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Relative abundance, size and age structure, and stock status of blue cod from the 2021 survey in Marlborough Sounds

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This report describes the 2021 Marlborough Sounds random-site potting surveys and provides information on relative abundance, population length and age structure, sex ratios, and stock status of blue cod (*Parapercis colias*). The 2021 survey was the third random-site survey in Queen Charlotte Sound (QCH), Pelorus Sound (PEL), and D'Urville Island (DUR), and the fourth for Cook Strait (CKST). The results of the 2021 survey are presented and compared with nine fixed-site (1995–2017) and previous random-site surveys in the time series and in the context of the fisheries management regulations that were in place.

Sixty-six random sites (9 pots per site, producing 594 pot lifts) were successfully surveyed in thirteen strata in QCH, PEL, DUR, and CKST between 29 September and 25 October 2021. A total of 773 kg of blue cod (1579 fish) was caught. Catch rates for all blue cod were: QCH 1.21 kg pot^{-1} (coefficient of variation CV=25%), PEL 0.66 kg pot^{-1} (CV=21%), DUR 2.23 kg pot^{-1} (CV=21%), CKST 0.71 kg pot^{-1} (CV=16%), and overall for Marlborough Sounds (MS) 1.18 kg pot^{-1} (CV=13%). Of the 594 pots, 281 (47%) had zero catch of blue cod. In all four regions (QCH, PEL, DUR, and CKST) scaled length-frequency distributions for all males and females were unimodal and generally similar, with mean size ranging from 31 to 33 cm for males and 27 to 31 cm for females. Sex ratios of all blue cod were dominated by males (QCH 74% male, PEL 82%, DUR 63%, CKST 80%, MS 72%). The von Bertalanffy growth parameters estimated from all age data collected in 2021 were: males K = 0.27 yr^{-1}, t_0 = -0.18 yr, L_∞ = 43.4 cm, N = 351; females K = 0.34 yr^{-1}, t_0 = -0.38 yr, L_∞ = 34.0 cm, N = 234. MS scaled length-frequency distributions for both males and females were unimodal with mean lengths of 31.8 and 29.7 cm. Males had a higher proportion of larger fish than females and were the largest fish. MS mean ages were 4.8 years (2–12 years) for males and 6.6 years (1–20 years) for females. The MS Chapman-Robson total mortality (Z) estimate for males only, for male age-at-full recruitment (AgeR) of six years, was 0.65 yr^{-1} (95% confidence intervals 0.43–0.90). Based on the default M of 0.17, fishing mortality (F) on males was 0.48 yr^{-1} (95% confidence intervals 0.26–0.73). Using the Fisheries New Zealand target reference point of F=0.15 (F=0.87M), the estimated F of 0.48 in 2021, is over three times higher than the target, indicating that the stock is overfished. Macroscopic examination of gonads showed clear indication of spawning activity during the survey period and, overall, nearly 20% of males and 30% of females were running ripe.

Random-site survey time series

Catch rates of all blue cod in QCH roughly doubled between 2013 and 2017 with no change in 2021. PEL catch rates show a clear decline, halving from 2013 to 2021. DUR catch rates nearly doubled in 2017 and then returned to the levels of 2013 in 2021. CKST catch rates fluctuated over the four surveys with no trend. MS catch rates (excluding CKST) showed no clear trends between 2013 and 2021.The sex ratios of all blue cod were 66–74% male (QCH), 77–90% male (PEL), 57–65% male (DUR), 80–87% male (CKST), and 66%–72% male (MS excluding CKST), all without trend from 2013 to 2021. There was little difference in the shapes of length distributions among the four regions, and also within regions over the three or four surveys. Z and F increased from 0.5 to 0.74 and 0.38 to 0.57, respectively, and spawner-per-recruit ratios ($F_{SPR\%}$), increased from 24% to 27% in 2017 and then declined to 16% in 2021.

Long Island-Kokomohua Marine Reserve

Eight random sites (9 pots per site, producing 72 pot lifts) from inside the Long Island Marine Reserve (LIMR) were surveyed from 23 to 24 October 2021. A total of 748 blue cod (575 kg) was taken and all were released alive. Catch rate for all blue cod was 7.98 kg pot^{-1} (CV of 13%). Blue cod catch rates in

[1] All authors: National Institute of Water and Atmospheric Research (NIWA), New Zealand.

LIMR in 2017 and 2021 were 5- and 6-fold greater, and mean length was 3 cm and 5 cm greater than the adjacent fished QCH strata (outside), respectively. The proportion of catch rates inside LIMR in 2017 and 2021 that was recruited (33 cm and over) was 78% and 86%, compared with 38% and 45% outside, and 7% and 10% of pots were empty in the marine reserve, compared with 39% and 47% outside, respectively. The mean and median condition factors (*K*) of blue cod in 2021 was higher in the marine reserve than outside (mean *K* inside LIMR 1.61, outside 1.41).

1. INTRODUCTION

This report describes the results of the blue cod (*Parapercis colias*) random-site potting survey carried out in Marlborough Sounds in October 2021. Estimates are provided for population abundance, size and age structure, sex ratio, total mortality (*Z*), and spawner biomass-per-recruit ratio. This is the third full random-site blue cod survey carried out in the Marlborough Sounds and the tenth survey overall, with nine fixed-site surveys carried between 1995 and 2017. 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 substantial overlap between the commercial and recreational fishing grounds for some surveys, i.e., Foveaux Strait, north and south Otago. Surveys are generally carried out every four years to monitor local relative abundance, size, age, and sex structure of geographically separate blue cod populations. The surveys provide a measure of the response of populations to changes in fishing pressure and management intervention, such as changes to the daily bag limit, minimum legal size, and area closures. In addition to the Marlborough Sounds, there are currently eight other areas surveyed, located in key recreational fisheries: Kaikōura, Motunau, Banks Peninsula, north Otago, south Otago, Foveaux Strait, Paterson Inlet, and Dusky Sound (Appendix 1). In the Marlborough Sounds, previous potting surveys were carried out in 1995, 1996, 2001, 2004, 2007, 2008, 2010, 2013, and 2017 (Blackwell 1997, 1998, 2002, 2006, 2008, Beentjes & Carbines 2012, Beentjes et al. 2017, Beentjes et al. 2018). 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 (Appendix 2, glossary of terms), where sites with predetermined locations (fixed sites) were randomly drawn from a limited list of such sites (Beentjes & Francis 2011, Beentjes 2019). Fixed sites represent ‘good’ fishing spots or locations where blue cod were known to be abundant. The South Island potting surveys were reviewed by an international expert panel in 2009, which recommended that blue cod would be more appropriately surveyed using random-site potting surveys (Stephenson et al. 2009). A random site is any location (single latitude and longitude) generated randomly from within a stratum (Beentjes & Francis 2011, Beentjes 2019). Subsequently, in 2010, experimental random sites were trialled in selected strata within Pelorus Sound, D’Urville Island, and the entire Cook Strait region (Beentjes & Carbines 2012); and in 2013 and 2017, full random-site and full fixed-site surveys were conducted concurrently (Beentjes et al. 2017, Beentjes et al. 2018). The 2021 survey was the first solely random-site survey carried out in Marlborough Sounds and this survey time series has now fully transitioned to the random-site design. The 2017 and 2021 random-site surveys also included Long Island-Kokomohua Marine Reserve .

1.2 Status of blue cod in the Marlborough Sounds

The previous method of assessing the stock status of blue cod in Marlborough Sounds by Fisheries New Zealand was to estimate fishing mortality (*F*) and the associated spawner-biomass-per-recruit ratio (*SPR*), which are used as a proxy for B_{MSY} (maximum sustainable yield biomass) (Beentjes et al. 2018, Fisheries New Zealand 2022). Spawner-biomass-per-recruit is defined as the expected lifetime contribution to the spawning biomass for the average recruit to a fishery. The recommended Harvest Strategy Standard maximum sustainable yield reference point for blue cod (a low productivity stock) is $F_{45\%SPR}$ (Ministry of Fisheries 2011), i.e., target fishing mortality should be at or below a level that reduces the spawner biomass (the total weight of sexually mature fish in the stock) to 45% of that if there was no fishing.

However, the Fisheries New Zealand Stock Assessment Plenary meeting on 18 July 2022 agreed that *SPR* is not appropriate as a target reference point for blue cod in Marlborough Sounds for the following reasons.

1. As this species is a diandric protogynous hermaphrodite, with behavioural triggers for females changing to secondary males, it is difficult to reliably model this process, especially since the

rate of sex change appears to increase in an unpredictable manner with the removal of dominant males by fishing,
2. Few females currently grow large enough to recruit to the fishery, presumably because some of the larger females change to males when dominant males are removed, so fishing mortality is mostly experienced by the males.
3. The standard spawner per recruit approach does not account for the reduction in female spawner biomass resulting from the increased rate of sex change, implied by the sex ratio being heavily skewed to males.
4. Current growth rates of both males and females are likely to have been substantially modified by the increased rate of sex change induced by fishing. It is therefore not possible to estimate the growth rate of the virgin unfished population.

The Plenary recommended F=0.87M (natural mortality) as an overfishing threshold for Marlborough Sounds blue cod based on the study of Zhou et al. (2012), where Z (total mortality) and F are estimated from the male-only age composition in the population. The age-at-full recruitment should be the same as the male average age-at-minimum legal size, plus a one year to ensure more than 50% of males are recruited to the fishery.

Because 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, Beentjes 2021). 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, Beentjes 2021).

Blue cod is the third most common recreational finfish species caught in New Zealand with a total catch of 292 t (nearly 600 000 fish) estimated during the 2017–18 national panel survey involving face to face interviews with fishers (Wynne-Jones et al. 2019). Blue cod can be caught in a few metres depth to about 150 m, in a range of habitats, including reef edges, shingle/gravel, biogenic reefs, or sandy bottoms close to rocky outcrops. Quota Management Area (QMA) BCO 7 extends northwards from the Clarence River (north of Kaikōura) to the top of the South Island then southwards to Awarua Point in Westland and includes southern Cook Strait and the Marlborough Sounds. Blue cod is the second most important recreational target species in the Marlborough Sounds and Tasman Bay/Golden Bay after snapper. The recreational take of blue cod within BCO 7 was estimated at 63 t from the 2017–18 national panel survey (Wynne-Jones et al. 2019) and 75 t from a 2016 aerial-access survey (Fisheries New Zealand 2022). Recreational catch estimates were similar to those of 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 2022).

In the Marlborough Sounds, there have been frequent changes to both the minimum/maximum legal size and to the daily bag limit (DBL), as well as area closures in the 'Marlborough Sounds Area' (Figures 1 and 2). The DBL progressively declined from 12 blue cod in 1985 to 2 since 2011, while the inner sounds was closed to target blue cod fishing from October 2008 to April 2011. The minimum legal size (MLS) varied from 28 cm to 33 cm, with a slot limit of 30 to 35 cm from April 2011 to December 2015 (Figure 2). From December 2015 to July 2020, within 'Marlborough Sounds Area' and 'Challenger Area East', the MLS was 33 cm, DBL was 2 blue cod (or 2 from each area), with a maximum of two hooks per line permitted, and the fishery was closed from 1 September to 19 December. The area from Farewell Spit to Clarence River (out to 12 nautical miles), including Marlborough Sounds, is known as the 'Tasman Area', and on 1 July 2020, was assigned a 'traffic light' colour of red by Fisheries New Zealand, indicating that the blue cod stocks in this area are considered to be overfished. The only change in July 2020 was that the DBL was set at two blue cod per person within the Tasman Area (Marlborough Sounds Area and Challenger Area East).

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 Fisheries New Zealand potting surveys began monitoring the population. The Marlborough Sounds potting surveys showed a decline in abundance in the inner sounds of about 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 October 2010 (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 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 results of the 2013 survey indicated that blue cod abundance and length had declined in the previously closed areas (inner Pelorus Sound and Queen Charlotte Sound) after the re-opening of the fishery and slot limit introduction 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

This is the final reporting requirement of Fisheries New Zealand research project BCO2021-01.

Overall objective

1. To estimate relative abundance, 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, age structure, size- and age-at-maturity, and 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.

2. METHODS

2.1 2021 Marlborough Sounds potting survey

2.1.1 Timing and survey area

A potting survey of the Marlborough Sounds area was carried out by National Institute of Water & Atmospheric Research Ltd (NIWA) between 29 September and 25 October 2021. The survey dates were consistent with previous surveys and coincided with the known spawning time in this region.

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

Four regions (Queen Charlotte Sound, QCH; Pelorus Sound, PEL; D'Urville Island, DUR; and Cook Strait, CKST), comprising 13 strata, were covered including, for the second time, Long Island Marine Reserve (LIMR) (Figure 3). The 2021 survey did not include Separation Point (SEPR), which was surveyed only in 2004 and 2007. Coastline length was measured using ArcMap (GIS system) and recorded in kilometres before the 2010 survey (Beentjes & Carbines 2012). The 2010 coastline estimates replaced those reported in the 1995 to 2007 surveys because these were inaccurate. The length (kilometres) 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.

2.1.2 Survey design

The survey design and all terminology used here are consistent with the blue cod potting manual (Beentjes 2019). The 2021 survey was a random-site design with systematic pot placement. A random site has a location (single latitude and longitude) generated randomly within a stratum (Beentjes & Francis 2011, Beentjes 2019).

The coastlines of all 13 strata were divided into 1.01 km segments (excluding coastline sections less than 1.01 km such as rocks or small islands) and a latitude and longitude at the centre of each segment was assigned, giving 1195 potential random sites. From this list, the allocated number of random sites per stratum to be surveyed was randomly selected.

Simulations using NIWA's Optimal Station Allocation Program (*allocate*, Francis 2006) were carried out using catch rates from previous Marlborough Sounds surveys to determine the optimal allocation of sites among the strata within each of the four regions. Random site allocations for QCH were based on the 2013 and 2017 random-site surveys and, those for PEL/DUR/CKST, on the 2010, 2013, and 2017 random-site surveys. Simulations were constrained to have a minimum of three sites per stratum and a CV (coefficient of variation) of no greater than 20% for each region. The simulations indicated that 66 random sites were required. Of the possible 10 random sites in Long Island Marine Reserve, nominally 8 were randomly selected.

In the Marlborough Sounds, because blue cod habitat is largely restricted to a band of reef and rubble adjacent to the coastline, pots were set along the coastline, no further than 0.5 km from the random-site position. Nine pots (Pot Plan 1) were set along the shoreline every 100 m, starting from a point 450 m from the random-site position, each in a randomly selected depth over the extent of the habitat as it extends out perpendicular from the shore, but not less than 2 m depth (Beentjes 2019).

The random-site survey used a two-phase stratified random station design (Francis 1984). 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 2.

2.1.3 Vessel and gear

The 2021 survey was carried out using the Wellington-based NIWA inshore research vessel *Ikatere*. The R.V. *Ikatere* is an aluminium-alloy catamaran with a length of 13.9 m, beam of 4.85 m, equipped with 322 Hamilton water-jet units, and powered by twin Cummins QSC engines rated at 500 HP, capable of

25 knots cruising speed. This vessel was also used on the 2013 and 2017 surveys. The *Ikatere* was skippered by Richard Leppard.

Nine custom designed and built cod pots were used to conduct the survey (Pot Plan 1 given by Beentjes 2019). Pots were baited with 700 g of pāua viscera in 'snifter pottles' and replaced after every lift. The proportion of bait remaining was recorded after every lift. 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.

2.1.4 Sampling methods

All sampling methods adhered strictly to the blue cod potting survey standards and specifications (Beentjes & Francis 2011, Beentjes 2019). The survey initially completed Queen Charlotte Sound and Cook Strait, before moving to Pelorus Sound, and D'Urville Island, consistent with the 2010, 2013, and 2017 surveys. The Long Island Marine Reserve was sampled last.

At each site, nine pots were set and left to fish (soak) for a target period of one hour during daylight hours. As each pot was placed, a record was made of sequential pot number (1 to 9), latitude and longitude from GPS, depth, and time of day. After each site was completed, the next closest site in the stratum was sampled. The ADCP was deployed at the centre of each site prior to the setting of pots and recovered after the last pot of each set was lifted. After pot placement, the following environmental data were recorded: wind direction, speed, and force; air temperature and pressure; water clarity using secchi disc, sea condition and colour; swell height and direction; bottom type and contour; and surface water temperature. These variables and their units are defined in the potting manual (Beentjes 2019).

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

Both sagittal otoliths were removed from a representative length range of blue cod males and females. Separate otolith collections were made for each of the four regions with a target of about 150 otoliths per region. To ensure that adequate numbers of large and small fish and females were included, the following blue cod otolith collection schedule was adhered to for each region, while ensuring that collection was spread across strata within each region:

Males: four otoliths per one-centimetre size class; and all males under 27 and over 36 cm.
Females: all otoliths, except for DUR, where it was 4 otoliths per one-centimetre size class and all females under 28 and over 34 cm.

Sex and maturity were determined by dissection and macroscopic examination of the gonads (Carbines 1998, 2004). Blue cod gonad staging was undertaken using the five stage Stock Monitoring method used on previous surveys: 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

2.1.5 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. As each pot was hauled, the blue cod catch was weighed and transferred into a bin with circulating seawater, before being measured for length and weight, and returned alive below the sea surface through a 100 mm diameter pipe fed with running seawater. Catch weight and numbers of bycatch species 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. Maximum exposure time to air of fish was approximately 1 minute and processing time was less than 5 minutes between pots.

All sampling within the reserve was conducted under a Department of Conservation Special Permit issued to NIWA (Authorisation to undertake specified scientific study within a marine reserve, Authorisation number 96198-MAR).

2.1.6 Data storage

The trip code for the 2021 survey is IKA2111. 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 2019). All analyses were carried out from data extracted from the *trawl* database. Random sites were entered into *trawl* table *t_station* in attribute *stn_code* (concatenating stratum number and site label and prefixed with R, e.g., R1F, R2B). Random-site locations were also entered into *trawl* table *t_site.* Pot locations were entered in table *t_station* in attribute *station_no* (concatenating set number and pot number e.g., 11 to 19, or 31 to 39). In the *age* database the *sample_no* is equivalent to *station_no* in the *trawl* database.

Acoustic Doppler current profiler data were sent to the Research Database Manager in spreadsheet format.

2.1.7 Age estimates

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

2.1.8 Analyses of data

Analyses of catch rates, sex ratios, and scaled length and age distributions were conducted and presented for each of the four regions (QCH, PEL, DUR, CKST) and MS overall. Analyses of catch-at-age, total mortality Z, and fishing mortality F, were carried out for all four regions combined to provide Marlborough Sounds wide estimates. Analyses of catch rates and coefficients of variation (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, Beentjes 2019).

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 for LIMR because fish caught in the marine reserve were not aged, and it is likely that age and growth outside the marine reserve were unrepresentative of fish inside the marine reserve.

2.1.8.1 Catch rates

The catch rate (kg pot^{-1}) estimates are pot-based and the CV estimates are set-based (Beentjes & Francis 2011, Beentjes 2019). Catch rates and 95% confidence intervals (± 1.96 standard error) were estimated for all blue cod and for recruited blue cod (33 cm and over, 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 (kilometres) shown in Table 2 were used as the ‘area’ of the stratum (A_t) when scaling catch rates (equations 3 and 5 of Beentjes & Francis 2011, Beentjes 2019). Catch rates are presented by stratum, overall for each region, and overall for Marlborough Sounds.

2.1.8.2 Length-weight parameters

The length-weight parameters a_k, b_k from the 2021 Marlborough Sounds survey were estimated by the following equation:

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

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 the y-intercept. This can then be used to calculate the expected weight (g) for a fish of sex k and length l (cm) in the survey catch.

2.1.8.3 Growth parameters

A von Bertalanffy growth model (von Bertalanffy 1938) was fitted to the 2021 Marlborough Sounds survey length-age data by sex as follows:

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

where L_t is the length (centimetres) 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. Growth models were fitted by region and overall.

2.1.8.4 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 (kilometres) shown in Table 2, was taken as the 'area' of the stratum (A_t), and the sex-specific length-weight parameter estimates were made from the 2021 survey data.

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

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

Catch-at-age was estimated, for each of the four regions (QCH, PEL, DUR, CKST) and Marlborough Sounds overall using the region-specific length data or from MS overall, and the sex-based age-length key (ALK) generated from all regions combined. A single ALK was used because there were insufficient larger and older fish in each region, particularly in Cook Strait and Pelorus Sound. An analysis was carried out to compare mean length-at-age among the four regions and determine if combining all the age data by sex was justified. For each region and Marlborough Sounds overall, scaled length-frequency and age-frequency proportions are presented with the CV for each length and age class and the mean weighted coefficients of variation (MWCV).

2.1.8.5 Sex ratios and mean length and age

Sex ratios (expressed as percentage male for all and recruited blue cod) and mean length, for the stratum, region, and survey level were calculated using equations 10 and 11 of the manual (Beentjes & Francis 2011, Beentjes 2019) from the stratum or survey scaled length-frequency data. Mean ages were calculated analogously from the scaled age frequencies. Confidence intervals (95%) around sex ratios were generated from the 300 bootstraps. Similarly, 95% confidence intervals around mean recruited length of all blue cod were generated from the 300 bootstraps.

2.1.8.6 Condition Factor

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

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

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

2.1.8.7 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 CR total mortality (Z) were calculated for age-at-recruitment values of 5 to 10 yr 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, females, and both sexes combined. Unlike previous estimates of Z in 2013 and 2017 that were based on the combined male and female age compositions (Beentjes et al. 2018), total mortality in 2021 was estimated from the male-only catch-at-age, with age-at-full recruitment determined from the average age of males at minimum legal size (33 cm), plus one year to ensure more than 50% of males are recruited to the fishery (i.e., 6 years). The Inshore Working Group (INSWG, 23 June 2022) and Plenary Stock Assessment Working Group (18 July 2022) recommended this revised methodology, because only a very low proportion of females in any age class in 2021 grew larger than the minimum legal size – female $L_{infinity}$ was 34 cm. Fishing mortality was estimated from the results of the Chapman-Robson analyses and the current default estimate of *M* (i.e., *F* = *Z–M*), assumed to be 0.17, revised from 0.14 in 2019 (Doonan 2020). Sensitivity analyses of *F* were carried out for *M* values 20% above and below the default (0.14 and 0.20).

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

2.1.8.8 Analyses of 2013 and 2017 Marlborough Sounds random-site surveys

To allow valid comparison of *Z* and *F* estimates among the last three random-site surveys (2013, 2017, and 2021), which were all carried out on age compositions determined using the age-determination protocol, the 2013 and 2017 survey analyses were updated as follows: *Z* and *F* were estimated for males only, with male age-at-full recruitment of 6 years, and using the default *M* value of 0.17 (previously 0.14).

2.1.8.9 Random-site survey time series

Trends were compared for mean catch rates, sex ratio, and mean recruited length from random-site surveys for each region and overall for the Marlborough Sounds (QCH, PEL, and DUR combined, but excluding CKST). Cook Strait was not included in the all Marlborough Sounds random-site survey time series catch rates and sex ratios to allow valid comparison of catch rates from the same strata (1 to 9) between fixed-site and random-site surveys. The fixed-site survey catch rates and sex ratios are shown for completeness.

3. RESULTS

3.1 Marlborough Sounds 2021 random-site blue cod potting survey

3.1.1 Sites surveyed and catch

Sixty-six random sites (9 pots per site, producing 594 pot lifts) from twelve strata (excluding the LIMR) throughout the Marlborough Sounds were surveyed in 2021 (Table 2, Figure 4). Depths sampled were 4–77 m (mean = 13 m). Sixty sites were carried out in phase 1 and six in phase 2, of which all were in stratum 6.

A total of 773 kg of blue cod (1579 fish) was caught, comprising 76% by number of the catch of all species on the survey (Table 3). Bycatch species included 10 teleost fishes, 1 shark, 1 octopus, and 2 generic invertebrate groups. The three most abundant vertebrate bycatch species, by number, were banded wrasse (*Notolabrus fucicola*), spotted wrasse (*Notolabrus celidotas*), and scarlet wrasse (*Pseudolabrus miles*).

3.1.2 Blue cod catch rates, length, and sex ratio

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

Queen Charlotte Sound

Queen Charlotte Sound (QCH) mean catch rates by stratum for blue cod (all sizes) were 0.24–1.44 kg pot^{-1}, increasing markedly from the inner to the outer Sounds; catch rates were nearly 6-fold greater in EQCH than IQCH (Table 4, Figure 6). The overall QCH all blue cod catch rate was 1.21 kg pot^{-1} with a CV of 25.2%. 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 0.53 kg pot^{-1} (CV 24%). All but two of the 18 random sites had some blue cod catch, but of the 162 pots, 72 (44%) had zero catch of blue cod.

All 435 blue cod caught in QCH were measured for length and weight and all but one fish was sexed. The sex ratio was 64–80% male across the three strata and the weighted sex ratio was 74% male (Table 5). Length range was 17–49 cm for males and 11–39 cm for females and the weighted mean length was 30.9 cm for males and 28.6 cm for females. The length-frequency distributions lacked the numbers in the inner sounds strata to describe length composition well, but overall males appeared to be unimodal in QCH (Figure 7).

Pelorus Sound
Pelorus Sound (PEL) mean catch rates by stratum for blue cod (all sizes) were 0.19–1.19 kg pot^{-1}, increasing markedly from the inner to the outer sounds and were more than 6-fold greater in EOPE than IPEL (Table 4, Figure 6). The overall PEL all blue cod catch rate was 0.66 kg pot^{-1} with a CV of 21%. 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 0.36 kg pot^{-1} (CV 21%). All but two of the 18 random sites had some blue cod catch, but of the 162 pots, 91 (56%) had zero catch of blue cod.

All 249 blue cod caught in PEL were sexed and measured for length and weight. The sex ratio was 54–92% male across the four strata and the weighted sex ratio was 82% male (Table 5). Length range was 17–46 cm for males and 16–38 cm for females; the weighted mean length was 31.9 cm for males and 29.2 cm for females. The length-frequency distributions lacked the numbers in the inner sounds strata to describe length composition well but overall appeared to be unimodal for PEL (Figure 8).

D’Urville Island
D’Urville (DUR) mean catch rates by stratum for blue cod (all sizes) were 2.05–2.39 kg pot^{-1}, with the higher catch rates in DURE (Table 4, Figure 6). The overall DUR all blue cod catch rate was 2.23 kg pot^{-1} with a CV of 21%. Catch rates for recruited blue cod 33 cm and over, followed a similar pattern among strata as for all blue cod and the overall catch rate was 1.34 kg pot^{-1} (CV 21%). All 17 random sites had some blue cod catch, but, of the 153 pots, 57 (37%) had zero catch of blue cod.

All 665 blue cod caught in DUR were sexed and measured for length and weight. The sex ratio was 59–66% male across the two strata and the weighted sex ratio was 63% male (Table 5). Length range was 18–46 cm for males and 21–41 cm for females and the weighted mean length was 32.8 cm for males and 30.8 cm for females. The length-frequency distributions were unimodal (Figure 9).

Cook Strait
Cook Strait (CKST) mean catch rates by stratum for blue cod (all sizes) were 0.07–2.13 kg pot^{-1}, with highest catch rates in Arapara Island east (APAE) (Table 4, Figure 6). The overall CKST all blue cod catch rate was 0.71 kg pot^{-1} with a CV of 16%. 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 0.41 kg.pot^{-1} (CV 22%). All but three of the 13 random sites had some blue cod catch, but of the 117 pots, 61 (52%) had zero catch of blue cod.

All 230 blue cod caught in CKST sites were sexed and measured for length and weight. The sex ratio was 50–85% male across the three strata and the weighted sex ratio was 80% male (Table 5). Length range was 22–45 cm for males and 21–34 cm for females and the weighted mean length was 32.3 cm for males and 27.5 cm for females. The length-frequency distributions lacked the numbers in the Port Underwood stratum (UNDW) to describe length composition well but overall appeared to be unimodal for CKST (Figure 10).

Marlborough Sounds

Marlborough Sounds overall catch rate for all blue cod (all sizes) was 1.18 kg pot^{-1} with a CV of 13.0%. The highest catch rates were in DURE and the lowest in UNDW (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 overall was 0.64 kg pot^{-1} (CV 13%). All but seven of the 66 random sites had some blue cod catch, but of the 594 pots, 281 (47%) had zero catch of blue cod.

Of the 1579 blue cod caught in Marlborough Sounds, all but one fish were sexed, and all were measured for length and weight. The length weight coefficients were: a = 0.006090, b = 3.2459, n = 1141 with 4 outliers removed (males); a = 0.005954, b = 3.2619, n = 430, with 3 outliers removed (females). The weighted sex ratio was 72% male across the 12 strata (Table 5). Length range was 17–49 cm for males and 11–41 cm for females and the weighted mean length was 31.8 cm for males and 29.7 cm for females. The length-frequency distributions were unimodal (Figure 11).

Cumulative plots of population length for each of the four regions in 2021 showed only minor differences in length distributions for males or females among the regions, although cumulative curves were unlikely to be fully representative of the population for PEL and CKST, where only 40 and 42 females, respectively, were sampled (Figure 12).

3.1.3 Age and growth

Otoliths from 351 males and 234 females were used to estimate the population age structure of Marlborough Sounds in 2021 (Table 6). Otoliths were collected from all regions and all lengths, for both sexes (Appendix 3). Plots of length-at-age and modelled von Bertalanffy curves for each region indicated that older fish were not well represented in any region, resulting in implausible von Bertalanffy parameters or in curves that did not reach an asymptote (Figure 13). 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 14). On this basis, sex-specific ALKs were produced for the combined regions (Figure 15). The von Bertalanffy growth parameters were: L_∞ = 43.36 cm, K = 0.276 yr^{-1}, t_0 = -0.184 yr, n = 351 (males); L_∞ = 34.02 cm, K = 0.336 yr^{-1}, t_0 = -0.381 yr, n = 234 (females).

There was a large range in age-at-length for both sexes and males grew faster and were larger than females, typical of blue cod. The von Bertalanffy curves for 2013 and 2017 were similar, whereas for 2021, both sexes attained a greater asymptotic length (Figure 16).

Between-reader comparisons are presented in Figure 17. The two readers achieved agreement on 86% of read otoliths. Overall, no bias existed between readers, with a between-reader precision (CV) of 2.1% and an index of average percentage error (IAPE) of 1.5%.

Age estimates from previous surveys

With regard to age estimates for historical surveys, only otoliths from the 2013 and 2017 surveys were aged using the ADP. Although otoliths collected from the 2001 to 2010 surveys have been read, this was before the ADP was established and the ages are not likely to be accurate. These otoliths would need to be re-aged under the ADP before any comparisons of age composition for surveys before 2013 are attempted.

3.1.4 Blue cod spawning activity

Gonad stages of blue cod sampled on the 2021 survey between late September and late October are presented by region and for all regions combined (Table 7). There was a clear indication of spawning activity during the survey period and, overall, approximately 20% of males and 30% of females were running ripe.

3.1.5 Blue cod population length and age composition

The scaled length-frequency and age distributions for the 2021 random-site survey are shown for all regions combined (Marlborough Sounds) (Figure 18) and separately for each of the four regions (Appendix 4).

Marlborough Sounds scaled length-frequency distributions for both males and females were unimodal with mean lengths of 31.8 and 29.7 cm, respectively (Figures 11 and 18). The cumulative distribution plots of the length-frequency clearly showed that a higher proportion of larger fish were males and that the largest fish were males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 21% for males and 31% for females, indicating that the population was reasonably well represented.

Marlborough Sounds age estimates of blue cod were 2–12 years for males and 1–21 years for females, but most males were 3–5 years old and females were 4–7 years old (Figure 18). The estimated population age distributions indicate knife-edge selectivity to the potting method at two to three years. Strong four-year-old and weak six-year-old age classes were present for males, whereas for females the five-year-old age class was strong, and the eight-year-old age class was weak. These strong and weak age classes were apparent in the cumulative distribution plots of age frequency (Figure 18). The estimated population age distributions were unimodal for males, with a peak at 4 years, and bimodal for females, with peaks at 5 and 9 years. The cumulative distribution plots of the age-frequency clearly showed that females had a much higher proportion of older fish. Further, the mean age of females was greater than the mean age of males (6.6 years for females and 4.8 years for males). The MWCVs around the age distributions were 16% for males and 27% for females, indicating that the population was reasonably well represented.

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

Chapman-Robson (CR) total mortality estimates (*Z*) for males, and 95% confidence intervals, are shown for a range of recruitment ages (5–10 years) for the 2021 Marlborough Sounds random-site survey (all regions combined) in Table 8. Age-at-full recruitment (AgeR) was assumed to be equal to the average age at which males reached the MLS of 33 cm, plus one year (i.e., 6 years) (see Figure 15). The male CR *Z* for AgeR of six years for Marlborough Sounds was 0.65 yr^{-1} (95% confidence interval of 0.43–0.90) (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 19). The 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 parameter (CR *Z*, *F*) estimates for males at three values of *M* (default of 0.17, and 20% above and below the default) are shown for the 2021 Marlborough Sounds random-site survey (all regions combined) in Table 9. Based on the default *M* of 0.17, male fishing mortality (*F*) was estimated at 0.48 yr^{-1}.

3.2 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 23 to 24 October 2021 (Table 2, Figures 4 and 20). Depths sampled were 5–32 m (mean = 14 m). A total of 748 blue cod (575 kg) was sampled comprising 99% by number of the catch of all species on the survey (Table 3). Bycatch species included two teleost species: scarlet wrasse (*Pseudolabrus mile*) and leatherjacket (*Meuschenia scaber*). No mortality of blue cod was observed after release.

The mean catch rate of all blue cod (all sizes) was 7.98 kg pot^{-1} (CV of 13%) and for recruited blue cod 33 cm and over it was 6.89 kg pot^{-1} (CV 14%) (Table 4, Figure 21). Catch rates of all blue cod were nearly six times higher, and recruited blue cod nearly eight times higher in LIMR than in adjacent fished strata in Queen Charlotte Sound.

All eight random sites had some blue cod catch, but of the 72 pots, 7 (9.7%) 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 22).

Of the 748 blue cod caught in LIMR random sites, all were measured for length and individual weight before being released alive. Consequently, sex was not determined and no otoliths were collected to estimate age. Length was 19–50 cm (Table 5) and the weighted mean length was 35.7 cm (Figure 23). The length-frequency distributions in the LIMR appear to be unimodal with a peak at about 35 cm and a more pronounced right-hand tail than the unimodal distributions from adjacent strata in Queen Charlotte Sound (Figure 23). The mean size was 5.8 cm and 4.7 cm greater in the LIMR than OQCH and EQCH, respectively.

The mean and median Fulton's condition factor (*K*) for blue cod in the LIMR was the highest for any of the 13 strata surveyed in 2021, with a mean of 1.61 (Table 10, Figure 24). This compares with mean values of 1.41 in adjacent strata in Queen Charlotte Sound and 1.44 overall for Marlborough Sounds (excluding LIMR). The 2021 condition factor was also determined for fish of the same length range to rule out differences that may be related to spawning condition of the larger fish in the marine reserve (Table 10). Restricting fish to 40 cm and below included 99% of fish outside the marine reserve and 80% of fish inside the marine reserve. The resulting condition factor mean values were virtually the same as for the full dataset, i.e., 1.62 in LIMR, 1.41 in adjacent strata in Queen Charlotte Sound, and 1.44 overall for Marlborough Sounds (excluding LIMR), indicating that the differences in condition factor inside and outside the marine reserve were unrelated to size and/or spawning condition (Table 10).

3.3 Random-site survey time series

For random-site surveys there are only three surveys in the time series for QCH, PEL, and DUR (2013, 2017, and 2021), and four for Cook Strait (2010, 2013, 2017, 2021), therefore conclusions on trends are tentative.

Catch rates

Mean catch rates (kg pot^{-1}) for all blue cod from random-site and fixed-site surveys are shown in Figure 25. Random-site survey mean catch rates (kg pot^{-1}) of all blue cod in QCH roughly doubled between 2013 and 2017, but there was only a small increase in 2021; PEL catch rates showed a clear decline, halving from 2013 to 2021; DUR catch rates nearly doubled in 2017 and then returned to the 2013 levels; CKST catch rates fluctuated with no clear trend. Marlborough Sounds catch rates showed an increase and then decrease to the 2013 level (Figure 25). The proportions of pots that had no blue cod in the random-site surveys was 44%–62% in QCH, 53%–58% in PEL, 32%–38% in DUR and 44%–53% in CKST, with no clear changes over time (Figure 26).

Sex ratios

Sex ratios (percent male) for all blue cod and recruited blue cod from random-site and fixed-site surveys are shown in Figure 27. For the random-site surveys, QCH sex ratio of all blue cod was 66–74% male, with indications of an increasing trend, and about 15% higher for recruited blue cod, also with an increasing trend; 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 80–87% male with no trend, and recruited blue cod were nearly all male. The MS sex ratio of all blue cod was 66–71% male with no clear trend and the recruited sex ratio was about 86% male with no trend (Figure 27).

Length composition

The scaled length-frequency distributions and cumulative distributions for 2010 (CKST only), and the 2013, 2017, and 2021 random-site surveys for QCH, PEL, DUR, CKST, and Marlborough Sounds are shown in Figures 28 and 29. There was little difference in the shapes of these distributions among the four regions or within regions over the three surveys, although in QCH, PEL, and Marlborough Sounds overall the 2021 distributions appear to have fewer larger male fish (Figures 28 and 29). Mean length of recruited blue cod and 95% confidence intervals for each region and for Marlborough Sounds are plotted in Figure 30. There were no clear trends in mean length except in QCH and CSKT, where male mean length declined or increased, respectively (Figure 30).

Growth, age composition, and mortality

Growth rates were consistent between 2013 and 2017 with similar shaped von Bertalanffy curves, whereas for 2021 the length at infinity values were noticeably higher (see Figure 16). The scaled age compositions for males were broadly similar for the three surveys for all regions combined, but less so for females (Figure 31). There appears, however, to have been a gradual shift towards younger ages in the population over time, shown by the cumulative percent plots and the reduction in mean ages (Figure 31). There is no clear evidence of cohort progression, with the possible exception of the weak four-year-old female age class in 2017, progressing to a weak eight-year-old age class in 2021.

The CR male total mortality estimates (Z) ranged from 0.60 to 0.75 over the three random-site surveys (Table 11). Fishing mortality (F) ranged from 0.43 to 0.58.

3.4 Fixed-site versus random-site surveys

The fixed-site survey results were analysed and documented in the 2017 survey report (Beentjes et al. 2018). For all three regions in 2013, catch rates of all blue cod were higher from fixed than from random sites; this was statistically significant for QCH and PEL ($p<0.05$), but not for DUR (see Figure 25). In 2017, there was no statistically significant difference between fixed-site and random-site catch rates in QCH, but, in PEL and DUR, fixed-site catch rates were statistically higher ($p<0.01$ and $p<0.05$, respectively) (see Figure 25). There was little or no difference in length-frequency distributions from the fixed- or random-site surveys in 2013 and 2017 (not shown) (Beentjes et al. 2018).

4. DISCUSSION

4.1 General

The 2021 random-site survey was the third in Queen Charlotte Sound, Pelorus Sound, and D'Urville Island and the fourth for Cook Strait in which all strata in these regions were sampled. The 2021 survey was the first solely random-site survey carried out in Marlborough Sounds and this survey time series has now fully transitioned to the random-site design following concurrent fixed- and random-site surveys in 2013 and 2017. The fixed-site surveys were discontinued because the random-site design was deemed to be more accurate, statistically robust, and more likely to represent the entire blue cod population (Stephenson et al. 2009).

Differences in catch rates between fixed- and random-site surveys suggest that there may be no suitable way of quantitatively linking the two series. Notwithstanding the differences in catch rates that can be ascribed to the survey design (fixed or random), there are no clear indications that blue cod biomass has declined substantially between 2004 and 2021 (see Figure 25). Future analyses could determine whether information in the fixed-site surveys could be combined into a single series by, for example, using a GLM to standardise catch rates from fixed- and random-site surveys by including survey type as a predictor.

The results of all previous surveys in the time series are discussed in the context of the fisheries management regulations that were in place in the Marlborough Sounds area. The key findings from the previous fixed-site surveys are also briefly summarised for completeness.

4.2 Fixed-site survey trends

The highest catch rates of all blue cod from fixed sites by region were from DUR, followed by PEL and QCH, although there was considerable variation among strata within a region (see Figure 25).

Queen Charlotte Sound

The large increase in QCH catch rates in 2010 was consistent with the closure of the inner sounds to fishing two years earlier in 2008 (see Figure 25). 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 September–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 (not shown). The QCH population appeared to have responded 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 closure, slot limit, and 33 cm MLS did not appear to have had any effect on QCH sex ratio, which remained stable at about 60–70% male (see Figure 27).

Pelorus Sound

Similar to QCH, the steep increase in PEL catch rates in 2010 was consistent with the closure of the inner Pelorus Sounds two years earlier (see Figure 25). 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 have been 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, a decline in 2013, and increase again in 2017 (not shown). 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 had the most skewed sex ratio of the three regions (see Figure 27). 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 25). Similarly, length distributions showed no trends over time until 2017, when mean length increased (not shown). DUR was not closed to target fishing of blue cod as were the inner QCH and PEL in 2008, and the stable catch rates and length distributions 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 was then stable at 61–70% male, unaffected by the various fisheries management regulations (see Figure 27).

4.3 Random-site survey trends

With only three random-site surveys in QCH, PEL, and DUR, a detailed examination of trends in the times series is premature. The 2013 random-site survey took place more than two years after the introduction of the 30–35 cm slot limit and the 2017 and 2021 surveys two and six years, respectively, after the slot limit was removed and replaced by a MLS of 33 cm, a DBL of 2 blue cod, and the fishery closed from 1 September to 19 December.

The highest catch rates of all blue cod from the three random-site surveys were consistently from DUR, where they were 2- to 3-fold higher than in the other regions (see Figure 25), although there was considerable variation among strata within a region, i.e., low catch rates in the inner sounds (IQCH, IPEL) and high catch rates around the outer sounds, D'Urville Island, and the Cook Strait side of Arapara Island (strata EOPE, OQCH, DURE, DURW, and APAE) (see Figure 5). This pattern of abundance was generally consistent in 2013, 2017, and 2021. Notwithstanding the limitations of a three-survey time series, there were differing trends in the three areas that are difficult to rationalise in terms of management measures, which were the same in each region, including increasing catch rates in QCH, decreasing catch rates in PEL (see Figure 25), and no trend in DUR. There was little difference in the length distributions among and within the four regions over the three surveys, although the 2021 distributions appear to have fewer larger male fish in QCH and PEL (see Figure 28).

The only regulation change that applied to Cook Strait was the increase in the MLS from 30 to 33 cm in December 2015 and the associated seasonal closure. There was no trend, however, in catch rates for Cook Strait, except in 2017 when catch rates were about one-third higher than 2013, two years after the regulation changes (see Figure 25). The CKST length distributions from the four random-site surveys were similar, although male mean length showed indications of an increasing trend (see Figure 30). Sex ratio, however, has remained male dominated and unchanged over the four surveys (see Figure 27).

4.3.1 Stock status trends (random sites)

The *Harvest Strategy Standard* specifies that a Harvest Strategy should include a fishery target reference point and it may be expressed in terms of biomass or fishing mortality (Ministry of Fisheries 2011). The Fisheries New Zealand Stock Assessment Plenary meeting on 18 July 2022 agreed that the *SPR* is not appropriate as a target reference point for blue cod in Marlborough Sounds and recommended $F=0.87M$ (natural mortality) as an overfishing threshold based on the study of Zhou et al. (2012), where Z and F are estimated from the male-only age composition in the population (see Introduction). Using this method, the target reference point is $F=0.15$. The estimated F of 0.48 in 2021, is over three times higher than the target indicating that the stock is overfished.

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, bag limits throughout the inner and outer sounds, and the slot limit. Only estimates of Z and F and *SPR* from random-site surveys are considered to be valid and these should be considered with regard to potential violations of the mortality estimates.

The revised method of estimating Z and F using only males, rather than using the conventional method where male and female age compositions were combined, has resulted in higher estimates of mortality (see Table 11).

Most female blue cod in Marlborough Sounds have historically been less than 33 cm in length (see Figure 28) and, in 2021, 82% of female blue cod were less than 33 cm in Marlborough Sound. 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.

4.4 Population response to fisheries management regulations

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 (see Figure 25). 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'. 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.

The Marlborough Sounds random-site surveys (2013, 2017, and 2021) have not shown any clear increases in abundance, size, or a change in the high proportion of males, despite the reduced bag limit of 2 blue cod and increase in MLS to 33 cm in December 2015 (see Figures 25, 27, and 28).

4.5 Long Island-Kokomohua Marine Reserve survey

The key finding from the random-site surveys of Long Island Marine Reserve in 2017 and 2021 was that blue cod were more abundant and larger inside the marine reserve; catch rates were 5- and 6-fold greater in the marine reserve than outside in the adjacent fished strata in Queen Charlotte Sound (Figure 32), and mean length was 3 cm and 5 cm larger, in 2017 and 2021, respectively (Figure 33). The proportion of blue cod catch rates that were recruited fish (33 cm and over) was also greater in the marine reserve at 78% and 86% compared with 38% and 45% outside, in 2017 and 2021, respectively (see Figure 32). Further, only 7% and 10% of pots were empty in the marine reserve compared with 39% and 47% outside in 2017 and 2021, respectively, indicating that blue cod distribution was less patchy within the reserve (Figure 34).

The mean and median condition factor of blue cod in 2021 was substantially higher in the marine reserve than outside (Table 10, see Figure 24), even for fish of comparable size, indicating that gonad stage did not contribute to this difference. The higher condition factor indicates that blue cod are heavier for a given length in the marine reserve; the reasons for this difference are outside the scope of this report. Surprisingly, the abundance of bycatch species was very low in the marine reserve compared with other strata in Marlborough Sounds (see Table 3B).

These potting survey results are consistent with a time series of line fishing surveys of the marine reserve and adjacent fished areas that 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 in taking a baited hook than larger fish (Rob Davidson pers. comm.) and this may have biased the abundance and size estimates from the line fishing survey in the marine reserve downward.

The results are a clear indicator that fishing effort in Queen Charlotte Sound and throughout the Marlborough Sounds has markedly reduced blue cod size and, particularly, abundance. The authors 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 continue 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 the Department of Conservation.

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7. TABLES

Table 1: Fixed- and random-site blue cod potting survey time series in the Marlborough Sounds by region, including the 2021 survey. See Figure 3 for locations of regions. Surveys before 2013 were carried out on F.V. *Lady H R* and thereafter on the NIWA vessel R.V. *Ikatere*. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait; SEPR, Separation Point; LIMR, Long Island Marine Reserve; all, all strata surveyed; partial, not all strata surveyed; – no survey.

	Fixed-site surveys by region					Random-site surveys by region				
Year	QCH	PEL	DUR	CKST	SEPR	QCH	PEL	DUR	CKST	LIMR
1995	all	partial	–	–	–	–	–	–	–	–
1996	–	all	partial	–	–	–	–	–	–	–
2001	all	all	partial	–	–	–	–	–	–	–
2004	all	all	all	–	all	–	–	–	–	–
2007	all	all	all	–	all	–	–	–	–	–
2008	–	–	–	all	–	–	–	–	–	–
2010	all	all	all	–	–	–	partial	partial	all	–
2013	all	all	all	–	–	all	all	all	all	–
2017	all	all	all	–	–	all	all	all	all	all
2021	–	–	–	–	–	all	all	all	all	all

Table 2: Regions, strata names, codes, area (coastline length), number of sites, number of pots, catch of blue cod (in number and weight), and depth sampled for the 2021 random-site Marlborough Sounds potting survey. 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	Random	3		27	14	6.5	16.7	6	33
QCH	2	OQCH	176.6	Random	7		63	207	84.2	14.0	5	38
QCH	3	EQCH	83.1	Random	8		72	214	104.3	11.4	5	30
PEL	4	EOPE	69.5	Random	6		54	131	64.2	12.6	5	29
PEL	5	OPEL	94.8	Random	4		36	78	37.6	12.9	4	77
DUR	6	DURE	105.1	Random	3	6	81	396	193.9	11.0	5	23
PEL	7	IPEL	100.1	Random	3		27	13	5.2	9.9	5	19
PEL	8	MPEL	72.3	Random	5		45	27	12.5	8.7	5	14
DUR	9	DURW	96.2	Random	8		72	269	147.8	10.5	5	24
CKST	11	APAE	21.6	Random	5		45	188	95.8	26.8	6	53
CKST	12	COOK	30.0	Random	5		45	38	18.7	13.2	7	25
CKST	13	UNDW	34.0	Random	3		27	4	1.9	10.3	5	18
Totals					60	6	594	1 579	772.6	13.2	4	77
QCH	14	LIMR	10.0	Random	8		72	748	574.9	14.4	5	32

Table 3: Total catch and numbers of blue cod and bycatch species caught on the 2021 Marlborough Sounds random-site potting survey (A) and in the Long Island Marine Reserve potting survey (B).

(A)

Common name	Species	Code	Catch (kg)	Number	% catch
Blue cod	*Parapercis colias*	BCO	772.6	1 579	75.59
Banded wrasse	*Notolabrus fucicola*	BPF	171.1	59	16.74
Common octopus	*Macroctopus maorum*	OCT	42.7	9	4.18
Carpet shark	*Cephaloscyllium isabella*	CAR	8.9	3	0.87
Scarlet wrasse	*Pseudolabrus miles*	SPF	6.4	9	0.63
Southern conger	*Conger verreauxi*	CVR	6.0	1	0.59
Starfish	Asteroidea & Ophiuroidea	SFI	4.3	40	0.42
Red mullet	*Upeneichthys lineatus*	RMU	3.3	5	0.32
Spotted wrasse	*Notolabrus celidotas*	STY	2.3	12	0.23
Tarakihi	*Nemadactylus macropterus*	NMP	1.4	3	0.14
Copper moki	*Latridopsis forsteri*	CMO	1.1	1	0.11
Triplefin	Tripterygiidae	TRP	0.7	8	0.07
Leatherjacket	*Meuschenia scaber*	LEA	0.6	2	0.06
Crab	Decapod	CRB	0.5	7	0.05
Dwarf scorpionfish	*Scorpaena papillosa*	RSC	0.2	2	0.02
Totals			1 022.1	1 740	

(B)

Common name	Species	Code	Catch (kg)	Number	% catch
Blue cod	*Parapercis colias*	BCO	574.9	748	98.97
Common octopus	*Macroctopus maorum*	OCT	5.0	1	0.86
Scarlet wrasse	*Pseudolabrus miles*	SPF	0.7	1	0.12
Leatherjacket	*Meuschenia scaber*	LEA	0.3	1	0.05
Totals			580.9	751	

Table 4: Mean catch rates for all blue cod and recruited blue cod (33 cm and over) caught from the 2021 Marlborough Sounds random-site potting survey 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.

				All blue cod			Recruited blue cod (33 cm and over)		
Region	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	27	0.24	0.12	50.4	0.16	0.08	50.0
	2 (OQCH)	Random	63	1.34	0.51	38.4	0.54	0.22	39.9
	3 (EQCH)	Random	72	1.45	0.22	15.0	0.72	0.08	10.6
	Overall		**162**	**1.21**	**0.31**	**25.2**	**0.53**	**0.13**	**23.9**
PEL	4 (EOPE))	Random	54	1.19	0.40	34.0	0.69	0.23	32.7
	5 (OPEL)	Random	36	1.04	0.37	35.7	0.60	0.19	32.0
	7 (IPEL)	Random	27	0.19	0.10	50.0	0.08	0.05	66.6
	8 (MPEL)	Random	45	0.28	0.14	52.0	0.14	0.07	51.7
	Overall		**162**	**0.66**	**0.14**	**21.4**	**0.36**	**0.07**	**20.5**
DUR	6 (DURE)	Random	81	2.39	0.68	28.2	1.28	0.33	25.5
	9 (DURW)	Random	72	2.05	0.68	33.2	1.40	0.48	34.2
	Overall		**153**	**2.23**	**0.48**	**21.5**	**1.34**	**0.29**	**21.3**
CKST	11 (APAE)	Random	45	2.13	0.36	17.1	1.18	0.30	25.9
	12 (COOK)	Random	45	0.42	0.19	45.0	0.26	0.12	46.9
	13 (UNDW)	Random	27	0.07	0.07	100.0	0.05	0.05	100.0
	Overall		**117**	**0.71**	**0.12**	**16.3**	**0.41**	**0.09**	**22.1**
MS	**Overall**	**Random**	**594**	**1.18**	**0.15**	**13.0**	**0.64**	**0.08**	**12.6**
QCH	14 (LIMR	Random	72	7.98	1.04	13.0	6.89	0.99	14.3

Table 5: Descriptive statistics for blue cod caught on the 2021 Marlborough Sounds and random-site potting survey. Mean length and sex ratio are raw (not scaled to the catch) for each stratum and weighted overall. Recruited size is 33 cm and over. See Table 2 for region and stratum names. m, male; f, female; u, unsexed, excl., excluding; –, no data. (Continued on next page)

					Length (cm)			Percent male	
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited
QCH	1 (IQCH)	Random	m	9	32.6	22.9	37.2	64.1	82.3
			f	5	26.4	18.8	33.5		
			u	–	–	–	–		
	2 (OQCH)	Random	m	148	30.9	17.5	40.6	72.0	94.6
			f	58	28.9	11.0	37.0		
			u	1	17.0	17.0	17.0		
	3 (EQCH)	Random	m	173	31.9	18.6	49.3	80.5	89.0
			f	41	29.6	16.4	39.2		
			u	–	–	–	–		
QCH	Overall	Random	m	330	30.9	17.5	49.3	74.4	92.1
			f	104	28.6	11	39.2		
			u	1	17.0	–	–		
QCH	14 (LIMR)	Random	m	–	–	–	–		
			f	–	–	–	–		
			u	748	36.1	18.9	50.0		

					Length (cm)			Percent male	
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited
PEL	7 (IPEL)	Random	m	7	33.2	30.5	41.1	53.6	100
			f	6	27.5	19.8	31.3		
			u	–	–	–	–		
	8 (MPEL)	Random	m	19	33.6	29.7	46.2	71.5	100
			f	8	28.5	25.6	32.0		
			u	–	–	–	–		
	5 (OPEL)	Random	m	63	32.0	17.5	41.7	81.2	85.6
			f	15	31.5	23.5	38.4		
			u	–	–	–	–		
	4 (EOPE)	Random	m	120	32.2	19.8	45.2	91.7	98.3
			f	11	29.1	16.0	33.6		
			u	–	–	–	–		
PEL	Overall	Random	m	209	31.9	17.5	46.2	81.6	92.3
			f	40	29.2	16.0	38.4		
			u	–	–	–	–		

					Length (cm)			Percent male	
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited
DUR	6 (DURE)	Random	m	260	32.8	22.0	45.0	65.6	86.5
			f	136	30.5	23	37.4		
			u	–	–	–	–		
	9 (DURW)	Random	m	158	33.7	18.1	46.1	58.7	68.6
			f	111	31.9	21.0	40.9		
			u	–	–	–	–		
DUR	Overall	Random	m	418	32.8	18.1	46.1	62.8	78.1
			f	247	30.8	21.0	40.9		
			u	–	–	–	–		

					Length (cm)			Percent male	
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited
CKST	11 (APAE)	Random	m	159	32.6	21.7	45.5	84.7	98.5
			f	29	28.5	20.9	33.4		
			u	–	–	–	–		
	12 (COOK)	Random	m	27	33.6	26.0	42.5	71.0	100
			f	11	25.5	19.8	31.2		
			u	–	–	–	–		
	13 (UNDW)	Random	m	2	31.2	25.6	36.8	50.0	50.0
			f	2	31.5	29.0	34.0		
			u	–	–	–	–		
CKST	Overall	Random	m	188	32.3	21.7	45.4	80.4	96.3
			f	42	27.5	20.9	34.0		
			u	–	–	–	–		

					Length (cm)			Percent male	
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited
MS (excl. LIMR)	Overall	random	m	1 145	31.8	17.5	49.3	71.7	86.2
			f	433	29.7	11.0	40.9		
			u	1	17	17	17		

Table 6: Otolith ageing data used in the catch-at-age, *Z* estimates, and in the *SPR* analyses for the 2021 Marlborough Sounds blue cod survey.

			Length of aged fish (cm)		Age (years)	
Survey strata	Sex	No. otoliths	Minimum	Maximum	Minimum	Maximum
QCH	Male	100	17	49	2	10
	Female	103	11	39	1	21
PEL	Male	61	17	46	2	8
	Female	32	19	38	2	12
DUR	Male	101	18	46	2	12
	Female	59	21	40	3	17
CKST	Male	89	21	45	3	12
	Female	40	19	34	3	7
Overall	Male	351	17	49	2	12
	Female	234	11	40	1	21
		585				

Table 7: Gonad stages of Marlborough Sounds blue cod in September–October 2021 by region. Stages are: 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*
QCH	Males	1.5	17.9	40.3	37.0	3.3	303
	Females	17.3	21.2	43.3	15.4	2.9	104
PEL	Males	1.9	25.8	56.5	9.6	6.2	209
	Females	15.0	10.0	40.0	35.0		40
DUR	Males	1.0	61.0	29.4	5.7	2.9	418
	Females	4.5	15.4	44.1	35.6	0.4	247
CKST	Males	3.2	30.3	29.8	22.9	13.8	188
	Females	52.4	19.0	19.0	4.8	4.8	42
All regions	Males	1.7	37.1	37.6	18.3	5.4	1 145
	Females	13.2	16.6	41.1	27.7	1.4	433

Table 8: Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals (CI) for blue cod from the 2021 Marlborough Sounds random-site blue cod potting survey for all regions combined. Results are for males only. AgeR, age-at-full recruitment (years).

Sex	AgeR	*Z*	Lower CI	Upper CI
Males	5	0.74	0.49	1.02
	6	0.65	0.43	0.90
	7	0.91	0.60	1.33
	8	0.66	0.43	0.93
	9	0.82	0.50	1.26
	10	1.08	0.59	1.66

Table 9: Mortality parameter (*Z*, *F*) and 95% confidence intervals at three values of *M* for blue cod from the 2021 Marlborough Sounds random-site potting survey for all regions combined. Results are for males only, where AgeR (6 years) is the age at which males reached minimum legal size (MLS) of 33 cm plus one year. AgeR, age-at-full recruitment; *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality; CI, 95% confidence intervals.

Sex	*M*	*Z* (CIs)	*F* (CIs)
Males	0.14	0.65 (0.43–0.90)	0.51 (0.29–0.76)
	0.17	0.65 (0.43–0.90)	0.48 (0.26–0.73)
	0.20	0.65 (0.43–0.90)	0.45 (0.23–0.70)

Table 10: Fulton's mean condition factor (*K*) for blue cod for the 2017 and 2021 Marlborough Sounds random-site blue cod potting surveys. Mean values are shown for all strata combined, all strata excluding LIMR, LIMR, and outside LIMR. LIMR, Long Island Marine Reserve. Outside refers to combined strata OQCH and EQCH.

		Mean (*K*)			
Survey	Size	All strata	All strata excl. LIMR	LIMR	Outside LIMR
2017	All	1.45	1.45	NA	1.44
2021	All	1.50	1.44	1.61	1.41
2021	Below 41 cm	1.49	1.44	1.62	1.41

Table 11: Mortality parameter (*Z*, *F*) estimates and 95% confidence intervals for blue cod from the 2013, 2017, and 2021 Marlborough Sounds fixed- and random-site potting surveys for all regions combined for the default *M* of 0.17. Results are for males only, where AgeR (6 years) is the age at which males reached minimum legal size (MLS) of 33 cm plus one year. AgeR, age-at-full recruitment; *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality; CIs, 95% confidence intervals; MLS, minimum legal size.

Survey	Sex	Site type	*M*	*Z* (CIs)	*F* (CIs)
2013	Males	Fixed	0.17	0.66 (0.46–0.88)	0.49 (0.29–0.71)
2017			0.17	0.77 (0.54–1.03)	0.60 (0.37–0.86)
2013		Random	0.17	0.60 (0.42–0.81)	0.43 (0.25–0.64)
2017			0.17	0.75 (0.52–1.02)	0.58 (0.35–0.85)
2021			0.17	0.65 (0.43–0.90)	0.48 (0.26–0.73)

8. FIGURES

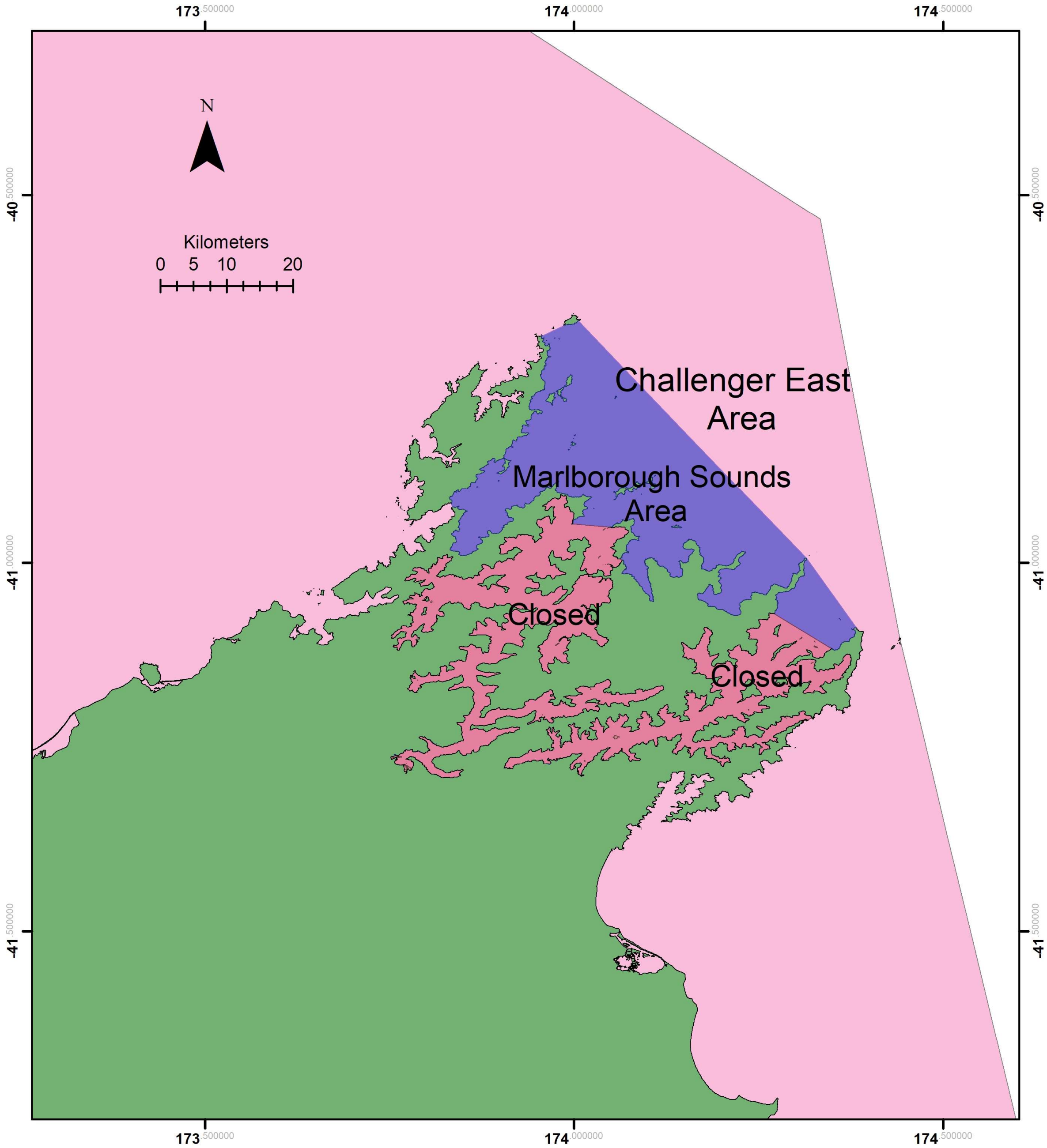


Figure 1: Marlborough Sounds showing fisheries management areas 'Marlborough Sounds Area' and the 'Challenger East Area'. From 1 October 2008 to April 2011, the inner Queen Charlotte Sound and inner Pelorus Sound (part of the Marlborough Sounds Area) were closed to fishing. The Challenger East Area includes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

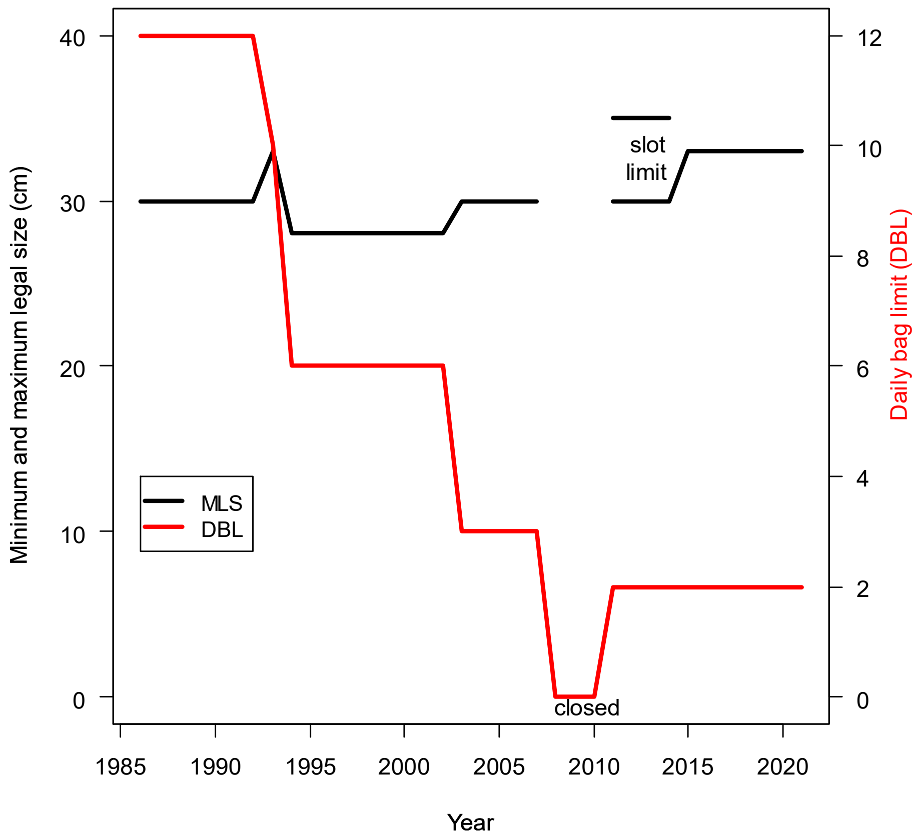


Figure 2: Minimum and maximum legal size (MLS) and daily bag limit (DBL) within the 'Marlborough Sounds Area' since 1985 (see Figure 1 for areas). From 1 October 2008 to April 2011, outside the inner Queen Charlotte and Pelorus Sounds, the minimum legal size was 30 cm and DBL was 3 blue cod.

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

1 October 2008 to April 2011: The Queen Charlotte Sound and Pelorus Sound 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 20 December. In the 'Challenger Area East', the MLS was 30 cm and DBL 3 blue cod.

20 December 2015 to 1 July 2020: 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.

1 July 2020: The area from Farewell Spit to Clarence River (out to 12 nautical miles), including Marlborough Sounds, known as the 'Tasman Area' was assigned a 'traffic light' colour of red by Fisheries New Zealand, indicating that the blue cod stocks in this area are considered to be overfished. The MLS in this area is 33 cm the DBL is 2 per person.

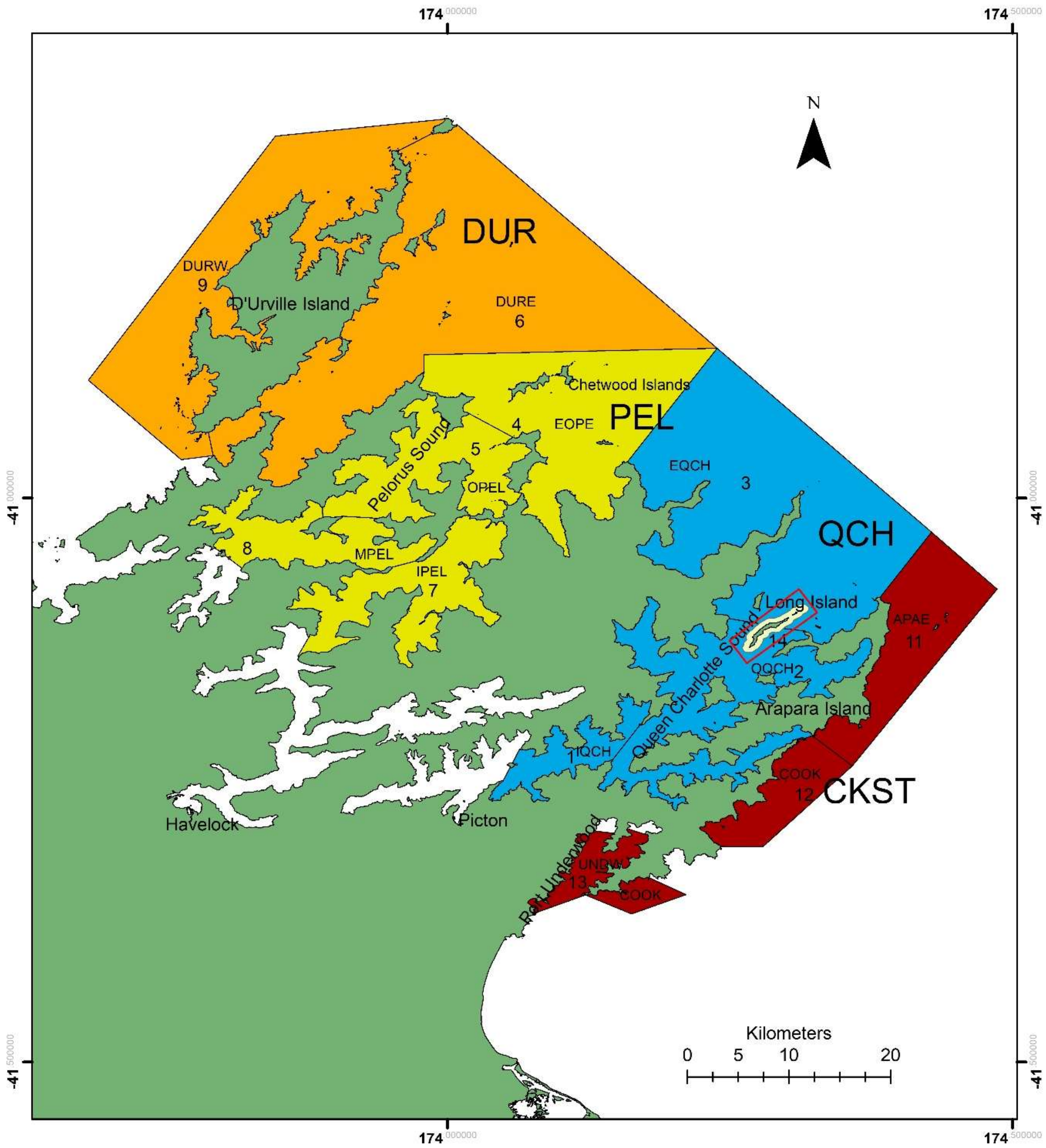


Figure 3: Map of Marlborough Sounds showing the 13 strata surveyed in 2021. The regions are colour coded: orange, D'Urville (DUR); yellow, Pelorus Sound (PEL); blue, Queen Charlotte Sound (QCH); red, Cook Strait (CKST). See Table 2 for strata names. Long Island Marine Reserve was also surveyed in 2021 and is shown in the red box at the head of Queen Charlotte Sound. Stratum 10 (Separation Point) in Tasman Bay is not shown on this figure.

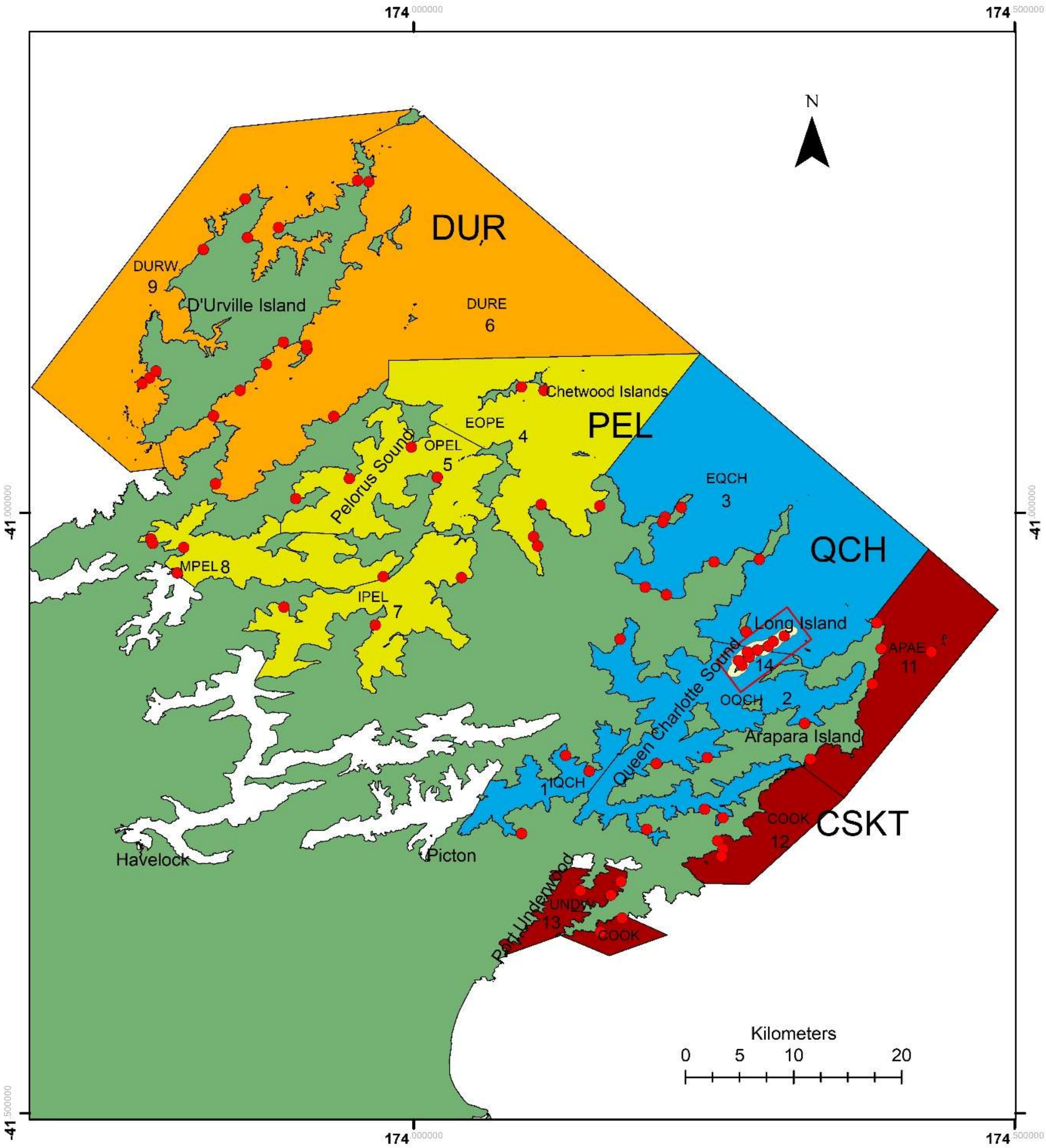


Figure 4: Map of Marlborough Sounds showing the strata and location of the 74 random sites surveyed in 2021, including 8 within the Long Island Marine Reserve. The regions are colour coded: orange, D'Urville (DUR); yellow, Pelorus Sound (PEL); blue, Queen Charlotte Sound (QCH); red, Cook Strait (CKST). See Table 2 for strata names. Long Island Marine Reserve is shown in the red box at the head of Queen Charlotte Sound.

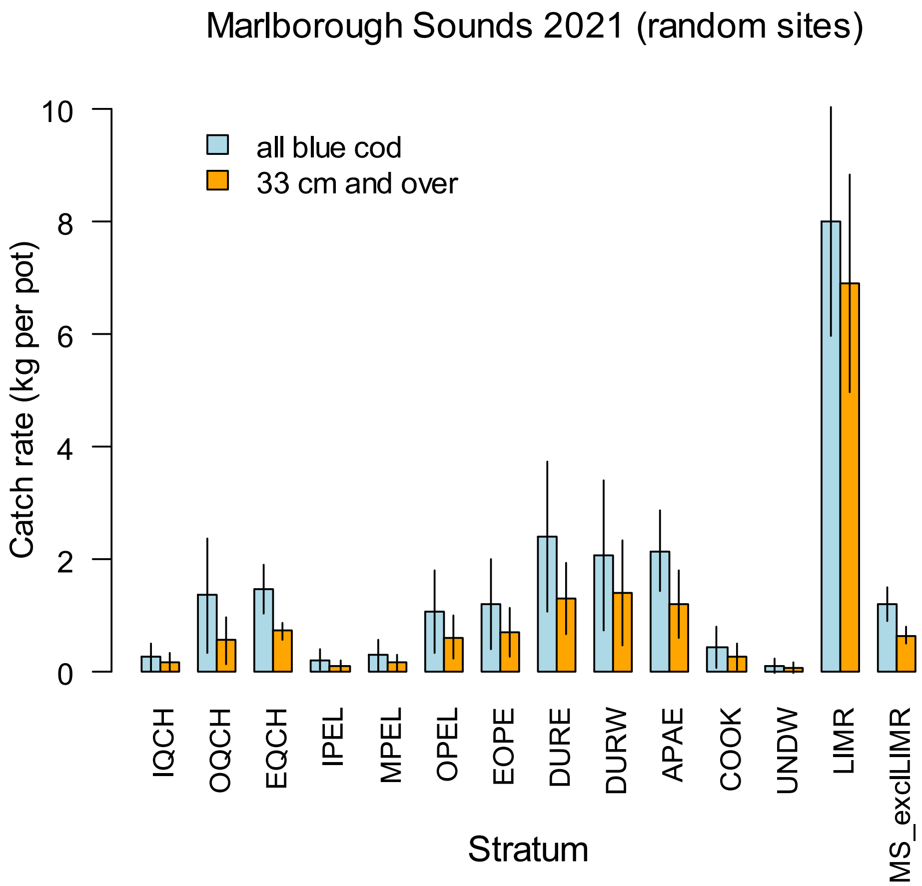


Figure 5: Marlborough Sounds 2021 random-site potting survey catch rates of all blue cod and recruited blue cod by strata and for Marlborough Sounds (MS) overall (all strata combined). Error bars are 95% confidence intervals. See Figure 3 for location of strata and Table 2 for strata names. MS_exclLIMR, Marlborough Sounds excluding Long Island Marine Reserve.

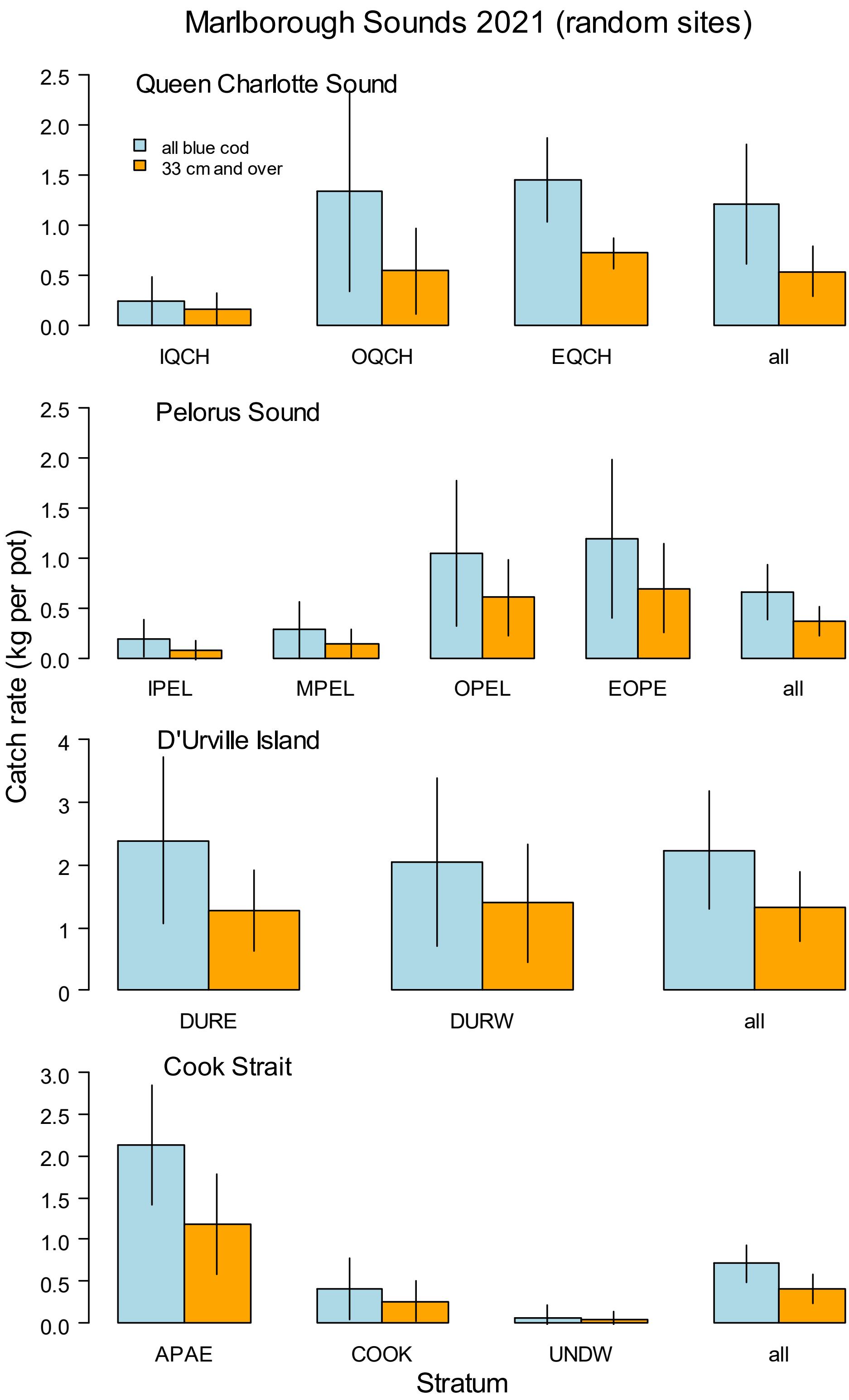


Figure 6: Marlborough Sounds 2021 random-site potting survey catch rates of all blue cod and recruited blue cod by strata and overall for each region. Error bars are 95% confidence intervals. See Figure 3 for location of strata and Table 2 for strata names.

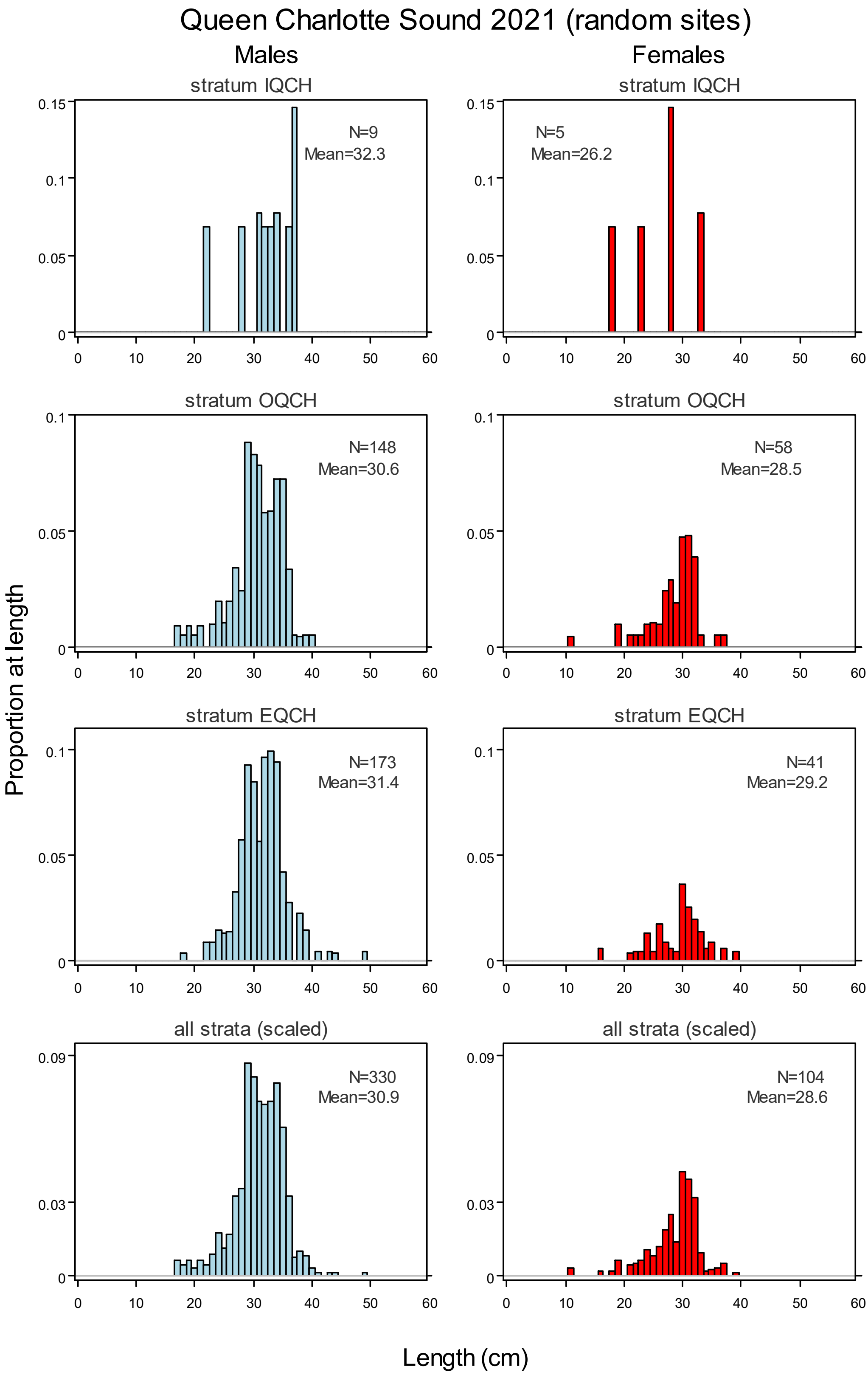


Figure 7: Scaled length-frequency distributions by strata and overall for the 2021 Queen Charlotte Sound random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

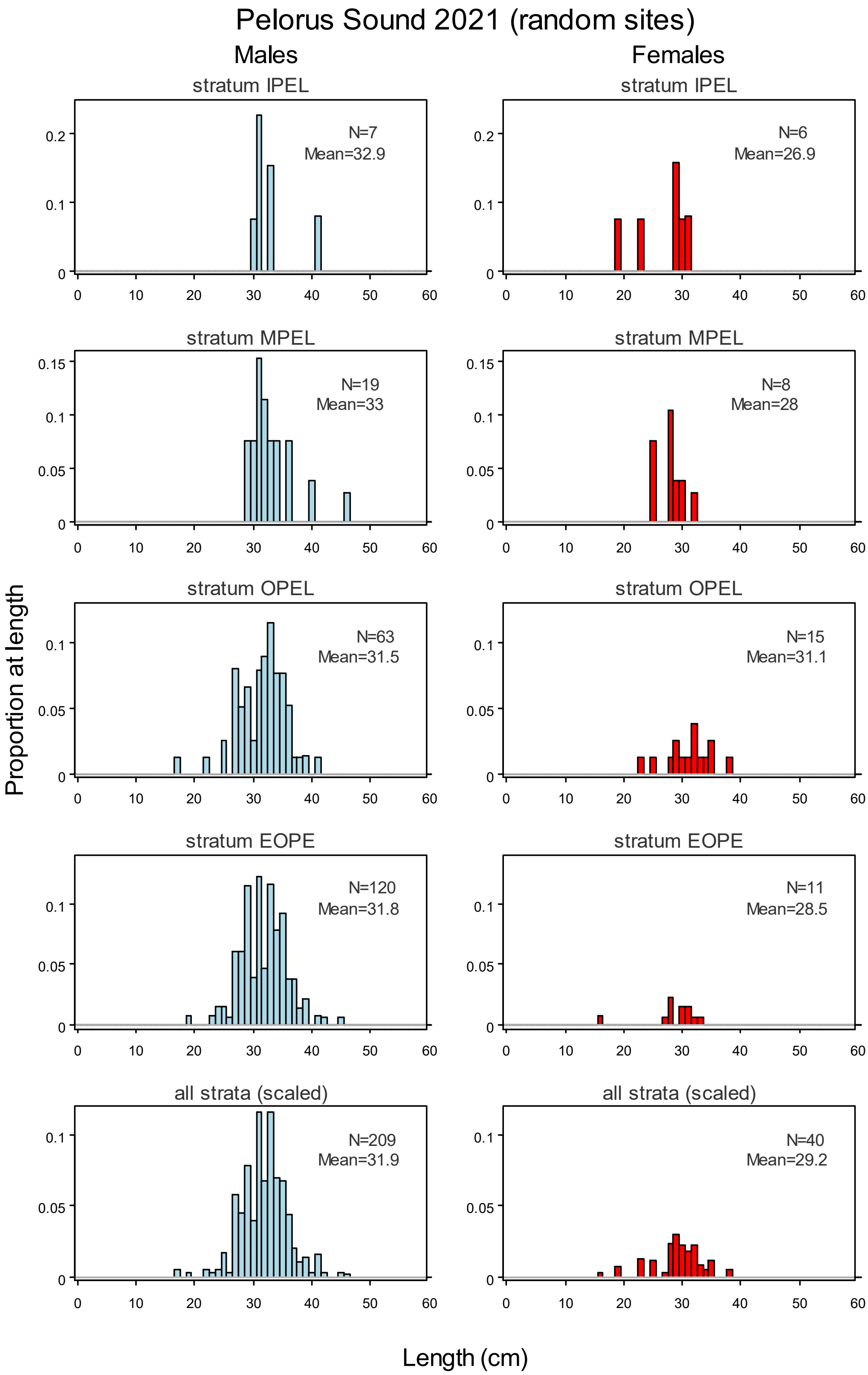


Figure 8: Scaled length-frequency distributions by strata and overall for the 2021 Pelorus Sound random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

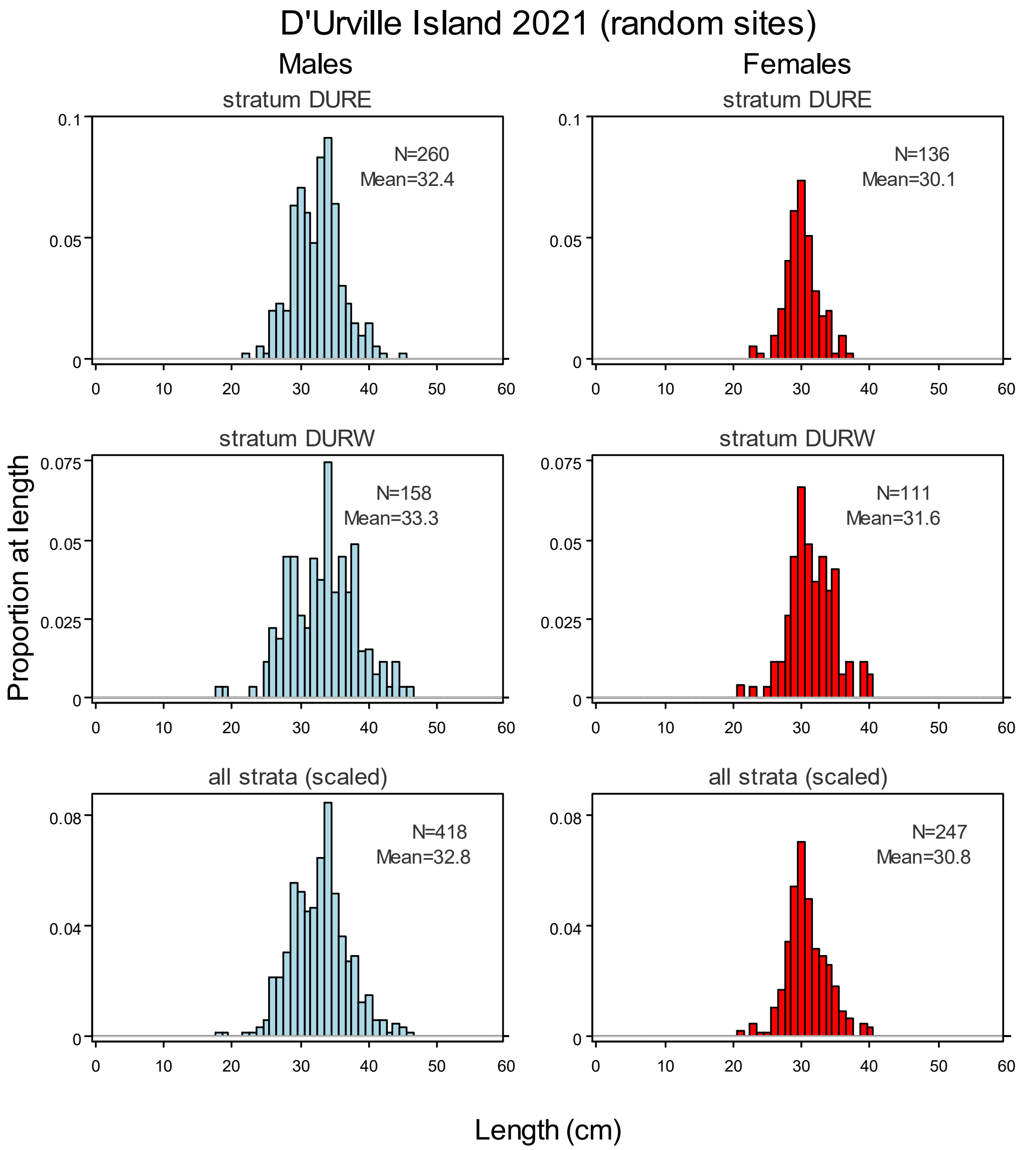


Figure 9: Scaled length-frequency distributions by strata and overall for the 2021 D'Urville Island random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

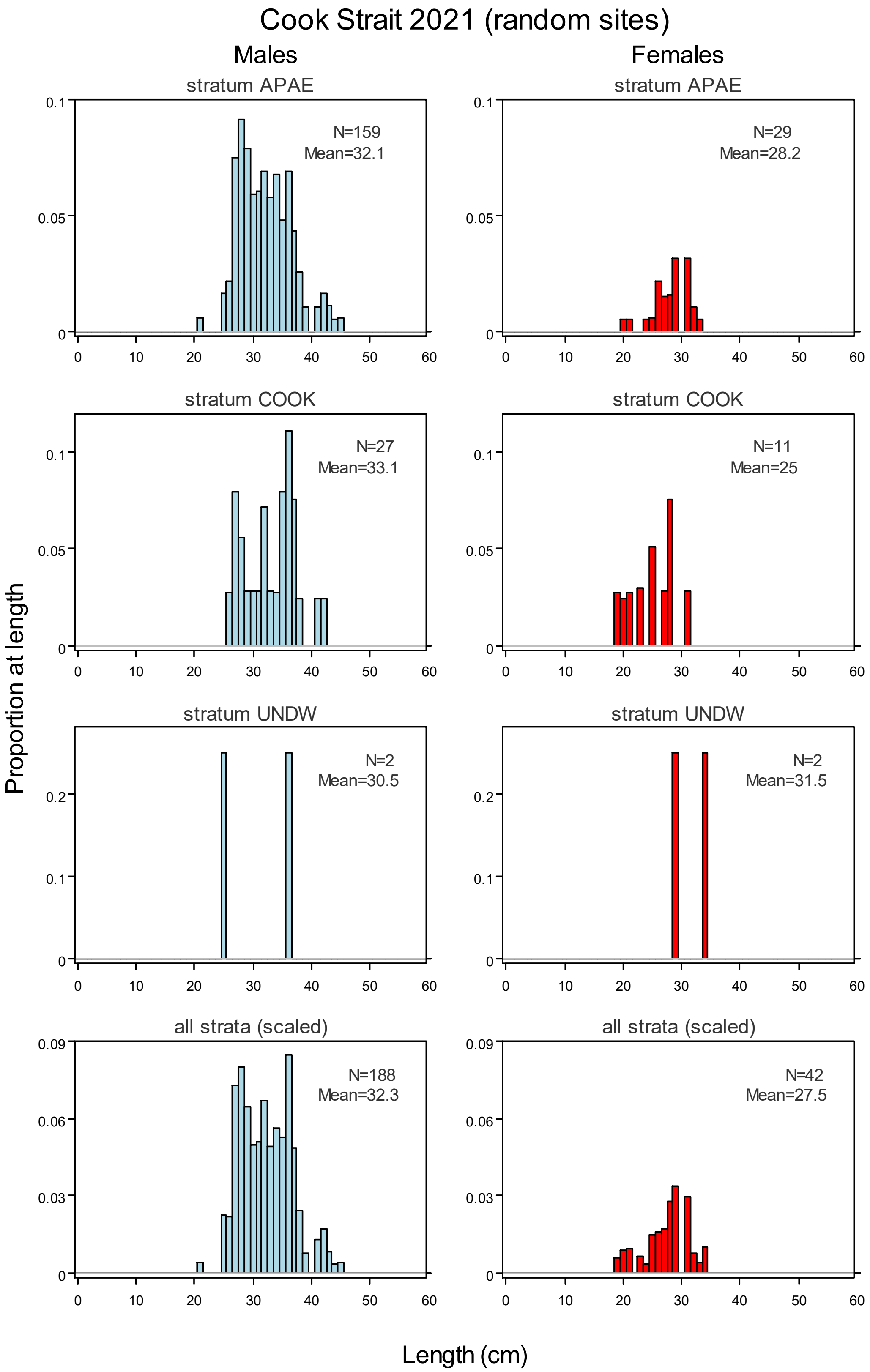


Figure 10: Scaled length-frequency distributions by strata and overall for the 2021 Cook Strait random-site potting survey. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

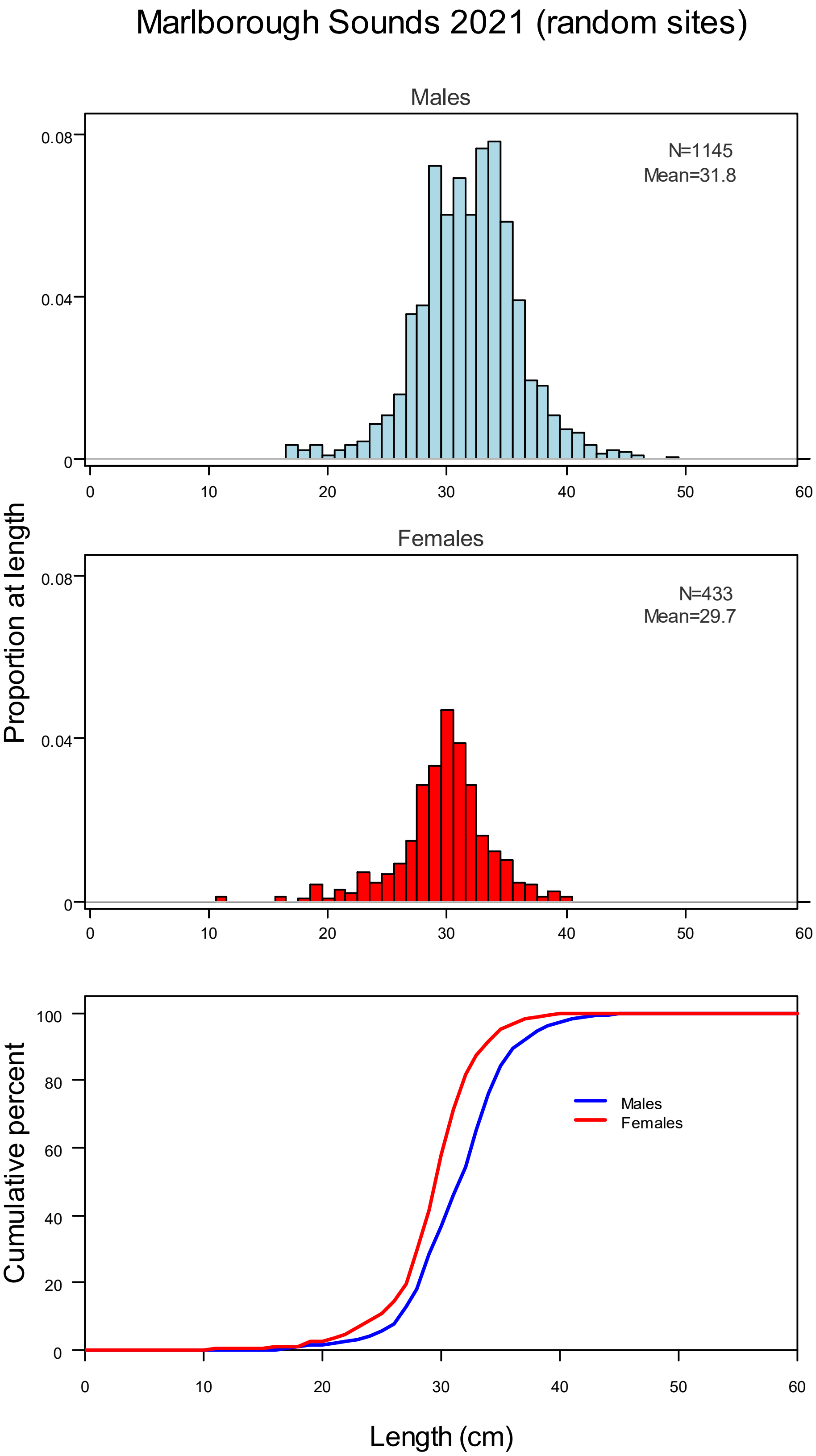


Figure 11: Scaled length-frequency and cumulative distributions for the 2021 Marlborough Sounds random-site potting survey for the 12 strata combined. N, sample numbers; Mean, mean length (cm). Proportions sum to one within each stratum. See Table 2 for strata names.

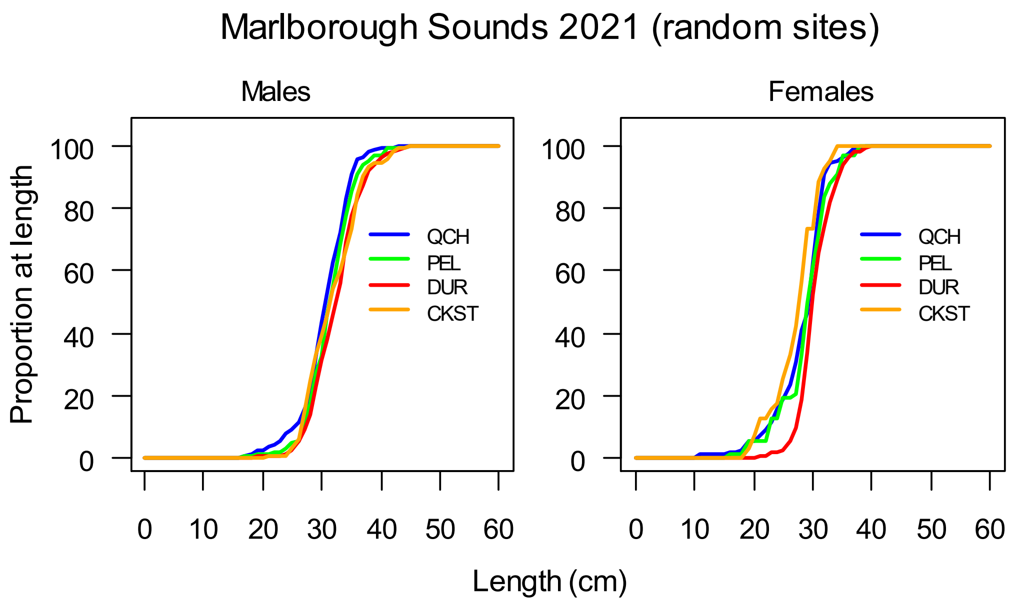


Figure 12: Cumulative distributions of scaled length frequencies for male and female blue cod for the 2021 Marlborough Sounds random-site potting survey by region. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait.

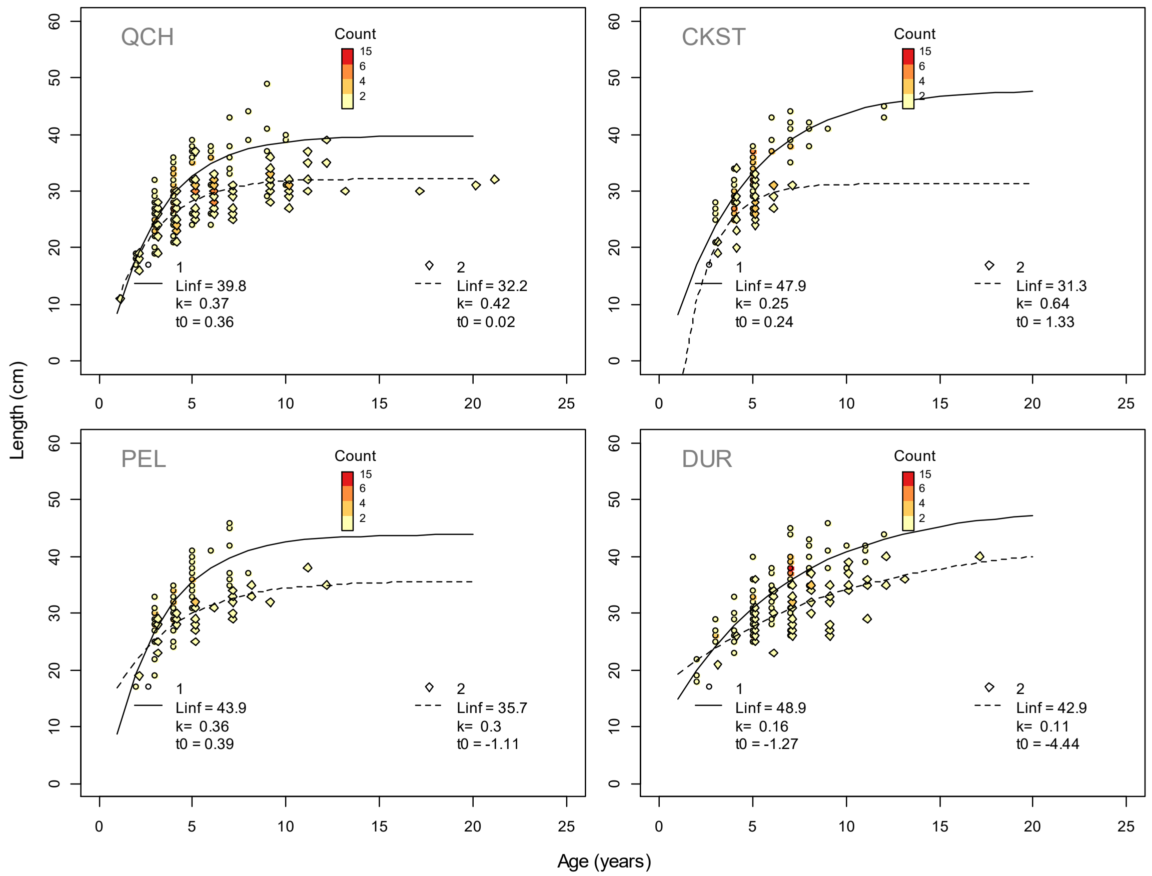


Figure 13: Age and length data by sex and region for blue cod from the 2021 Marlborough Sounds random-site potting survey with von Bertalanffy growth models fitted to the data (males, solid line and circles; females, dotted line and diamonds). QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait. L_{inf} 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.

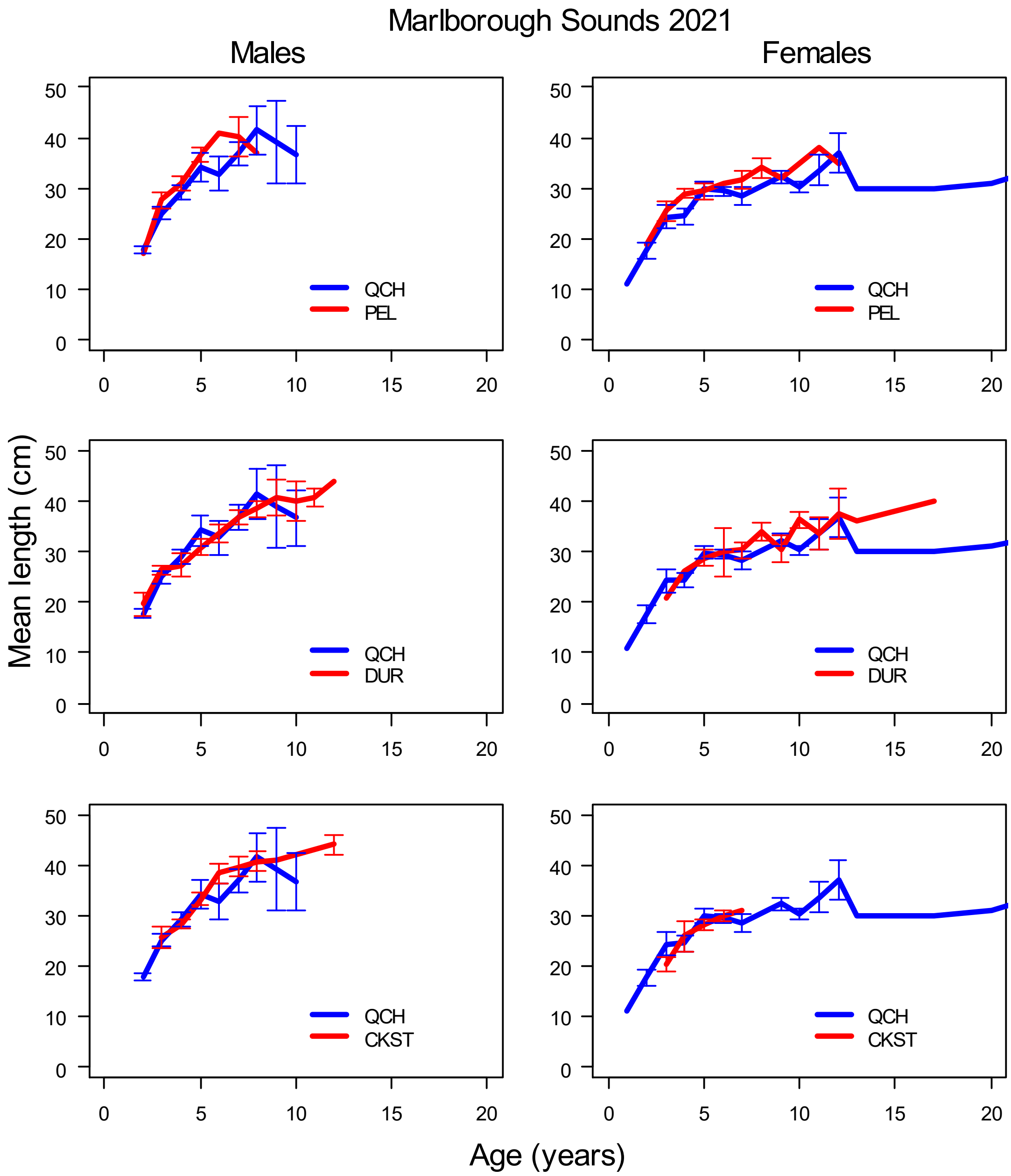


Figure 14: Mean length-at-age by sex for blue cod from the 2021 Marlborough Sounds survey. QCH (blue line) is compared with the other three regions (red lines). Error bars are 95% confidence intervals. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait.

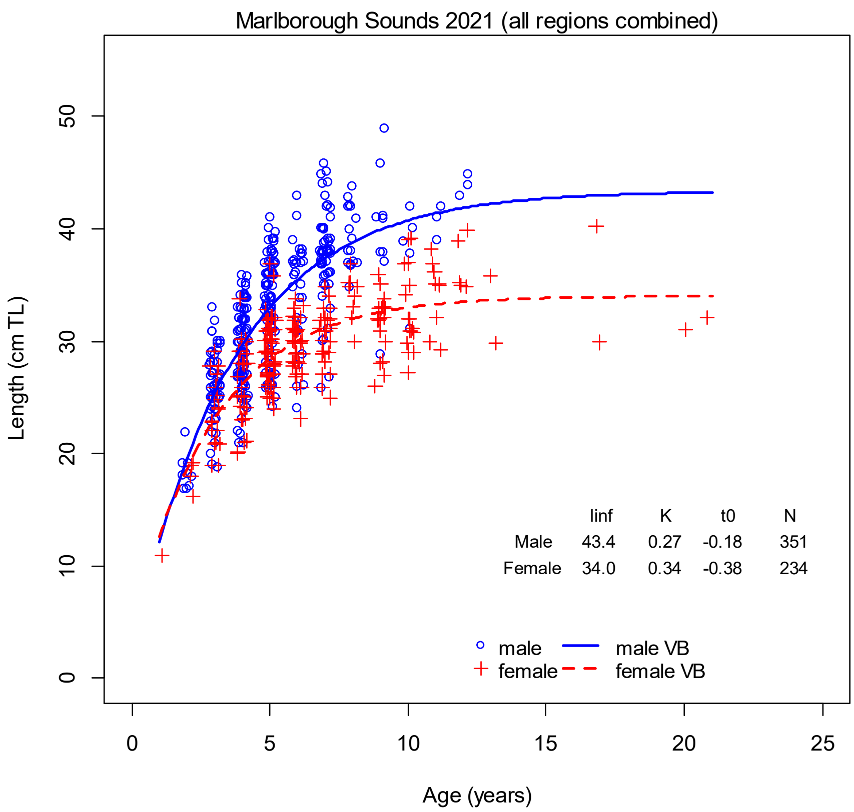


Figure 15: Observed age and length data by sex for blue cod from the 2021 Marlborough Sounds survey (all regions combined) with fitted von Bertalanffy growth models.

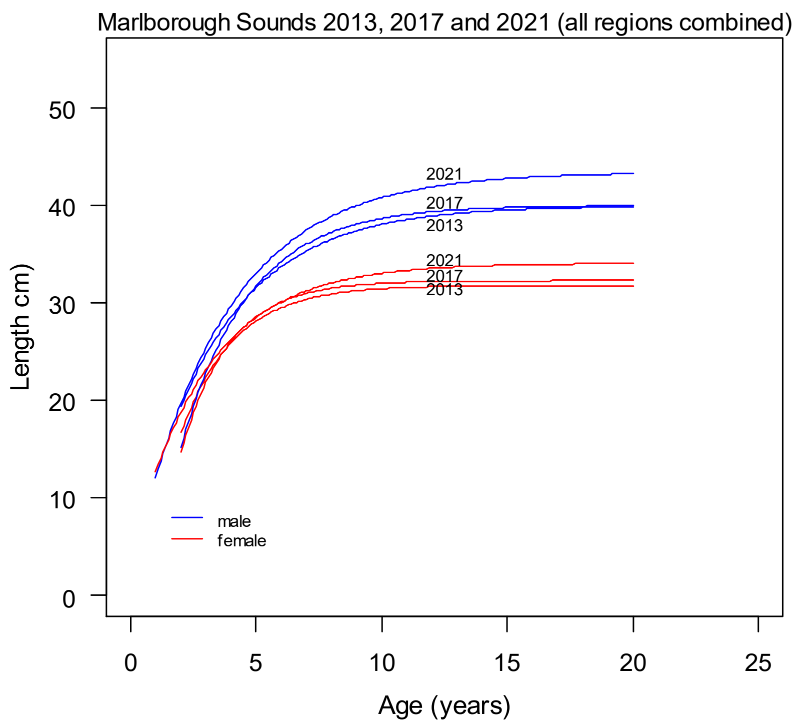


Figure 16: von Bertalanffy growth models fitted to the 2013, 2017, and 2021 blue cod survey age and length data (all regions combined).

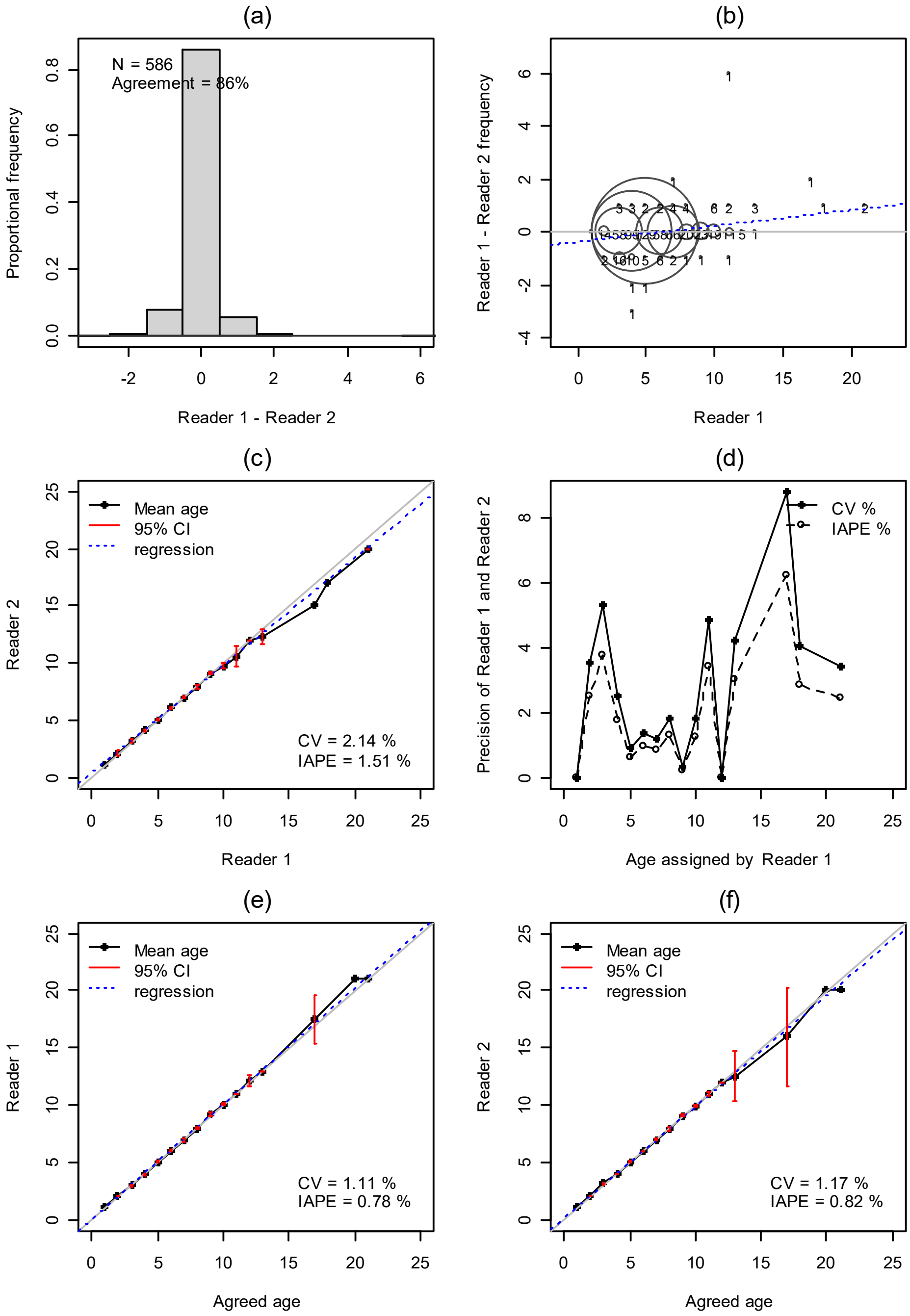


Figure 17: Blue cod otolith reader comparison plots between reader 1 and reader 2 for the 2021 Marlborough Sounds survey: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each 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, c, e, and f, solid lines show perfect agreement, dashed lines show the trend of a linear regression of the actual data.

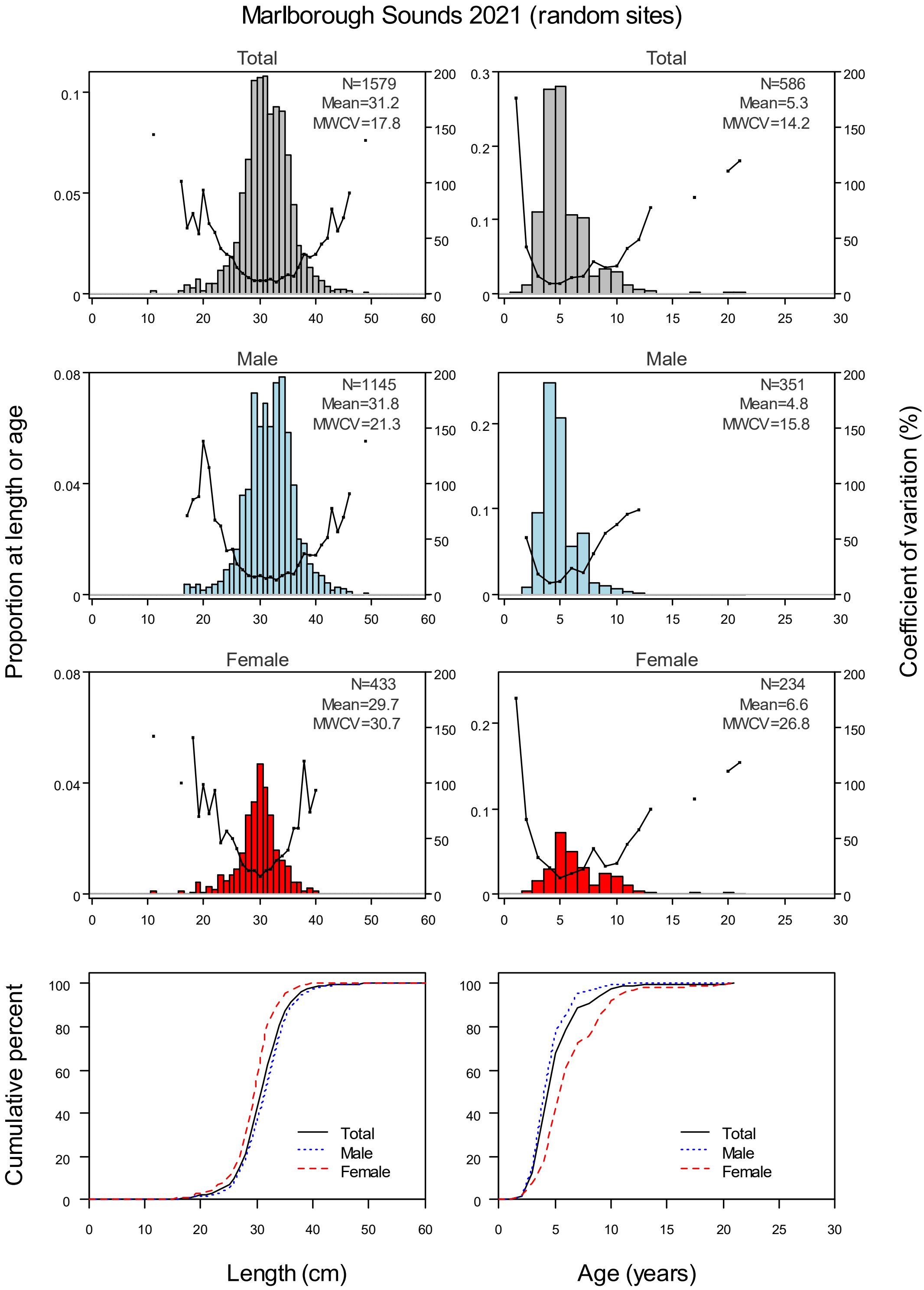


Figure 18: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for the 2021 Marlborough Sounds random-site potting survey (QCH, PEL, DUR and CKST combined). N, sample size; MWCV, mean weighted coefficient of variation (%). Proportions at length or age sum to one.

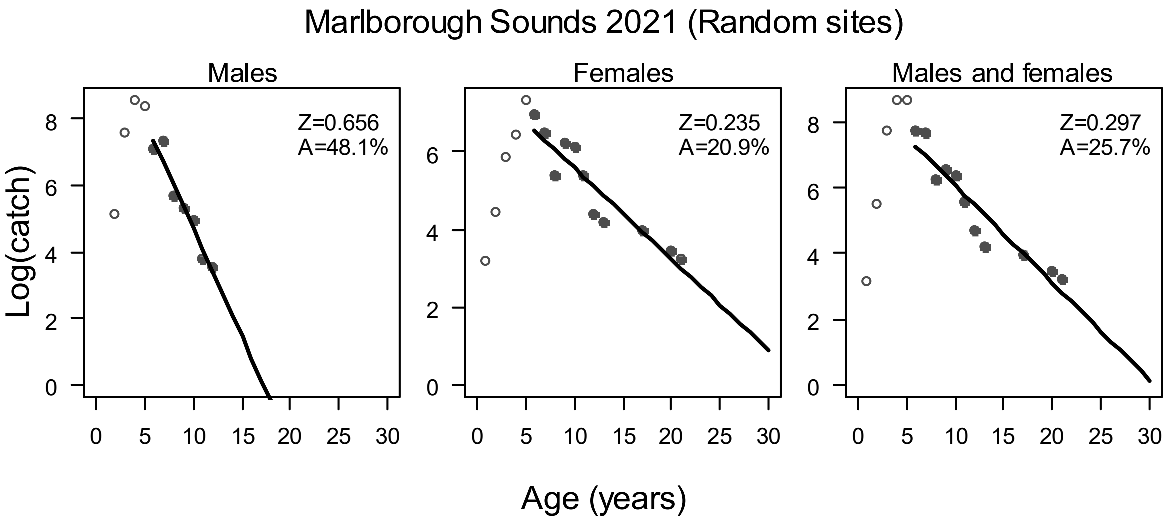


Figure 19: Catch curves (natural log of catch numbers versus age) for the 2021 Marlborough Sounds random-site survey. The regression line is plotted from age-at-full recruitment of 6 years (i.e., dark points on the graph). ***Z*****, instantaneous total mortality;** ***A*****, the annual mortality rate or the proportion of the population that suffers mortality in a given year.**

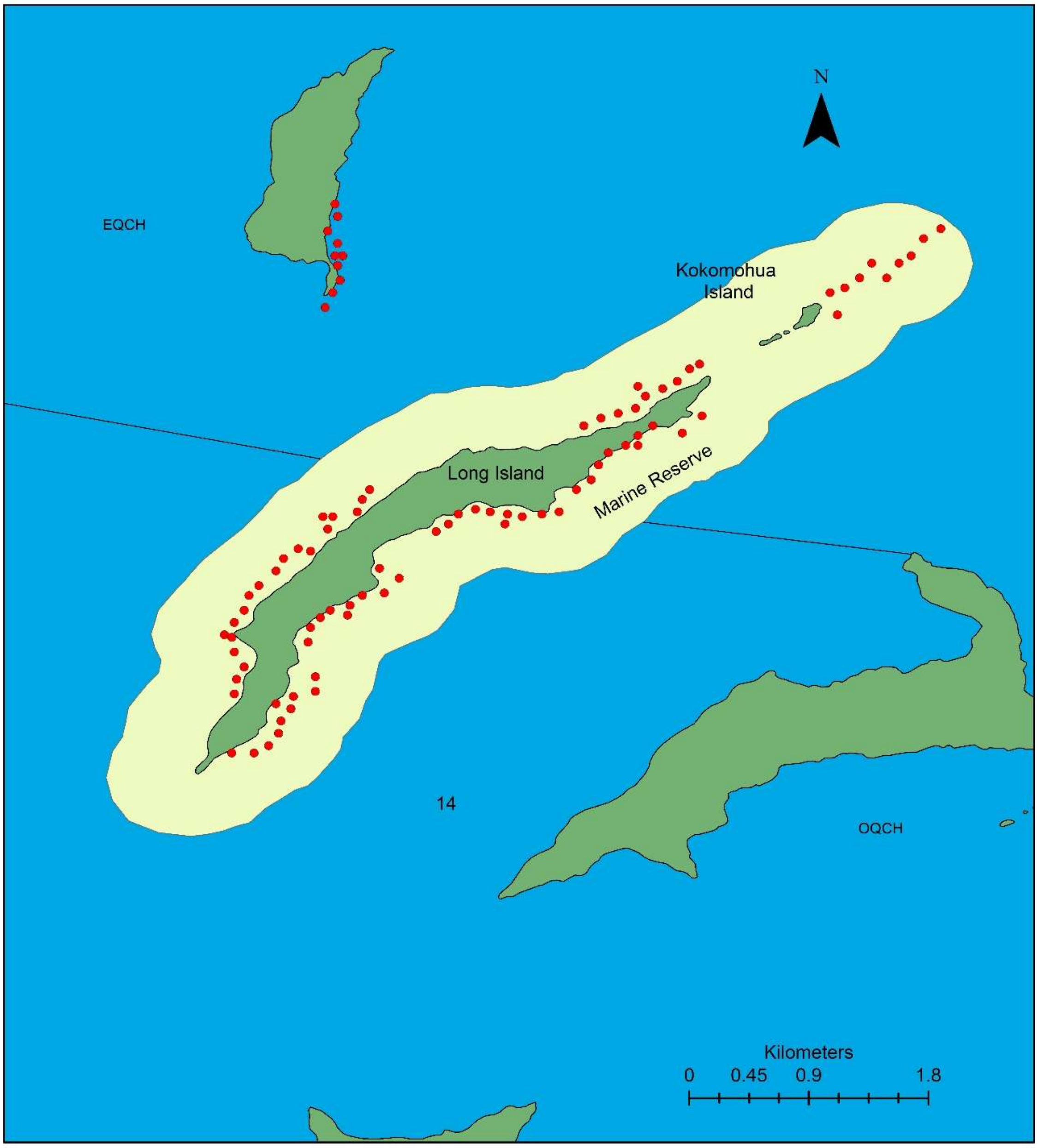


Figure 20: Map of Long Island Marine Reserve showing the eight random sites and 72 pot locations surveyed in 2021. One site with pots is also shown outside of the reserve in stratum EQCH (top left).

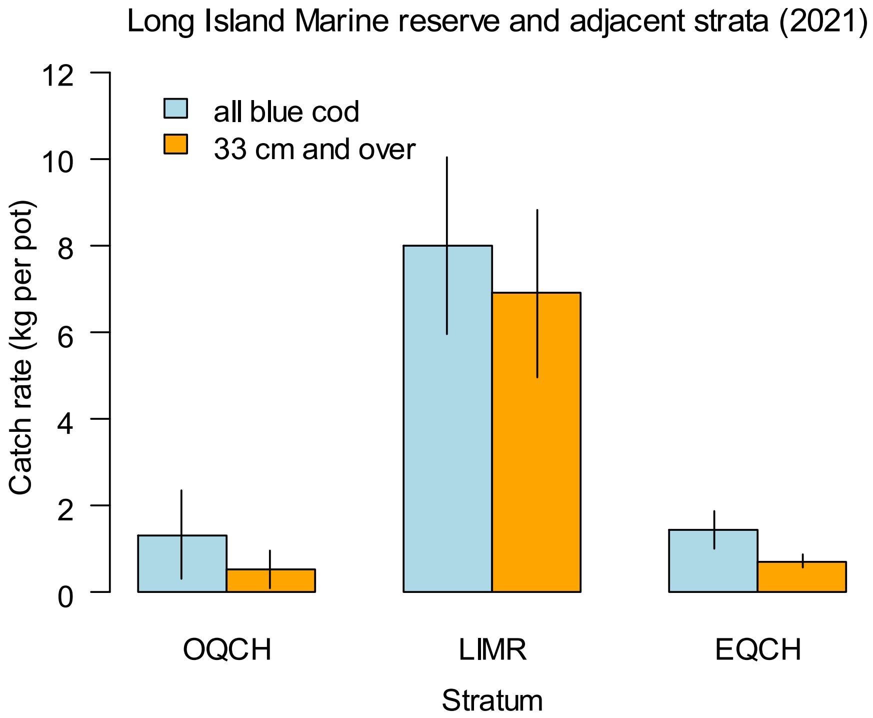


Figure 21: Marlborough Sounds 2021 random-site potting survey catch rates of all blue cod and recruited blue cod from sites inside the Long Island Marine Reserve (LIMR) and from all sites in adjacent strata in Queen Charlotte Sound (OQCH, EQCH). Error bars are 95% confidence intervals. See Figure 3 for location of strata and Table 2 for strata names.

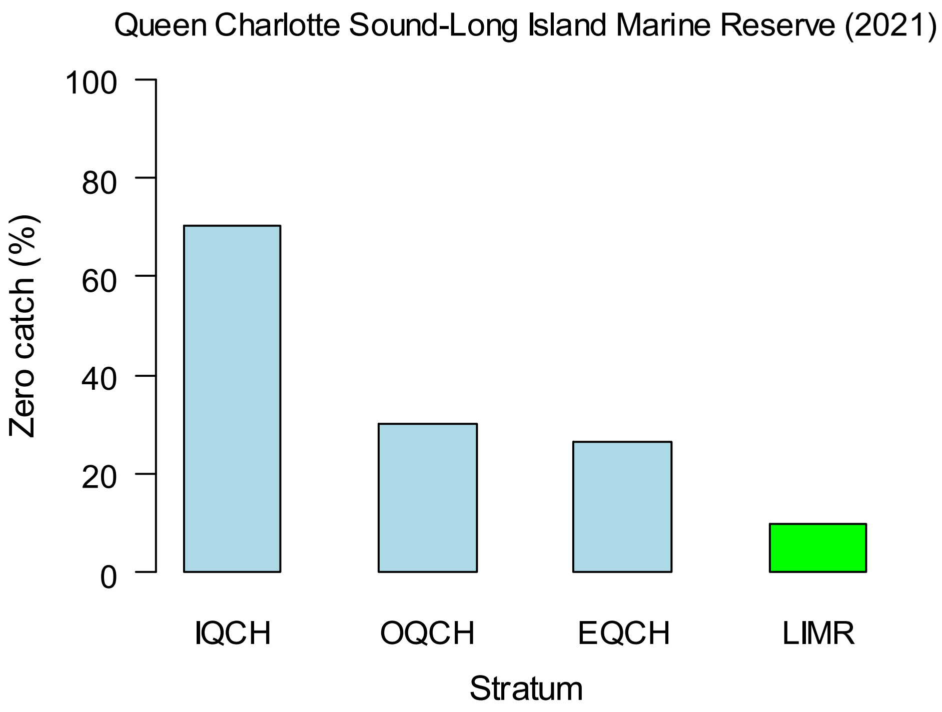


Figure 22: Marlborough Sounds 2021 random-site potting survey proportion of pots with zero blue cod from sites inside the Long Island Marine Reserve (LIMR) and from all sites in Queen Charlotte Sound strata (IQCH, OQCH, EQCH). See Figure 3 for location of strata and Table 2 for strata names.

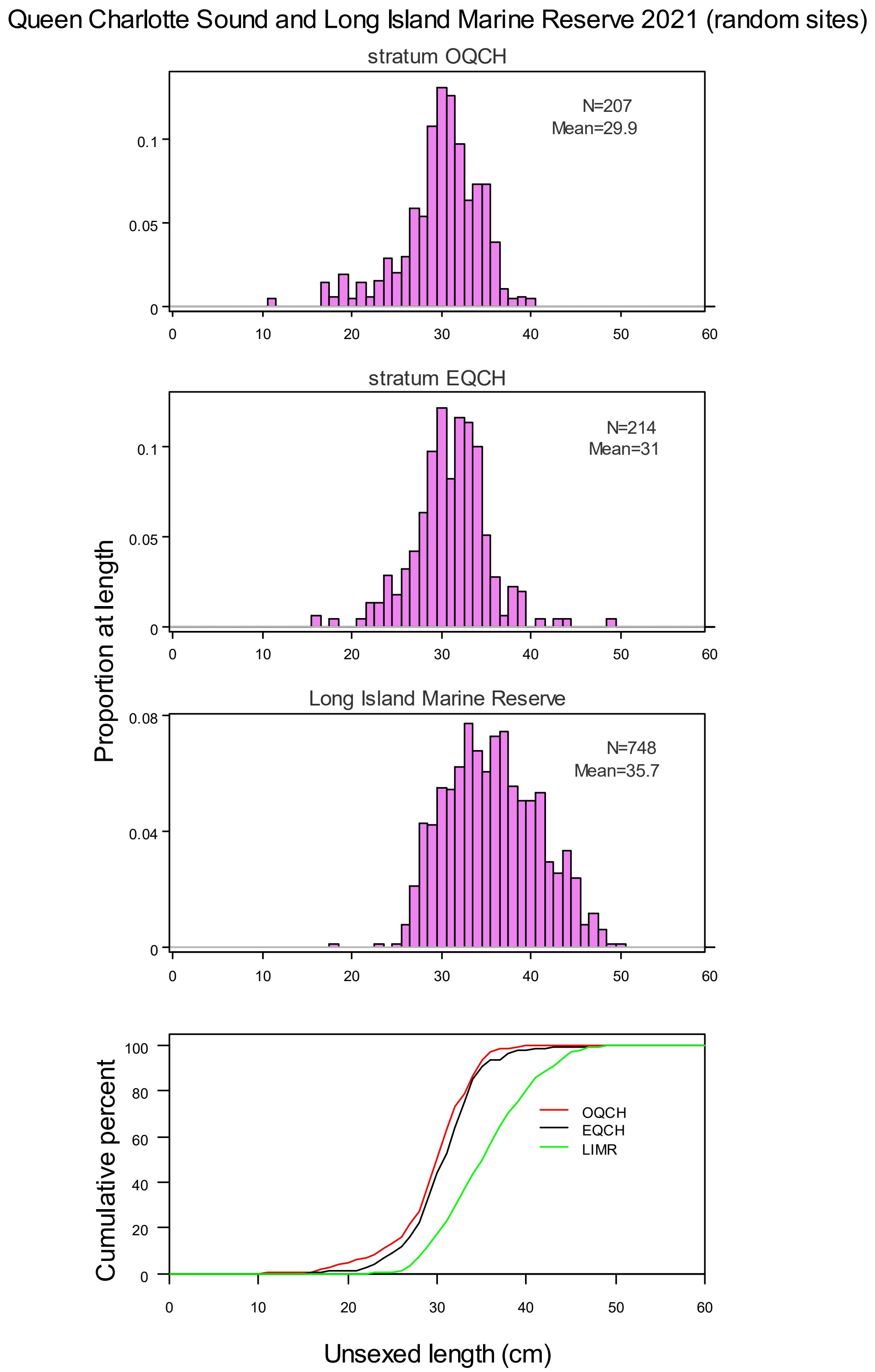


Figure 23: Marlborough Sounds 2021 random-site potting survey scaled length-frequency and cumulative distributions of unsexed blue cod for sites inside Long Island Marine Reserve (LIMR) and from all sites in the adjacent Queen Charlotte Sound strata (OQCH, EQCH). N, sample numbers; Mean, mean length (cm). See Figure 3 for strata locations and Table 2 for strata names.

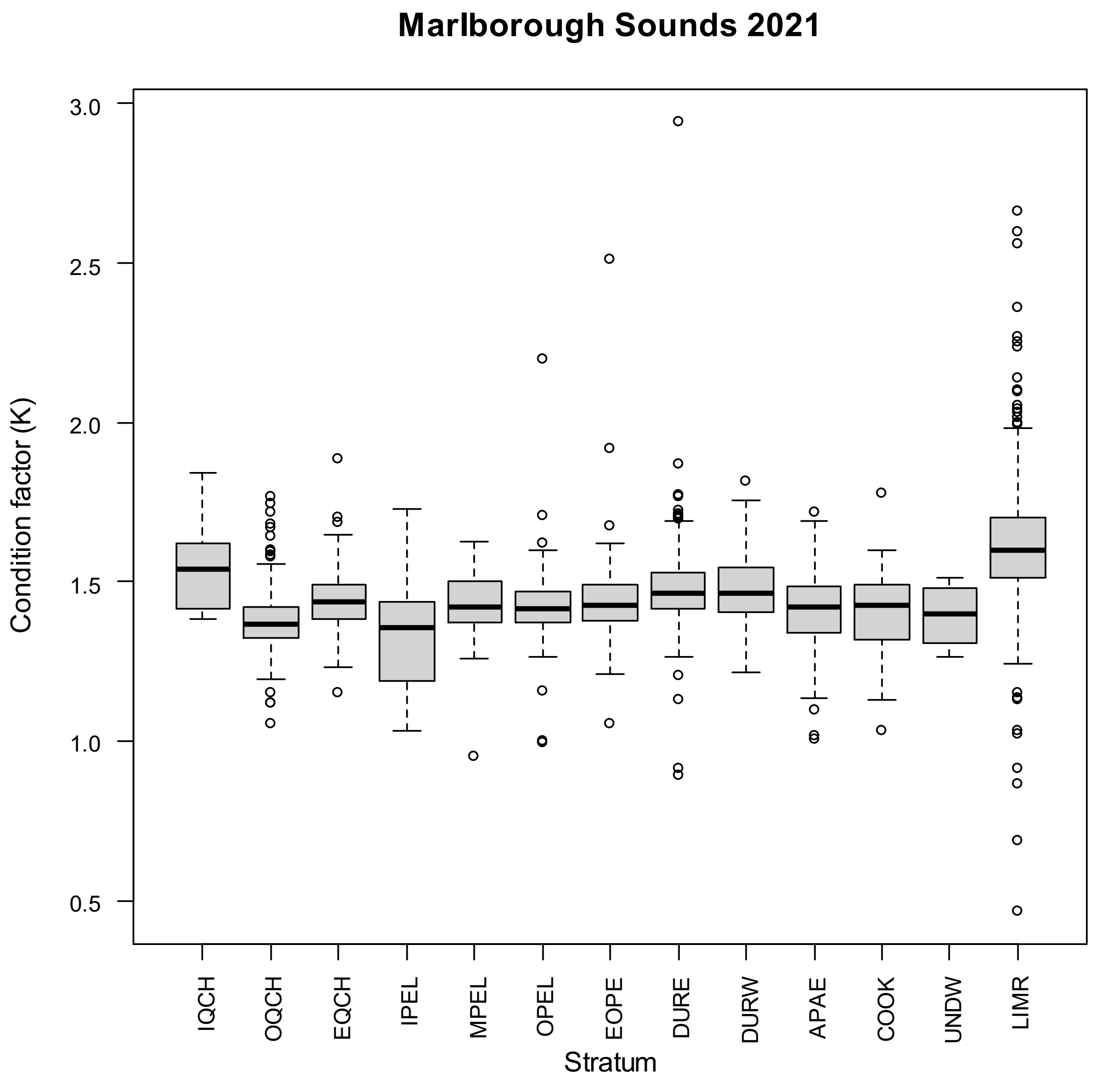


Figure 24: Box plot of Fulton's condition factor (*K*) for blue cod on the Marlborough Sounds 2021 random-site potting survey by strata. Data shown are the minimum and maximum (whiskers), 25th and 75th percentiles (shaded box), median (dark line), and outliers (open circles). See Figure 3 for location of strata and Table 2 for strata names.

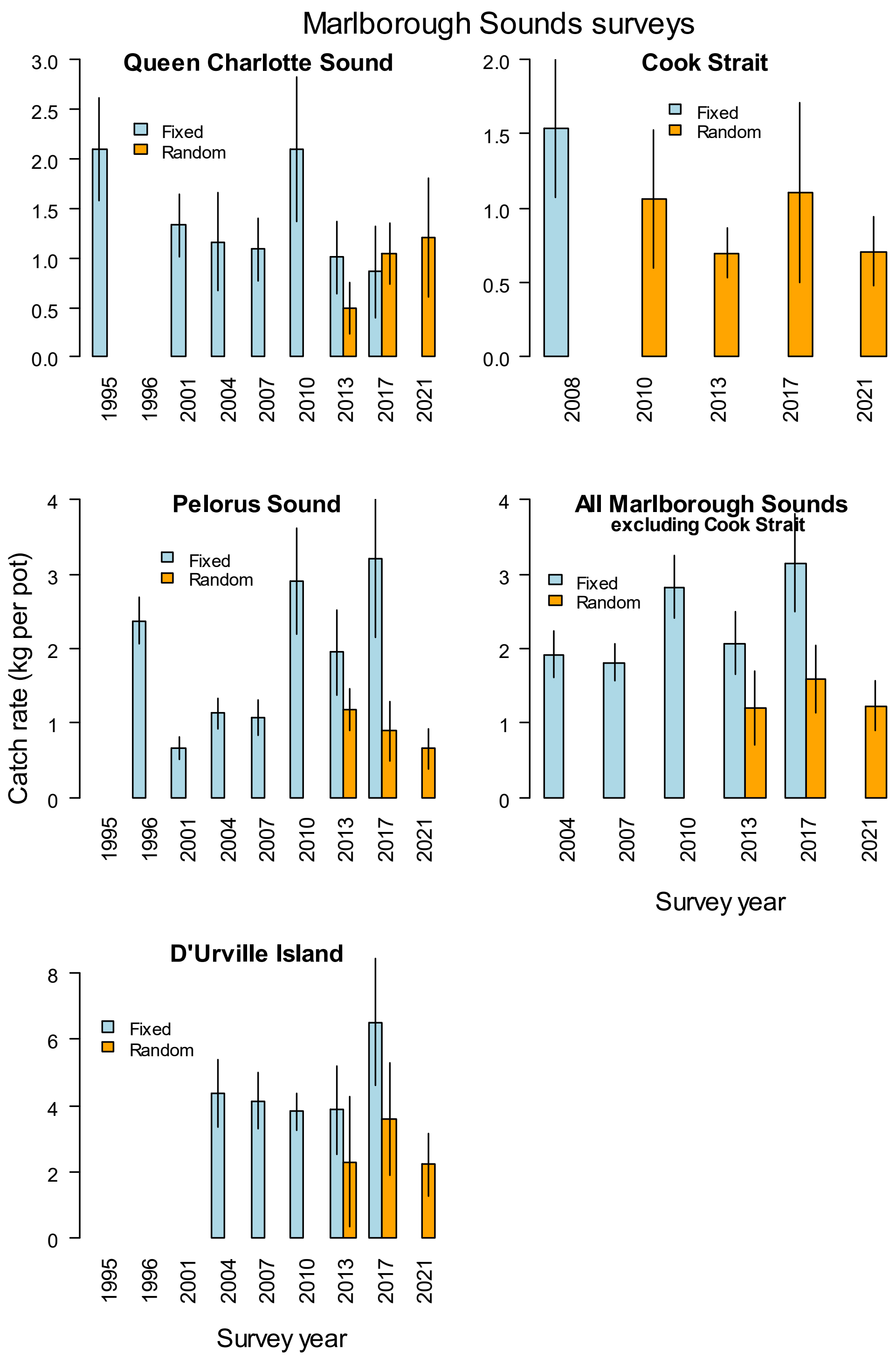


Figure 25: Marlborough Sounds fixed-site and random-site potting survey catch rates of all blue cod by survey year for each region and overall for Marlborough Sounds from 2004. Marlborough Sounds excluded Cook Strait from the random-site surveys because strata were otherwise not consistent. Error bars are 95% confidence intervals. There were no complete surveys in QCH in 1996, PEL in 1996, or DUR between 1995 and 2001 (see Table 1). See Figure 3 for location of regions.

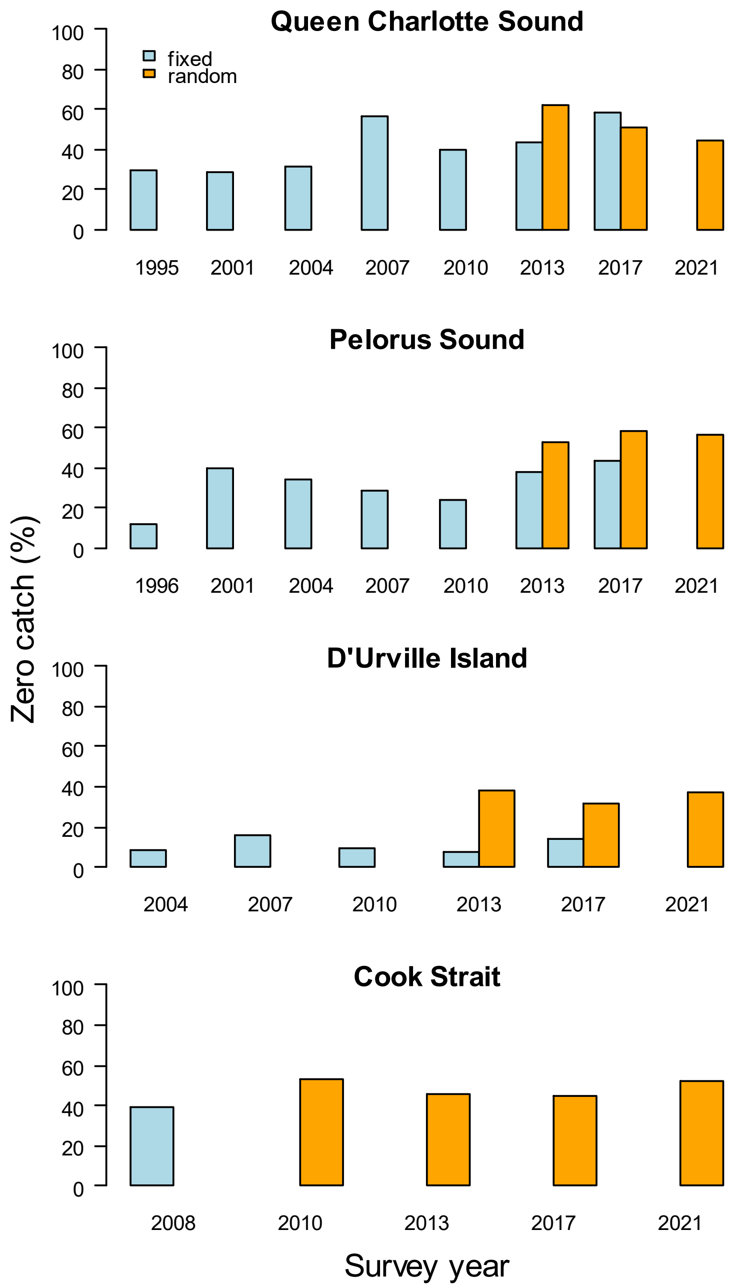


Figure 26: Proportion of pots with zero catch of blue cod for the Marlborough Sound fixed-site and random-site potting surveys by region and survey year.

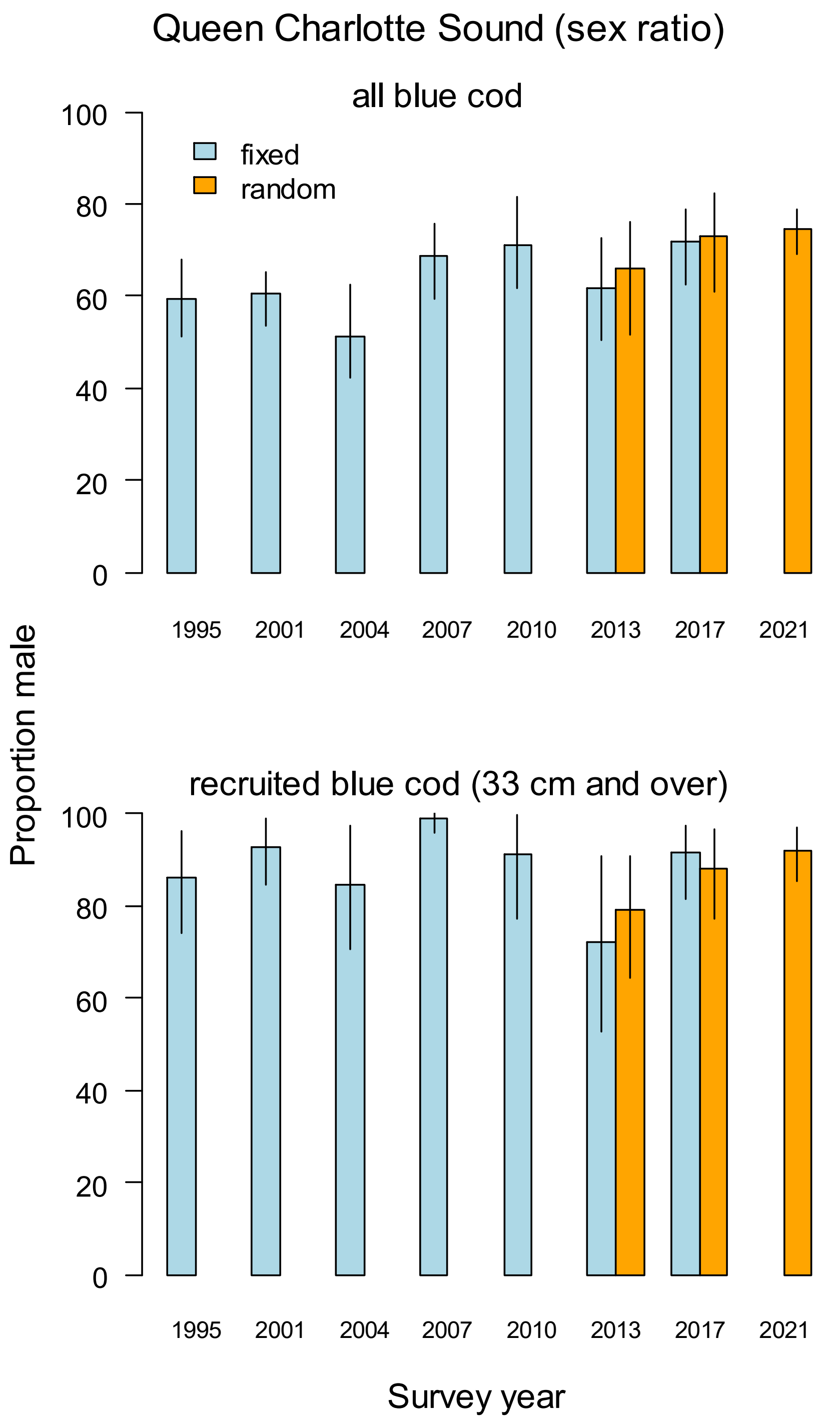


Figure 27: Sex ratio (expressed as percent male) for all blue cod and recruited blue cod for fixed-site and random-site potting surveys for each region and overall for Marlborough Sounds, by survey year. Error bars are 95% confidence intervals. (Contined on next 4 pages)

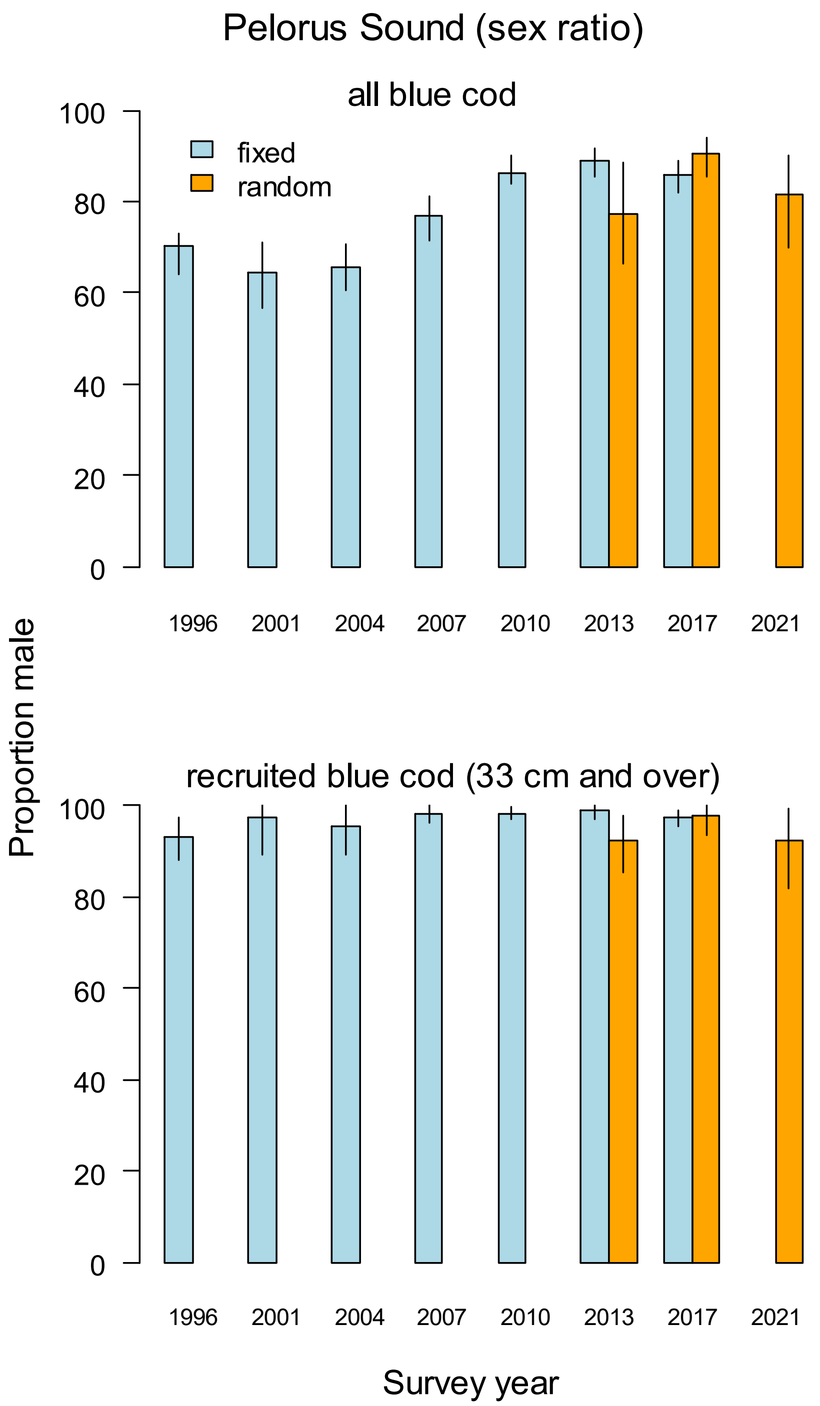


Figure 27–*continued*

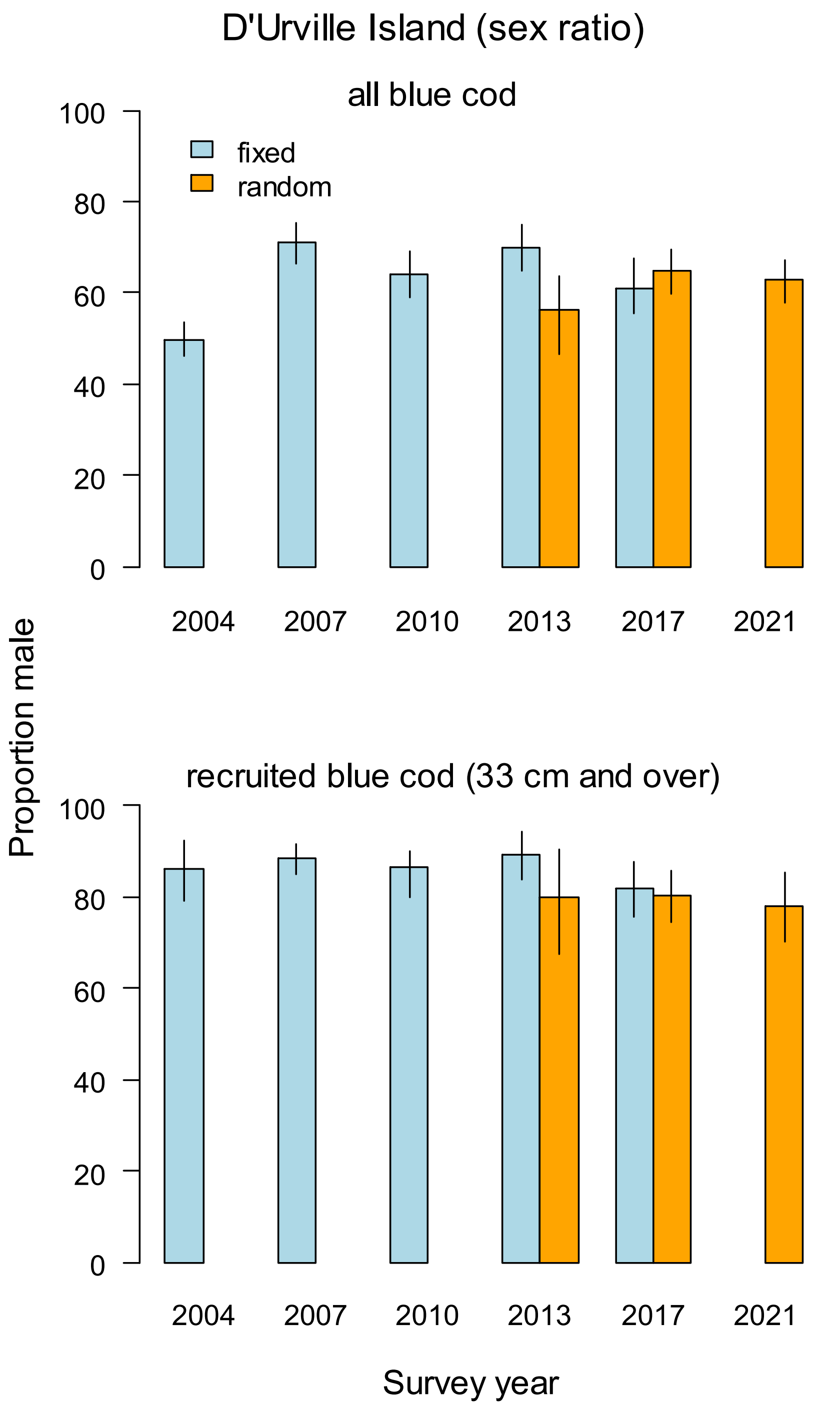


Figure 27–*continued*

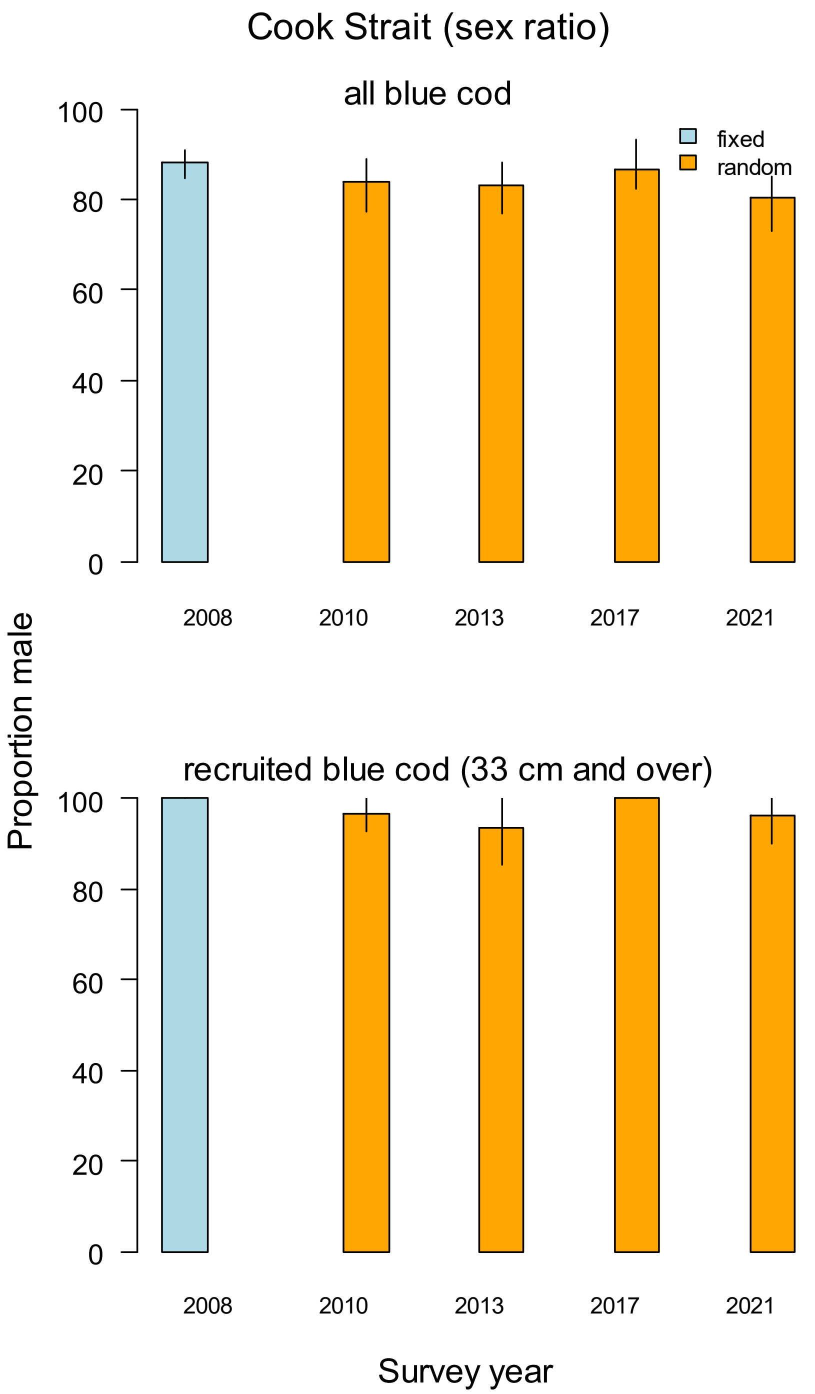


Figure 27–*continued*

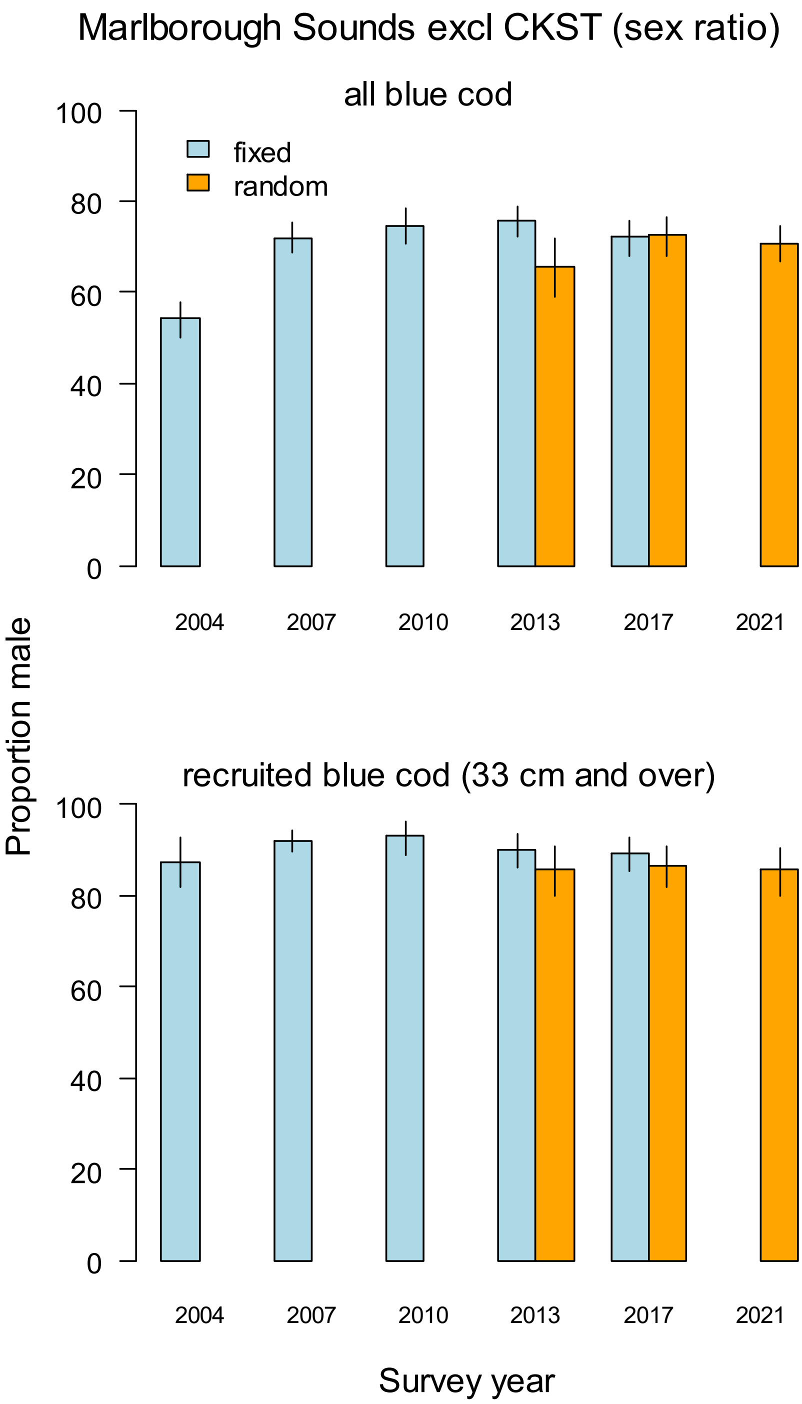


Figure 27–*continued*

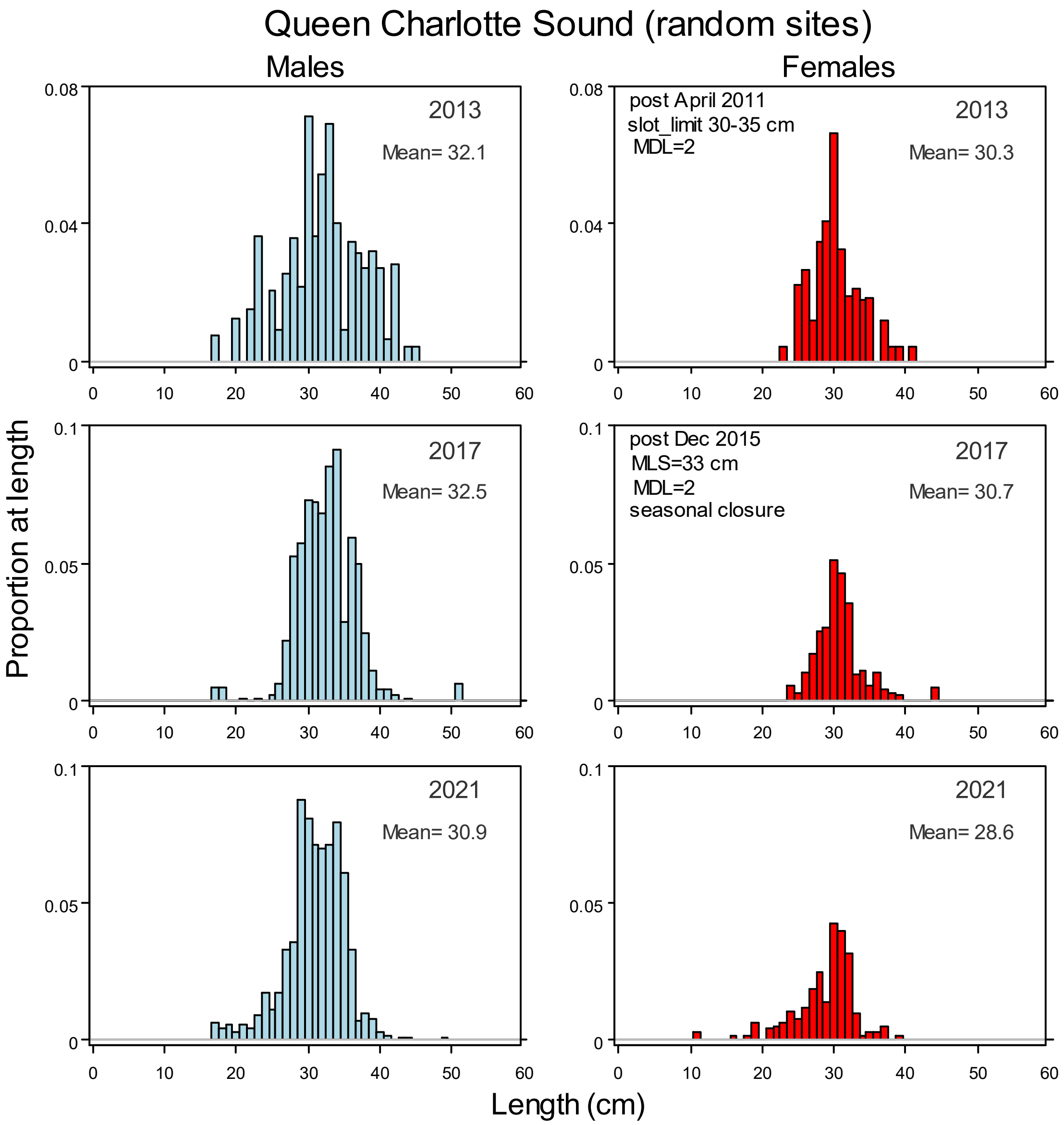


Figure 28: Scaled length distributions for male and female blue cod from random-site potting surveys in 2010 (CKST only), 2013, 2017, and 2021 for each region. Changes in fisheries regulations are annotated on the female panels. MLS, minimum legal size; MDL, maximum daily limit. The seasonal closure is from 1 September to 19 December. Proportions-at-length sum to one. (Contined on next 4 pages)

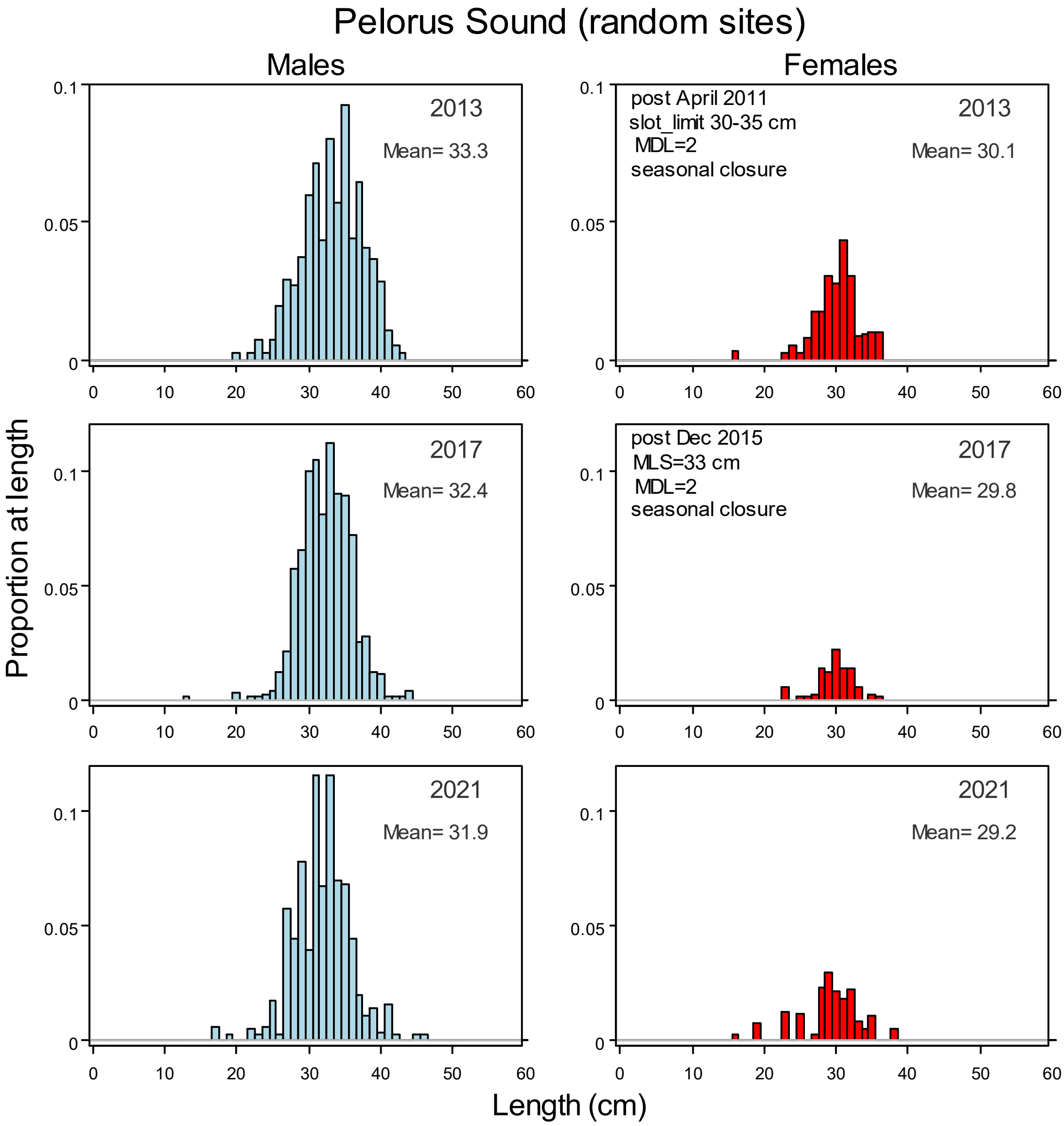


Figure 28–*continued*

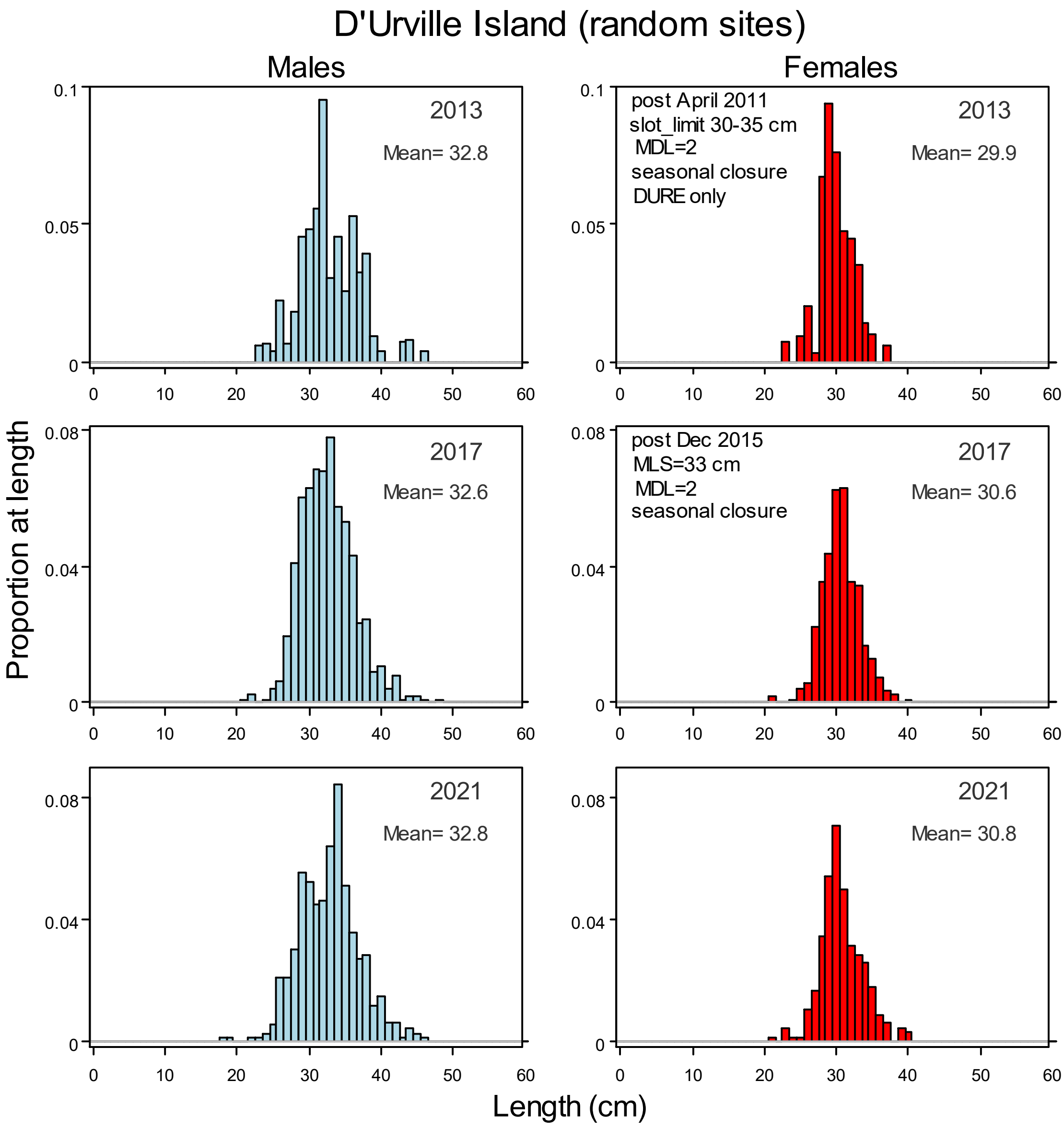


Figure 28–*continued*

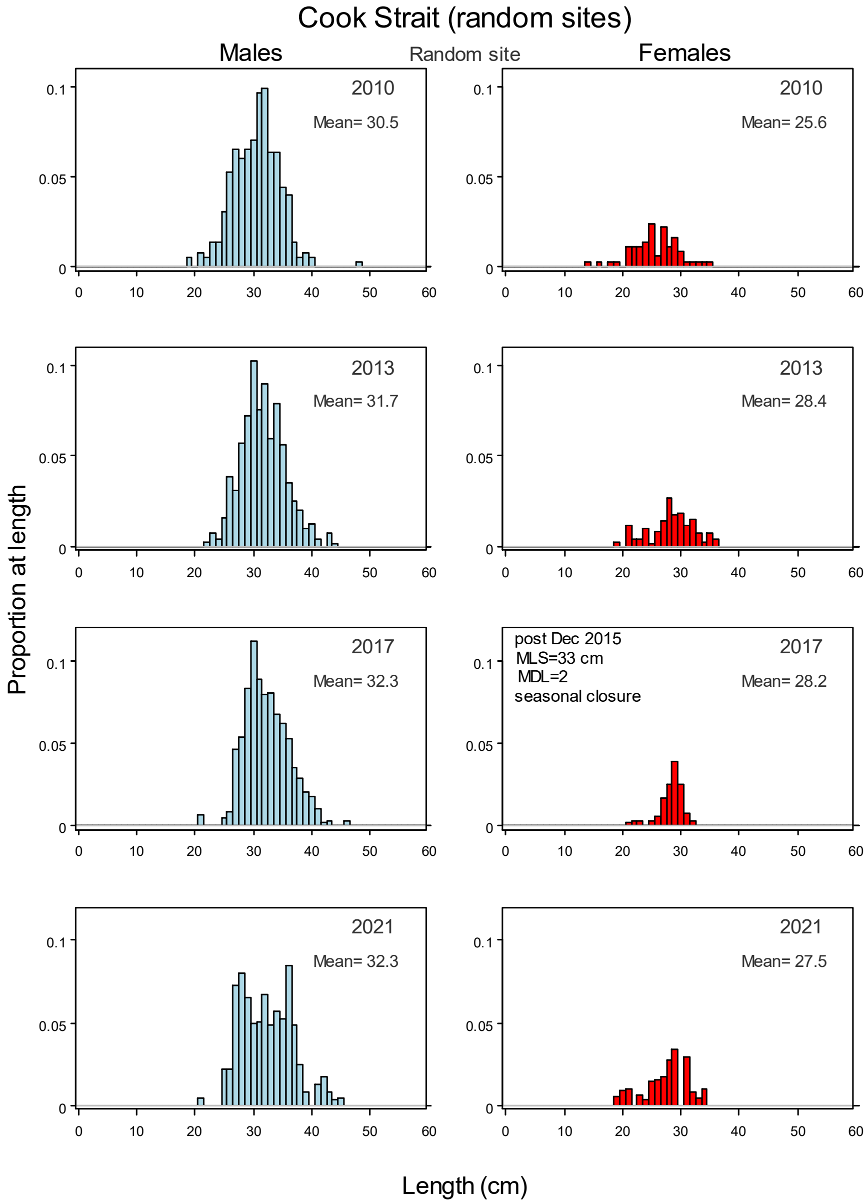


Figure 28–*continued*

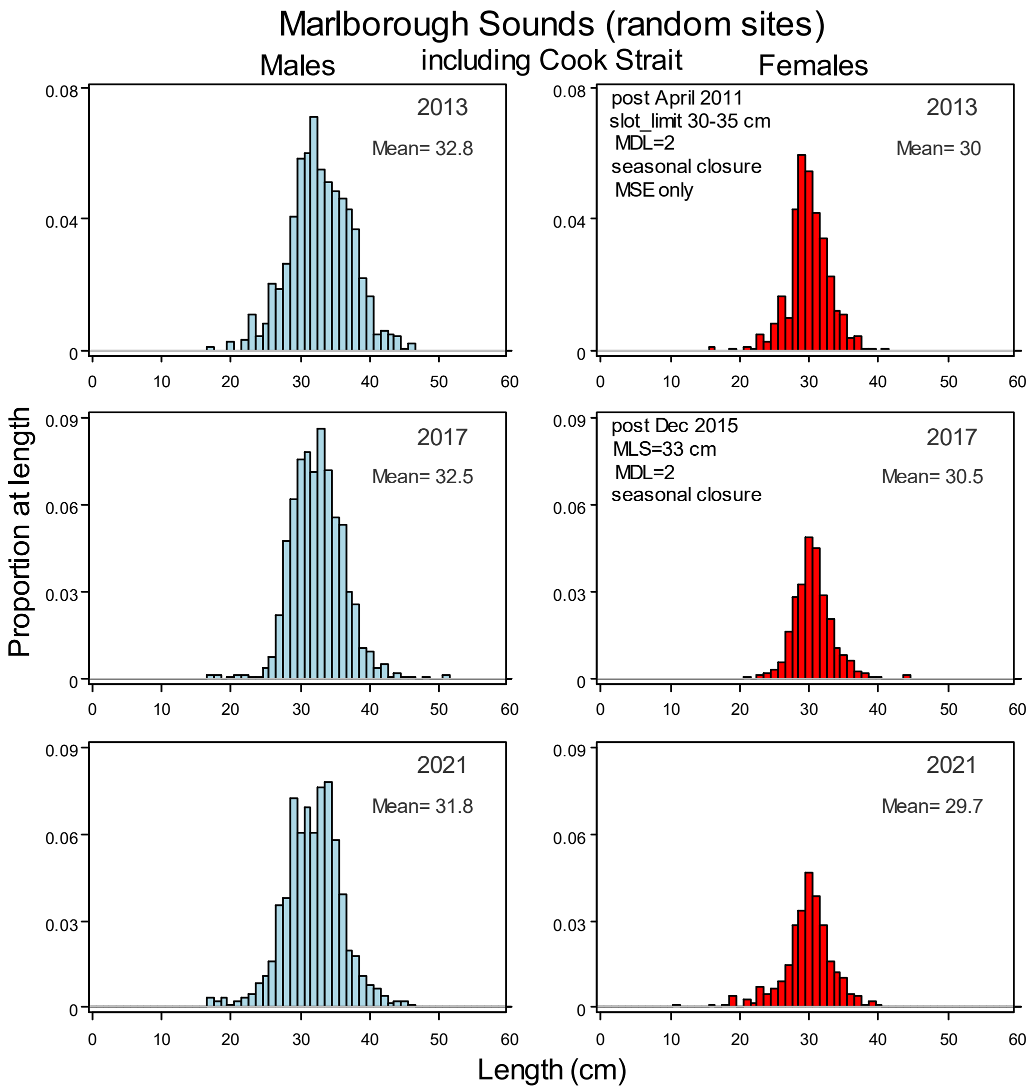


Figure 28–*continued*

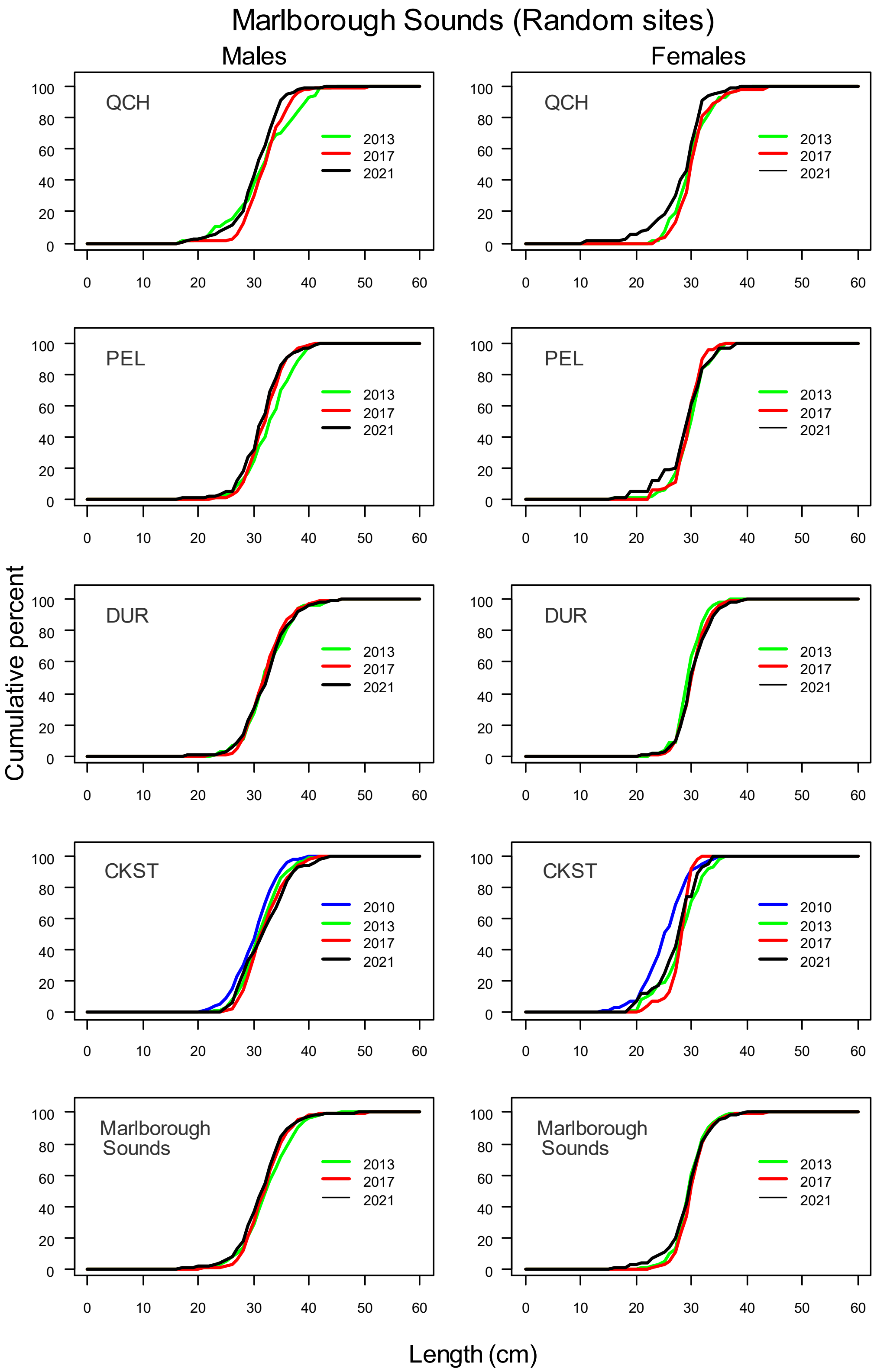


Figure 29: Cumulative distributions of scale length frequencies for male and female blue cod from random-site potting surveys by region and all Marlborough Sounds.

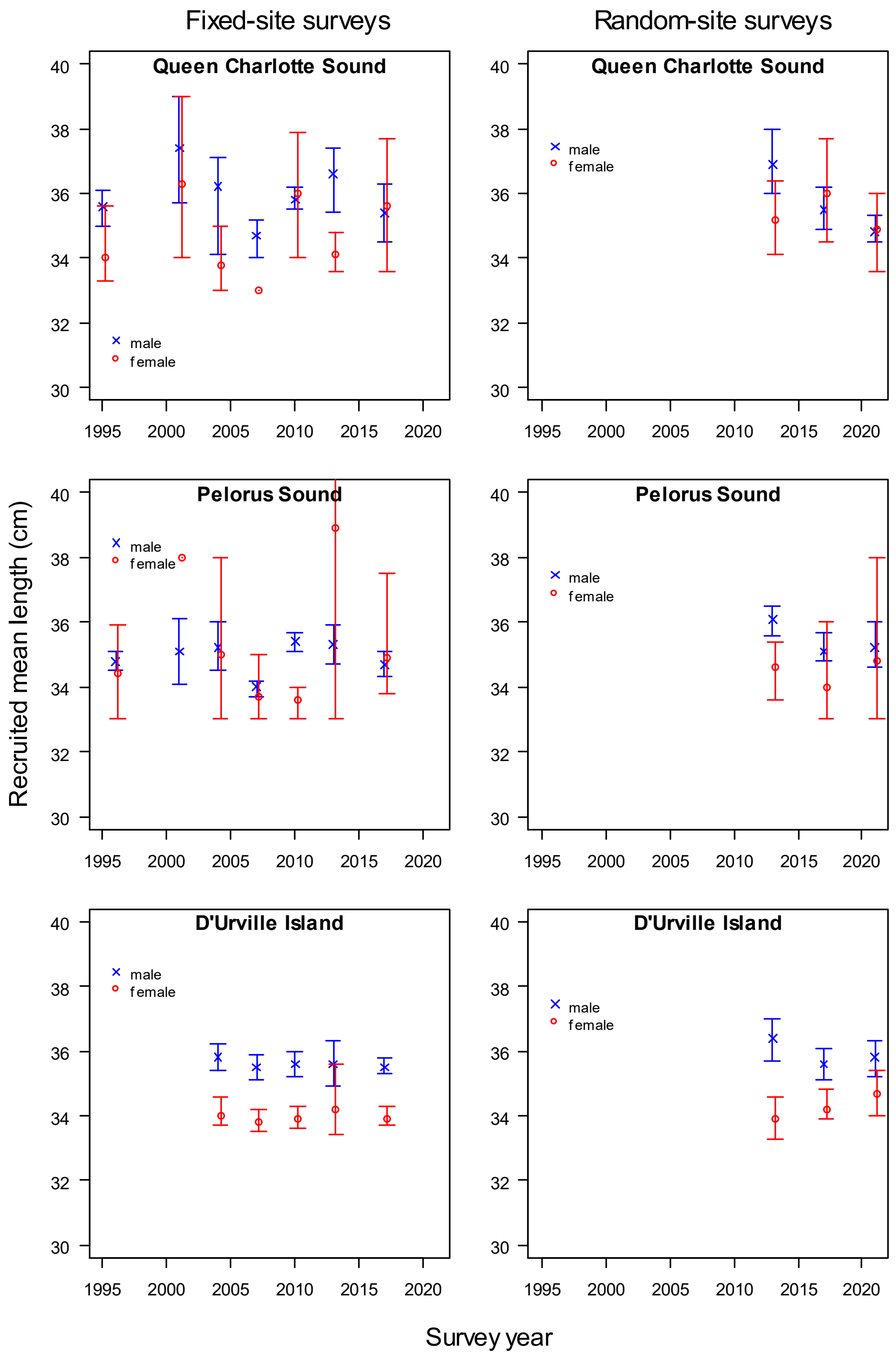


Figure 30: Scaled mean lengths for male and female recruited blue cod (33 cm and over) by region and overall for Marlborough Sounds for fixed-site and random-site surveys. Error bars are 95% confidence intervals. [Continued on next page]

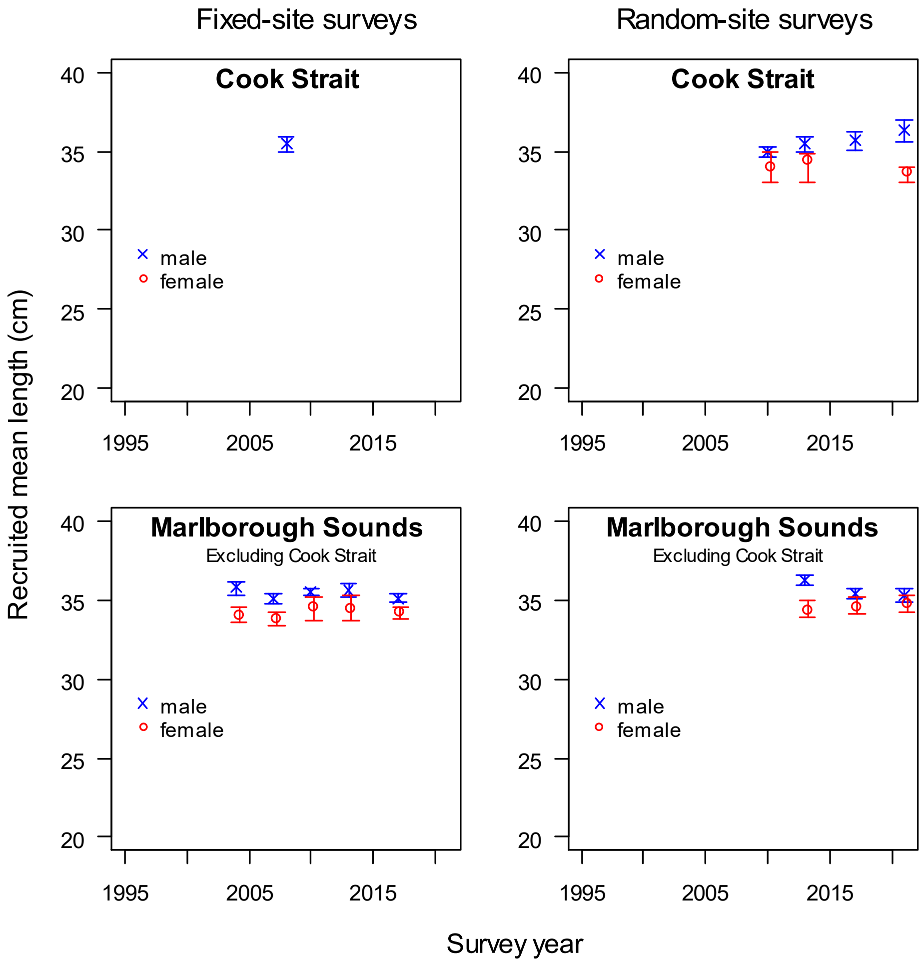


Figure 30–*continued*

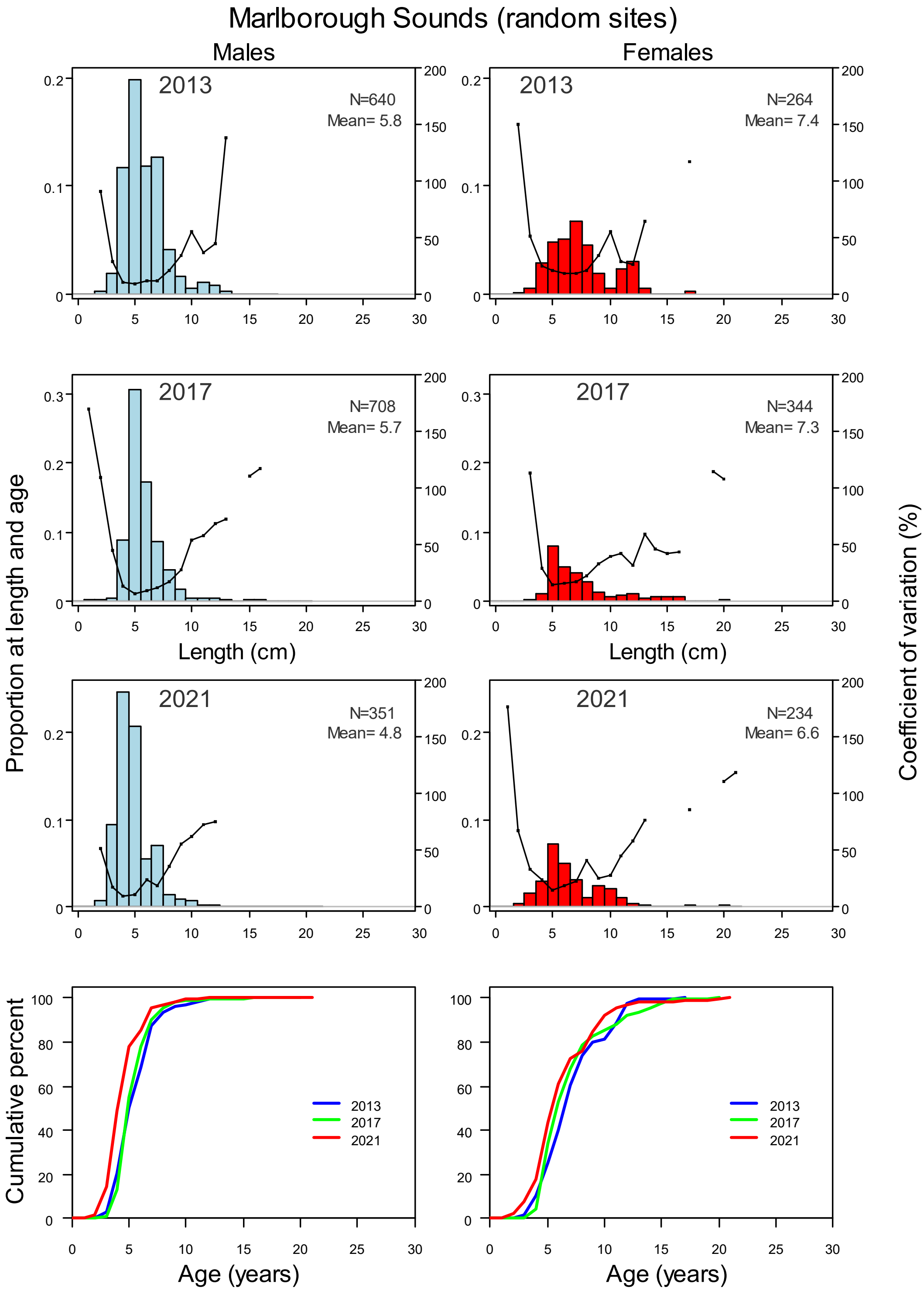


Figure 31: Scaled age-frequency and cumulative distributions for male and female blue cod for the 2013, 2017, and 2021 Marlborough Sounds random-site potting surveys (QCH, PEL, DUR, and CKST combined). N, sample size. Proportions-at-age sum to one.

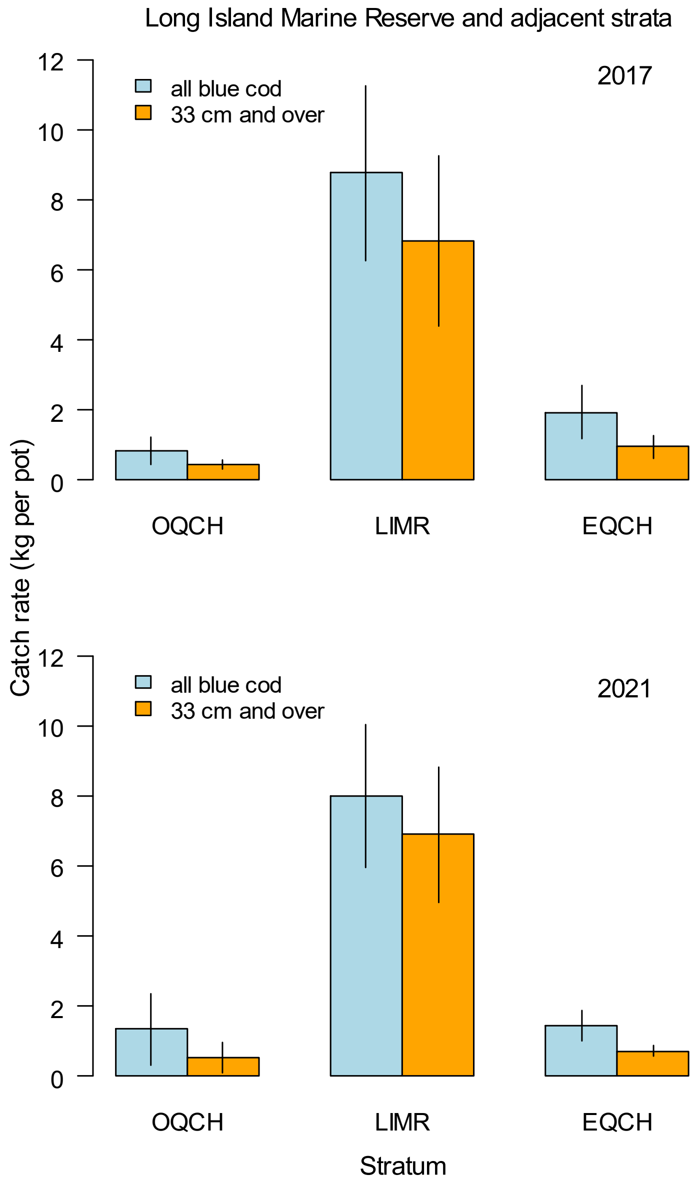


Figure 32: Marlborough Sounds 2017 and 2021 random-site potting survey catch rates of all blue cod and recruited blue cod from sites inside the Long Island Marine Reserve (LIMR) and from all sites in adjacent strata in Queen Charlotte Sound (OQCH, EQCH). Error bars are 95% confidence intervals. See Figure 3 for location of strata and Table 2 for strata names.

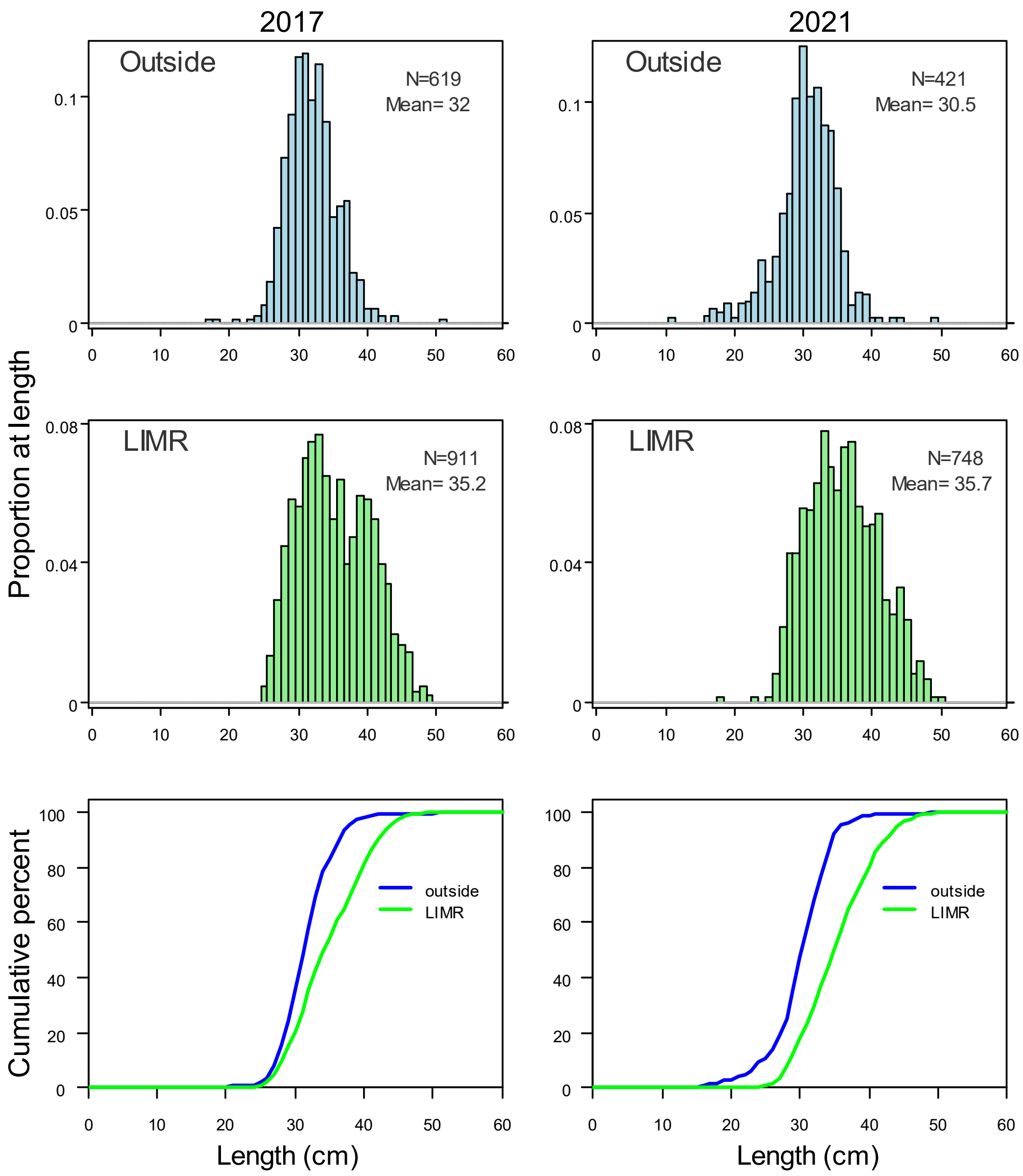


Figure 33: Marlborough Sounds 2017 and 2021 random-site potting survey length-frequency and cumulative distributions of blue cod from sites inside the Long Island Marine Reserve (LIMR) and from sites 'outside' the marine reserve in adjacent strata in Queen Charlotte Sound (OQCH, EQCH combined). See Figure 3 for location of strata.

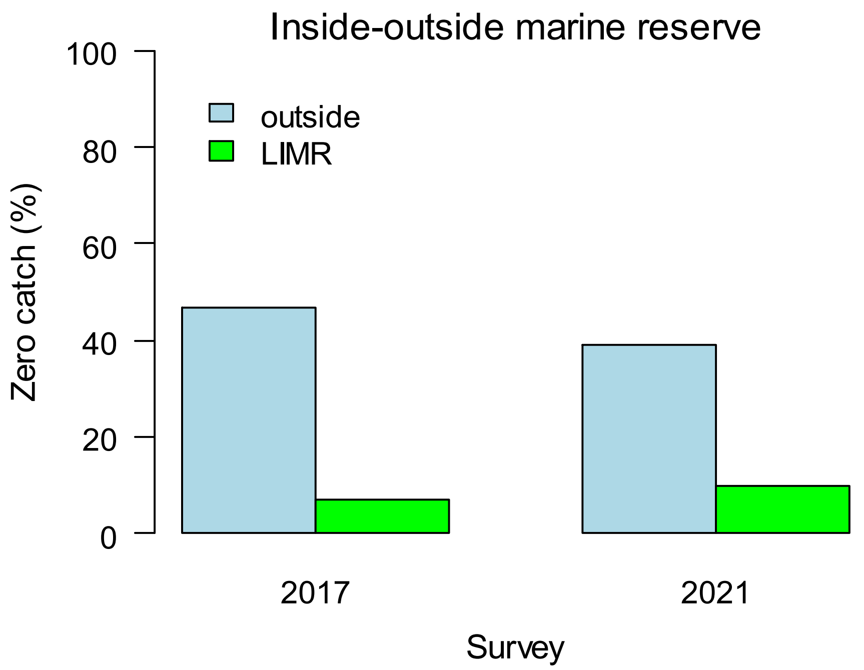


Figure 34: Marlborough Sounds 2017 and 2021 random-site potting survey proportion of pots with zero blue cod from sites inside the Long Island Marine Reserve (LIMR) and from sites 'outside' the marine reserve in adjacent strata in Queen Charlotte Sound (OQCH, EQCH combined). See Figure 3 for location of strata.

9. APPENDICES

Appendix 1: Blue cod potting surveys carried out for Fisheries New Zealand in nine South Island recreational fisheries. See Appendix 2 for definitions of fixed-site and random-site surveys, and directed and systematic pot placement.

Survey area	Survey year	Survey design type	Pot placement	References
Marlborough Sounds	1995, 1996, 2001, 2004, 2007, 2008	Fixed-site	Directed	(Blackwell 1997, 1998, 2002, 2005, 2008)
	2010	Fixed-site and partial Random-site	Directed and systematic	(Beentjes & Carbines 2012)
	2013	Fixed-site and Random-site	Directed and systematic	(Beentjes et al. 2017)
	2017	Fixed-site and Random-site	Directed and systematic	(Beentjes et al. 2018)
	2021	Random-site	Systematic	This report
Kaikōura	2004, 2007	Fixed-site	Directed	(Carbines & Beentjes 2006a, 2009)
	2011, 2015	Fixed-site and Random-site	Directed and systematic	(Carbines & Haist 2012, Beentjes & Page 2017)
	2017	Random-site	Systematic	(Beentjes & Page 2018)
	2019	Random-site	Systematic	(Beentjes & Page 2021)
Motunau	2005, 2008	Fixed-site	Directed	(Carbines & Beentjes 2006a, 2009)
	2012, 2016	Fixed-site and Random-site	Directed and systematic	(Carbines & Haist 2012, Beentjes & Sutton 2017)
	2020	Random-site	Systematic	(Beentjes & Miller 2021)
Banks Peninsula	2002, 2005, 2008	Fixed-site	Directed	(Beentjes & Carbines 2003, 2006, 2009)
	2012	Fixed-site and Random-site	Directed and systematic	(Carbines & Haist 2017b)
	2016	Fixed-site and Random-site	Directed and systematic	(Beentjes & Fenwick 2017)
	2021	Random-site	Systematic	(Beentjes et al. 2022)
North Otago	2005, 2009	Fixed-site	Directed	(Carbines & Beentjes 2006b, 2011b)
	2013, 2018	Fixed-site and Random-site	Directed and systematic	(Carbines & Haist 2018b, Beentjes & Fenwick 2019a)
	2022	Random-site		2022 survey report pending
South Otago	2010	Fixed-site and Random-site	Directed and systematic	(Beentjes & Carbines 2011)
	2013, 2018, 2022	Random-site	Systematic	(Carbines & Haist 2018c, Beentjes & Fenwick 2019b), 2022 survey report pending
Foveaux Strait	2010, 2014, 2018	Random-site	Systematic	(Carbines & Beentjes 2012, Carbines & Haist 2017a, Beentjes et al. 2019)
Paterson Inlet	2006	Fixed-site	Directed	(Carbines 2007)
	2010, 2014	Fixed-site and Random-site	Directed and systematic	(Carbines & Haist 2014, 2018a)
	2018	Random-site	Systematic	(Beentjes & Miller 2020)
Dusky Sound	2002, 2008	Fixed-site	Directed	(Carbines & Beentjes 2003, 2011a)
	2014	Fixed-site and Random-site	Directed and systematic	(Beentjes & Page 2016)

Appendix 2: Glossary of terms used in this report (modified from Beentjes & Francis 2011, Beentjes 2019). 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	Pot placement is the method used to determine where to place the pot on the seafloor. There are two types of pot placement: Directed – used only for fixed sites where the position of each pot is directed by the skipper using local knowledge and the vessel echo-sounder to locate a suitable area of reef/cobble or biogenic habitat. Directed pot placement depends on the perceived suitability of the habitat. Systematic – used only for random sites where the position of each pot is arranged 1) systematically around the site in a hexagon pattern, or 2) either side of the site position for a length of coastline. Systematic pot placement is independent of the perceived suitability of the habitat.
Random site	A site that has the location (single latitude and longitude) generated randomly within a stratum, given the constraints of proximity to other selected sites for a specific survey.
Site	A geographical location near to which sampling may take place during a survey. A site may be either fixed or random (see below). A site may be specified as a latitude and longitude or a section of coastline (for the latter, use the latitude and longitude at the centre of the section).
Site label	An alphanumeric label of no more than four characters, unique within a survey time series. A site label identifies each fixed site and also specifies which stratum it lies in. Site labels are constructed by concatenating the stratum code with an alpha label (A–Z) that is unique within that stratum. Thus, sites within stratum 2 could be labelled 2A, 2B, and sites in stratum 3 could be labelled 3A, 3B, etc. Site labels for random sites are constructed in the same way but prefixed with R (e.g., R4A, R4B, etc).
Station	The position (latitude and longitude) at which a single pot (or other fishing gear such as ADCP) is deployed at a site during a survey, i.e., it is unique for the trip.
Station number	A number which uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be *station_no* 234. This convention is important in enabling users of the *trawl* database to determine whether two pots are from the same set. Note that the set numbers for potting surveys are not recorded anywhere else in the *trawl* database.

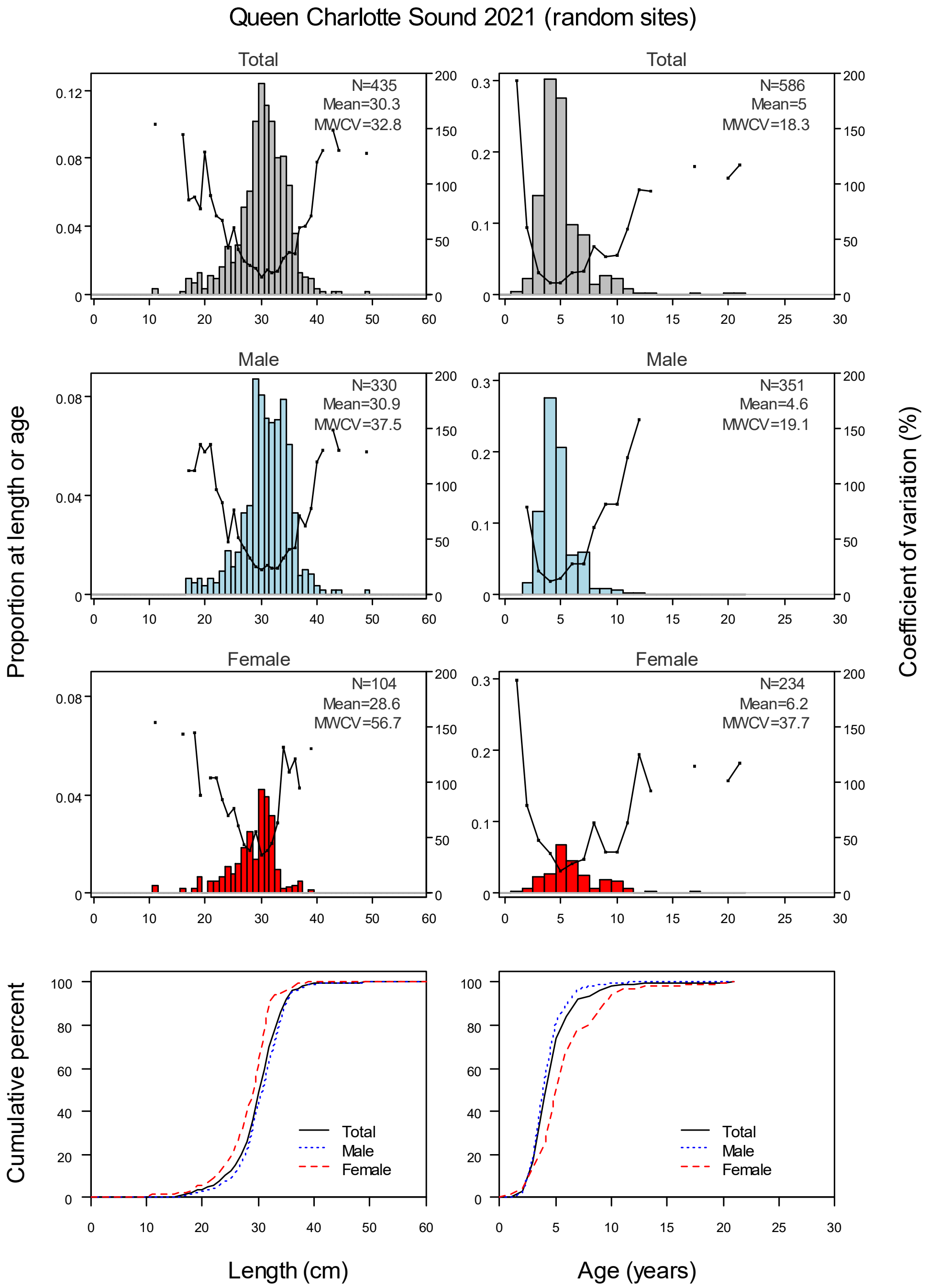
Appendix 3: Numbers of otoliths collected during the 2021 Marlborough Sounds survey for males and females, by strata and length class.

Length (cm)	Stratum 1	2	3	4	5	6	7	8	9	11	12	13	Male total
17		2			1								3
18		1	1						1				3
19		2		1					1				4
20		1											1
21		2								1			3
22	1		2		1	1							5
23		2	2						1				5
24		4	3	1									8
25		2	3	1	2				3	3		1	15
26		4	3			4			6	4	1		22
27		2	4	2	2				4	9	2		25
28	1	1	2		4				3	4			15
29		5		2	1			1	4	4	1		18
30		4			2		1	1	4	4			16
31	1	4		1	1		3		4	4			18
32	1	2	1		2			2	4	6			18
33	1	3		1			2	1	4	4			16
34		4		1	2			1	4	4			16
35		2	2	1	3				4	4			16
36	1	2	5		4				4	3		1	20
37	2	1		2	1	2			8	8	2		26
38		1	4	1	1	1			13	5	1		27
39		1	3	1	1	1			4	2			13
40		1				2		1	4				8
41			1	1			1		2	2	1		8
42				1					3	3	1		8
43			1						1	2			4
44			1						2	1			4
45				1					1	1			3
46								1	1				2
47													
48													
49			1										1
Totals	8	53	39	18	28	11	7	8	90	78	9	2	351

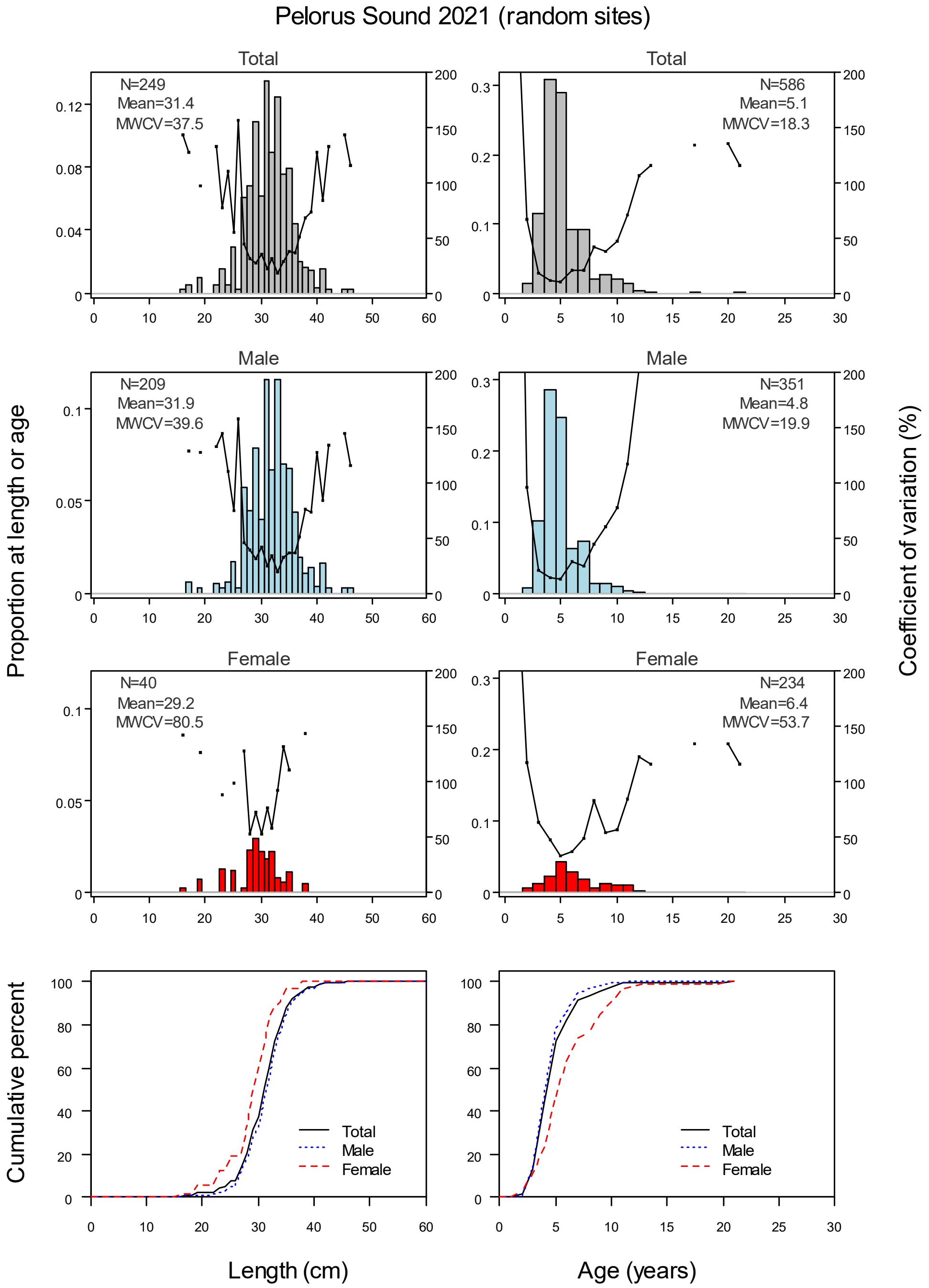
Appendix 3 – *continued*

Length (cm)	Stratum 1	2	3	4	5	6	7	8	9	11	12	13	Female total
11		1											1
12													
13													
14													
15													
16			1										1
17													
18	1												1
19		2					1				1		4
20										1	1		2
21		1	1						1	1	1		5
22		1	1										2
23	1	1	1		1		1		1		1		7
24		2	3							1			6
25		2	1		1			2	1	1	2		10
26		2	4			2			3	4			15
27		5	2	1		1			3	3	1		16
28	2	6	1		1			3	4	3	2		22
29		4	1		2	1	2	1	4	5		1	21
30		10	8		1		1	1	3				24
31		10	4		1		1		3	6	1		26
32		8	4	1	3			1	5	2			24
33	1	1	3	1	1				4	1			12
34			1		1				4			1	7
35			2		2				9				13
36		1				3							4
37		1	1			1			2				5
38					1								1
39			1						2				3
40									2				2
Totals	5	58	40	3	15	8	6	8	50	28	10	2	234

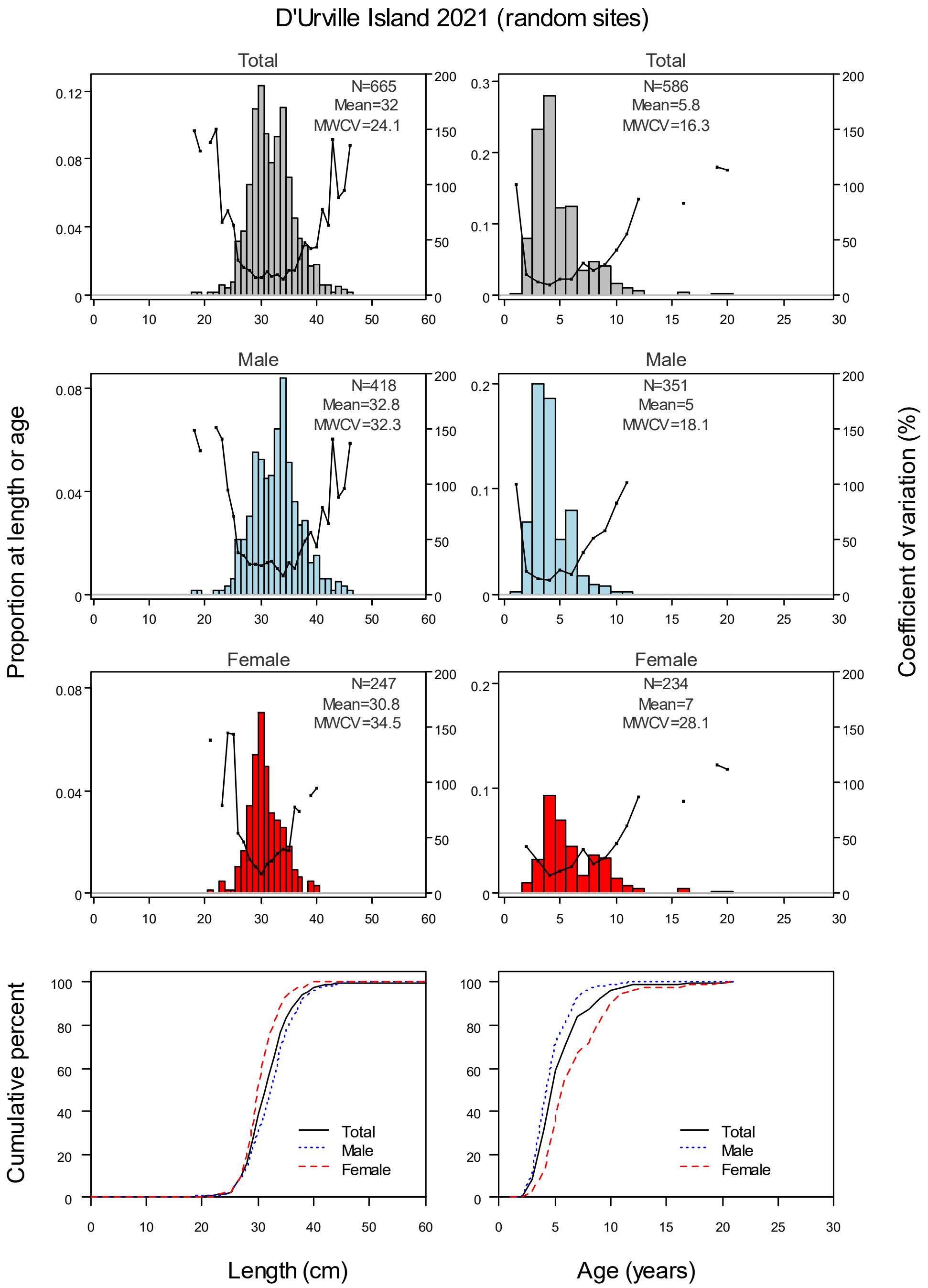
Appendix 4: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for Queen Charlotte Sound, Pelorus Sound, D'Urville Island, and Cook Strait for the 2021 Marlborough Sounds random-site potting survey. N, sample size; MWCV, mean weighted coefficient of variation (%). Proportions at length or age sum to one. (Continued on next 3 pages)



Appendix 4 – *continued*



Appendix 4 – *continued*



Appendix 4 – *continued*