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Relative abundance, size and age structure, and stock status of blue cod from the 2017 survey in Marlborough Sounds, and review of historical surveys.

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This report describes the 2017 Marlborough Sounds concurrent fixed-site and random-site potting surveys of relative abundance, population length and age structure, and stock status of blue cod. The 2017 fixed site survey was the seventh in the time series for Queen Charlotte Sound (QCH) and Pelorus Sound (PEL), and the fifth for D'Urville Island (DUR). For Marlborough Sounds overall (MS), the 2017 survey was the fifth in the fixed site time series, beginning in 2004 when strata were the same for all surveys. The 2017 random-site survey was the second in QCH, PEL and DUR, and the third for Cook Strait (CKST). The results of the 2017 surveys are presented standalone, and are compared with previous surveys in the time series in the context of the fisheries management regulations that were in place.

2017 fixed-site survey

Thirty-six fixed sites (9 pots per site, producing 324 pot lifts) were successfully surveyed from nine strata in QCH, PEL and DUR between 23 September and 28 October 2017. A total of 1118 kg (2278 fish) of blue cod was caught. Catch rates for all blue cod were: QCH 0.86 kg.pot^{-1} (CV=27%), PEL 3.20 kg.pot^{-1} (CV=17%), DUR 6.52 kg.pot^{-1} (CV=15%), and MS 3.15 kg.pot^{-1} (CV=10%). Of the 324 fixed-site pots, 129 (39.8%) had zero catch of blue cod. The scaled length-frequency distributions for all males and females were unimodal, and similar in all three regions, with mean size about 32 cm for males and 30 cm for females. Sex ratios of all blue cod were dominated by males (QCH 72% male, PEL 86%, DUR 61%, MS 72%). The von Bertalanffy growth parameters from all age data combined, from the fixed and random-site surveys were: males K = 0.37 yr^{-1}, t_0 = 0.69 yr, L_∞ 39.9 cm, N= 708; females K = 0.52 yr^{-1}, t_0 = 0.83 yr, L_∞ 32.2 cm, N= 344. MS scaled length-frequency distributions for both males and females were unimodal with mean lengths of 32.4 and 30.0 cm. Males had a higher proportion of larger fish than females, and were the largest fish. Age estimates were 2–16 years for males and 3–20 years for females. Mean ages were 5.7 years for males and 7.2 for females. The MS Chapman-Robson total mortality (Z) estimate for the age at recruitment (AgeR) of six years, was 0.53 yr^{-1}. Based on the default M of 0.14, estimated fishing mortality (F) was 0.39 and the associated spawner-per-recruit ratio was 39.0%, close to, but below the Ministry F_{MSY} target reference point of $F_{45\%SPR}$.

Macroscopic examination of gonads from the fixed and random-site surveys showed indications of spawning activity during the survey period with nearly one-third of males and about 10% of females in the running ripe condition.

2017 random-site survey

Seventy-four fixed sites (9 pots per site, producing 666 pot lifts) within twelve strata covering QCH, PEL, DUR and CKST were successfully surveyed from 23 September and 28 October 2017. A total of 1250 kg (2527 fish) of blue cod was caught. Catch rates for all blue cod were: QCH 1.04 kg.pot^{-1} (CV=15%), PEL 0.90 kg.pot^{-1} (CV=23%), DUR 3.59 kg.pot^{-1} (CV=24%), CKST 1.10 kg.pot^{-1} (CV = 28%), MS 1.55 kg.pot^{-1} (CV=13%), and MS excluding CKST 1.59 kg.pot^{-1} (CV=14%). Of the 666 random-site pots, 322 (48%) had zero catch of blue cod. The scaled length-frequency distributions for all males and females were unimodal, and similar in all four regions with mean size about 32 cm for males and 30 cm for females. Sex ratios of all blue cod were dominated by males (QCH 73% male, PEL 90%, DUR 65%, MS 73%). MS scaled length-frequency distributions for both males and females were unimodal with mean lengths of 32.5 and 30.5 cm. Males had a higher proportion of larger fish than females, and were the largest fish. Age estimates were 1–16 years for males and 3–20 years for females. Mean ages were 5.7 years for males and 7.3 for females. The MS Chapman-Robson total mortality (Z) estimate for age at recruitment (AgeR) of six years, was 0.52. Based on the default M of 0.14, estimated fishing mortality (F) was 0.38 and the associated spawner-per-recruit ratio was 39.4%, close to, but below the Ministry F_{MSY} target reference point of $F_{45\%SPR}$.

Fixed-site surveys time series

In QCH a large increase in catch rates in 2010 was consistent with the closure of the inner Sounds to fishing two years earlier in 2008. The 2013 survey took place two and a half years after the slot limit (30–35 cm) was in effect, and catch rates returned to the levels observed in 2007, before the closure. In 2017, nearly two years after the slot limit was removed and replaced by a minimum legal size (MLS) of 33 cm and a seasonal closure (1 Sept–19 December), QCH catch rates were similar to 2013. The QCH length distributions and changes in mean length were consistent with catch rate trends and showed a substantial overall increase in mean length in 2010 after which it was stable, but markedly higher than before 2010. QCH sex ratio, has remained stable, but male dominated. The pattern of catch rates and size in PEL was similar to QCH, until 2017 when they increased. The proportion of males in the PEL population increased over time and has the most skewed sex ratio of the three regions. DUR was not closed to target fishing blue cod in 2008 and there were no trends in DUR catch rates of all blue cod until 2017 when catch rates increased by 40% and mean length increased. The sex ratio (proportion male) of all blue cod in DUR increased markedly in 2007 and was then stable, but male dominated. Blue cod abundance and the population size distribution for each region, and for the whole Marlborough Sounds appears to have responded to changes in fisheries management regulations. See random sites time series for trends in *Z* and spawner-per-recruit ratio.

Random-site surveys time series

There are only two random-site surveys in QCH, PEL and DUR, so comments on trends in the time series are unwarranted. There was no trend in abundance for CKST (three surveys), but in 2017 catch rates were about one-third higher and male blue cod mean length was greater than in 2013. Sex ratio, however, has remained male dominated and unchanged over the three surveys. The only regulation change affecting CKST was the increase in the MLS from 30 cm to 33 cm in December 2015 and the associated seasonal closure. The catch rates for Marlborough Sound (excluding Cook Strait) were higher in 2017 than 2013.

Stock status analysis from random-site surveys is preferred to that from fixed-site surveys. There were two random-site surveys with valid ageing (2013 and 2017). Growth rates, length and age compositions, and Chapman-Robson (CR) total mortality estimates (*Z*) were similar for the 2013 and 2017 random-site surveys (Z = 0.46 in 2013, and 0.52 in 2017), but the spawner-per-recruit ratios ($F_{SPR\%}$), differed substantially and were 27% and 39%, respectively. The difference was primarily a result of having different selectivity ages to the fishery because the MLS was 30 cm in 2013 and 33 cm in 2017, resulting in few females being selected, and hence these ratios cannot be validly compared.

Fixed versus random-site surveys

Catch rates were much higher from the concurrent fixed-site than the random-site surveys in both 2013 and 2017. Comparison of random-site catch rates by region do not always show the same pattern as fixed sites in terms of increasing, decreasing or no change, but overall for the Marlborough Sounds (excluding Cook Strait) catch rates increased from 2013 to 2017 for both survey types. Length distributions and mean size of blue cod from the concurrent surveys were similar. CVs were overall higher for random sites, despite more effort than fixed site surveys.

Long Island (Kokomohua) Marine Reserve survey

Eight random sites (9 pots per site, producing 72 pot lifts) from inside the Long Island Marine Reserve (LIMR) were surveyed from 25–27 October 2017. A total of 911 blue cod (estimated weight 630 kg) was taken and all were released alive. Catch rate for all blue cod was 8.76 $kg.pot^{-1}$ (CV of 15%). The key finding was that blue cod catch rates in LIMR were 4-fold greater and mean length was 3.2 cm greater than the adjacent fished QCH strata. Further, only 7% of pots were empty compared to 86% and 72% for the two adjacent Queen Charlotte Sound strata, indicating that within the reserve, blue cod distribution was less patchy.

1. INTRODUCTION

This report describes the 2017 Marlborough Sounds potting survey of relative abundance, population length/age structure and stock status of blue cod (*Parapercis colias*). This is the ninth blue cod survey carried out in the Marlborough Sounds, with the first survey in 1995. The report also presents time series comparisons of these indices.

1.1 Blue cod potting surveys

South Island recreational blue cod fisheries are monitored using potting surveys. These surveys take place in the most important blue cod recreational fisheries areas, although there is often substantial overlap between the commercial and recreational fishing grounds. In addition to the Marlborough Sounds, there are currently eight other areas surveyed, located in key recreational fisheries: Kaikoura, Motunau, Banks Peninsula, north Otago, south Otago, Foveaux Strait, Paterson Inlet and Dusky Sound. In the Marlborough Sounds, previous potting surveys were carried out in 1995, 1996, 2001, 2004, 2007, 2008, 2010, and 2013 (Blackwell 1997, 1998, 2002, 2006, 2008, Beentjes & Carbines 2012, Beentjes et al. 2017). The length of the time series for the Marlborough Sounds varies among the regions and survey design type (Table 1).

All Marlborough Sounds potting surveys before 2010 used a fixed site design (see Appendix 1, glossary of terms), where sites with predetermined locations (fixed sites) were randomly drawn from a limited list of such sites (Beentjes & Francis 2011). Fixed sites represent 'good' fishing spots or locations where blue cod were considered to be abundant. The South Island potting surveys were reviewed by an international expert panel in 2009, which recommended that blue cod would be more appropriately surveyed using random site potting surveys (Stephenson et al. 2009). A random site is any location (single latitude and longitude) generated randomly from within a stratum (Beentjes & Francis 2011). Random sites were used in conjunction with fixed sites from 2010 onward, although in 2010 the random sites were experimental; and the first full random-site survey took place in 2013. Fisheries New Zealand intends to transition to a fully random-site 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. The next survey in the time series will use only a random site design.

Surveys are carried out every three to four years and provide data used to monitor local relative abundance as well as size, age, and sex structure of geographically separate blue cod populations. Surveys provide a measure of the response of blue cod populations to changes in fishing pressure and to management initiatives such as changes to the daily bag limit, minimum legal size, and area closures.

1.2 Status of blue cod in the Marlborough Sounds

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

Blue cod (*Parapercis colias*) is the second most important recreational target species in the Marlborough Sounds and in Tasman/Golden Bay, after snapper. The most reliable recreational catch estimates from BCO 7 are 77 t from a national panel survey in 2012 and 75 t from a 2016 aerial-access survey (Fisheries New Zealand 2018). Catch estimates are similar to the commercial fishery in BCO 7, which is confined

to the outer Sounds and Cook Strait (Davey et al. 2008), with reported landings of 50–70 t annually over the last 10 years (Fisheries New Zealand 2018).

In the Marlborough Sounds there have been frequent changes to both the minimum/maximum legal size and to the daily bag limit, as well as area closures in the 'Marlborough Sounds Area' (Fisheries New Zealand 2018) (Figures 1 and 2) . The daily bag limit progressively declined from 12 blue cod in 1985 to 2 blue cod since 2011 (the inner Sounds was closed to blue cod fishing from October 2008 to April 2011). The minimum legal size varied from 28 cm to 33 cm, with a slot limit of 30 to 35 cm from April 2011 to December 2015 (Figure 2).

There was a marked reduction in length of blue cod in the Marlborough Sounds from the late 1930s (Rapson 1956) to the mid-1990s when Ministry potting surveys began monitoring the population. The Marlborough Sounds potting surveys showed a decline in abundance in the inner Sounds of between one-third to a half between 1995/96 and 2001, and indicated that local depletion had occurred in the inner Sounds where blue cod catch rates were consistently lower and mean length was smaller than the outer Sounds (Beentjes & Carbines 2012, Beentjes et al. 2017). The closure of the inner Marlborough Sounds to blue cod fishing from October 2008 had a dramatic effect on the population length composition and abundance in the closed area by the October 2010 survey (Beentjes & Carbines 2012). For the first time since 2001, and presumably for many years before that, blue cod were larger and more abundant within the inner than the outer Sounds, indicating that fishing in the inner Sounds has had a substantial effect on the length distribution and abundance of fish. There may have been some movement of blue cod from the outer to the inner Sounds that contributed to the improved size structure and higher abundance, so the change may not necessarily have been solely due to growth of resident inner Sounds fish.

The last survey in 2013 survey took place 30 months after the inner Sounds were reopened with a slot limit legal size (30–35 cm) covering the entire 'Marlborough Sounds Area'. The 2013 survey results indicated that blue cod abundance and length declined in the previously closed areas (inner Pelorus and Queen Charlotte Sounds) after the re-opening and slot limit in April 2011, indicating that the blue cod population was responding to fishing effort (Beentjes et al. 2017). The blue cod potting survey time series appears to have successfully tracked trends in abundance and length distributions that resulted from changes in the fisheries management regime.

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

1.3 Objectives

Overall objective

1. To estimate relative abundance, maturity state, sex ratio, and age structure of blue cod (*Parapercis colias*) in the Marlborough Sounds.

Specific objectives

1. To undertake a potting survey in the Marlborough Sounds (BCO 7) to estimate relative abundance, size- and age-at-maturity, sex ratio and collect otoliths from pre-recruited and recruited blue cod.
2. To analyse biological samples collected from this potting survey.
3. To determine stock status of blue cod populations in this area, and establish how this has changed in response to management interventions.

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

2. METHODS

2.1 2017 Marlborough Sounds potting survey

2.1.1 Timing

A potting survey of the Marlborough Sounds area was carried out by NIWA between 23 September and 28 October 2017. The survey dates were consistent with previous surveys and coincided with the known spawning times in this region.

2.1.2 Survey area

Four regions (Queen Charlotte Sound, Pelorus Sound, D'Urville Island and Cook Strait), comprising 14 strata were covered, including for the first time Long Island Marine Reserve (Figure 3). The 2017 survey did not include Separation Point (stratum 10), which was surveyed only in 2004 and 2007. Coastline length was measured using ArcMap (GIS system) and recorded in kilometres before the 2010 survey. The 2010 coastline estimates replaced those reported in the 1995 to 2007 surveys as these were considered to be less accurate. The length (km) of coastline within each stratum was taken as a proxy of available habitat for blue cod in the absence of specific habitat information, or a clear understanding of the habitat requirements of blue cod.

2.1.3 Survey design

Full fixed-site and random-site surveys were carried out concurrently in Queen Charlotte Sound (QCH), Pelorus Sound (PEL) and around D'Urville Island (DUR) (Figure 1). In Cook Strait (CKST) (strata 11 to 13) and the Long Island Marine Reserve, only random-site surveys were carried out.

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 survey are randomly selected from the list of all available fixed sites in each stratum. For the 2017 Marlborough Sounds survey, the allocated fixed sites were randomly selected from the list of 97 possible fixed sites (stored in the *trawl* database in table *t_site*). About one-half of possible sites are used in Marlborough Sounds fixed-site surveys.

Pot configuration and placement for fixed sites is 'directed' (Beentjes & Francis 2011). In the Marlborough Sounds, blue cod habitat is largely restricted to a band of reef and rubble adjacent to the coastline. Nine pots (Pot Plan 1) were set along the coastline, no further than 0.5 km from the site position, but separated by at least 100 m. Pot placement in Marlborough Sounds fixed sites is determined by the skipper using local knowledge and the vessel echo sounder to locate a suitable area of reef/cobble or biogenic reef within the band of coastal habitat. This method was used in all previous Marlborough Sounds surveys.

Random sites

A random site has a location (single latitude and longitude) generated randomly within a stratum (Beentjes & Francis 2011). In all 12 Marlborough Sounds strata, coastline was divided into 1.01 km blocks (excluding coastline sections less than 1.01 km such as rocks or small islands) and a latitude and longitude at the centre of each block was assigned, giving 1195 potential random sites. From this list, the allocated number of random sites per stratum to be surveyed was randomly selected. If a random

site was within 1 km of an allocated fixed site, an alternative fixed site was selected to avoid biasing random-site location, which takes priority as the future survey design.

Pot placement in random-site surveys is 'systematic' (Beentjes & Francis 2011). In the Marlborough Sounds, pot configuration and placement is the same as for fixed sites, except that pots are placed 100 m apart in a randomly selected depth over the extent of the habitat, as it extends out from the shore.

Site allocation

Simulations using NIWA's Optimal Station Allocation Program (*allocate*) were carried out using catch rates from previous Marlborough Sounds surveys to determine the optimal allocation of sites among the four regions and 12 strata. Fixed site allocations in QCH, PEL, and DUR were based on catches from 2001 to 2013 surveys. Random site allocations for QCH were based on the 2013 survey; and those for PEL/DUR/CKST on the 2010 and 2013 surveys. Simulations were constrained to have a minimum of three sites per stratum and a CV (coefficient of variation) of no greater than 15% for fixed sites and 20% for random sites. The simulations indicated that 36 fixed sites and 71 random sites were required. Of the possible 10 random sites in Long Island Marine Reserve, nominally 8 were randomly selected.

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

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

where for the ith stratum $mean_i$ is the mean catch rate of blue cod per pot, $area_i$ is the fishable stratum area, and n_i is the number of sets in phase 1. In the iterative application of this equation, n_i is incremented by 1 each time a phase 2 set is allocated to stratum i. About 10% of sites were allocated to phase 1.

As for previous fixed-site surveys, the 2017 survey used a one-phase random stratified survey design.

2.1.4 Vessel and gear

The Wellington-based NIWA inshore research vessel R.V. *Ikatere* was used. The *Ikatere* is an aluminium-alloy catamaran with a length of 13.9 m, beam of 4.85 m and is equipped with a 322 Hamilton water jet unit, and powered by twin Cummins QSC engines rated at 500 HP, capable of 25 knots cruising speed. The *Ikatere* was skippered by Andrew James and Matt McGlone, both of whom have considerable experience in commercial blue cod potting and were skippers on the 2013 survey.

Nine custom designed and built cod pots were used to conduct the survey (Pot Plan 1 in Beentjes & Francis 2011). Pots were baited with 700 g of paua viscera in 'snifter pottles'. Bait was replaced after every lift and the proportion of bait remaining was recorded. The same pot design and bait were used in all previous Marlborough Sounds blue cod potting surveys.

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

2.1.5 Sampling methods

All sampling methods adhered strictly to the blue cod potting survey standards and specifications (Beentjes & Francis 2011). The survey started in Cook Strait and Queen Charlotte Sound before moving to Pelorus Sound, D'Urville Island, consistent with the 2010 and 2013 surveys. The Long Island Marine Reserve was sampled last.

At each site (fixed or random) nine pots were set and left to fish (soak) for a target period of one hour during daylight hours. Soak time was standardised to be consistent with all previous potting surveys. After each site was completed (nine pot lifts) the next closest site (either random or fixed) in the stratum was sampled. While it was not logistically possible to standardise for time of day or tides, each stratum was surveyed throughout the day, collectively giving strata roughly equal exposure to all daily tidal and time regimes.

As each pot was placed, a record was made of sequential pot number (1 to 9), latitude and longitude from GPS, depth and time of day. 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.

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 and the number of individuals of each species per pot was also recorded. Total length to the nearest centimetre below actual length, individual weight (to the nearest 10 g), sex, and gonad maturity was recorded for all blue cod. Sagittal otoliths were removed from a representative length range of blue cod males and females (a target of up to five fish of each sex per 1 cm length class over the available length range, ensuring that the otolith collection was spread across strata from each region). Separate otolith collections were made for each of the four regions with a target of about 250 otoliths per region. Sex and maturity were determined by dissection and macroscopic examination of the gonads (Carbines 1998, 2004). Blue cod gonad staging was undertaken using a 5-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. A photographic guide of gonad stages was made during the survey with photos taken of each of the five gonad stages for each sex.

2.1.6 Long Island Marine Reserve

Pot placement and sampling of blue cod in the Long Island Marine Reserve was carried out using the standard random site methodology described above. Pots were cleaned with freshwater, dried and cleaned of any fouling organisms prior to being deployed in the Marine Reserve. All blue cod and bycatch species were returned alive, therefore only individual blue cod length was recorded. To reduce potential mortality, neither the catch per pot, nor individual fish were weighed. Weights were instead estimated from the length-weight relationship obtained from blue cod caught on the main survey. After hauling blue cod were transferred directly from pots into bins with circulating water using wet cotton gloves, then measured for length to the neatest millimetre and returned alive below the sea surface through a 100 mm diameter pipe equipped with running water. Bycatch species numbers were recorded before being released alive in the same way. The release chute was deployed about 300 mm below the water surface to protect blue cod and other bycatch species from predation by shags and facilitate return to their place of capture. Maximum exposure time to air was approximately 1 minute. Processing time was less than 5 minutes between pots.

Two DOC staff (Kirsten Rodgers and Phil Clerke) joined the vessel to assist on the Long Island survey. All sampling within the reserve was permitted under a Department of Conservation Special Permit issued to NIWA (Authorisation to undertake specified scientific study within a marine reserve, Authorisation number 61105).

2.1.7 Data storage (potting survey)

The trip code for the survey is IKA1704. At the completion of the survey, data were entered into the *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., 1F, 2B etc.). Similarly, random sites were entered into attribute *stn_code*, but were prefixed with R (e.g., R3A, R4B). 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 19, or 31 to 39 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.

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

2.1.8 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).

2.1.9 Analyses of data

Analyses of catch rates, sex ratios, scaled length distribution, total mortality *Z*, fishing mortality *F*, and spawner-per-recruit (SPR) were conducted and presented for each of the four regions (QCH, PEL, DUR, CKST) for random sites, and for all regions except CKST for fixed sites. Analyses of catch-at-age, total mortality *Z*, fishing mortality *F*, and spawner-per-recruit (SPR), were also carried out for all regions combined to provide Marlborough Sounds wide estimates. For the Long Island Marine Reserve, analyses were limited to catch rate and scaled length frequencies; Catch at age and Z estimates were not carried out because the ageing data was unrepresentative of the larger fish found in the marine reserve.

Analyses of catch rates and CV, length-weight parameters, scaled length and age frequencies and CV, 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).

2.1.9.1 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 (33 cm and over, MLS). Catch rates of recruited blue cod are based on the sum of the weights of individual fish 33 cm and over. The coastline lengths (km) shown in Table 2 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 by stratum and overall for each region.

2.1.9.2 Length-weight parameters

The length-weight parameters a_k, b_k from the 2017 survey data were used in the equation

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

which 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.

2.1.9.3 Growth parameters

A von Bertalanffy growth model (von Bertalanffy 1938) was fitted to the 2017 survey length-age data by sex as follows:

$$L_t = L_\infty(1 - \exp^{-K[t - t0]})$$

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.

2.1.9.4 Scaled length and age frequencies

Length and age compositions of Marlborough Sounds populations 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 and if the actual weight of the catch is close to the estimated weight of the catch.

Because suitable blue cod habitat is a narrow strip around the coast, the coastline length (km) shown in Table 2, was taken as the area of the stratum (A_t), and the length-weight parameter estimates were made from the 2017 survey data for males and females separately.

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

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

For each of the four regions (QCH, PEL, DUR, CKST) catch-at-age was estimated using the length data collected from that region and the age length key (ALK) by sex, generated from all regions combined. A single ALK was used because there were few larger and older fish in Cook Strait and Pelorus Sound. An analysis of mean-length-at-age was carried out to compare growth among the four regions and determine if combining all the age data by sex was justified. The same ALKs were used for both random and fixed sites catch at age analyses. For each region and overall for Marlborough Sounds (fixed and random-site), scaled length-frequency and age-frequency proportions are presented, together with CV for each length and age class, and the mean weighted coefficients of variation (MWCV).

2.1.9.5 Sex ratios, and mean length and age

Sex ratios (expressed as percentage male) and mean lengths, for both the stratum and survey level, were calculated using equations 10 and 11 of Beentjes & Francis (2011) from the stratum or survey scaled length frequency data. Mean ages were calculated analogously from the scaled age frequencies. Sex ratios were also estimated for recruited blue cod (33 cm and over) with 95% confidence intervals generated from the 300 bootstraps. Similarly, 95% confidence intervals around mean length of all blue cod were generated from the 300 bootstraps.

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

In addition, traditional catch curve regression plots were made for each sex and region in which age (years) was plotted against natural log of the catch or numbers at age.

2.1.9.7 Spawner-per-recruit estimates

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

Input parameters used in the SPR analysis

Growth parameters — von Bertalanffy growth parameters and length-weight coefficients were estimated from the 2017 survey data (see below). Ages for all regions were combined because of the wide scatter of length versus age and lack of older large fish resulting in unlikely values for K, L_∞ and t_0 in Pelorus Sound and Cook Strait regions.

Parameter	Males	Females
L_∞ (cm)	39.94	32.24
K (yr^{-1})	0.37	0.52
t_0 (yr)	0.69	0.83
A	0.006740	0.006485
B	3.218	3.238

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

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

Selectivity — selectivity to the recreational fishery is described as knife-edge equal to age-at-MLS calculated from the 2017 Marlborough Sounds survey von Bertalanffy combined model. Recreational MLS in 2017 was 33 cm and selectivity was 5.4 years for males and 10 years for females. The von Bertalanffy curve for females indicated that virtually no females were selected to the fishery and hence 10 y was used as a nominal value where the curve flattens.

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 for age-at-full recruitment ordinarily corresponds to age at full recruitment of females at the MLS. In this case, few female blue cod reach 33 cm, so instead age-at-recruitment was taken from males and females combined, calculated from the 2017 Marlborough Sounds von Bertalanffy model (6 years).

Maximum age — assumed to be 31 years.

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

3. RESULTS

3.1 2017 Marlborough Sounds fixed-site blue cod potting survey

3.1.1 Fixed sites surveyed and catch

Thirty-six fixed sites (9 pots per site, producing 324 pot lifts) from nine strata throughout the Marlborough Sounds were surveyed from 24 September to 20 October 2017 (Table 2, Figure 4). Depths sampled were 2–50 m (mean = 14 m).

A total of 1118 kg of blue cod (2278 fish) was taken comprising 96% by number of the catch of all species on the survey (Table 3). Bycatch species included 11 teleost fishes, 1 shark, 1 octopus, and 1 starfish species. The three most common vertebrate bycatch species, by number, were leatherjacket (*Meuschenia scaber*), carpet shark (*Cephaloscyllium isabella*), and scarlet wrasse (*Pseudolabrus miles*).

Of the 324 fixed-site pots, 129 (39.8%) had zero catch of blue cod.

3.1.2 Blue cod catch rates (fixed sites)

Mean catch rates (kg.pot^{-1}) of all blue cod and recruited blue cod (33 cm and over) from fixed sites are presented by stratum, overall for each region, and for Marlborough Sounds overall (Table 4, Figures 5 and 6).

Queen Charlotte Sound (QCH) mean catch rates of all blue cod (all sizes) were 0.18–1.95 kg.pot^{-1}, increasing markedly from the inner to the outer Sounds and were more than 10-fold greater in extreme outer Queen Charlotte Sound (EQCH) than inner Queen Charlotte Sound (IQCH) (Table 4, Figure 6). The QCH all blue cod catch rate was 0.86 kg.pot^{-1} with a CV of 27%. Catch rates for recruited blue cod, 33 cm and over, followed the same pattern among strata as for all blue cod, and the overall catch rate was 0.43 kg.pot^{-1} (CV 35%), i.e., low or high catch rate estimates for all fish were generally mirrored by low or high values for recruited fish. All 13 fixed sites had some blue cod catch, but of the 117 pots, 68 (58%) had zero catch of blue cod.

Pelorus Sound (PEL) mean catch rates of all blue cod (all sizes) were 0.11–10.06 kg.pot^{-1}, increasing markedly from the inner to the outer sounds and were more than 90-fold greater in extreme outer Pelorus Sound (EOPE) than mid Pelorus Sound (MPEL) (Table 4, Figure 6). The PEL all blue cod catch rate was 3.20 kg.pot^{-1} with a CV of 17%. Catch rates for recruited blue cod 33 cm and over, followed the same pattern among strata as for all blue cod, and the overall catch rate was 1.38 kg.pot^{-1} (CV 26%), i.e., low or high catch rate estimates for all fish were generally mirrored by low or high values for recruited fish. All but one of the 12 fixed sites had some blue cod catch, but of the 108 pots, 47 (43%) had zero catch of blue cod.

D'Urville (DUR) mean catch rates of all blue cod (all sizes) were 4.50–8.73 kg.pot^{-1}, with highest catch rates in D'Urville west (DURW) (Table 4, Figure 6). The DUR all blue cod catch rate was 6.52 kg.pot^{-1} with a CV of 15%. Catch rates for recruited blue cod 33 cm and over, followed the same pattern among strata as for all blue cod, and the overall catch rate was 2.94 kg.pot^{-1} (CV 16%), i.e., low or high catch rate estimates for all fish were generally mirrored by low or high values for recruited fish. All 11 fixed sites had some blue cod catch, but of the 111 pots, 16 (14%) had zero catch of blue cod.

There were large differences in catch rates in the three regions, increasing markedly from east to west (QCH 0.86 kg.pot^{-1}; PEL 3.2 kg.pot^{-1}, DUR 6.52 kg.pot^{-1}) (Table 4, Figure 6).

The Marlborough Sounds mean catch rate of all blue cod (all sizes) was 3.13 kg.pot^{-1} with a CV of 10.5%. The highest catch rates were in extreme outer Pelorus Sound (EOPE) and the lowest in MPEL (Table 4, Figure 5). Catch rates for recruited blue cod 33 cm and over, followed the same pattern among strata as for all blue cod, and the overall catch rate was 1.41 kg.pot^{-1} (CV 13.5%), i.e., low or high catch rate estimates for all fish were generally mirrored by low or high values for recruited fish. All but one of the 36 fixed sites had some blue cod catch, but of the 324 pots, 130 (40%) had zero catch of blue cod.

3.1.3 Blue cod biological and length-frequency data (fixed sites)

Queen Charlotte Sound

Of the 221 blue cod caught in QCH fixed sites, all were sexed and measured for length and weight. The sex ratio was 20–85% male across the three strata and the overall weighted sex ratio was 72% male (Table 5). Length was 22–48 cm for males and 24–38 cm for females, and the overall weighted mean length was 32.2 cm for males and 29.6 cm for females. The length-frequency distributions lack the numbers in the inner Sounds strata to describe length composition well, but appear to be unimodal (Figure 7).

Pelorus Sound

Of the 806 blue cod caught in PEL fixed sites, all but one were sexed, and all were measured for length and weight. The sex ratio was 65–91% male across the four strata and the overall weighted sex ratio was 86% male (Table 5). Length was 24–42 cm for males and 24–39 cm for females and the overall weighted mean length was 32.0 cm for males and 29.5 cm for females. The length-frequency distributions lack the numbers in the inner Sounds strata to describe length composition well, but appear to be unimodal (Figure 8).

D'Urville Island

Of the 1251 blue cod caught in DUR fixed sites, all but one were sexed, and all were measured for length and weight. The sex ratio was 57–68% male across the two strata and the overall weighted sex ratio was 61% male (Table 5). Length was 23–48 cm for males and 24–38 cm for females and the overall weighted mean length was 32.9 cm for males and 30.6 cm for females. The length-frequency distributions are unimodal (Figure 9).

Marlborough Sounds

Of the 2278 blue cod caught in Marlborough Sounds fixed sites, all but two were sexed, and all were measured for length and weight. The overall weighted sex ratio was 72% male across the nine strata (Table 5). Length was 22–48 cm for males and 24–39 cm for females and the overall weighted mean length was 32.4 cm for males and 30.2 cm for females. The length-frequency distributions are unimodal (see Figures 7–9).

3.1.4 Age and growth

Otolith section ages from 708 males and 344 females collected from fixed and random sites were used to estimate the population age structure from Marlborough Sounds in 2017 (Table 6). Otoliths were collected from all regions, and all lengths, for both sexes (Appendix 2). Plots of length-at-age and modelled von Bertalanffy curves for each region indicated that older fish were not well represented in Pelorus Sound and Cook Strait, resulting in implausible von Bertalanffy parameters (Figure 10). Analyses of mean length-at-age indicate that growth from about 4 to 8 years old, which includes most fish, is not discernibly different among regions (Figure 11). On this basis, sexed based ALKs were produced by combining all the male ages, and all the female ages from all regions. The all-regions combined length-age data for 2017 are plotted and the von Bertalanffy model fits are shown for males and females separately (Figure 12). The growth parameters (K, t_0 and L_∞) are shown in the methods table of input data for the SPR analysis (Section 2.1.9.7) and in Figure 12. There is a large range in age-at-length for both sexes, and males grow larger than females, typical of blue cod. The 2017 fitted von Bertalanffy curves are similar to the 2013 Marlborough Sounds survey (Figure 13).

Between-reader comparisons are presented in Figure 14. The two readers achieved agreement on 87% of read otoliths, and overall there was no bias between readers with a between-reader precision (CV) of 1.5% with an index of average percentage error (IAPE) of 1.1%.

Age estimates from previous surveys

Only ageing from 2017 and 2013 surveys was carried out under the ADP. Although otoliths collected from the 2001 to 2010 surveys were read, this was before the ADP was established and the ages are not likely to be accurate. Otoliths would need to be re-aged under the ADP before any comparisons of age composition for surveys before 2013, could be validly attempted.

3.1.5 Blue cod spawning activity

Gonad stages of blue cod sampled on the 2017 survey between late September and late October are presented by region and for all blue cod (Table 7). There was a clear indication of spawning activity

during the survey period, particularly for males and nearly one-third of males and about 10% of females were running ripe.

3.1.6 Blue cod population length and age composition (fixed sites)

The scaled length-frequency and age distributions for the 2017 fixed-site survey are shown separately for each of the three regions as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Appendix 3), and for all regions combined (Figure 15).

Marlborough Sounds scaled length-frequency distributions for both males and females were unimodal with mean lengths of 32.4 and 30.0 cm respectively (Figure 15). The cumulative distribution plots of length-frequency show clearly that males had a higher proportion of larger fish than females, and also that the largest fish were males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 15% for males and 22% for females, indicating that the population was well represented.

Marlborough Sounds age estimates of blue cod were 2–16 years for males and 3–20 years for females, but most males were 4–6 years old and females were 5–8 years old (Figure 15). The estimated population age distributions were unimodal with peaks at 5 years for both sexes and long right hand tails, particularly for females. The cumulative distribution plots of age-frequency showed clearly that females had a much higher proportion of older fish than males. Further, the mean age of females was greater than the mean age of males (7.2 for females and 5.7 years for males). The MWCVs around the age distributions are 10% for males and 21% for females, indicating that the population was well represented.

Cumulative plots of population length for each of the three regions from fixed sites in 2017 showed that there was little difference in length distributions for males and females between the three regions, with indications that blue cod in DUR, particularly females, are slightly larger than from the other regions (Figure 16).

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

Fixed-site Chapman-Robson (CR) total mortality estimates (*Z*) and 95% confidence intervals are shown for a range of recruitment ages (5–10 years) for each region in Appendix 4, and for all regions combined in Table 8. Age-at-full recruitment (AgeR) was assumed to be six years, equal to the age at which males and females combined reach the MLS of 33 cm. The CR *Z* for AgeR of six years, for the three regions combined, was 0.53 (95% confidence interval of 0.38–0.72) (Table 8).

The traditional catch curve based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment of six years, was plotted for diagnostic purposes (Figure 17). The fixed-site catch curves display the traditional shape characterised by smooth ascending and descending limbs, and an intermediate domed portion, adding confidence to CR Z estimates.

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 each region in Appendix 5, and for all regions combined in Table 9. Based on the default *M* of 0.14, estimated fishing mortality (*F*) was 0.39 and associated spawner-per-recruit ratio was 39.0% for all regions combined for the fixed-site survey (Figure 18). This indicates that at the 2017 levels of fishing mortality, the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 39% of the contribution in the absence of fishing. The 95% confidence interval bounds were $F_{34\%}$–$F_{47\%}$ (Table 9).

3.2 2017 Marlborough Sounds random-site blue cod potting survey

3.2.1 Random sites surveyed and catch

Seventy-four random sites (9 pots per site, producing 666 pot lifts) from twelve strata throughout the Marlborough Sounds were surveyed from 24 September to 23 October 2017 (Table 2, Figure 4). Depths sampled were 2–36 m (mean = 11 m).

A total of 1250 kg of blue cod (2527 fish) was taken comprising 96% by number of the catch of all species on the survey (Table 3). Bycatch species included 13 teleost fishes, 1 shark, 1 octopus, and 3 invertebrate species. The four most common vertebrate bycatch species, by number, were leatherjacket (*Meuschenia scaber*), scarlet wrasse (*Pseudolabrus miles*), banded wrasse (*Notolabrus fucicola*), and tarakihi (*Nemadactylus macropterus*).

Of the 666 random-site pots, 322 (48.3%) had zero catch of blue cod.

3.2.2 Blue cod catch rates (random sites)

Mean catch rates (kg.pot^{-1}) of all blue cod and recruited blue cod (33 cm and over) from random sites are presented by stratum and overall for each region (Table 4, Figures 19 and 20). There were large differences in catch rates in the three Marlborough Sounds regions, increasing markedly from east to west (QCH 1.04 kg.pot^{-1}; PEL 0.90 kg.pot^{-1}, DUR 3.59 kg.pot^{-1}) (Table 4, Figure 20). Catch rates in CKST also showed large between-strata differences, progressively increasing north-eastward along the coast (Table 4, Figure 20).

Queen Charlotte Sound

Queen Charlotte Sound (QCH) mean catch rates of all blue cod (all sizes) were 0.11–1.94 kg.pot^{-1}, increasing markedly from the inner to the outer Sounds and were nearly 20-fold greater in EQCH than IQCH (Table 4, Figure 20). The QCH all blue cod catch rate was 1.04 kg.pot^{-1} with a CV of 15%. Catch rates for recruited blue cod 33 cm and over, followed the same pattern among strata as for all blue cod, and the overall catch rate was 0.54 kg.pot^{-1} (CV 11%), i.e., low or high catch rate estimates for all fish were generally mirrored by low or high values for recruited fish. All but one of the 26 random sites had some blue cod catch, but of the 234 pots, 120 (51%) had zero catch of blue cod.

Pelorus Sound

Pelorus Sound (PEL) mean catch rates of all blue cod (all sizes) were 0.07–2.77 kg.pot^{-1}, increasing markedly from the inner to the outer Sounds and were more than 40-fold greater in EOPE than IPEL (Table 4, Figure 20). The PEL all blue cod catch rate was 0.90 kg.pot^{-1} with a CV of 23%. Catch rates for recruited blue cod 33 cm and over, followed the same pattern among strata as for all blue cod, and the overall catch rate was 0.47 kg.pot^{-1} (CV 23%), i.e., low or high catch rate estimates for all fish were generally mirrored by low or high values for recruited fish. All but two of the 20 random sites had some blue cod catch, but of the 180 pots, 104 (58%) had zero catch of blue cod.

D'Urville Island

D'Urville (DUR) mean catch rates of all blue cod (all sizes) were 2.92–4.33 kg.pot^{-1}, with highest catch rates in DURW (Table 4, Figure 20). The DUR all blue cod catch rate was 3.59 kg.pot^{-1} with a CV of 24%. Catch rates for recruited blue cod 33 cm and over, followed the same pattern among strata as for all blue cod, and the overall catch rate was 1.62 kg.pot^{-1} (CV 21%), i.e., low or high catch rate estimates for all fish were generally mirrored by low or high values for recruited fish. All 14 random sites had some blue cod catch, but of the 126 pots, 40 (32%) had zero catch of blue cod.

Cook Strait

Cook Strait (CKST) mean catch rates of all blue cod (all sizes) were 0.08–2.67 kg.pot^{-1}, with highest catch rates in Arapara Island east (APAE) (Table 4, Figure 20). The CKST all blue cod catch rate was

1.10 kg.pot^{-1} with a CV of 28%. Catch rates for recruited blue cod 33 cm and over, followed the same pattern among strata as for all blue cod, and the overall catch rate was 0.54 kg.pot^{-1} (CV 28%), i.e., low or high catch rate estimates for all fish were generally mirrored by low or high values for recruited fish. All but one of the 13 random sites had some blue cod catch, but of the 117 pots, 52 (44%) had zero catch of blue cod.

Marlborough Sounds

Marlborough Sounds mean catch rates of all blue cod (all sizes) was 1.55 kg.pot^{-1} with a CV of 13.5% including Cook Strait, and 1.59 kg.pot^{-1} (CV 14.3) excluding Cook Strait. The highest catch rates were in DURW and the lowest in IPEL (Table 4, Figure 19). Catch rates for recruited blue cod 33 cm and over, followed the same pattern among strata as for all blue cod, and including Cook Strait was 0.75 kg.pot^{-1} (CV 11.6%) and excluding Cook Strait was 0.77 kg.pot^{-1} (CV 12.3%), i.e., low or high catch rate estimates for all fish were generally mirrored by low or high values for recruited fish. All but four of the 74 random sites had some blue cod catch, but of the 666 pots, 322 (48%) had zero catch of blue cod.

3.2.3 Blue cod biological and length-frequency data (random sites)

Queen Charlotte Sound

Of the 628 blue cod caught in QCH random sites, all were sexed and measured for length and weight. The sex ratio was 11–81% male across the three strata and the weighted sex ratio was 73% male (Table 5). Length was 17–51 cm for males and 24–44 cm for females, and the weighted mean length was 32.5 cm for males and 30.7 cm for females. The length-frequency distributions lack the numbers in the inner Sounds strata to describe length composition well, but appear to be unimodal (Figure 21).

Pelorus Sound

Of the 572 blue cod caught in PEL random sites, all fish were sexed and measured for length and weight. The sex ratio was 84–100% male across the four strata and the weighted sex ratio was 90% male (Table 5). Length was 12–44 cm for males and 22–36 cm for females and the weighted mean length was 32.4 cm for males and 29.8 cm for females. The length-frequency distributions lack the numbers in the inner Sounds strata to describe length composition well, but appear to be unimodal (Figure 22).

D'Urville Island

Of the 982 blue cod caught in DUR random sites, all fish were sexed and measured for length and weight. The sex ratio was 59–72% male across the two strata and the weighted sex ratio was 65% male (Table 5). Length was 21–48 cm for males and 21–40 cm for females and the weighted mean length was 32.6 cm for males and 30.6 cm for females. The length-frequency distributions are unimodal (Figure 23).

Cook Strait

Of the 345 blue cod caught in CKST random sites, all were sexed and measured for length and weight. The sex ratio was 85–100% male across the three strata and the weighted sex ratio was 87% male (Table 5). Length was 20–46 cm for males and 21–32 cm for females, and the weighted mean length was 32.3 cm for males and 28.2 cm for females. The length-frequency distributions lack the numbers in the Port Underwood stratum (UNDW) to describe length composition, but appear to be unimodal (Figure 24).

Marlborough Sounds

Of the 2527 blue cod caught in Marlborough Sounds random sites, all were sexed and were measured for length and weight. The weighted sex ratio was 73% male across the 13 strata (Table 5). Length was 12–51 cm for males and 21–44 cm for females and the weighted mean length was 32.5 cm for males and 30.5 cm for females. The length-frequency distributions are unimodal (see Figures 21–24).

3.2.4 Blue cod population length and age composition (random sites)

The scaled length-frequency and age distributions for the 2017 random-site survey are shown separately for each of the four regions as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Appendix 6), and for all regions combined (Figure 25).

Marlborough Sounds scaled length-frequency distributions for both males and females were unimodal with mean lengths of 32.5 and 30.5 cm respectively (Figure 25). The cumulative distribution plots of length-frequency show clearly that males had a higher proportion of larger fish than females, and also that the largest fish were males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 16% for males and 25% for females, indicating that the population was well represented.

Marlborough Sounds age estimates of blue cod were 1–16 years for males and 3–20 years for females, but most males were 4–6 years old and most females were 5–8 years old (Figure 25). The estimated population age distributions were unimodal with peaks at 5 years for both sexes and long right hand tails, particularly for females. The cumulative distribution plots of age-frequency showed clearly that females had a much higher proportion of older fish than males. Further, the mean age of females was greater than the mean age of males (7.3 for females and 5.7 years for males). The MWCVs around the age distributions are 11% for males and 22% for females, indicating that the population was well represented.

Cumulative plots of population length for each of the four regions from random sites in 2017 showed that there was little difference in length distributions for males and females between the regions, although only 47 females were caught in CKST so the cumulative curve is unlikely to be representative of the population (Figure 26).

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

Random-site Chapman-Robson (CR) total mortality estimates (*Z*) and 95% confidence intervals are shown for a range of recruitment ages (5–10 years) for each region in Appendix 4, and for all regions combined in Table 8. Age-at-full recruitment (AgeR) was assumed to be six years, equal to the age at which males and females combined reach the MLS of 33 cm. The CR *Z* for AgeR of six years, for the three regions combined, was 0.52 (95% confidence interval of 0.37–0.69) (Table 8).

The traditional catch curve based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment of six years, was plotted for diagnostic purposes (Figure 17). The random site catch curves display the traditional shape characterised by smooth ascending and descending limbs, and an intermediate domed portion, adding confidence to CR Z estimates.

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 each region in Appendix 5, and for all regions combined in Table 9. Based on the default *M* of 0.14, estimated fishing mortality (*F*) was 0.38 and associated spawner-per-recruit ratio was 39.4% for all regions combined for the random-site survey (see Figure 18). At the 2017 levels of fishing mortality, the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 39% of the contribution in the absence of fishing. The 95% confidence interval bounds were $F_{34\%}$–$F_{48\%}$ (Table 9).

3.3 Long Island Marine Reserve survey

Eight random sites (9 pots per site, producing 72 pot lifts) from inside the Long Island Marine Reserve (LIMR) were surveyed from 25–27 October 2017 (Table 2, Figures 4 and 27). Depths sampled were 2–19 m (mean = 8 m). A total of 911 blue cod (estimated weight 630 kg) was taken comprising 99% by number of the catch of all species on the survey (Table 3). Bycatch species included two teleost species: leatherjacket (*Meuschenia scaber*), and red moki (*Cheilodactylus spectabilis*). Mortality was scored by Department of Conservation staff as 'live' if they swam on entering the water, or 'dead' if they drifted downwards or were predated upon by shags. One fish died of stress and one was taken by a shag with an estimated mortality of 0.2%.

The mean catch rate of all blue cod (all sizes) was 8.76 kg.pot^{-1} (CV of 15%) and for recruited blue cod 33 cm and over it was 6.83 kg.pot^{-1} (CV 18%) (Table 4, Figure 19). Catch rates were substantially higher in LIMR than adjacent fished strata in Queen Charlotte Sound (Figure 28).

All 8 random sites had some blue cod catch, but of the 72 pots, 5 (7%) had zero catch of blue cod. The proportion of empty pots was substantially less than for the three Queen Charlotte Sound strata, including those adjacent to the marine reserve (OQCH and EQCH) (Figure 29)

Of the 911 blue cod caught in LIMR random sites, all were measured for length and released alive so no data were collected on sex, or otoliths collected to estimate age. Length was 24–49 cm, and the weighted mean length was 35.1 cm. The length-frequency distributions in the LIMR appear to be bimodal with peaks at about 33 cm and 40 cm and are in contrast to the unimodal distributions from adjacent strata in Queen Charlotte Sound (Figure 30). The mean size is 3.2 cm greater in the LIMR.

3.4 Comparison of fixed-site and random-site surveys

For all QCH strata and the inner strata in PEL there was no real difference in blue cod catch rates (all blue cod or recruited) between fixed and random sites (Figure 31). For the outer PEL and for DUR strata, however, catch rates were substantially larger from fixed than random sites (Figure 31). When catch rates are expressed by region there was no difference between fixed and random sites in QCH, but for PEL and DUR fixed sites catch rates were statistically different ($P<0.01$ in both cases) (Figure 32).

Cumulative plots of population length and age from the fixed-site and random-site surveys are presented by region in Figures 33–35. There was little or no difference in length or age distributions of either sex, except for QCH females which were slightly larger and older than in random sites; only 59 females were caught in fixed sites from QCH so this is probably not representative of the population.

3.5 Survey time series (fixed sites)

3.5.1 Catch rates and sex ratio (fixed sites)

Mean catch rates (kg.pot^{-1}) for all blue cod, from fixed-site surveys are presented for each region and for the Marlborough Sounds (QCH, PEL and DUR combined) for each complete survey in the time series (Figure 36).

QCH catch rates of all blue cod declined by about a third between 1995 and 2001, and continued to decline slightly in 2004 and 2007, before nearly doubling in 2010, and then halving in 2013 (Figure 36). Catch rates in 2017 were similar to those in 2013. The pattern was the same for the recruited blue cod, but the increase in 2010 was about three-fold (Table 4). The proportion of pots that had no blue cod in fixed-site surveys was 30%–58% with indications that the proportion of zeros has increased over time (Figure 37). The QCH sex ratio of all blue cod was 50–72% male with no clear trend, and for recruited blue cod it was about 20% higher (Figure 38), also with no trend.

PEL catch rates declined by about two-thirds between 1996 and 2001, nearly doubled in 2004, were stable in 2007, then nearly tripled in 2010, before dropping down by about one-third in 2013 (Figure 36). In 2017, catch rates were similar to 2010. The pattern was the same for the recruited blue cod, but the increase in 2010 was about four-fold (Table 4). The proportion of pots that had no blue cod in fixed-site surveys was 12%–43% with indications that the proportion of zeros has increased over time (Figure 37). PEL sex ratio of all blue cod was 65–90% male and the proportion of males increased over time. Recruited blue cod were nearly all male (Figure 38)

There was no change in catch rates in DUR until 2017 when they increased by 40% from 2013 (Figure 36). The pattern was the same for the recruited blue cod, but the increase in 2017 was about two-fold (Table 4). The proportion of pots that had no blue cod in fixed-site surveys was 8%–16% with no trend (Figure 37). The DUR sex ratio of all blue cod was 50–71% male with a large increase in proportion male in 2007, after which there was no trend. The DUR recruited sex ratio was 80–90% male with no trend (Figure 38).

There was only one CKST fixed-site survey (in 2008) before changing to a random-site design.

For Marlborough Sounds (QCH, PEL and DUR regions combined) since 2004, when strata were consistent (i.e., strata 1 to 9 sampled), catch rates increased by about one-third from 2007 to 2010, declined to the 2007 level in 2013 and then increased again by about one-third in 2017, the highest abundance estimate of the time series (Figure 36). The pattern was the same for the recruited blue cod (Table 4).

3.5.2 Length distributions (fixed sites)

The QCH scaled length-frequency distributions were similar in shape for the seven surveys but tended to shift left or right changing the mean length (Figure 39). The mean length of males was greatest in 2010, and was also greater in the last three surveys than the earlier surveys (Figure 40). The cumulative distributions of these length frequencies showed a decrease in overall male length from 1995 to 2001, no change in 2004, an increased length again in 2007 followed by a large increase in 2010, a smaller decrease in 2013 and an increase again in 2017 (Figure 41). Female length tracked in a similar manner, but the increased length in 2010 was less marked than for males. Male and female blue cod in QCH were larger from 2010 onward. The PEL scaled length-frequency distributions and the trends in mean length over the seven surveys closely mirrored those of QCH, but the first complete survey was in 1996 and not 1995 (Figures 40–42). In contrast, the DUR scaled length-frequency distributions were remarkably consistent and showed very little difference for either sexes over the five surveys from 2004 to 2017, although blue cod were largest in 2017 (Figures 40, 41 and 43).

The Marlborough Sounds scaled length-frequency distributions from 2004 onward, when all nine strata were completed, were similar in shape for the five surveys, with a trend of increasing mean length for both males and females over time (Figures 40, 41 and 44).

3.5.3 Stock status (fixed sites)

Growth rates were consistent between 2013 and 2017 with similar shaped von Bertalanffy curves (see Figure 13). The length and age compositions were broadly similar for the 2013 and 2017 fixed-site surveys for males for all regions combined, but less so for females where the dominant age class was 5 years in 2017 and 7 years in 2013 (Figure 45). CR total mortality estimates (Z) for age at recruitment of 6 years were very close at 0.51 in 2013 and 0.53 in 2017. Spawner-per-recruit ratios ($F_{SPR\%}$), however, differed substantially and were 25% in 2013 and 39% in 2017. The difference was primarily a result of having different ages of selectivity to the fishery because the MLS was 30 cm in 2013 and 33 cm in 2017, so these ratios cannot be validly compared.

3.6 Survey time series (random sites)

For random-site surveys there are two surveys in the time series for QCH, PEL and DUR (2013 and 2017), and three for Cook Strait (2010, 2013 and 2017), so comments on trends are speculative.

Mean catch rates ($kg.pot^{-1}$) for all blue cod, from random-site surveys are presented for each region and for the Marlborough Sounds (QCH, PEL and DUR combined, but excluding CKST) for each survey in the time series (see Figure 36). Cook Strait was not included in the all Marlborough Sounds to allow valid comparison of catch rates from the same strata (1 to 9) between fixed and random-site surveys. Catch rates of all blue cod in QCH and DUR roughly doubled between 2013 and 2017, and for PEL they declined slightly. CKST catch rates fluctuated over the three surveys with no trend. For Marlborough Sounds, catch rates showed no difference between 2010 and 2017 (see Figure 36).

The proportion of pots that had no blue cod in random-site surveys was 51%–62% in QCH, 53%–58% in PEL, 32%–38% in DUR and 44%–53% in CKST, with no clear changes over time (see Figure 37).

Sex ratio (percent male) by survey for each region is shown in Figure 38. The QCH sex ratio of all blue cod was 66–73% male in 2013 and 2017 respectively, with no clear trend and for recruited blue cod it was about 20% higher, also with no trend. Similarly, the PEL sex ratio of all blue cod was 77–90% male with no trend and recruited blue cod were nearly all male. The DUR sex ratio of all blue cod was 57–65% male with no clear trend, and the recruited sex ratio was about 80% male with no trend. The CKST sex ratio for all blue cod was 83–87% male with no trend and recruited blue cod were nearly all male.

The scaled length-frequency distributions and mean length were similar in shape between 2013 and 2017 for the QCH, PEL, and DUR random-site surveys (Figures 40, 46–49). Cook Strait male blue cod, however, were larger in 2017 than in the 2010 and 2013 random-site surveys (Figures 40, 47 and 50). For Marlborough Sounds mean length and the length distributions were similar for 2013 and 2017 (Figures 40, 47 and 51).

3.6.1 Stock status (random sites)

Growth rates were consistent between 2013 and 2017 with similar shaped von Bertalanffy curves (see Figure 13). The length and age compositions were broadly similar for the 2013 and 2017 random-site surveys for males for all regions combined, but less so for females where the dominant age class was 5 years in 2017 and 7 years in 2013 (Figure 52). CR total mortality estimates (Z) for age at recruitment of 6 years were very close at 0.46 in 2013 and 0.52 in 2017. Spawner-per-recruit ratios ($F_{SPR\%}$), however, differed substantially and were 27% in 2013 and 39% in 2017. The difference was primarily a result of having different ages of selectivity to the fishery because the MLS was 30 cm in 2013 and 33 cm in 2017, so these ratios cannot be validly compared.

4. DISCUSSION

4.1 General

The 2017 fixed-site survey was the seventh in the time series for QCH and PEL, which began in 1995 and 1996, respectively (see Table 1) and the fifth for DUR, which began in 2004, for which all strata in these regions were sampled. The surveys provide relative abundance estimates and population structure of blue cod from these regions and overall for Marlborough Sounds. The 2017 random-site survey was the second in QCH, PEL and DUR, and the third for Cook Strait in which all strata in these regions were sampled. The long-term goal is to transition to random-site surveys, which are statistically more robust than fixed-site surveys, and more likely to represent the entire population. After reviewing the results

of the 2017 Marlborough Sounds survey in March 2018, the MPI Southern Inshore Working Group (SINSWG-2018/15) recommended moving to solely random sites for future surveys.

The results of the 2017 survey and previous surveys in the time series are discussed in the context of the fisheries management regulations that were in place.

4.2 Fixed-site survey time series

4.2.1 Abundance, size and sex ratio

The highest catch rates of all blue cod from 2017 fixed sites by region were from DUR, followed by PEL and QCH, although there was considerable variation among strata within a region, with very low catch rates in the inner QCH and PEL Sounds (see Figure 6). The area of highest abundance was between the west side of D'Urville Island and the Chetwood Islands (strata 6 and 4). This pattern of abundance was consistent among the fixed-survey time series.

Queen Charlotte Sound

The large increase in catch rates in 2010 was consistent with the closure of the inner Sounds to fishing two years earlier in 2008 (see Figure 36). The 2013 catch rates returned to the levels observed in 2007, despite the presence of a more restrictive legal catch size range (slot limit 30–35 cm) than in 2007 when the MLS was 30 cm. In 2017, nearly two years after the slot limit was removed and replaced by a MLS of 33 cm and a seasonal closure (1 Sept–19 December), catch rates were similar to 2013.

The QCH length distributions were consistent with catch rate trends and showed a substantial increase in mean length in 2010 after which it was stable, but still higher than before 2010 (see Figures 39 and 40). The QCH population appeared to respond to the inner Sounds fishery closure in October 2008, with confounding results following the opening, the slot limit, and then the 33 cm MLS.

The sex ratio of all blue cod in QCH strongly favoured males, and in 2017 was 72% male, similar to previous surveys in the time series (see Figure 38). Blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow (Carbines 2004). The finding that males were larger on average than females and that the largest fish were males is consistent with sex structure in protogynous hermaphrodites. However, the skewed sex ratios are contrary to an expected dominance of females resulting from selective removal of the larger terminal fish (males). Beentjes & Carbines (2005) suggested that the shift towards a higher proportion of males in heavily fished blue cod populations may be caused by removal of an inhibitory effect of large males, and a consequent higher rate (and possibly earlier onset) of sex change by primary females. This hypothesis is supported by the predominance of males in most South Island blue cod fisheries that are known to be heavily fished, in particular Motunau, inshore Banks Peninsula, and Marlborough Sounds (Blackwell 1997, 1998, 2002, Beentjes & Carbines 2003, 2006, Blackwell 2006, Carbines & Beentjes 2006, Blackwell 2008, Beentjes & Carbines 2009, Carbines & Beentjes 2009, Beentjes & Carbines 2012, Beentjes & Fenwick 2017, Beentjes et al. 2017, Beentjes & Sutton 2017). The closure, slot limit, and 33 cm MLS does not appear to have had any effect on QCH sex ratio, which remained stable, but male dominated.

Pelorus Sound

Catch rates of all blue cod were similar to QCH, until 2017. They declined between 1996 and 2007, increased substantially in 2010, then dropped in 2013 to levels similar to 1996, before increasing in 2017 where they were the highest of the series (see Figure 36). Similarly, the steep increase in catch rates in 2010 was consistent with the closure of the inner Pelorus Sounds two years earlier. The 2013 catch rates returned to levels intermediate between 1995 and 2001–07, despite the presence of a more restrictive legal catch size range (slot limit 30–35 cm) than before 2007 when the MLS ranged from 28 to 30 cm. The increase in abundance in 2017 may be related to the 33 cm MLS implemented two years earlier.

PEL length distributions were consistent with catch rate trends and showed a substantial overall increase in mean length in 2010, decline in 2013, and increase again in 2017 (see Figures 40 and 42). The PEL blue cod abundance and the population size distribution appears to have responded to changes in fisheries management regulations, and the fixed-site surveys were successful in monitoring these responses.

The proportion of males in the PEL population increased over time and has the most skewed sex ratio of the three regions (86% male in 2017) (see Figure 38). Factors controlling sex change in blue cod are not well understood and there are likely to be other drivers of this besides population size structure. The increase in abundance and mean size in 2010 and 2017 did not result in a more balanced sex ratio.

D'Urville Island

There were no trends in DUR catch rates of all blue cod until 2017 when catch rates increased by 40% (see Figure 36). Similarly, length distributions showed no trends over time until 2017 when mean length increased (see Figures 40 and 43). DUR was not closed to target fishing blue cod as the inner QCH and PEL were in 2008, and the stable catch rates and length distributions may reflect this. The slot limit does not appear to have had any influence on the 2013 catch rates or length distribution, although the west side of D'Urville Island did not have a slot limit, and was regulated with a 30 cm MLS at that time. The increase in abundance and mean size in 2017 may have been a result of the 33 cm MLS, implemented two years earlier, that applies to the entire DUR region (DURE and DURW). The sex ratio of all blue cod increased markedly in 2007 and then was 61–70% male, unaffected by the various fisheries management regulations (see Figure 38).

Marlborough Sounds

Combining the data from the three regions (QCH, PEL and DUR) provides a representation of the abundance, and population length structure for the entire Marlborough Sounds, but is clearly a blend of the trends from the three regions and is only valid from 2004 when strata were the same for all fixed-site surveys (see Figure 36).

Target CVs around estimates of relative abundance (catch rates) were not specified for the 2017 Marlborough survey. The achieved CV of 10.5% for the 2017 fixed-site Marlborough Sounds survey was low and indicates that the survey design and number of sites used was appropriate. Marlborough Sounds catch rates increased substantially in 2010, then dropped in 2013 to levels similar to 2004, before increasing in 2017, where they were the highest of the series. Marlborough Sounds length distributions of males were consistent with catch rate trends and showed a substantial overall increase in mean length in 2010, decline in 2013, and increase again in 2017. For females the mean length increased progressively from 2004 to 2017. As described for the regions, blue cod abundance and the population size distribution for the Marlborough Sounds reflects the 2008 inner Sounds closure, the 2011 opening with a slot limit, and 33 cm MLS and season closures in 2015.

Most female blue cod in Marlborough Sounds have historically been less than 33 cm in length (see Figure 44) and in 2017 89%, 93% and 82% of female blue cod were less than 33 cm in QCH, PEL and DUR, respectively. Hence the increase in the MLS from 30 cm to 33 cm MLS in 2015 has effectively removed all but the largest females from being of legal size, although there is still likely to be some mortality from caught and released undersize females.

4.2.2 Stock status trends (fixed sites)

The *Harvest Strategy Standard* specifies that a Harvest Strategy should include a fishery target reference point, and that this may be expressed in terms of biomass or fishing mortality (Ministry of Fisheries 2011). The most appropriate target reference point for blue cod is F_{MSY}, which is the amount of fishing mortality that results in the maximum sustainable yield. The recommended proxy for F_{MSY} is the level of spawner-per-recruit $F_{\%SPR}$ (Ministry of Fisheries 2011). Blue cod is categorised as an exploited species with low productivity 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 accuracy (Stephenson et al. 2009), so estimates of *Z* and SPR from random site surveys are likely to be more representative of the population.

Estimation of total mortality assumes that recruitment and mortality are constant, that all recruited fish are equally vulnerable to capture, and that there are no age estimation errors. In Marlborough Sounds, fishing mortality was not constant because of the various management changes that have occurred including the closure of the inner Sounds in 2008, and the subsequent changes in the MLS and bag limits throughout the inner and outer Sounds, including the slot limit. The spawner-per-recruit-ratio estimates are therefore also likely to be biased by these changes in fishing mortality.

Growth rates, length and age compositions, and CR total mortality estimates (*Z*) were similar for the 2013 and 2017 surveys. Spawner-per-recruit ratio ($F_{SPR\%}$), however, differed substantially and was 25% in 2013 and 39% in 2017. The difference was primarily a result of having different selectivity ages to the fishery because the MLS was 30 cm in 2013 and 33 cm in 2017, resulting in few females being selected, so these ratios cannot be validly compared. The 2017 fixed site spawner-per-recruit ratio of 39% is close to, but below the F_{MSY} target reference point of $F_{45\%SPR}$.

4.3 Random-site survey time series

4.3.1 Abundance, size and sex ratio

With only two random site surveys in QCH, PEL and DUR, a detailed examination of trends in the times series is unwarranted. With three Cook Strait surveys, however some discussion is appropriate.

The highest catch rates of all blue cod from 2017 random sites by region were from DUR, where they were more than three-fold higher than in the other regions, although there was considerable variation among strata within a region, with very low catch rates in the inner QCH and PEL Sounds (see Figure 19). The area of highest abundance is around D'Urville Island, the Chetwood Islands, and the Cook Strait side of Arapara Island (strata DURE, DURW, EOPE and APAE). This pattern of abundance is generally consistent in 2013 and 2017. Length distributions were also largely consistent between the two surveys for each region (see Figure 47).

In Cook Strait the only regulation change was the increase in the MLS from 30 to 33 cm in December 2015 and the associated seasonal closure. There was no trend in abundance for Cook Strait although, in 2017 catch rates were about one-third higher than 2013, two years after the regulation changes (see Figure 36). The CKST length distributions over the three random-site surveys were similar, but male blue cod mean length was larger in 2017 than in 2010 and 2013, and blue cod were smaller overall in 2010 (See Figure 47). It is possible that the CKST population responded to the 33 cm MLS and season closure with an increase in abundance and mean size since 2013. Sex ratio, however, has remained male dominated and unchanged over the three surveys (see Figure 38).

The catch rates for Marlborough Sounds (excluding Cook Strait) were higher in 2017 than 2013, but the confidence intervals suggest that this is not significant (see Figure 36).

4.3.2 Stock status trends (random sites)

Random-site surveys are considered to be superior to fixed sites surveys in design and accuracy (Stephenson et al. 2009), so estimates of *Z* and SPR from random-site surveys are likely to be more representative of the population. Growth rates, length and age compositions, and CR total mortality estimates (*Z*) were similar for the 2013 and 2017 random-site surveys. Notwithstanding the potential bias in *Z* as described above, the CR total mortality estimates (*Z*) were very close at 0.46 in 2013 and 0.52 in 2017, but the spawner-per-recruit ratios ($F_{SPR\%}$), differed substantially and were 27% and 39%,

respectively. The difference was primarily a result of having different selectivity ages to the fishery because the MLS was 30 cm in 2013 and 33 cm in 2017, resulting in few females being selected, and hence these ratios cannot be validly compared. For 2017 the random site spawner-per-recruit ratio of 39% was close to, but below the F_{MSY} target reference point of $F_{45\%SPR}$.

4.4 Comparison of blue cod fixed-site and random-site surveys

There were two concurrent fixed and random-site surveys (2013 and 2017). Catch rates in 2017 were all much higher from the fixed-site than the random-site surveys (see Figure 36). Comparison of random-site catch rates by region do not always show the same pattern as fixed sites in terms of increasing, decreasing or no change, but overall for the Marlborough Sounds (excluding Cook Strait) catch rates increased from 2013 to 2017. Length distributions and mean size of blue cod from the two survey types were similar, particularly in 2017 (see Figure 35). About 69% more random-site pots were set in the overlapping strata (1–9) than in fixed sites, but the CVs overall were still higher for random sites (see Table 4). The overall Marlborough Sounds CVs of 10% for fixed-site and 14% for random-site surveys (excluding CKST), are low and indicate that the effort applied in both surveys was more than adequate if the CV target is for Marlborough Sounds overall. Achieving similar CVs, despite vastly different effort, is not surprising given that fixed sites are located in areas where blue cod are known to be abundant ('hotspots') and that 40% of fixed-site pots had no blue cod compared to 48% for random-site pots. The 2017 survey results were consistent with those from 2013 where the catch rates from fixed sites were about twice the catch rates from random sites.

The MPI working group (SINSWG 2018-15) recognised that the previous fixed-site survey series provided an index of blue cod abundance at the fixed sites, which, although largely consistent with changes in management regulations, was unlikely to represent the entire population as well as the random-site surveys. Given that there were differences in trends in abundance between the fixed and random surveys for equivalent strata between 2013 and 2017, there was no acceptable way of quantitatively linking the fixed-site series with the random-site series. The working group therefore concluded that only random-site surveys should be conducted in the Marlborough Sounds in future.

4.5 Effect of the 2008 closure and the 2011 re-opening

The two-year period between the closure of the inner Marlborough Sounds to blue cod fishing on 1 October 2008, and when the 2010 survey was carried out, clearly had a dramatic effect on the population length composition and abundance inside the closed area. For the first time since 2001, and presumably for many years before this, blue cod were larger and more abundant within the inner than the outer Sounds, indicating that fishing in the inner Sounds was having a substantial effect on the size and abundance of fish. There may have been some movement of blue cod from the outer to the inner Sounds that contributed to the improved size structure, so the change may not necessarily have been solely due to growth of resident inner Sounds fish.

The 2013 fixed site survey took place two and half years after the fishery was reopened and a 30–35 cm MLS slot limit was put in place for the 'Marlborough Sounds Area'. Abundance and length of fish declined in the previously closed areas (PEL and QCH) after the re-opening of blue cod fishery, indicating that the blue cod population was responding to fishing effort. The 2017 survey took place about two years after the 33 cm MLS and seasonal closure were implemented for the 'Marlborough Sounds Area' and 'Challenger Area'. There were indications that abundance and mean size increased since the 2013 survey for both fixed and random site surveys. The blue cod fixed-site potting survey time series appears to have tracked changes in abundance and length resulting from changes in the fisheries management regulations.

4.6 Long Island (Kokomohua) Marine Reserve survey

The key finding from the random-site survey of Long Island Marine Reserve was that blue cod catch rates were substantially higher (4-fold greater than in the adjacent EQCH), and mean length was 3.2 cm greater than the adjacent fished strata (IQCH and EQCH) in Queen Charlotte Sound (see Figure 28). Further, only 7% of pots were empty compared to 86% and 72% for the two adjacent Queen Charlotte Sound strata, indicating that within the reserve, blue cod distribution was less patchy. These results are consistent with a time series of line fishing surveys of the marine reserve and adjacent fished areas which began in 1992, a year before the marine reserve was established by the Department of Conservation in April 1993 (Davidson et al. 2014). The potting survey indicated a greater contrast in abundance and size than the line surveys, possibly a result of selectivity issues relating to line versus potting. For example, small blue cod were observed to be more aggressive taking a baited hook than larger fish (pers. comm. Rob Davidson), and this may have biased the abundance and size estimates in the marine reserve downward. The results are a clear indicator that fishing effort in Queen Charlotte Sound has reduced blue cod abundance and size. We are unable to comment on the age structure or sex ratio of blue cod within the reserve, however, because all fish were returned alive. The intention is to include the Long Island Marine Reserve in future surveys of the Marlborough Sounds to provide ongoing control sites to compare with fished sites, an initiative supported by DOC.

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7. TABLES AND FIGURES

Table 1: Ministry fixed-site and random-site blue cod potting survey time series in the Marlborough Sounds by region, including the 2017 survey. See Figure 3 for locations of regions. 1995 to 2010 surveys were carried out on F.V. *Lady H R*, and 2013 and 2017 surveys on the NIWA vessel R.V. *Ikatere*. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait; SEPR, Separation Point. yes, all strata surveyed; partial, not all strata surveyed; – no survey; * Long Island Marine Reserve (LIMR) surveyed.

	Fixed-site surveys by region					Random-site surveys by region				
Year	QCH	PEL	DUR	CKST	SEPR	QCH	PEL	DUR	CKST	QCH
1995	yes	partial	–	–	–	–	–	–	–	–
1996	–	yes	partial	–	–	–	–	–	–	–
2001	yes	yes	partial	–	–	–	–	–	–	–
2004	yes	yes	yes	–	yes	–	–	–	–	–
2007	yes	yes	yes	–	yes	–	–	–	–	–
2008	yes	yes	yes	yes	–	–	–	–	–	–
2010	yes	yes	yes	–	–	–	partial	partial	yes	–
2013	yes	yes	yes	–	–	yes	yes	yes	yes	yes
2017	yes	yes	yes	–	–	yes	yes	yes	yes	yes*

Table 2: Regions, strata names, codes, area, number of sites, number of pots, catch of blue cod, and depth sampled for the fixed-site and random-site Marlborough Sounds 2017 potting surveys. Regions: QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait; Strata: IQCH, inner QCH; OQCH, outer QCH; EQCH, extreme outer QCH; IPEL, inner PEL; MPEL, mid PEL; OPEL, outer PEL; EOPE, extreme outer PEL; DURW, D'Urville Island west; DURE, D'Urville Island east; APAE, Arapawa Island east; UNDW, Port Underwood; COOK, Cook Strait; LIMR, Long Island Marine Reserve.

	Stratum				Sites (*N*)			Blue cod		Depth (m)		
Region	No.	Code	Area (km coast)	Site type	Phase 1	Phase 2	Pots (*N*)	No.	Catch (kg)	Mean	Min	Max
QCH	1	IQCH	43.2	Fixed	3		27	10	4.8	15	7	50
QCH	2	OQCH	176.6	Fixed	6		54	69	27.8	11	4	22
QCH	3	EQCH	83.1	Fixed	4		36	142	70.2	9	2	21
PEL	4	EOPE	69.5	Fixed	3		27	600	271.5	13	4	27
PEL	5	OPEL	94.8	Fixed	3		27	185	97.7	11	2	28
DUR	6	DURE	105.1	Fixed	6		54	492	242.8	22	4	40
PEL	7	IPEL	100.1	Fixed	3		27	15	7.4	12	2	33
PEL	8	MPEL	72.3	Fixed	3		27	6	3.1	16	3	36
DUR	9	DURW	96.2	Fixed	5		45	759	392.8	19	3	34
Totals					36		324	2 278	1118.1	14	2	50
QCH	1	IQCH	43.2	Random	5		45	9	4.9	10	3	35
QCH	2	OQCH	176.6	Random	6		54	95	45.9	11	3	23
QCH	3	EQCH	83.1	Random	15	4	135	524	261.7	10	3	20
PEL	4	EOPE	69.5	Random	5	3	81	450	224.6	10	2	25
PEL	5	OPEL	94.8	Random	3	1	54	107	51.4	14	2	32
DUR	6	DURE	105.1	Random	4		45	290	131.3	10	3	26
PEL	7	IPEL	100.1	Random	3		27	4	1.8	8	3	17
PEL	8	MPEL	72.3	Random	3	1	27	11	4.8	10	3	26
DUR	9	DURW	96.2	Random	8	4	81	692	350.4	14	4	29
CKST	11	APAE	21.6	Random	5		45	239	120.2	16	5	36
CKST	12	COOK	30	Random	5		45	102	50.9	13	3	23
CKST	13	UNDW	34	Random	3		27	4	2.1	8	4	11
Totals					65	9	666	2 527	1 250	11	2	36
QCH	14	LIMR		Random	8		72	911	630.3	8	2	19

Table 3: Total catch and numbers of blue cod and bycatch species caught on the 2017 Marlborough Sounds fixed-site and random-site potting surveys, and also the Long Island Marine Reserve. LIMR, Long Island Marine Reserve.

				Fixed sites	
Common name	Species	Code	Catch (kg)	Number	% catch
Blue cod	*Parapercis colias*	BCO	1 118.1	2 278	95.88
Carpet shark	*Cephaloscyllium isabella*	CAR	14.3	7	1.23
Leatherjacket	*Meuschenia scaber*	LEA	8.4	22	0.72
Hairy conger eel	*Bassanago hirsutus*	HCO	5	1	0.43
Common octopus	*Octopus maorum*	OCT	4.8	2	0.41
Scarlet wrasse	*Pseudolabrus miles*	SPF	4.1	6	0.35
Banded Wrasse	*Notolabrus fucicola*	BPF	3	5	0.26
Red cod	*Pseudophycis bachus*	RCO	2.7	3	0.23
Red mullet	*Upeneichthys lineatus*	RMU	1.7	2	0.15
Blue moki	*Latridopsis ciliaris*	MOK	1.2	1	0.10
Starfish	Asteroidea & Ophiuroidea	SFI	0.8	7	0.07
Sea perch	*Helicolenus percoides*	SPE	0.7	2	0.06
Tarakihi	*Nemadactylus macropterus*	NMP	0.7	2	0.06
Spotty	*Notolabrus celidotus*	STY	0.6	5	0.05
Totals			1 166.1	2 343	

				Random sites (excl. MR)	
Common name	Species	Code	Catch (kg)	Number	% catch
Blue cod	*Parapercis colias*	BCO	1 250	2 527	96.24
Southern conger	*Conger verreauxi*	CVR	12.3	2	0.95
Leatherjacket	*Meuschenia scaber*	LEA	6.3	20	0.49
Carpet shark	*Cephaloscyllium isabella*	CAR	6.1	2	0.47
Scarlet wrasse	*Pseudolabrus miles*	SPF	4.5	15	0.35
Banded Wrasse	*Notolabrus fucicola*	BPF	4.2	11	0.32
Tarakihi	*Nemadactylus macropterus*	NMP	4	11	0.31
Red mullet	*Upeneichthys lineatus*	RMU	3.7	6	0.28
Starfish	Asteroidea & Ophiuroidea	SFI	1.9	36	0.15
Maori chief	*Paranotothenia augustata*	MCH	1.1	1	0.08
Red cod	*Pseudophycis bachus*	RCO	0.8	1	0.06
Red scorpion fish	*Scorpaena papillosa*	RSC	0.5	3	0.04
Sea perch	*Helicolenus percoides*	SPE	0.3	1	0.02
Blue moki	*Latridopsis ciliaris*	MOK	0.3	1	0.02
Common octopus	*Octopus maorum*	OCT	2.4	1	0.18
Decorator crab	*Notomithrax minor*	NTM	0.2	8	0.02
Spotty	*Notolabrus celidotus*	STY	0.1	1	0.01
Sea cucumber	*Stichopus mollis*	SCC	0.1	1	0.01
Totals			1 298.8	2 648	

				LIMR random sites	
Common name	Species	Code	Catch (kg)	Number	% catch
Blue cod	*Parapercis colias*	BCO	630.3	911	99.24
Leatherjacket	*Meuschenia scaber*	LEA	–	6	0.65
Red moki	*Cheilodactylus spectabilis*	RMO	–	1	0.11
Total				918	

Table 4: Mean catch rates for all blue cod and recruited blue cod (33 cm and over) caught from the 2017 Marlborough Sounds fixed-site and random-site potting surveys by region and overall for the Marlborough Sounds (MS). Catch rates are pot-based, and s.e. and CV are set-based. s.e., standard error; CV, coefficient of variation. See Table 2 for region and stratum names. MS, Marlborough Sounds overall.

Fixed-site survey

				All blue cod			Recruited blue cod		
Region	Strata	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
QCH	1 (IQCH)	Fixed	27	0.18	0.08	42.5	0.09	0.05	58.0
	2 (OQCH)	Fixed	54	0.51	0.20	38.9	0.12	0.05	42.4
	3 (EQCH)	Fixed	36	1.95	0.74	38.0	1.27	0.55	43.0
	Overall		117	0.86	0.23	27.3	0.43	0.15	35.5
PEL	4 (EOPE))	Fixed	27	10.06	1.21	12.0	3.88	0.74	19.1
	5 (OPEL)	Fixed	27	3.62	1.70	46.9	1.82	1.17	64.0
	7 (IPEL)	Fixed	27	0.27	0.12	44.2	0.16	0.10	60.9
	8 (MPEL)	Fixed	27	0.11	0.09	81.4	0.06	0.06	100
	Overall		108	3.20	0.54	16.9	1.38	0.36	26.4
DUR	6 (DURE)	Fixed	54	4.50	0.88	19.6	2.04	0.33	16.3
	9 (DURW)	Fixed	45	8.73	1.82	20.9	3.92	0.90	22.9
	Overall		99	6.52	0.99	15.1	2.94	0.46	15.8
MS	Overall	Fixed	324	3.15	0.33	10.5	1.41	0.19	13.5

Random-site 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 (%)
QCH	1 (IQCH)	Random	45	0.11	0.05	46.9	0.07	0.03	47.3
	2 (OQCH)	Random	54	0.85	0.20	23.5	0.46	0.07	14.3
	3 (EQCH)	Random	135	1.94	0.39	20.1	0.96	0.17	17.7
	Overall		234	1.04	0.16	15.2	0.54	0.06	11.2
PEL	4 (EOPE))	Random	81	2.77	0.88	31.8	1.53	0.48	31.1
	5 (OPEL)	Random	54	0.95	0.32	33.2	0.46	0.14	31.3
	7 (IPEL)	Random	27	0.07	0.07	100	0.04	0.04	100
	8 (MPEL)	Random	27	0.18	0.08	46.1	0.06	0.04	70.7
	Overall		180	0.90	0.20	22.7	0.47	0.11	22.8
DUR	6 (DURE)	Random	45	2.92	1.05	36.0	1.10	0.33	29.9
	9 (DURW)	Random	81	4.33	1.37	31.8	2.18	0.62	28.4
	Overall		126	3.59	0.86	23.8	1.62	0.34	21.1
CKST	11 (APAE)	Random	45	2.67	1.08	40.4	1.07	0.37	34.8
	12 (COOK)	Random	45	1.13	0.41	36.6	0.72	0.34	47.1
	13 (UNDW)	Random	27	0.08	0.04	57.7	0.06	0.03	50.4
	Overall		117	1.10	0.31	28.1	0.54	0.15	27.9
QCH	14 (LIMR)	Random	72	8.76	1.27	14.5	6.83	1.24	18.1

Table 4 [Continued]:

				Random-site 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 (%)
MS (excl. CKST & LIMR)	Overall	Random	549	1.59	0.23	14.3	0.77	0.09	12.3
MS (excl. LIMR)	Overall	Random	666	1.55	0.21	13.5	0.75	0.09	11.6

Table 5: Descriptive statistics for blue cod caught on the 2017 Marlborough Sounds fixed-site and random-site potting surveys. Mean length and sex ratio are raw for each stratum, and weighted overall. See Table 2 for region and stratum names. m, male; f, female; u, unsexed. –, no data.

					Fixed-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
QCH	1 (IQCH)	Fixed	m	2	36.4	34.6	38.3	20.0
			f	8	30.4	27.5	38.0	
			u	–	–	–	–	
	2 (OQCH)	Fixed	m	39	30.8	24.1	36.0	56.1
			f	30	30.1	24.5	37.5	
			u	–	–	–	–	
	3 (EQCH)	Fixed	m	121	32.8	21.6	47.6	85.2
			f	21	28.6	23.8	33.5	
			u	–	–	–	–	
	Overall	Fixed	m	162	32.2	21.6	47.6	71.8
			f	59	29.6	23.8	38	
			u	–	–	–	–	

					Random-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
QCH	1 (IQCH)	Random	m	1	36.0	35.5	35.5	11.4
			f	8	32.2	25.5	39.1	
			u	–	–	–	–	
	2 (OQCH)	Random	m	63	32.5	17.3	51.0	66.1
			f	32	31.1	24.0	43.9	
			u	–	–	–	–	
	3 (EQCH)	Random	m	423	32.5	20.5	44.4	80.8
			f	101	30.0	24.2	39.0	
			u	–	–	–	–	
	Overall	Random	m	487	32.5	17.3	51	73.0
			f	141	30.7	24.0	43.9	
			u	–	–	–	–	

Table 5 [Continued]:

					Random-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
QCH	14 (LIMR)	Random	m	–	–	–	–	–
			f	–	–	–	–	
			u	911	35.2	24.5	49.0	

					Fixed-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
PEL	7 (IPEL)	Fixed	m	12	32.4	27.0	36.2	79.5
			f	3	30.3	27.8	34.3	
			u	–	–	–	–	
	8 (MPEL)	Fixed	m	4	33.3	26.6	40.9	65.4
			f	2	28.5	27.6	28.7	
			u	–	–	–	–	
	5 (OPEL)	Fixed	m	168	32.7	26.7	42.0	90.8
			f	17	29.3	24.2	32.0	
			u	–	–	–	–	
	4 (EOPE)	Fixed	m	503	31.6	24.0	40.8	83.9
			f	96	29.5	24.0	39.4	
			u	1	–	33.8	33.8	
	Overall	Fixed	m	687	32.0	24.0	42.0	85.7
			f	118	29.5	24.0	39.4	
			u	1	–	33.8	33.8	

					Random-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
PEL	7 (IPEL)	Random	m	4	31.0	26.3	34.3	100
			f	–	–	–	–	
			u	–	–	–	–	
	8 (MPEL)	Random	m	10	31.4	26.7	35.5	91.1
			f	1	28.0	28.1	28.1	
			u	–	–	–	–	
	5 (OPEL)	Random	m	90	32.4	19.5	44.0	84.4
			f	17	30.1	22.5	34.8	
			u	–	–	–	–	
	4 (EOPE)	Random	m	417	32.6	12.5	43.5	92.7
			f	33	29.6	25.0	35.7	
			u	–	–	–	–	

Table 5 [Continued]:

					Random-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
PEL	Overall	Random	m	521	32.4	12.5	44.0	90.3
			f	51	29.8	22.5	35.7	
			u	–	–	–	–	

					Fixed-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
DUR	6 (DURE)	Fixed	m	338	32.7	23.8	44.3	68.2
			f	153	30.3	24.5	36.0	
			u	1	–	28.0	28.0	
	9 (DURW)	Fixed	m	431	33.0	22.9	48.5	57.0
			f	328	30.7	25.2	37.7	
			u	–	–	–	–	
	Overall	Fixed	m	769	32.9	22.9	48.5	61.0
			f	481	30.6	24.5	37.7	
			u	1	–	28.0	28.0	

					Random-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
DUR	6 (DURE)	Random	m	208	32.0	24.5	42.0	71.8
			f	82	30.1	20.9	37.0	
			u	–	–	–	–	
	9 (DURW)	Random	m	412	33.2	21.0	48.2	59.5
			f	280	30.9	24.0	40.3	
			u	–	–	–	–	
	Overall	Random	m	620	32.6	21.0	48.2	65.0
			f	362	30.6	20.9	40.3	
			u	–	–	–	–	

					Random-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
CKST	11 (APAE)	Random	m	204	31.9	24.5	46.4	85.3
			f	35	28.6	21.3	32.3	
			u	–	–	–	–	
	12 (COOK)	Random	m	90	32.9	20.5	40.3	88.3
			f	12	27.4	21.5	30.0	
			u	–	–	–	–	

Table 5 [Continued]:

					Random-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
	13 (UNDW)	Random	m	4	32.9	28.5	37.5	100
			f	–	–	–	–	
			u	–	–	–	–	
	Overall	Random	m	298	32.3	20.5	46.4	86.9
			f	47	28.2	21.3	32.3	
			u	–	–	–	–	

					Fixed-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
MS	Overall	Fixed	m	1 618	32.4	21.6	48.5	72.4
			f	658	30.2	23.8	39.4	
			u	2	–	28.0	33.8	

					Random-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
MS (excl. LIMR)	Overall	random	m	1 926	32.5	12.5	51.0	73.5
			f	601	30.5	20.9	43.9	
			u	–				
MS (excl. LIMR & CKST)	Overall	random	m	1 628	32.5	12.5	51.0	72.5
			f	554	30.6	20.9	43.9	
			u					

Table 6: Otolith ageing data used in the catch-at-age, Z estimates and SPR analyses for the 2017 Marlborough Sounds blue cod survey.

			Length of aged fish (cm)		Age (years)	
Survey strata	Sex	No. otoliths	Minimum	Maximum	Minimum	Maximum
QCH	Male	203	17	51	2	12
	Female	23	23	43	4	16
PEL	Male	148	22	44	3	9
	Female	72	22	39	3	12
DUR	Male	183	21	48	3	16
	Female	128	20	38	3	20
CKST	Male	174	20	46	3	9
	Female	23	21	32	3	7
Overall	Male	708	17	51	2	16
	Female	344	20	43	3	20

Table 7: Gonad stages of Marlborough Sounds blue cod in September–November 2017 by region. 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. See Table 2 for region names.

		Gonad stage (%)					
Region	Sex	1	2	3	4	5	N
CKST	Males	18.8	8.4	8.7	28.9	35.2	298
CKST	Females	80.9	6.4	12.8	0.0	0.0	47
DUR	Males	1.4	15.8	13.7	34.0	35.1	1 389
DUR	Females	15.3	21.1	22.2	9.4	32.0	843
PEL	Males	4.3	18.0	25.5	21.0	31.2	1 208
PEL	Females	32.0	11.2	14.8	4.7	37.3	169
QCH	Males	2.9	9.9	25.1	42.7	19.4	649
QCH	Females	38.5	12.0	32.5	14.5	2.5	200
All regions	Males	4.1	14.8	19.4	30.7	30.9	3 544
All regions	Females	23.7	17.8	22.5	9.2	26.8	1 259

Table 8: Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals of blue cod for the 2017 Marlborough Sounds fixed-site and random-site blue cod potting surveys. ageR, age at full recruitment (years). See Appendix 4 for results by region. Fixed-site strata 1–9; random site strata 1–13.

Region	Site type	ageR	*Z*	lowerCI	upperCI
All regions combined	Fixed	5	0.56	0.39	0.76
		6	0.53	0.38	0.72
		7	0.49	0.35	0.65
		8	0.44	0.31	0.58
		9	0.35	0.25	0.46
		10	0.32	0.23	0.44
All regions combined	Random	5	0.54	0.37	0.72
		6	0.52	0.37	0.69
		7	0.48	0.35	0.64
		8	0.43	0.3	0.58
		9	0.35	0.25	0.47
		10	0.33	0.23	0.43

Table 9: Mortality parameters (*Z*, *F* and *M*) and spawner-per-recruit ($F_{SPR\%}$) point-estimates at three values of *M* for blue cod from the 2017 Marlborough Sounds fixed-site and random-site potting surveys for all regions combined. The mortality parameters and spawner-per-recruit estimates are also given for the default *M* (0.14) and the 95% confidence interval values of Z. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality; lowerCI, lower 95% confidence interval; upperCI, upper 95% confidence interval. AgeR = 6, where AgeR is the age at which males and females combined, reach MLS of 33 cm. See Appendix 5 for results by region. Fixed-site strata 1–9; random site strata 1–13.

Region	Site type	*M*	*Z*	*F*	$F_{\%SPR}$	Estimate
All regions combined	Fixed	0.11	0.53	0.42	$F_{31.7\%}$	Point
		0.14	0.53	0.39	$F_{39.0\%}$	Point
		0.17	0.53	0.36	$F_{45.8\%}$	Point
		0.14	0.38	0.24	$F_{47.1\%}$	lowerCI
		0.14	0.72	0.58	$F_{33.8\%}$	upperCI
All regions combined	Random	0.11	0.52	0.41	$F_{32.0\%}$	Point
		0.14	0.52	0.38	$F_{39.4\%}$	Point
		0.17	0.52	0.35	$F_{46.3\%}$	Point
		0.14	0.37	0.23	$F_{48.0\%}$	lowerCI
		0.14	0.69	0.55	$F_{34.4\%}$	upperCI

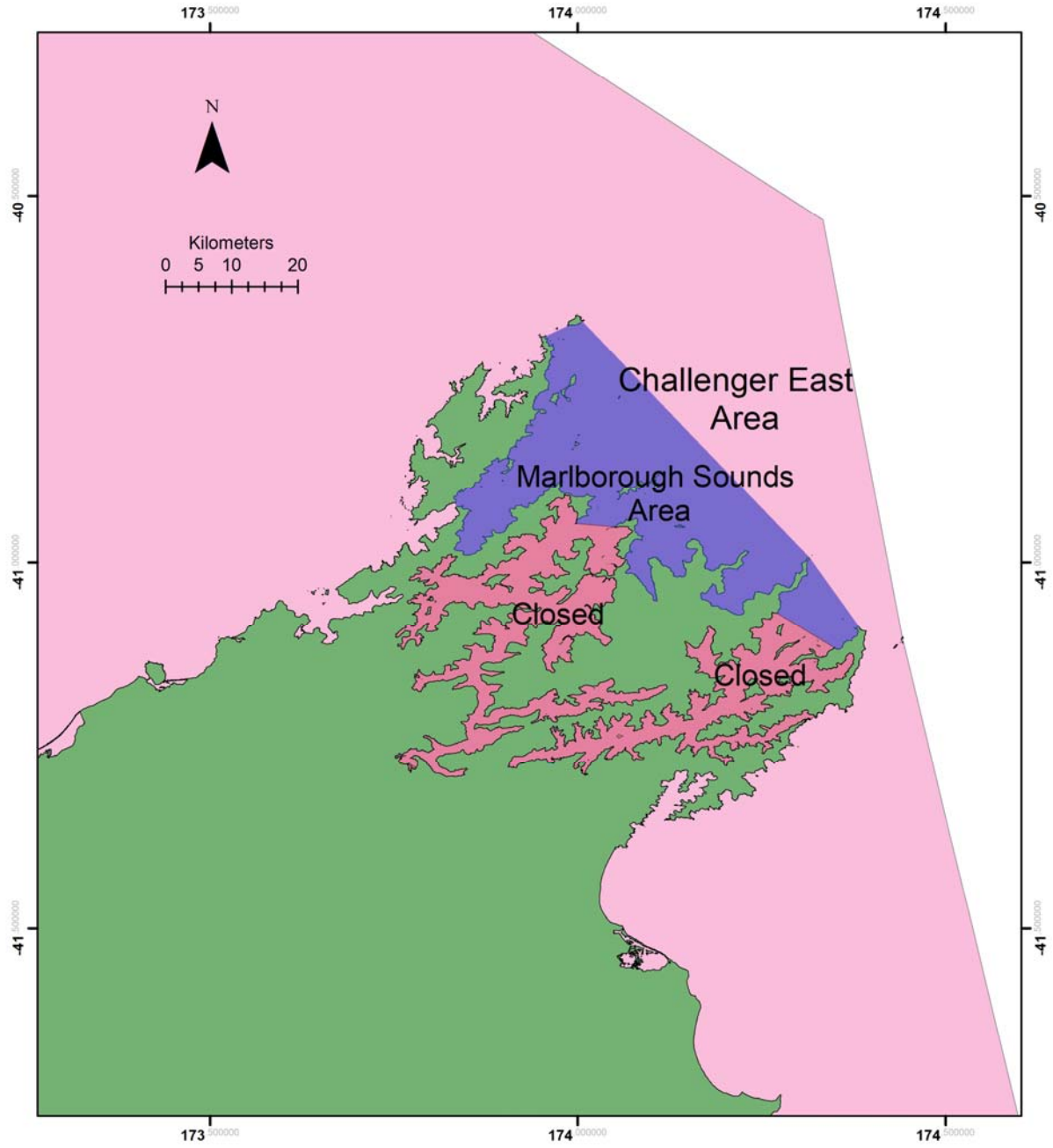


Figure 1: Marlborough Sounds showing fisheries management areas 'Marlborough Sounds Area' and the 'Challenger East Area'. From 1 October 2008 to April 2011 the inner Queen Charlotte Sound and inner Pelorus Sound (part of the Marlborough Sounds Area) were closed to fishing.

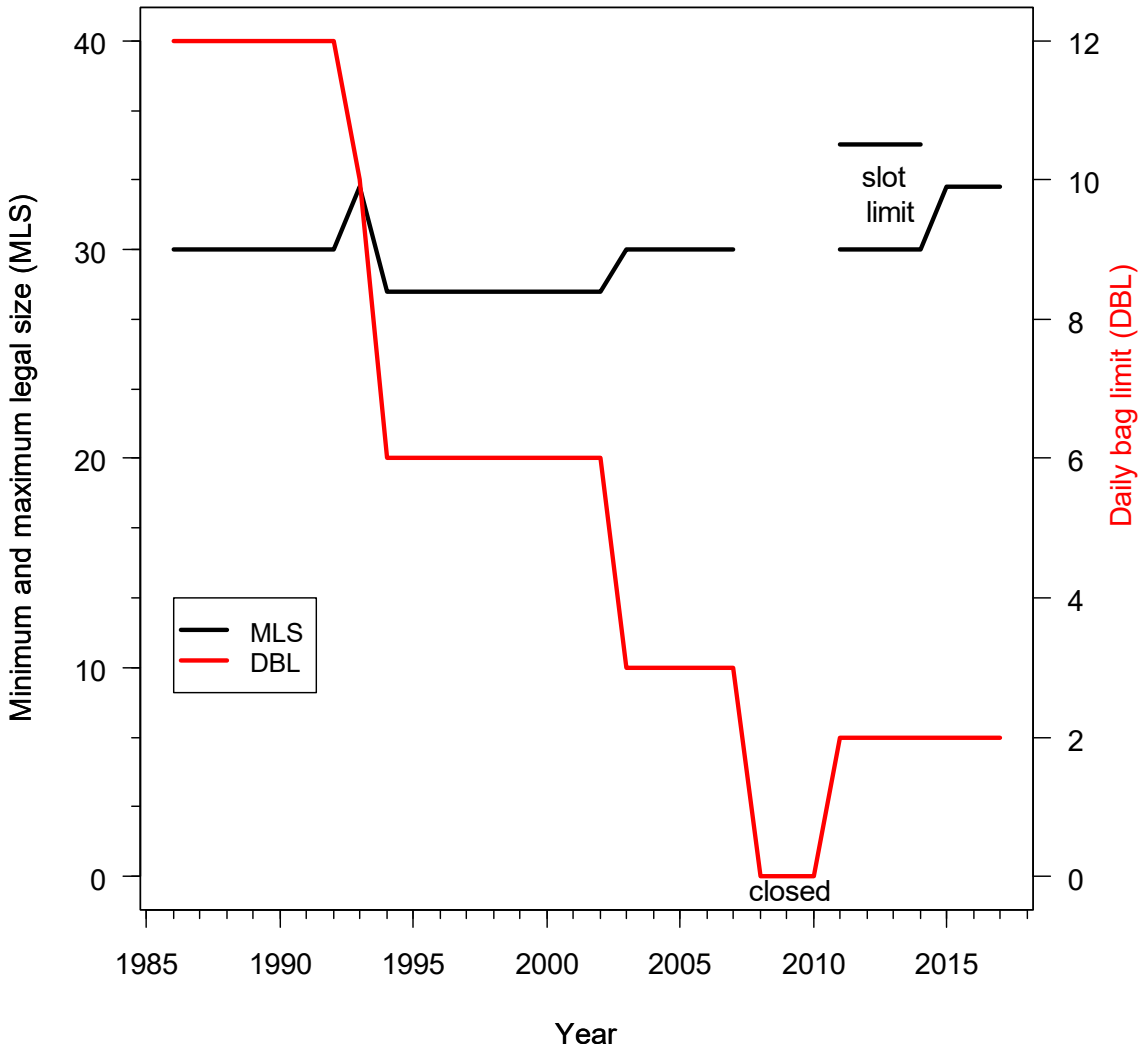


Figure 2: Minimum and maximum legal size, and daily bag limit (DBL) within the 'Marlborough Sounds Area' since 1985 (see Figure 1 for areas). From 1 October 2008 to April 2011, outside of the inner Queen Charlotte and Pelorus Sounds, the minimum legal size was 30 cm and DBL was 3 blue cod.

Chronology of changes to blue cod recreational fisheries regulations in the Marlborough Sounds:

1 October 2008 to April 2011: The Queen Charlotte and Pelorus Sounds were closed to fishing. Elsewhere in the 'Marlborough Sounds Area' and 'Challenger Area East' the minimum legal size (MLS) was 30 cm and DBL was 3 blue cod.

1 April 2011 to 20 December 2015: 30–35 cm slot limit within 'Marlborough Sounds Area' with DBL of 2 blue cod, max of 2 hooks per line, and fishery closed from 1 September to 19 December. In the 'Challenger Area East' the MLS was 30 cm and DBL 3 blue cod.

20 December 2015 to 2017: Within 'Marlborough Sounds Area' and 'Challenger Area East' a MLS of 33 cm, DBL of 2 blue cod (or 2 from each area), a maximum of two hooks per line, and the fishery closed from 1 September to 19 December.

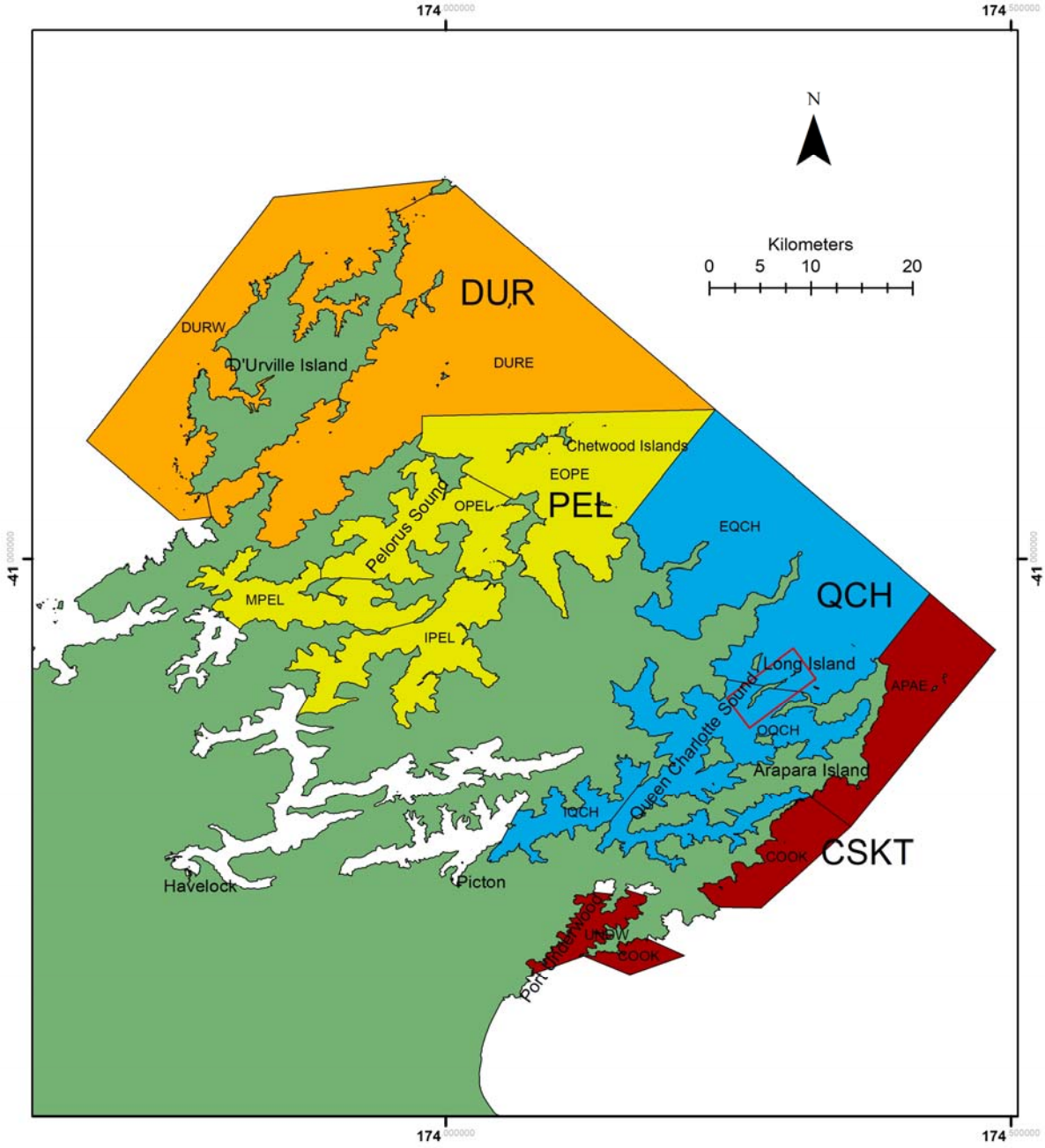


Figure 3: Map of Marlborough Sounds showing the strata surveyed in 2017. The regions are colour coded. orange, D'Urville (DUR); yellow, Pelorus Sound (PEL); blue, Queen Charlotte Sound (QCH); red, Cook Strait (CKST). See Table 2 for strata names. Long Island Marine Reserve was also surveyed in 2017 and is shown in the red box at the head of Queen Charlotte Sound.

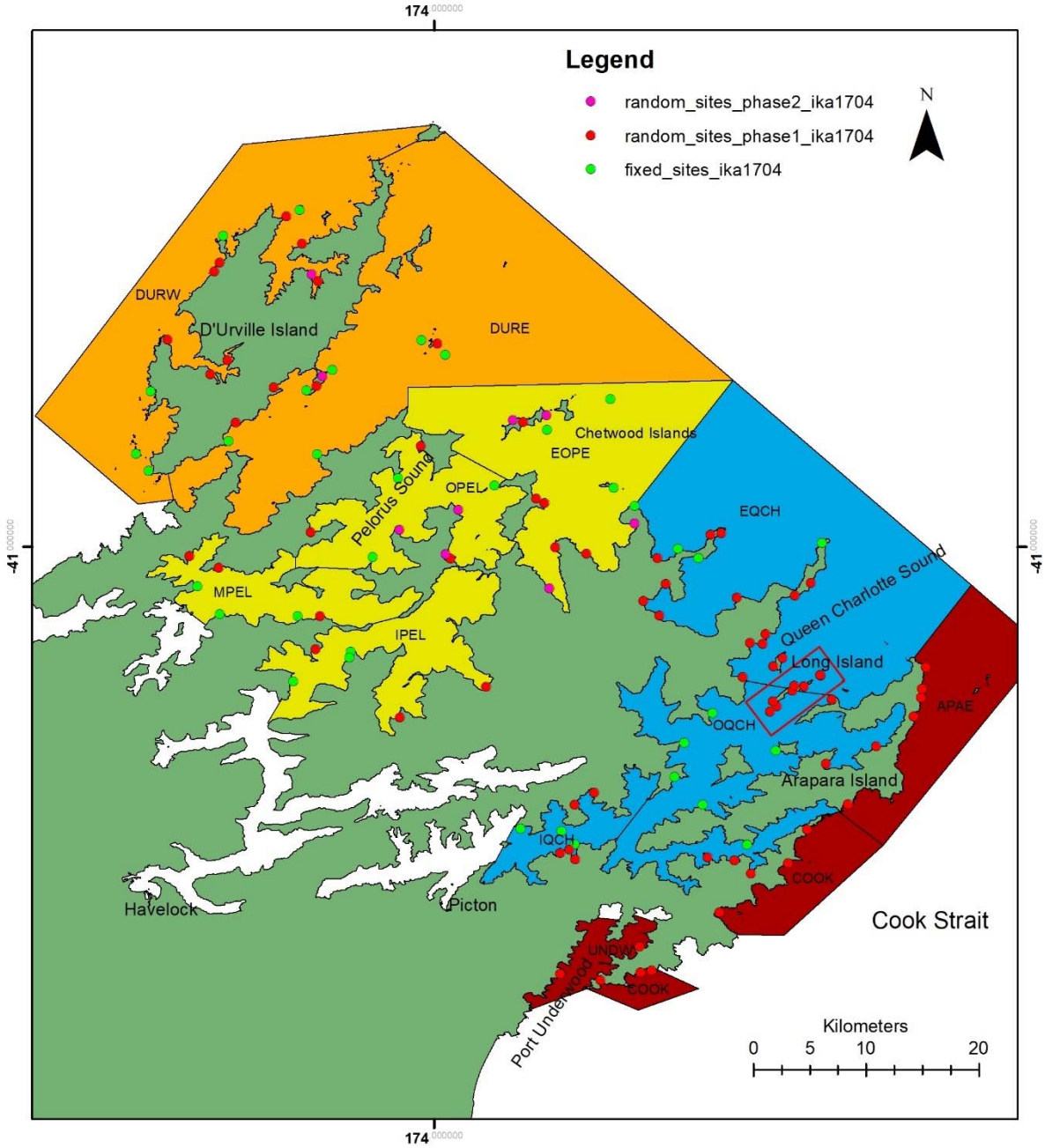


Figure 4: Map of Marlborough Sounds showing the strata, and location of fixed and random sites surveyed in 2017. The regions are colour coded. orange, D'Urville (DUR); yellow, Pelorus Sound (PEL); blue, Queen Charlotte Sound (QCH); red, Cook Strait (CKST). See Table 2 for strata names. Long Island Marine Reserve is shown in the red box at the head of Queen Charlotte Sound.

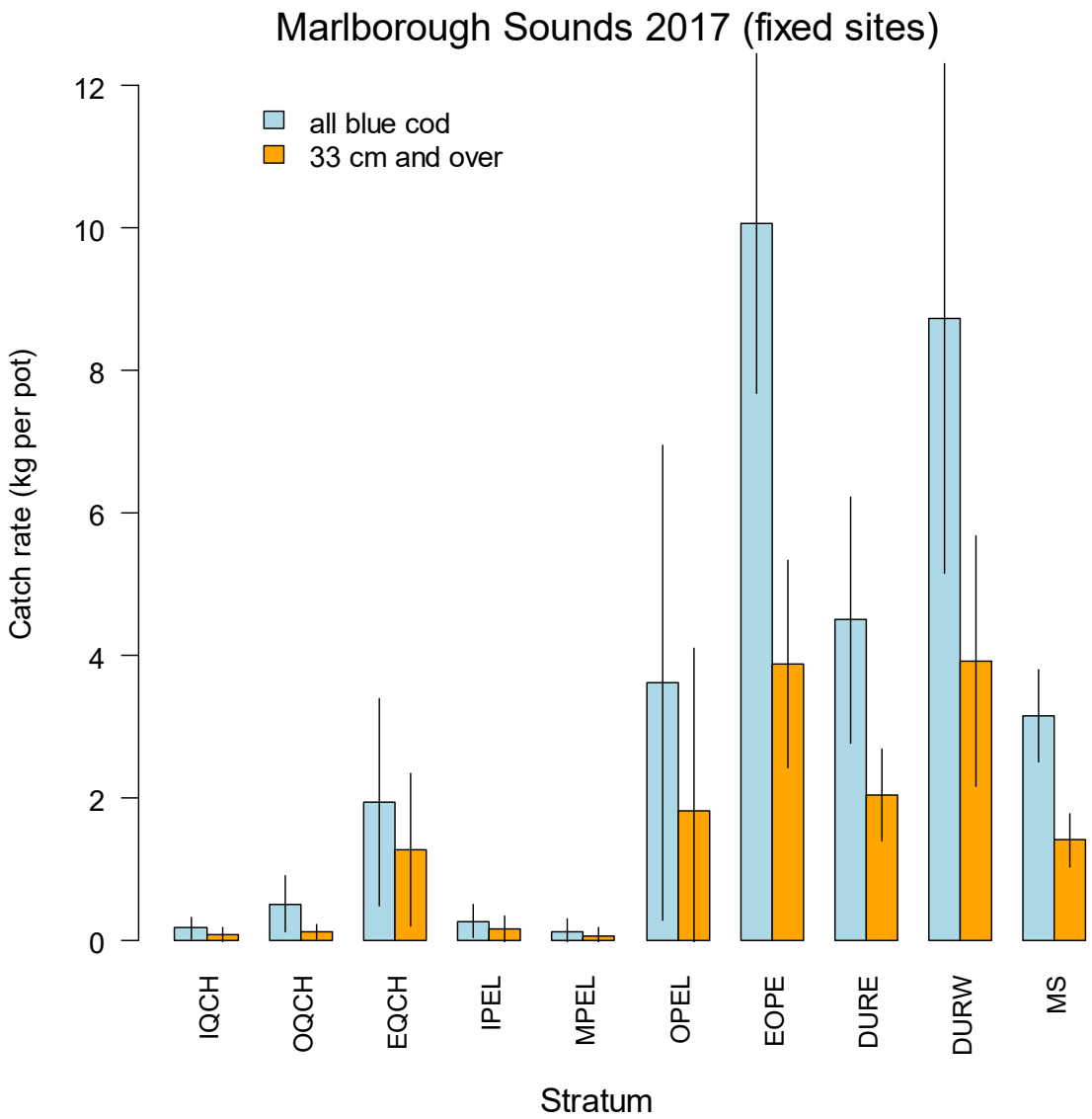


Figure 5: Marlborough Sounds 2017 fixed-site potting survey catch rates of all blue cod and recruited blue cod by strata, and for Marlborough Sounds overall (all strata combined) (MS). Error bars are 95% confidence intervals. See Figure 3 for location of strata, and Table 2 for strata names.

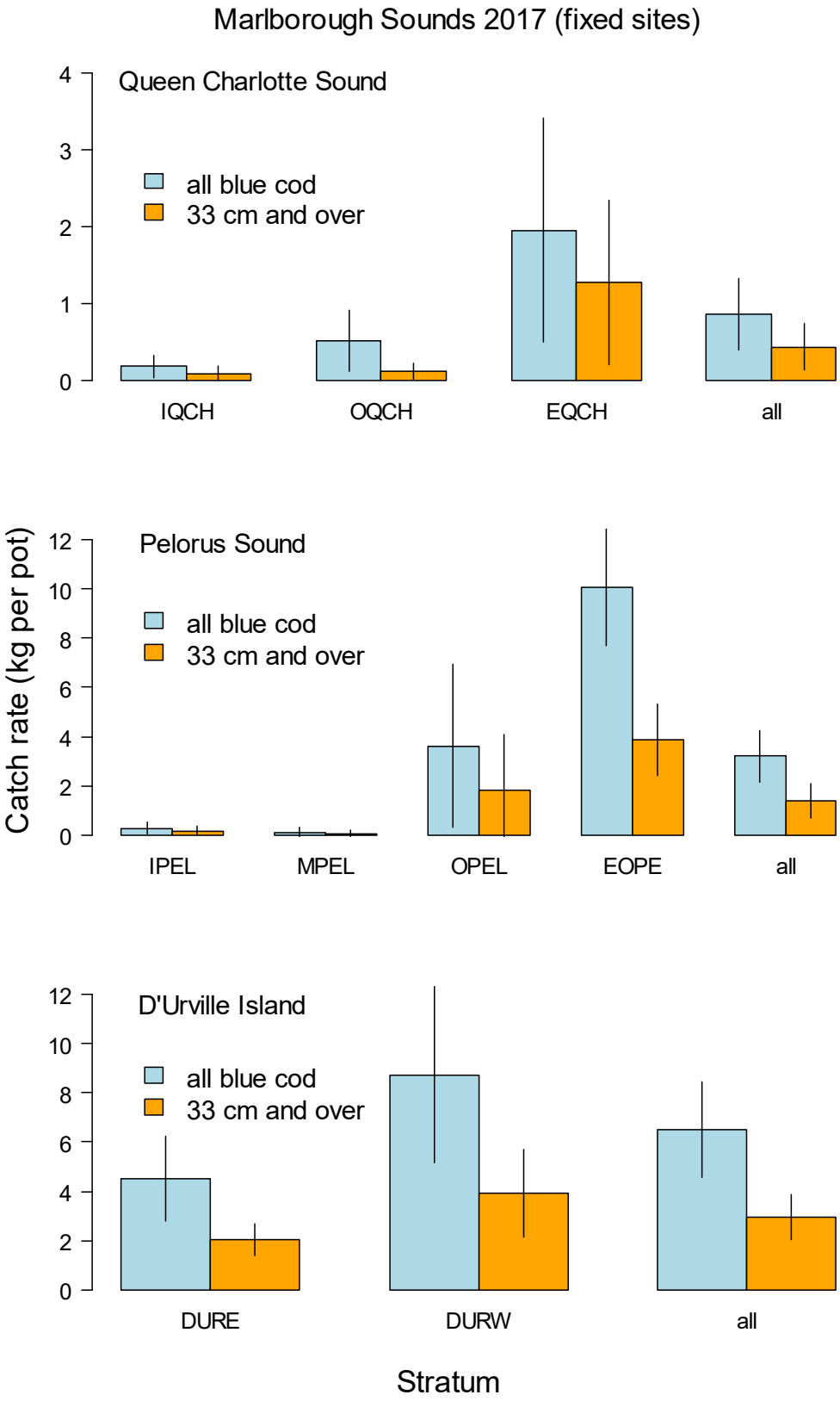


Figure 6: Marlborough Sounds 2017 fixed-site potting survey catch rates of all blue cod and recruited blue cod by strata and overall for each region. Error bars are 95% confidence intervals. See Figure 3 for location of strata, and Table 2 for strata names.

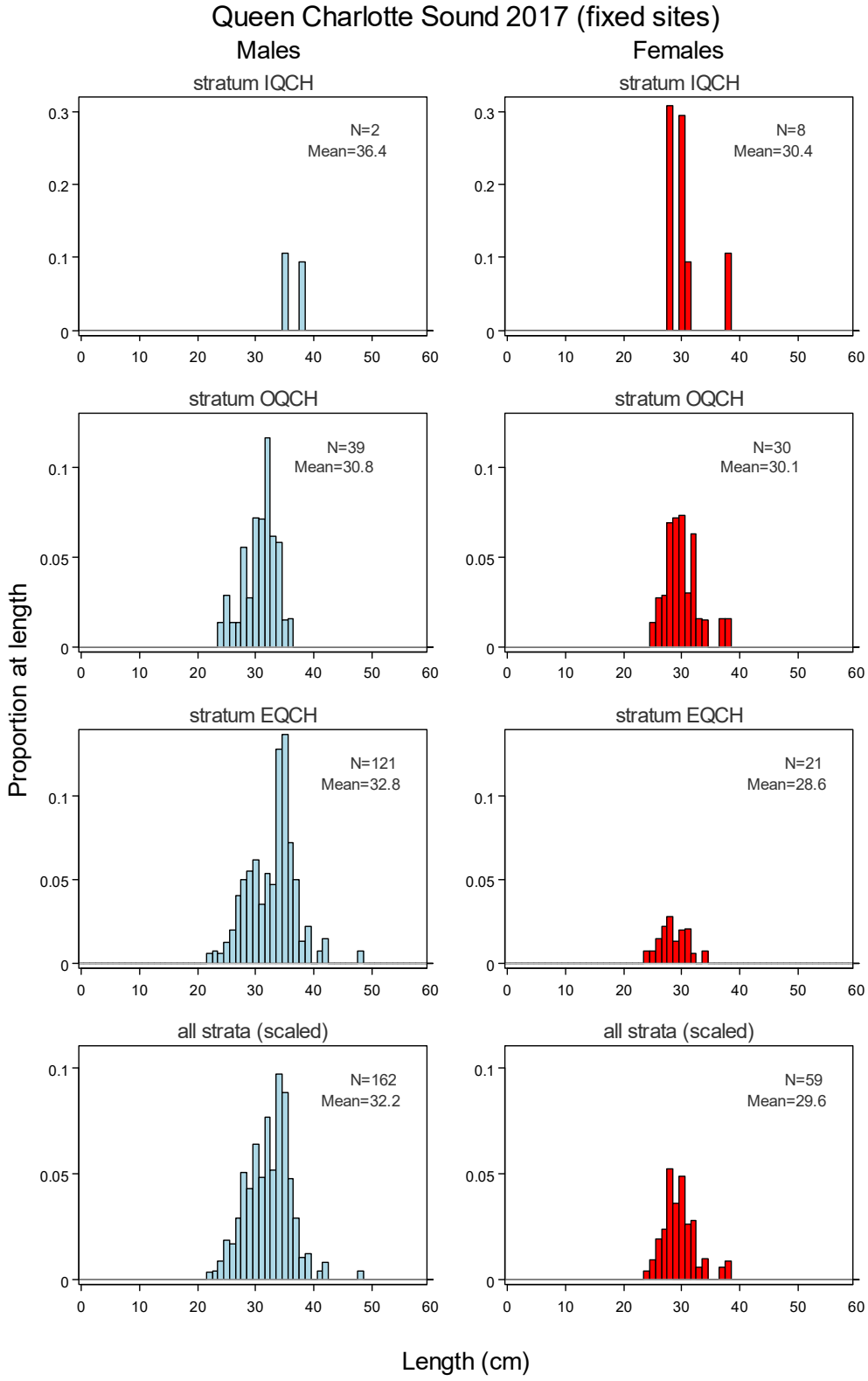


Figure 7: Scaled length frequency distributions by strata and overall for the 2017 Queen Charlotte Sound fixed-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

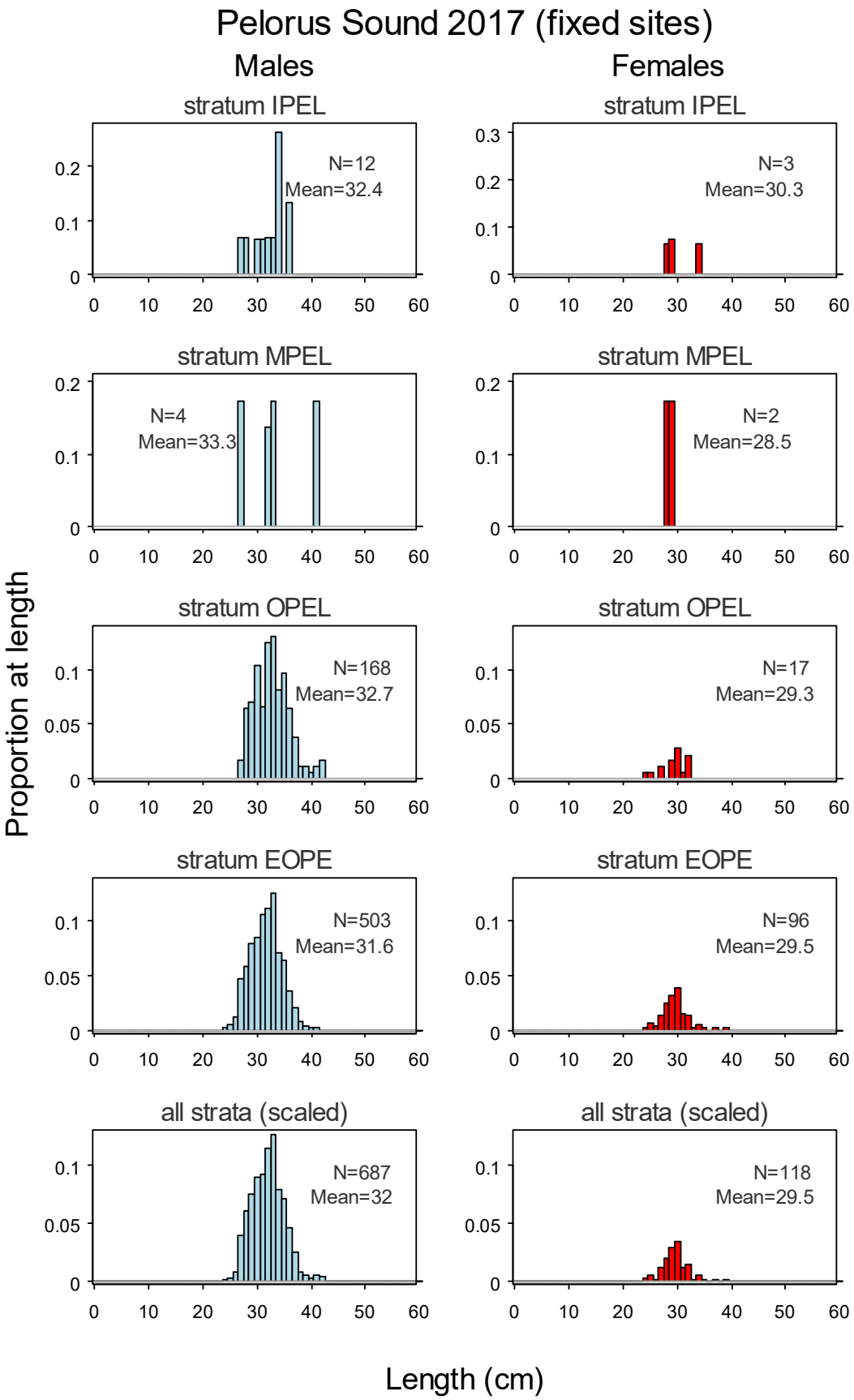


Figure 8: Scaled length frequency distributions by strata and overall for the 2017 Pelorus Sound fixed-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

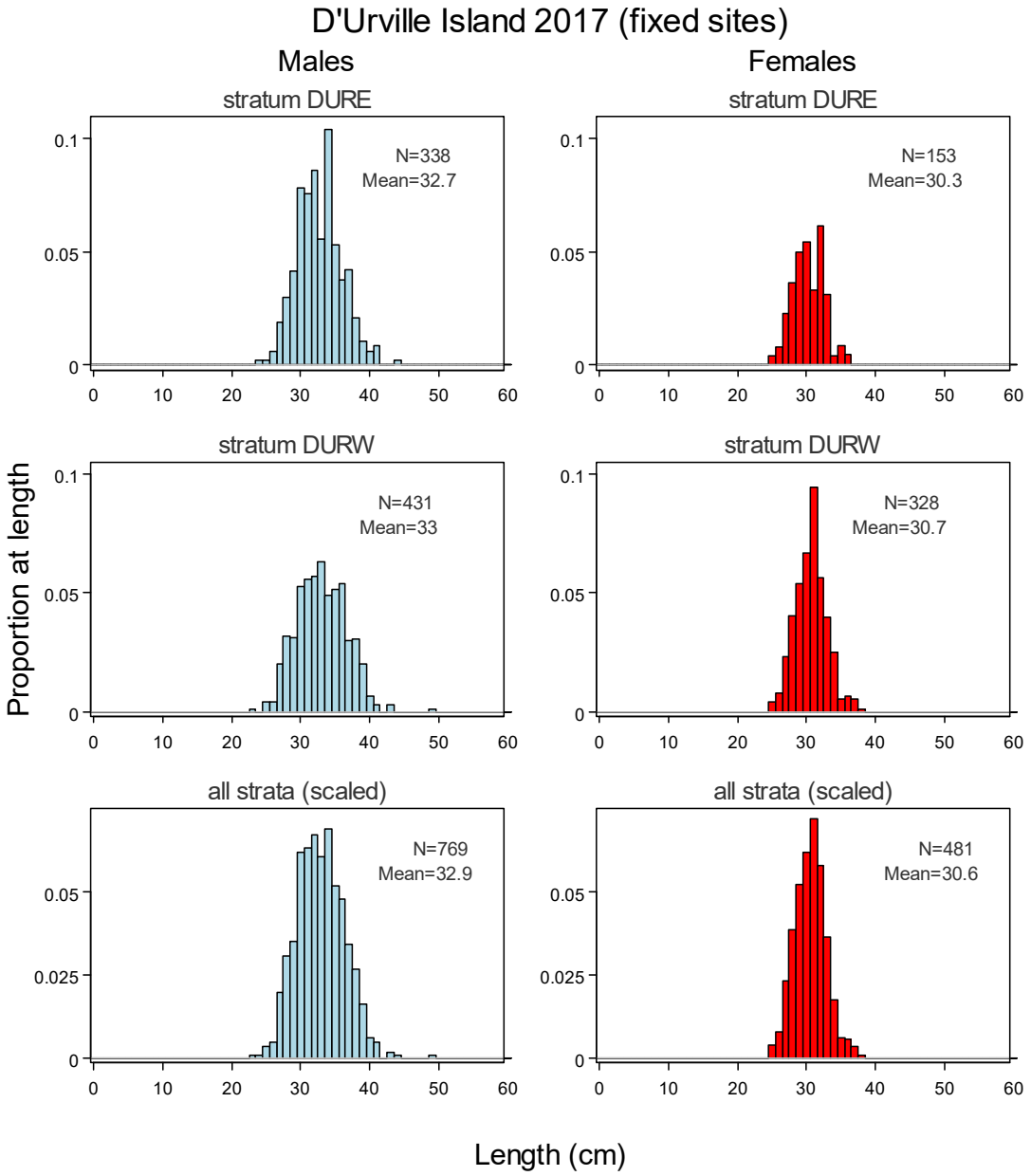


Figure 9: Scaled length frequency distributions by strata and overall for the 2017 D'Urville Island fixed-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

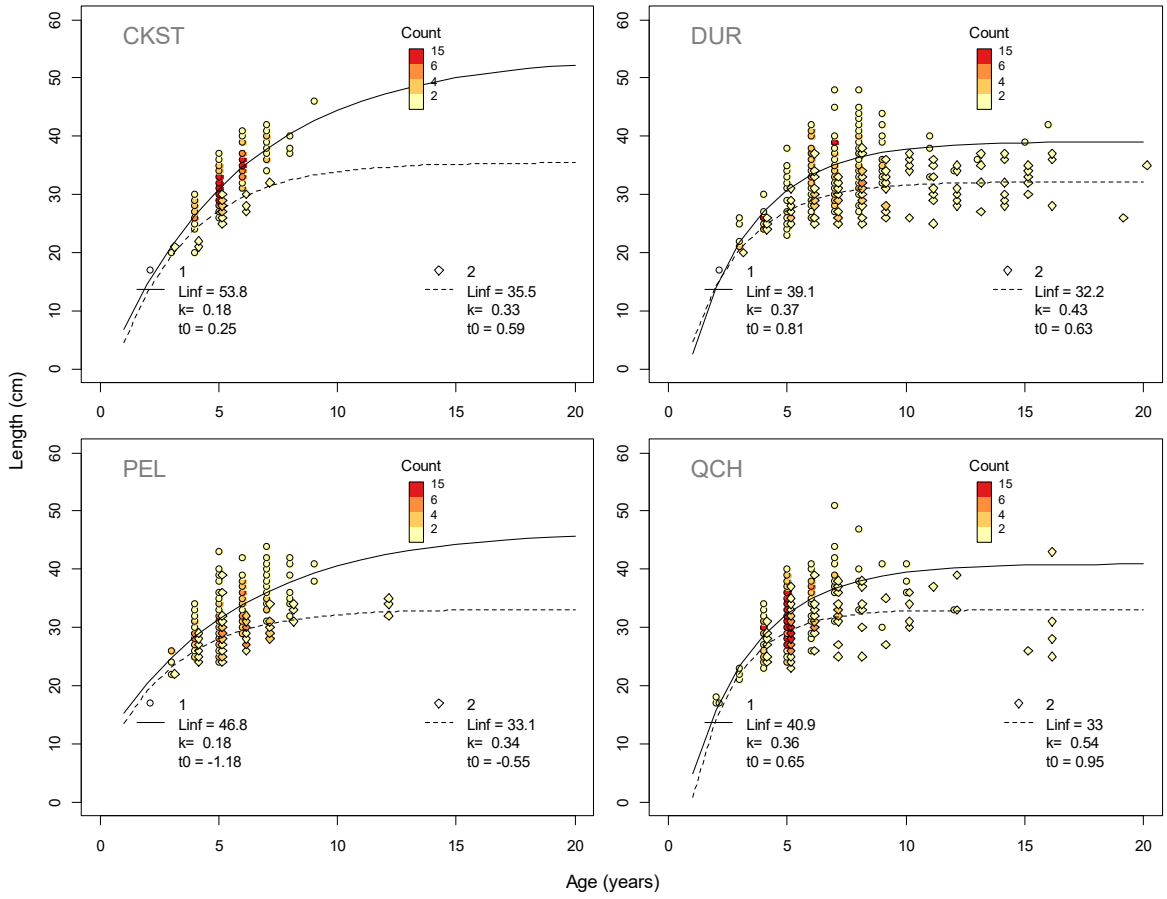


Figure 10: Observed age and length data by sex and region for blue cod from the 2017 Marlborough Sounds potting survey with von Bertalanffy growth models fitted to the data. Males are shown by circles and females by the diamonds. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait.

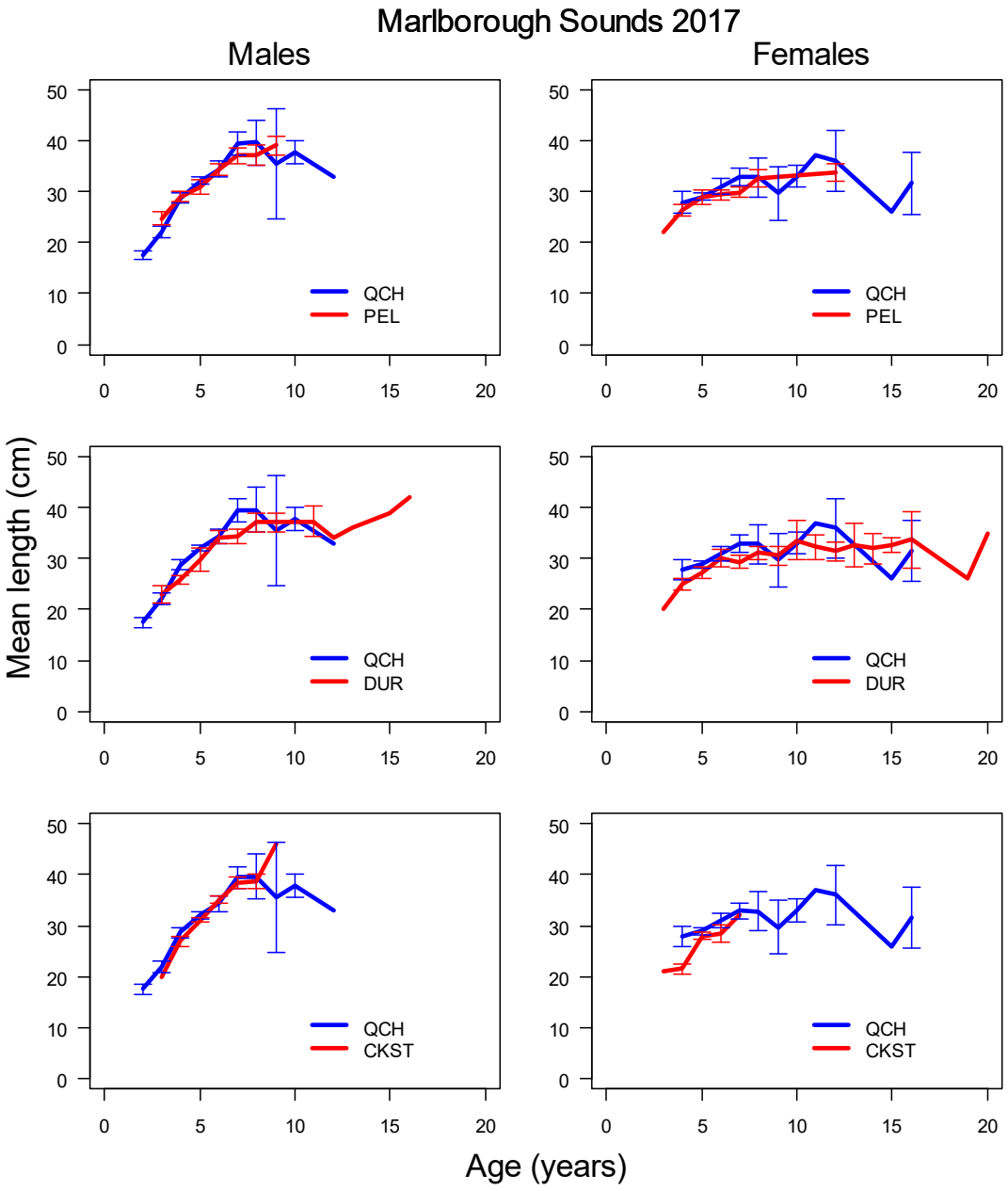


Figure 11: Mean length-at-age by sex for blue cod from the 2017 Marlborough Sounds survey. QCH is compared with the other three regions. Error bars are 95% confidence intervals. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait.

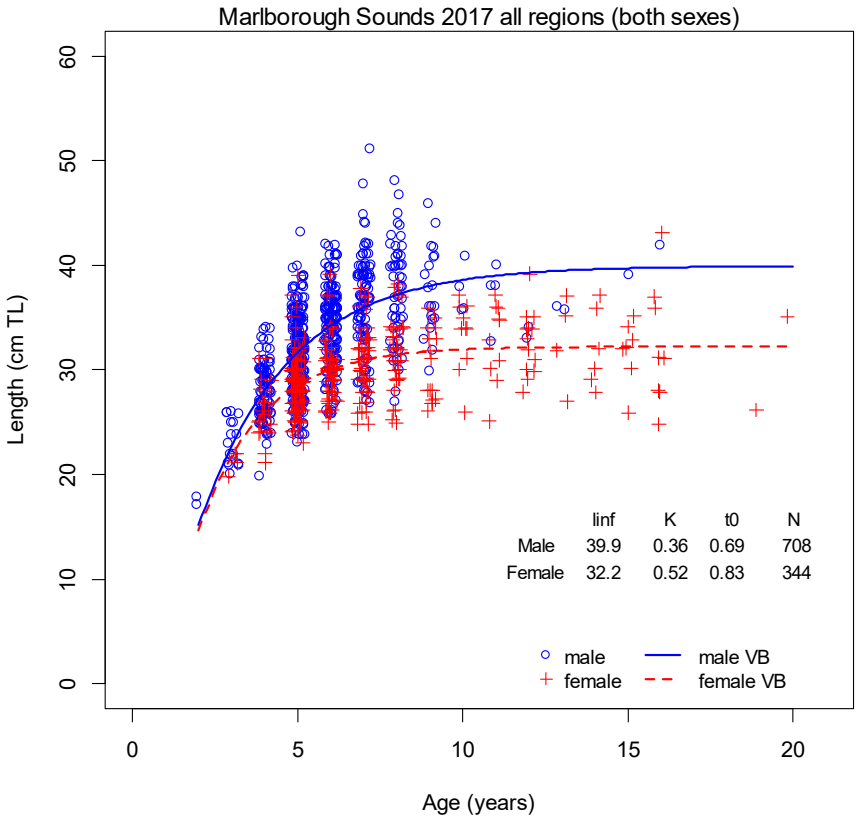


Figure 12: Observed age and length data by sex for blue cod from the 2017 Marlborough Sounds survey (all regions combined) with von Bertalanffy growth models fitted to the data.

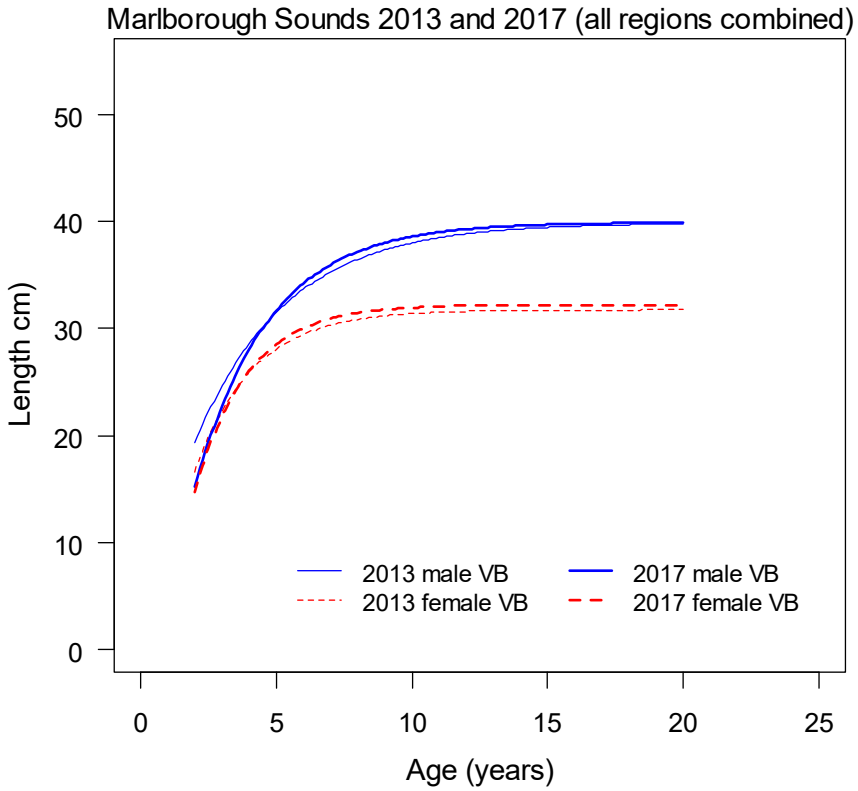


Figure 13: von Bertalanffy growth models fitted to the 2013 and 2017 blue cod survey age and length data (all regions combined).

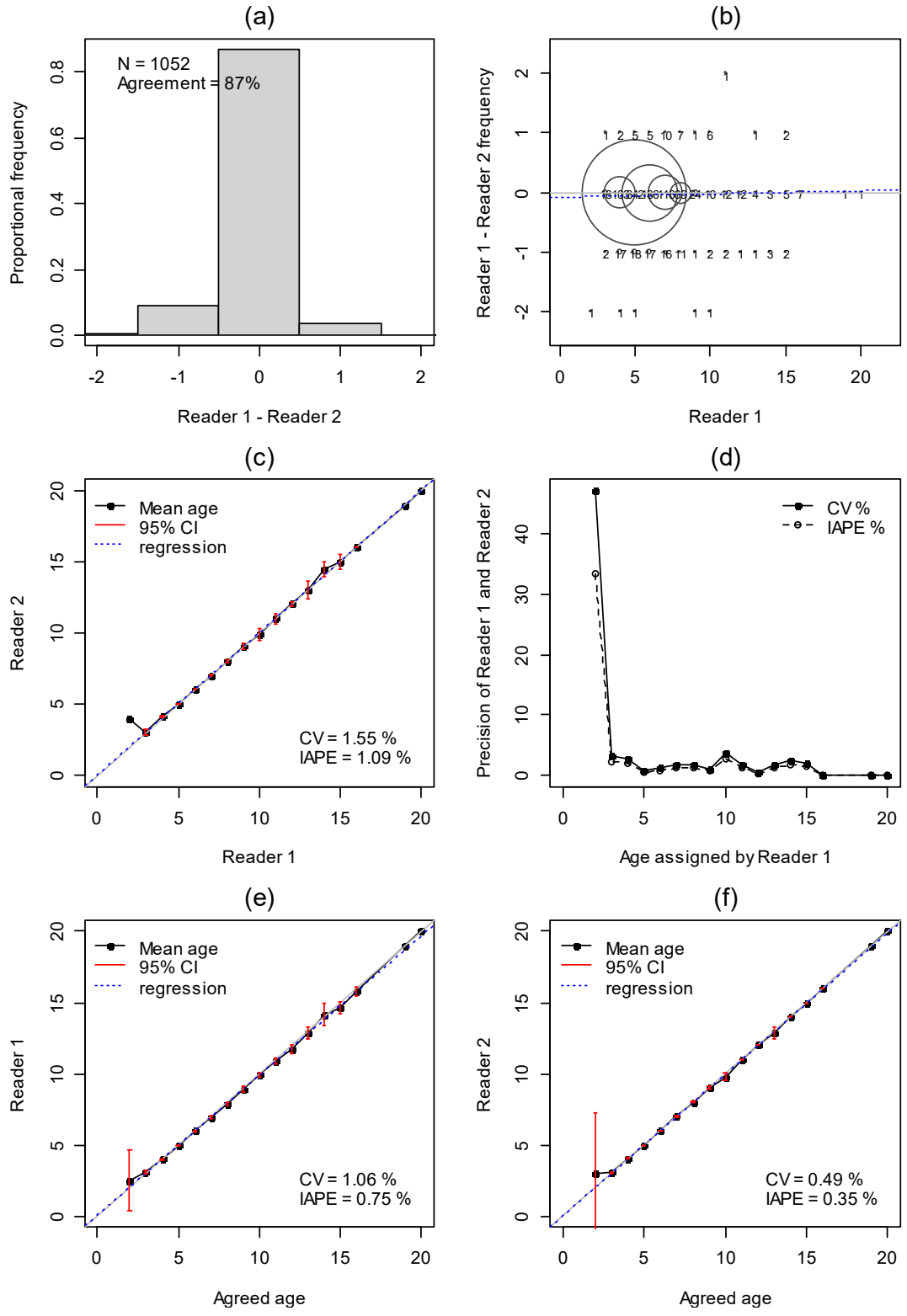


Figure 14: Blue cod age reader comparison plots between reader 1 and reader 2 for the 2017 Marlborough Sounds survey: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age bin are annotated and proportional to circle size; (c) age bias plot, showing the correspondence of ages between reader 1 and reader 2 for all ages; (d) precision of readers; (e and f) reader age compared with agreed age. In panels b and c, solid lines show perfect agreement, dashed lines show the trend of a linear regression of the actual data.

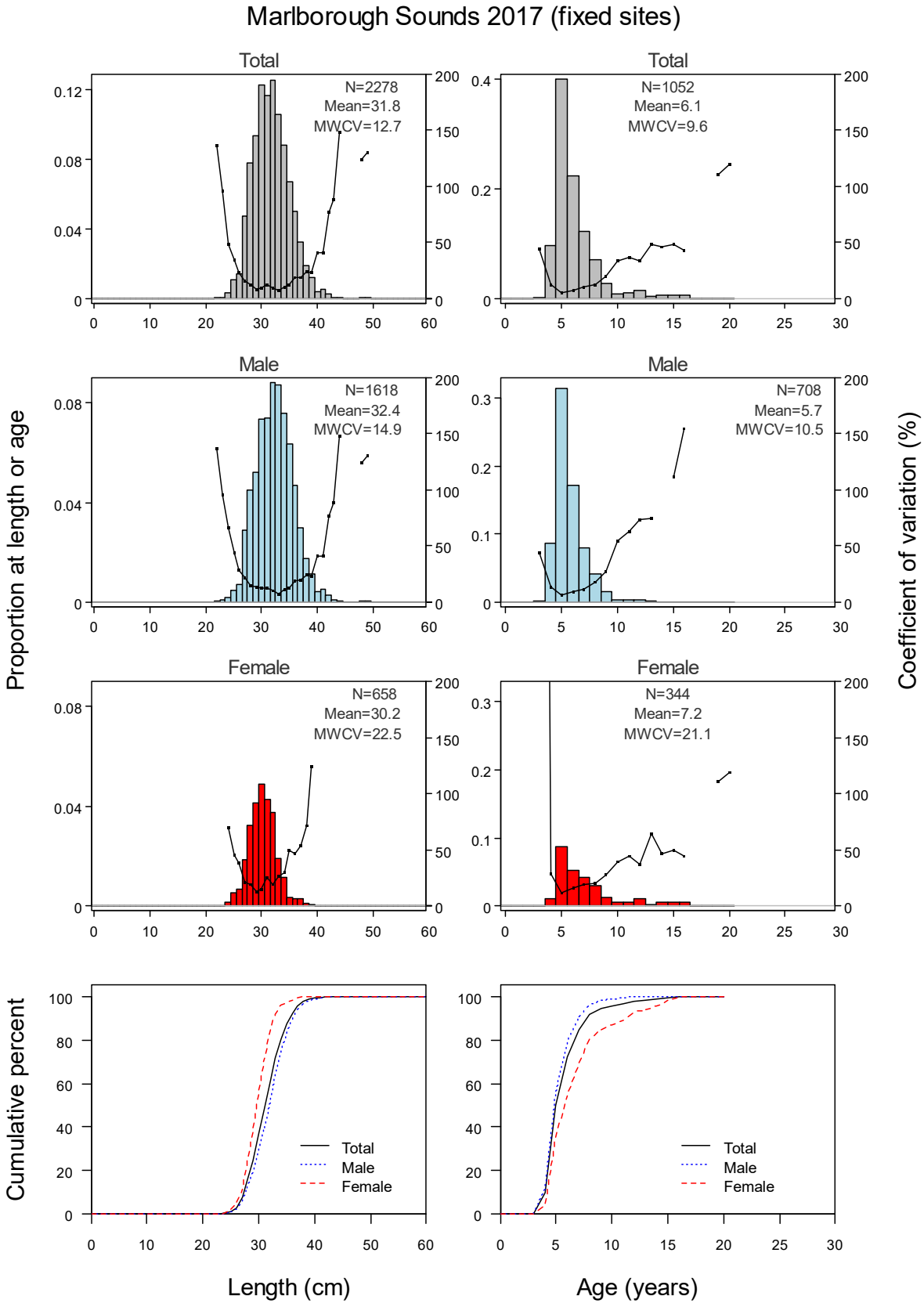


Figure 15: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for the 2017 Marlborough Sounds fixed-site potting survey (QCH, PEL and DUR combined). N, sample size; MWCV, mean weighted coefficient of variation.

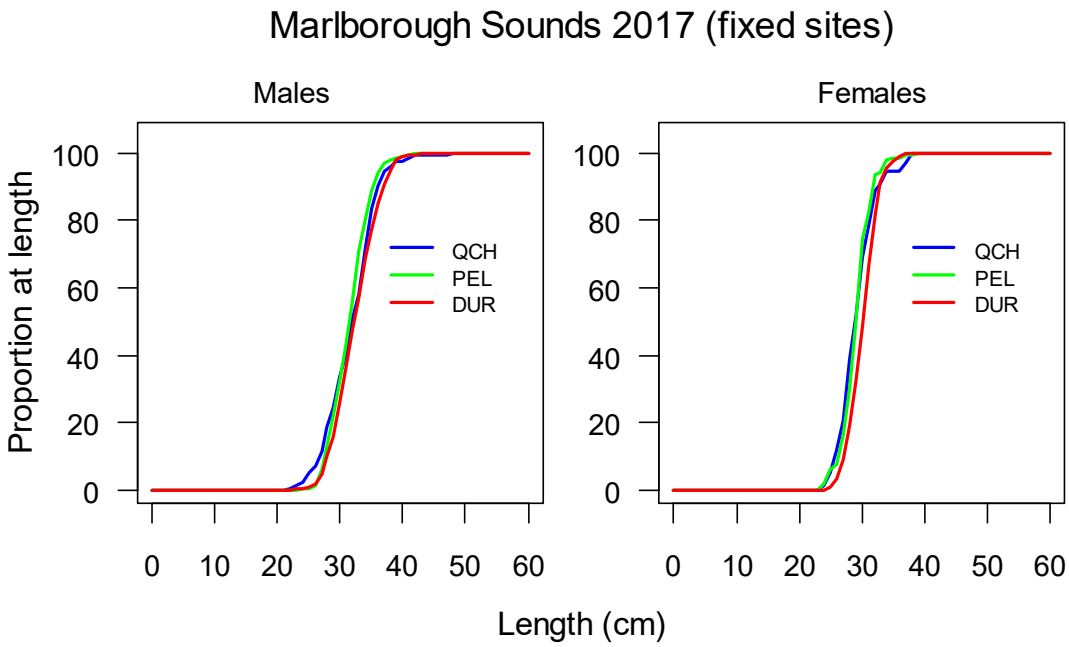


Figure 16: Cumulative distributions of scaled length frequencies for male and female blue cod for the 2017 Marlborough Sounds fixed-site potting survey by region. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island.

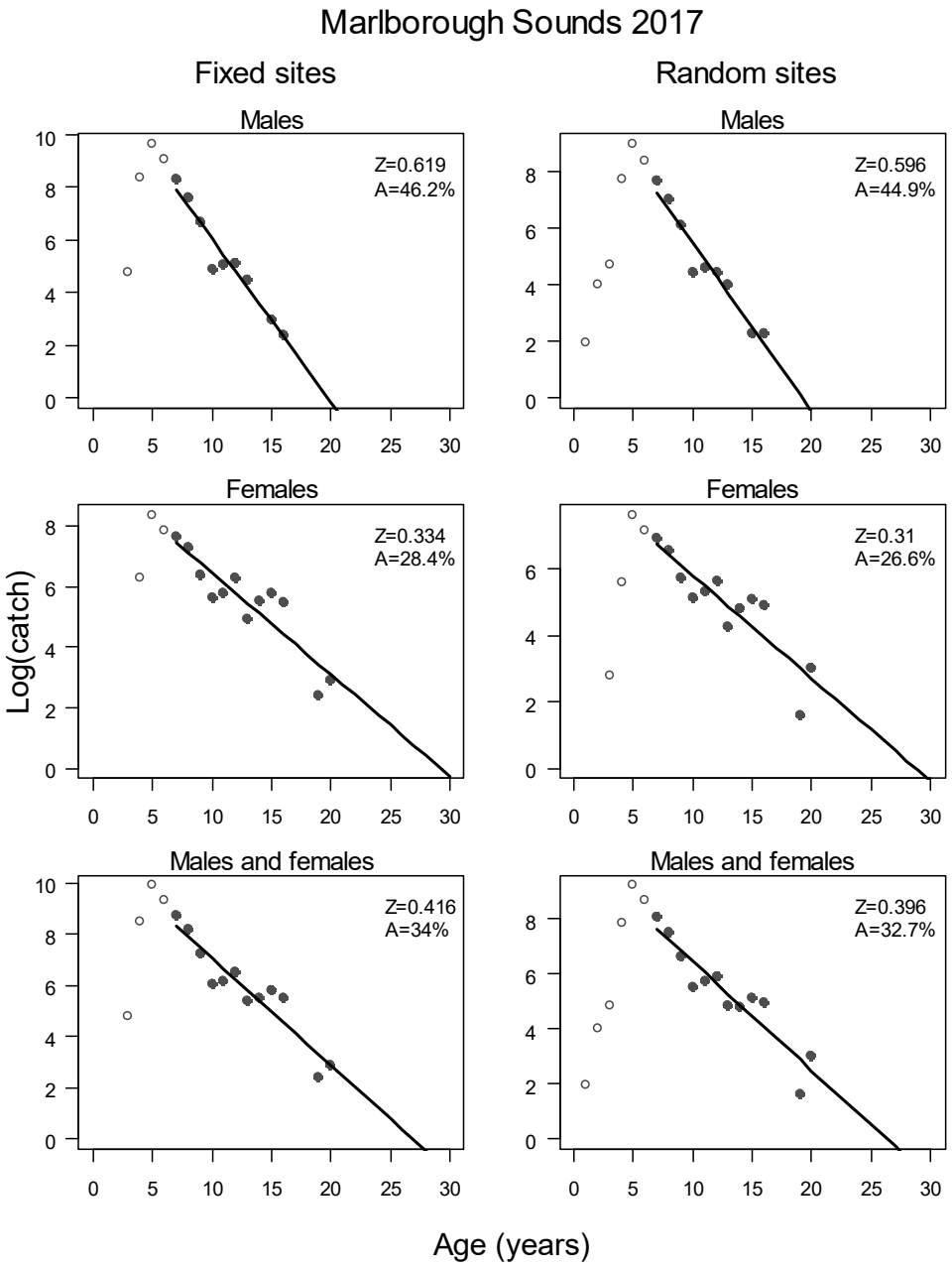


Figure 17: Catch curves (natural log of catch numbers versus age) for the 2017 Marlborough Sounds fixed-site and random-site surveys. The regression line is plotted from age at full recruitment of 6 years (i.e., dark points on the graph). Z, instantaneous total mortality; A, the annual mortality rate or the proportion of the population that suffers mortality in a given year.

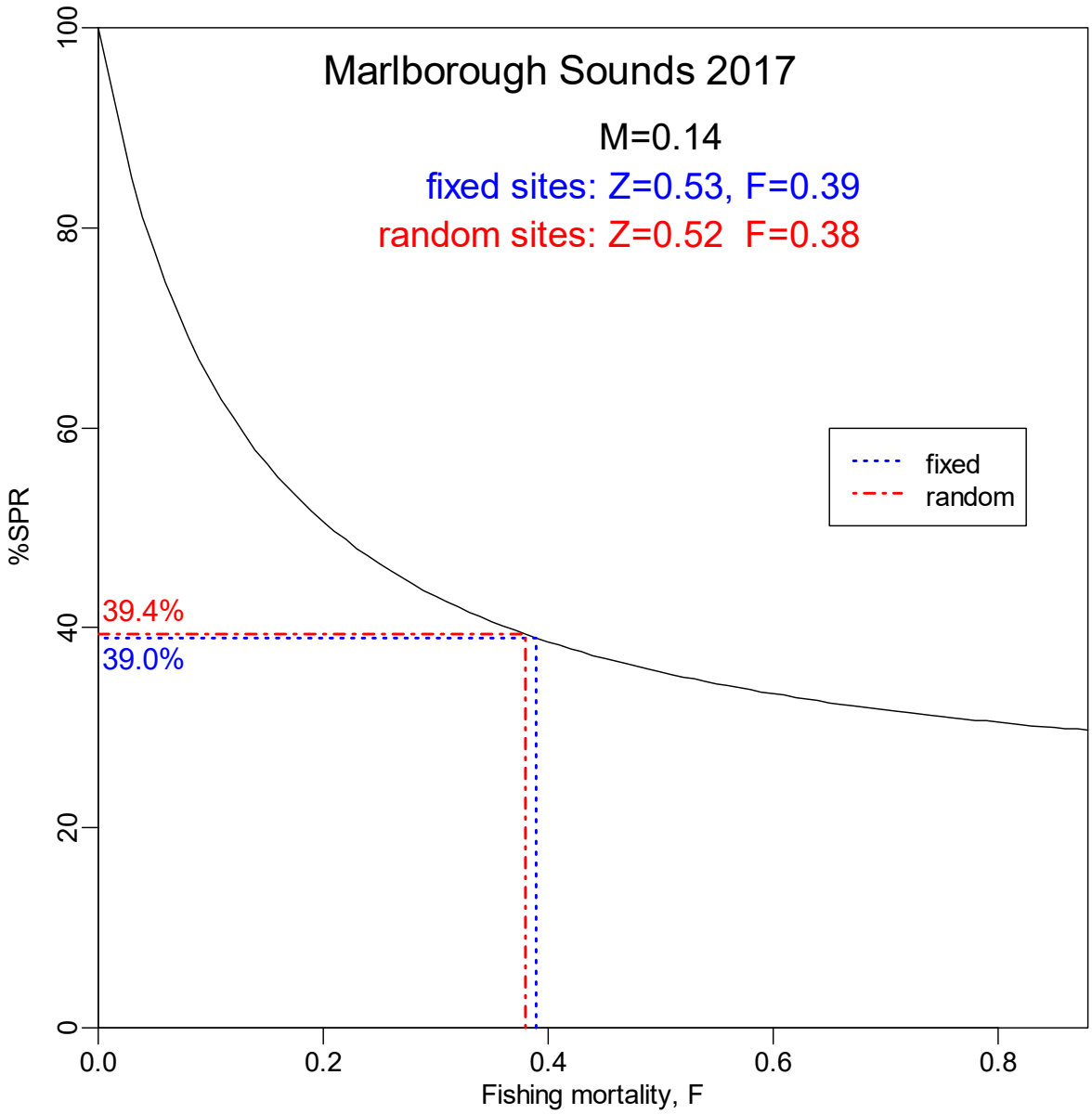


Figure 18: Spawner-per-recruit (SPR) as a function of fishing mortality (*F*) for the 2017 Marlborough Sounds fixed-site and random-site surveys for all regions combined. The %SPR values corresponding to the *F* values are annotated on the plot. In this plot *M* = 0.14, and *F* value is for age of full recruitment equal to 6 years for males and females combined.

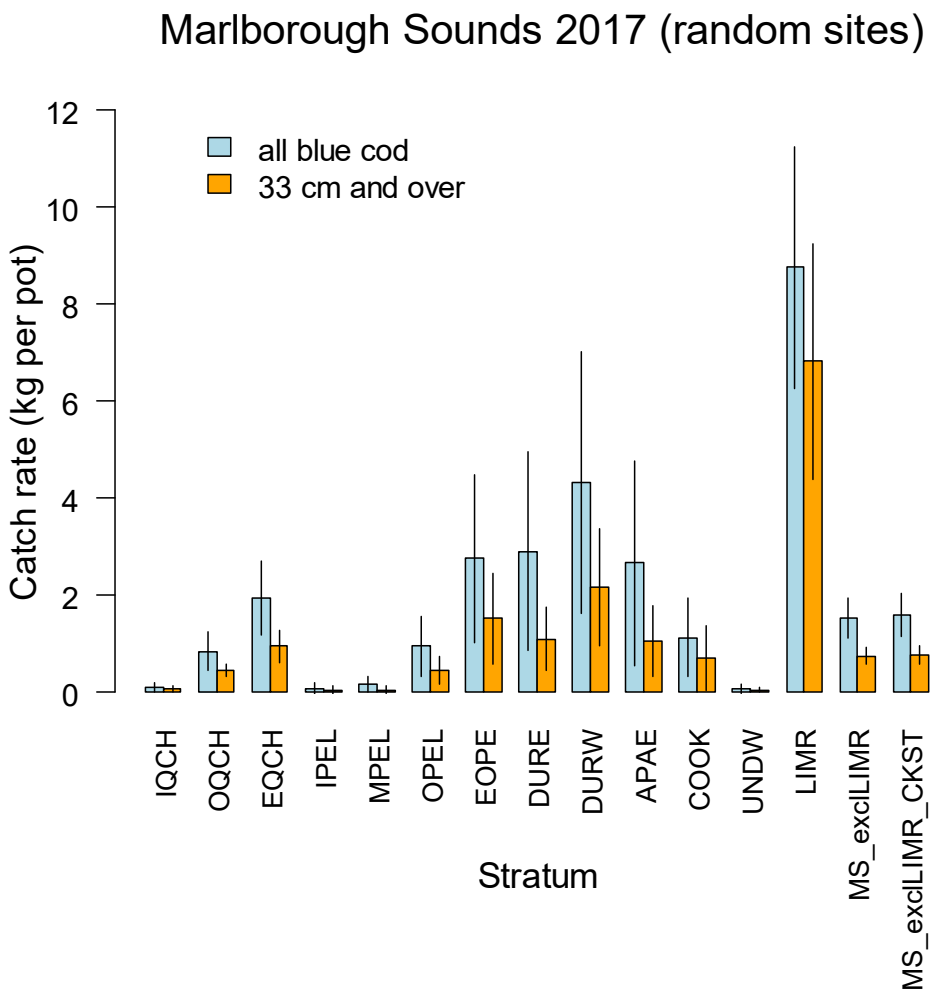


Figure 19: Marlborough Sounds 2017 random-site potting survey catch rates of all blue cod and recruited blue cod by strata, and for Marlborough Sounds overall excluding the marine reserve (MS_exclLIMR), and excluding the marine reserve and Cook Strait (MS_exclLIMR_CKST). Error bars are 95% confidence intervals. See Figure 3 for location of strata, and Table 2 for strata names.

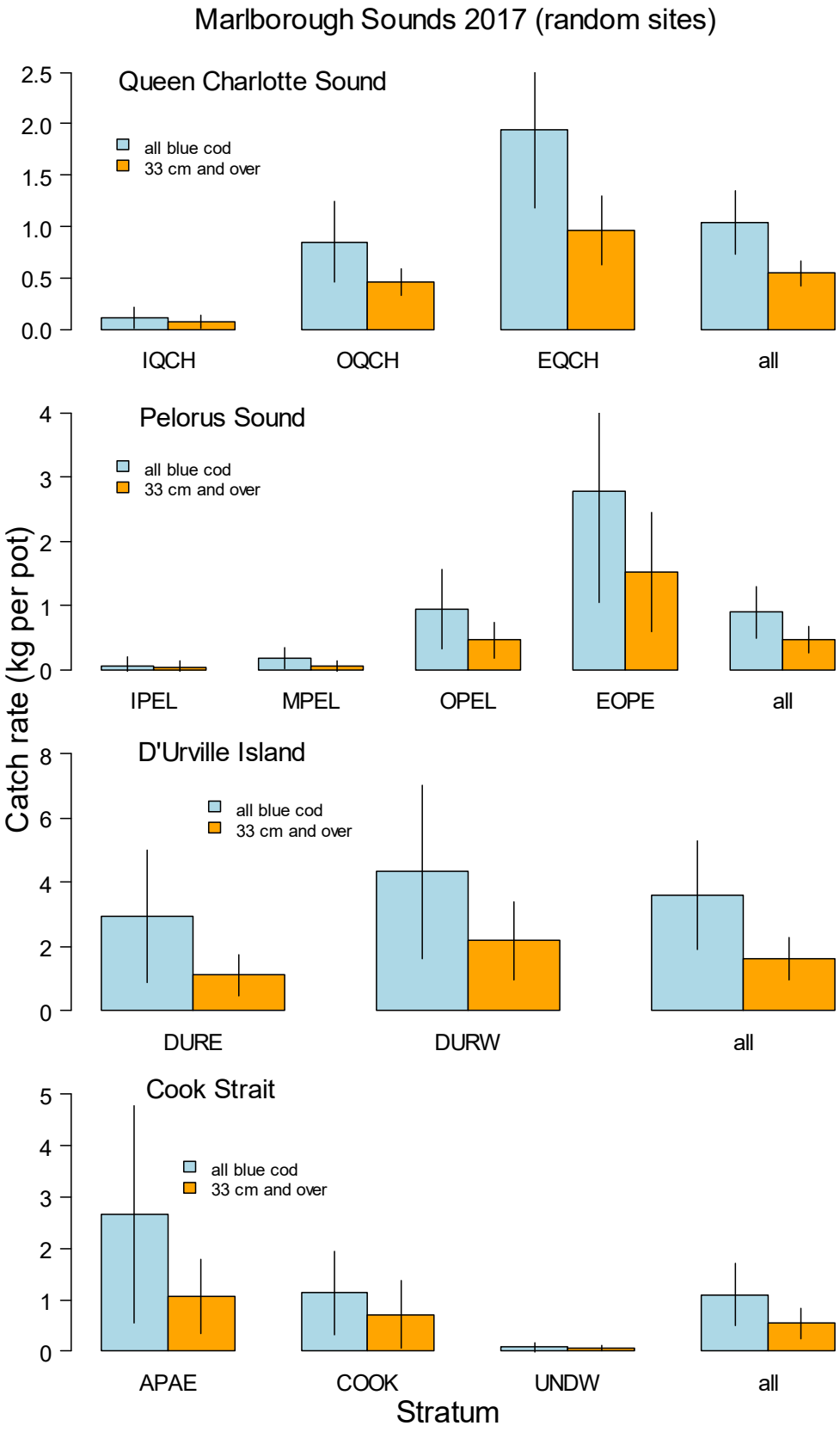


Figure 20: Marlborough Sounds 2017 random-site potting survey catch rates of all blue cod and recruited blue cod by strata and overall for each region. Error bars are 95% confidence intervals. See Figure 3 for location of strata, and Table 2 for strata names.

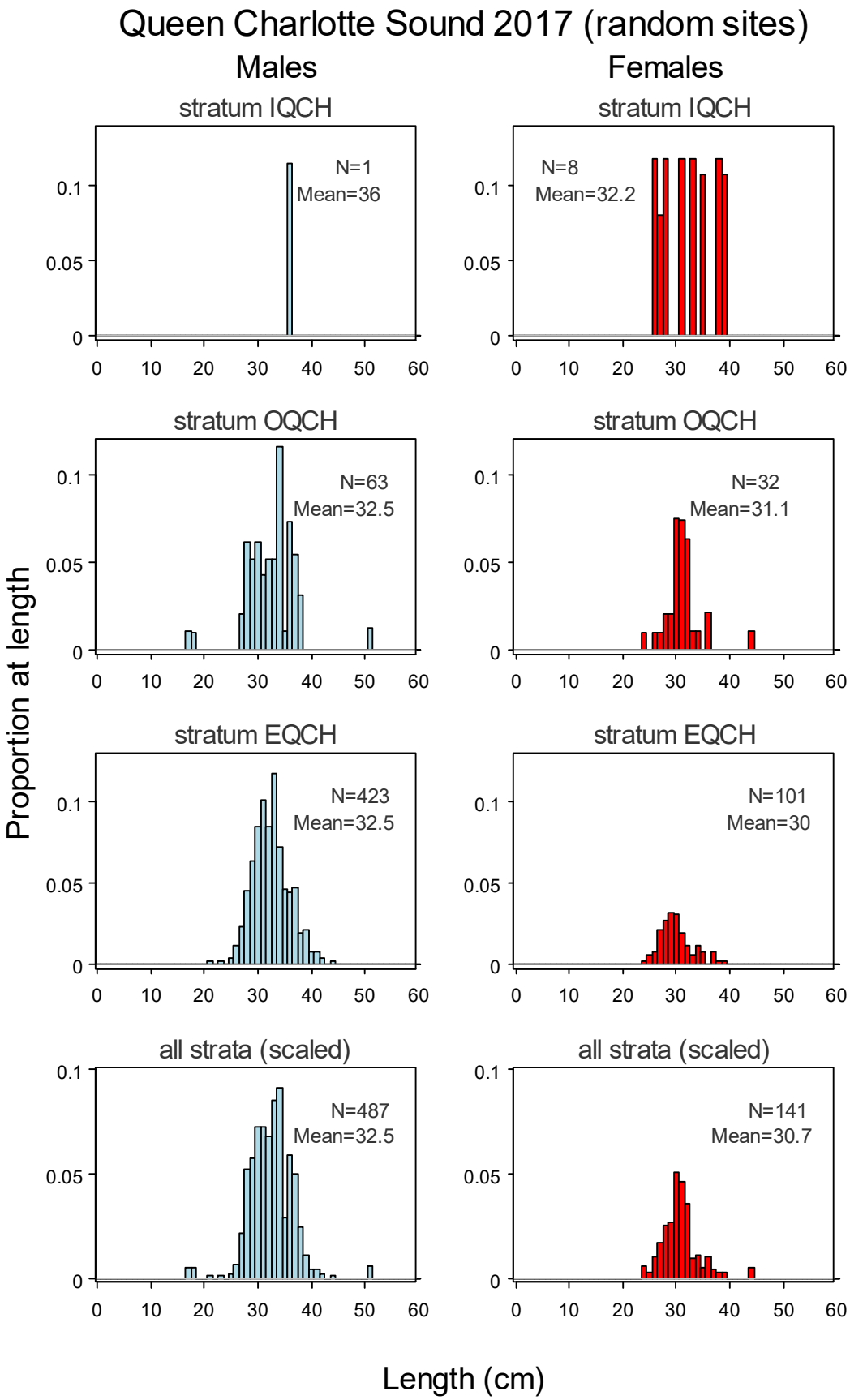


Figure 21: Scaled length frequency distributions by strata and overall for the 2017 Queen Charlotte Sound random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

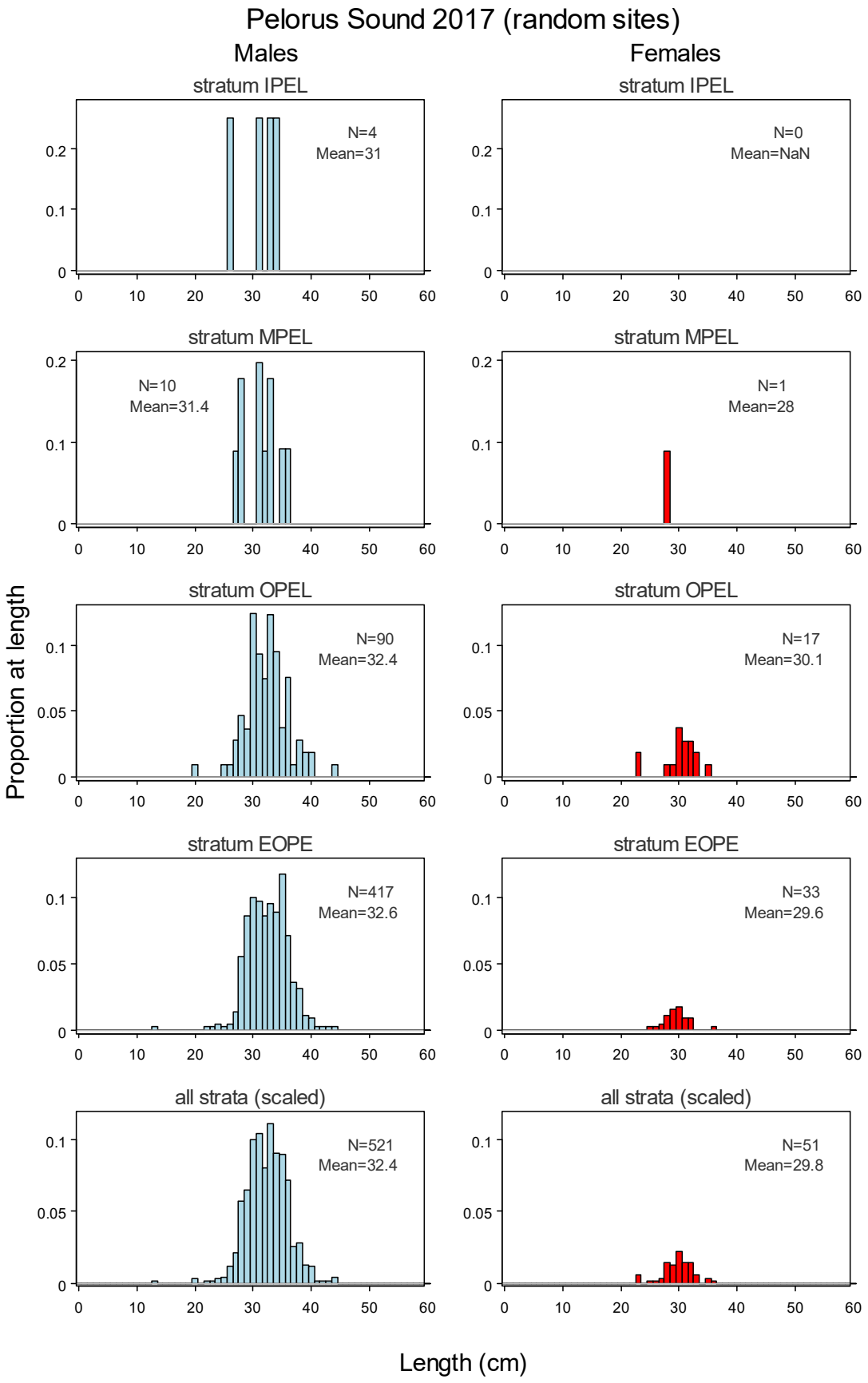


Figure 22: Scaled length frequency distributions by strata and overall for the 2017 Pelorus Sound random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

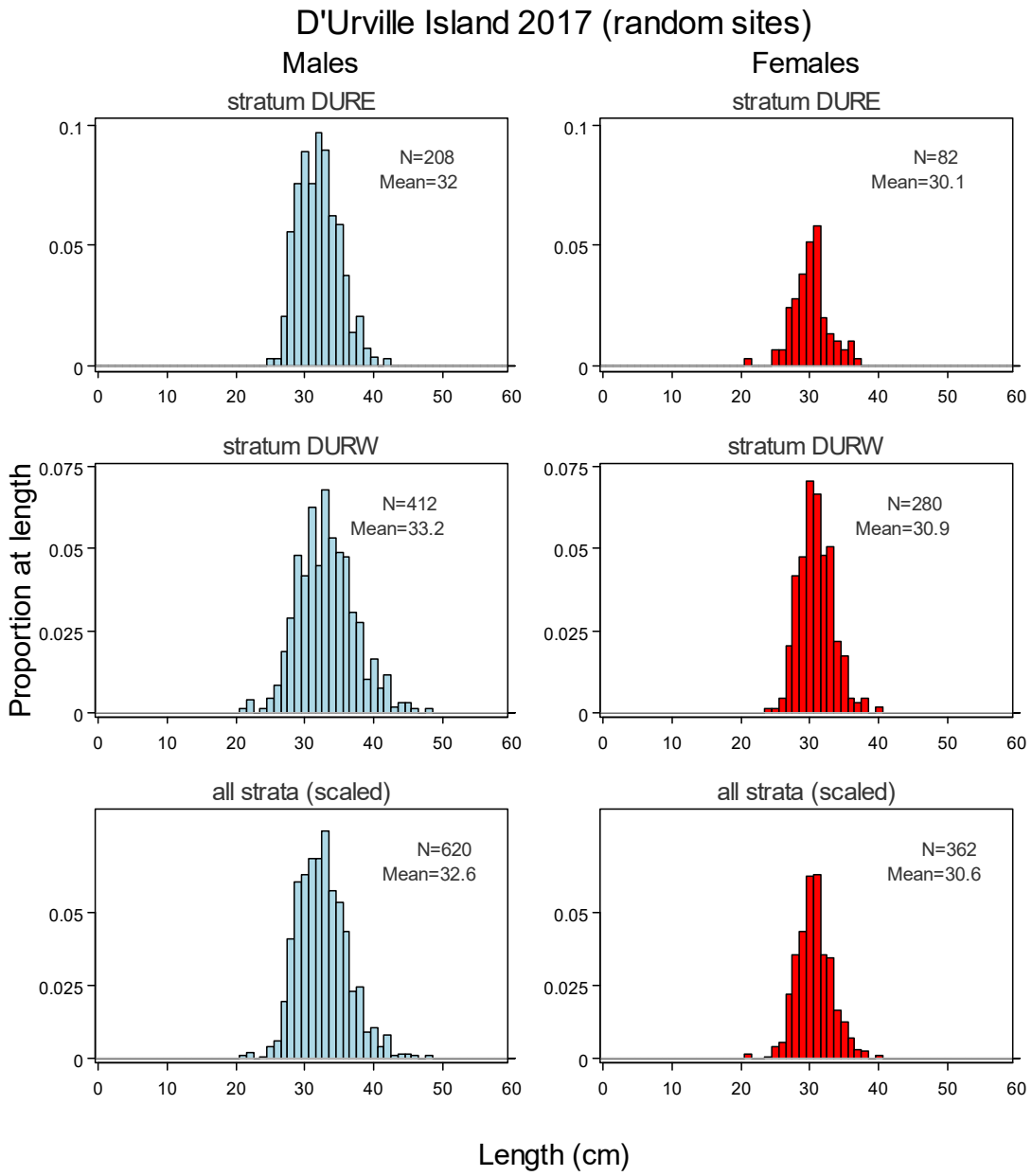


Figure 23: Scaled length frequency distributions by strata and overall for the 2017 D'Urville Island random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

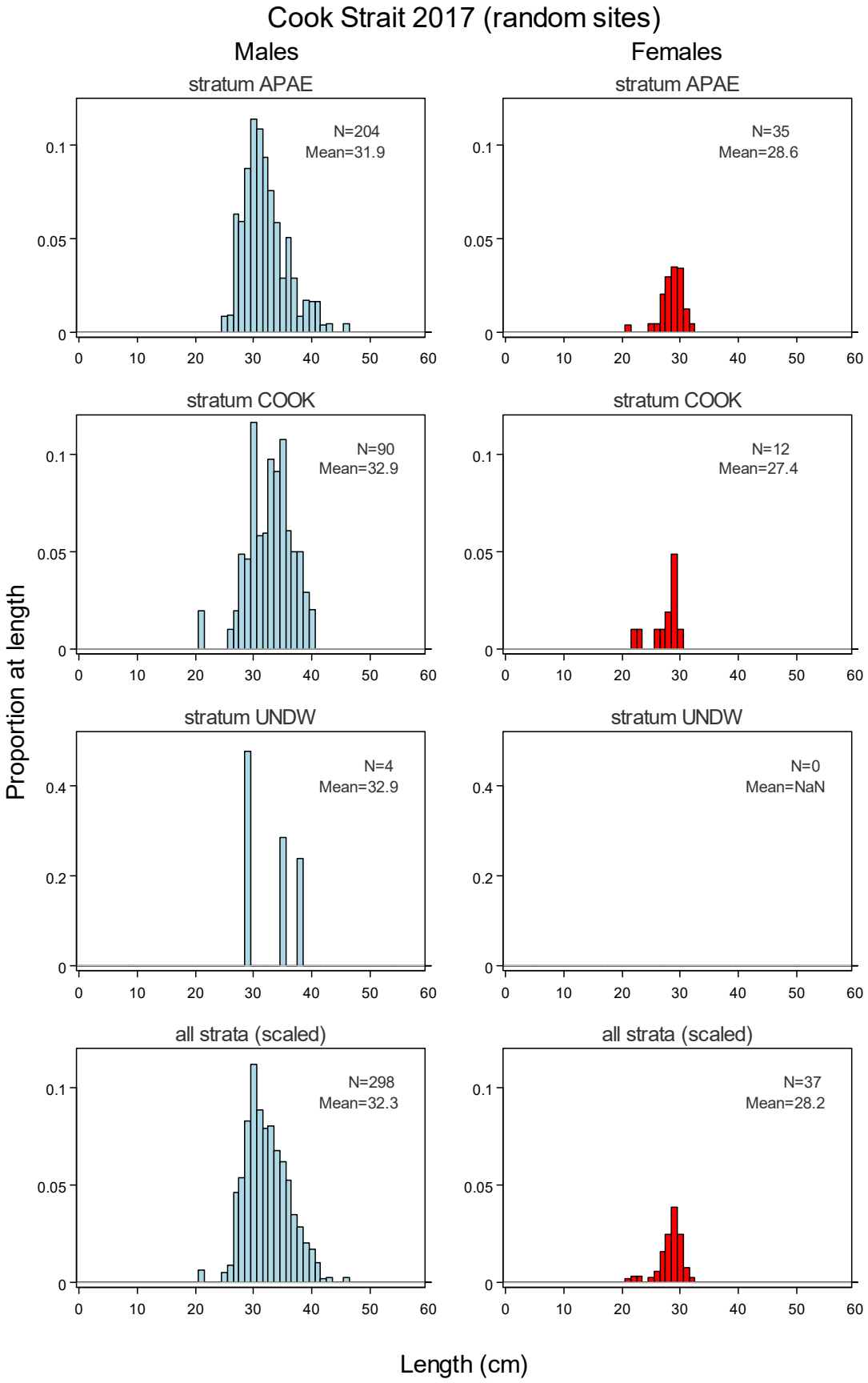


Figure 24: Scaled length frequency distributions by strata and overall for the 2017 Cook Strait random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

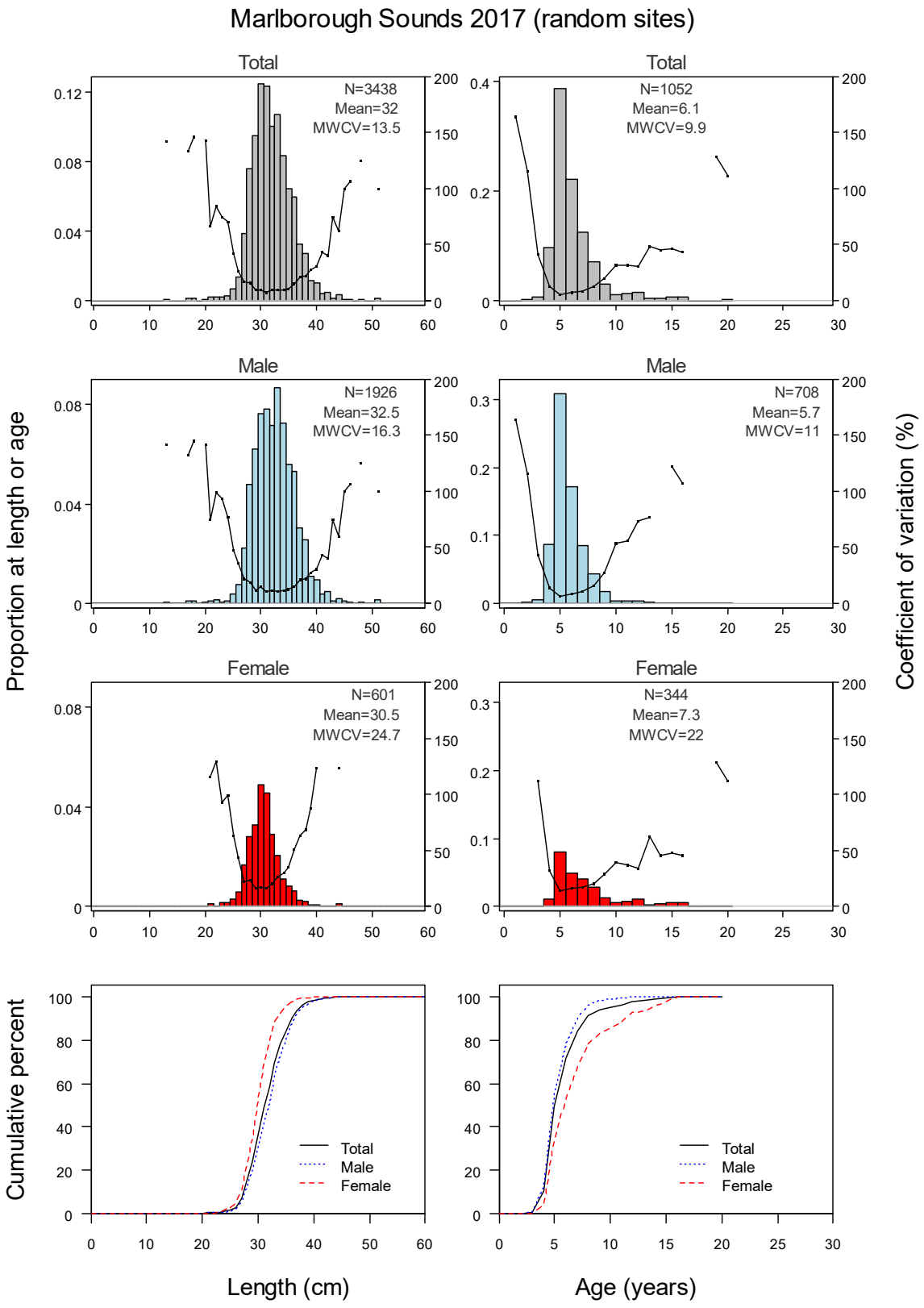


Figure 25: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for the 2017 Marlborough Sounds random-site potting survey (QCH, PEL, DUR and CKST combined), sample size; MWCV, mean weighted coefficient of variation.

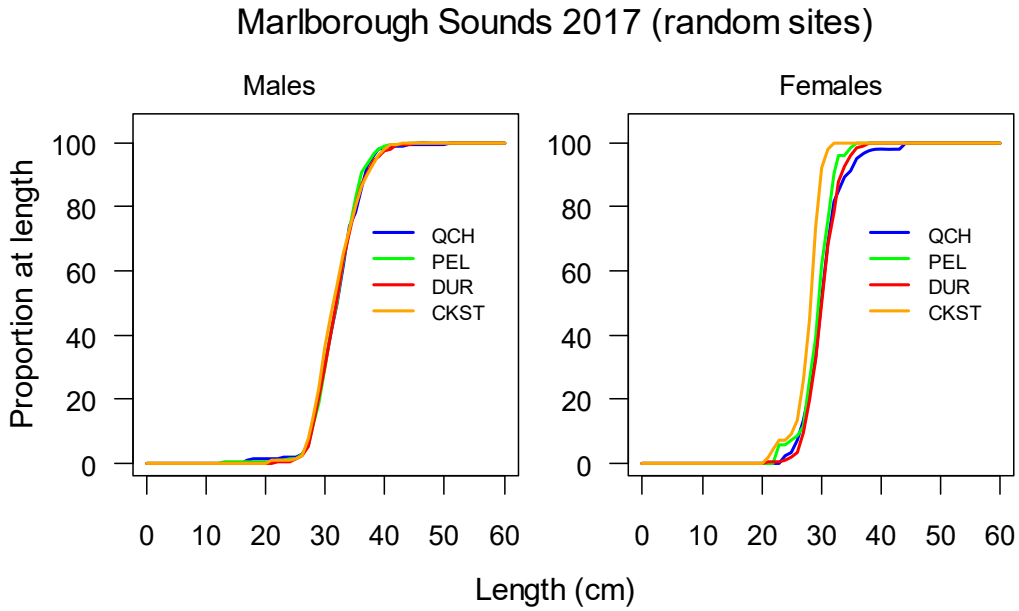


Figure 26: Cumulative distributions of scaled length frequencies for male and female blue cod for the Marlborough Sounds 2017 random-site potting survey by region. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait.

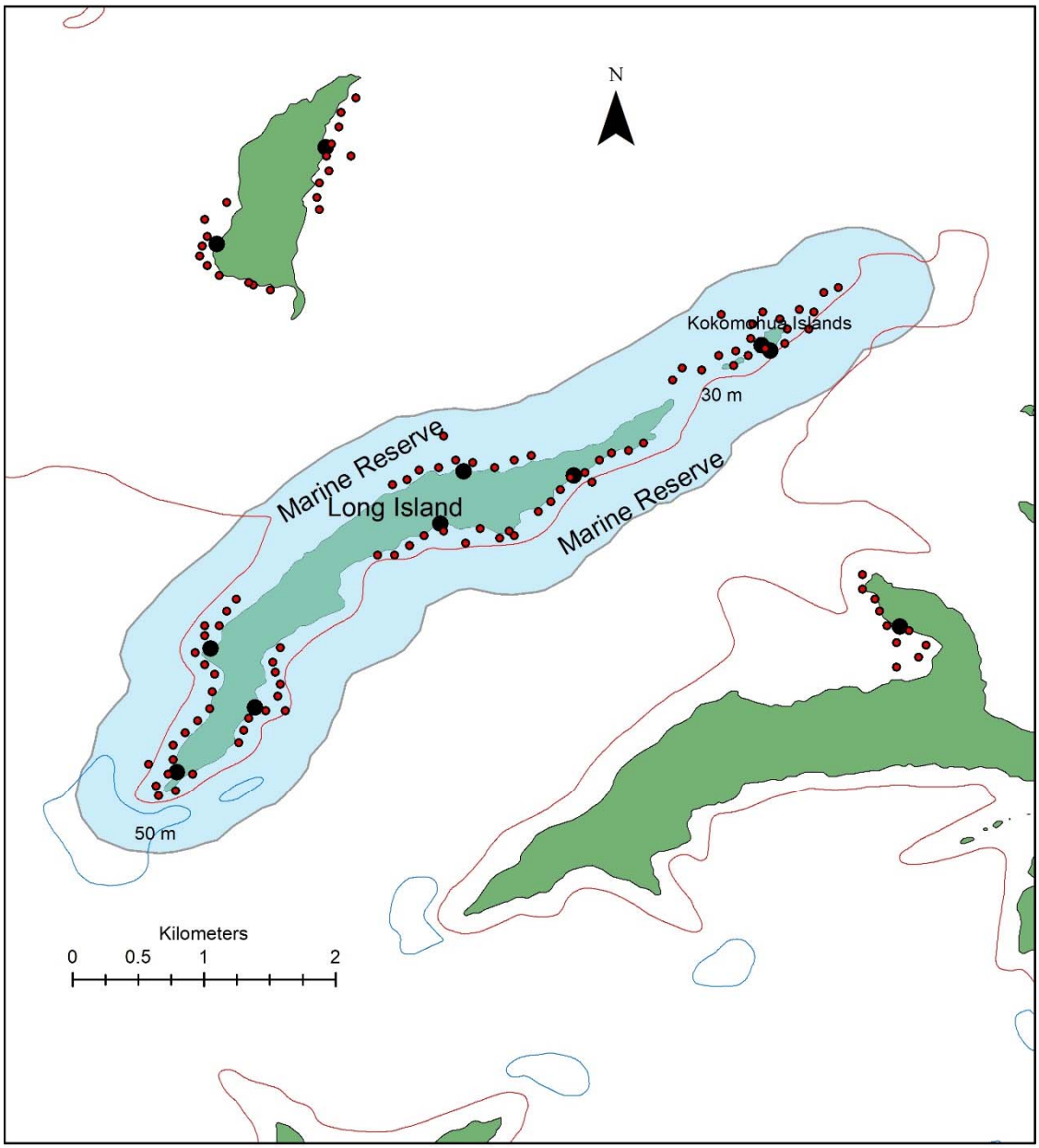


Figure 27: Map of Long Island Marine Reserve showing eight random sites and 72 pot locations surveyed in 2017. Three sites with pots, are also shown outside of LIMR in stratum EQCH (top left) and in stratum OQCH (far right).

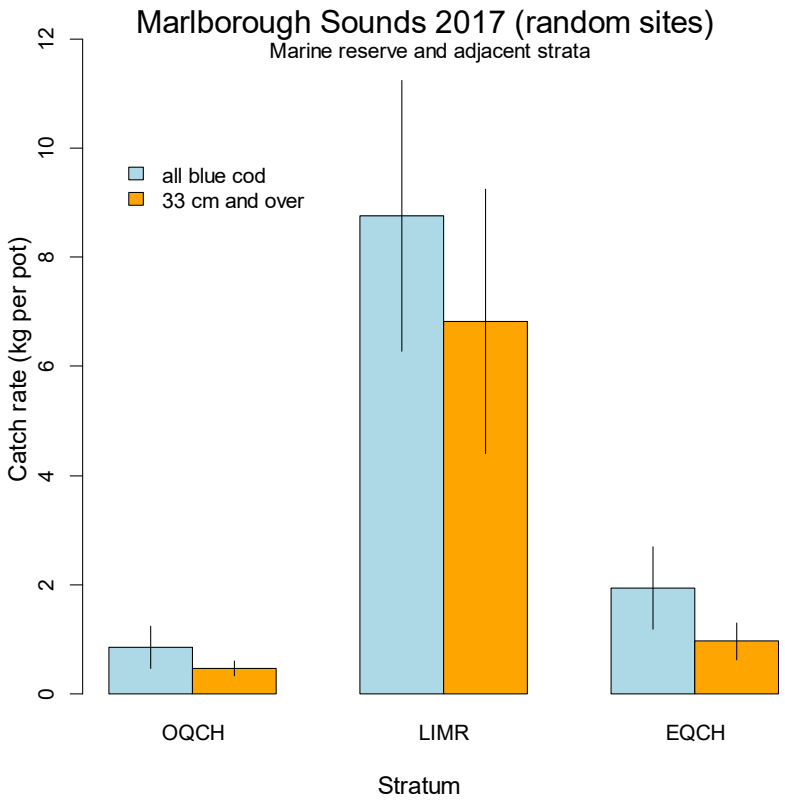


Figure 28: Marlborough Sounds 2017 random-site potting survey catch rates of all blue cod and recruited blue cod from sites inside the Long Island Marine Reserve (LIMR), and from all sites in adjacent strata in Queen Charlotte Sound (OQCH, EQCH). Error bars are 95% confidence intervals. See Figure 3 for location of strata, and Table 2 for strata names.

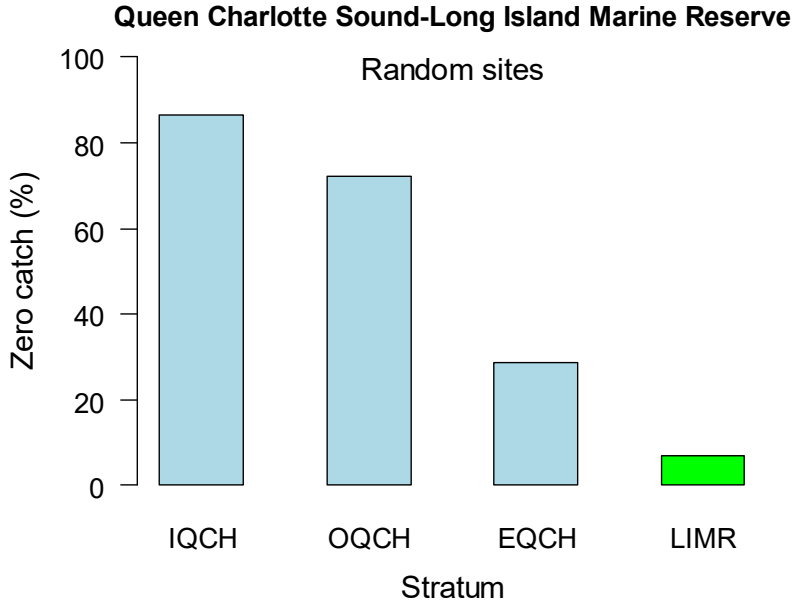


Figure 29: Marlborough Sounds 2017 random-site potting survey proportion of pots with zero blue cod from sites inside the Long Island Marine Reserve (LIMR), and from all sites in Queen Charlotte Sound strata (IQCH, OQCH, EQCH). See Figure 3 for location of strata, and Table 2 for strata names.

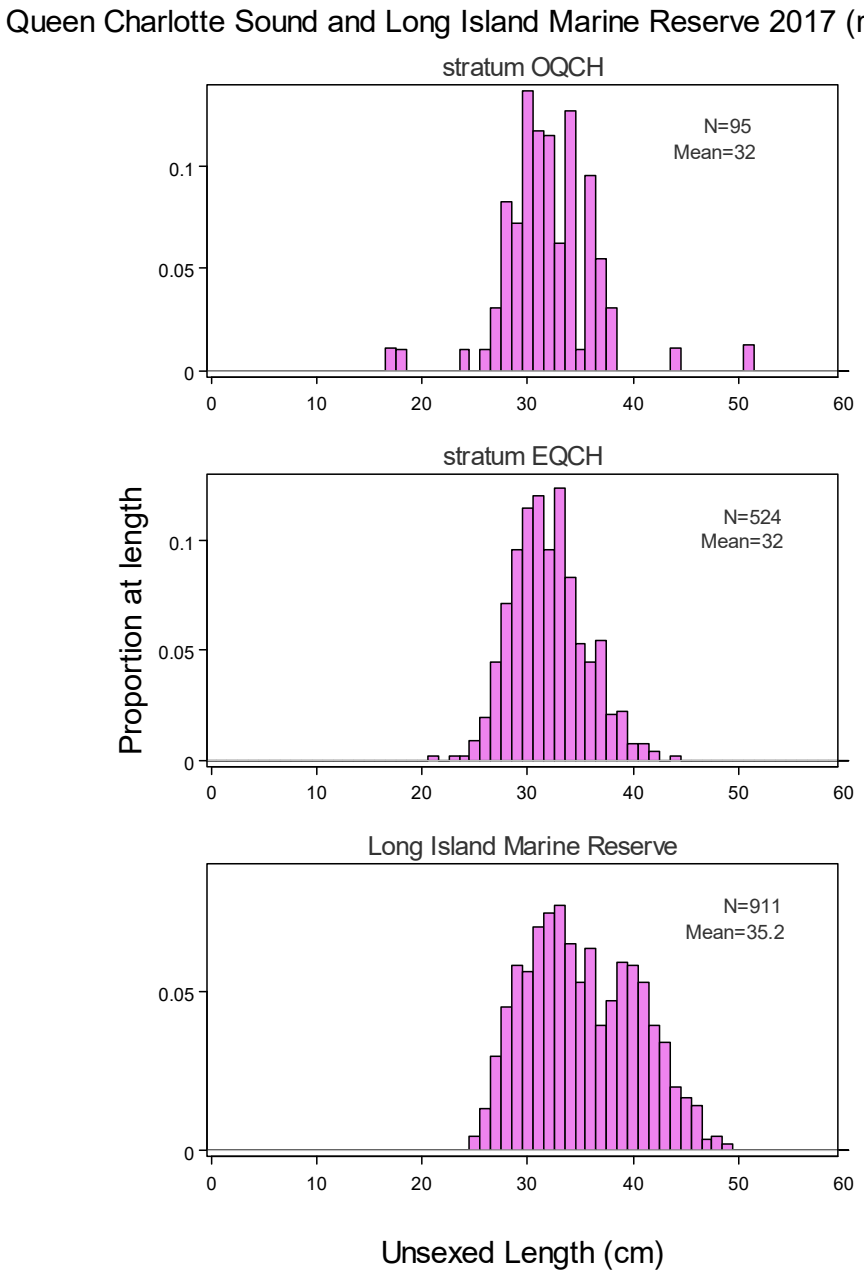


Figure 30: Marlborough Sounds 2017 random-site potting survey scaled length frequency distributions of unsexed blue cod for sites inside Long Island Marine Reserve (LIMR) and from all sites in the adjacent Queen Charlotte Sound strata (OQCH, EQCH). N, sample numbers; Mean, mean length (cm). See Table 2 for strata names.

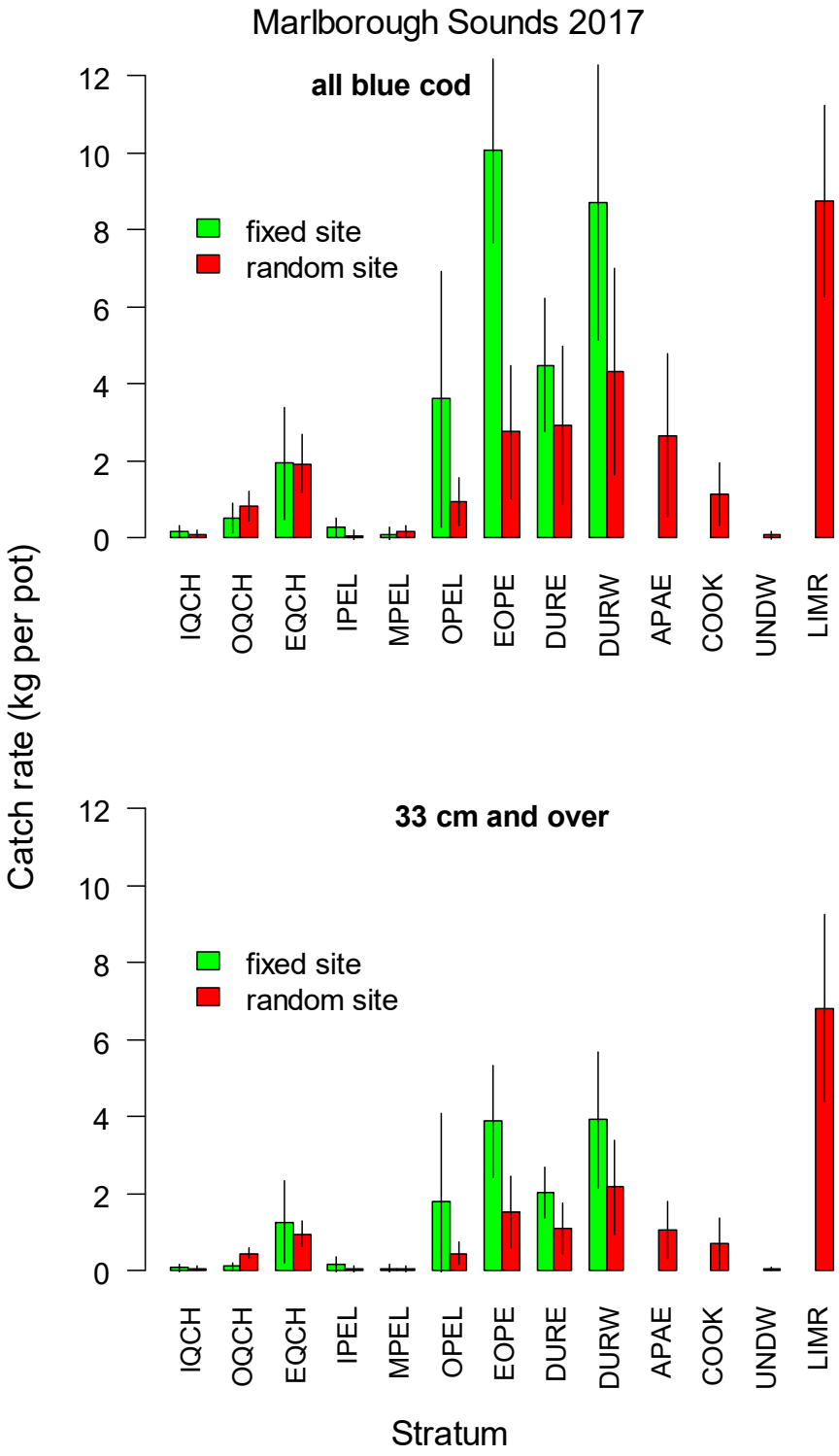


Figure 31: Marlborough Sounds 2017 fixed-site and random-site potting survey catch rates of all blue cod and recruited blue cod by strata. Error bars are 95% confidence intervals. See Figure 3 for location of strata, and Table 2 for strata names. There were no fixed-site surveys in strata APAE, COOK, UNDW and LIMR.

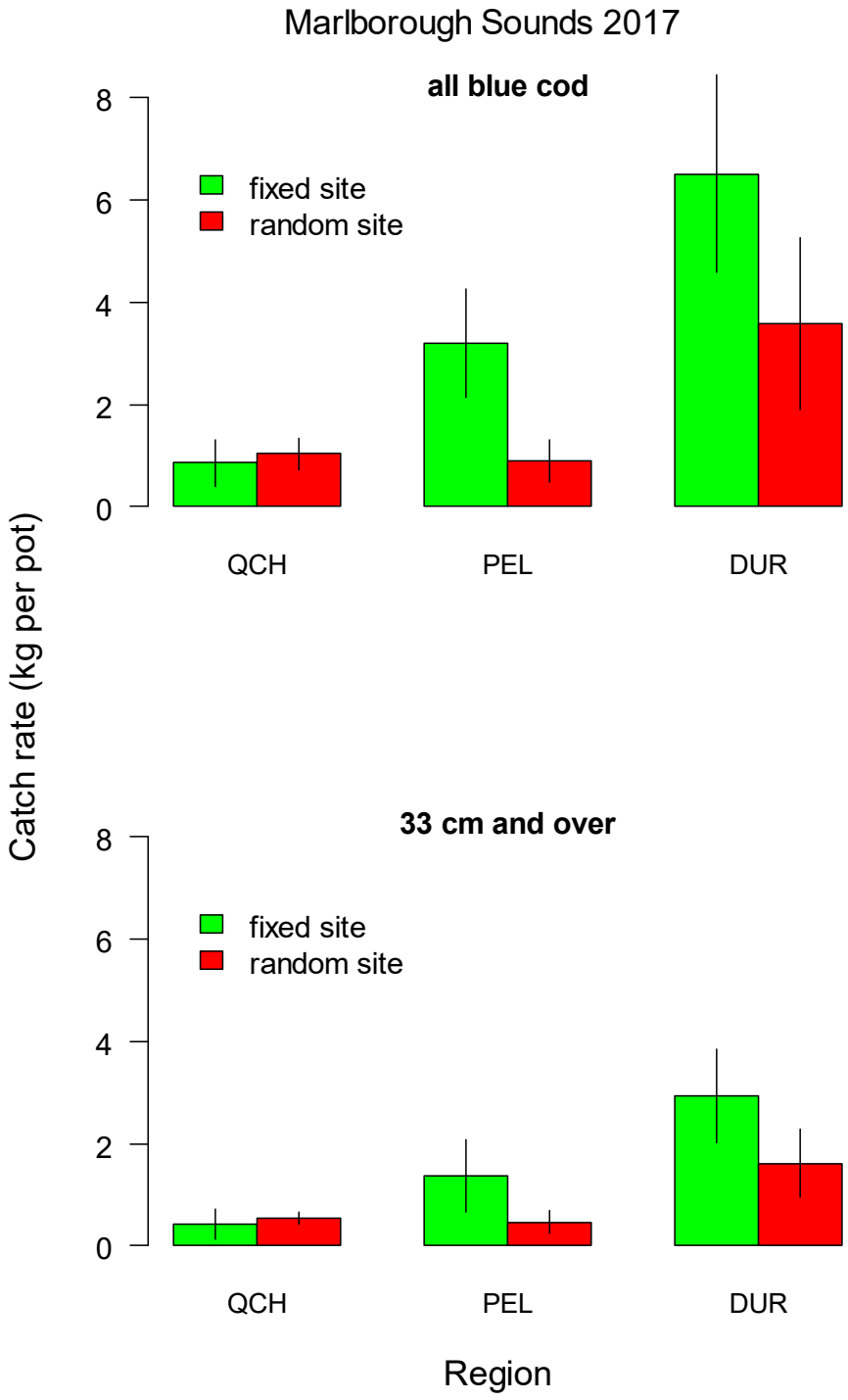


Figure 32: Marlborough Sounds 2017 fixed-site and random-site potting survey catch rates of all blue cod and recruited blue cod by region. Error bars are 95% confidence intervals. See Figure 3 for location of regions, and Table 2 for strata names.

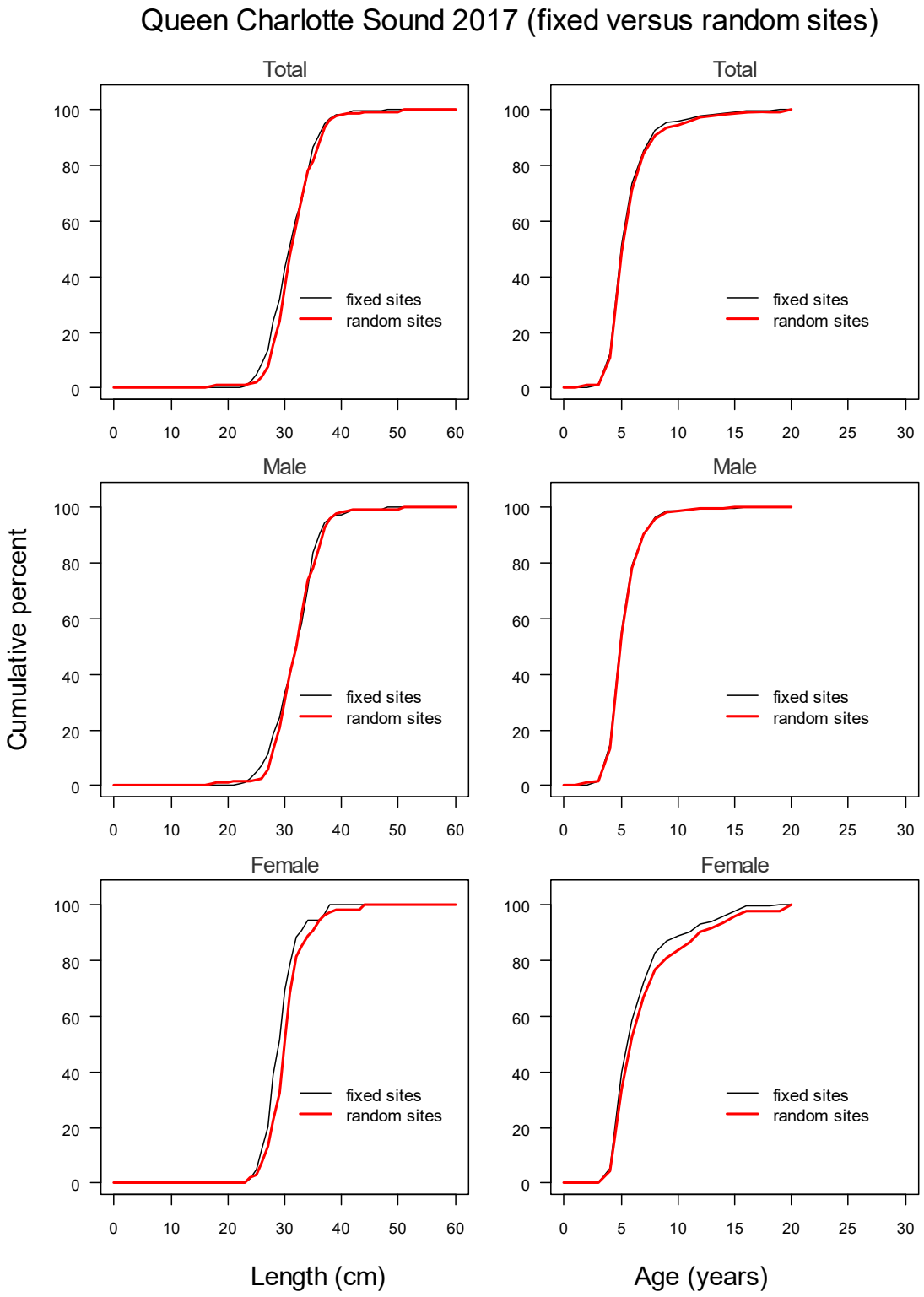


Figure 33: Cumulative distributions of scaled length and age frequencies for total, male and female blue cod for fixed-site and random-site potting surveys from Queen Charlotte Sound in 2017.

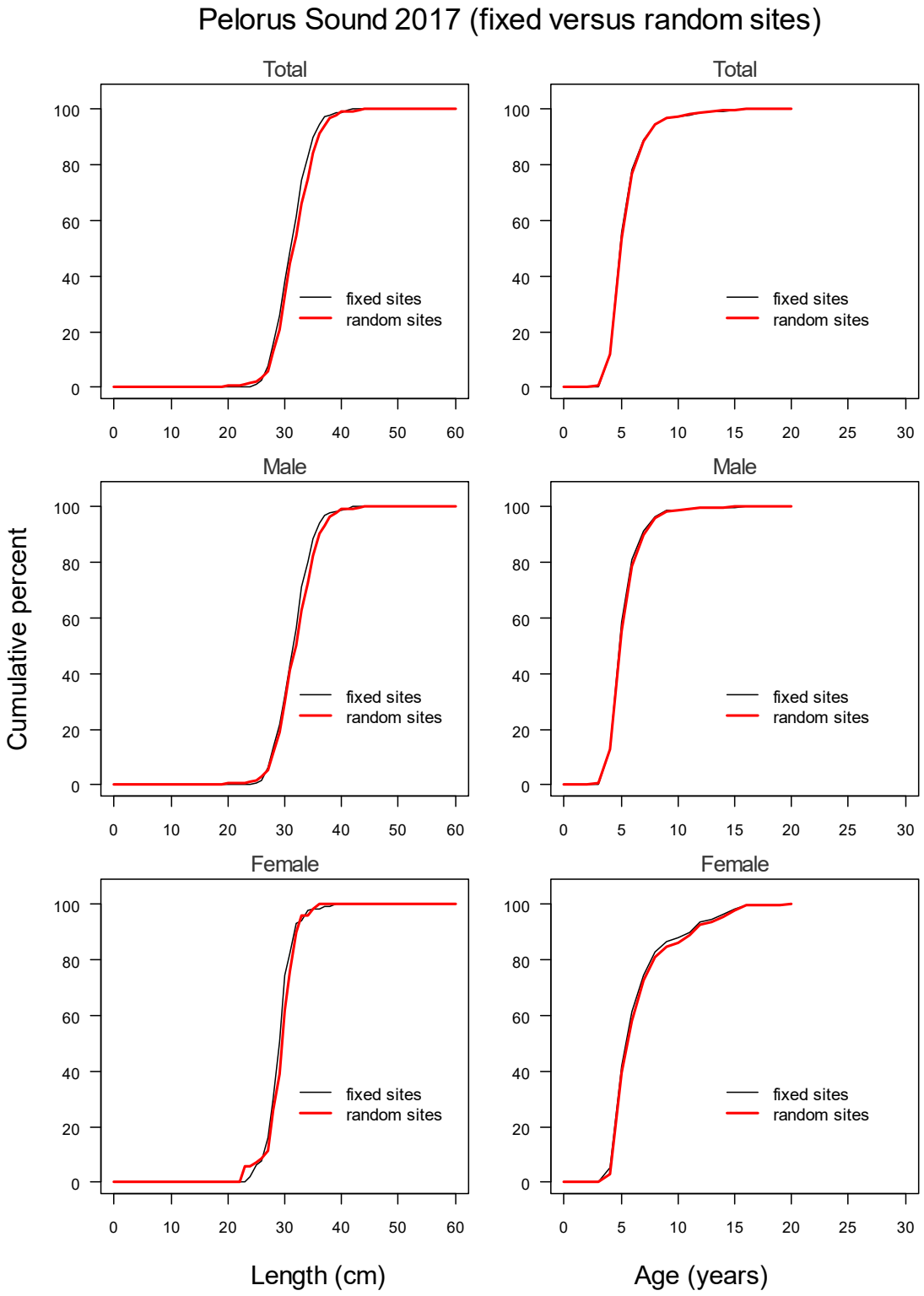


Figure 34: Cumulative distributions of scaled length and age frequencies for total, male and female blue cod for fixed-site and random-site potting surveys from Pelorus Sound in 2017.

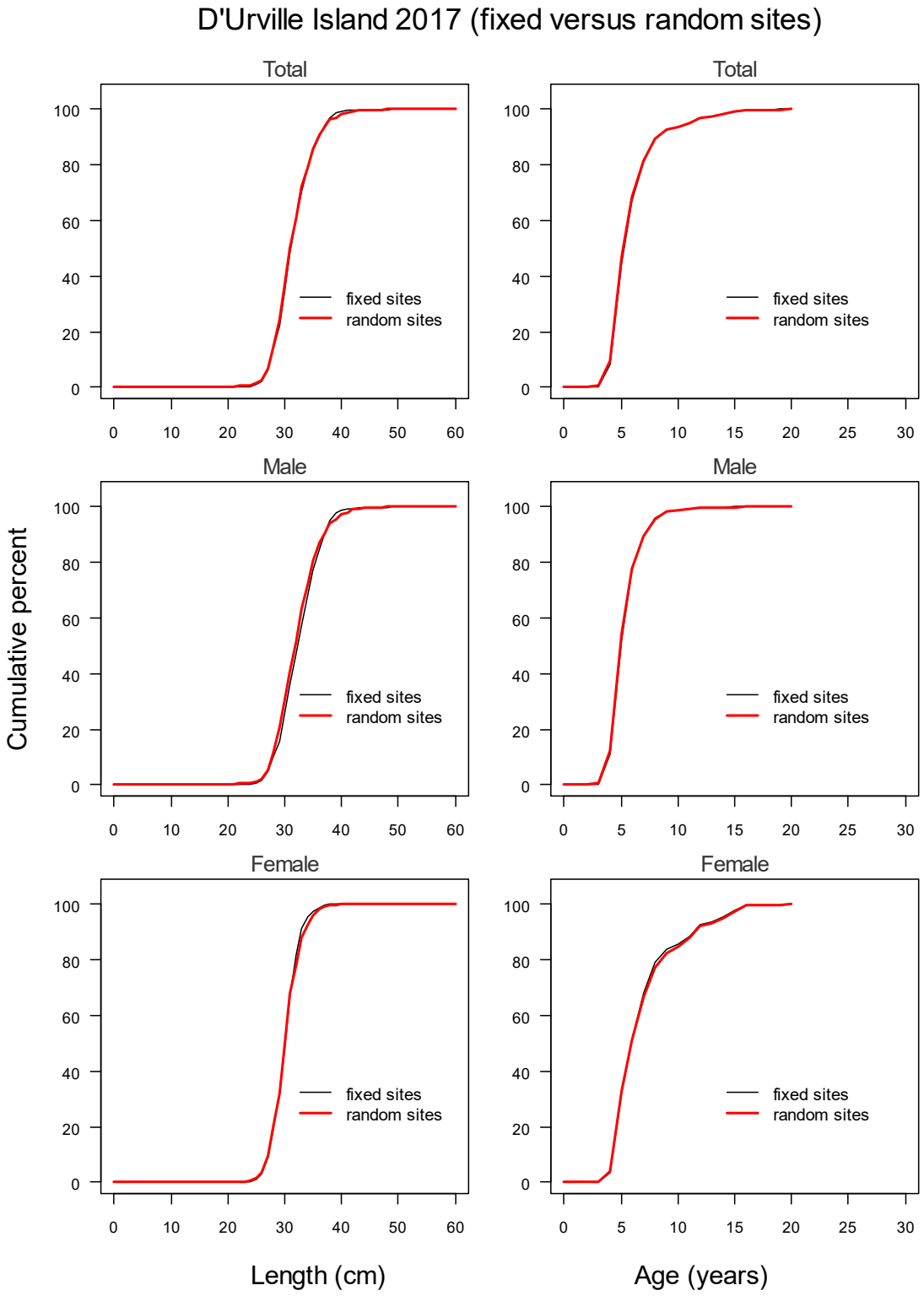


Figure 35: Cumulative distributions of scaled length and age frequencies for total, male and female blue cod for fixed-site and random-site potting surveys from D'Urville Island in 2017.

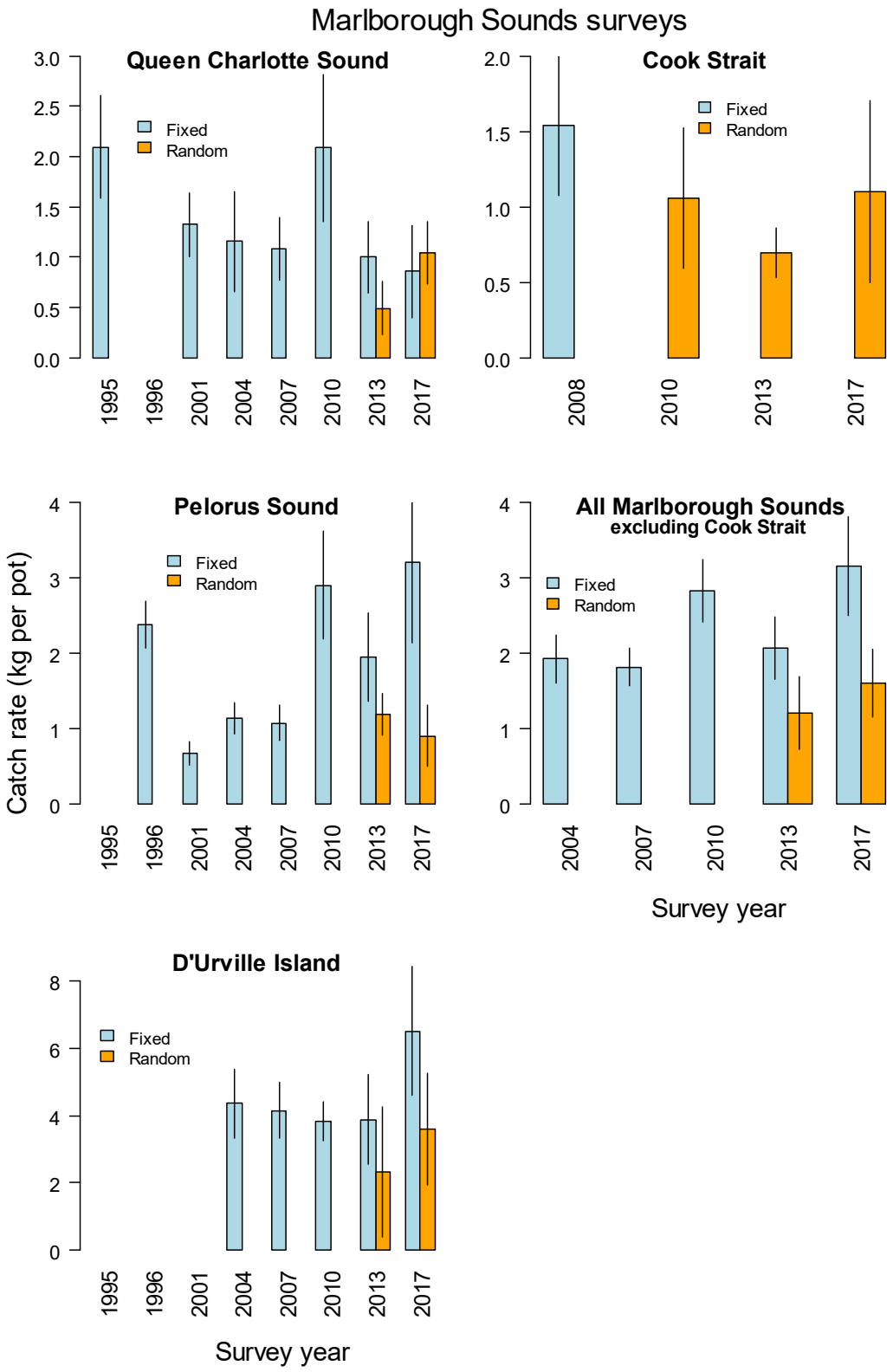


Figure 36: Marlborough Sounds fixed-site and random-site potting survey catch rates of all blue cod by survey year, for each region, and overall for Marlborough Sounds from 2004 (excluding Cook Strait) when strata were consistent. Error bars are 95% confidence intervals. There were no complete surveys in QCH in 1996, PEL in 1996, DUR from 1995 to 2001 (see Table 1). See Figure 3 for location of regions.

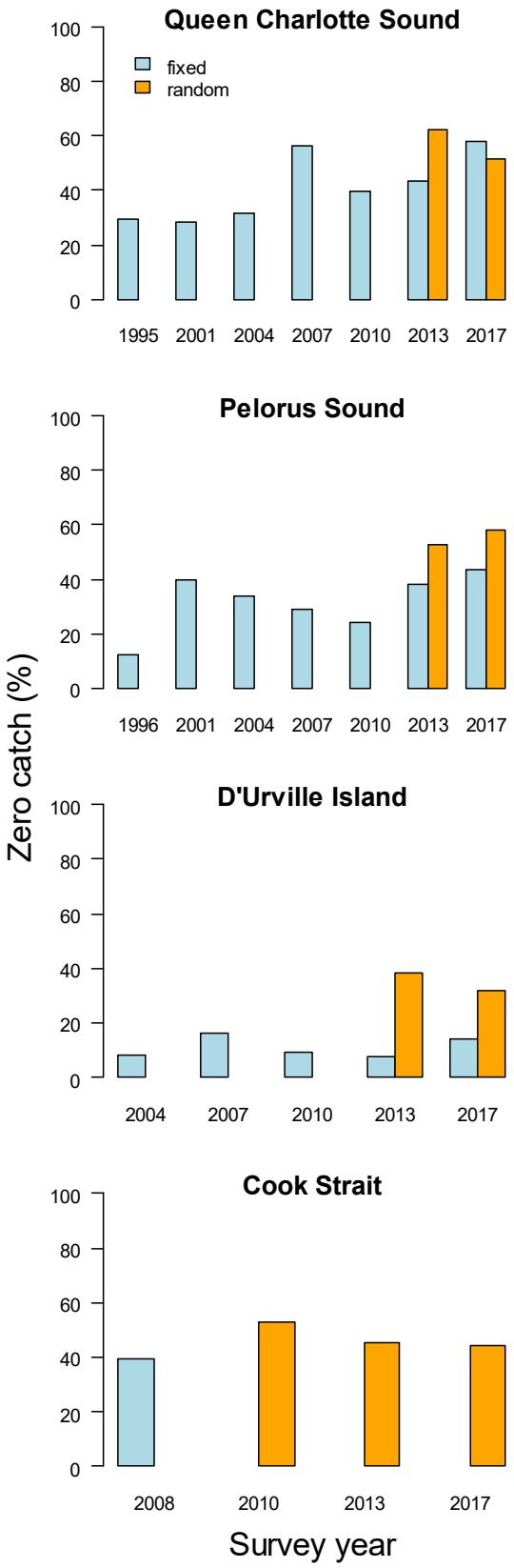


Figure 37: Proportion of pots with zero catch of blue cod for the Marlborough Sound fixed-site and random-site potting surveys by region.

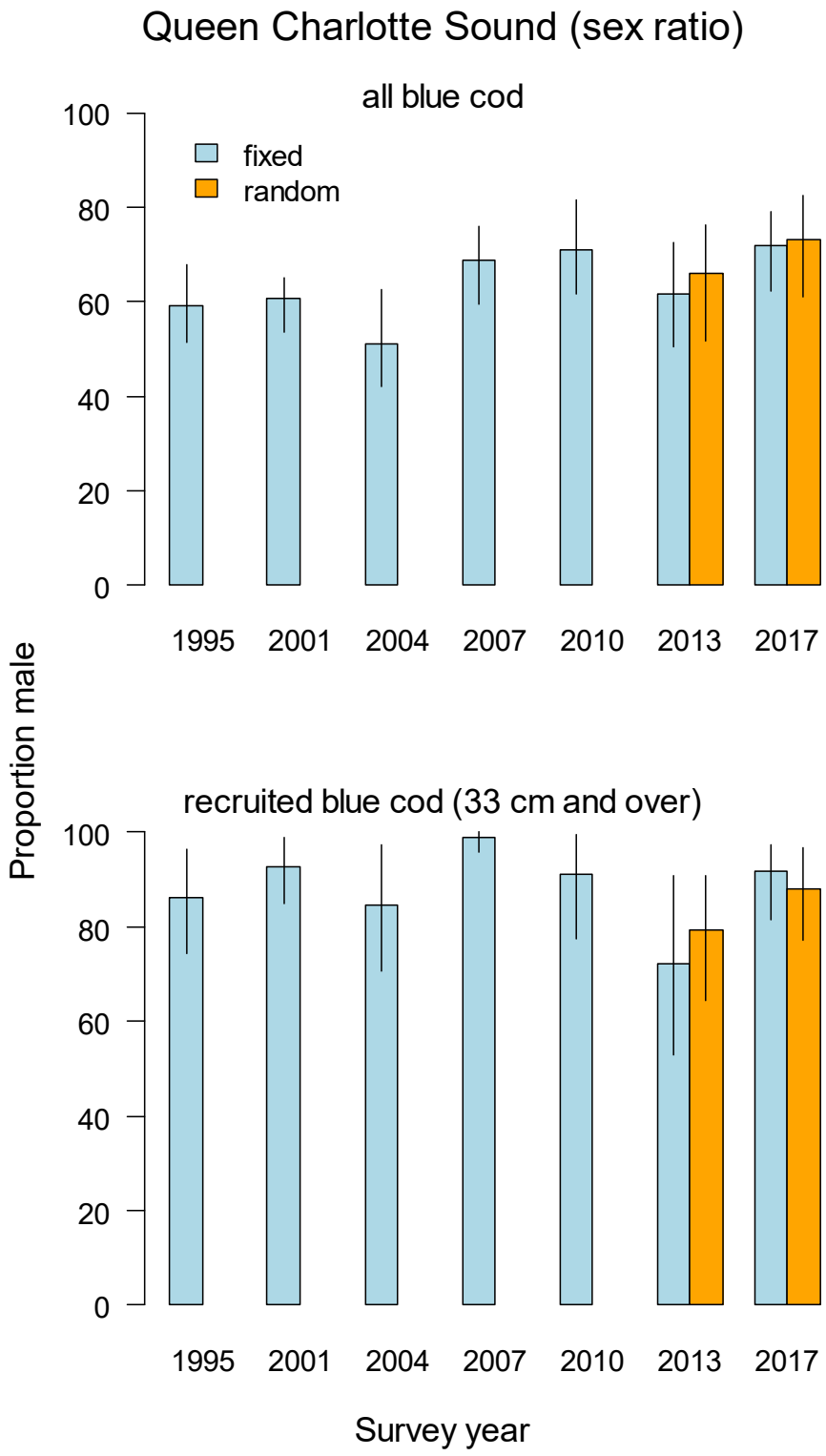


Figure 38: Sex ratio (expressed as percent male) for all blue cod and recruited blue cod for fixed-site and random-site potting surveys for each region. Error bars are 95% confidence intervals [Contined on next page].

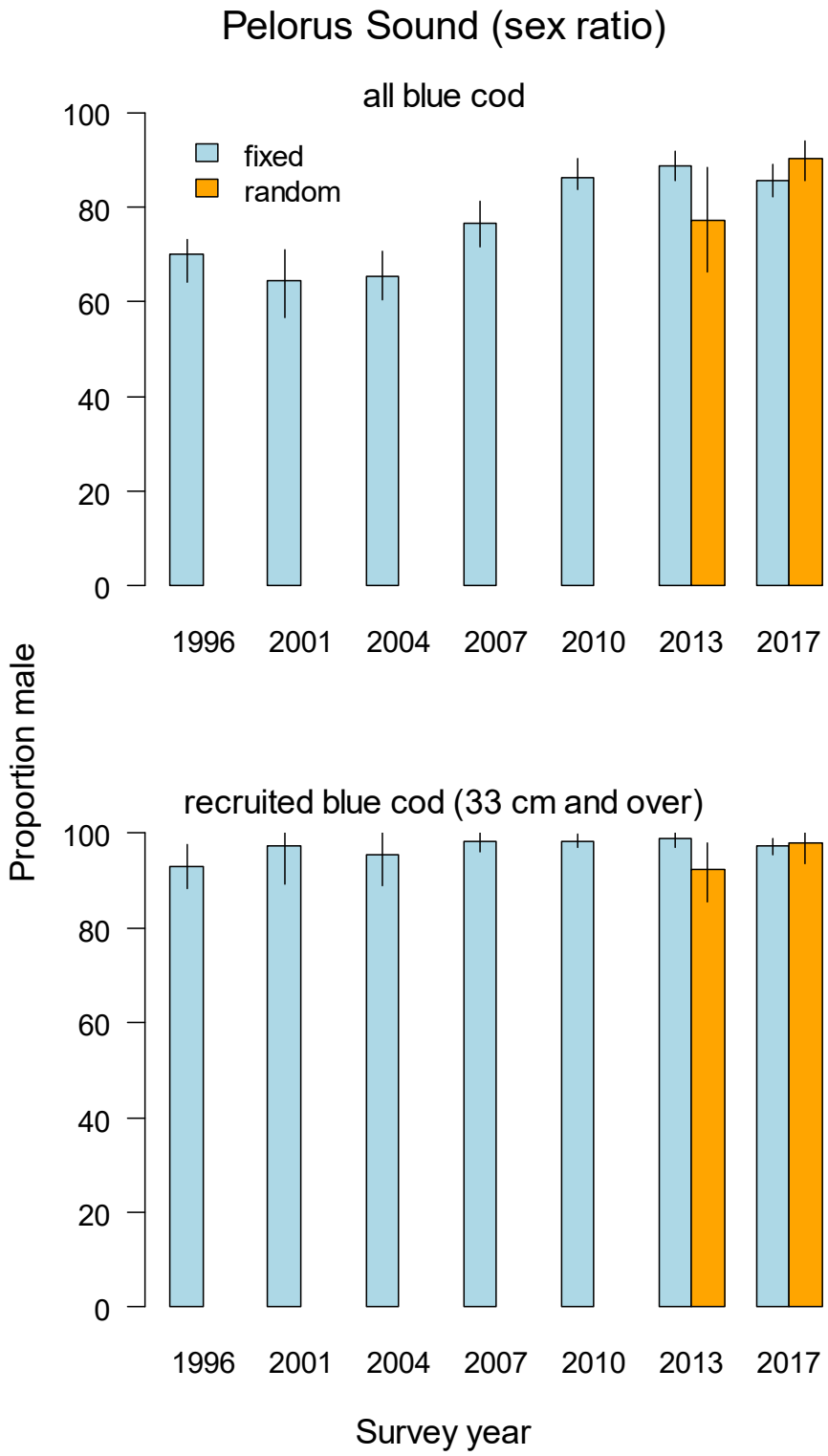


Figure 38–*continued*

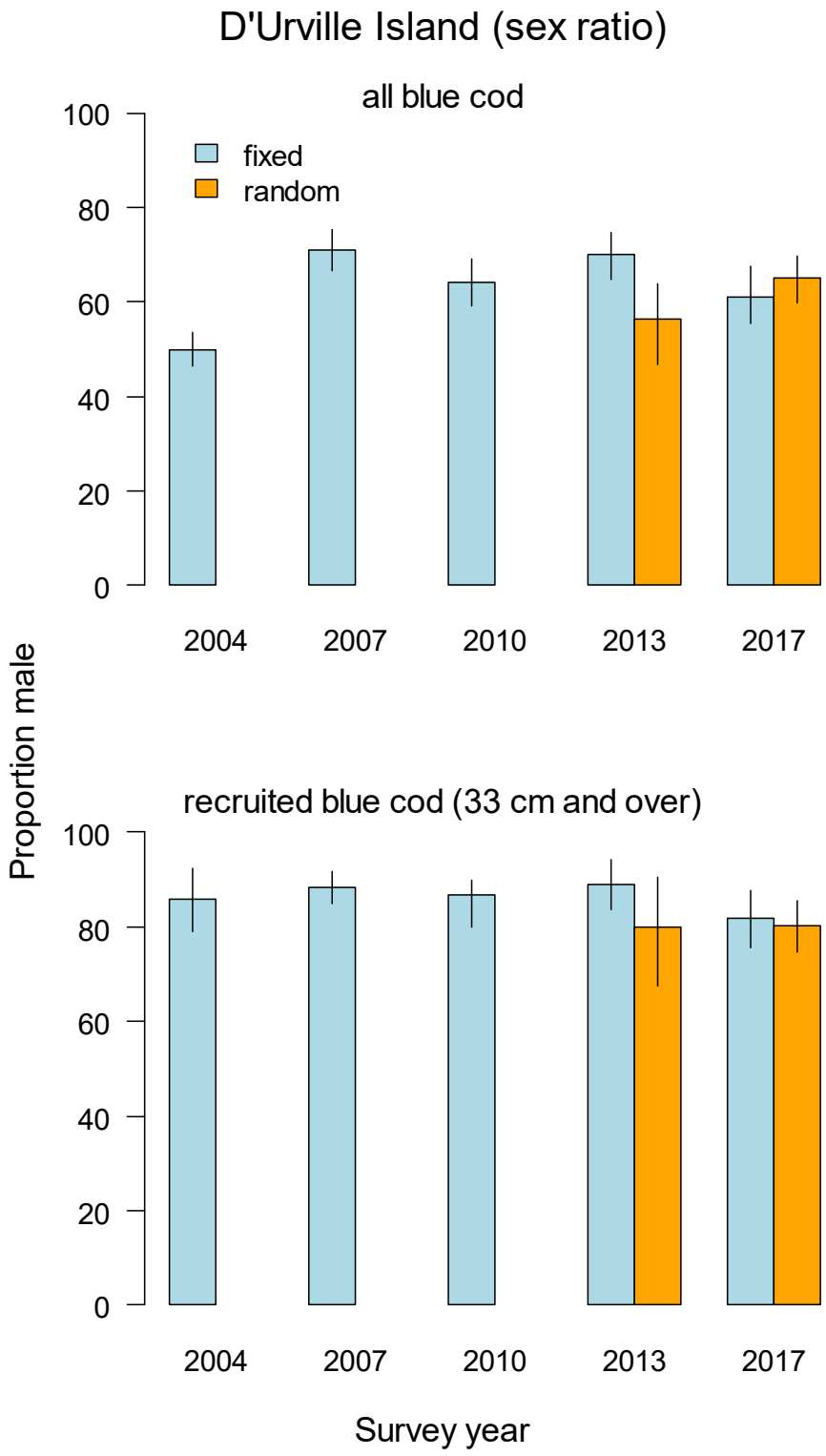


Figure 38–*continued*

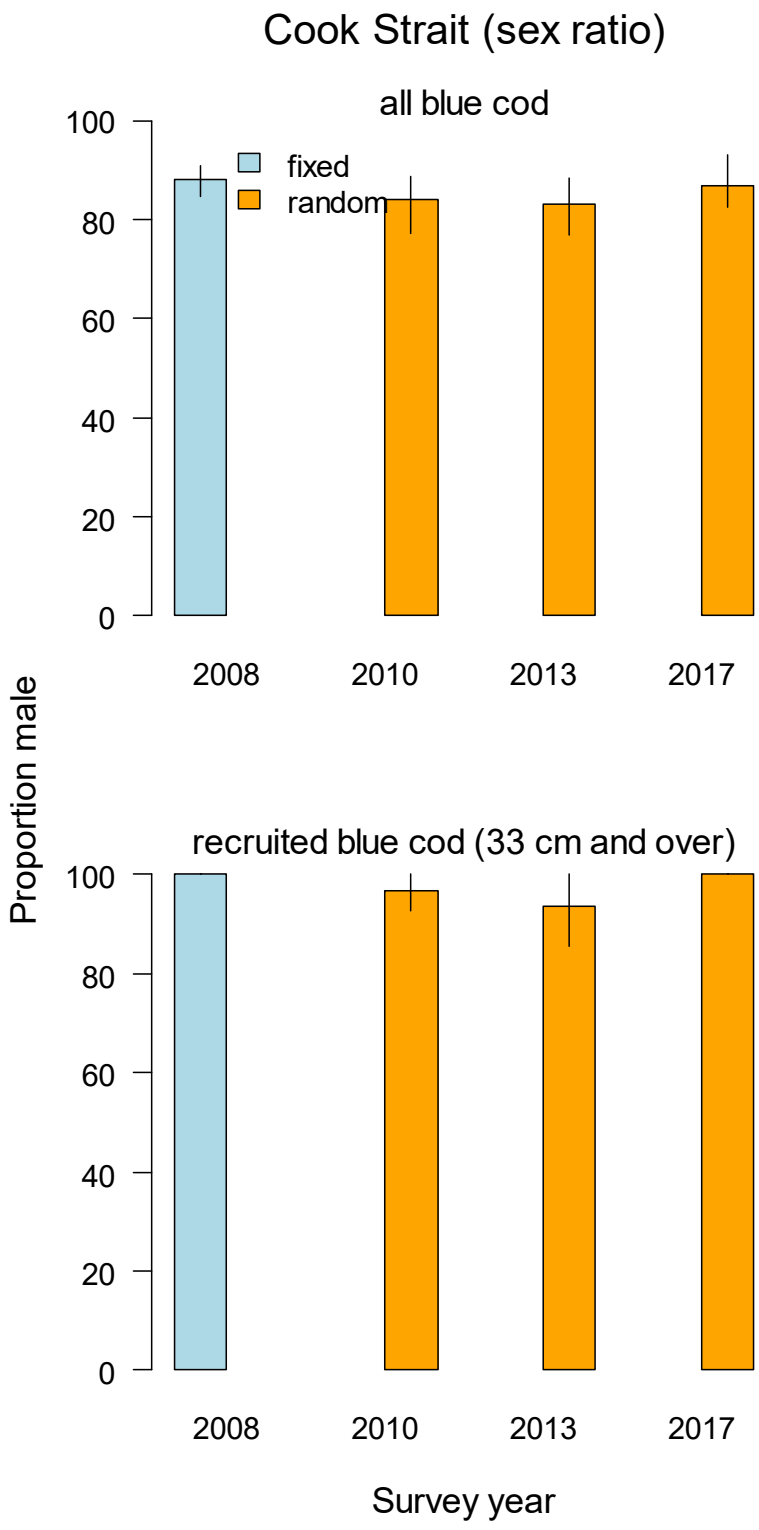


Figure 38–*continued*

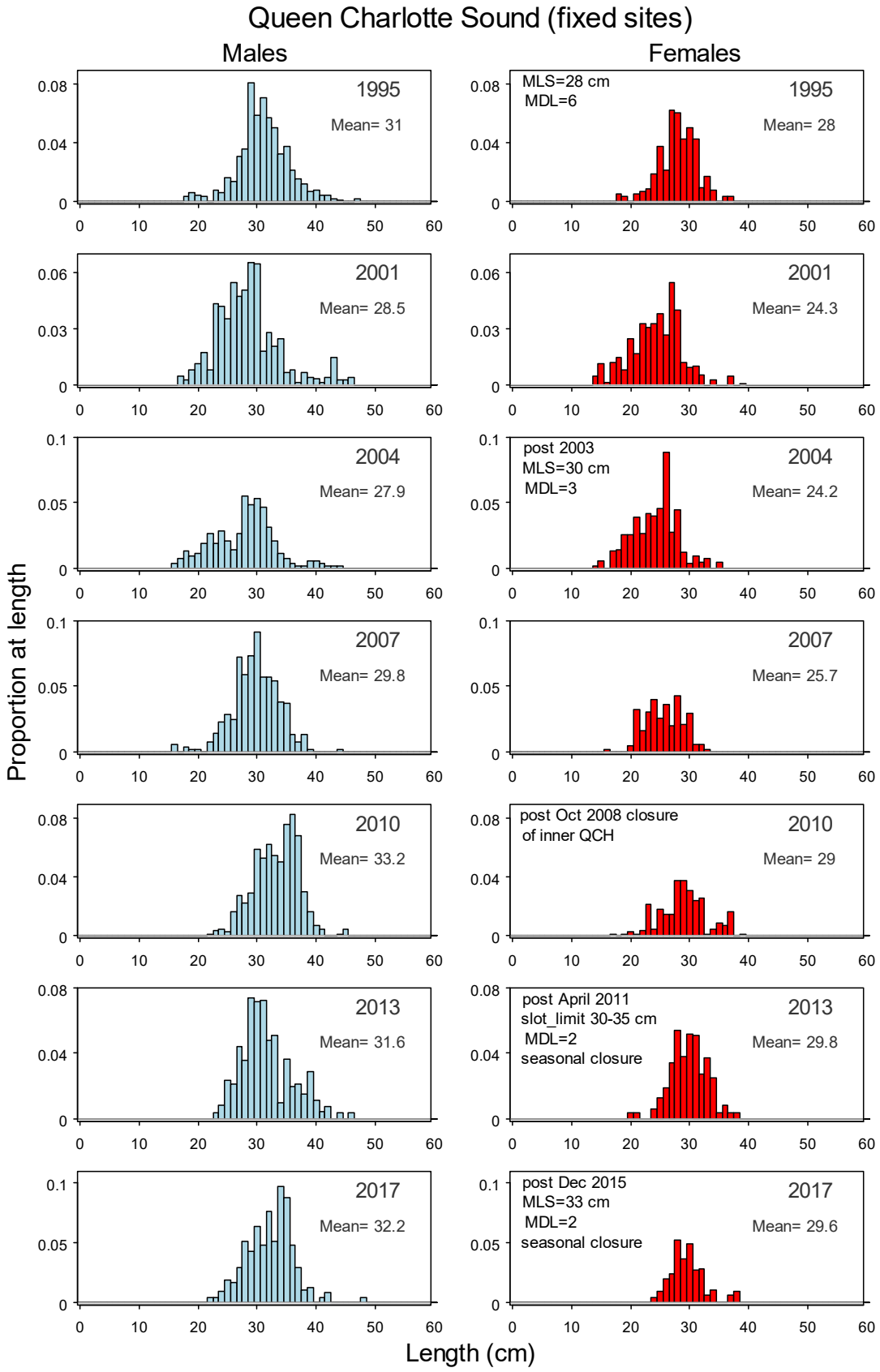


Figure 39: Scaled length distributions for male and female blue cod from Queen Charlotte Sound for fixed-site potting surveys. Changes in fisheries regulations are annotated on the female panels. MLS, minimum legal size; MDL, maximum daily limit.

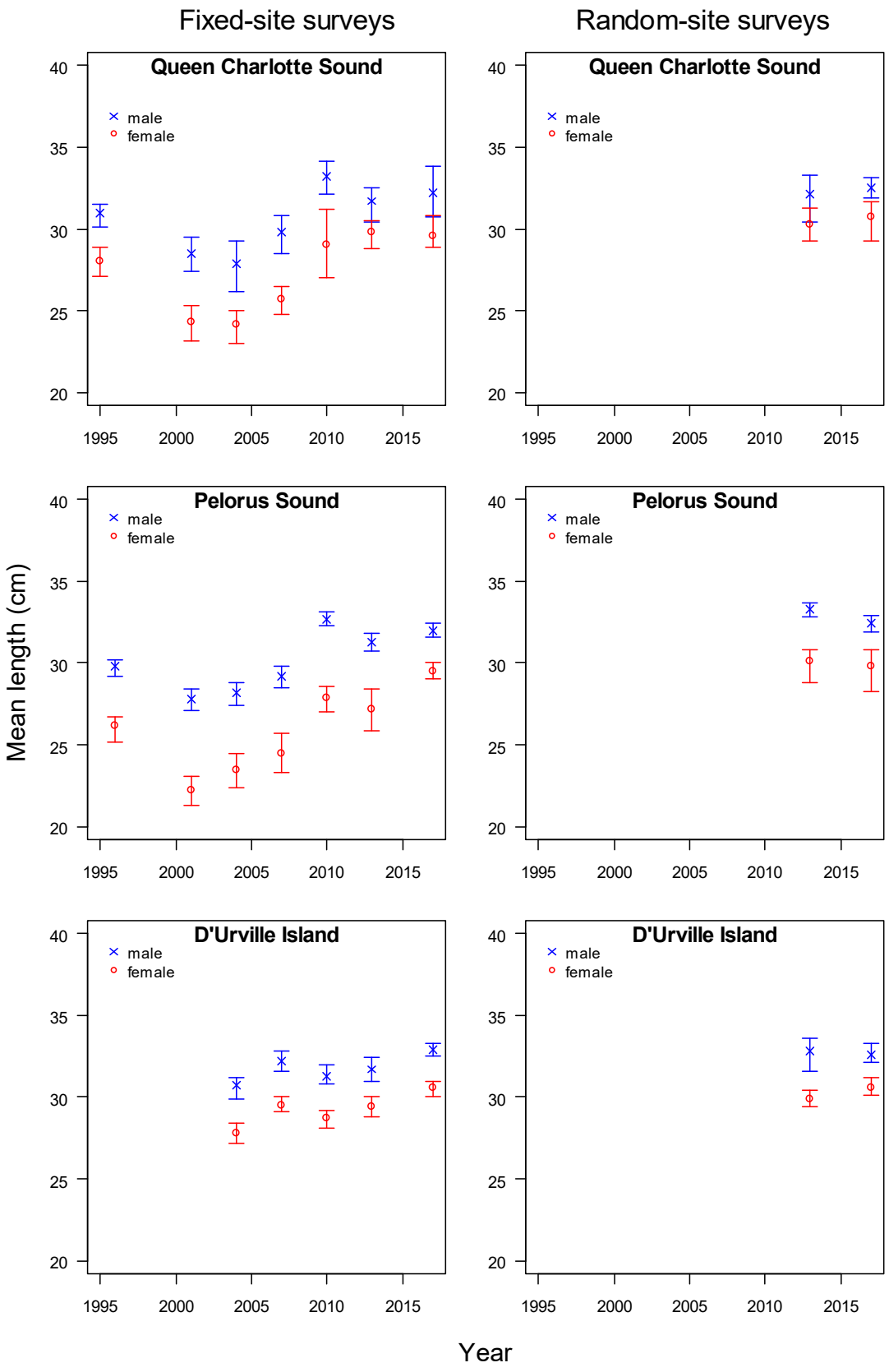


Figure 40: Scaled mean lengths for male and female blue cod by region and overall for Marlborough Sounds for fixed-site surveys and random-site surveys. Error bars are 95% confidence intervals.
[Continued on next page]

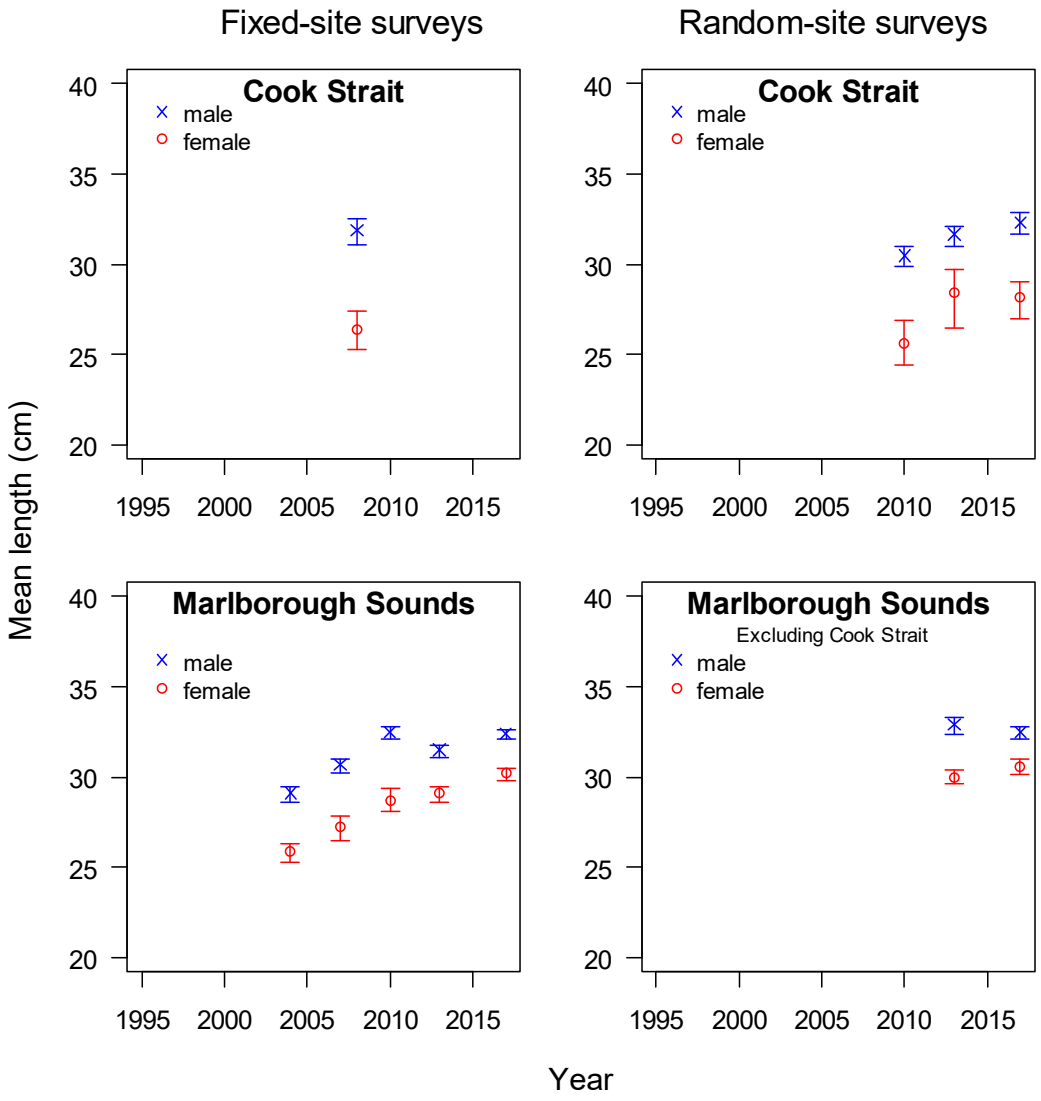


Figure 40 – *continued*

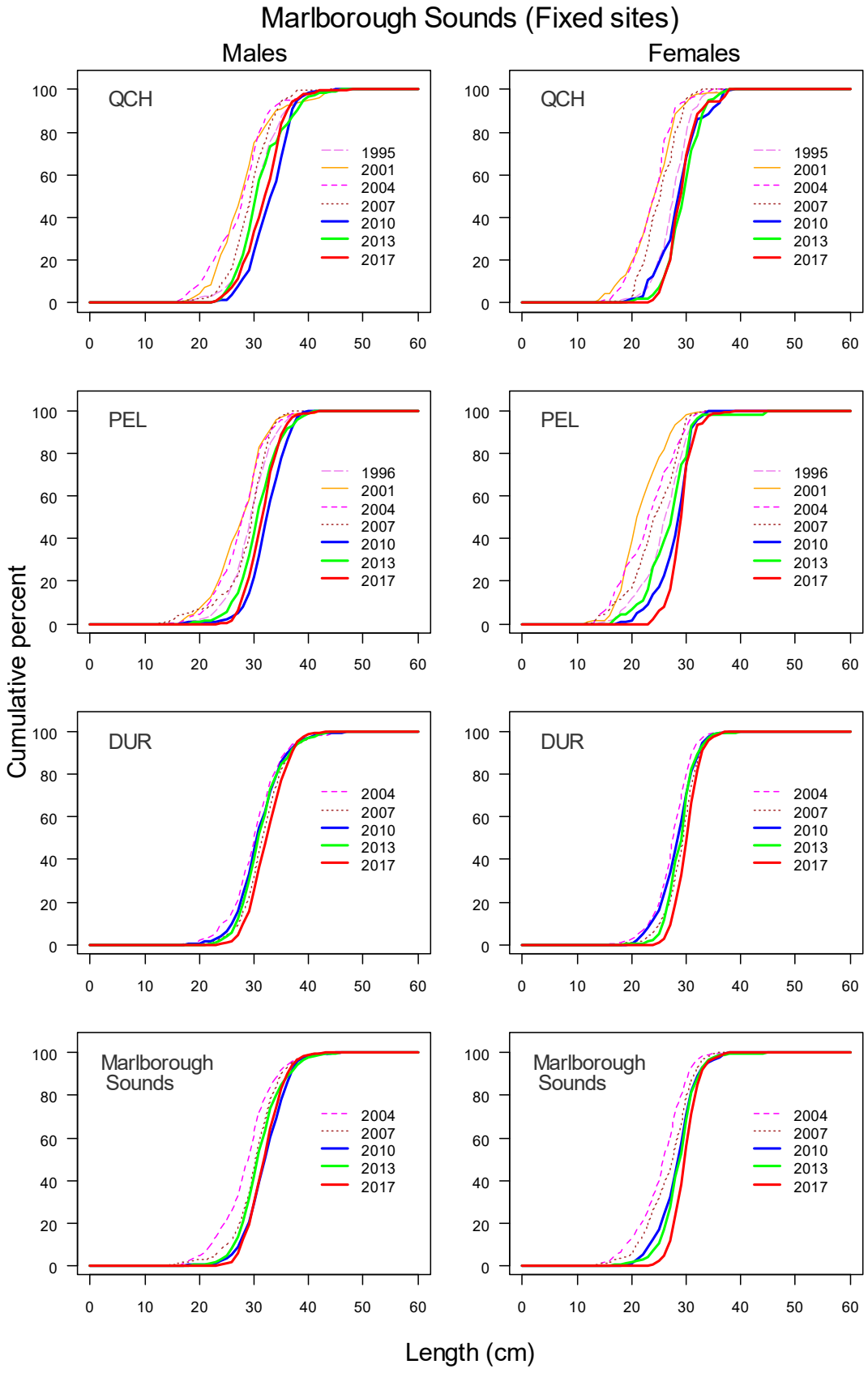


Figure 41: Cumulative distributions of scaled length frequencies for male, and female blue cod from fixed-site potting surveys by region.

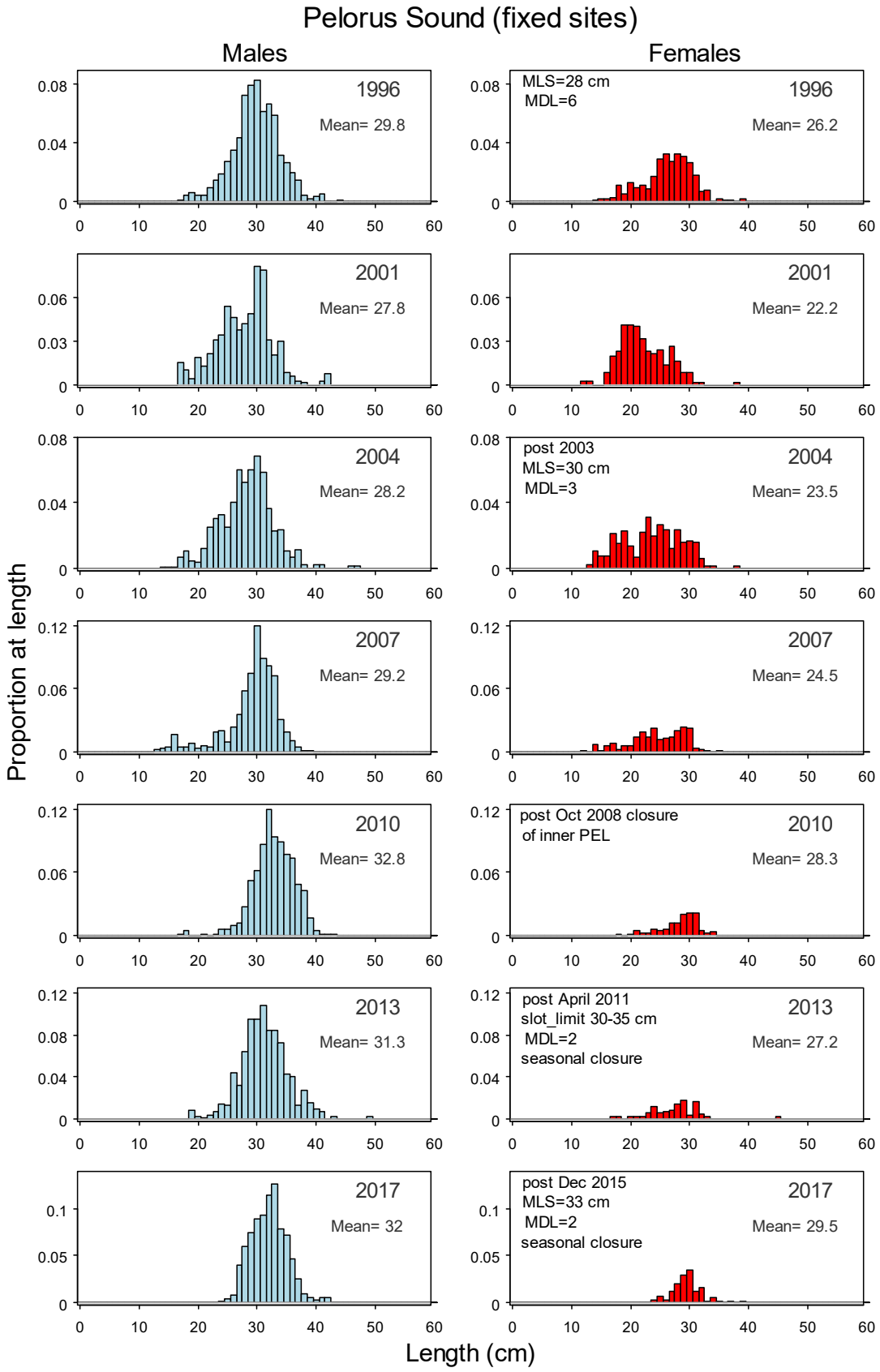


Figure 42: Scaled length distributions for male and female blue cod from Pelorus Sound for fixed-site potting surveys. Changes in fisheries regulations are annotated on the female panels. MLS, minimum legal size; MDL, maximum daily limit.

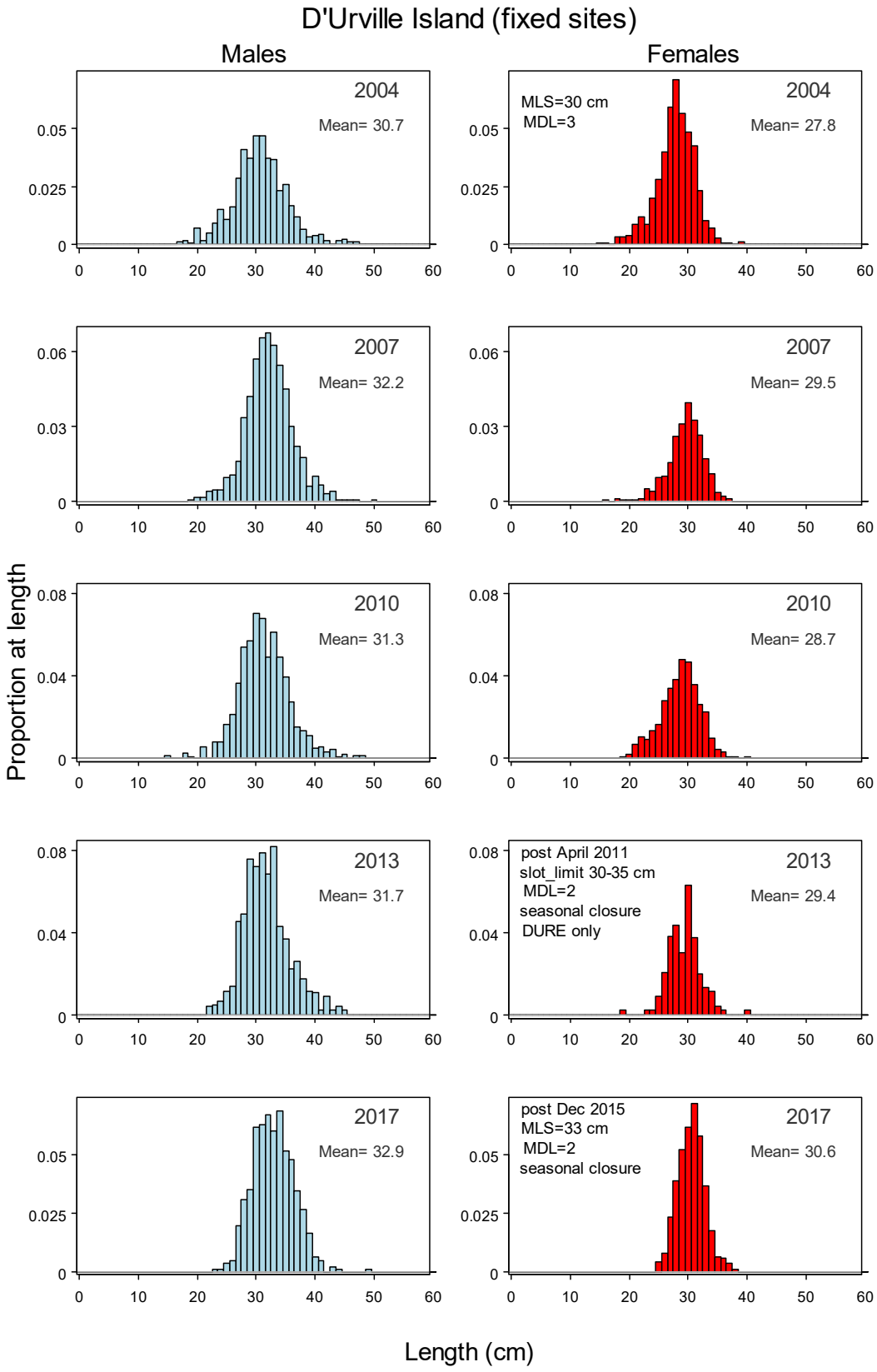


Figure 43: Scaled length distributions for male and female blue cod from D'Urville Island for fixed-site potting surveys. Changes in fisheries regulations are annotated on the female panels. MLS, minimum legal size; MDL, maximum daily limit.

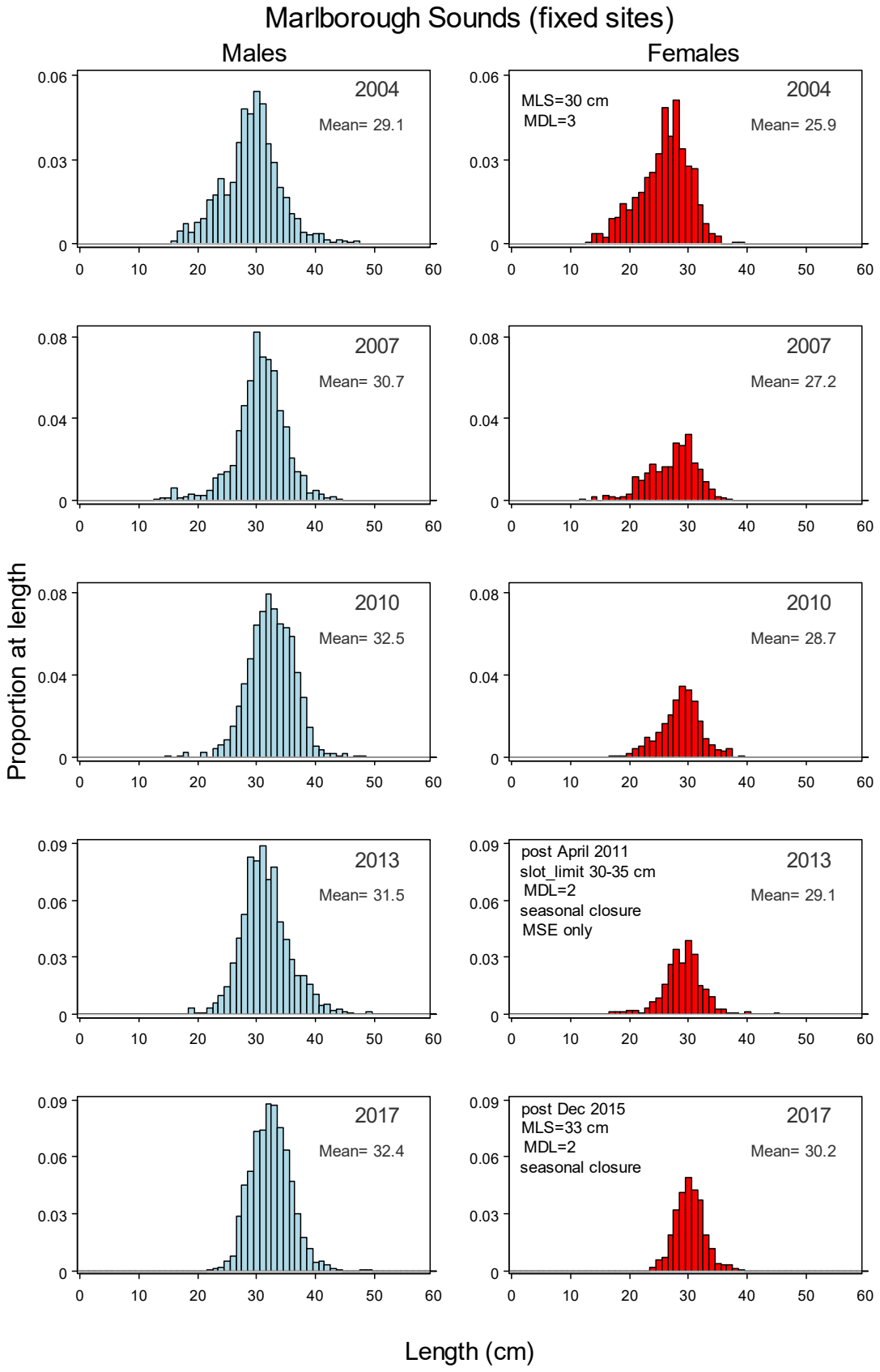


Figure 44: Scaled length distributions for male and female blue cod from Marlborough Sounds (QCH, PEL and DUR combined) for fixed-site potting surveys. Changes in fisheries regulations are annotated on the female panels. MLS, minimum legal size; MDL, maximum daily limit.

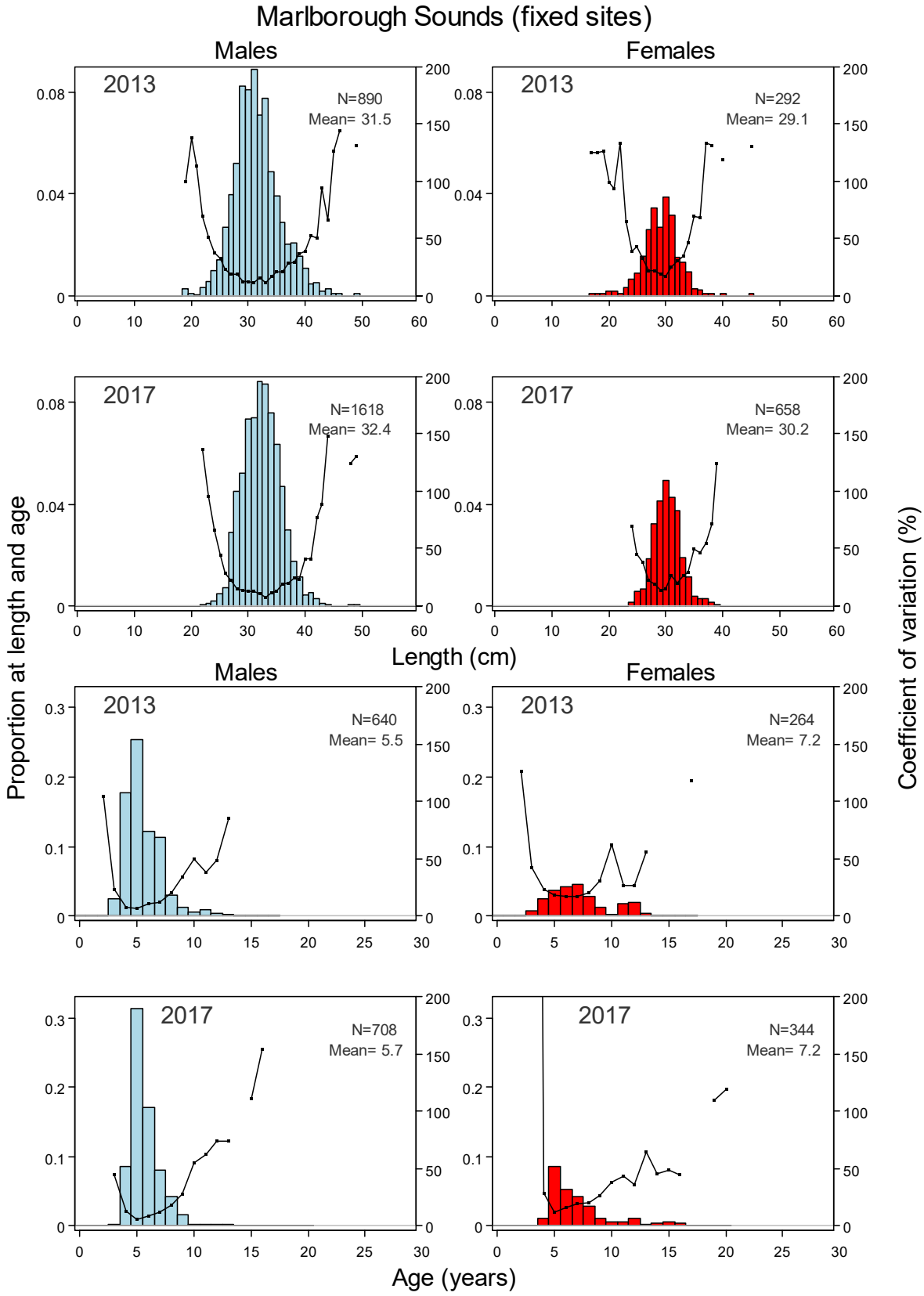


Figure 45: Scaled length-frequency and age-frequency distributions for male and female blue cod for the 2013 and 2017 Marlborough Sounds fixed-site potting surveys (QCH, PEL and DUR combined). N, sample size.

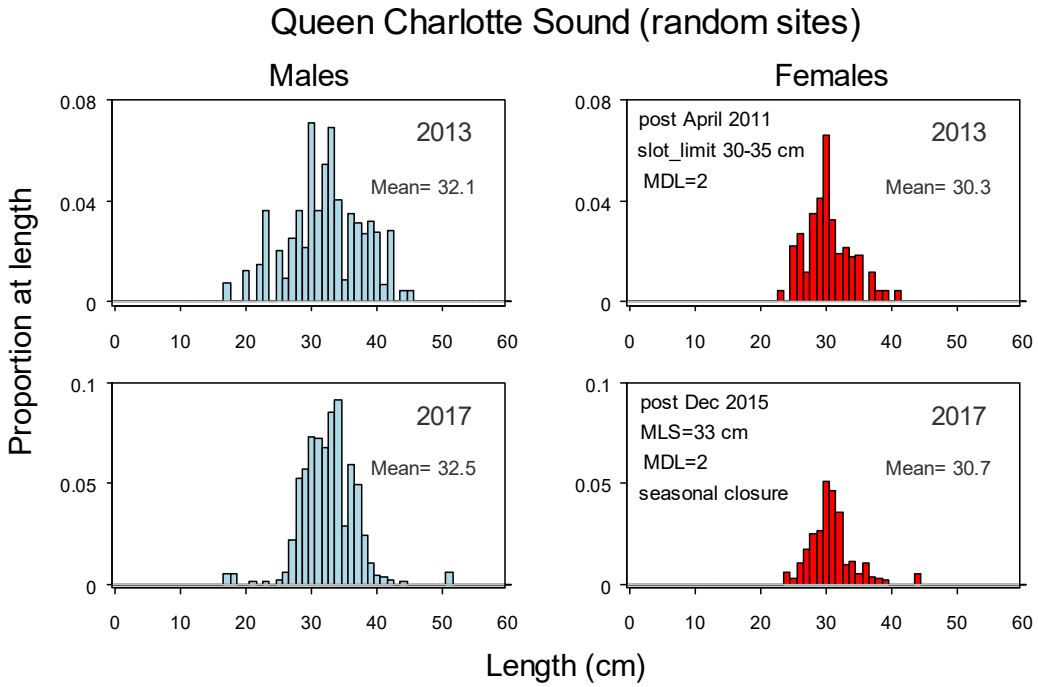


Figure 46: Scaled length distributions for male and female blue cod from Queen Charlotte Sound for random-site potting surveys. Changes in fisheries regulations are annotated on the female panels. MLS, minimum legal size; MDL, maximum daily limit.

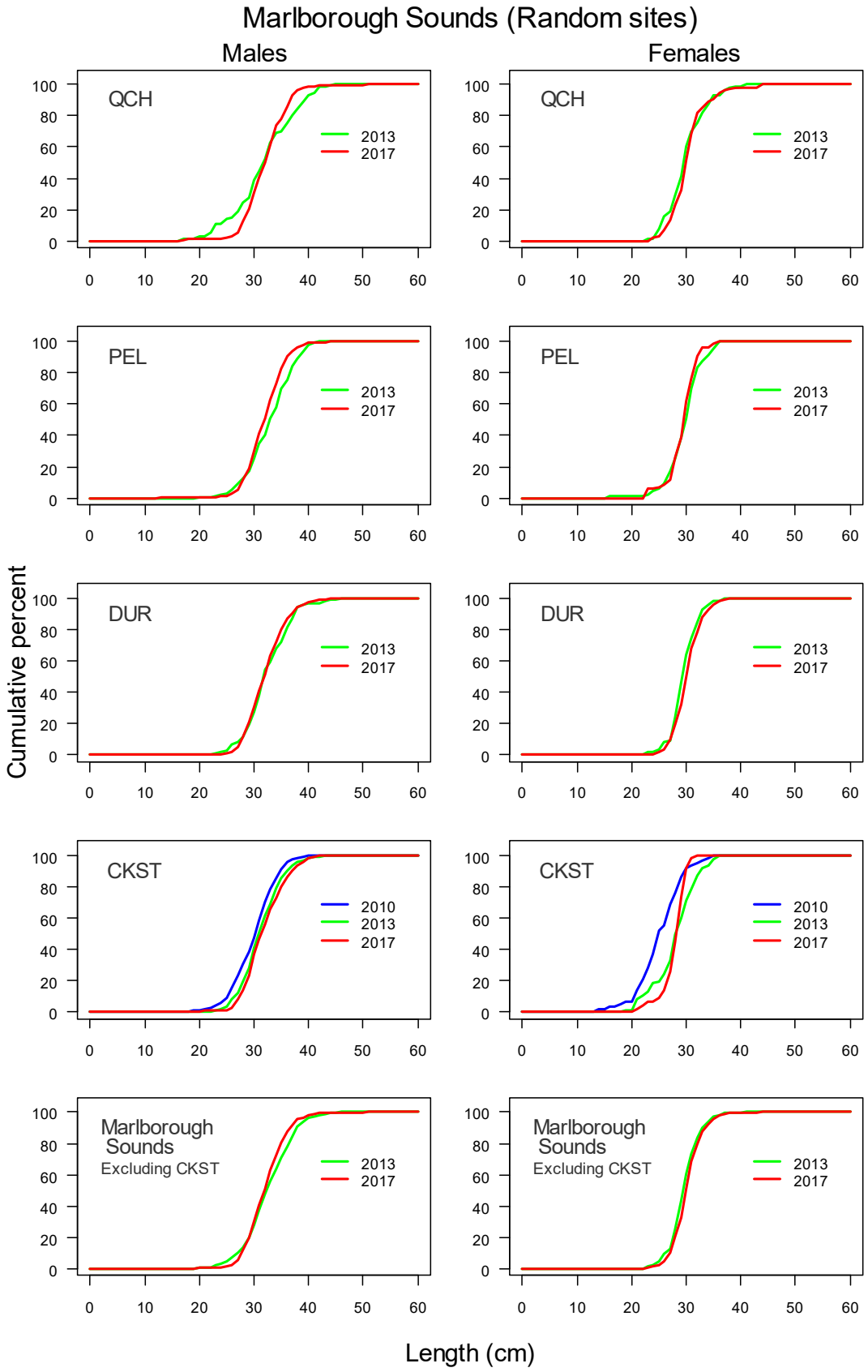


Figure 47: Cumulative distributions of scaled length frequencies for male, and female blue cod from random-site potting surveys by region and all Marlborough Sounds (QCH, PEL and DUR combined).

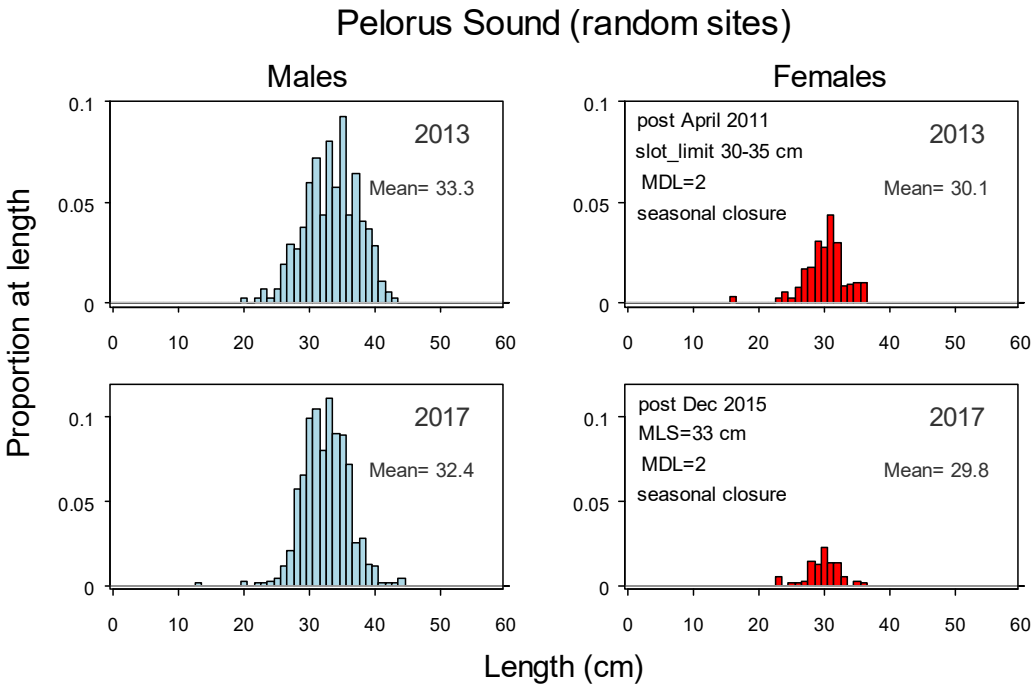


Figure 48: Scaled length distributions for male and female blue cod from Pelorus Sound for random-site potting surveys. Changes in fisheries regulations are annotated on the female panels. MLS, minimum legal size; MDL, maximum daily limit.

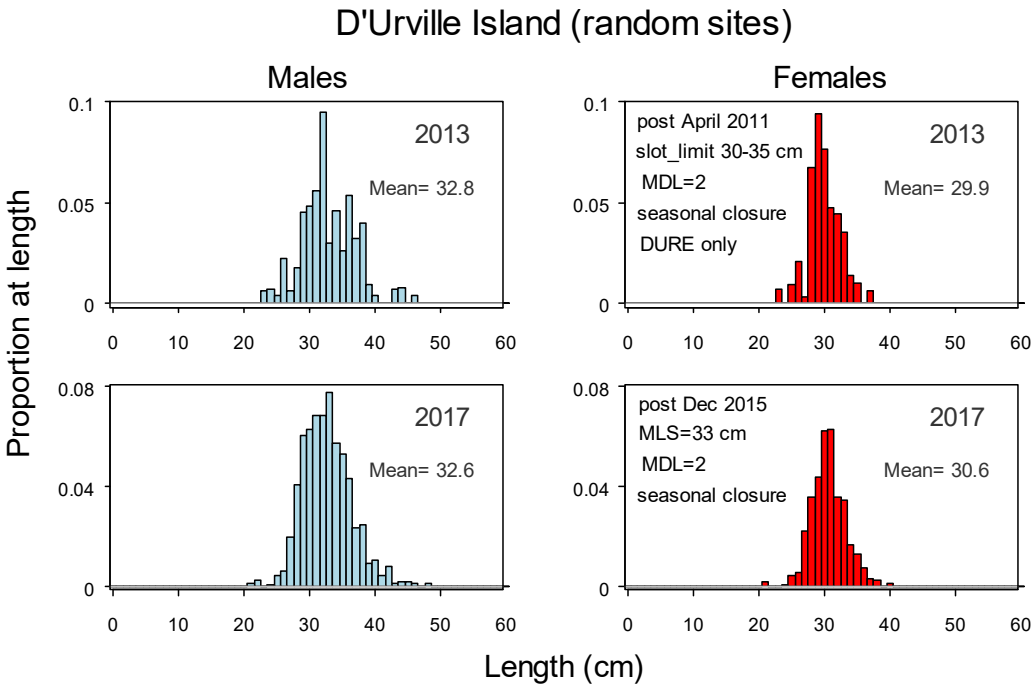


Figure 49: Scaled length distributions for male and female blue cod from D'Urville Island for random-site potting surveys. Changes in fisheries regulations are annotated on the female panels. MLS, minimum legal size; MDL, maximum daily limit.

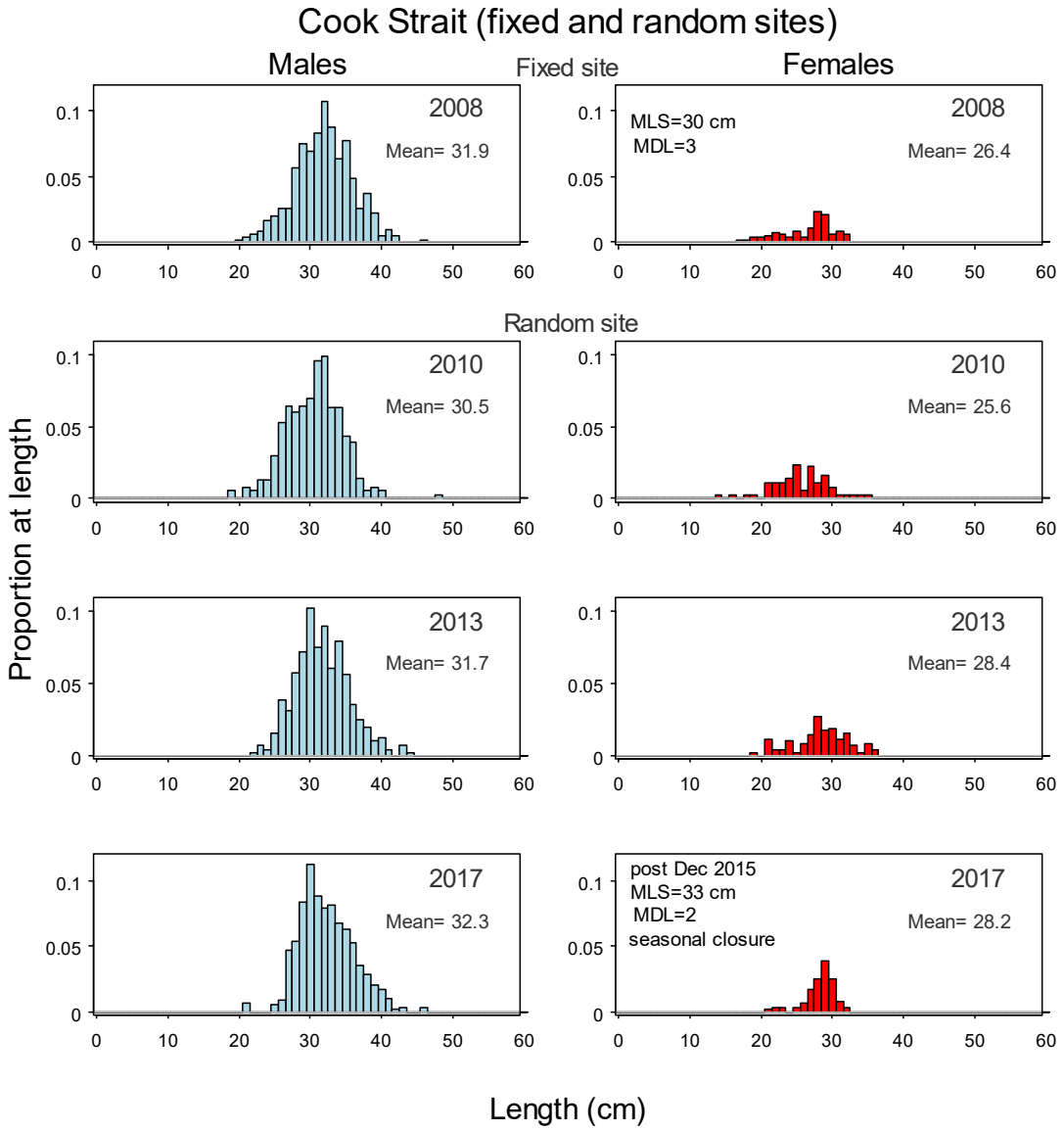


Figure 50: Scaled length distributions for male and female blue cod from Cook Strait for the 2008 fixed-site and 2010–2017 random-site potting surveys. Changes in fisheries regulations are annotated on the female panels. MLS, minimum legal size; MDL, maximum daily limit.

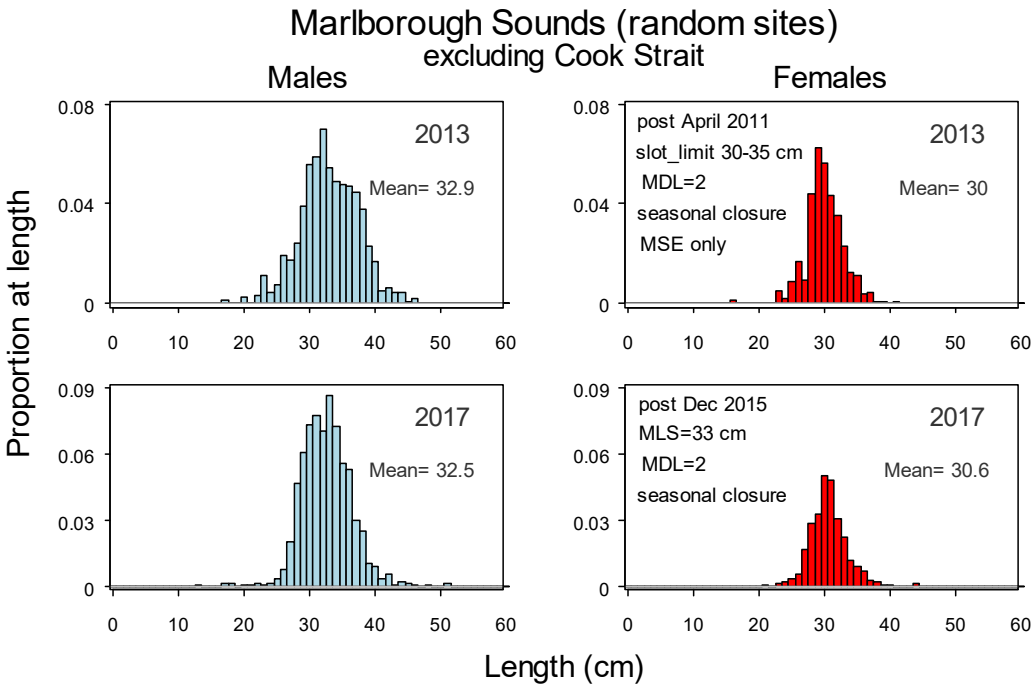


Figure 51: Scaled length distributions for male and female blue cod from Marlborough Sounds (QCH, PEL and DUR combined) from random-site potting surveys. Changes in fisheries regulations are annotated on the female panels. MLS, minimum legal size; MDL, maximum daily limit.

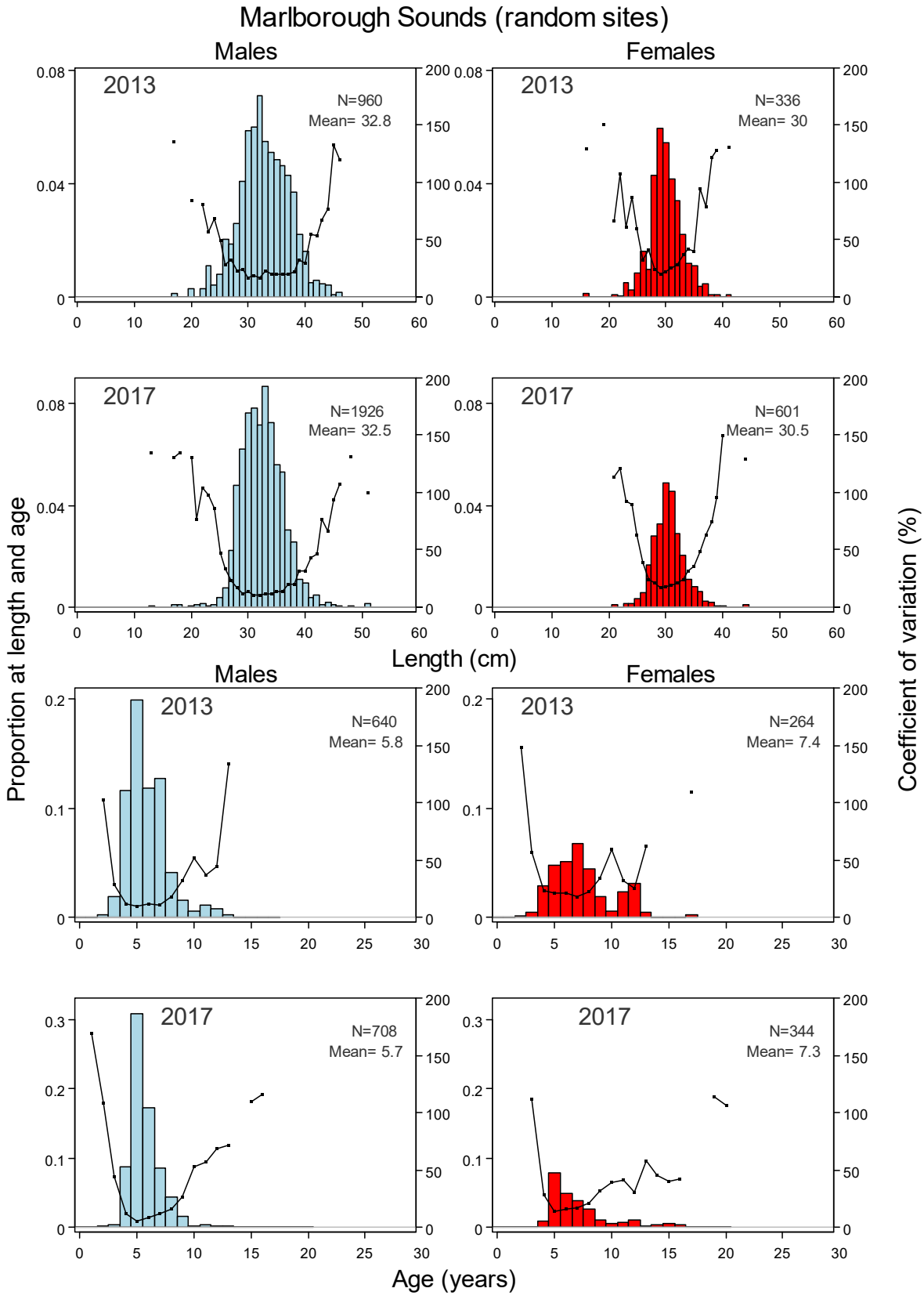


Figure 52: Scaled length-frequency and age-frequency distributions for male and female blue cod for the 2013 and 2017 Marlborough Sounds random-site potting surveys (QCH, PEL, DUR and CKST combined). N, sample size.

8. APPENDICES

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

Fixed site	A site that has a fixed location (single latitude and longitude or the centre point location of a section of coastline) in a stratum and is available to be used repeatedly on subsequent surveys in that area. The fixed sites used in a survey were randomly selected from the list of all available fixed sites in each stratum. Fixed sites are sometimes referred to as index sites or fisher-defined sites and were defined at the start of the survey time series (using information from recreational and commercial fishers)
Pot number	Pots are numbered sequentially (1–6 or 1–9) in the order they were placed during a set. In the Marlborough Sounds nine pots were used.
Pot placement	There are two types of pot placement: **Directed**–the position of each pot was directed by the skipper using local knowledge and the vessel echosounder to locate a suitable area of reef/cobble or biogenic habitat. **Systematic–**the position of each pot was arranged systematically around the site or along the site for a section of coastline. For the former site, the position of the first pot was 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.

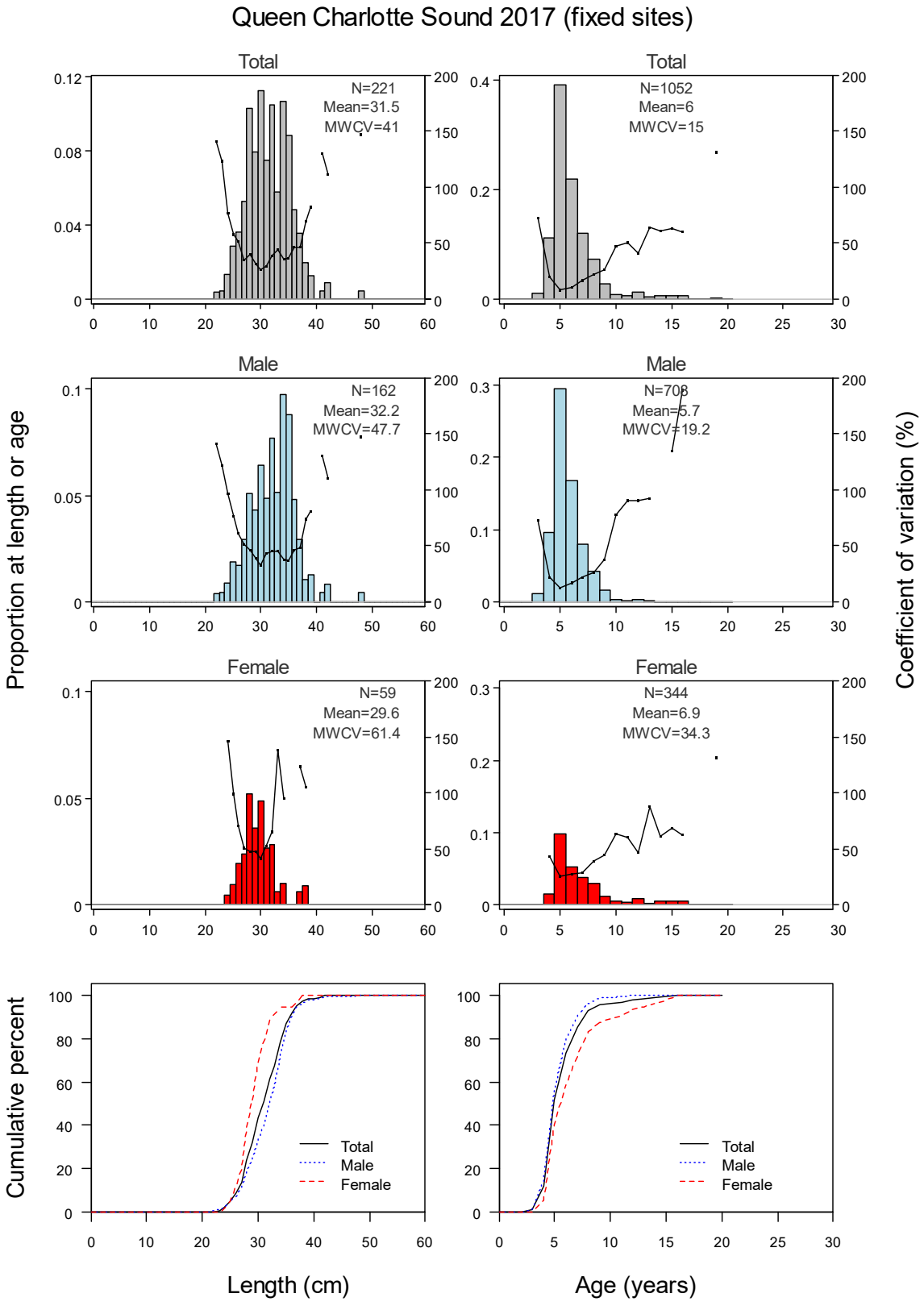
Appendix 2. Numbers of otoliths collected during the 2017 Marlborough Sounds survey for males and females, by strata and length class.

Length (cm)	Stratum												Male total
	1	2	3	4	5	6	7	8	9	11	12	13	
14													
15													
16													
17		1											1
18		1											1
19													
20										2			2
21			1					3					4
22			1	1				1					3
23			2			1							3
24		3	1	3		1		3	1				12
25			6	6				5	1				18
26		2	5	3	3	3	1	9	6	1			33
27		3	6	4	2	8	1	1	2	4			31
28		4	8	6	2	4	1	2	8	2			37
29		2	9	5	5	6		1	10	6	1		45
30		6	12	5	2	5		3	10	4			47
31		4	14	6	1	5	2	2	12	4			50
32		6	9	9	4	7	1	2	12	3			53
33		3	13	5	1	7	1	6	11	5			52
34	1	5	8	6	5	6		4	6	5		1	46
35	1	3	9	7	4	10		5	8	5	1	1	53
36		5	12	6	2	7		5	11	4			52
37		3	9	3	2	2		10	4	5	1		39
38	1	2	7	5	3	4		4	1	1		1	28
39			7	5	1	5		5	3	2			28
40			4	2		3	1	8	5	2			25
41			5	1	4	1		4	2				17
42			2	2	1	1		5	2				13
43				1				2					3
44			1		1	1		2					5
45								2					2
46									1				1
47			1										1
48								2					2
49													
50													
51		1											1
Totals	3	54	152	91	43	87	8	96	116	55	3	3	708

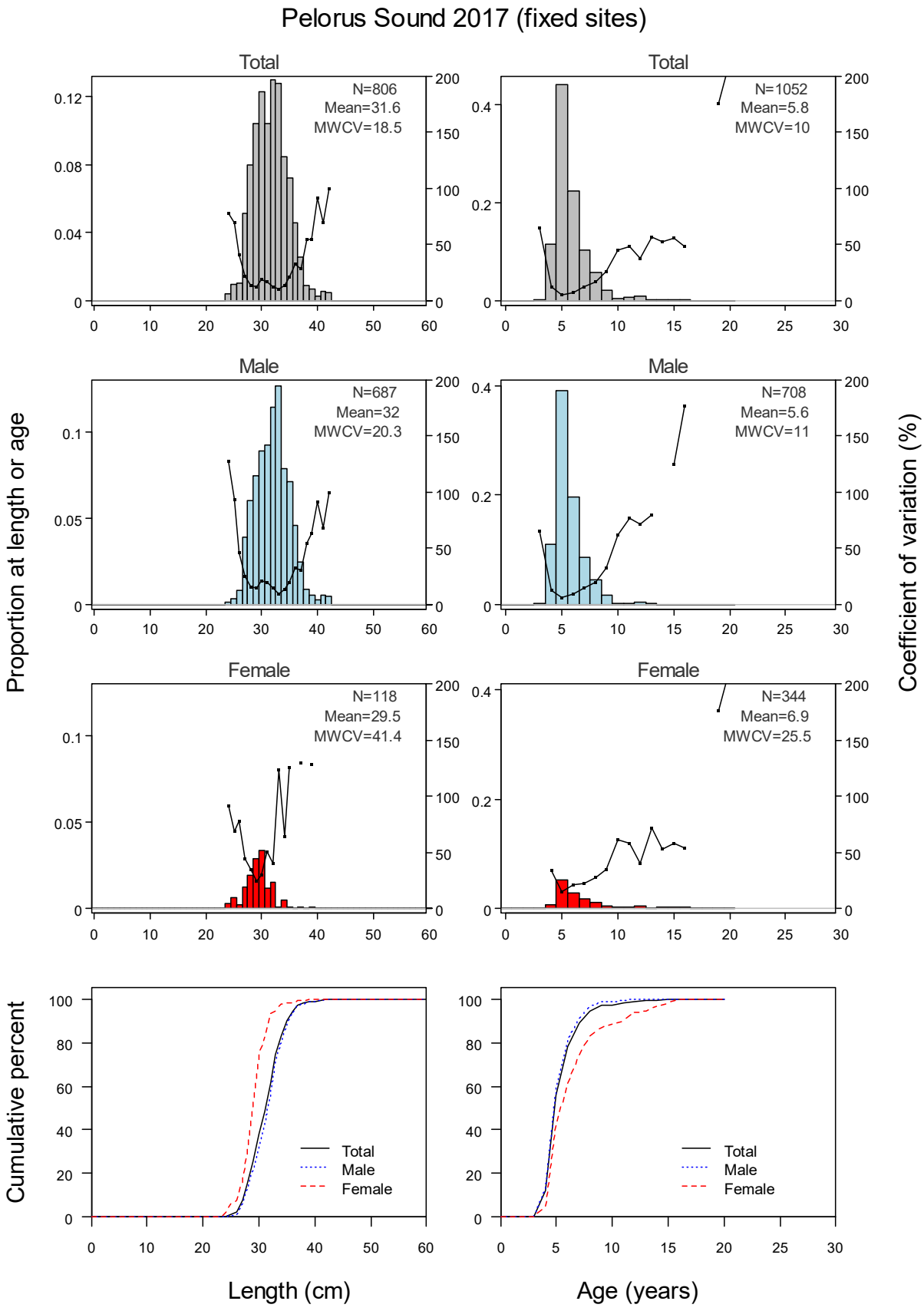
Appendix 2 – *continued*

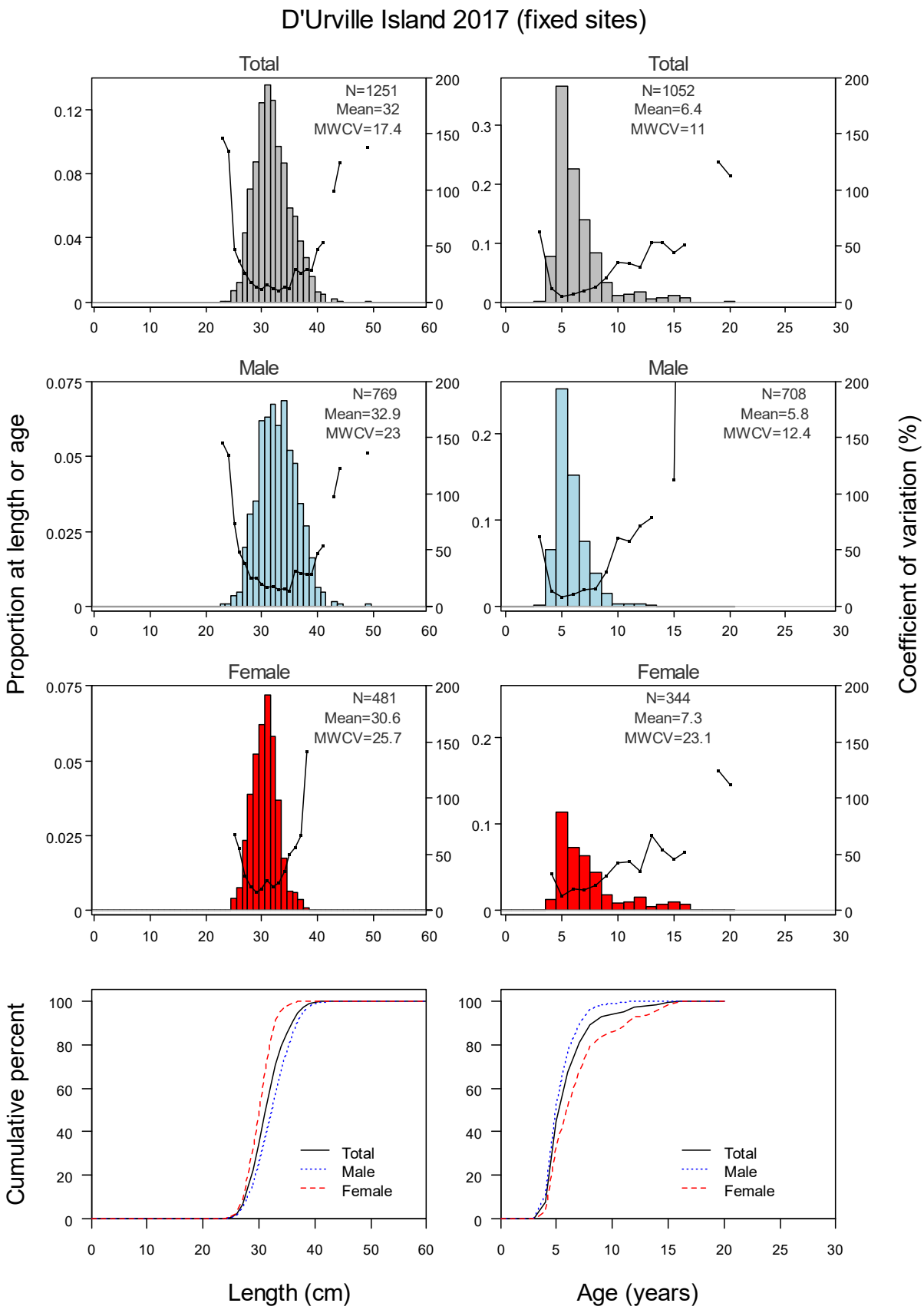
Length (cm)	Stratum 1	2	3	4	5	6	7	8	9	11	12	13	Female total
14													
15													
16													
17													
18													
19													
20						1							1
21										1	1		2
22					2						1		3
23			1										1
24		2	1	1	2				1				7
25	1	2	3	4		2			4	1		1	17
26		3	5	5		7			7	1	1		29
27	3	2	6	4	1	4		1	2	2	2	3	27
28	2	2	8	6	1	7		2	5	2	3	2	38
29	3	3	8	6	3	9	1		5	2	2	3	42
30	1	6	9	6	2	8			3	2	1	1	38
31	1	11	6	7		9			2			1	36
32	1	5	2	2	3	7			5	1		1	26
33		1	8			7			1				17
34		2	5	1	1	2	1		9				21
35	1	1		1		2			5			1	10
36		1	2	1		1			5				10
37	1	2	2			1			6			1	12
38	1		1						1			1	3
39	1		1	1								1	3
40													
41													
42													
43		1											1
44													
45													
46													
47													
48													
49													
50													
51													
Totals	16	44	68	45	15	67	2	3	61	12	11	16	344

Appendix 3: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for Queen Charlotte Sound, Pelorus Sound, and D'Urville Island for the 2017 Marlborough Sounds fixed-site potting survey. N, sample size; MWCV, mean weighted coefficient of variation. [Continued on next page]



Appendix 3 – *continued*




D'Urville Island 2017 (fixed sites)
Total
N=1251
Mean=32
MWCV=17.4
Total
N=1052
Mean=6.4
MWCV=11
Male
N=769
Mean=32.9
MWCV=23
Male
N=708
Mean=5.8
MWCV=12.4
Female
N=481
Mean=30.6
MWCV=25.7
Female
N=344
Mean=7.3
MWCV=23.1
Proportion at length or age
Coefficient of variation (%)
Cumulative percent
Total
Male
Female
Length (cm)
Age (years)

Appendix 4: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod for fixed-site and random-site potting surveys from each region surveyed in 2017. AgeR, age (years) at full recruitment. [Continued on next page]

			Fixed-site survey		
Region	Site type	ageR	*Z*	lowerCI	upperCI
QCH	Fixed	5	0.57	0.39	0.78
		6	0.55	0.39	0.73
		7	0.51	0.36	0.69
		8	0.46	0.31	0.63
		9	0.35	0.24	0.49
		10	0.3	0.19	0.42
PEL	Fixed	5	0.67	0.48	0.9
		6	0.64	0.45	0.86
		7	0.59	0.4	0.8
		8	0.53	0.37	0.72
		9	0.41	0.27	0.55
		10	0.35	0.23	0.48
DUR	Fixed	5	0.49	0.35	0.65
		6	0.48	0.34	0.65
		7	0.45	0.33	0.6
		8	0.4	0.28	0.54
		9	0.33	0.23	0.44
		10	0.32	0.22	0.42
All regions combined	Fixed	5	0.56	0.39	0.76
		6	0.53	0.38	0.72
		7	0.49	0.35	0.65
		8	0.44	0.31	0.58
		9	0.35	0.25	0.46
		10	0.32	0.23	0.44

			Random-site survey		
Region	Site type	ageR	*Z*	lowerCI	upperCI
QCH	Random	5	0.52	0.36	0.69
		6	0.49	0.35	0.67
		7	0.44	0.32	0.6
		8	0.37	0.26	0.5
		9	0.29	0.2	0.4
PEL	Random	5	0.65	0.45	0.87
		6	0.65	0.45	0.89
		7	0.62	0.43	0.83
		8	0.56	0.38	0.77
		9	0.44	0.3	0.61
		10	0.37	0.24	0.52

Appendix 4–*continued*

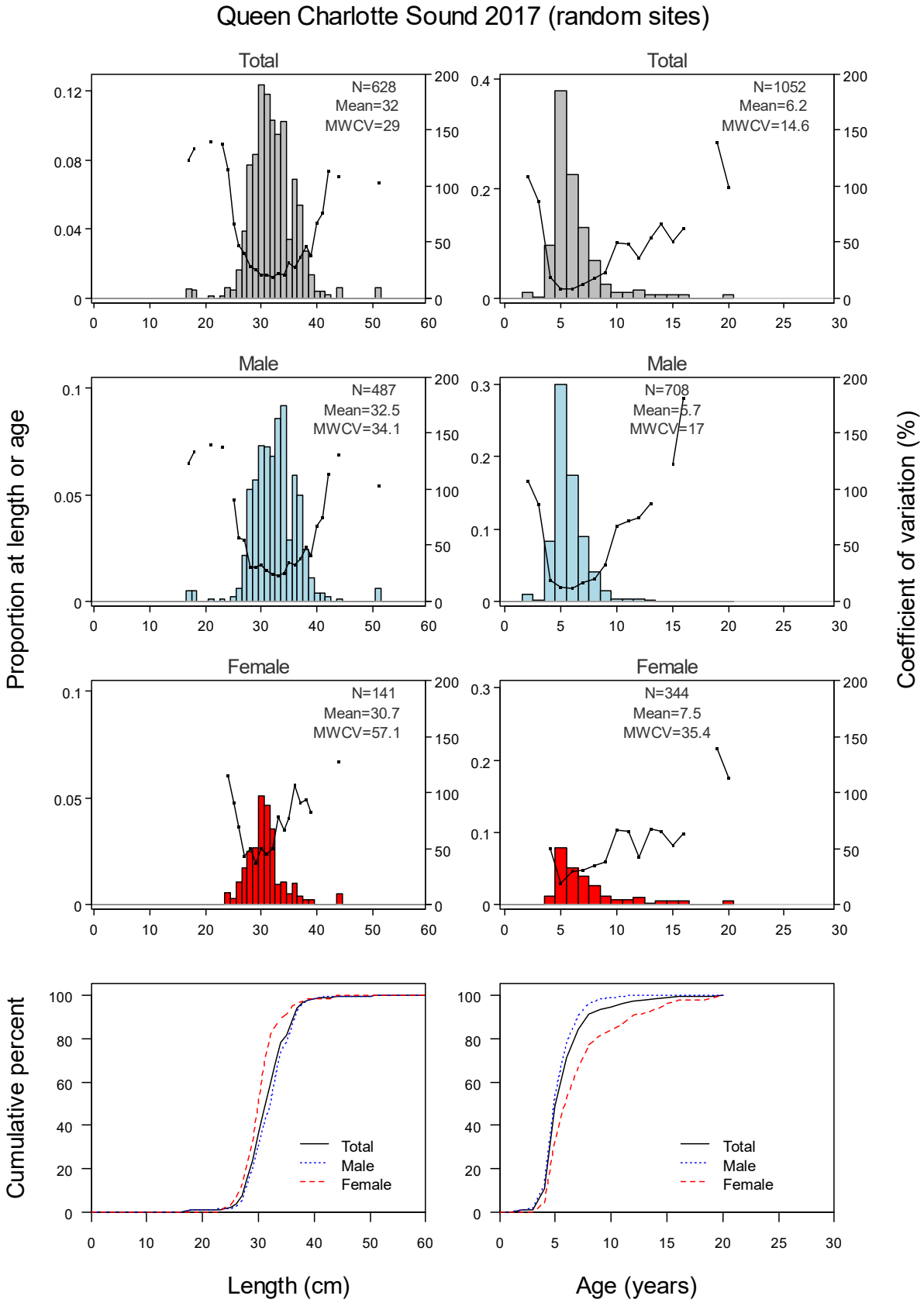
			Random-site survey		
Region	Site type	ageR	*Z*	lowerCI	upperCI
DUR	Random	5	0.5	0.35	0.67
		6	0.47	0.34	0.64
		7	0.44	0.32	0.59
		8	0.4	0.29	0.53
		9	0.33	0.24	0.45
		10	0.32	0.23	0.42
CKST	Random	5	0.66	0.46	0.9
		6	0.66	0.45	0.88
		7	0.65	0.45	0.87
		8	0.59	0.4	0.83
		9	0.48	0.32	0.67
		10	0.37	0.24	0.52
All regions combined	Random	5	0.54	0.37	0.72
		6	0.52	0.37	0.69
		7	0.48	0.35	0.64
		8	0.43	0.3	0.58
		9	0.35	0.25	0.47
		10	0.33	0.23	0.43

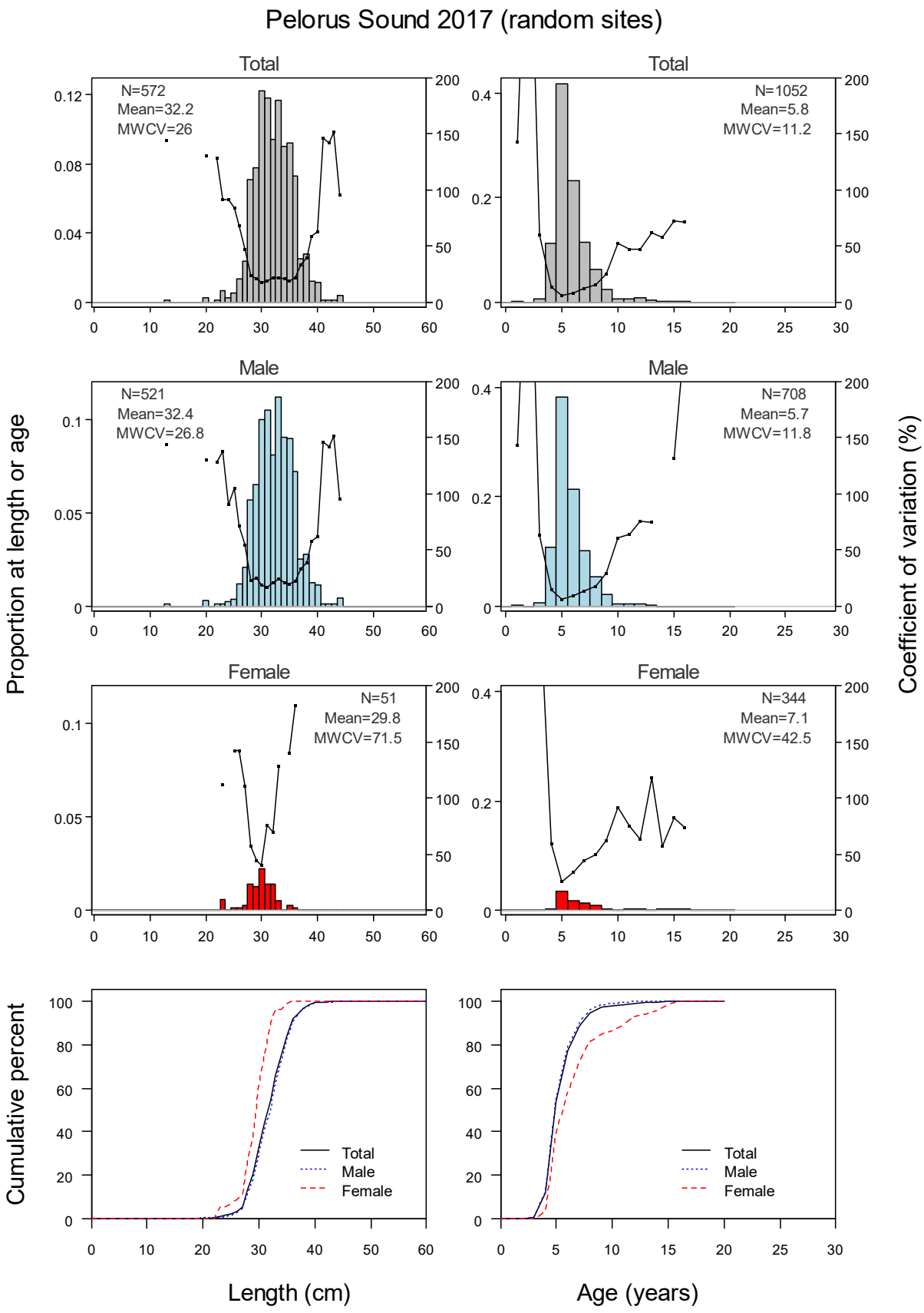
Appendix 5: Mortality parameters (*Z*, *F* and *M*) and spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* for blue cod from fixed- and random-site potting surveys from each region surveyed in the 2017 Marlborough Sounds. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality. AgeR = 6 years.

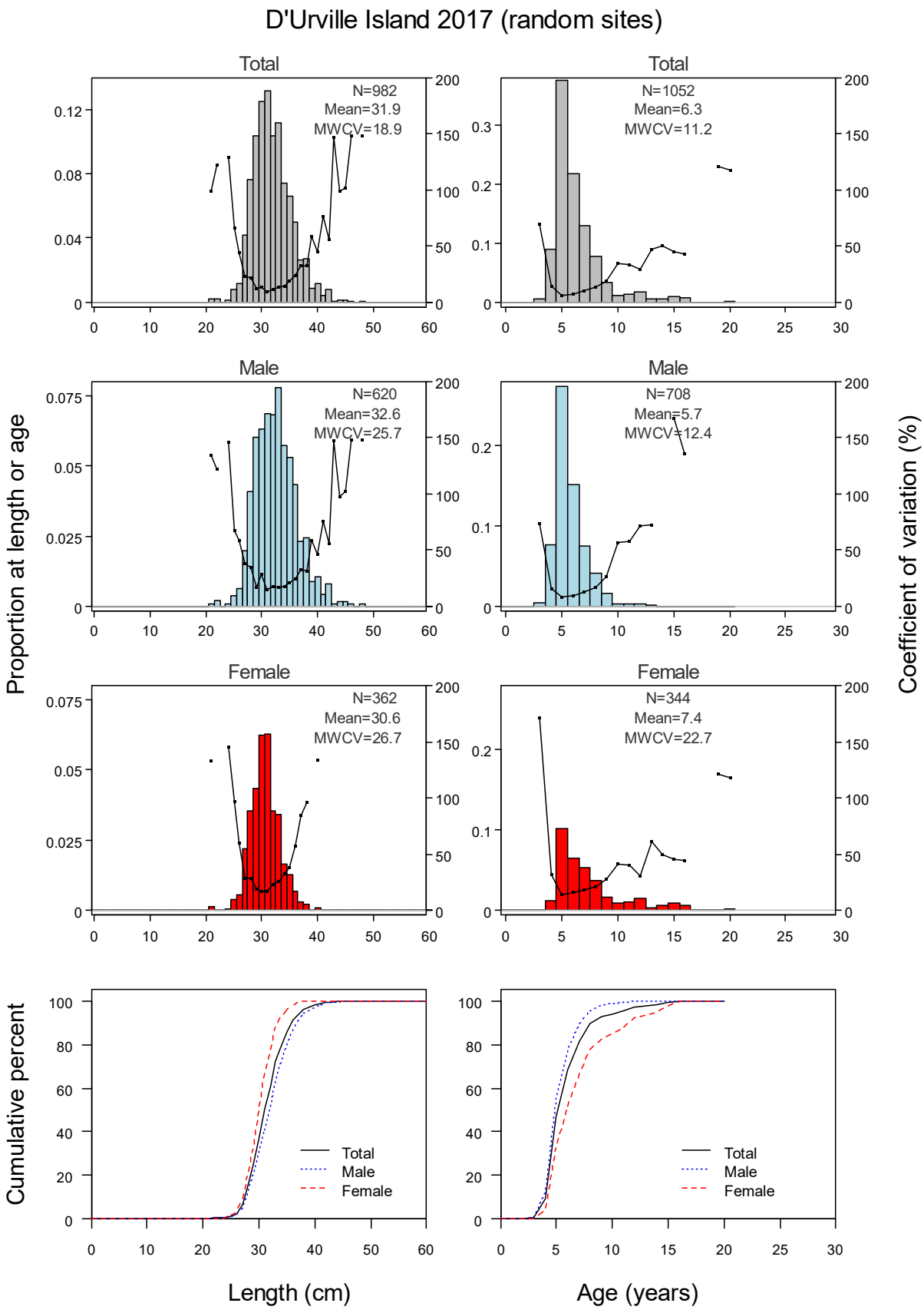
				Fixed-site survey	
Region	Site type	*M*	*Z*	*F*	$F_{\%SPR}$
QCH	Fixed	0.11	0.55	0.44	$F_{31.1\%}$
		0.14	0.55	0.41	$F_{38.3\%}$
		0.17	0.55	0.38	$F_{45.0\%}$
PEL	Fixed	0.11	0.64	0.53	$F_{28.9\%}$
		0.14	0.64	0.5	$F_{35.6\%}$
		0.17	0.64	0.47	$F_{41.8\%}$
DUR	Fixed	0.11	0.48	0.37	$F_{33.4\%}$
		0.14	0.48	0.34	$F_{41.1\%}$
		0.17	0.48	0.31	$F_{48.3\%}$
All regions combined	Fixed	0.11	0.53	0.42	$F_{31.7\%}$
		0.14	0.53	0.39	$F_{39.0\%}$
		0.17	0.53	0.36	$F_{45.8\%}$

				Random-site survey	
Region	Site type	*M*	*Z*	*F*	$F_{\%SPR}$
QCH	Random	0.11	0.49	0.38	$F_{33.0\%}$
		0.14	0.49	0.35	$F_{40.7\%}$
		0.17	0.49	0.32	$F_{47.8\%}$
PEL	Random	0.11	0.65	0.54	$F_{28.7\%}$
		0.14	0.65	0.51	$F_{35.3\%}$
		0.17	0.65	0.48	$F_{41.5\%}$
DUR	Random	0.11	0.47	0.36	$F_{33.8\%}$
		0.14	0.47	0.33	$F_{41.6\%}$
		0.17	0.47	0.3	$F_{48.9\%}$
CKST	Random	0.11	0.66	0.55	$F_{28.5\%}$
		0.14	0.66	0.52	$F_{35.1\%}$
		0.17	0.66	0.49	$F_{41.2\%}$
		M	*Z*	*F*	$F_{\%SPR}$
All regions combined	Random	0.11	0.52	0.41	$F_{32.0\%}$
		0.14	0.52	0.38	$F_{39.4\%}$
		0.17	0.52	0.35	$F_{46.3\%}$

Appendix 6: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for Queen Charlotte Sound, Pelorus Sound, D'Urville Island, and Cook Strait for the 2017 Marlborough Sounds random-site potting survey. N, sample size; MWCV, mean weighted coefficient of variation. [Continued on next page]




Pelorus Sound 2017 (random sites)
Total
N=572
Mean=32.2
MWCV=26
Total
N=1052
Mean=5.8
MWCV=11.2
Male
N=521
Mean=32.4
MWCV=26.8
Male
N=708
Mean=5.7
MWCV=11.8
Female
N=51
Mean=29.8
MWCV=71.5
Female
N=344
Mean=7.1
MWCV=42.5
Proportion at length or age
Coefficient of variation (%)
Cumulative percent
Total
Male
Female
Length (cm)
Age (years)


D'Urville Island 2017 (random sites)
Total
N=982
Mean=31.9
MWCV=18.9
Total
N=1052
Mean=6.3
MWCV=11.2
Male
N=620
Mean=32.6
MWCV=25.7
Male
N=708
Mean=5.7
MWCV=12.4
Female
N=362
Mean=30.6
MWCV=26.7
Female
N=344
Mean=7.4
MWCV=22.7
Proportion at length or age
Coefficient of variation (%)
Cumulative percent
Total
Male
Female
Length (cm)
Age (years)

Appendix 6–*continued*