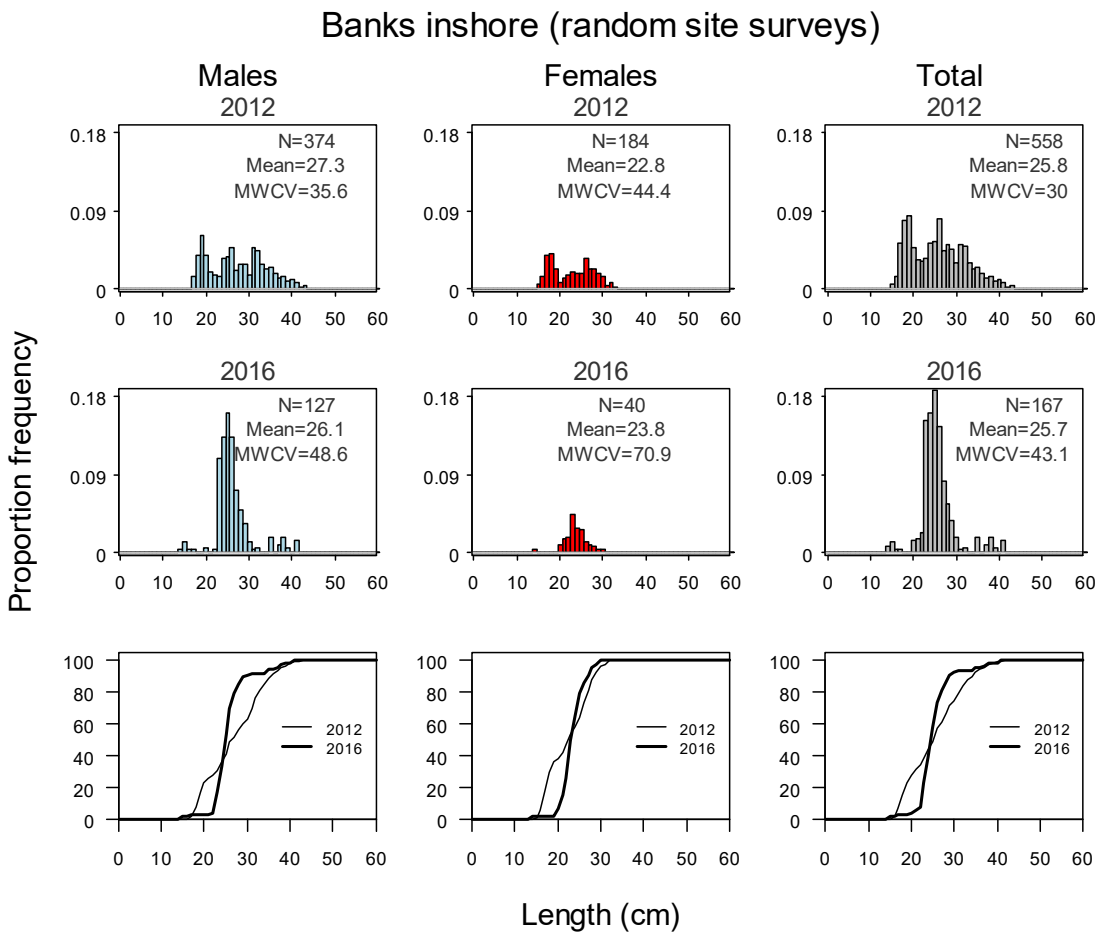

Figure 33: Scaled length frequency and cumulative distributions of scaled length frequencies for total, male, and female blue cod from Banks Peninsula random site inshore blue cod potting surveys in 2012 and 2016.

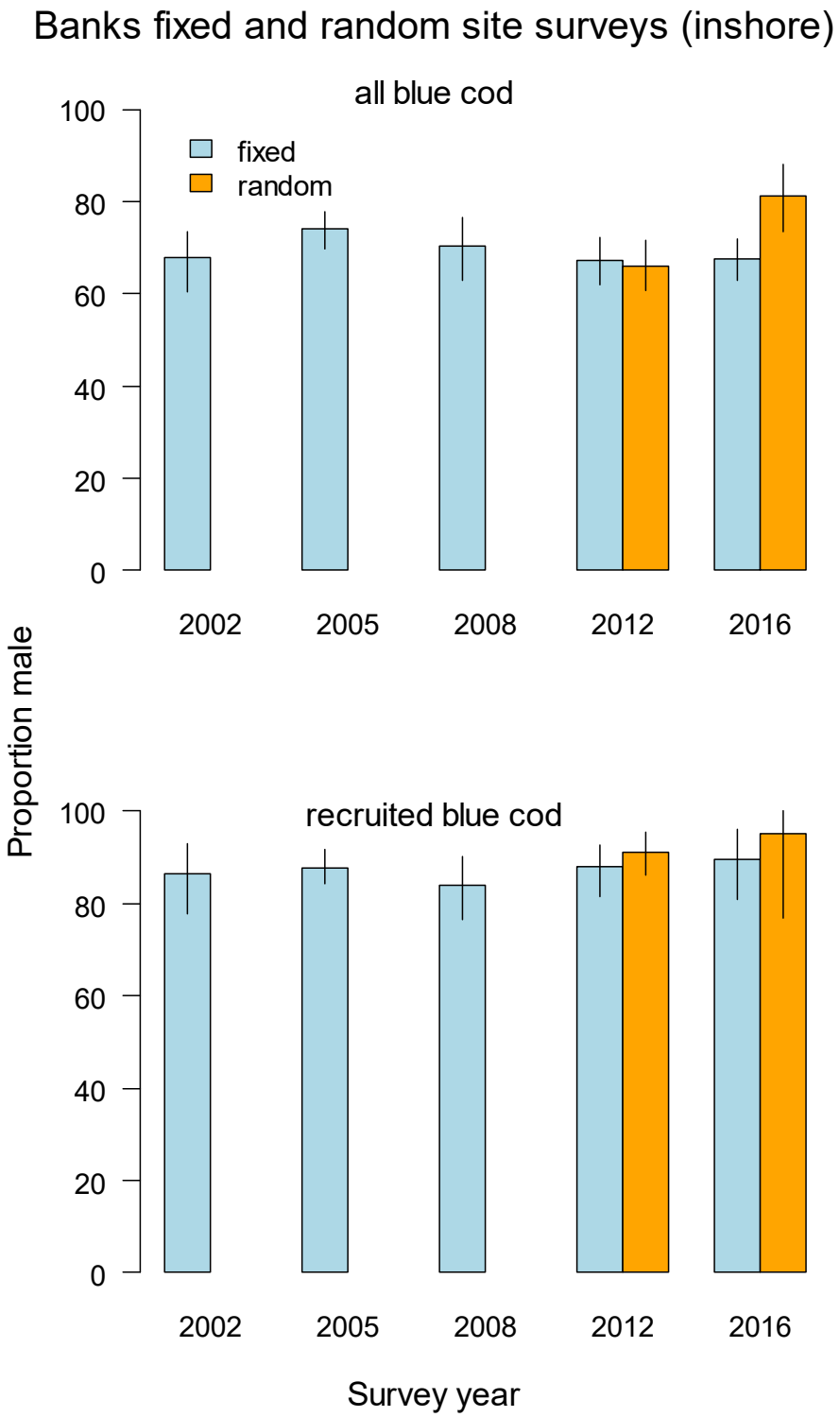

Figure 34: Sex ratio (percent male) of scaled length frequencies of all blue cod (top panel) and recruited blue cod (30 cm and over, bottom panel) for the Banks Peninsula fixed site inshore potting surveys in 2002, 2005, 2008, 2012, and 2016; and random site inshore potting surveys in 2012 and 2016. Error bars are 95% confidence intervals.

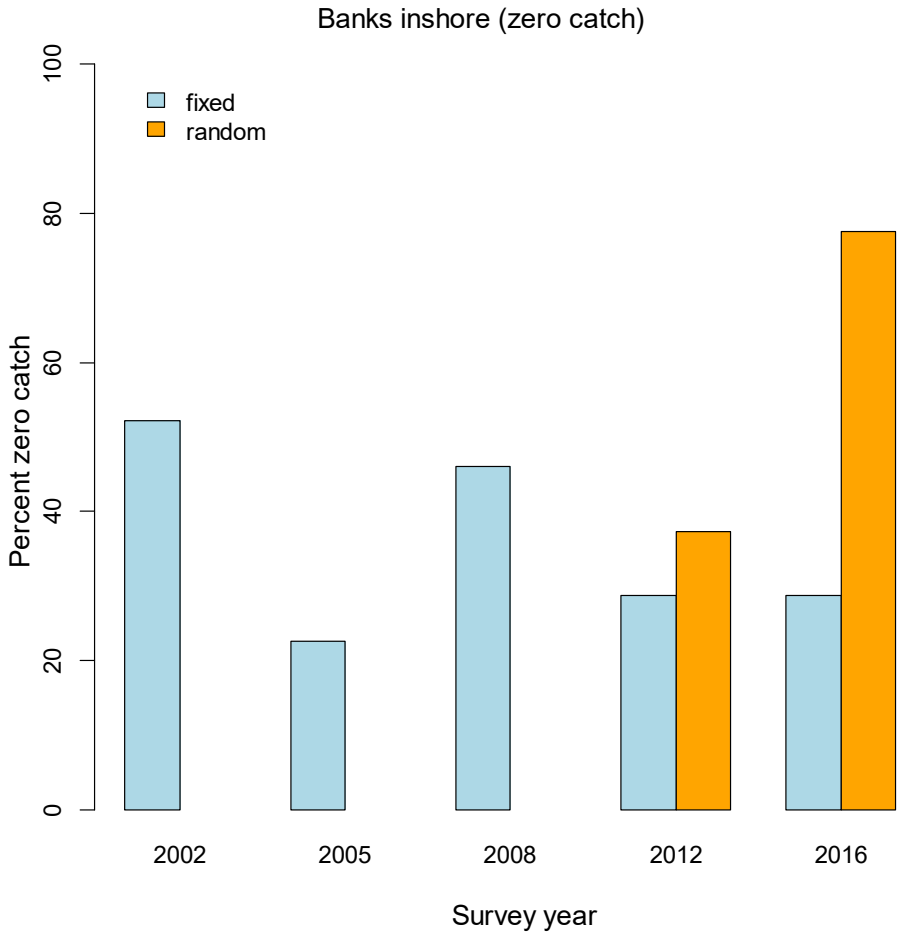

Figure 35: Proportion of pots with no blue cod for the Banks Peninsula fixed site inshore potting surveys in 2002, 2005, 2008, 2012, and 2016; and random site inshore potting surveys in 2012 and 2016.

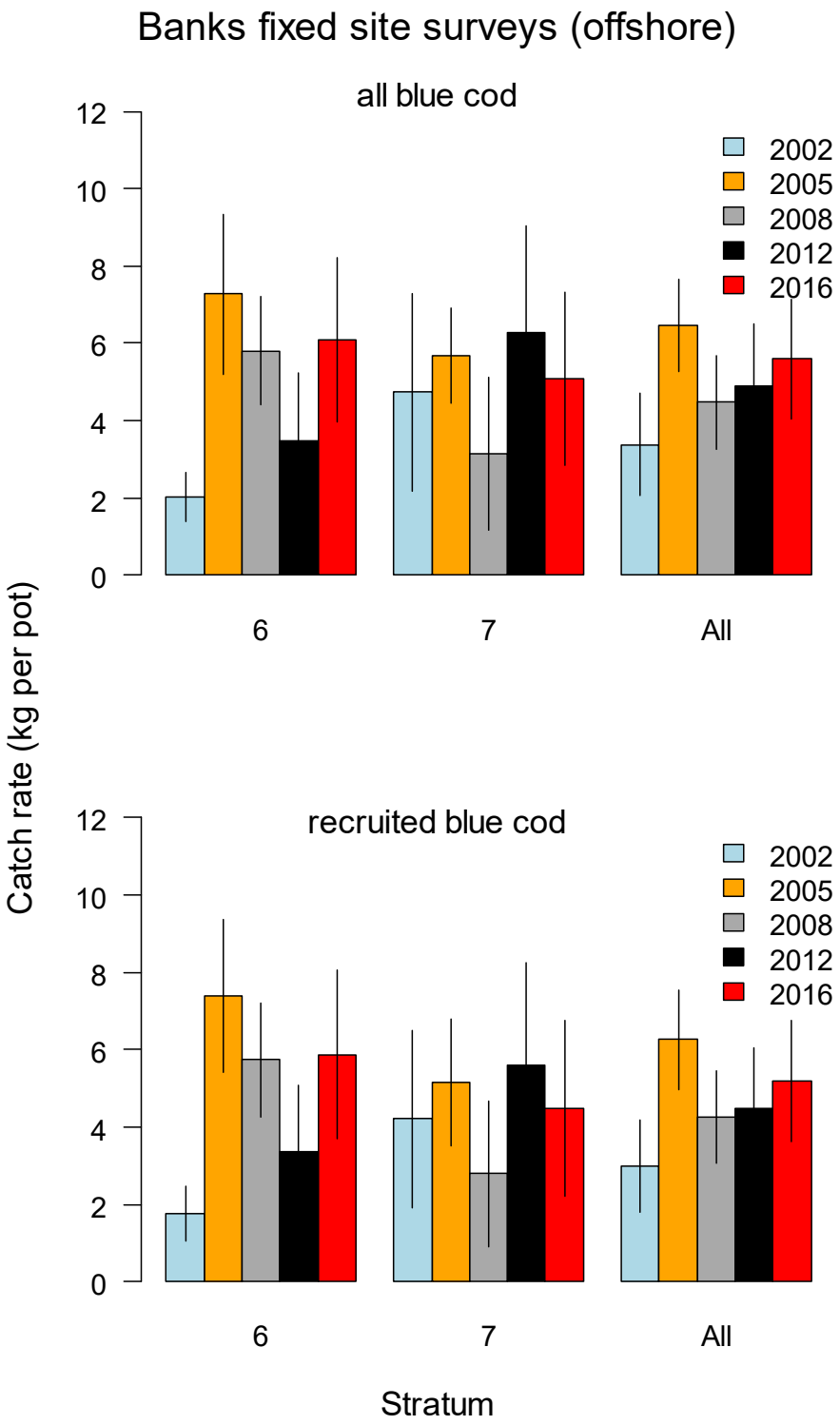

Figure 36: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and recruited blue cod (30 cm and over, bottom panel) for the Banks Peninsula fixed site offshore potting surveys in 2002, 2005, 2008, 2012, and 2016. Error bars are 95% confidence intervals.

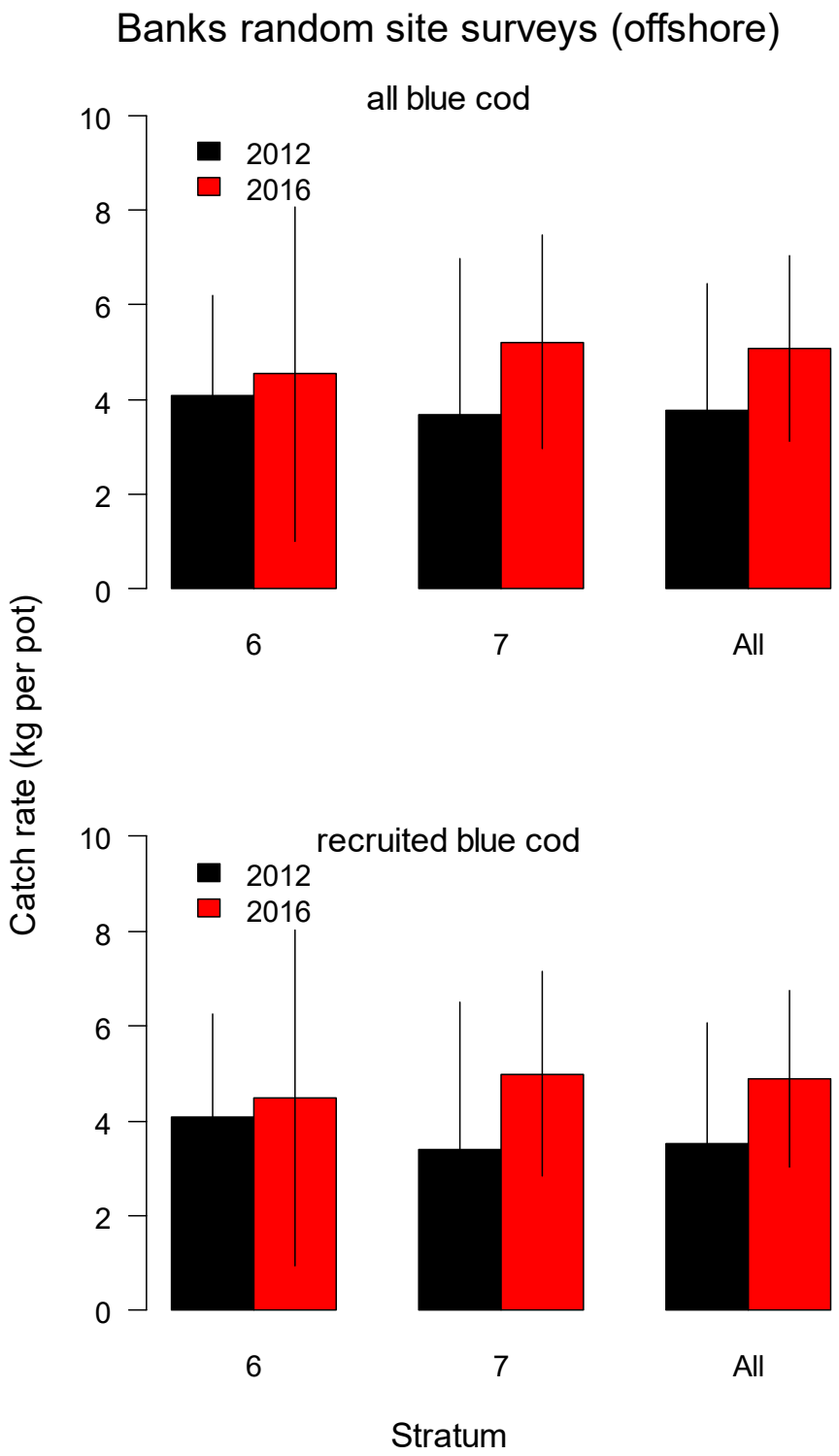

Figure 37: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and for recruited blue cod (30 cm and over, bottom panel) for the Banks Peninsula random site offshore potting surveys in 2012 and 2016. There were no random site surveys in 2002, 2005, and 2008. Error bars are 95% confidence intervals.

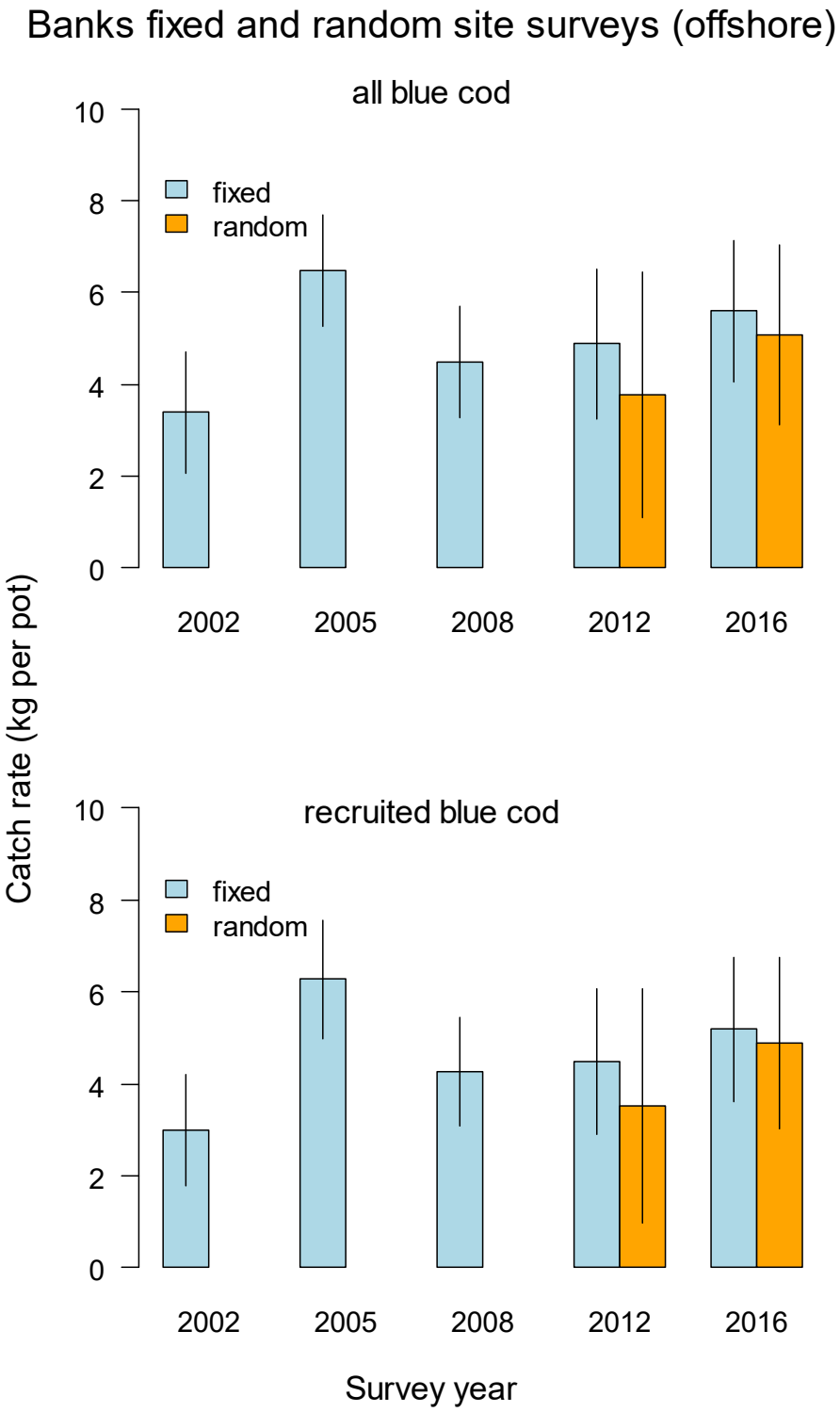

Figure 38: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and for recruited (30 cm and over, bottom panel) for the Banks Peninsula fixed site offshore potting surveys in 2002, 2005, 2008, 2012, and 2016; and random site surveys in 2012 and 2016. Error bars are 95% confidence intervals.

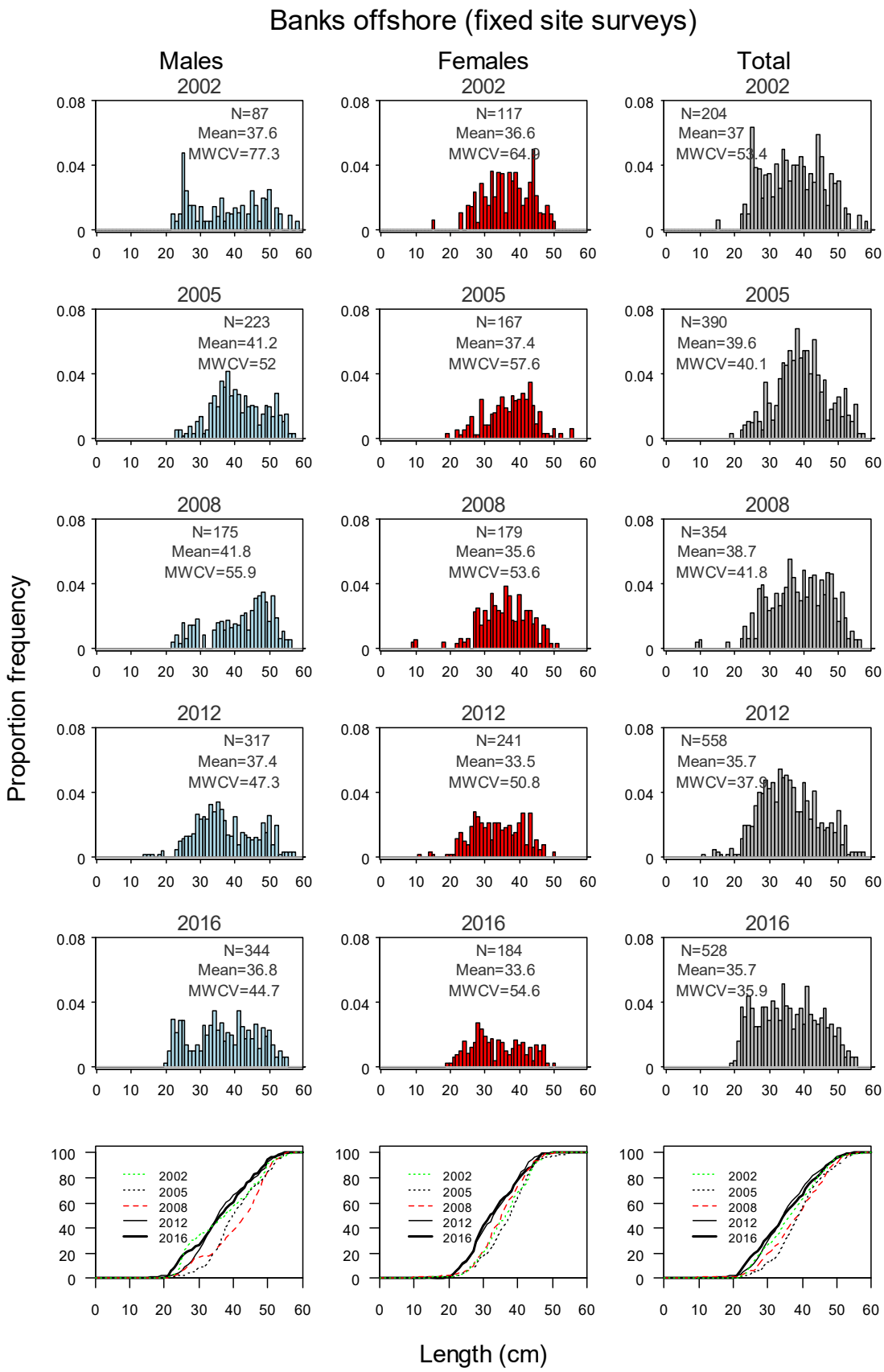

Figure 39: Scaled length frequency and cumulative distributions of scaled length frequencies for total, male, and female blue cod from Banks Peninsula fixed site offshore blue cod potting surveys in 2002, 2005, 2008, 2012 and 2016.

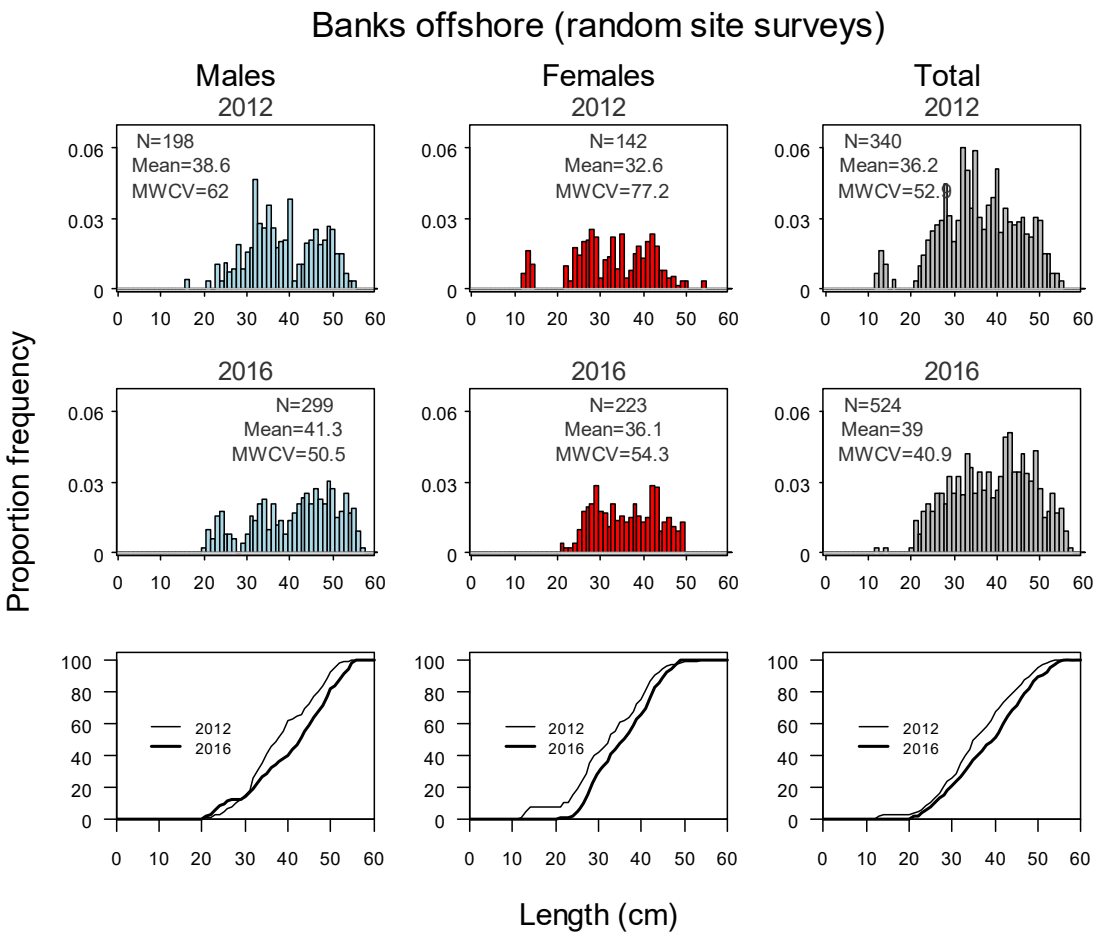

Figure 40: Scaled length frequency and cumulative distributions of scaled length frequencies for total, male, and female blue cod from Banks Peninsula random site offshore blue cod potting surveys in 2012 and 2016.

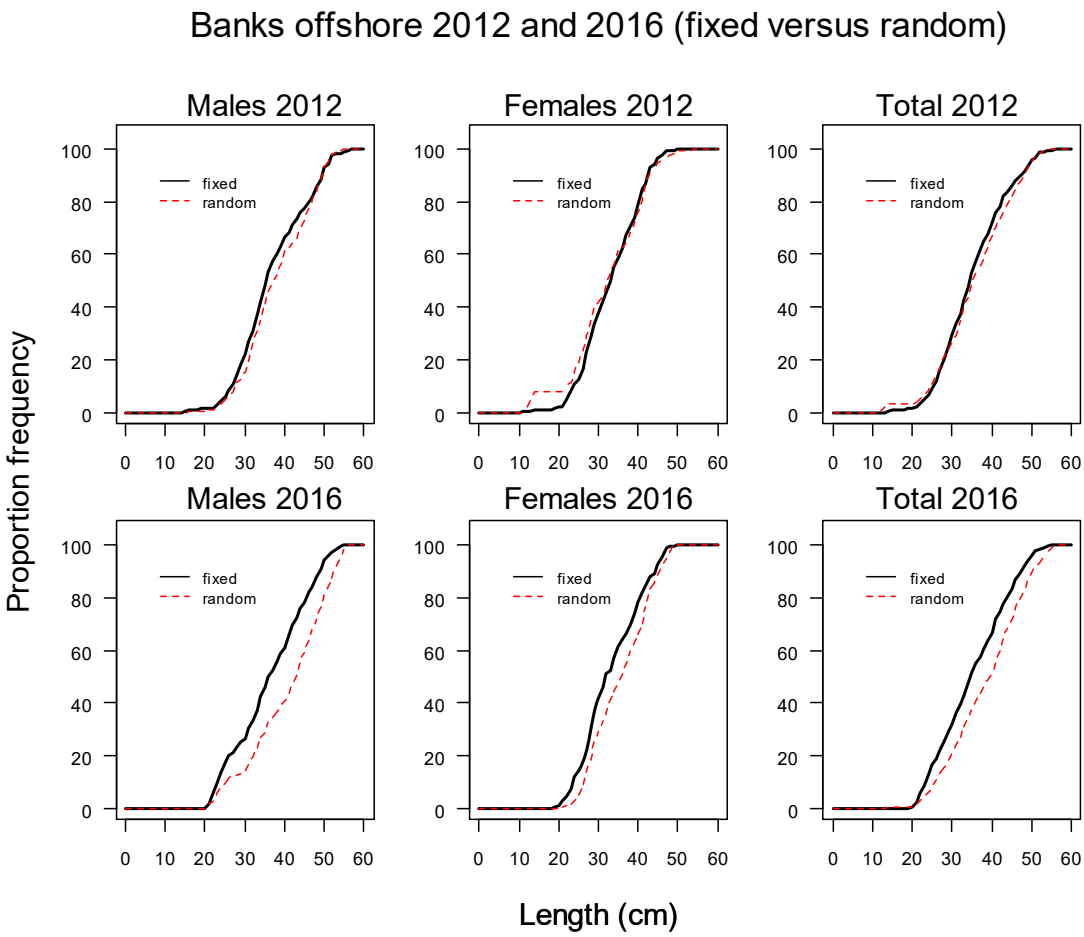

Figure 41: Cumulative distributions of scaled length frequencies for blue cod from Banks Peninsula fixed and random site offshore potting surveys in 2012 and 2016.

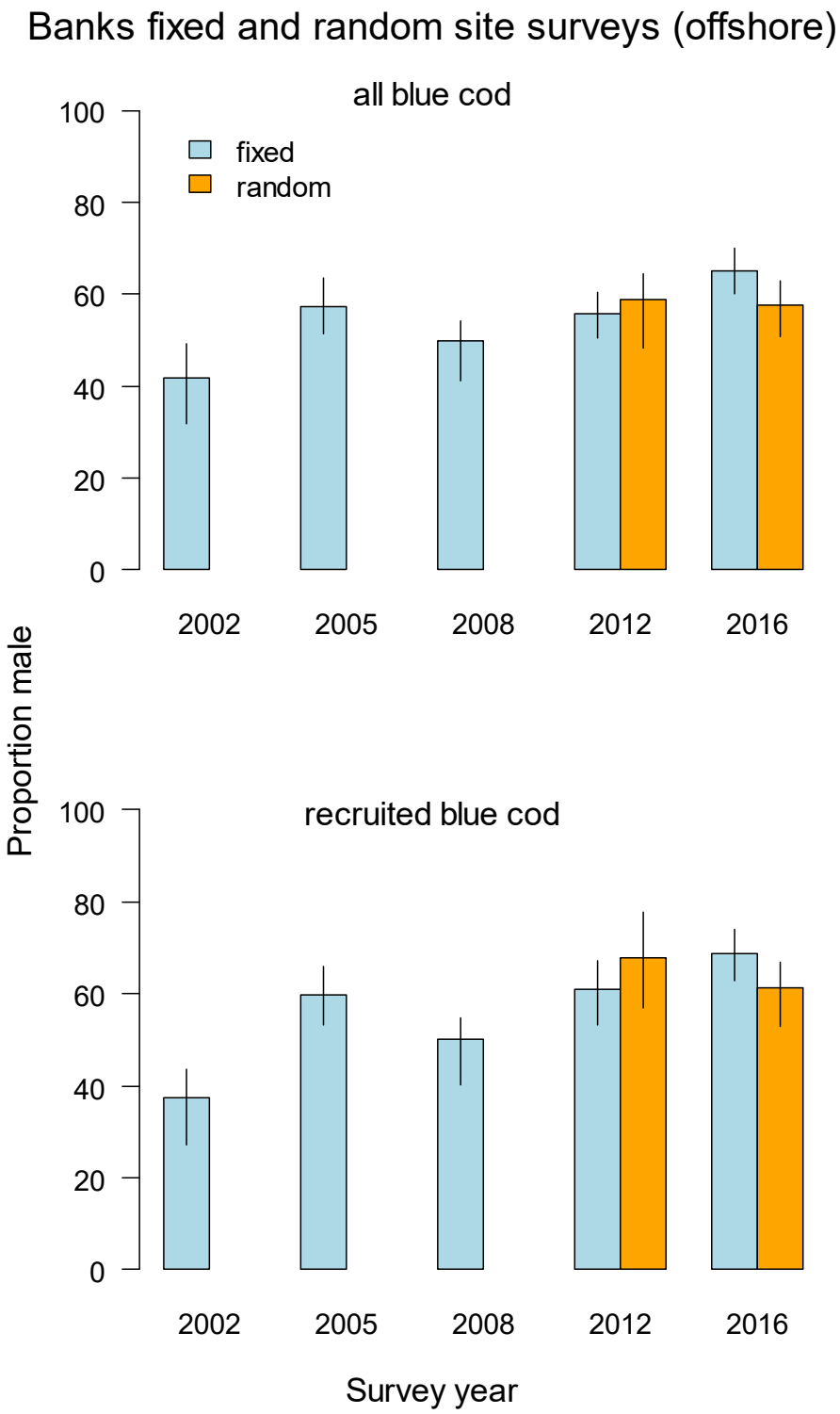

Figure 42: Sex ratio (percent male) of scaled length frequencies of all blue cod (top panel) and recruited blue cod (30 cm and over, bottom panel) for the Banks Peninsula fixed site offshore potting surveys in 2002, 2005, 2008, 2012, and 2016; and random site offshore potting surveys in 2012 and 2016. Error bars are 95% confidence intervals.

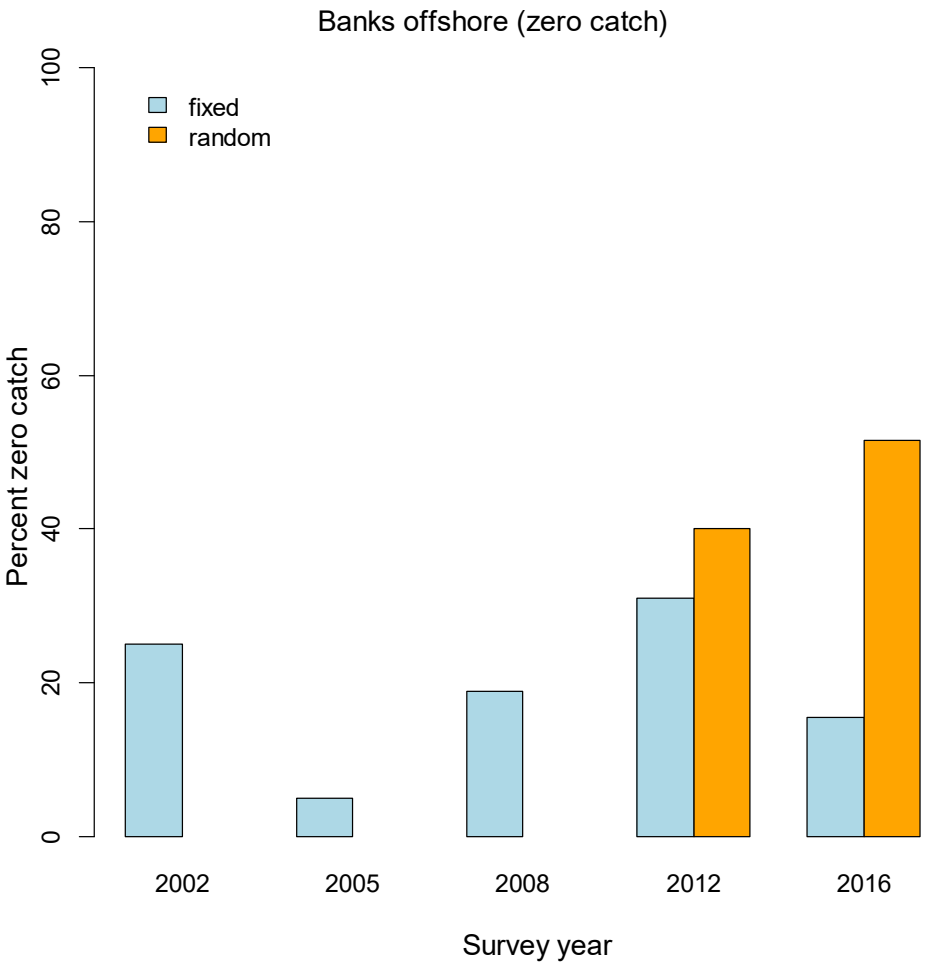

Figure 43: Proportion of pots with no blue cod catch for the Banks fixed site offshore potting surveys in 2005, 2008, 2012, and 2016; and random site offshore potting surveys in 2012 and 2016.

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 200 m to the north of the site location and remaining pots are set in a hexagon pattern around the site, at about 200 m from the site position.
Random site	A site that has the location (single latitude and longitude) generated randomly within a stratum, given the constraints of proximity to other selected sites for a specific survey.
Site	A geographical location near to which sampling may take place during a survey. A site may be either fixed or random (see below). A site may be specified as a latitude and longitude or a section of coastline (for the latter, use the latitude and longitude at the centre of the section).
Site label	An alphanumeric label of no more than four characters, unique within a survey time series. A site label identifies each fixed site and also specifies which stratum it lies in. Site labels are constructed by concatenating the stratum code with an alpha label (A–Z) that is unique within that stratum. Thus, sites within stratum 2 could be labelled 2A, 2B, and sites in stratum 3 could be labelled 3A, 3B etc. Site labels for random sites are constructed in the same way but prefixed with R (e.g., R4A, R4B etc).
Station	The position (latitude and longitude) at which a single pot (or other fishing gear such as ADCP) is deployed at a site during a survey, i.e., it is unique for the trip.
Station number	A number which uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be *station_no* 234. This convention is important in enabling users of the *trawl* database to determine whether two pots are from the same set. Note that the set numbers for potting surveys are not recorded anywhere else in the *trawl* database.

Appendix 2. Numbers of otoliths collected during the 2016 Banks Peninsula survey for males and females, by strata and length class. Lgth, length.

Lgth (cm)	Stratum 1	2	3	4	5	6	7	Male total	Stratum 1	2	3	4	5	6	7	Female total
14	1	1			1			3	1	1						2
15	2	1	2	1				6				1				1
16		3						3								
17		1						1		1			1			2
18		2	1					3			1	1			1	3
19			1	1	1			3	1	1	2	1	3			8
20	1	2	1	1		2	3	10	1	1	1	3	2	2		10
21	1	1	2	2	1	2	4	13	1	1	1	1	2	2	3	11
22	1		1	1	1	2	5	11	3	1	1	1	1	1	4	12
23	6	5	1	1	1	2	4	20	7	4	2	2	1	1	3	20
24	2	6	1	1		3	7	20		6	1	1	2		5	15
25	5	13	2	1	2	2	5	30		4	1	1	1		7	14
26	8	9	2	1	3	2	3	28	4	1	1	1	1	1	5	14
27	6	14	1	1	2		4	28	1	1		1	1	1	6	11
28	8	7		1		1	5	22		2	1			3	5	11
29		1	2	2	1		5	11			2	2		2	4	10
30		1		3	1	2	5	12			3			2	5	10
31		2					6	8			1	1	1	2	5	10
32			3		1	2	5	11				1		3	5	9
33		1	1	1	3	4	5	15						4	5	9
34		2		2	1	2	5	12						4	5	9
35		2				3	5	10					1	2	5	8
36	1	2		1	1	1	6	12						2	4	6
37			2	2	1	1	3	9						3	5	8
38	1		1	1	1	2	5	11						3	5	8
39		1		3	1	1	7	13						4	5	9
40	2	2	1	1		3	5	14				1		2	5	8
41		1	2	1	1	3	4	12						2	5	7
42						2	5	7						2	5	7
43			1	1		5	5	12						4	5	9
44						2	5	7						2	3	5
45						2	5	7						4	3	7
46						2	5	7						2	5	7
47						5	5	10						2	3	5
48						3	5	8						2	3	5
49						2	5	7						3	1	4
50						2	5	7						1		1
51						3	5	8								
52						2	5	7								
53						2	5	7								
54						2	4	6								
55						2	5	7								
56						3	1	4								
57							1	1								
Totals	45	80	28	30	24	79	177	463	19	24	18	19	17	68	130	295