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Blue cod relative abundance, size and age structure, and habitat surveys of Marlborough Sounds in 2013

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This report describes the 2013 Marlborough Sounds fixed-site potting survey of relative abundance, population length and age structure, and stock status of blue cod for this area, the seventh in the time series that began in 1995. In addition, a random-site survey was carried out concurrently to enable a possible future transition to a random-site pot survey. Analyses of the 2013 survey catch rates, length, sex ratio, catch-at-age, total mortality (Z), and spawner-per-recruit (SPR) were carried out for each region (D'Urville Island, DUR; Pelorus Sound, PEL; Queen Charlotte Sound, QCH; and Cook Strait, CKST). The 1995 and 1996 surveys were re-analysed in accordance with the potting manual survey standards and specifications, and comparisons were made for all surveys in the fixed-site time series for each region.

2013 fixed-site survey

Thirty-two randomly selected fixed sites were successfully surveyed from nine strata in QCH, PEL and DUR between 26 September and 7 November 2013. At each site, 9 pots were set, using directed pot placement, resulting in 288 pots overall, of which 100 (35%) had zero catch of blue cod. A total of 556 kg (1182 fish) of blue cod was caught. Catch rates varied across all three regions with the all blue cod catch rate for QCH (1.0 kg.pot^{-1}, CV=18%) being about half that of PEL (1.95 kg.pot^{-1}, CV=15%) and one-quarter that of DUR (3.88 kg.pot^{-1}, CV=18%).

Sex ratios of all blue cod were dominated by males (QCH 62%, PEL 89%, DUR 70%). The scaled length-frequency distributions for males and females were unimodal and the proportions (by number) of blue cod over the minimum legal size (30 cm TL and over) were similar (62%, 63% and 64%, respectively). Blue cod were of similar mean size in all three regions (31 cm for males and 29 for females), except for PEL where females were 2–3 cm smaller (27 cm).

Fixed-site time series

The Marlborough Sounds fixed-site potting survey indices of abundance increased markedly in 2010 in QCH and PEL following the closure of the fishery in the same areas in 2008. The survey indices were stable in DUR where the fishery remained open. The QCH and PEL fisheries were reopened to a limited size range of blue cod (30–35 cm) in April 2011 and the estimated 2013 survey abundance in those regions declined, but no change was observed in DUR. Although abundance of fish over 35 cm declined in 2013 in both QCH and PEL, catch rates remained higher than prior to the closure (i.e., 2007 survey).

The size composition of the survey catch showed similar trends to catch rates. In PEL and QCH there was a substantial increase in the proportion of larger fish in 2010 (i.e., after the fishery was closed) followed by a slight decrease in proportions of larger fish in 2013 (after fishing recommenced). No temporal trend in size composition was observed for DUR.

Analysis of sex ratios demonstrated that while catches were dominated by males the proportion of females in the 30–35 cm category increased substantially from 2007 to 2013 in QCH, but were stable in PEL and DUR.

2013 random-site survey

Seventy-one random sites were successfully surveyed from 13 strata in QCH, PEL, DUR and CKST between 26 September and 7 November 2013. At each site, 9 pots were set, using systematic pot placement, resulting in 639 pots overall, of which 315 (49%) had zero catch of blue cod. A total of 676 kg (1310 fish) of blue cod was caught. Catch rates of all blue cod varied across all four regions (QCH 0.5 kg.pot^{-1}, CV=27%; PEL 1.2 kg.pot^{-1}, CV=12%; DUR 2.3 kg.pot^{-1}, CV=43%; CKST 0.7 kg.pot^{-1}, CV=12%). The relative proportions of the total catch rates by length category varied among the regions,

i.e., 30–35 cm was 37–50%, over 35 cm 23–37%, and under 30 cm 17–28% of the total catch rate. Sex ratios (all blue cod) were dominated by males (QCH 66%, PEL 77%, DUR 57% and CKST 83%). The scaled length-frequency distributions for males and females were unimodal and the proportions (by number) over the minimum legal size (30 cm and over) were similar in QCH, PEL and DUR at about 68%, but higher in PEL (77%). Blue cod were of similar length in all four regions (mean length 32–33 cm for males and 28–30 cm for females).

Random-site surveys are considered to be superior to fixed-site surveys in design and precision and hence stock status is presented in the executive summary only for random sites. Random site total mortality (Z) for age-at-full recruitment (7 years), were QCH = 0.4, PEL = 0.7, DUR = 0.7 and CKST = 0.62. Based on the default M of 0.14, estimated fishing mortalities (F) and associated spawner-per-recruit ratios were QCH (0.26, $F_{34.3\%}$), PEL (0.56, $F_{21.3\%}$), DUR (0.56, $F_{21.3\%}$) and CKST (0.48, $F_{23.4\%}$). In Marlborough Sounds fishing mortality has not been constant because of the various management changes and this has likely biased estimates of Z and SPR. Notwithstanding this, the level of exploitation (F) of Marlborough Sounds blue cod stocks in all four regions, is greater than the F_{MSY} target reference point of $F_{45\%SPR}$.

Fixed versus random-site surveys
The fixed-site survey catch rates for all blue cod in QCH, PEL and DUR were all much higher than the random-site survey catch rates from the same regions. Length of fish from the two survey types was similar in QCH and DUR, but fish were larger, especially females, in the PEL random sites. Random-site surveys require more effort to achieve the same abundance estimate precision compared to fixed-site surveys in Marlborough Sounds. A switch to exclusively random-site surveys in Marlborough Sounds may require more comparisons of the concurrent fixed- and random-site surveys.

Multibeam echo-sounder survey
The multibeam echo-sounder survey recorded a suite of physical data over each of the pot sites including the seafloor bathymetry, topography, ruggedness, slope, aspect and substrate type. This is the first time these data have been collected during a blue cod potting survey in Marlborough Sounds or elsewhere in New Zealand. Graphical examples of these outputs were provided for site 3E, the western entrance to Port Gore. These seafloor descriptors were extracted using ArcGIS software.

Pot selectivity
Pot selectivity experiments that compared the size selection of the standard Marlborough Sounds pots with the standard pots from other South Island surveys were conducted on the 8th and 9th November 2013. This aimed to understand selectivity of pots relative to sampling the population present in an area and to qualify comparisons of survey catches from different regions using different pot configurations. Results indicated that the standard South Island pots were more efficient at capturing blue cod less than 28 cm in length, but showed equal selectivity above that length. There was no detected interaction effect of sex.

Gonad collection
Gonad samples from 542 blue cod (407 male, 125 female, and 10 unidentified) were preserved in 10% formalin and subsequently transferred to 70% ethanol for future fecundity and sex change analyses.

1. INTRODUCTION

This report describes the 2013 Marlborough Sounds potting survey of relative abundance, population length/age structure and stock status of blue cod (*Parapercis colias*). This is the seventh in the time series that began in 1995. All previous surveys were fixed-site surveys (see Appendix 1, glossary of terms), except for 2010, which also included an experiment comparing random sampling with standard fixed-site sampling in selected strata in DUR and PEL, and only random sites were used in CKST strata in 2010 (Beentjes & Carbines 2012). In 2013, full fixed-site and full random-site surveys were conducted together. Further, for the first time on any of the blue cod potting surveys in New Zealand, each potting site was swath-mapped using a multibeam echo-sounder providing a 3-dimensional surface map of the seafloor and information on substrate type (sand, mud, rock, cobble). At the end of the survey, a pot selectivity experiment comparing pot type 1 and pot type 2 (Marlborough Sounds and South Island pots, respectively) was carried out at eight selected sites.

A re-analysis of the 1995 and 1996 survey data was also carried out in accordance with the standards and specifications defined for blue cod pot surveys (Beentjes & Francis 2011). This ensured results from all surveys were directly comparable.

1.1 Blue cod potting surveys

South Island recreational blue cod stocks are monitored using potting surveys. These surveys take place predominantly in areas where recreational fishing is common, but in some areas there is substantial overlap between the commercial and recreational fishing grounds. The aim is to repeat each survey about every four years. In addition to the Marlborough Sounds, there are currently eight other areas surveyed, located in key recreational fisheries: Kaikoura (Carbines & Beentjes 2006a, 2009), Motunau (Carbines & Beentjes 2006a, 2009), Banks Peninsula (Beentjes & Carbines 2003, 2006, 2009), north Otago (Carbines & Beentjes 2006b, 2011b), south Otago (Beentjes & Carbines 2011), Paterson Inlet (Carbines 2007, 2011, Carbines & Haist 2014), Dusky Sound (Carbines & Beentjes 2003, 2011a) and Foveaux Strait (Carbines & Beentjes 2012). In the Marlborough Sounds, previous potting surveys were carried out in 1995, 1996, 2001, 2004, 2007 (Blackwell 1997, 1998, 2002, 2006, 2008), and in 2010 (Beentjes & Carbines 2012). A 2008 survey in Cook Strait was analysed and documented in Beentjes & Carbines (2012). The Marlborough Sounds regions and strata surveyed are not consistent across all surveys (Table 1).

The surveys provide abundance indices, and monitor the length, weight, age and sex structure of geographically separate blue cod populations. They provide information on stock status and data to evaluate the response of populations to changes in fishing pressure and to management initiatives such as changes to the daily bag limit, minimum/maximum legal size, and/or area closures. In the Marlborough Sounds there were several changes to the daily bag limit, minimum/maximum legal size since 1986, as well as area closures (Ministry for Primary Industries 2016). As blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow, monitoring the sex ratio of the populations is important because the largest fish in the populations are invariably males (Carbines 2004b). In heavily fished blue cod populations sex ratios skewed towards males are often observed (Beentjes & Carbines 2009). This is thought to result from the removal of the inhibitory effect of large males, and a consequent higher rate (and possibly earlier onset) of sex change by primary females (Beentjes & Carbines 2005).

1.2 Status of blue cod in the Marlborough Sounds

Blue cod (*Parapercis colias*) is the second most important recreational target species in the Marlborough Sounds and in Tasman/Golden Bay. The most reliable recreational catch estimates from BCO 7 is 75 t from a national panel survey in 2012 (Ministry for Primary Industries 2016). This is on par with the commercial fishery in BCO 7 confined to the outer Sounds and Cook Strait (Davey et al. 2008), which has landed only 50 to 70 t annually, over the last 10 years (Ministry for Primary Industries 2016).

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 the potting survey time series began. The Marlborough Sounds potting surveys showed a decline in abundance in the inner Sounds of between one-third to a half between 1995/1996 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). The closure of the inner Sounds to all blue cod fishing in October 2008 resulted in increased abundance and a concomitant increased mean length in the closed areas two years later, as shown in the 2010 survey (Beentjes & Carbines 2012). Tagging experiments suggested 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 2004b). This suggests that blue cod are susceptible to localised and serial depletion within an FMA.

In response to concerns for the sustainability of the blue cod fishery the daily bag limit in the Marlborough Sounds was progressively reduced from 12 in 1986, to 10 in 1993, to 6 in 1994, and finally to 3 in 2003 (Ministry for Primary Industries 2016). The minimum legal size (MLS) ranged from 28 to 33 cm over this time, but was 30 cm since 2003. On 1 October 2008, the inner Marlborough Sounds (Pelorus and Queen Charlotte Sounds) was closed to target blue cod fishing for about 2.5 years, with a whole-take-area (where fish had to be landed green or gutted) applying in the outer Sounds and a maximum daily limit (MDL) of only 3 blue cod per fisher (Ministry for Primary Industries 2016). In April 2011 the inner and outer Marlborough Sounds was opened to blue cod target fishing seasonally between 20 December and 31 August each year, with a ‘slot limit’ of 30 to 35 cm legal size and a MDL of 2 fish per person per day. The 2013 survey took place 18 months after the slot limit legal size management regime was implemented.

1.3 Quantifying habitat complexity over potted sites

A multibeam echo-sounder was used for the first time in the 2013 survey to map the seafloor over potted sites and inform the placement of pots. For all previous Marlborough Sounds potting surveys, information on the substrate type and complexity over which pots were set was based on the skipper knowledge and interpretation of the vessel echo-sounder. Catch rates can vary substantially among sites and even pots at a single site. Quantifying the seafloor habitat from each potted site using multibeam echo-sounder swath-mapping may enhance our understanding of the factors that influence catch rates and even the size, age and gender of fish that we catch in each pot. The long-term goal of this approach would be to continue to collect habitat information on subsequent surveys so that we can begin to explain these factors and eventually standardise our abundance estimates. Other useful environmental data that could be used to standardise catch rates include current speed and water temperature, which are routinely recorded using an Acoustic Doppler Current Profile (ADCP) deployed at each potted site. To date, catch rates (= abundance estimates) are scaled to strata coastline length, but no attempt has been made to standardise catch rates using environmental data or other ancillary information such as gear specifications.

1.4 Pot selectivity

Two different types of pots are used for surveys of blue cod in New Zealand. The pots used in the Marlborough Sounds (Pot Plan 1, PP1) have slightly different specifications to those used in all other surveys (Pot Plan 2, PP2) (see Beentjes & Francis 2011 for detailed plans). The main differences that would influence selectivity are in the spacing and angle of the welded steel rods comprising the entrance funnels, with spacing of those in Pot Plan 1 having wider spacing and a lower angle. Additional differences in the placement and size of the covering mesh materials may influence selectivity. Recent work indicated that there may be differences in the catchability of pots of PP1 vs. PP2, with PP1 having a lower selectivity of very small blue cod and also fish longer than 40 cm (Carbines & Beentjes 2012).

All fish sampling gears select particular characteristics of their target species depending on the configuration or use of the gear with a given population. This is most commonly observed as length selectivity, but may also include sex, age, colouration or behavioural characteristics (e.g., aggressiveness).

Relative abundance surveys aim to track the change in the selected portion of the population through time. As long as the gear is consistent in its configuration and usage between surveys, the time series is internally consistent. However, interpreting the survey data for population components that are not fully selected, or comparing population characteristics from different sampling gears is difficult because often the relative selectivity of different gear types are unknown. The pot selectivity objective aims to determine the relative selectivity of the two pot types.

1.5 Objectives

Overall objective

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

Specific objectives

1. To undertake a potting survey in the Marlborough Sounds (BCO 7) to estimate relative abundance, size- and age-at-maturity, sex ratio and collect otoliths from pre-recruited and recruited blue cod.
2. To analyse biological samples collected from this potting survey.
3. To determine stock status of blue cod populations in this area, and compare to other survey areas.
4. To test the gear selectivity of Pot Plan 1 vs. Pot Plan 2.
5. To collect and preserve gonads for future fecundity and sex change analysis.
6. To quantify the habitat complexity of the pot sites surveyed.

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

2. METHODS

2.1 2013 Marlborough Sounds potting survey

2.1.1 Timing

A potting survey of the Marlborough Sounds area was carried out by NIWA between 26 September and 7 November 2013. The survey was consistent with the previous survey dates and coincided with the known spawning times in this region.

2.1.2 Survey area

Four regions (Queen Charlotte Sound, Pelorus Sound, D'Urville Island and Cook Strait), comprising 13 strata, were covered (Figure 1). The 2013 survey did not include Separation Point (stratum 10), which was surveyed only in 2004 and 2007. Coastline length was measured using ArcMap (GIS system) and recorded in kilometres before the 2010 survey. These replaced all previous coastline estimates reported in the 1995 to 2007 surveys as these were considered to be less accurate. In the absence of specific habitat information or a clear understanding of the habitat requirements of blue cod, the length (km) of coastline within each stratum was taken as a proxy of available habitat for blue cod.

2.1.3 Survey design

Full fixed-site and a full random-site surveys were carried out concurrently in Queen Charlotte Sound, Pelorus Sound and around D'Urville Island (Figure 1). In Cook Strait (strata 11 to 13) only a random-site survey was carried out.

Fixed sites

A fixed site has a fixed location (single latitude and longitude or the centre point location of a section of coastline) in a stratum and is available to be used repeatedly on subsequent surveys (Beentjes & Francis 2011). The fixed sites used in a survey are randomly selected from the list of all available fixed sites in each stratum. For the 2013 Marlborough Sounds survey, the allocated fixed sites were randomly selected from the list of 97 possible fixed sites (stored in the MPI *trawl* database in table *t_site*). Generally, about one-half of possible sites are used in Marlborough Sounds fixed-site surveys.

Pot configuration and placement for fixed sites is 'directed' (Beentjes & Francis 2011). In the Marlborough Sounds, blue cod habitat is largely restricted to a band of reef and rubble adjacent to the coastline. Nine pots (Pot Plan 1) were set along the coastline, no further than 0.5 km from the site position, but separated by at least 100 m. Pot placement in Marlborough Sounds fixed sites is determined by the skipper using local knowledge and the vessel sonar to locate a suitable area of reef/cobble or biogenic reef within the band of coastal habitat. This method was used in all previous Marlborough Sounds surveys. In 2013, however, the extent of blue cod habitat was identified from multibeam echo-sounder scans of the site, which were used to inform pot placement.

Random sites

A random site has a location (single latitude and longitude) generated randomly within a stratum (Beentjes & Francis 2011). In all 12 Marlborough Sounds strata, coastline was divided into 1.01 km blocks (excluding coastline sections less than 1.01 km such as rocks or small islands) and a latitude and longitude at the centre of each block was assigned, giving 1195 potential random sites (Table 1). From this list, the allocated number of random sites per stratum to be surveyed was randomly selected with the constraint that that they were not closer than 1 km to an allocated fixed site to avoid biasing random-site location, which takes priority as the future survey design (Table 2).

Pot placement in random-site surveys is 'systematic' (Beentjes & Francis 2011). In the Marlborough Sounds, pot configuration and placement is the same as for fixed sites, except that pots are placed 100 m apart in a randomly selected depth over the extent of the habitat, as it extends out from the shore. This method was used in 2010, but in 2013, random-site pot placement used multibeam echo-sounder scans to identify the extent of the habitat.

Site allocation

Simulations using NIWA's Optimal Station Allocation Program (*allocate*) were carried out using catch rates from the 2010 Marlborough Sounds survey (Beentjes & Carbines 2012) to determine the optimal allocation of sites among the four regions and 12 strata. Simulations were first carried out for fixed sites and constrained to have a minimum of three sites per strata and a CV (coefficient of variation) of no greater than 15%. Because there were no random sites surveyed in 2010 in Queen Charlotte Sound and few in Pelorus and D'Urville, random-site allocation was nominally the same as for the fixed sites, but one additional site was added to each stratum in these three regions because results from 2010 indicated that random sites were more likely to have higher CVs than fixed sites (Table 2). Cook Strait random-site allocation was based on simulations using the 2010 random-site catch rates in this region. The simulations indicated that 32 fixed sites and 71 random sites were required.

The 2013 random-site survey used a two-phase random stratified design (Francis 1984), with 91% of sites (N=65) allocated to phase 1. All previous fixed-site surveys used a one-phase random stratified survey design.

2.1.4 Vessel and gear

The Wellington-based NIWA inshore research vessel S.L. *Ikatere* was used. The *Ikatere* is an aluminium-alloy catamaran with a length of 13.9 m, beam of 4.85 m and is equipped with 322 Hamilton water jets, and powered by Twin Cummins QSC engines rated at 500HP, capable of 25 knots cruising speed. The *Ikatere* was skippered by Andrew James who was previously a commercial fisher with considerable experience in commercial blue cod potting.

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

A high-performance, 3-axis (3D) acoustic Doppler current profiler (SonTek/YSI ADP; Acoustic Doppler Profiler, 500 kHz, ADCP) was deployed at each site. The ADCP recorded current flow and direction in 5 m depth bins.

The multibeam echo-sounder survey over each site before potting occurred was carried out using a Kongsberg EM3002D multibeam Echo-sounder.

2.1.5 Sampling methods

All sampling methods adhere strictly to the blue cod potting survey standards and specifications (Beentjes & Francis 2011). Consistent with 2010, the 2013 survey started in Cook Strait and Queen Charlotte Sound before moving to Pelorus Sound and finally D'Urville Island.

Fixed-sites

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

As each pot was placed, a record was made of sequential pot number (1 to 9), latitude and longitude from GPS, depth and time of day. An ADCP was deployed at the centre of each site prior to the setting of pots and recovered after the last pot of each set was lifted.

Pots were lifted aboard using the vessel's hydraulic pot lifter in the order they were set, and the time of each lift was recorded. Pots were then emptied and the contents sorted by species. Total catch weight per pot was recorded for each species to the nearest 10 g using 0–6/6–15 kg Marel motion compensating scales. The number of individuals of each species per pot was also recorded. Total length to the nearest centimetre below actual length and sex were recorded for all finfish, and gonad maturity was recorded for all blue cod. Sagittal otoliths were removed from a representative length range of blue cod males and females (a target of up to five fish of each sex per 1 cm length class over the available length range, ensuring that the otolith collection was spread across strata from each region) and weight of each fish was recorded to the nearest 10 g. Separate otolith collections were made for each of the four regions with a target of about 250 otoliths per region. Sex and maturity were determined by dissection and macroscopic examination of the gonads (Carbines 1998, 2004b). Blue cod gonad staging was undertaken using a 6-stage method (BC), modified from the 5-stage Stock Monitoring (SM) method used on previous surveys, with the addition of a separate resting stage 6. Gonads were recorded as follows: 1, immature; 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; 6, resting. Six stages were entered into the *trawl* database, but in the analyses presented, gonad stages 1 and 6 were combined, consistent with previous surveys where for the SM method, stage 1 includes immature and resting.

Gonad collection

Gonads were collected and preserved from fish sampled along with all associated data for future analysis of maturity, fecundity, atresia and sex change in relation to length. Reproductive development analysis is also typically conducted in relation to age, so otoliths and biological data were also collected for any fish for which gonads were collected.

Both male and female gonads were collected in a 'single flat sample' design from throughout the survey area. The flat sample consisted of up to 5 samples from each 1 cm length class encountered for each sex, targeting the length range from 15–45 cm throughout the surveyed area.

One gonad was isolated, scored to allow fixative to penetrate the tissue, and stored in 10% buffered formalin at a volume ratio of 4 parts formalin to one part tissue (Murua et al. 2003). Samples were transferred to 70% ethanol for storage for future histological or fecundity analysis and a database maintained to track the status and analysis of each sample. Samples are stored at NIWA, Nelson.

2.1.6 Data storage (potting survey)

The trip code for the survey is ika1301. At the completion of the survey, data were entered into the Ministry for Primary Industries (MPI) *trawl* and *age* databases in accordance with the business rules and the blue cod potting survey standards and specifications (Beentjes & Francis 2011). All analyses were carried out from data extracted from the *trawl* database. Fixed sites were entered into *trawl* table *t_station* in attribute *stn_code* (concatenating stratum number and site label, e.g., 1F, 2B etc.). Similarly, random sites were entered into attribute *stn_code*, but were prefixed with R (e.g., R3A, R4B). Random site locations were also entered into *trawl* table *t_site*. Pot locations were entered in table *t_station* in attribute *station_no* (concatenating set number and pot number e.g., 11 to 19, or 31 to 39 etc.) with no distinction between fixed and random sites. In the *age* database the *sample_no* is equivalent to *station_no* in the *trawl* database.

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

2.1.7 Age estimates

The original 2013 survey otolith readings were rejected by the MPI Southern Inshore Working Group in April 2014 (SINSWG-2014/14), and an MPI blue cod ageing workshop in July 2014 recommended that the otoliths be re-aged. Otoliths were re-read in 2017 following the methods of the blue cod age determination protocol (ADP) (Walsh 2017). Otolith preparation could not, however, be altered and is described below as it was carried out. The main difference between this and the preparation method set out in the ADP, is that the otolith section thickness is recommended to be 350 µm, and not 2 mm.

Preparation

1. A thin section technique was used for ageing blue cod otoliths (Carbines 2004a). The whole otolith was embedded in Araldite polymer resin, baked (50ºC for at least three hours), and sectioned transversely close to the nucleus with a diamond-tipped cut-off wheel. The sectioned surface of the otolith half was then glued to a glass slide and a second cut made resulting in a section of about 2 mm thickness. The resultant thin section on the slide was then coated with a slide mountant and sanded with 600-grit sandpaper to about 1 mm thickness before viewing.

Reading

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

2.1.8 Analyses of data

Analyses (catch rates, sex ratios, scaled length distribution, catch-at-age, *Z* estimates and SPR) were conducted and presented for each of the four regions (Queen Charlotte Sound, QCH; Pelorus Sound, PEL;

D'Urville Island, DUR; CKST, Cook Strait) for random sites, and for all regions except CKST for fixed sites (Table 2).

Analyses of catch rates and CV, length-weight parameters, scaled length and age frequencies and CV, sex ratios, mean length and mean age were carried out using the equations documented in the blue cod potting survey standards and specifications (Beentjes & Francis 2011).

2.1.8.1 Catch rates

The catch rate ($kg.pot^{-1}$) estimates are pot-based and the CV estimates are set-based (Beentjes & Francis 2011). Catch rates and 95% confidence intervals (± 1.96 * standard error) were estimated for all blue cod and for three length categories (under 30 cm, pre-recruited; 30–35 cm, slot limit legal size; over 35 cm, above slot limit). Weights of individual blue cod that were not weighed during the survey (291 of 2492 blue cod) were calculated from the length-weight relationship for the survey (see below). Derived individual fish weights were then used to determine catch rates and CV of these length categories. The coastline lengths (km) shown in Table 2 were used as the area of the stratum (A_t) when scaling catch rates (equations 3 and 5 in Beentjes & Francis 2011). Catch rates are presented by stratum and overall for each region.

2.1.8.2 Length-weight parameters

The length-weight parameters a_k, b_k from the 2013 survey data were used in the equation

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

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

2.1.8.3 Growth parameters

A von Bertalanffy growth model (von Bertalanffy 1938) was fitted to the 2013 survey length-age data by sex as follows:

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

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

2.1.8.4 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 (km) shown in Table 2 was taken as the area of the stratum (A_t), and the length-weight parameter estimates were made from the 2013 survey data for males and females separately.

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

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

For each of the four regions (QCH, PEL, DUR, CKST) catch-at-age was estimated using the length and age data collected from that region, e.g., using the age length key (ALK) generated from the QCH region applied to the length data from the QCH region. The same ALKs were used for both random and fixed sites within each region. For each region and survey (fixed and random site), scaled length-frequency and age-frequency proportions are presented, together with CV for each length and age class, and the mean weighted coefficients of variation (MWCV).

2.1.8.5 Sex ratios, and mean length and age

Sex ratios (expressed as percentage male) and mean lengths, for both the stratum or survey level, were calculated using equations 10 and 11 of Beentjes & Francis (2011) from the stratum or survey scaled length frequency data. Mean ages were calculated analogously from the scaled age frequencies. Sex ratios were also estimated for blue cod in the slot limit legal size (30–35 cm) and for fish longer than the slot limit (over 35 cm) with 95% confidence intervals generated from the 300 bootstraps. Sex ratios were also calculated for six length categories (under 25 cm, 25–29 cm, 30–34 cm, 35–39 cm, 40–44 cm and 45–49 cm) used in the analyses of the six previous surveys (1995, 1996, 2001, 2004, 2007 and 2010).

2.1.8.6 Total mortality estimates

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

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

2.1.8.7 Spawner-per-recruit estimates

A spawner-per-recruit analysis was used to estimate the $F_{\%SPR}$ using the CASAL (Bull et al. 2005). The calculations involved simulating fishing with constant fishing mortality, F, in a population with deterministic recruitment, and estimating the equilibrium spawning biomass per recruit (SPR) associated with that value of F. The %SPR for that F is then simply that SPR, expressed as a percentage of the equilibrium SPR when there is no fishing (i.e., when $F = 0$).

Input parameters used in the 2013 SPR analysis

Growth parameters — von Bertalanffy growth parameters and length-weight coefficients were estimated from the 2013 survey data (see below). Ages for all regions were combined because of the wide scatter of length versus age, which resulted in unlikely values for K, L_∞ and t_0 in some regions.

Parameter	Males	Females
L_∞ (cm)	39.90	31.75
K (yr^{-1})	0.300	0.473
t_0 (yr)	-0.209	0.432
a	0.011	0.00825
b	3.0952	3.1849

Natural mortality	default assumed to be 0.14. Sensitivities were carried out for M values 20% above and below the default (0.11 and 0.17).
Maturity	the following maturity ogive was used: 0, 0, 0, 0.1, 0.4, 0.7, and 1; where 10% of blue cod are mature at 4 years old and all are mature at 7 years.
Selectivity	selectivity to the recreational fishery is described as knife-edge equal to age-at-MLS calculated from the 2013 Marlborough Sounds survey von Bertalanffy combined model. Recreational MLS in 2013 was 30 cm and selectivity was 4.5 years for males and 6.6 years for females.
Fishing mortality (*F*)	fishing mortality was estimated from the results of the Chapman-Robson analyses and the assumed estimate of *M* (i.e., $F = Z–M$). The *Z* value for age-at-full recruitment (7 years) was the age of females at MLS calculated from the 2013 Marlborough Sounds survey female combined von Bertalanffy model.
Maximum age	assumed to be 31 years.

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

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

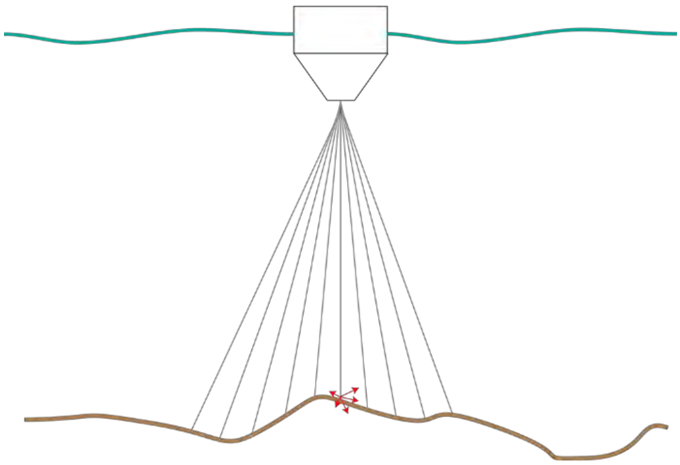
The SPR estimates are based on age at recruitment (7 years).

2.1.8.8 Analyses of historical surveys (1995 and 1996)

The catch rates from the 1995 and 1996 surveys reported in the 2010 report (Beentjes & Carbines 2012) were interpreted from the data and figures in the published survey reports (Blackwell 1997, 1998). However, close examination of the potting data used in previous analyses of these two surveys showed that this included line fish sites, repeated potting sites, and sites described as extras. Hence data were re-analysed for the 1995 (QCH) and 1996 (PEL) surveys using the potting survey standards and specifications equations and valid input data. 1995 and 1996 surveys can now be validly compared with all surveys in the time series. Catch rates and sex ratios were estimated in the same way as for other surveys after 1996.

2.2 Multibeam echo-sounder (MBES)

Multibeam echo-sounders (MBES) map the seafloor by measuring the water depth in a line perpendicular to the ship's direction. A swath or fan of acoustic beams is directed to the seafloor, and from the time between emission and reception of the signal the water depth can be estimated. The acoustic energy reaching the seafloor is not fully reflected, as various physical factors generate a backscatter effect (see below). This backscatter effect is influenced by incidence angle, water column properties, and also depends on the properties of the seafloor. Because of this the amount of backscatter (measured in loss of transmitted energy at reception) can be used to estimate seafloor composition.



The sound waves progressing through the water column are affected by the water properties (temperature, salinity, depth/pressure), changing the speed with which the sound can progress. This effects the depth measured, and also the geographic location of the measurement. Sound-Velocity or Sound-Speed Profiles (SVP) are taken regularly to accommodate for this effect. Critical for the correct function of the MBES are three factors. The alignment of the sounder with the motion sensor and GPS antennae, the ship motion (speed, heading, yaw, pitch, roll, heave) and position, and the SVP.

2.2.1 MBES Operation

The *Ikatere* has a moonpool with a permanently installed deployment pole that is regularly used with the Kongsberg EM3002D MBES (Figure 2). Figure 3 shows the EM3002D (red disks either side) mounted at the base of the pole in the up position. Additionally, the mount carries the motion sensor (not visible), and the constant sound velocity probe (upper left of image in green mounts).

All components together with two rooftop mounted GPS antennae were surveyed into a common reference frame to assure correct alignment. The motion sensor on *Ikatere* measures heave, roll, pitch and yaw, and the processing unit can determine speed and heading using the information from the two GPS antennae. The constant SVP and a manually deployed probe assure the correct sound-velocities are applied. All this information is combined with the soundings in the processing unit, controlled by an operator using specialised PC software.

Each potting site was surveyed, usually at least a day before potting occurred. The vessel steamed parallel to the shore at a maximum speed of 8 knots making two passes of about 1.5 km in length, collecting high resolution bathymetry and backscatter data of the seafloor over the potted sites. The width of the MBES swathed area was approximately four to five times the water depth, which ranged from 3 to 51 m depth.

2.2.2 MBES data processing and analyses

The raw data were processed using CARIS HIPS software, an industry standard bathymetry data processing and editing software. Regional tide data from the NIWA tide model were applied, the data merged, all corrections from the motion sensors checked and applied, and the Total Propagated Uncertainty (TPU) computed. This value expresses the uncertainties of each sounding based on GPS data quality, sounding location (near the nadir of the swath, on outer beams), and motion of the boat at the time of the sounding. This value was then used to rank the soundings, and compute a seafloor surface model using the soundings according to their quality. The processed data was then checked for spikes, and faulty soundings were flagged and removed from the seafloor model. The finished model was exported to ESRI ASCII grid format for further analysis in ESRI GIS software.

ESRI ArcGIS was used to construct the seafloor model, or bathymetry. Data were converted from ESRI ASCII grid format to ESRI binary grid formats. All subsequent analyses were done using ArcGIS and data stored in ESRI File Geo Databases (FGDB).

2.3 Pot selectivity methods

Length selectivity of the two pot designs (PP1 and PP2) was compared from samples of length for each sex from each pot type within a local population. The local populations at eight sites were sampled on the 8th and 9th of November 2013, with four pot deployments of each gear type. A random site was chosen from the site list in a stratum, and four pots of each type were placed within the site in a randomised order with respect to pot plan and depth.

This type of catch comparison characterises the consistency of the numbers and proportions of fish at each length class present in the catch of at least one gear type, and is therefore a relative analysis. It does not provide information about components of the population that are not selected by either gear type. Consistency in the proportions-at-length are also more precise for higher sample sizes, so areas of high catch rates were chosen to maximise the catch for this objective.

The comparison was carried out in two strata to increase the range of lengths present (e.g., in case very small or very large fish were not present in some areas). Following the main survey, eight sites were chosen that were not fished during the survey. These were in strata that had high densities of blue cod in the current and previous surveys (stratum 6 of DUR, and stratum 4 of PEL), had a broad range of fish length present, and were contained in a relatively small spatial area. The sites were selected based on an assessment of the seafloor habitat from multibeam echo-sounder results.

At each site, 4 pots of each type were fished giving a total of 64 pot lifts. Pots were deployed in a random order at 100 m spacing. An ADCP was deployed at the centre of each site immediately prior to setting the pots at that site and was recovered after the last pot of each set was lifted. Pot placement was systematic and randomised with respect to depth as described for random-site pot placement, and soak time was one hour. All fish captured were measured, and sex and gonad stage determined.

Analyses of gear selectivity between PP1 and PP2 were conducted using custom NIWA relative length selectivity analysis in R (Parker & Fu 2012). The analytical approach was similar to the trawl selectivity work of Millar & Fryer (1999), but focused on the paired nature of the proposed design and the selectivity differences between the gear types. The numbers and proportions of fish captured in each 1 cm length class for the pooled catch by gear type within each site were compared to determine the relative length selectivity of PP1 versus PP2. As a main-effects analysis, the values for PP2 were subtracted from PP1 by length for each site, yielding a difference-at-length. These were then summarised to generate a mean relative selectivity with respect to length for each sex and as a composite for both sexes.

To estimate the uncertainty in this relationship, length values for each pot type at each site were bootstrapped 500 times and the resulting relative selectivity relationship was summarised to yield the relative selectivity relationship for each sex and in total. By definition, the relative length selectivity is zero if neither gear type captures a given length fish. Although fewer fish are captured at the upper and lower ends of the length distribution, the relative selectivity for these lengths are still well estimated by the bootstrapping procedure. For example, if a few fish of one length are captured by one gear type and none by the other, then the bootstrap process will capture the relative frequency difference and the variability in that number and proportion will be well represented. If a variable number of fish is captured at a given length class, then the bootstrapping process will capture that variability. Low numbers of fish in a length class means that the proportion of fish will be poorly determined compared to the number of fish, but that variation is captured in the bootstrap process.

3. RESULTS

3.1 2013 Marlborough Sounds fixed-site blue cod potting survey

3.1.1 Fixed sites surveyed

Thirty-two fixed sites (9 pots per site, producing 288 pot lifts) from nine strata throughout the Marlborough Sounds were surveyed from 26 September to 7 November 2013 (Table 2, Figure 4). Depths sampled were 3–50 m (mean = 15.6 m).

3.1.2 Catch (fixed sites)

A total of 556 kg of blue cod (= 1182 fish) was taken comprising 94% by number of the catch of all species on the survey (Table 3). Bycatch species included 11 teleost fishes, 1 shark, and 1 octopus. The three most common bycatch species, by number, were tarakihi (*Nemadactylus macropterus*), scarlet wrasse (*Pseudolabrus miles*) and leatherjacket (*Parika scaber*).

Of the 288 fixed-site pots, 100 (35%) had zero catch of blue cod.

3.1.3 Blue cod catch rates (fixed sites)

Mean catch rates ($kg.pot^{-1}$) of blue cod (all lengths, 30–35 cm (slot limit), over 35 cm, and under 30 cm) from fixed sites are presented by stratum and for each region (Tables 4 to 7) and plotted by stratum in Figure 5 and by each region in Figure 6.

Queen Charlotte Sound (QCH) catch rates of all blue cod in the inner Sounds (stratum IQCH) were about one-quarter of those from the outer Sounds strata (OQCH and EQCH), which had similar catch rates (Figure 5). The catch rates by length category also reflect the smaller length of fish sampled from the inner Sounds.

Pelorus Sounds (PEL) catch rates of all blue cod in the inner and mid Sounds (strata IPEL and MPEL) were substantially less than those from the outer Sounds strata (OPEL and EOPE) with the largest catch rates recorded in the extreme outer Sounds (EOPE) (Figure 5). The catch rates by length category also reflect the smaller length of fish from the inner Sounds.

D'Urville (DUR) catch rates of all blue cod were more similar east and west of D'Urville Island, but overall were about one-quarter higher in the west (Figure 5). The catch rates by length category indicate similar length distributions in both strata.

Catch rates varied across all three regions and the all blue cod catch rate for QCH (1.0 $kg.pot^{-1}$) was about half that of PEL (1.95 $kg.pot^{-1}$) and one-quarter that of DUR (3.88 $kg.pot^{-1}$) (Figure 6). The relative proportions of the total catch rates for each length category overall were similar among the regions, i.e., 30–35 cm, 45–49%; above 35 cm, 22–26%; and under 30 cm, 26–30% (Table 8).

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

Queen Charlotte Sound

Of the 251 blue cod caught, all were sexed and measured. The weighted sex ratio was 65–90% male across the three strata and the overall weighted sex ratio was 62% male (Table 9). Length was 23–45 cm for males and 20–38 cm for females, although this varied among strata and the overall weighted mean length was 31.7 cm for males and 29.8 cm for females. The raw length-frequency distributions lack the numbers in some strata to describe length composition well, but appear to be unimodal (Appendix 2).

Pelorus Sound

Of the 475 blue cod caught, all were sexed and measured. The weighted sex ratio was 82–93% male across the four strata and the overall weighted sex ratio was 89% male (Table 9). Length was 19–49 cm for males and 17–44 cm for females, although this varied among strata and the overall weighted mean length was 31.3 cm for males and 27.2 cm for females. The raw length-frequency distributions lack the numbers for females to describe strata length composition well, but appear to be unimodal, at least for males (Appendix 2).

D'Urville Island

Of the 456 blue cod caught, all were sexed and measured. The weighted sex ratio was 65–75% male across the two strata and the overall weighted sex ratio was 70% male (Table 9). Length was 21–45 cm for males and 19–40 cm for females, although this varied between strata and the overall weighted mean length was 31.7 cm for males and 29.4 cm for females. The raw strata length-frequency distributions are unimodal (Appendix 2).

3.1.5 Age and growth in 2013

Otolith section ages from 640 males and 264 females collected from fixed and random sites were used to estimate the population age structure from Marlborough Sounds in 2013. There were 123 males and 96 females aged from QCH, 177 males and 63 females, and one unsexed aged from PEL, 163 males and 59 females aged from DUR, and 177 males and 46 females, and 10 unsexed aged from CKST. A single ALK for males and females was produced for each region. The all regions combined length-age data for 2013 are plotted and the von Bertalanffy model fits are shown for males and females separately (Figure 7). The growth parameters (K, t_0 and L_∞) are shown in the methods table of input data for the SPR analysis (Section 2.1.8.7). There is a large range in age-at-length for both sexes, typical of blue cod. The mean ages-at-length of these fish are consistent with 2015/16 surveys of North Canterbury and Banks Peninsula (Beentjes & Fenwick 2017, Beentjes & Page 2017, Beentjes & Sutton 2017), suggesting that the revised ages based on the ADP are credible.

Between-reader comparisons are presented in Figure 8. The two readers achieved agreement on 27% of read otoliths, with conferment required on those where assigned ages differed. The between-reader precision (CV) was 14% with an index of average percentage error (IAPE) of 10%. These values are higher than desired for blue cod, but are partly explained by the difficulty in reading otolith sections that were too thick, sometimes making it difficult to distinguish annual growth rings. Reader 1 showed closer agreement to the agreed age than reader 2. Reader 1 has estimated ages for all blue cod surveys since the ADP was established in 2014.

Age estimates from previous surveys

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. Otoliths would need to be re-aged under the ADP before any comparisons of age composition among surveys, and with 2013, could be validly attempted.

3.1.6 Blue cod spawning activity

Gonad stages of blue cod sampled on the 2013 survey between late September and early November 2013 are presented by region for all lengths, pre-recruited (under 30 cm), and recruited fish (over 30 cm) (Table 10), and are also plotted for all lengths (Figure 9). The data presented are from fixed and random sites. There was a clear indication of spawning activity during the survey period, particularly in QCH where half the males were ripe or running ripe, whereas in other regions the high proportion of spent males suggested spawning had peaked. In contrast, female spawning did not appear to have peaked, except for CKST where there was a relatively high proportion of spent fish. There were also high proportions of running ripe and spent males (up to 27 and 51%, respectively) and running ripe and spent females (15 and 60%, respectively) in fish under 30 cm.

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

The scaled length-frequency and age distributions for the 2013 fixed-site survey are shown separately for each of the three regions as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Figures 10–12).

Queen Charlotte Sound

Scaled length-frequency distributions for both males and females were unimodal with a right-hand tail and mean lengths of 31.6 and 29.8 cm respectively (Figure 10). The cumulative distribution plots of length-frequency show clearly that males had a higher proportion of larger fish than females, and also that the largest fish were males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 48% for males and 54% for females, higher than desired for the survey to provide a reasonable representation of the overall population. Fish 30 cm and over comprised 61.7% of the scaled numbers (see Table 8).

Age estimates of blue cod were 3–13 years for males and 3–17 years for females, but most males were 4–7 years old and females were 5–8 and 11–12 years old (Figure 10**).** The estimated population age distributions were unimodal for males and possibly bimodal for females. Male ages were skewed to the right with the peak at 5. Females showed peaks between 5 and 8 years, and at 12 years. The cumulative distribution plots of age-frequency showed clearly that females had a much higher proportion of older fish than males. Further, the mean age of females was greater than the mean age of males (8.2 for females and 6.2 years for males). The MWCVs around the age distributions were 36% for males and 46% for females, higher than desired to provide a good representation of the overall population.

Pelorus Sound

Scaled length-frequency distributions for both males and females were unimodal with mean lengths of 31.3 and 27.2 cm, respectively (Figure 11). The cumulative distribution plots of length-frequency showed that males had a higher proportion of larger fish than females, and also that the largest fish were males, although there were relatively few females caught. The MWCVs around the length distributions were 27% for males and 66% for females, higher than desired for females to provide a reasonable representation of the overall population. Fish 30 cm and over comprised 63.2% of the scaled numbers (see Table 8).

Age estimates of blue cod were 2–12 years for both males and females, but most fish were 4–7 years old (Figure 11). The estimated population age distributions were unimodal for both sexes, but ages were skewed to the right with the peak at 4 years for both sexes. The cumulative distribution plots of age-frequency showed that females had a slightly higher proportion of older fish than males and were marginally older on average (5.8 years for females and 5.2 years for males). The MWCVs around the age distributions were 20% for males and 52% for females, higher than desired for females to provide a good representation of the overall population.

D'Urville Island

Scaled length-frequency distributions for both males and females were unimodal with mean lengths of 31.7 and 29.4 cm, respectively (Figure 12). The cumulative distribution plots of length-frequency show clearly that males had a higher proportion of larger fish than females and also that the largest fish were males. The MWCVs around the length distributions were 31% for males and 38% for females, higher than desired for females to provide a reasonable representation of the overall population. Fish 30 cm and over comprised 64.1% of the scaled numbers (see Table 8).

Age estimates of blue cod were 4–12 years for both males and females, but most fish were 4–7 years old (Figure 12). The estimated population age distributions were unimodal for both sexes, but ages were skewed to the right with the peak at 5 years for males and 7 years for females. The cumulative distribution plots of age-frequency showed that females had a higher proportion of older fish than males and were older on average (6.9 years for females and 5.9 years for males). The MWCVs around the age distributions were 20% for males and 38% for females, higher than desired for females to provide a good representation of the overall population.

Fixed-site length distribution among regions

Cumulative plots of population length for each of the three regions from fixed sites in 2013 showed that overall there was little difference in length distributions for males between the three regions (Figure 13). Female length was similar in QCH and DUR, but considerably smaller, on average, in PEL. Female numbers were low for PEL (N = 55), which may distort the trend for this region.

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

Fixed-site total mortality estimates (*Z*) and 95% confidence intervals for each region are given for a range of recruitment ages (5–10 years) in Appendix 3. For age-at-full-recruitment (7 years), total mortality estimates were QCH = 0.37, PEL = 0.75, and DUR = 0.87.

Mortality parameters used, and the resulting spawner-per-recruit ($F_{SPR\%}$) estimates (where age-at-recruitment was 7 years), are shown in Appendix 4 for all regions. Based on the default *M* of 0.14, estimated fishing mortalities (*F*) and associated spawner-per-recruit ratios were QCH (0.23, $F_{37.1\%}$), PEL (0.61, $F_{20.2\%}$) and DUR (0.73, $F_{18.2\%}$). This indicates that at the 2013 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to between 18% and 37% of the contribution in the absence of fishing.

3.2 2013 Marlborough Sounds random-site blue cod potting survey

3.2.1 Random sites surveyed

Seventy-one random sites (9 pots per site, producing 639 pot lifts) from 12 strata throughout Marlborough Sounds and Cook Strait were surveyed from 26 September to 7 November 2013 (Table 2, Figure 14). Depths sampled were 3–51 m (mean = 11.1 m).

3.2.2 Catch (random sites)

A total of 676 kg of blue cod (= 1310 fish) was taken comprising 75% by number of the catch of all species on the survey (Table 3). Bycatch species included 14 teleost fish, 1 shark, 1 octopus, and 2 gastropods. The three most common bycatch species, by number, were butterfly perch (*Caesioperca lepidoptera*), scarlet wrasse (*Pseudolabrus miles*) and leatherjacket (*Parika scaber*).

Of the 639 random site pots, 315 (49%) had zero catch of blue cod.

3.2.3 Blue cod catch rates (random sites)

Mean catch rates ($kg.pot^{-1}$) of blue cod (all lengths, 30–35 cm (slot limit), over 35 cm, and under 30 cm) are presented by stratum and overall for each region (Tables 4 to 7) and plotted by stratum in Figure 15 and overall in Figure 16.

Queen Charlotte Sound (QCH) catch rates of all fish lengths in the inner Sounds (stratum IQCH) were about twice those from the outer Sounds (OQCH) and about half that of the extreme outer Sounds (EQCH) (Figure 15). Pelorus Sound (PEL) catch rates of all fish lengths in the inner and mid Sounds (strata IPEL and MPEL) were substantially less than those from the outer Sounds strata (OPEL and EOPE) with the largest catch rates recorded in the extreme outer Sounds (EOPE) (Figure 15). D'Urville (DUR) catch rates of all fish lengths were more than two times higher in the west (DURW) than east of D'Urville Island (DURE). Cook Strait (CKST) catch rates of all fish lengths in Port Underwood (UNDW) were the lowest with the highest rates around Arapawa Island (APAE).

Catch rates varied across all four regions with the all fish length catch rate in DUR double that of PEL, two-thirds higher than CKST, and over four times greater than QCH (Figure 16). The relative proportions of the total catch rates for each length category varied among the regions, i.e., 30–35 cm, 37–50%; above 35 cm, 23–37%; and under 30 cm, 17–28% of the total catch rate (Table 8).

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

Queen Charlotte Sound

All the 188 blue cod caught, were sexed and measured. The weighted sex ratio was 48–80% male across the three strata and the overall weighted sex ratio was 66% male (Table 9). Length was 17–45 cm for males and 23–41 cm for females, although this varied among strata, and the overall weighted mean length was 32.1 cm for males and 30.3 cm for females. The raw length-frequency distributions lack the numbers to describe strata length composition well (Appendix 5).

Pelorus Sound

All the 341 blue cod caught (except one fish) were sexed and measured. The weighted sex ratio was 46–89% male across the four strata and the overall weighted sex ratio was 77% male (Table 9). Length was 20–43 cm for males and 16–36 cm for females, although this varied among strata, and the overall weighted mean length was 33.3 cm for males and 30.1 cm for females. The raw length-frequency distributions lack the numbers to describe length composition well for each stratum, except those for the extreme outer sound (EOPE), which were unimodal (Appendix 5).

D'Urville

All the 276 blue cod caught were sexed and measured. The weighted sex ratio was 53–59% male across the two strata and the overall weighted sex ratio was 57% male (Table 9). Length was 23–46 cm for males and 23–37 cm for females, although this varied between strata and the overall weighted mean length was 32.8 cm for males and 29.9 cm for females. The DUR raw length-frequency distributions in both strata lack the numbers to describe length composition well, but appear to be unimodal (Appendix 5).

Cook Strait

All the 400 blue cod caught (except 13 fish) were sexed and measured. The weighted sex ratio was 80–100% male across the three strata and the overall weighted sex ratio was 83% male (Table 9). Length was 22–44 cm for males and 19–36 cm for females, although this varied between strata, and the overall weighted mean length was 31.7 cm for males and 28.4 cm for females. The raw length-frequency distributions in Port Underwood (UNDW) lack the numbers to describe length composition well, but in the other strata distributions were unimodal (Appendix 5).

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

The scaled length-frequency and age distributions for the 2013 random-site survey are shown separately for each of the four regions as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Figures 17–20).

Queen Charlotte Sound

The scaled length-frequency distributions for both males and females were unimodal with mean lengths of 32.1 and 30.3 cm, respectively (Figure 17). The cumulative distribution plots of length-frequency show clearly that males had a higher proportion of larger fish than females and also that the largest fish were males. The MWCVs around the length distributions were 57% for males and 68% for females, much higher than desired for the survey to provide a reasonable representation of the overall population. Fish 30 cm and over comprised 67.6% of the scaled numbers (see Table 8).

Age estimates of blue cod were 3–13 years for males and 3–17 years for females, but most males were 4–7 years old and females were 5–8 and 12 years old (Figure 17). The estimated population age distributions were unimodal for males and possibly bimodal for females. Male ages were skewed to the right with the peak at 5. Females showed peaks between 5 and 8 years, and at 12 years. The cumulative distribution plots of age-frequency showed clearly that females had a much higher proportion of older fish than males. Further, the mean age of females was greater than the mean age of males (8.3 for females and 6.3 years for males). The MWCVs around the age distributions were 41% for males and 51% for females, higher than desired to provide a good representation of the overall population.

Pelorus Sound

The scaled length-frequency distributions for both males and females were unimodal with mean lengths of 33.3 and 30.1 cm, respectively (Figure 18). The cumulative distribution plots of length-frequency showed clearly that males had a higher proportion of larger fish than females and also that the largest fish were males, although there were relatively few females caught in PEL. The MWCVs around the length distributions were 35% for males and 62% for females, higher than desired to provide a reasonable representation of the overall population. Fish 30 cm and over comprise 77.5% of the scaled numbers (see Table 8).

Age estimates of blue cod were 2–12 years for both males and females, but most fish were 4–7 years old (Figure 18). The estimated population age distributions were unimodal for both sexes, but ages were skewed to the right with the peak at 5 years for males and 7 years for females. The cumulative distribution plots of age-frequency showed that females had a slightly higher proportion of older fish than males and were marginally older on average (7 years for females and 5.6 years for males). The MWCVs around the age distributions were 25% for males and 60% for females, higher than desired for females to provide a good representation of the overall population.

D'Urville

The scaled length-frequency distributions for both males and females were unimodal with mean lengths of 32.8 and 29.9 cm, respectively (Figure 19). The cumulative distribution plots of length-frequency showed clearly that males had a higher proportion of larger fish than females and also that the largest fish were males. The MWCVs around the length distributions were 44% for males and 37% for females, higher than desired to provide a reasonable representation of the overall population. Fish 30 cm and over comprised 69.1% of the scaled numbers (see Table 8).

Age estimates of blue cod were 4–12 years for both males and females, but most fish were 5–7 years old (Figure 19). The estimated population age distributions were unimodal for both sexes, but ages were skewed to the right with the peak at 5 years for males and 7 years for females. The cumulative distribution plots of age-frequency showed that females had a higher proportion of older fish than males and were marginally older on average (7 years for females and 6.2 years for males). The MWCVs around the age distributions were 28% for males and 40% for females, higher than desired for females to provide a good representation of the overall population.

Cook Strait

The scaled length-frequency distributions for both males and females were unimodal with mean lengths of 31.7 and 28.4 cm, respectively (Figure 20). The cumulative distribution plots of length-frequency showed clearly that males had a higher proportion of larger fish than females and also that the largest fish were males. The MWCVs around the length distributions were 30% for males and 61% for females, higher than desired for females to provide a reasonable representation of the overall population. Fish 30 cm and over comprised 68.2% of the scaled numbers (see Table 8).

Age estimates were 2–11 years for males and 3–12 years for females, but most fish were 4–6 years old (Figure 20). The estimated population age distributions were unimodal with ages skewed to the right for males and a peak at 5 years, whereas the distribution was less clear cut for females with a small peak at 6 years. The cumulative distribution plots of age-frequency showed that females had a higher proportion of older fish than males and were older on average (6.2 years for females and 5.1 years for males). The MWCVs around the age distributions were 20% for males and 60% for females, higher than desired for females to provide a good representation of the overall population.

Length distributions between regions (random sites)

Cumulative plots of population length for each of the four regions showed that overall there was little difference in length distributions of males between the four regions except that QCH had higher proportions of smaller blue cod and Cook Strait lower proportions of larger blue cod (Figure 21). Female length was also similar between regions, but overall CKST had lower proportions of smaller blue cod. Female numbers were low for PEL (N = 70) and CKST (N = 86), which may have distorted the trends.

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

Random-site total mortality estimates (*Z*) and 95% confidence intervals for each region are given for a range of recruitment ages (5–10 years) in Appendix 3. For age-at-full-recruitment (7 years), total mortality estimates were QCH = 0.4, PEL = 0.7, DUR = 0.7, and CKST = 0.62.

Mortality parameters used, and the resulting spawner-per-recruit ($F_{SPR\%}$) estimates (where age-at-recruitment was 7 years), are shown in Appendix 4 for all regions. Based on the default *M* of 0.14, estimated fishing mortalities (*F*) and associated spawner-per-recruit ratios were QCH (0.26, $F_{34.3\%}$), PEL

(0.56, $F_{21.3\%}$), DUR (0.56, $F_{21.3\%}$), and CKST (0.48, $F_{23.4\%}$). This indicates that at the 2013 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to between 21% and 33% of the contribution in the absence of fishing.

3.3 Comparison of fixed-site and random-site surveys

For all three regions, catch rates of all blue cod were higher in fixed than random sites (Figure 22). Catch rates by length category were also lower in random than fixed sites except for the largest fish (above 35 cm) where catch rates were similar.

Cumulative plots of population length from the two surveys are presented in Figures 23–25. In QCH overall there was little difference in length distributions of either sex, although males from random sites had a slightly wider length distribution (Figure 23). Fish in PEL were overall larger from random sites than fixed sites and this was more evident for females (Figure 24). In DUR length distributions were similar for both sexes (Figure 25).

3.4 Marlborough Sounds blue cod historical surveys (1995 and 1996)

Catch and effort details for the 1995 and 1996 surveys are provided in Appendix 6 and catch rates and CVs in Appendix 7. These surveys were re-analysed using only valid pots based on the specifications of the potting survey standards and specifications (Beentjes & Francis 2011). Hence, these results should be used in preference to those in the standalone reports for these surveys (Blackwell 1997, 1998), and also to those in the 2010 survey report (Beentjes & Carbines 2012).

The scaled length-frequency distributions for 1995 (QCH) and 1996 (PEL) are presented in Appendices 8 and 9, respectively. Scaled length-frequency distributions are not presented for the partial surveys of PEL in 1995 (strata 4 and 5) and DUR in 1996 (stratum 6). Length-distribution results from this re-analysis should be used in preference to those in the standalone reports for these surveys (Blackwell 1997, 1998).

3.5 Survey time series (fixed sites)

3.5.1 Blue cod catch rates (fixed sites)

Mean catch rates ($kg.pot^{-1}$) by length (all lengths, 30–35 cm, over 35 cm, and under 30 cm) from fixed sites are presented for each region and for each survey in the time series (Figure 26).

QCH catch rates of all lengths declined by about a third between 1995 and 2001, and continued to decline slightly in 2004 and 2007, before nearly doubling in 2010, and halving in 2013 (Figure 26). The pattern was repeated for the other length categories except pre-recruited fish (under 30 cm), for which catch rates were stable from 1995 to 2004 and then declined from 2007 to 2013.

The overall pattern in PEL was similar to QCH. Catch rates declined by about two-thirds between 1996 and 2001, nearly doubled in 2004, were stable in 2007, then nearly tripled in 2010, before dropping down by about one-third in 2013 (Figure 26). The pattern is similar for the other length categories except pre-recruited fish (under 30 cm), which did not appear to show any pattern.

Although abundance of fish over 35 cm had declined from 2010 to 2013 in both Pelorus and Queen Charlotte Sounds, catch rates remained higher than prior to the closure (i.e., 2007 survey).

There were no patterns in DUR catch rates for any of the length categories from 2004 to 2013, and catch rates appeared to be stable (Figure 26).

3.5.2 Blue cod sex ratios (fixed sites)

The sex ratios within discrete length categories for each survey in the time series are shown in Figures 27–29 for QCH, PEL and DUR, respectively.

QCH – the sex ratio in QCH was 20–48% male for small blue cod (less than 25 cm) and gradually increased with length until above 40 cm where the population was 100% male (Figure 27, top panel). Sex ratio is closest to parity overall in the 25–29 cm length range (top panel). The pattern of sex ratio change with increased length followed the same general trends between all six QCH surveys although the proportion male in the 30–34 cm length category was particularly low in 2013 compared to the other surveys. Similarly, the slot limit legal size (30–35 cm) length category sex ratios (bottom panel) show that 2013 has lower proportions of males than the other five surveys. Overall the sex ratio of all lengths (second from top panel) and fish over 35 cm (larger than the slot limit) (third from top panel) showed no trend over time. Sex ratio of all length fish in QCH was 50–70% male.

PEL – the sex ratio in PEL was 35–55% male for small fish (less than 25 cm) and gradually increased with length until above 40 cm, where the population was 100% male (Figure 28, top panel). Sex ratio was closest to parity overall in the smallest length category under 25 cm (top panel). The pattern of sex ratio change with increased length followed the same general trends for all six PEL surveys. Overall the sex ratio of fish around the slot limit (30–35 cm) (bottom panel) and blue cod over 35 cm (larger than the slot limit) (third from top panel) showed no trends over time. The sex ratio of all blue cod in PEL was 65–90% male, and has increased markedly between 2004 and 2007, and again from 2007 to 2010.

DUR – the sex ratio in DUR was 38–71% male for small fish (less than 25 cm) and gradually increased with length until above 45 cm where the population is 100% male (Figure 29, top panel). Sex ratio was closest to parity overall in the under 25 cm and 25–29 cm length ranges (top panel). The pattern of sex ratio change with increasing length followed the same general trends among all four DUR surveys, although the proportion male in the smaller lengths in 2004 was lower compared to the other surveys. The slot limit legal size (30–35 cm) length category sex ratios (bottom panel) show that 2004 is low relative to the other three surveys. The sex ratio of all length fish (second from top panel) (50–71% male) also shows a marked increase from 2004 to 2007, whereas the sex ratio for fish over 35 cm (larger than the slot limit) (third from top panel) was stable.

3.5.3 Blue cod length distributions (fixed sites)

The QCH scaled length-frequency distributions were generally similar in shape for the six surveys but tended to shift left or right and this changed the mean length (Figure 30). The cumulative distributions of these length frequencies showed a decrease in overall male length from 1995 to 2001, no change in 2004, increased length again in 2007 followed by a significant increase in 2010, and a smaller decrease in 2013 (Figure 31). Female length tracked in a similar manner, but the increased length in 2010 was less marked than for males. The PEL scaled length-frequency distributions over the six surveys closely mirrored those of QCH but the first survey is in 1996 and not 1995 (Figures 32 and 33). In contrast, the DUR scaled length-frequency distributions were remarkably consistent and showed very little difference for either sexes and over the four surveys from 2004 to 2013 (Figures 34 and 35).

3.6 Survey time series (random sites)

3.6.1 Cook Strait (random sites)

Mean catch rates ($kg.pot^{-1}$) of blue cod (all lengths, 30–35 cm, over 35 cm, and under 30 cm) from fixed sites are presented for Cook Strait region (CKST) for the 2010 and 2013 surveys (Figure 36). Catch rates declined by about a third between 2010 and 2013 for all length categories except over 35 cm, which was unchanged.

The sex ratios within discrete length categories for each survey in the time series are shown in Figure 37. The sex ratio was 30–45% male for small blue cod (less than 25 cm) and gradually increased with length until above 40 cm where the population was 100% male (Figure 37, top panel). Sex ratio was closest to parity overall in the under 25 cm length range (top panel). The pattern of sex ratio change with increased length followed the same general trend for both surveys. More surveys are required to interpret any differences in sex ratio of all length fish (second from top panel), over 35 cm fish (larger than the slot limit) (third from top panel), and fish within the slot limit (30–35 cm) (bottom panel). The sex ratio of all fish was 84% male in 2010 and 83% male in 2013.

The scaled length-frequency distributions were generally similar in shape in the 2010 and 2013 surveys (Figure 38), but the cumulative distributions of these length frequencies showed that males and especially females were larger on average in 2013 than in 2010 (Figure 39).

3.7 Multibeam echo-sounder results

All 32 fixed potted sites and 71 random potted sites were swath-mapped using the MBES. In the following we show the ArcGIS graphical outputs from one site (3E), on the western entrance to Port Gore (Figure 40).

Bathymetry data gives a general overview of the seafloor morphology (Figure 41). The bathymetry is shown as colour-coded overlying the hillshade model (Figure 42). Additionally, in all maps the bathymetry is indicated by contours, and sample stations (nine potting stations and one ADCP station) are marked as red dots.

The hillshade map is a good visual means to evaluate the general structure of the seafloor, making flat, rippled, or rocky seafloor easily identifiable, and is used in all maps as an underlying layer to help relate the depicted data (bathymetry, slope, aspect, etc.) to the seafloor morphology (Figure 42).

Backscatter causes the loss of transmitted energy, and is commonly described as a map of the amount of reflectivity (Figure 43). High values usually indicate rock, gravel or compacted sediments, while low reflectivity indicates fine grained, soft sediments, however, as there are a large number of factors influencing the amount of transmission loss, this is only indicative.

The ruggedness or rugosity map indicates the relation of actual surface area to the plan (flat) surface area of a given area such as a grid cell, and highlights areas with strong changes, specifically rock outcrops with high surface variability (Figure 44).

The aspect map, which here is shown grouped in 22.5° segments, shows the general direction of the seafloor slope (Figure 45). This is useful in habitat projects to identify exposed and sheltered parts of seafloor.

The slope map indicates the amount of slope (in degrees), which helps identify seafloor morphology and small features like sediment ripples (Figure 46).

The curvature map indicates the change of slope and is used to identify the base of slopes on the seafloor, indicating features such as rocks, cliffs, etc. (Figure 47).

The Benthic Terrain Model (BTM) classes map is built using specialised software (Wright et al. 2012), which is an ArcGIS collection of tools that computes the position index of a bathymetry grid and, from this and other associated derivatives of the bathymetry, generates a classification of the seafloor (Figure 48). These are dependent on the classification dictionary used, and as such are only shown in a very generic example. Further work would be needed to make this useful for comparison over the whole survey area.

For all other 102 sites, bathymetry and backscatter grids were extracted and these can be plotted using ArcGIS as shown for site 3E in Figures 41 and 43. The output grids for the other seafloor descriptors (hillshade, slope, ruggedness, aspect, curvature and BTM) were not generated for the other sites.

3.7.1 Multibeam echo-sounder data storage

All data for the MBES component of this survey (currently 715 GB), are stored on NIWA's marine data file server at Greta Point, Wellington. All the data shares are located on a Storage Attached Network (SAN) with RAID configuration. As with all NIWA data storage, the shares are regularly backed up onto tape, which in turn is stored in a secure facility off site. This data includes the raw MBES data in Kongsberg *all format*, and all auxiliary files such as Sound Velocity Profiles, configuration files, processing files in CARIS HIPS and QPS Fledermaus format, and, where applicable, data extracts into ESRI ArcGIS formats (Site 3E). The routine tools used to generate the derivate layers shown in Figures 41 to 48 are not stored in this database.

3.8 Pot selectivity

Pot Plan 1 (PP1) is smaller and lighter than Pot Plan 2 (PP2), and the spacing and angle of the welded steel rods comprising the entrance funnels differs. In PP1 the spacing is wider (Figure 49). The locations of the pot placements from the eight sites are shown in Figure 50.

The 64 pot sets caught a total of 300 blue cod in PP1 versus 455 in PP2. The vast majority were males in both pot types (91% in PP1 and 80% in PP2). The length distributions were similar among the sites sampled although the magnitude of catch varied for each sex (Figures 51 and 52). For pooled catches among sites, females were smaller than males (32.9 vs 29.0 cm) for PP1 and (30.2 vs 26.3 cm) for PP2 and were more prevalent in PP2 catches (Figure 53).

If there were two length classes (small and big), it is possible for the relationship in selectivity to appear different expressed in the units of numbers of fish or in proportion of the catch (Table 11). No difference is indicated by a constant relationship with length. A higher selectivity for a given length would appear as a shift in the mean relationship relative to a zero difference, and a slope in the relationship indicates a different selectivity with length.

Overall, PP2 had a higher selectivity for fish less than 30 cm by number, and less than 28 cm by proportion (Figure 54). Both pots caught similar numbers of fish from 31–39 cm, though in proportion PP1 caught slightly more fish. Neither pot had catches of fish less than 18 cm or greater than 45 cm in the selectivity experiment.

Because of the difference in mean length between male and female blue cod, and the potential for differences in behaviour of different sexes relative to capture in fish pots, we examined the catch data to determine if there was a sex–length interaction. This is visualised by plotting the relative selectivities by length for each sex with the associated variance in catch by length. Despite differences in length between males and females, the pattern in relative selectivity was the same by number and proportion (Figure 55). By number, the confidence intervals overlapped for all lengths. The shallower distribution for females reflected the lower numbers in the catch, and the crossover point (where the mean relative selectivity changes from one pot plan to the other) was in the same place for males and females. By proportion, a similar pattern was observed for males and females, although the confidence intervals did not overlap for the 22 cm length bin but did at all other lengths (Figure 55). The more variable distribution in relative proportion for females reflected the low numbers of females caught and therefore the poor estimation of proportion of catch at each length (i.e., a single fish can change the proportion significantly if few fish overall were captured).

3.9 Gonad collection

Gonads were collected from a total of 542 blue cod, spread throughout the survey area in strata 1–8, 11–13. Most samples collected were male (407), with 125 females and 10 unidentified gonads (from small fish) preserved (Appendix 10). Otoliths were collected from 511 of these fish. Most samples collected were stage 5 (spent) for both sexes, followed by stage 2 (maturing) for males and stage 3 (mature) for females (Appendix 11). Few samples were collected from immature or maturing females (stages 1 or 2). Preserved samples are stored at NIWA, Nelson for future fecundity and sex change analysis. Fish number and the station number of fish for which gonads were collected are stored in the *trawl* database in table *t_fish_bio* and attribute *comment.*

4. DISCUSSION

4.1 History of Marlborough Sounds potting surveys

The 2013 survey is the seventh in the fixed-site time series for QCH and PEL, which began in 1995 and 1996, respectively (see Table 1) and the fourth in the time series for DUR, which began in 2004. The 2010 survey was carried out two years after the inner Sounds (QCH and PEL) were closed to target fishing for blue cod, while the take from the outer Sounds was restricted to only three fish per person per day. The results of the 2010 survey were compared to surveys before the closure to assess the effect of the closure on the blue cod population (Beentjes & Carbines 2012). The 2013 survey took place about 18 months after the fishery was reopened with a slot limit legal size (30–35 cm) in place for the inner and outer Sounds. The results of the 2013 survey, and the survey time series are discussed in the context of these fisheries management regimes.

The 2013 survey included the first full random-site surveys in QCH, PEL and DUR, although some experimental random sites were surveyed from selected strata in 2010. Cook Strait was surveyed exclusively with random sites in 2010 and 2013, with fixed sites used on the standalone survey of Cook Strait in 2008. The overall long-term goal of MPI is to transition to random-site surveys, which the Southern Inshore Group consider to be statistically more robust than fixed-site surveys. The transition will require an analysis of one or more comparable (place and time) fixed-site and random-site surveys to determine if there are any differences in catch rates, population length and age, and sex composition between the two sampling designs. This approach of comparing both fixed-site and random-site designs is also being trialled in other South Island blue cod potting surveys.

4.2 2013 fixed-site survey

Overall 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, with very low catch rates in the inner QCH and PEL Sounds (see Figures 5 and 6). Catch rates of the various length categories including recruited fish followed the same order (high to low, DUR, PEL, QCH).

Queen Charlotte Sound

The catch rates of all blue cod over the time series for QCH showed a clear decline between 1995 and 2001, and continued to decline slightly in 2004 and 2007, before nearly doubling in 2010, then halving in 2013 (see Figure 26). The steep increase in catch rates in 2010 was consistent with the inner Sounds fishery closure in 2008. The proportion of the catch rate of recruited fish (30 cm and over) also peaked at 84% of the total catch rates in 2010 before declining to 71% in 2013. 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 2007 when the MLS was 30 cm. The QCH length distribution over the survey time series was consistent with catch rate trends and showed a substantial overall increase in mean length in 2010 followed by a decline in 2013 (see Figures 30 and 31). Fish above the 35 cm slot limit legal size also declined in abundance in 2013. Overall, the QCH population appeared to respond to changes in fisheries management regulations and the surveys were successful in monitoring these responses in catch rate and length.

The sex ratio of all blue cod for QCH in 2013 was 62% male, similar to all the surveys in the time series (see Figure 27). Blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow (Carbines 2004b). The finding that males were larger on average than females (Table 15) and that the largest fish were males is consistent with sex structure in protogynous hermaphrodites. However, the skewed sex ratios are contrary to an expected dominance of females resulting from selective removal of the larger terminal fish (males). Beentjes & Carbines (2005) suggested that the shift towards a higher proportion of males in heavily fished blue cod populations may be caused by removal of an inhibitory effect of large males, and a consequent higher rate (and possibly earlier onset) of sex change by primary females. This hypothesis is supported by the predominance of males in most South Island blue cod fisheries that are known to be heavily fished, in particular Motunau, inshore Banks Peninsula, and Marlborough Sounds (Blackwell 1997, 1998, 2002, Beentjes & Carbines 2003, 2006, Blackwell 2006, Carbines & Beentjes 2006a, Blackwell 2008, Beentjes & Carbines 2009, Carbines &

Beentjes 2009, Beentjes & Carbines 2012). The slot limit does not appear to have had any effect on QCH sex ratio, which has remained stable, but male dominated. This is probably not surprising given that the slot limit has not yet resulted in an increase in large males.

Pelorus Sound

The overall pattern of catch rates of all blue cod was similar to QCH, which declined between 1996 and 2007, increased substantially in 2010, then dropped in 2013 to levels similar to 1996 (see Figure 26). Similarly, the steep increase in catch rates in 2010 was consistent with the closure two years earlier. The proportion of the catch rate of recruited fished (30 cm and over) also peaked at 88% of the total catch rates in 2010 before declining to 74% in 2013. 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 PEL length distribution over the time series was consistent with catch rates trends and showed a substantial overall increase in mean length in 2010, declining in 2013 (see Figures 32 and 33). Although abundance of fish over 35 cm had declined in 2013 in both Pelorus and Queen Charlotte Sounds, catch rates remained higher than prior to the closure (i.e., 2007 survey). Exploitation of fish in the slot would result in fewer fish recruiting to the largest size category than when the fishery was closed. Illegal retention of fish over 35 cm, and incidental mortality of fish returned to the water, would also result in declines in abundance of larger fish with the opening of the fishery. Complex stock assessment modelling is required to estimate the degree to which each of the above factors played a role in the decline in relative abundance of the over 35 cm category. Overall, the PEL population appeared to respond to changes in fisheries management regulations and the surveys were successful in monitoring these responses in catch rate and length.

The proportion of males in the PEL population has increased over time (see Figure 28) and has the most skewed sex ratio of the three regions (89% male in 2013) (see Figure 28). 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.

D’Urville Island

There are no trends in DUR catch rates of all blue cod or any of the length categories from 2004 to 2013 (see Figure 26). Similarly, length distribution shows no trends over time (see Figures 34 and 35). DUR was not closed to target fishing blue cod, as QCH and PEL were in 2008, and the stable catch rates and length distributions may reflect this. The slot limit does not appear to have had any influence on the 2013 catch rates or length distribution, possibly because this region has less fishing pressure than QCH and PEL. The sex ratio of all blue cod increased markedly in 2007 and remained at 65–70% (see Figure 29).

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

The 2013 catch rates for all blue cod in QCH, PEL and DUR were all much higher from the fixed-site than the random-site surveys (see Figure 22). Length distributions of fish from the two surveys were similar in QCH and DUR, but in PEL the fixed-site fish were smaller overall, especially females (see Figures 23–25). About 25% fewer pots were set in the fixed-site survey, with mixed results in terms of precision at estimating abundance, i.e., CVs. Precision was similar in PEL (15% CV for fixed sites compared to 12% for random), but CVs were substantially lower precise for the fixed-site surveys in QCH (CVs were 18% for fixed and 27% for random), and DUR (CVs were 18% for fixed and 43% for random). Random-site survey effort was very high in CKST compared to the other three regions and resulted in a relatively low CV of 12%, suggesting that random-site surveys require more effort to achieve the same precision as fixed-site surveys in Marlborough Sounds. This is not surprising given that fixed sites are located in areas where blue cod are known to be abundant (‘hotspots’) and that 35% of fixed-site pots had no blue cod compared to 49% for random-site pots. The experimental random sites carried out in 2010, although not as comprehensive in terms of effort and coverage, showed higher catch rates in PEL for fixed sites, but in DUR random-site catch rates were much higher than those from fixed sites (Beentjes & Carbines 2012). The 2013 survey results are consistent with those from the 2010 south Otago survey where the catch rates from fixed sites were about twice the catch rates from random sites

(Beentjes & Carbines 2011). A switch to exclusively random-site surveys in Marlborough Sounds may require more comparisons of concurrent fixed- and random-site surveys.

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

The closure of the inner Marlborough Sounds to all fishing between 1 October 2008 and December 2010, when the 2010 survey was carried out, clearly had a dramatic effect on the population length composition and abundance inside the closed area (Beentjes & Carbines 2012). 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 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, so the change may not necessarily be solely due to growth of resident inner Sounds fish.

The 2013 survey suggested that abundance and length of fish declined in the previously closed areas (PEL and QCH) after the re-opening of blue cod fishing throughout the Sounds in April 2011, indicating that the blue cod population was responding to fishing effort. The blue cod potting survey time series has successfully tracked changes in abundance and length distributions that resulted from changes in the fisheries management regime.

4.5 Stock status

The MPI *Harvest Strategy Standard* specifies that a Fishery Plan should include a fishery target reference point, and that this may be expressed in terms of biomass or fishing mortality (Ministry of Fisheries 2011). The most appropriate target reference point for blue cod is F_{MSY}, which is the amount of fishing mortality that results in the maximum sustainable yield. The recommended proxy for F_{MSY} is the level of spawner-per-recruit $F_{\%SPR}$ (Ministry of Fisheries 2011). Blue cod is categorised as an exploited species with low productivity and the recommended default proxy for F_{MSY} is $F_{45\%SPR}$.

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 has not been constant because of the various management changes that have occurred including the closure of the inner Sounds in 2008, and the subsequent changes in MLS and bag limits throughout the inner and outer Sounds, including the slot limit. The spawner-per-recruit-ratio estimates are therefore also likely to be biased by these changes in fishing mortality.

Random-site surveys are considered to be superior to fixed sites surveys in design and precision (Stephenson et al. 2009), so estimates of Z and SPR from random-site surveys are likely to be more representative of the population. Notwithstanding the potential bias in Z, the 2013 random-site survey spawner-pre-recruit-ratio estimates ranged from 21 to 34%. The level of exploitation (F) of Marlborough Sounds blue cod stocks in all four regions therefore, is greater than the F_{MSY} target reference point of $F_{45\%SPR}$.

4.6 Multibeam echo-sounder survey

The multibeam survey recorded a suite of physical data over each of the potted sites including seafloor bathymetry, topography, ruggedness, slope, aspect and substrate type. This was the first time such data have been collected during a blue cod potting survey, anywhere in New Zealand. Graphical examples of these outputs were provided for site 3E the western entrance to Port Gore (see Figures 41 to 48). If these physical seafloor descriptors are to be used as predictor variables to standardise catch rates at some time in the future, the data can be easily extracted at the resolution considered to be most appropriate using ArcGIS software, for example, directly under the pot, at a prescribed diameter around each pot, or overall for the site. The backscatter outputs, which provide indicators of habitat type (rock, sand, mud, etc.) could be expected to be useful predictors of blue cod catch rates, but these outputs have not been ground-truthed. This could potentially be carried out for the 11 sites where drift underwater video (DUV) was also carried out. A time series of catch rates and concurrent multibeam surveys would be required before the seafloor descriptors can be analysed and used for standardising catch rates.

4.7 Blue cod pot selectivity experiment

This demonstrated that the South Island pot (PP2) tended to catch shorter fish than the Marlborough Sounds pot (PP1), but that selectivity was similar for fish greater than 28 cm. PP2 captured more females and showed a lower percentage of males in the catch (by weight or numbers), because females in the sampled population were shorter than males on average. There was no evidence of a sex selection effect compared to a simple length selection process. Neither pot type captured fish greater than 45 cm or less than 18 cm, which may reflect the lack of availability of fish that length in the areas sampled.

The reason for the difference in size selectivity is most likely due to differences in pot construction. The reason for the difference was not investigated in this study, as several components were different between the two pot plans. The funnel entrances are likely to have a large impact on size selectivity, both in bar spacing and in angle of elevation. The mesh sizes covering the pots were similar, but were made of different materials, which may influence the ability of fish to escape the pot. The pot selectivity experiment was carried out to evaluate the potential implications of switching the Marlborough Sounds blue cod potting survey to the same design used throughout the rest of the South Island blue cod surveys. The observed differences suggest that switching to a single standardised pot design would have a large influence on the abundance index for the Marlborough Sounds blue cod survey time series. Switching the Marlborough Sounds survey to PP2 would require either breaking the survey time series (because selectivity is not the same), or adjusting the catches from previous Marlborough Sounds surveys by the size and sex observed in each catch retrospectively (as both vary within the survey area and through time). This adjustment would be highly uncertain, especially for females because of the small number of sites used in the experiment, with no comparison from some strata, and the relative paucity of females in the catch. Additional selectivity comparisons would be required to inform a retrospective adjustment analysis of catches by size and sex. But, the benefits of switching to the South Island pot plan include better comparability with catches in other regions, higher catch rates (50% higher in PP2, though the catch rate would be specific to the size composition of the population sampled at the observed sex ratio), better information on the abundance of smaller recruiting fish, and better access to females for biological samples. Although Pot Plan 1 is less efficient at capturing fish under 28 cm, selectivity is likely to be constant, and relative trends are informative.

5. ACKNOWLEDGMENTS

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7. TABLES AND FIGURES

Table 1: Marlborough Sounds regions surveyed, survey design, and vessels used from 1995 to 2013 (current survey). See Figure 1 for locations of regions.

Year	Regions	Survey design	Vessel
1995	Queen Charlotte Sd, part Pelorus Sd	Fixed site	F.V. *Lady H.R.*
1996	Pelorus Sd, part D'Urville	Fixed site	F.V. *Lady H.R*
2001	Queen Charlotte Sd, Pelorus Sd, part D'Urville	Fixed site	F.V. *Lady H.R*
2004	Queen Charlotte Sd, Pelorus Sd, D'Urville, Separation Pt	Fixed site	F.V. *Lady H.R*
2007	Queen Charlotte Sd, Pelorus Sd, D'Urville, Separation Pt	Fixed site	F.V. *Lady H.R*
2008	Cook Strait	Fixed site	F.V. *Lady H.R*
2010	Cook Strait	Random site	F.V. *Lady H.R*
	Queen Charlotte Sd, Pelorus Sd, D'Urville	Fixed and some random sites	
2013	Cook Strait	Random site	R.V. *Ikatere*
	Queen Charlotte Sd, Pelorus Sd, D'Urville	Fixed and random sites	

Table 2: Catch and effort summary data for the fixed-site and random-site Marlborough Sounds 2013 potting surveys. All random sites were phase 1 except three in stratum 3, two in stratum 13 and one in stratum 12, which were phase 2. Regions: QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait; Strata: SEPR, Separation Point; 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.

	Stratum								Depth (m)		
Region	Number	Code	Area (km coastline)	Site type	*N* sets (sites)	*N* pots (stations)	No. blue cod	Catch (kg)	Mean	Min	Max
QCH	1	IQCH	43.2	Fixed	3	27	23	8.6	11.7	5	25
QCH	2	OQCH	176.6	Fixed	8	72	167	80.4	20.3	3	50
QCH	3	EQCH	83.1	Fixed	3	27	61	30.1	17.5	9	38
PEL	4	EOPE	69.5	Fixed	3	27	275	133.4	17.3	5	38
PEL	5	OPEL	94.8	Fixed	3	27	136	66.2	15.6	7	41
DUR	6	DURE	105.1	Fixed	3	27	200	90.9	18.0	6	37
PEL	7	IPEL	100.1	Fixed	3	27	26	9	11.6	4	20
PEL	8	MPEL	72.3	Fixed	3	27	38	17.2	9.4	4	18
DUR	9	DURW	96.2	Fixed	3	27	256	119.8	19.3	10	30
Totals					32	288	1 182	555.6	15.6	3	50
QCH	1	IQCH	43.2	Random	4	36	28	18	11.7	4	51
QCH	2	OQCH	176.6	Random	9	81	44	17.9	11.5	4	32
QCH	3	EQCH	83.1	Random	7	63	116	67.7	8.5	3	21
PEL	4	EOPE	69.5	Random	4	36	251	142.5	13.5	5	29
PEL	5	OPEL	94.8	Random	4	36	65	32.9	10.5	4	25
DUR	6	DURE	105.1	Random	4	36	107	51	11.1	6	24
PEL	7	IPEL	100.1	Random	3	27	10	6.1	10.4	4	24
PEL	8	MPEL	72.3	Random	4	36	16	6.6	10.3	3	22
DUR	9	DURW	96.2	Random	3	27	169	88.6	9.3	3	18
CKST	11	APAE	21.6	Random	11	99	317	160.3	14.5	4	45
CKST	12	COOK	30	Random	13	117	179	78.3	13.3	4	26
CKST	13	UNDW	34	Random	5	45	8	6.1	8.2	3	14
Totals					71	639	1310	676	11.1	3	51
Grand total					103	927	2 492	1 231.6			

Table 3: Total catch and numbers of blue cod and bycatch species caught on the 2013 Marlborough Sounds fixed-site and random-site potting surveys.

			Fixed sites		
Common name	Species	Code	Catch (kg)	Number	% catch
Blue cod	*Parapercis colias*	BCO	555.6	1 182	94.25
Octopus		OCT	16	3	2.71
Scarlet wrasse	*Pseudolabrus miles*	SPF	3.5	6	0.59
Tarakihi	*Nemadactylus macropterus*	TAR	2.6	11	0.44
Leatherjacket	*Parika scaber*	LEA	2.6	5	0.44
Carpet shark	*Cephaloscyllium isabellum*	CAR	2.5	1	0.42
Blue moki	*Latridopsis ciliaris*	MOK	2.1	3	0.36
Red cod	*Pseudophycis bachus*	RCO	1.4	2	0.24
Southern bastard cod	*Pseudophycis barbata*	SBR	1	2	0.17
Sea perch	*Helicolenus percoides*	SPE	1	2	0.17
Goatfish	*Upeneichthys lineatus*	RMU	0.8	1	0.14
Butterfly perch	*Caesioperca lepidoptera*	BPE	0.2	1	0.03
Dwarf scorpion fish	*Scorpaena papillosa*	RRC	0.1	1	0.02
Spotty	*Notolabrus celidotus*	STY	0.1	1	0.02
Totals			589.5	1 221	

			Random sites		
Common name	Species	Code	Catch (kg)	Number	% catch
Blue cod	*Parapercis colias*	BCO	676	1 310	75.10
Scarlet wrasse	*Pseudolabrus miles*	SPF	86.3	50	9.59
Butterfly perch	*Caesioperca lepidoptera*	BPF	84.4	75	9.38
Octopus		OCT	25.9	6	2.88
Leatherjacket	*Parika scaber*	LEA	6.6	23	0.73
Conger eel	*Conger verreauxi*	CON	6	1	0.67
Blue moki	*Latridopsis ciliaris*	MOK	4	3	0.44
Carpet shark	*Cephaloscyllium isabellum*	CAR	2	1	0.22
Hagfish	*Eptatretus cirrhatus*	HAG	2	1	0.22
Tarakihi	*Nemadactylus macropterus*	TAR	1.8	6	0.20
Sea perch	*Helicolenus percoides*	SPE	1.3	3	0.14
Goatfish	*Upeneichthys lineatus*	RMU	0.8	1	0.09
Dwarf scorpion fish	*Scorpaena papillosa*	RRC	0.8	3	0.09
Red cod	*Pseudophycis bachus*	RCO	0.7	1	0.08
Triplefins	Tripterygiidae	TRP	0.7	19	0.08
Pagurid	Pagurid	PAG	0.3	4	0.03
Spotty	*Notolabrus celidotus*	STY	0.2	2	0.02
Spotted whelk	*Cominella maculosa*	CMC	0.1	3	0.01
Longsnout pipefish	*Leptonotus norae*	LNO	0.1	1	0.01
Large ostrich foot	*Struthiolaria papulosa*	LOF	0.1	1	0.01
Totals			900.1	1 514	

Table 4: Mean catch rates for all blue cod caught from the 2013 Marlborough Sounds fixed-site and random-site potting surveys by region. 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 names.

All blue cod

		Fixed-site survey				
Region	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)
QCH	1	Fixed	27	0.32	0.07	21.2
	2	Fixed	72	1.12	0.19	16.6
	3	Fixed	27	1.11	0.53	47.9
	Overall	Fixed	126	1.00	0.18	18.2
PEL	4	Fixed	27	4.94	0.88	17.8
	5	Fixed	27	2.45	0.79	32.2
	7	Fixed	27	0.33	0.08	22.7
	8	Fixed	27	0.64	0.32	50.9
	Overall	Fixed	108	1.95	0.30	15.2
DUR	6	Fixed	27	3.37	0.48	14.2
	9	Fixed	27	4.44	1.33	30.0
	Overall	Fixed	54	3.88	0.68	17.6

		Random-site survey				
Region	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)
QCH	1	Random	36	0.50	0.30	59.0
	2	Random	81	0.22	0.08	34.5
	3	Random	63	1.07	0.44	40.6
	Overall	Random	180	0.49	0.13	27.2
PEL	4	Random	36	3.96	0.45	11.4
	5	Random	36	0.91	0.34	37.6
	7	Random	27	0.23	0.12	53.6
	8	Random	36	0.18	0.15	82.8
	Overall	Random	135	1.18	0.14	12.1
DUR	6	Random	36	1.42	0.23	16.4
	9	Random	27	3.28	2.06	62.9
	Overall	Random	63	2.31	0.99	43.0
CKST	11	Random	99	1.62	0.27	16.7
	12	Random	117	0.67	0.13	18.7
	13	Random	45	0.14	0.06	47.3
	Overall	Random	261	0.70	0.09	12.2

Table 5: Mean catch rates for recruited blue cod 30–35cm (slot limit) caught from the 2013 Marlborough Sounds fixed-site and random-site potting surveys by region. 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 names.

30–35 cm (slot limit)

		Fixed-site survey				
Region	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)
QCH	1	Fixed	27	0.08	0.06	74.8
	2	Fixed	72	0.46	0.09	20.1
	3	Fixed	27	0.62	0.14	22.6
	Overall	Fixed	126	0.45	0.07	14.9
PEL	4	Fixed	27	2.32	0.36	15.5
	5	Fixed	27	1.35	0.20	14.8
	7	Fixed	27	0.11	0.05	50.0
	8	Fixed	27	0.34	0.22	64.9
	Overall	Fixed	108	0.96	0.11	11.0
DUR	6	Fixed	27	1.54	0.41	26.3
	9	Fixed	27	2.28	0.66	28.9
	Overall	Fixed	54	1.89	0.38	20.0

		Random-site survey				
Region	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)
QCH	1	Random	36	0.17	0.12	67.7
	2	Random	81	0.08	0.03	44.5
	3	Random	63	0.42	0.20	47.6
	Overall	Random	180	0.18	0.06	33.0
PEL	4	Random	36	1.58	0.18	11.1
	5	Random	36	0.43	0.16	36.9
	7	Random	27	0.07	0.05	71.4
	8	Random	36	0.11	0.11	100.0
	Overall	Random	135	0.49	0.06	13.0
DUR	6	Random	36	0.53	0.14	25.9
	9	Random	27	1.53	1.01	66.4
	Overall	Random	63	1.00	0.49	48.7
CKST	11	Random	99	0.87	0.15	16.8
	12	Random	117	0.29	0.06	20.9
	13	Random	45	0.06	0.04	61.7
	Overall	Random	261	0.35	0.05	13.1

Table 6: Mean catch rates for blue cod larger than the slot limit (over 35 cm) caught from the 2013 Marlborough Sounds fixed-site and random-site potting surveys by region. 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 names.

Over 35 cm

		Fixed-site survey				
Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
QCH	1	Fixed	27	0.06	0.03	51.4
	2	Fixed	72	0.32	0.12	36.9
	3	Fixed	27	0.26	0.26	100.0
	Overall	Fixed	126	0.26	0.10	37.4
PEL	4	Fixed	27	1.32	0.39	29.1
	5	Fixed	27	0.63	0.46	73.4
	7	Fixed	27	0.03	0.03	100.0
	8	Fixed	27	0.12	0.06	51.7
	Overall	Fixed	108	0.48	0.15	31.6
DUR	6	Fixed	27	0.75	0.31	41.3
	9	Fixed	27	1.01	0.47	46.0
	Overall	Fixed	54	0.87	0.27	31.4

		Random-site survey				
Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
QCH	1	Random	36	0.25	0.15	58.4
	2	Random	81	0.05	0.02	54.1
	3	Random	63	0.50	0.19	38.6
	Overall	Random	180	0.20	0.06	29.5
PEL	4	Random	36	1.80	0.37	20.6
	5	Random	36	0.31	0.13	41.9
	7	Random	27	0.13	0.07	57.0
	8	Random	36	0.00	0.00	NA
	Overall	Random	135	0.49	0.09	17.6
DUR	6	Random	36	0.45	0.08	18.2
	9	Random	27	0.95	0.65	67.8
	Overall	Random	63	0.69	0.31	45.2
CKT	11	Random	99	0.35	0.09	25.0
	12	Random	117	0.13	0.05	37.1
	13	Random	45	0.07	0.04	61.4
	Overall	Random	261	0.16	0.03	20.3

Table 7: Mean catch rates for blue cod under 30 cm caught from the 2013 Marlborough Sounds fixed-site and random-site potting surveys by region. 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 names.

Under 30 cm

		Fixed-site survey				
Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
QCH	1	Fixed	27	0.19	0.04	20.3
	2	Fixed	72	0.33	0.05	15.6
	3	Fixed	27	0.21	0.13	58.6
	Overall	Fixed	126	0.28	0.05	16.6
PEL	4	Fixed	27	1.31	0.17	12.6
	5	Fixed	27	0.52	0.15	28.9
	7	Fixed	27	0.20	0.08	39.9
	8	Fixed	27	0.17	0.08	45.2
	Overall	Fixed	108	0.51	0.06	12.0
DUR	6	Fixed	27	1.10	0.13	11.7
	9	Fixed	27	1.26	0.44	34.6
	Overall	Fixed	54	1.18	0.22	18.6

		Random-site survey				
Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
QCH	1	Random	36	0.08	0.04	47.1
	2	Random	81	0.09	0.03	34.0
	3	Random	63	0.15	0.05	33.7
	Overall	Random	180	0.10	0.02	22.2
PEL	4	Random	36	0.60	0.04	6.7
	5	Random	36	0.18	0.11	59.0
	7	Random	27	0.03	0.01	50.1
	8	Random	36	0.07	0.05	63.7
	Overall	Random	135	0.20	0.03	16.7
DUR	6	Random	36	0.43	0.17	40.3
	9	Random	27	0.75	0.41	55.1
	Overall	Random	63	0.58	0.22	37.3
CKT	11	Random	99	0.43	0.09	21.6
	12	Random	117	0.24	0.04	16.4
	13	Random	45	0.00	0.00	NA
	Overall	Random	261	0.19	0.03	14.1

Table 8: Summary of weighted outputs from fixed- and random-site potting surveys of Marlborough Sounds in 2013. See Table 2 for region names.

		Mean length (cm)					Proportion of total catch rate (%)			
Region	Site type	Male	Female	Sex ratio (% male)	≥30 cm (% by no.)	Catch rate ($kg.pot^{-1}$) (CV %)	≥30 cm	>35 cm	30–35 cm (slot limit)	<30 cm
QCH	Fixed	31.7	29.8	61.6	61.7	1.0 (18)	71.4	26.4	45.1	27.7
PEL	Fixed	31.3	27.2	88.8	63.2	1.9 (15)	74.3	24.9	49.4	26.4
DUR	Fixed	31.7	29.4	69.9	64.1	3.9 (18)	71.4	22.5	48.8	30.5
QCH	Random	32.1	30.3	65.9	67.6	0.5 (27)	77.9	37.4	37.2	21.2
PEL	Random	33.3	30.1	77.3	77.5	1.2 (12)	83.4	33.7	41.5	16.8
DUR	Random	32.8	29.9	56.6	69.1	2.3 (43)	73.4	24.4	43.5	25.3
CKST	Random	31.7	28.4	83.1	68.2	0.7 (12)	73.1	23.2	49.9	27.6

Table 9: Weighted mean lengths and weighted sex ratio (percent male) for all the survey regions and strata in the 2013 Marlborough Sounds fixed- and random-site potting surveys. See Table 2 for region names. m, male; f, female; u, unsexed. –, no data. [Continued on next pages]

Fixed-site survey

					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
QCH	1	Fixed	m	15	29.8	24.5	39.0	65.0
			f	8	26.7	23.5	28.5	
			u	0	–	–	–	
	2	Fixed	m	81	31.8	23.0	45.5	48.6
			f	86	29.8	20.2	37.6	
			u	0	–	–	–	
	3	Fixed	m	55	31.7	23.9	41.4	90.3
			f	6	32.0	28.9	33.9	
			u	0	–			
	Overall	Fixed	m	151	31.7	23.0	45.5	61.6
			f	100	29.8	20.2	37.6	
			u	0	–	–	–	

Random-site survey

					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
QCH	1	Random	m	14	34.4	27.4	45.4	49.9
			f	14	32.0	23.0	41.0	
			u	0	–	–	–	
	2	Random	m	21	28.6	17.2	41.7	48.3
			f	23	29.2	24.6	37.2	
			u	0				
	3	Random	m	94	33.1	19.8	42.3	80.5
			f	22	31.2	26.0	36.5	
			u	0	–	–	–	
	Overall	Random	m	129	32.1	17.2	45.4	65.9
			f	59	30.3	23.0	41.0	
			u	0	–	–	–	

Table 9 [Continued]:

					Fixed-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
PEL	4	Fixed	m	240	31.7	22.3	42.5	87.3
			f	35	28.0	21.9	32.2	
			u	0	–	–	–	
	5	Fixed	m	126	31.4	19.0	48.9	92.6
			f	10	25.7	17.9	31.0	
			u	0	–	–	–	
	7	Fixed	m	23	28.3	23.6	35.8	88.7
			f	3	24.4	16.9	31.5	
			u		–	–	–	
	8	Fixed	m	31	30.2	19.9	41.3	82.0
			f	7	27.9	22.8	44.5	
			u	0	–	–	–	
	Overall	Fixed	m	420	31.3	19.0	48.9	88.8
			f	55	27.2	16.9	44.5	
			u	0	–	–	–	

					Random-site survey			
					Length (cm)			
Region	Stratum	Site type	Sex	N	Mean	Minimum	Maximum	Percent male
PEL	4	Random	m	222	33.4	20.3	42.8	88.8
			f	28	29.0	23.4	34.6	
			u	1	24	24.0	24	
	5	Random	m	30	33.5	23.0	39.9	45.9
			f	35	30.9	26.5	35.3	
			u	0	–	–	–	
	7	Random	m	7	33.7	29.5	41.6	69.4
			f	3	33.5	28.5	36.0	
			u	0	–	–	–	
	8	Random	m	12	30.7	25.8	34.7	75.6
			f	4	24.2	16.1	29.0	
			u	0	–	–	–	
	Overall	Random	m	271	33.3	20.3	42.8	77.3
			f	70	30.1	16.1	36.0	
			u	1	24	24	24	

Table 9 [Continued]:

Region	Stratum	Site type	Sex	N	Length (cm) Mean	Minimum	Maximum	Fixed-site survey Percent male
DUR	6	Fixed	m	151	31.4	21.5	42.5	75.3
			f	49	29.0	24.9	34.2	
			u	0	–	–	–	
	9	Fixed	m	168	32.0	21.9	45.0	65.3
			f	88	29.6	18.8	39.8	
			u	0	–	–	–	
	Overall	Fixed	m	319	31.7	21.5	45.0	69.9
			f	137	29.4	18.8	39.8	
			u	0	–	–	–	

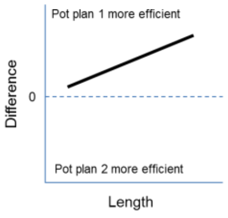
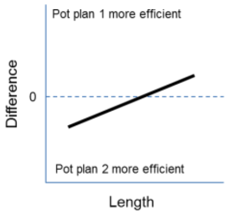
Region	Stratum	Site type	Sex	N	Length (cm) Mean	Minimum	Maximum	Random-site survey Percent male
DUR	6	Random	m	56	32.3	23.3	42.8	52.7
			f	51	29.9	23.3	36.8	
			u	0	–	–	–	
	9	Random	m	99	33.1	24.3	45.8	58.6
			f	70	30.0	22.6	34.7	
			u	0	–	–	–	
	Overall	Random	m	155	32.8	23.3	45.8	56.6
			f	121	29.9	22.6	36.8	
			u	0	–	–	–	

Region	Stratum	Site type	Sex	N	Length (cm) Mean	Minimum	Maximum	Random-site survey Percent male
CKST	11	Random	m	250	31.8	22.5	43.8	80.2
			f	61	29.0	19.4	36.1	
			u	6	25.3	21.1	27	
	12	Random	m	148	30.8	22.3	39.0	85.7
			f	25	27.1	20.8	33.6	
			u	6	23.2	17.0	36.9	
	13	Random	m	7	36.3	32.2	43.3	100
			f	0	–	–	–	
			u	1	31.2	31.2	31.2	
	Overall	Random	m	405	31.7	22.3	43.8	83.1
			f	86	28.4	19.4	36.1	
			u	13	24.8	17.0	36.9	

Table 10: Gonad stages of Marlborough Sounds blue cod in September–November 2013 by region and size. 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	Size range	1	2	3	4	5	N
CKST	Males	All sizes	6.9	23.8	7.2	4.7	57.4	404
CKST	Females		8.1	14.0	4.7	18.6	54.7	86
CKST	Males	Pre-recruited (under 30 cm)	16.3	26.5	6.1	3.4	47.6	147
CKST	Females		12.3	17.5	3.5	7.0	59.6	57
CKST	Males	Recruited (30 cm and over)	1.6	22.2	7.8	5.4	63.0	257
CKST	Females		0.0	6.9	6.9	41.4	44.8	29
DUR	Males	All sizes	1.7	7.6	9.7	26.0	55.0	473
DUR	Females		0.4	1.9	65.4	13.2	19.1	257
DUR	Males	Pre-recruited (under 30 cm)	4.6	9.8	10.5	24.2	51.0	153
DUR	Females		0.7	2.0	64.0	15.3	18.0	150
DUR	Males	Recruited (30 cm and over)	0.3	6.6	9.4	26.9	56.9	320
DUR	Females		0.0	1.9	67.3	10.3	20.6	107
PEL	Males	All sizes	4.5	11.3	6.5	21.7	56.0	691
PEL	Females		3.2	6.4	49.6	5.6	35.2	125
PEL	Males	Pre-recruited (under 30 cm)	9.4	13.1	5.2	26.8	45.5	213
PEL	Females		5.1	8.9	39.2	2.5	44.3	79
PEL	Males	Recruited (30 cm and over)	2.3	10.5	7.1	19.5	60.7	478
PEL	Females		0.0	2.2	67.4	10.9	19.6	46
QCH	Males	All sizes	3.2	17.5	18.2	32.9	28.2	280
QCH	Females		0.0	9.5	33.5	12.7	44.3	158
QCH	Males	Pre-recruited (under 30 cm)	8.2	21.6	15.5	25.8	28.9	97
QCH	Females		0.0	11.7	33.8	9.1	45.5	77
QCH	Males	Recruited (30 cm and over)	0.5	15.3	19.7	36.6	27.9	183
QCH	Females		0.0	7.4	33.3	16.0	43.2	81

Table 11: Example of relative trend in selectivity in numbers of fish and in proportion of fish for a sample of large and small fish.

	Small fish (Number)	Big fish (Number)	Trend	Small fish (Proportion)	Big fish (Proportion)	Trend
Pot Plan 1	10	40		0.20	0.80	
Pot Plan 2	5	10		0.33	0.66	

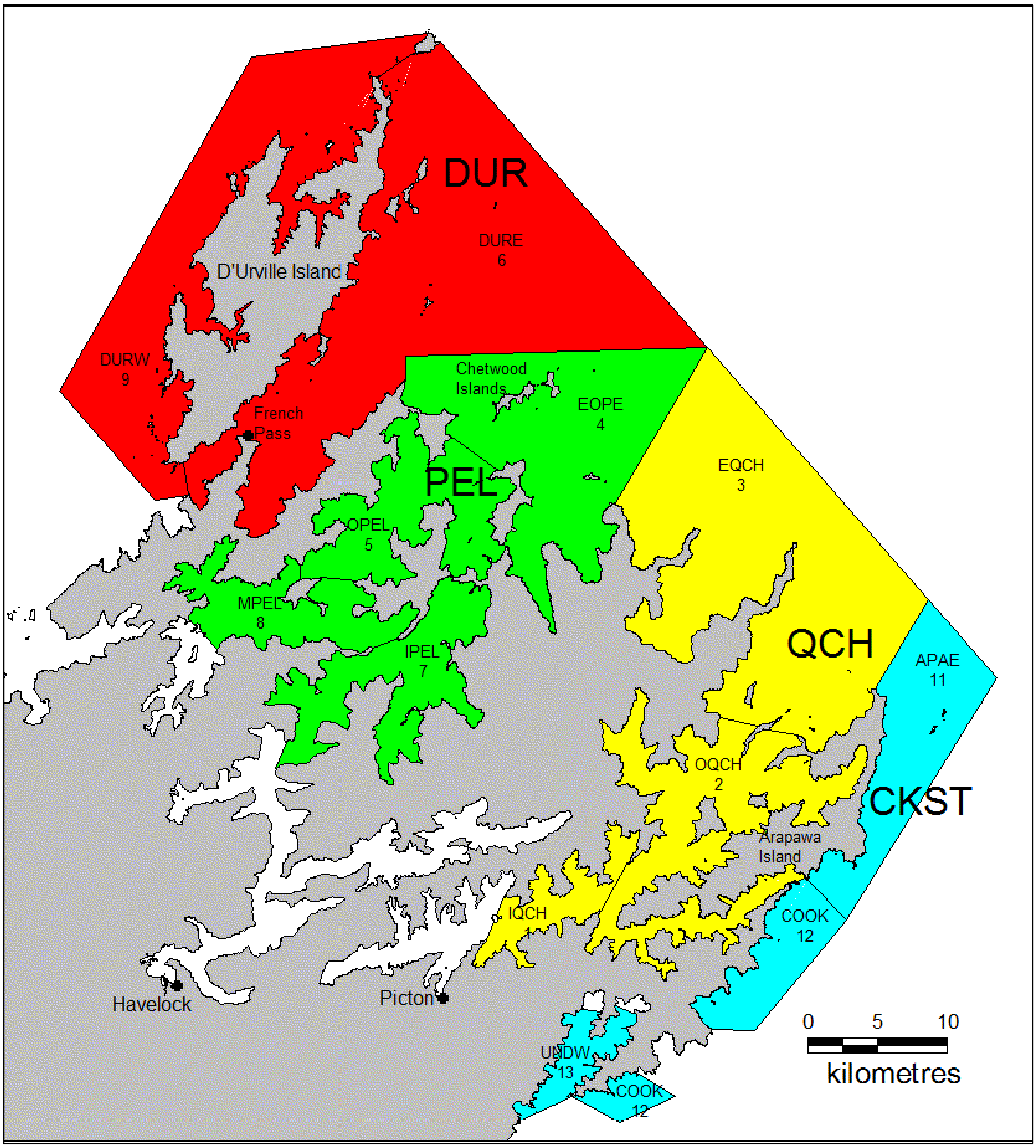


Figure 1: Map of Marlborough Sounds showing the strata surveyed in 2013. The regions are colour coded. Red, D'Urville (DUR); green, Pelorus Sound (PEL); yellow, Queen Charlotte Sound (QCH); blue, Cook Strait (CKST). See Table 1 for regions and strata names.

Figure 2: S.L. *Ikatere* from aft showing extended multibeam echo-sounder (EM30022D) pole amidships. Photo by Arne Pallentin.

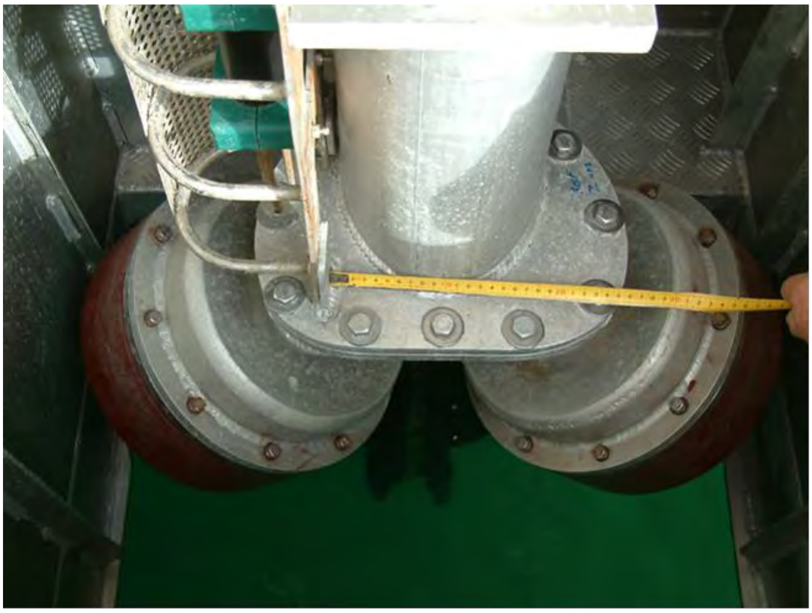


Figure 3: Multibeam echo-sounder (EM3002D) in moonpool on S.L. *Ikatere*. Photo by Arne Pallentin.

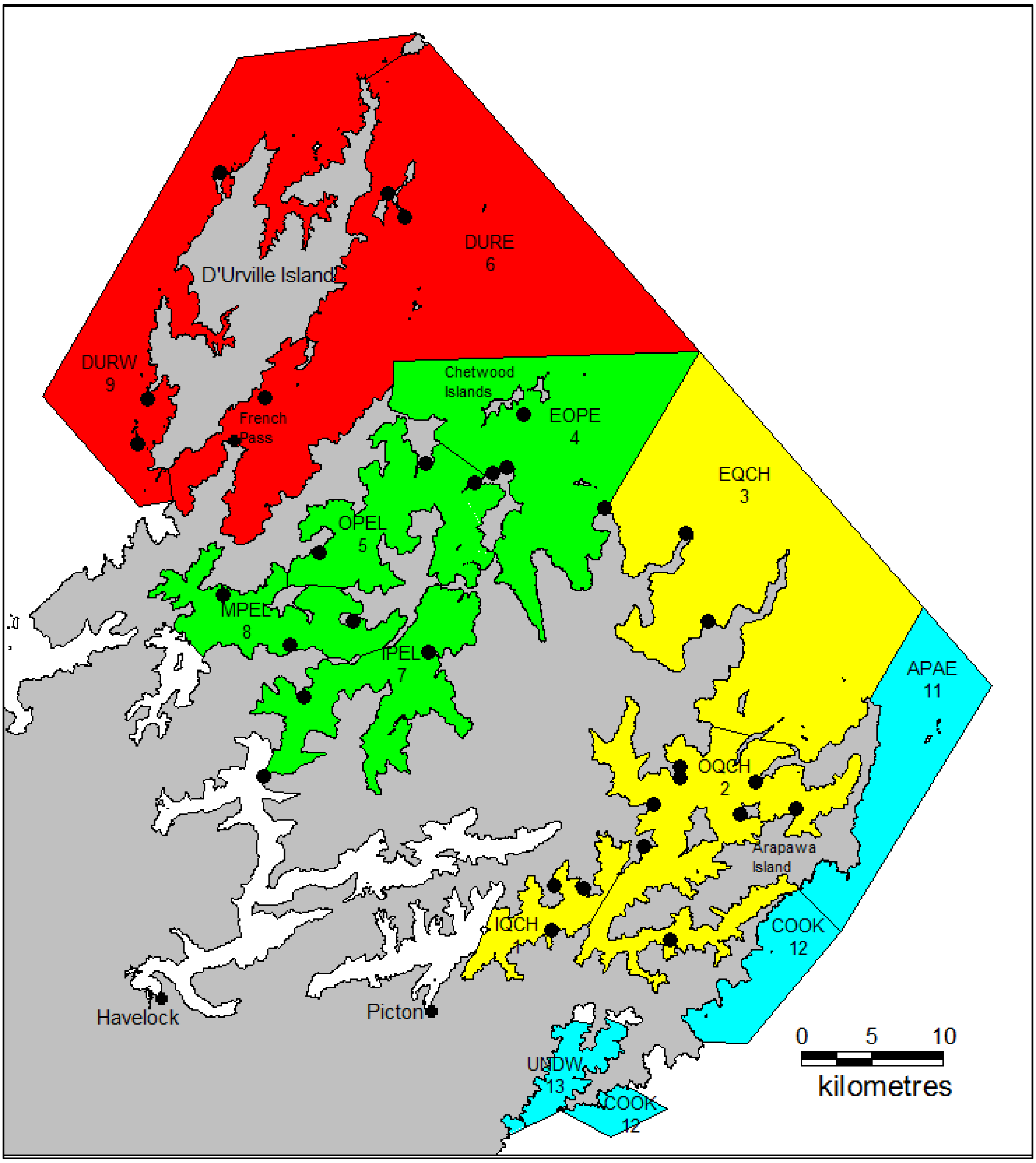


Figure 4: Map of Marlborough Sounds showing the locations of all fixed sites surveyed in 2013. The regions are colour coded. See Table 1 for strata and region names.

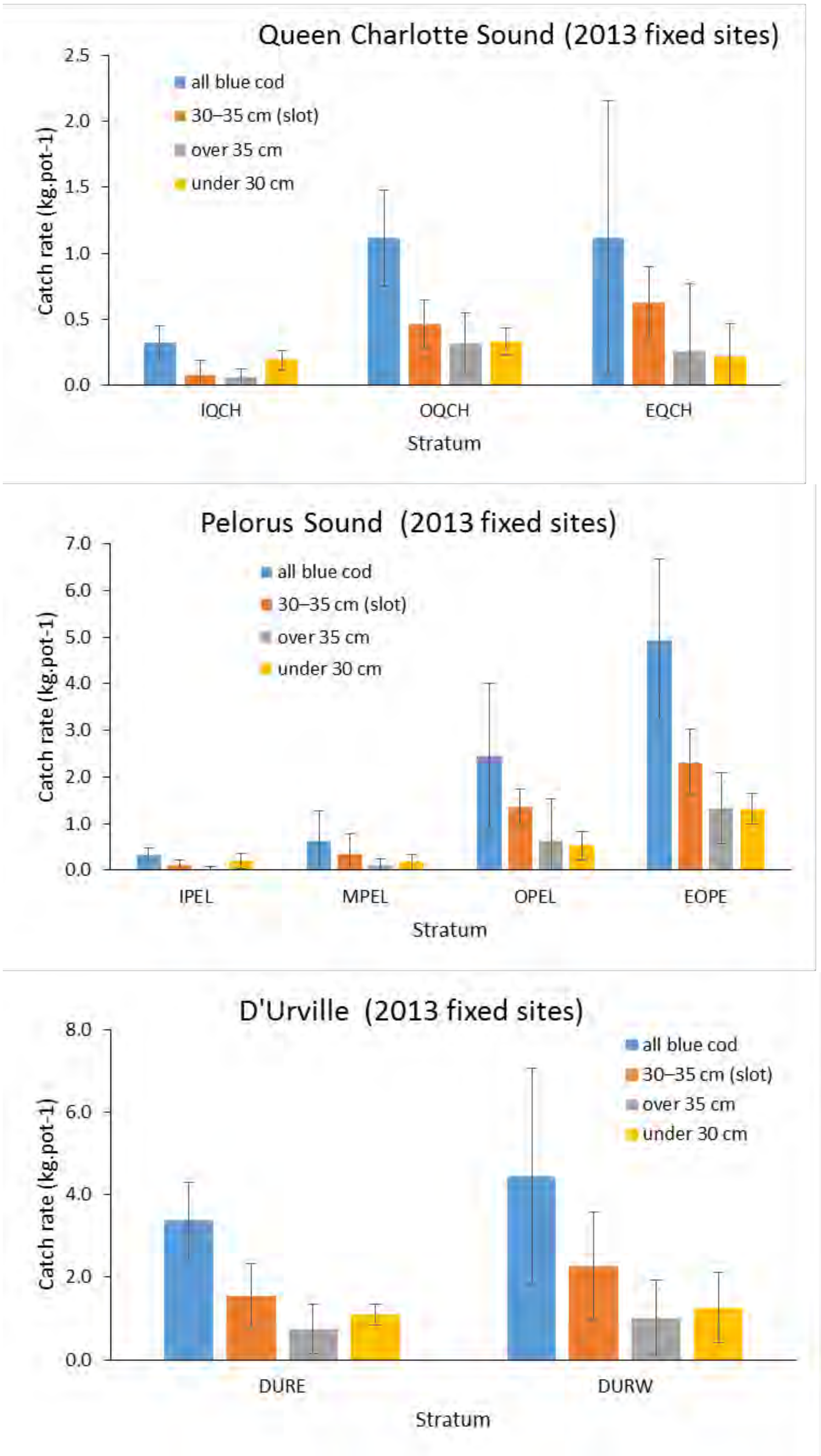


Figure 5: Marlborough Sounds 2013 potting survey catch rates of all blue cod and by size category for fixed sites by strata, for each region. Error bars are 95% confidence intervals. See Figure 1 for location of strata.

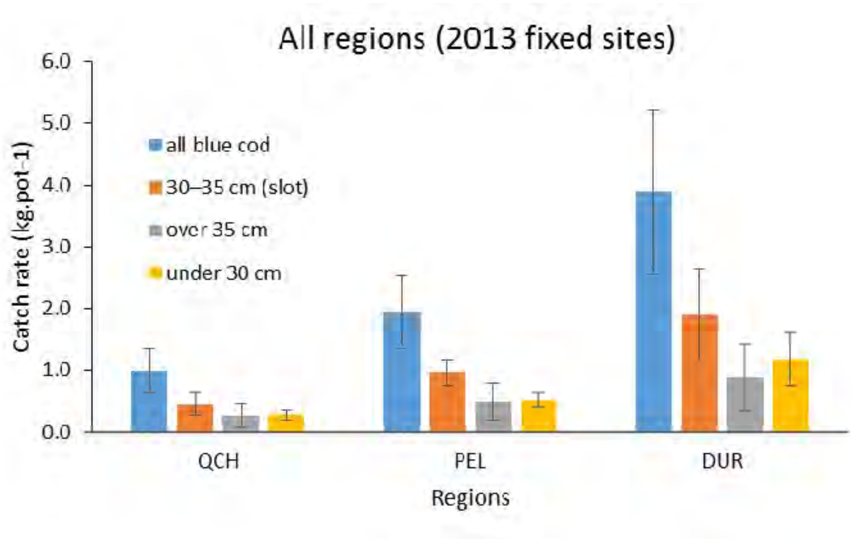


Figure 6: Marlborough Sounds 2013 potting survey catch rates of all blue cod and by size category for fixed sites by region. Error bars are 95% confidence intervals. See Figure 1 for location of regions and Table 1 for region names.

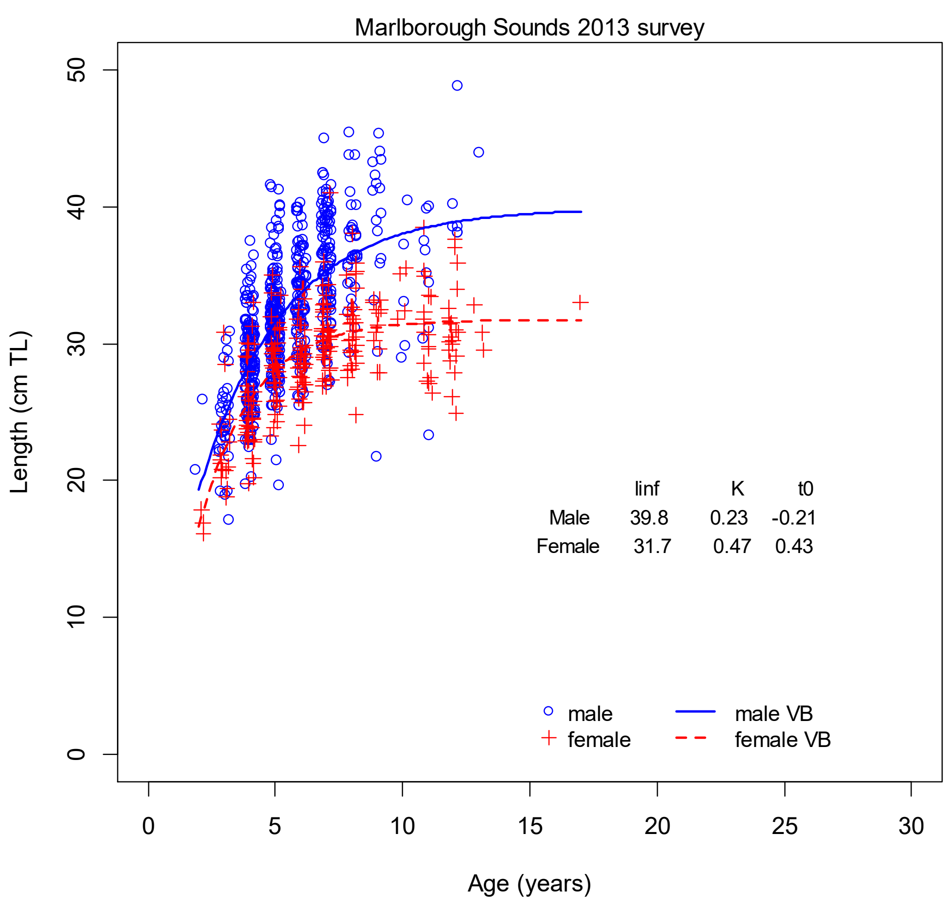


Figure 7: Observed age and length data by sex for the 2013 Marlborough Sounds survey (all regions combined) with von Bertalanffy growth models fitted to the data. N = 640 males and 264 females.

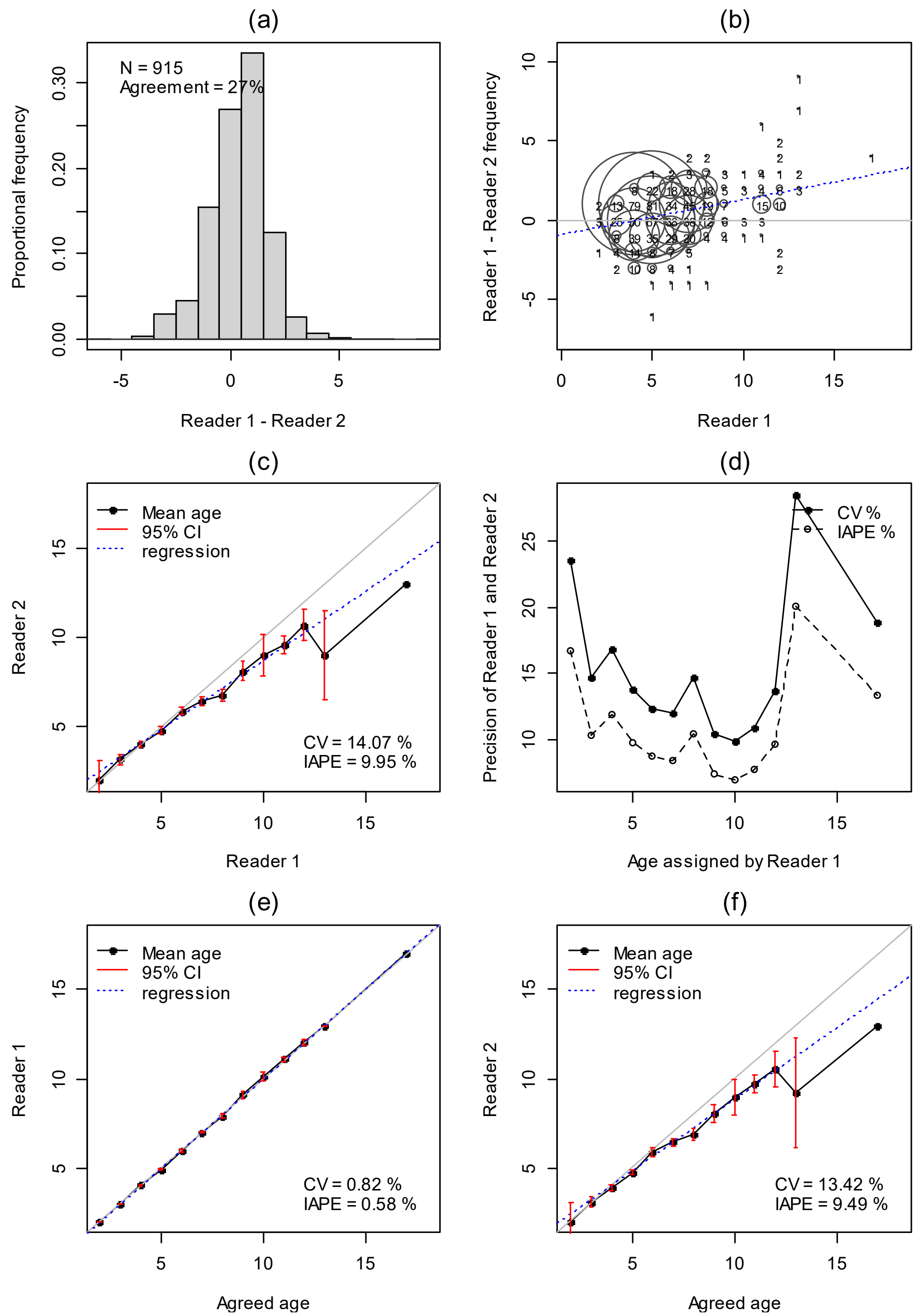


Figure 8: Blue cod age otolith reader comparison plots between reader 1 and reader 2 for the 2013 Marlborough Sounds survey: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age bin are annotated and proportional to circle size; (c) age bias plot, showing the correspondence of ages between reader 1 and reader 2 for all ages; (d) precision of readers; (e and f) reader age compared with agreed age. In panels b and c, solid lines show perfect agreement, dashed lines show the trend of a linear regression of the actual data.

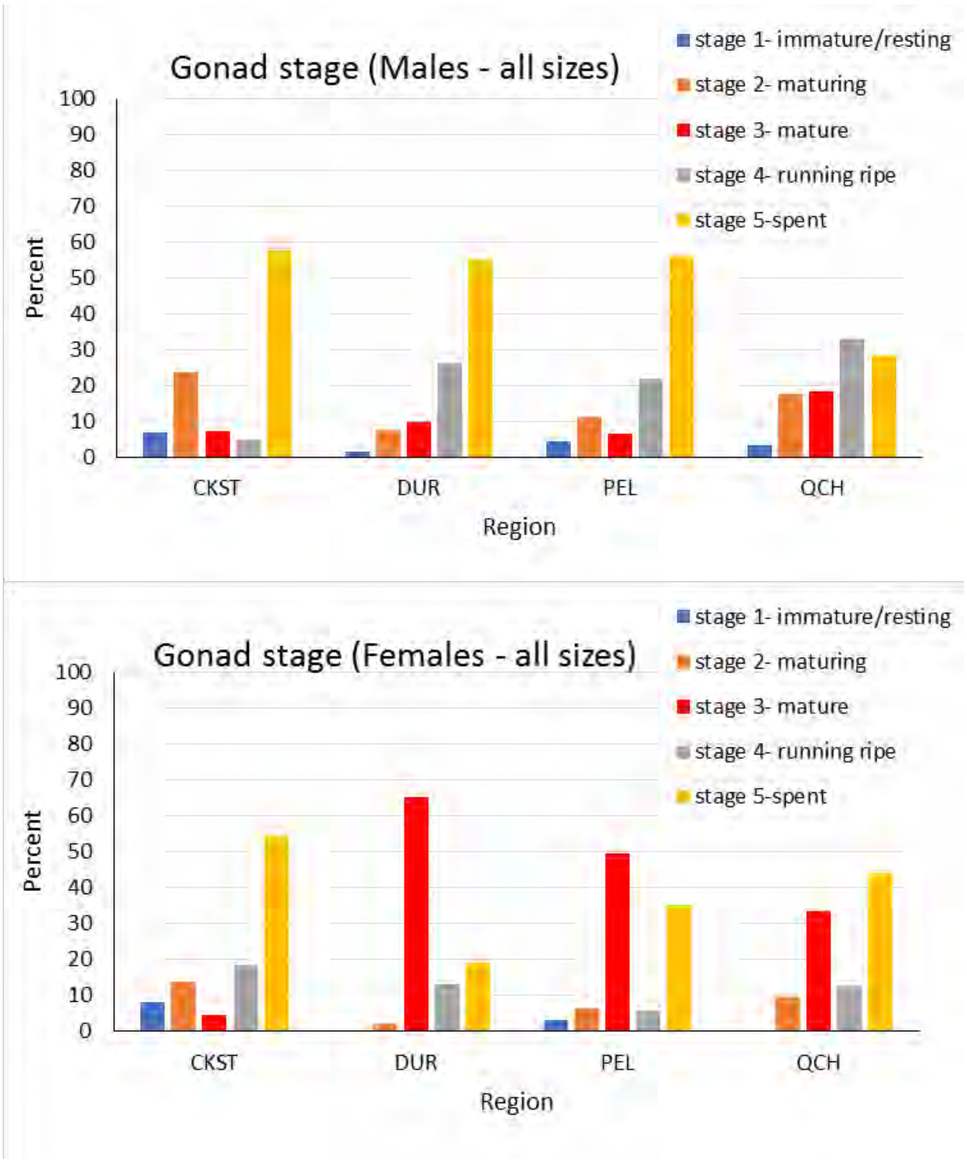


Figure 9: Gonad stages of all blue cod sampled between late September and early November 2013 by region. See Table 1 for regions names.

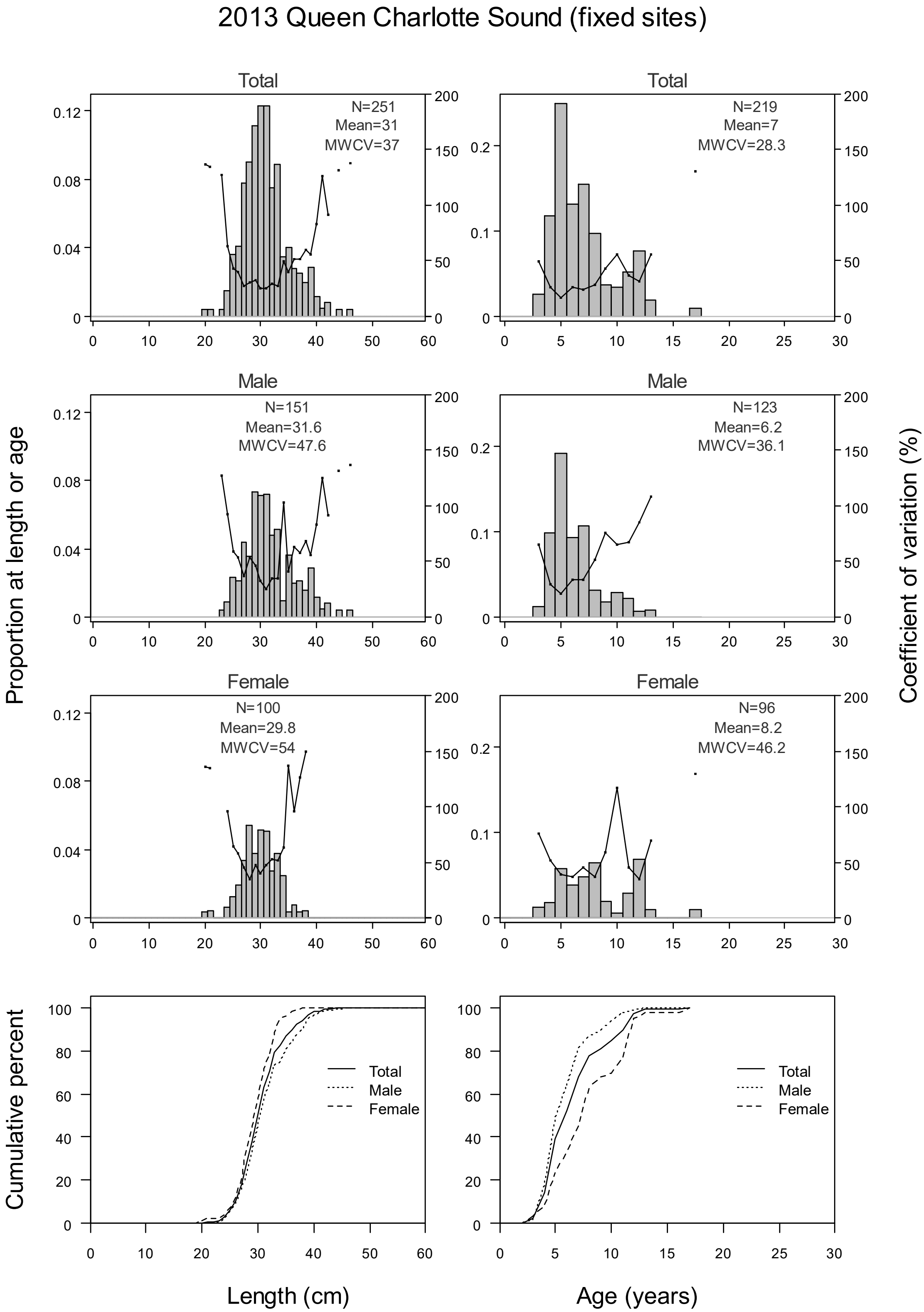


Figure 10: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for all strata (1–3) combined from Queen Charlotte Sound (fixed sites) for the 2013 Marlborough Sounds potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

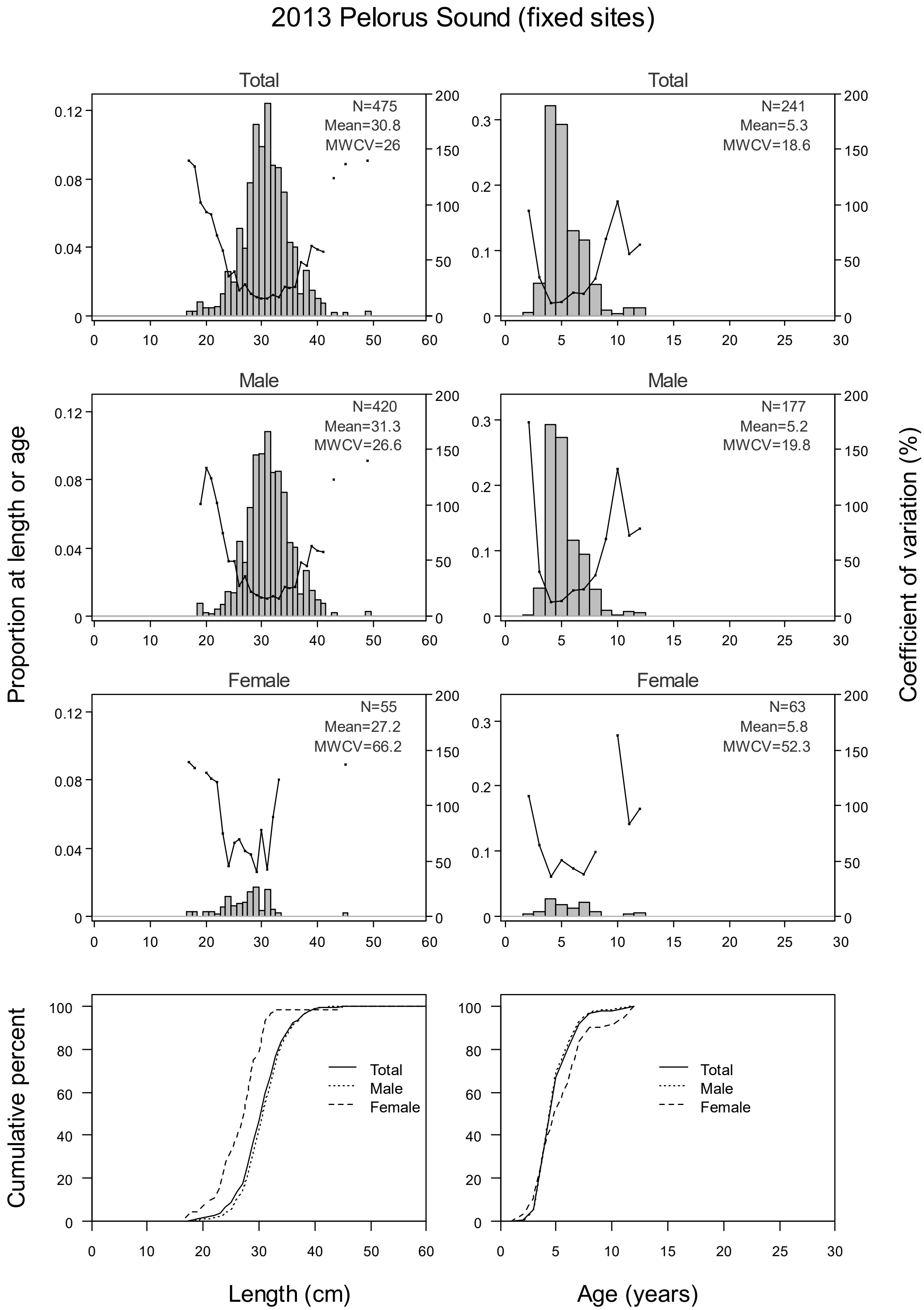


Figure 11: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for all strata (4, 5, 7 and 8) combined from Pelorus Sound (fixed sites) for the 2013 Marlborough Sounds potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

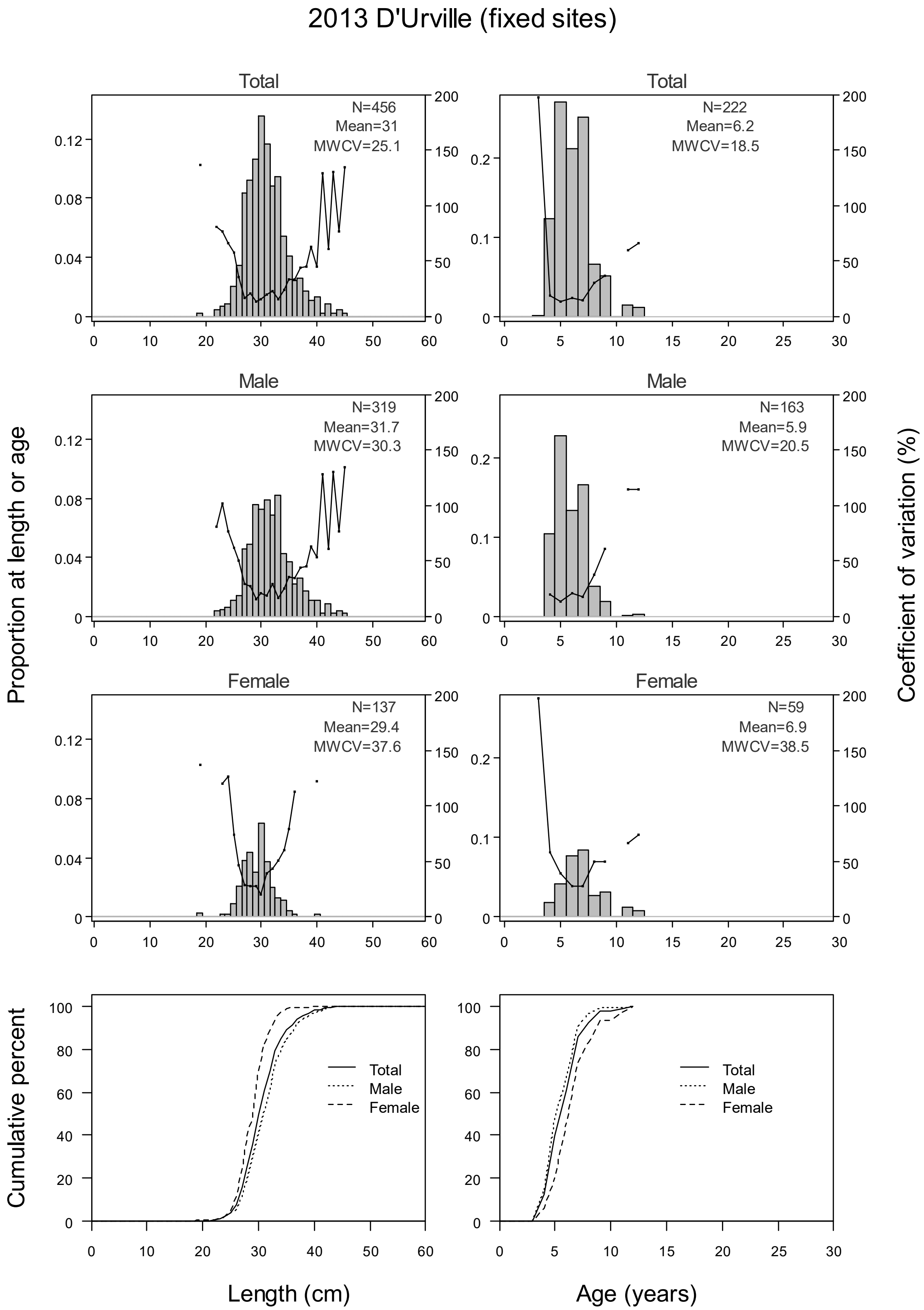


Figure 12: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for all strata (6 and 9) combined from D'Urville Island (fixed sites) for the 2013 Marlborough Sounds potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

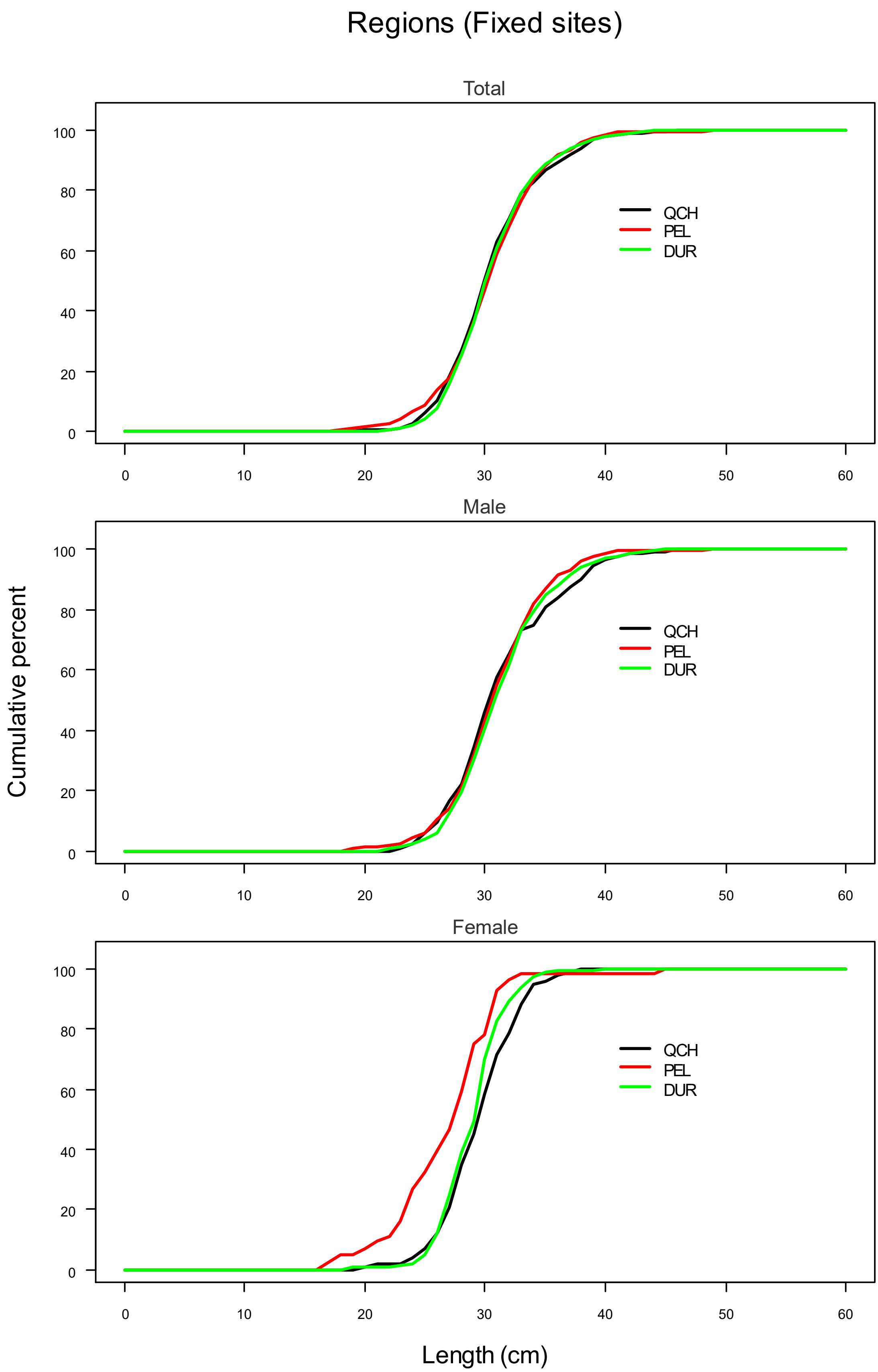


Figure 13: Cumulative distributions of scaled length frequencies for total, male, and female blue cod for the fixed-site potting survey in 2013. See Table 2 for region names.

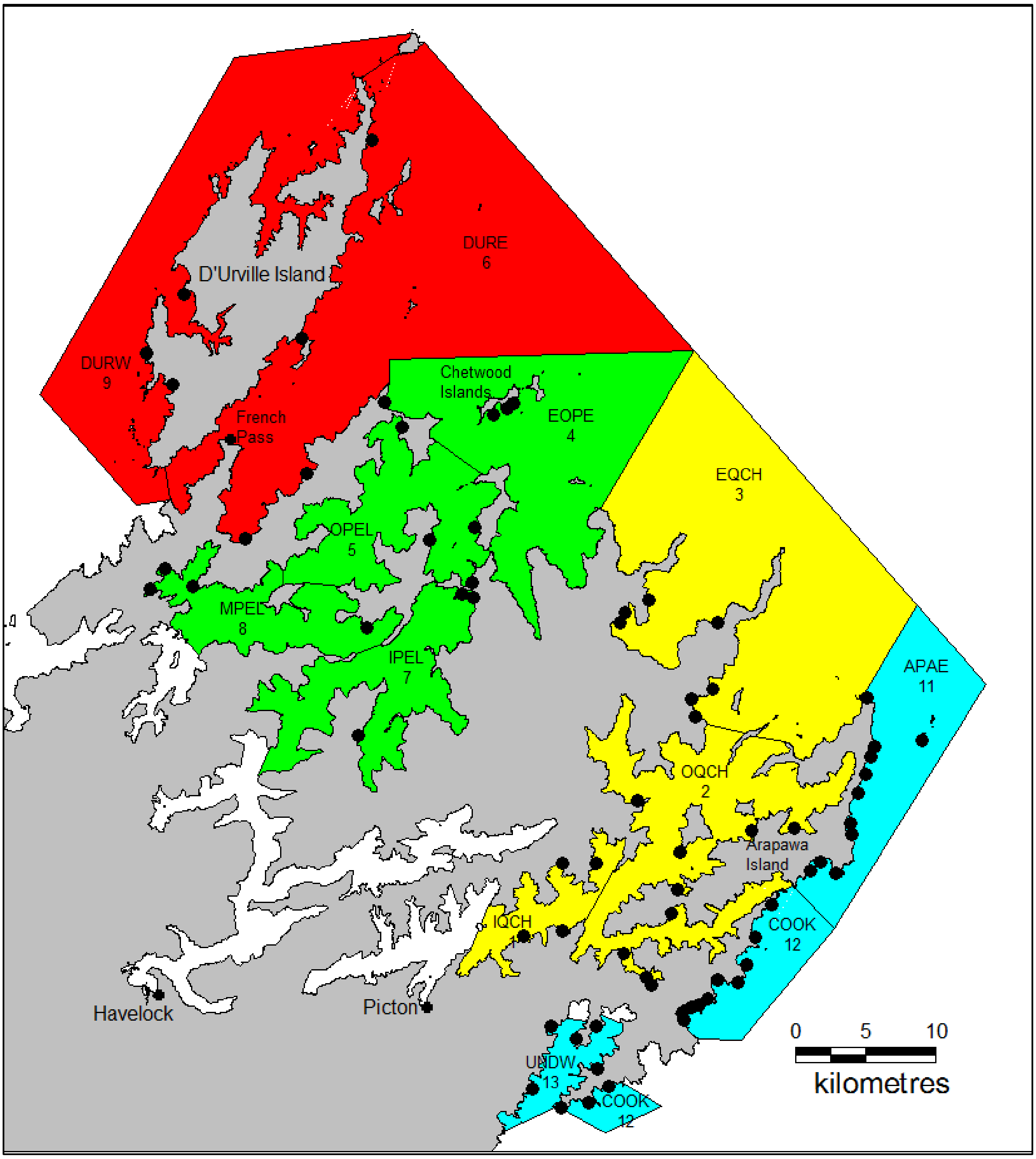


Figure 14: Map of Marlborough Sounds showing the locations of all random sites surveyed in 2013. The regions are colour coded. Red, D'Urville Island (DUR); green, Pelorus Sound (PEL); yellow, Queen Charlotte Sound (QCH); blue, Cook Strait (CKST). See Table 1 for strata names.

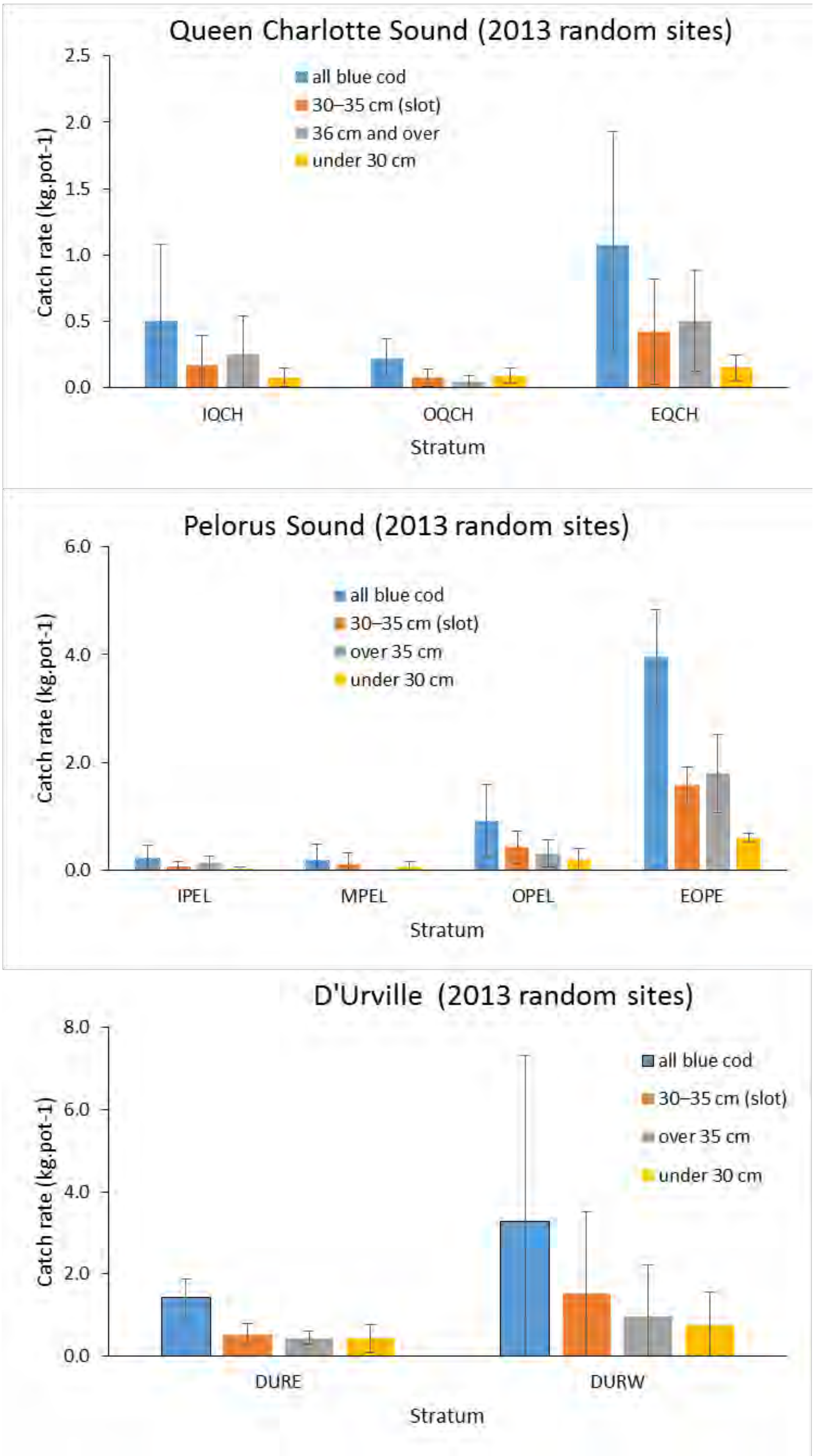


Figure 15: Marlborough Sounds 2013 potting survey catch rates of all blue cod and by size category for random sites by strata, for each region. Error bars are 95% confidence intervals. See Figure 1 for location of strata. [Continued on next page]

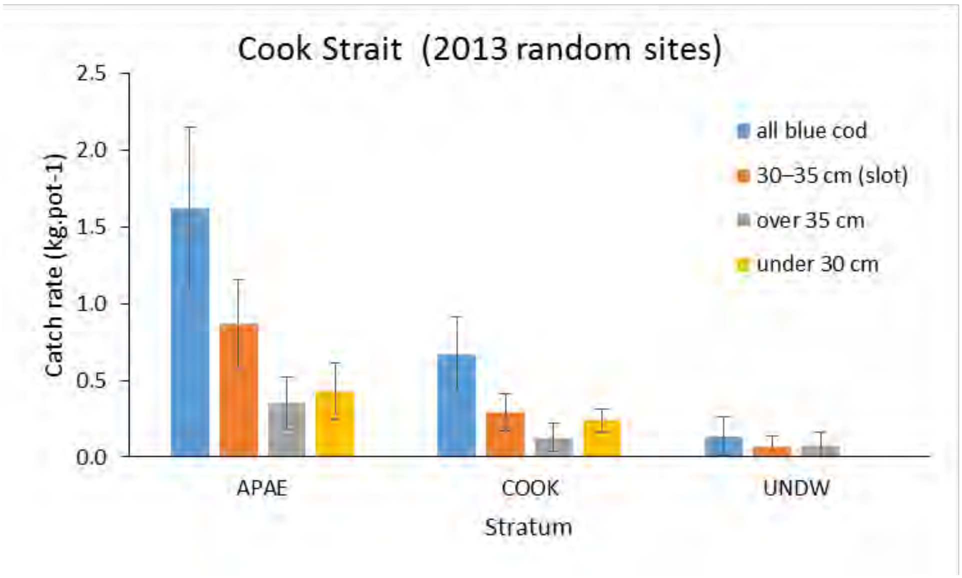


Figure 15 [Continued]

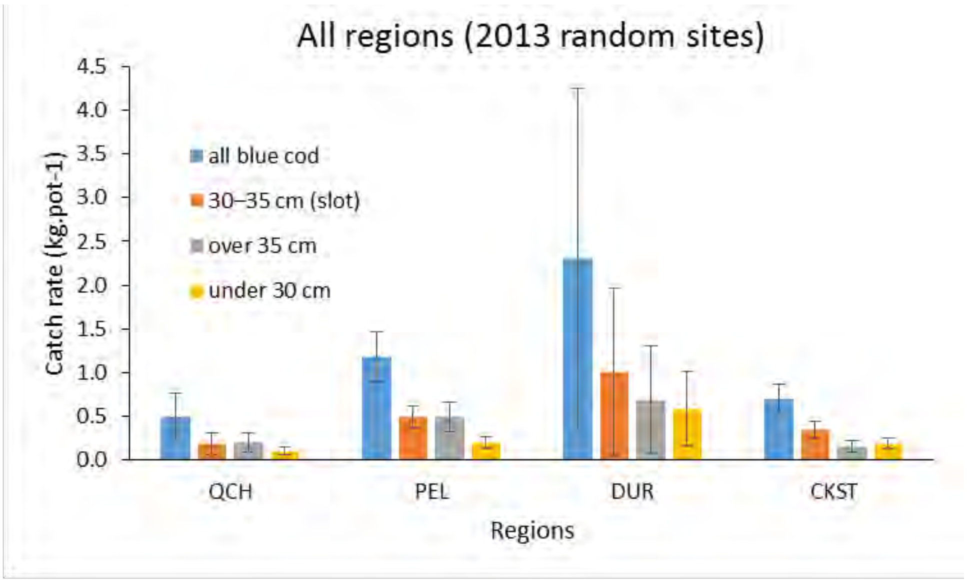


Figure 16: Marlborough Sounds 2013 potting survey catch rates of all blue cod and by size category for random sites by region. Error bars are 95% confidence intervals. See Figure 1 for location of regions and Table 1 for region names.

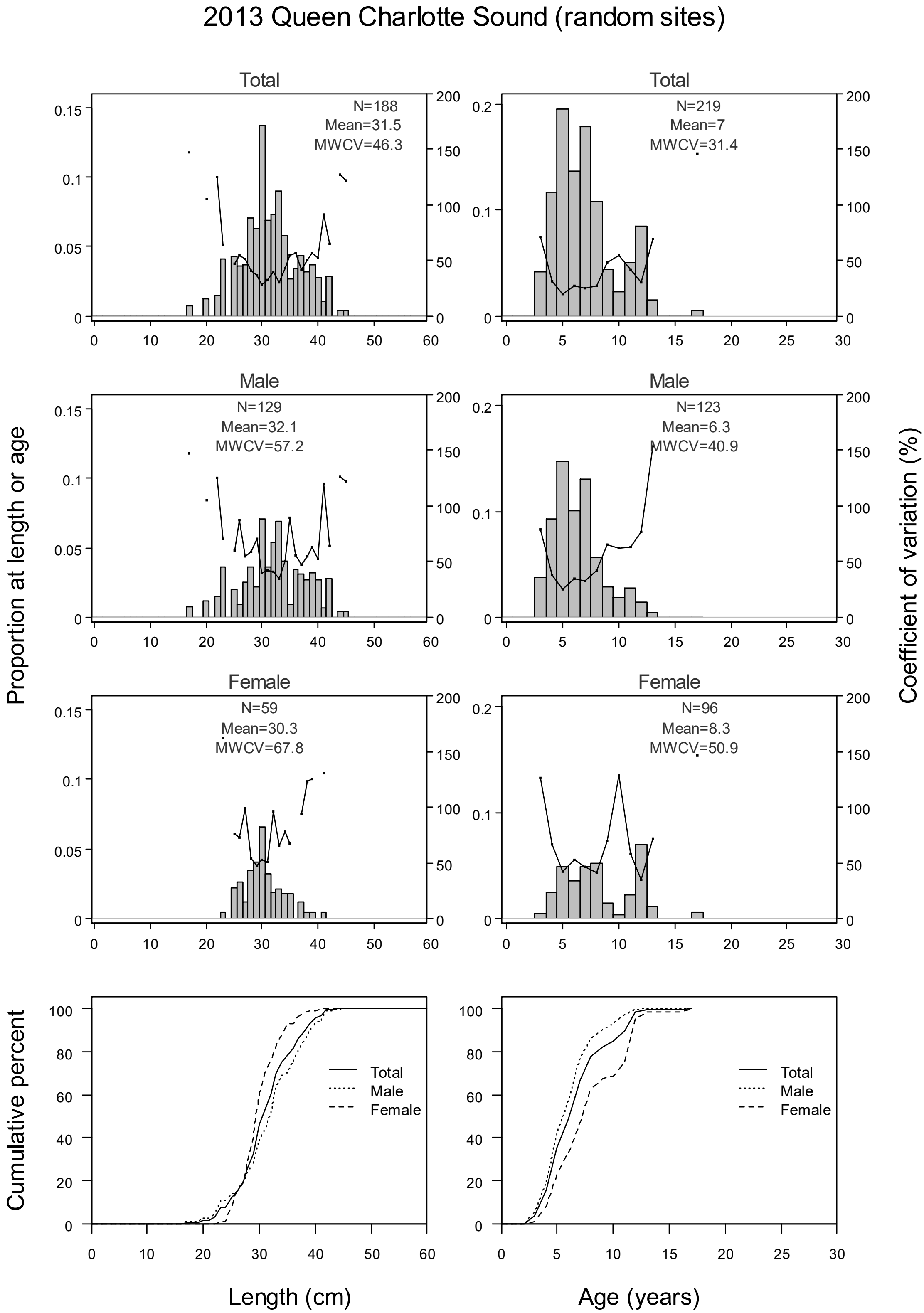


Figure 17: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for all strata (1–3) combined from Queen Charlotte Sound (random sites) for the 2013 Marlborough Sounds potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

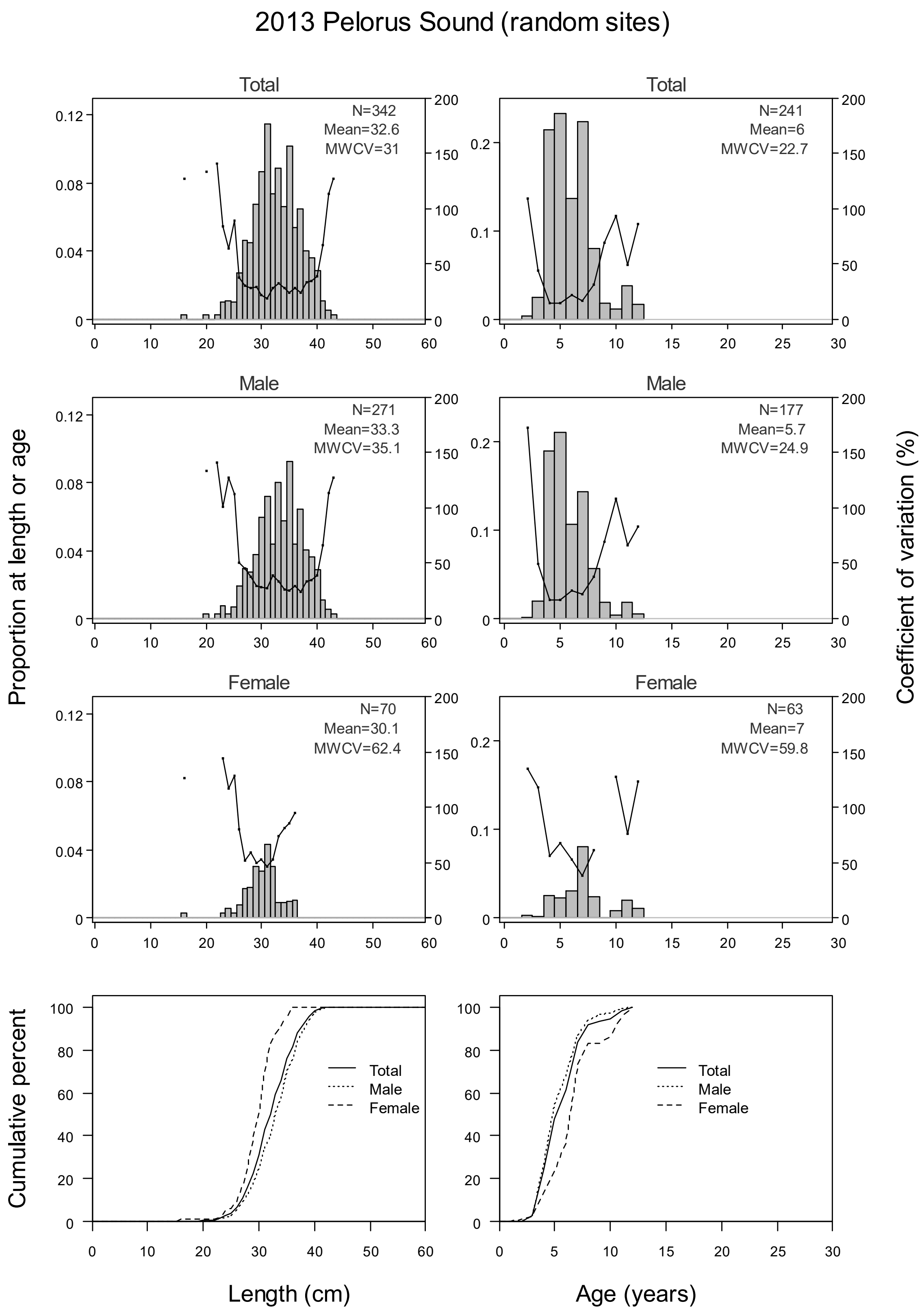


Figure 18: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for all strata (4, 5, 7 and 8) combined from Pelorus Sound (random sites) for the 2013 Marlborough Sounds potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

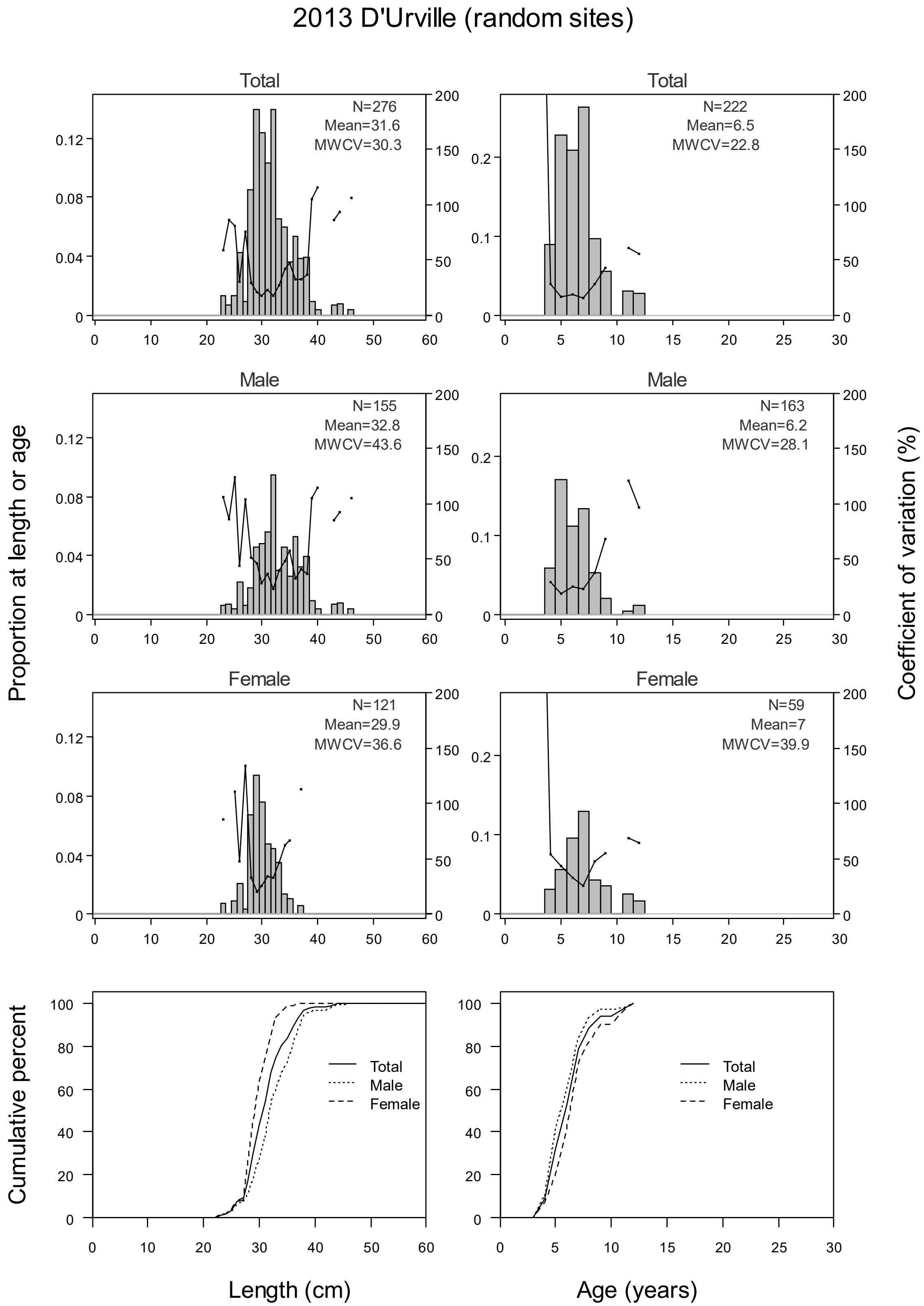


Figure 19: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for all strata (6 and 9) combined from D'Urville Island (random sites) for the 2013 Marlborough Sounds potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

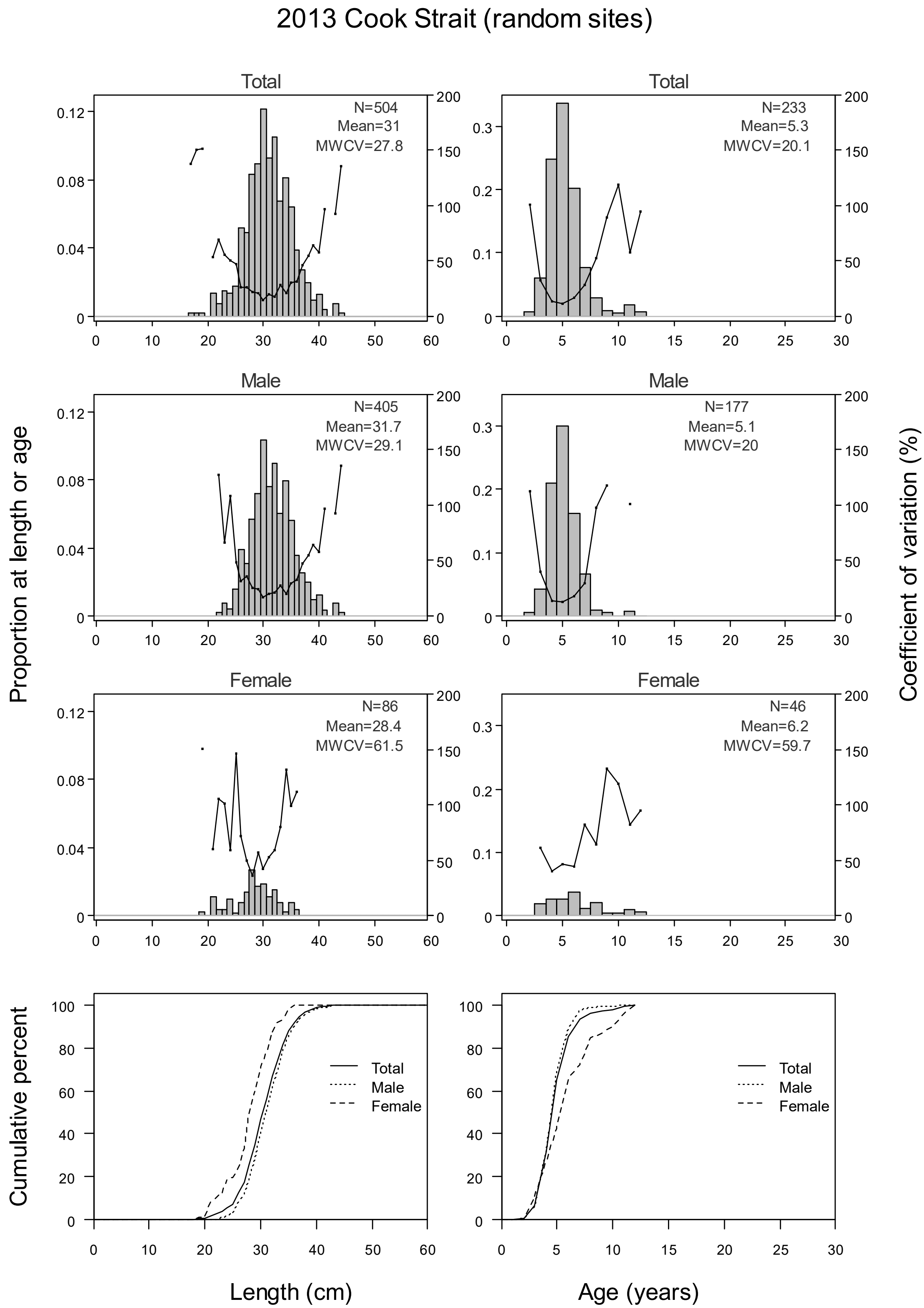


Figure 20: Scaled length-frequency, age-frequency, and cumulative distributions for total, male, and female blue cod for all strata (11–13) combined from Cook Strait (random sites) for the 2013 Marlborough Sounds potting survey. N, sample size; MWCV, mean weighted coefficient of variation.

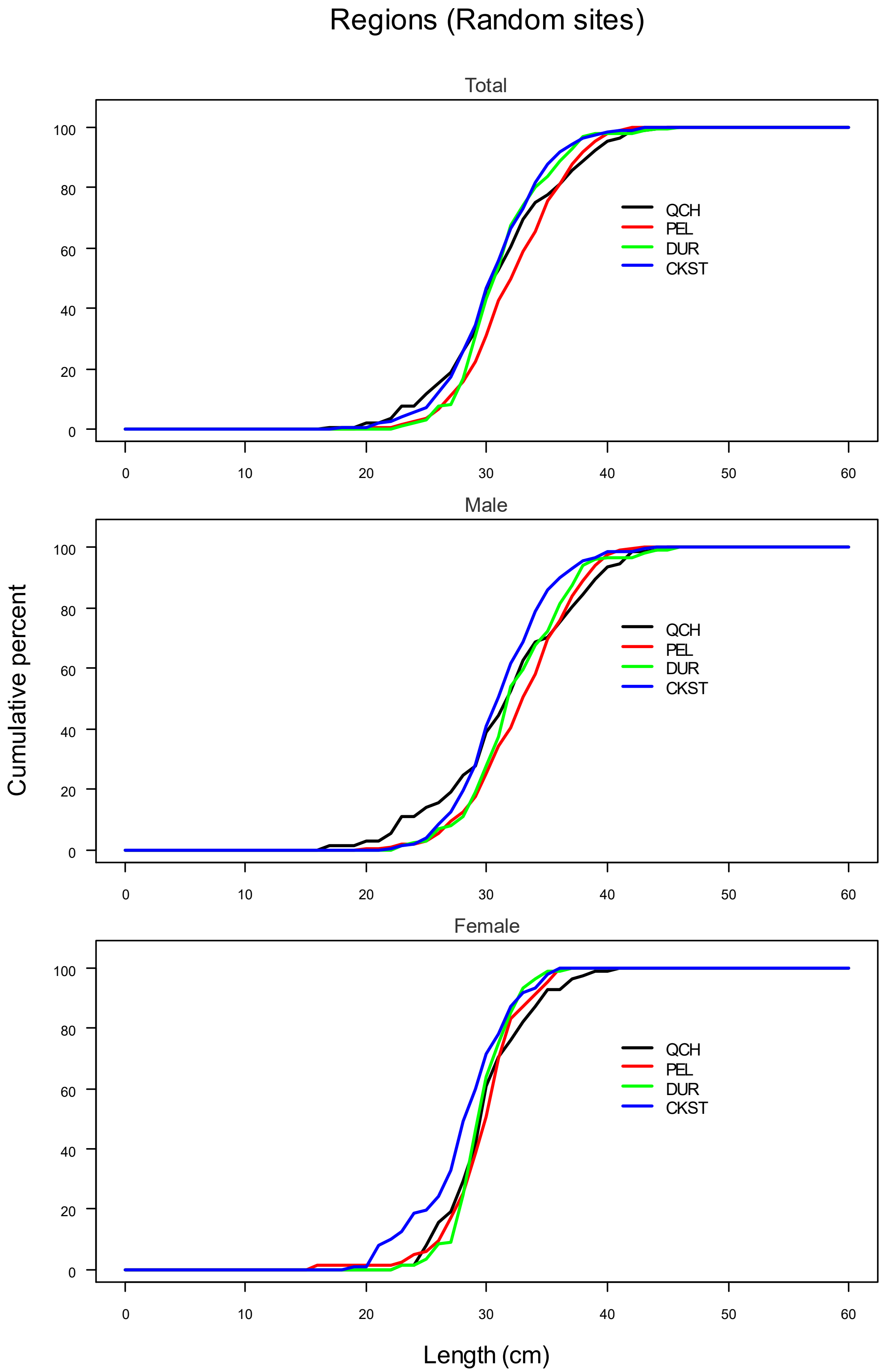


Figure 21: Cumulative distributions of scaled length frequencies for total, male, and female blue cod for the random-site potting survey in 2013. See Table 2 for region names.

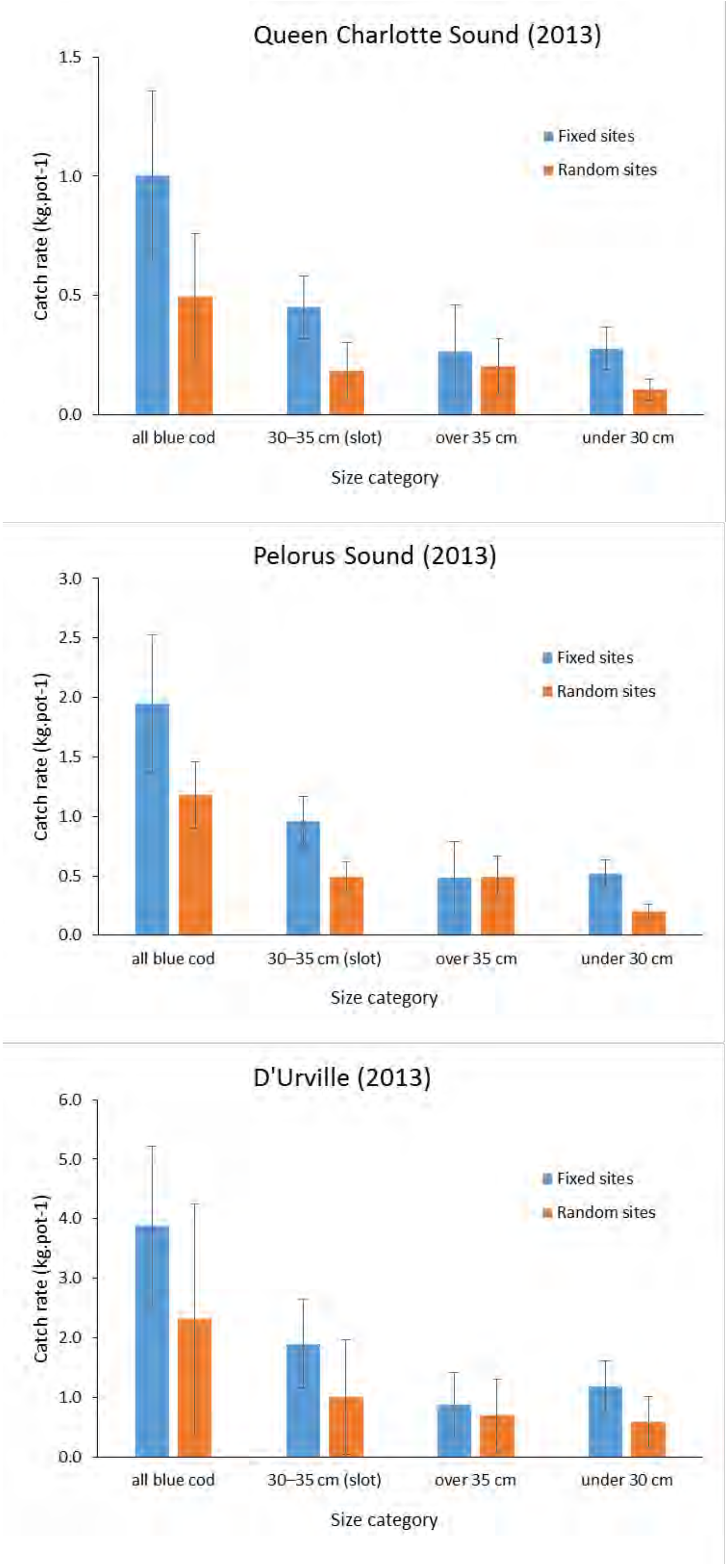


Figure 22: Marlborough Sounds 2013 potting survey catch rates of all blue cod and by size category for fixed and random sites for each region. Error bars are 95% confidence intervals.

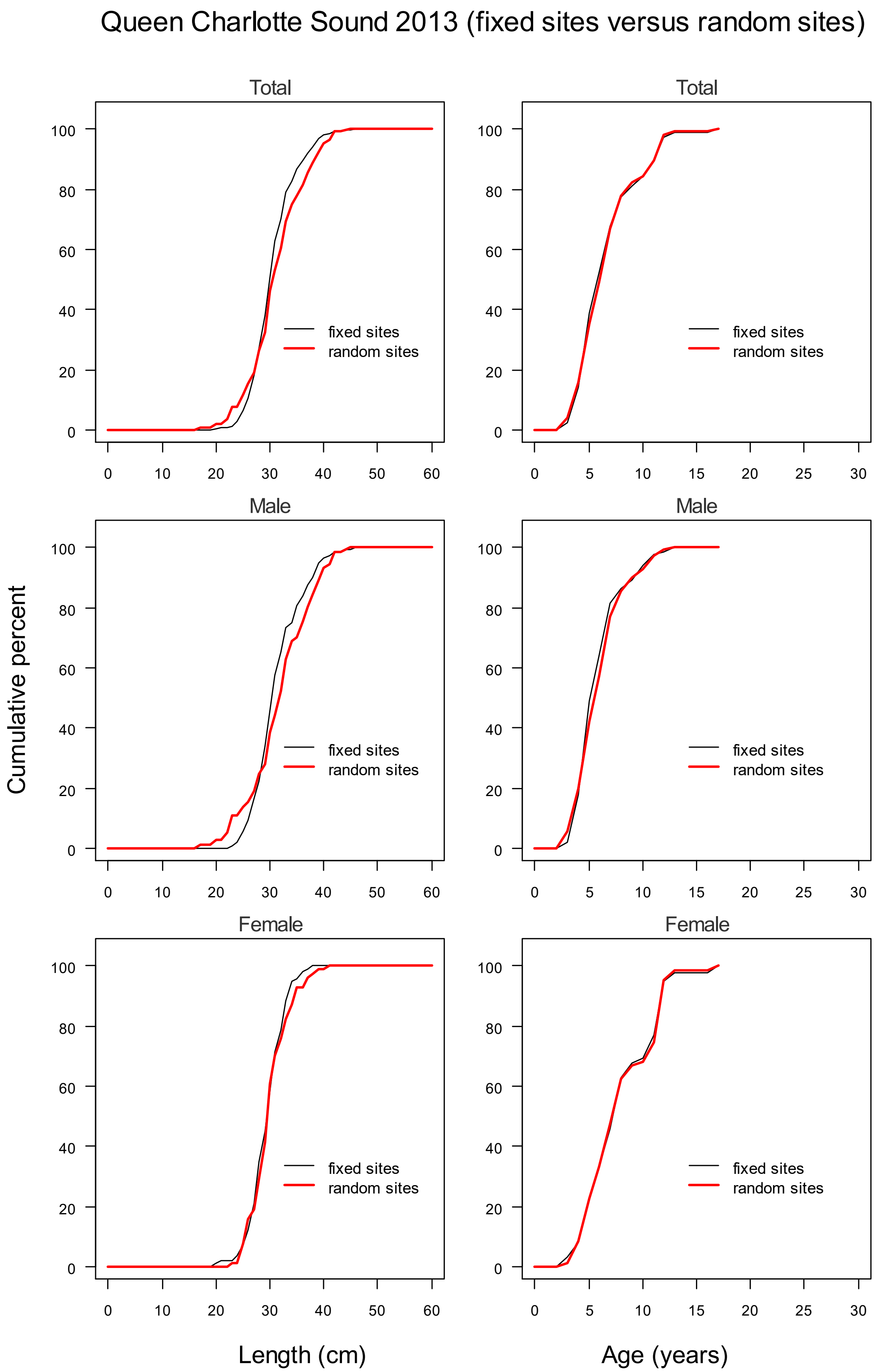


Figure 23: Cumulative distributions of scaled length frequencies for total, male, and female blue cod for fixed- and random-site potting surveys from Queen Charlotte Sound in 2013.

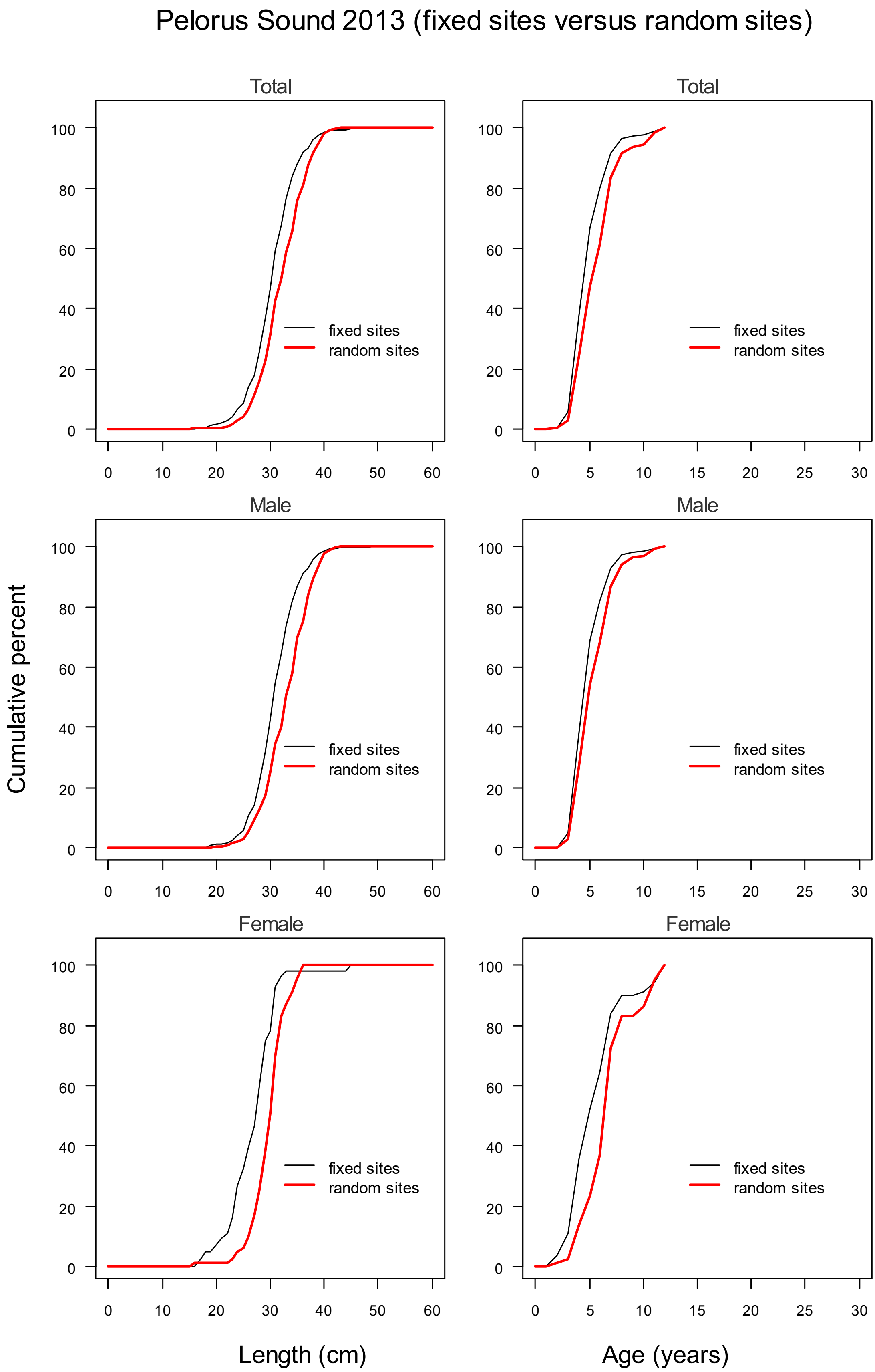


Figure 24: Cumulative distributions of scaled length frequencies for total, male, and female blue cod for fixed- and random-site potting surveys from Pelorus Sound in 2013.

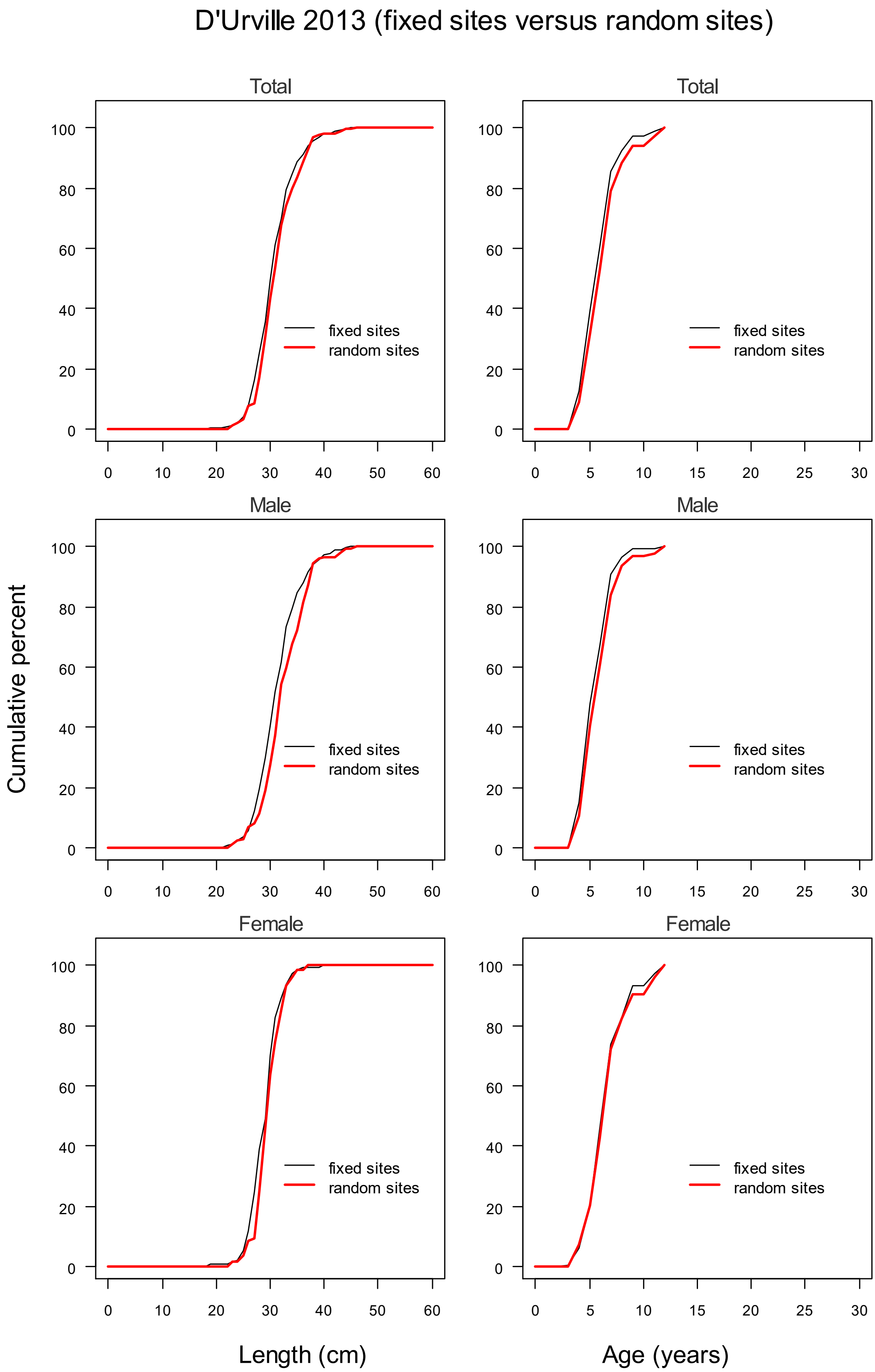


Figure 25: Cumulative distributions of scaled length frequencies for total, male, and female blue cod for fixed- and random-site potting surveys from D'Urville Island in 2013.

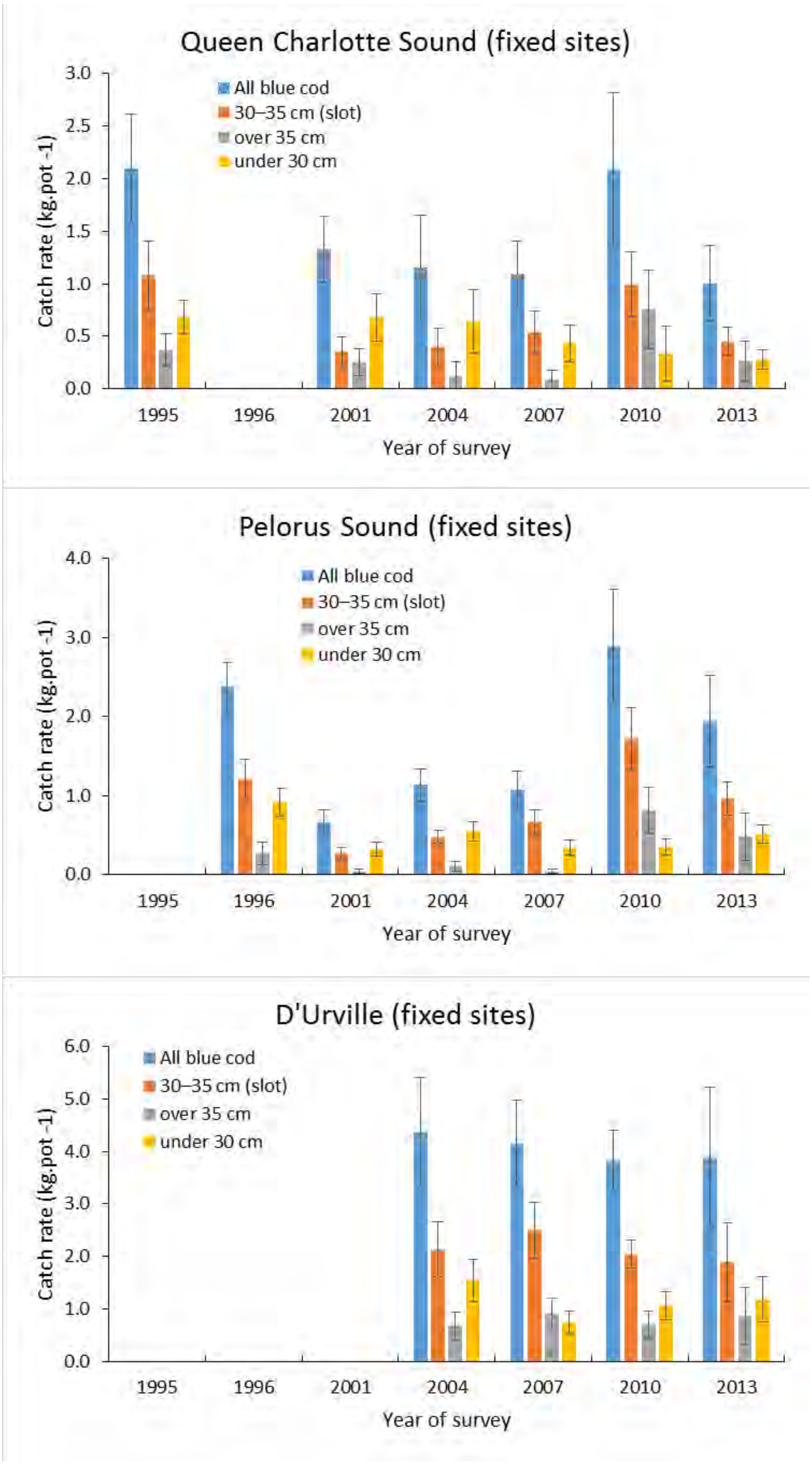


Figure 26: Marlborough Sounds potting survey catch rates of all blue cod and by size category for fixed sites by survey year, for each region. Error bars are 95% confidence intervals. See Figure 1 for location of regions. There were no complete surveys in QCH in 1996, PEL in 1996, and DUR from 1995 to 2001 (see Table 1).

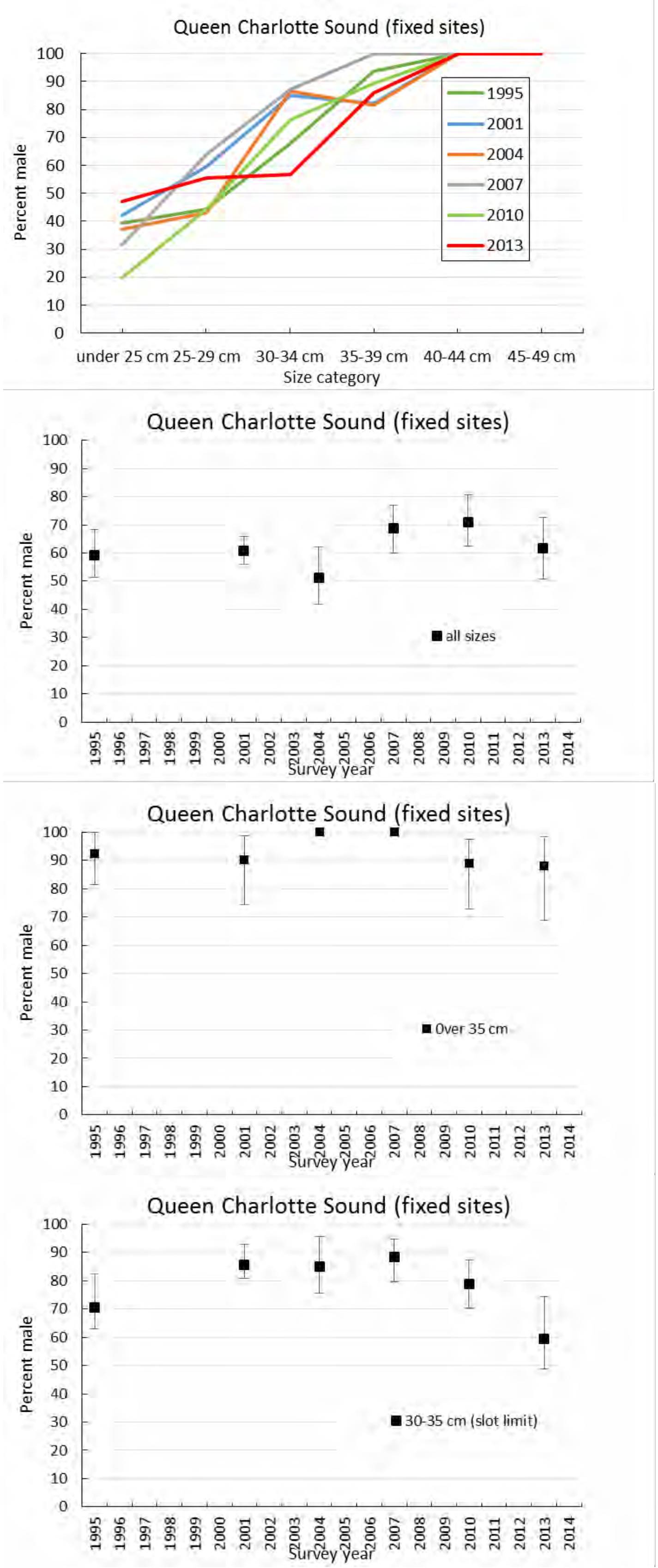


Figure 27: Queen Charlotte Sound sex ratio (percent male) by size category for each of the Marlborough Sounds fixed-site potting surveys (top panel), and for three size categories across all surveys (bottom three panels). Error bars are 95% confidence intervals.

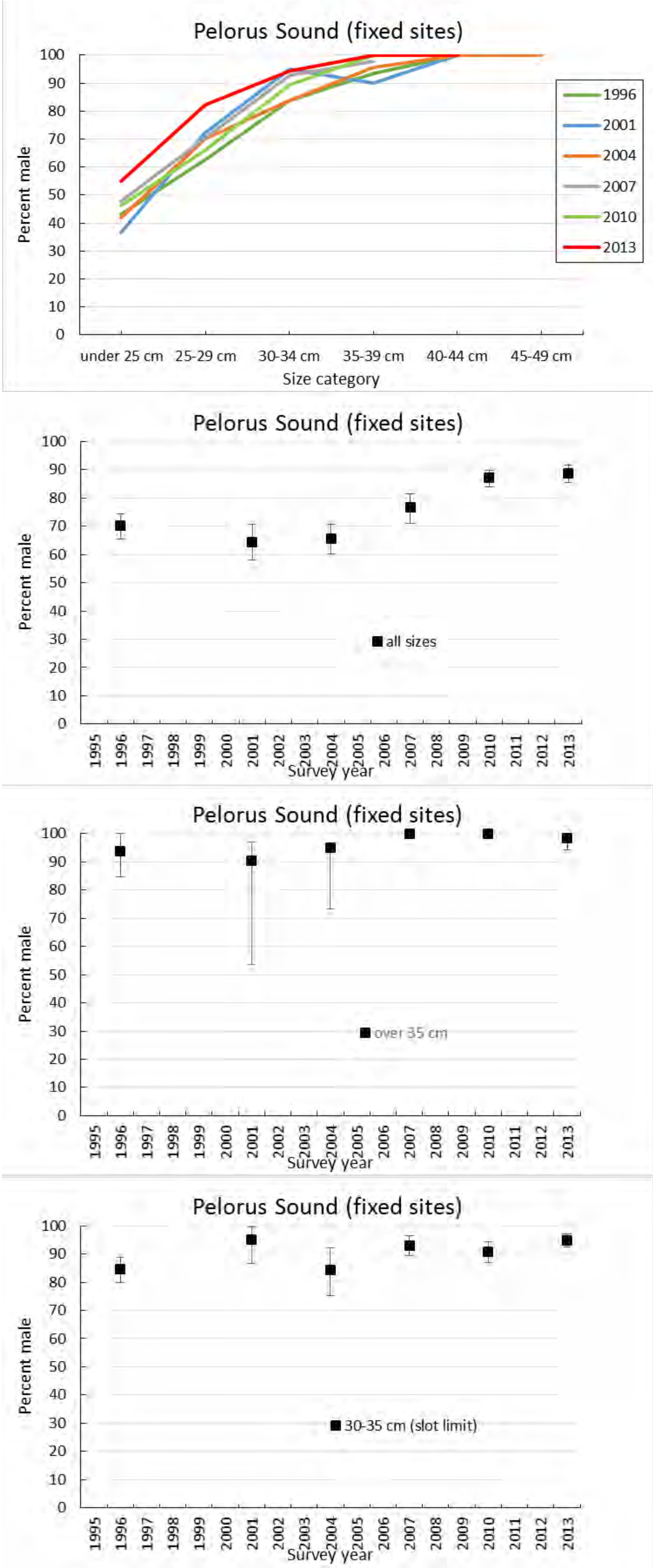


Figure 28: Pelorus Sound sex ratio (percent male) by size category for each of the Marlborough Sounds fixed-site potting surveys (top panel), and for three size categories across all surveys (bottom three panels). Error bars are 95% confidence intervals.

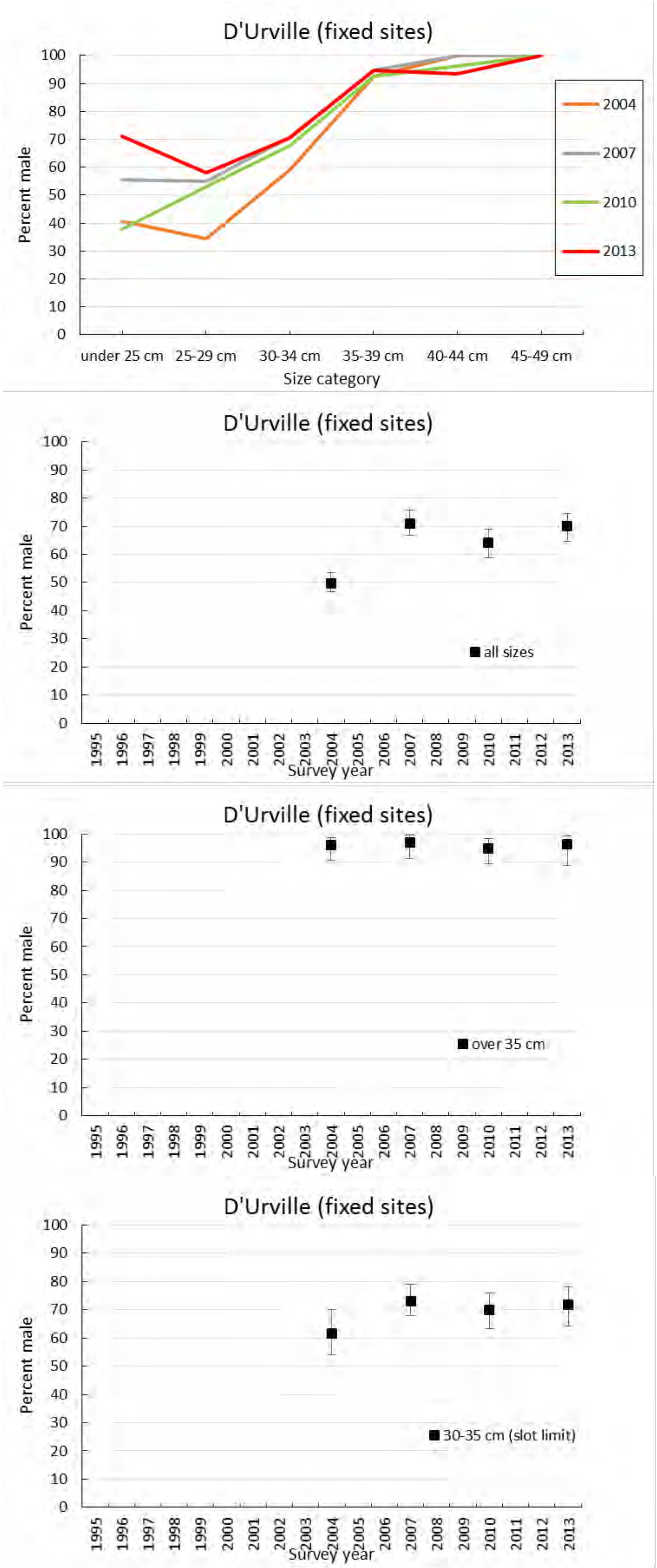


Figure 29: D'Urville sex ratio (percent male) by size category for each of the Marlborough Sounds fixed-site potting surveys (top panel), and for three size categories across all surveys (bottom three panels). Error bars are 95% confidence intervals.

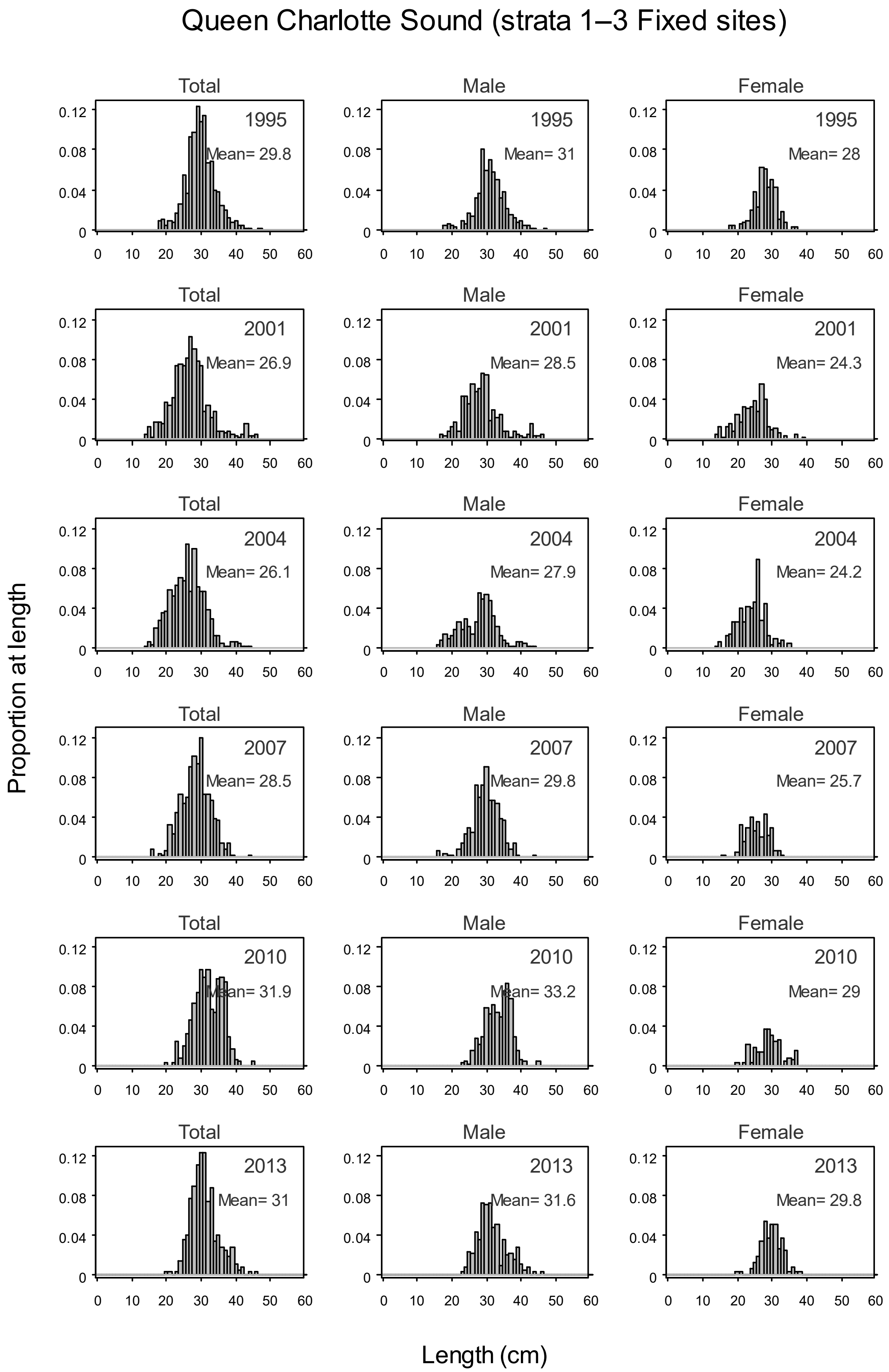


Figure 30: Scaled length distributions for total, male, and female blue cod from Queen Charlotte Sound for fixed-site potting surveys.

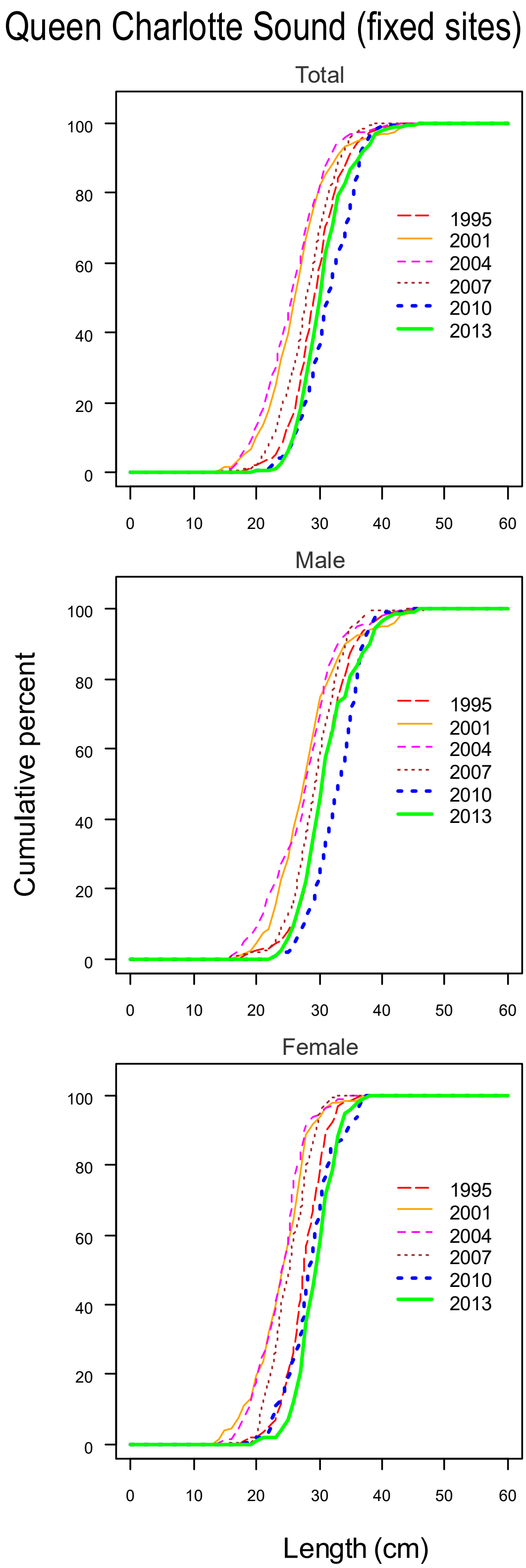


Figure 31: Cumulative distributions of scaled length frequencies for total, male, and female blue cod from Queen Charlotte Sound for fixed-site potting surveys.

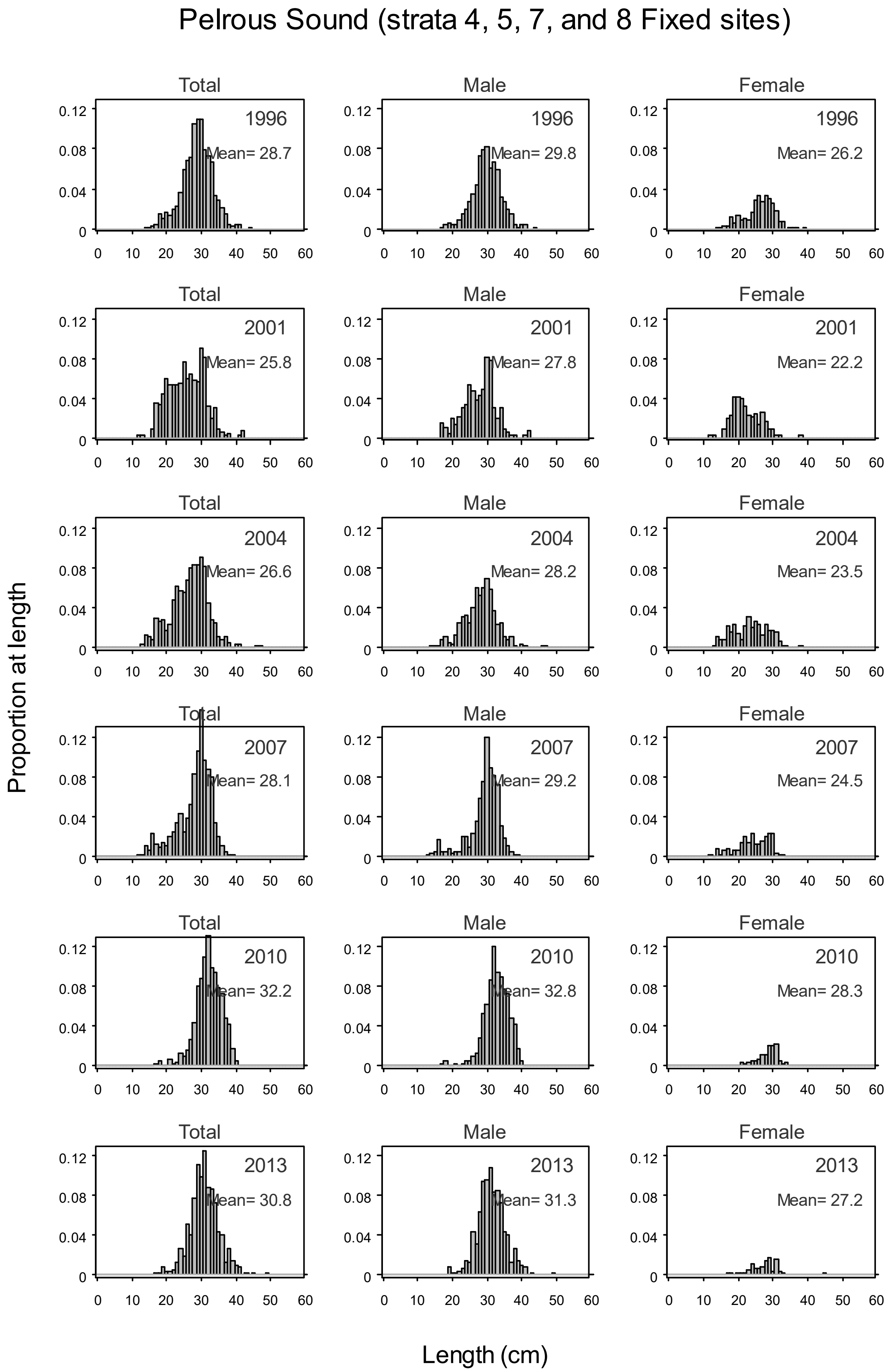


Figure 32: Scaled length distributions for total, male, and female blue cod from Pelorus Sound for fixed-site potting surveys.

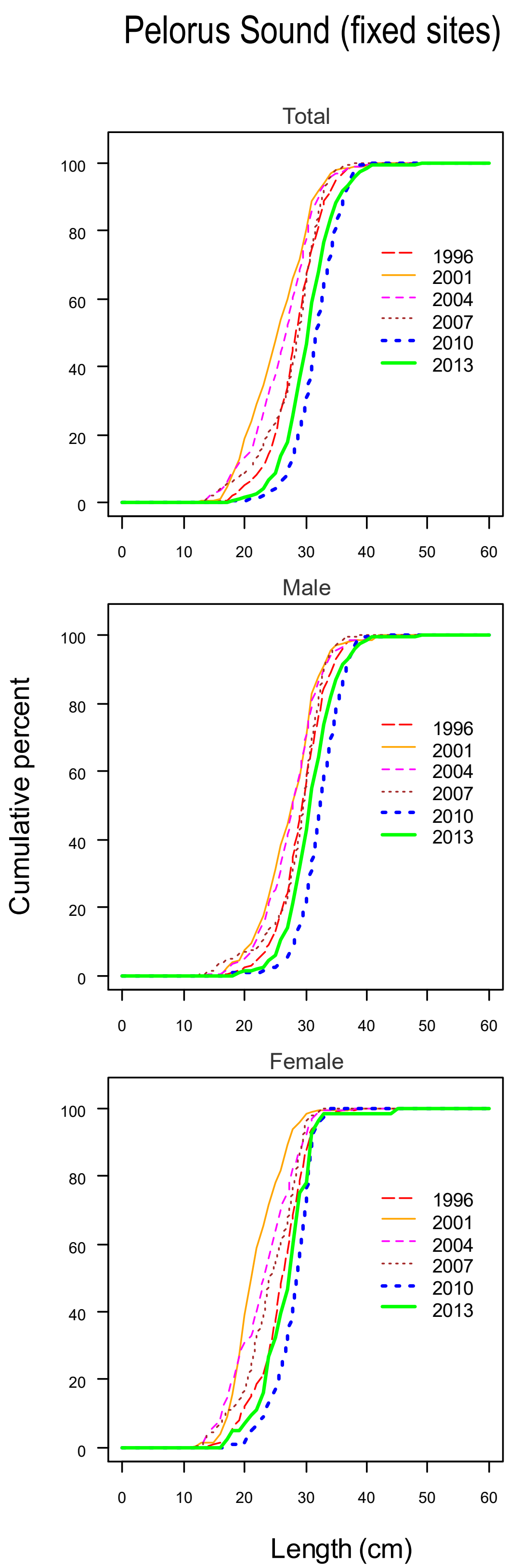


Figure 33: Cumulative distributions of scaled length frequencies for total, male, and female blue cod from Pelorus Sound for the fixed-site potting surveys.

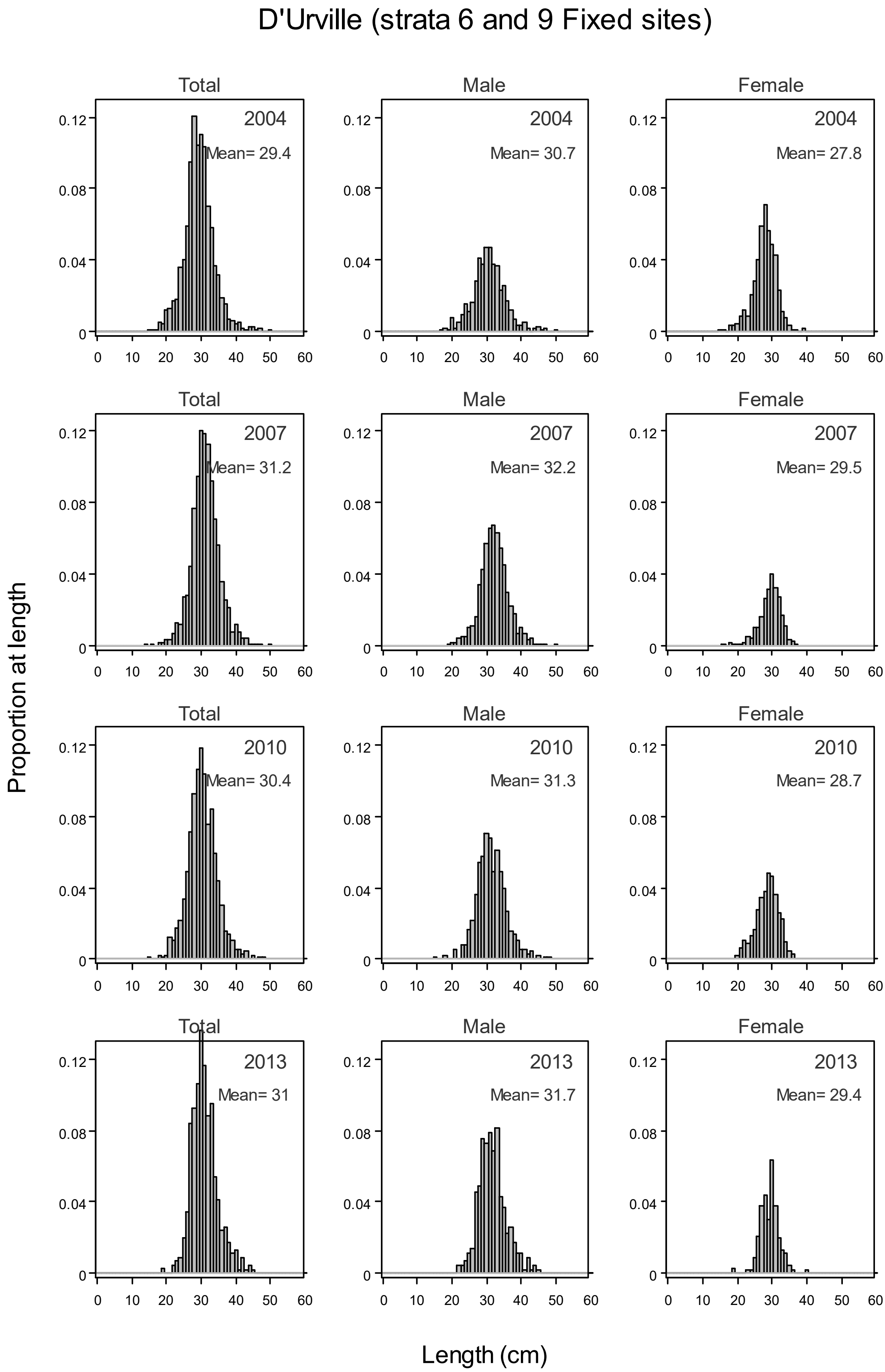


Figure 34: Scaled length distributions for total, male, and female blue cod from D'Urville for fixed-site potting surveys.

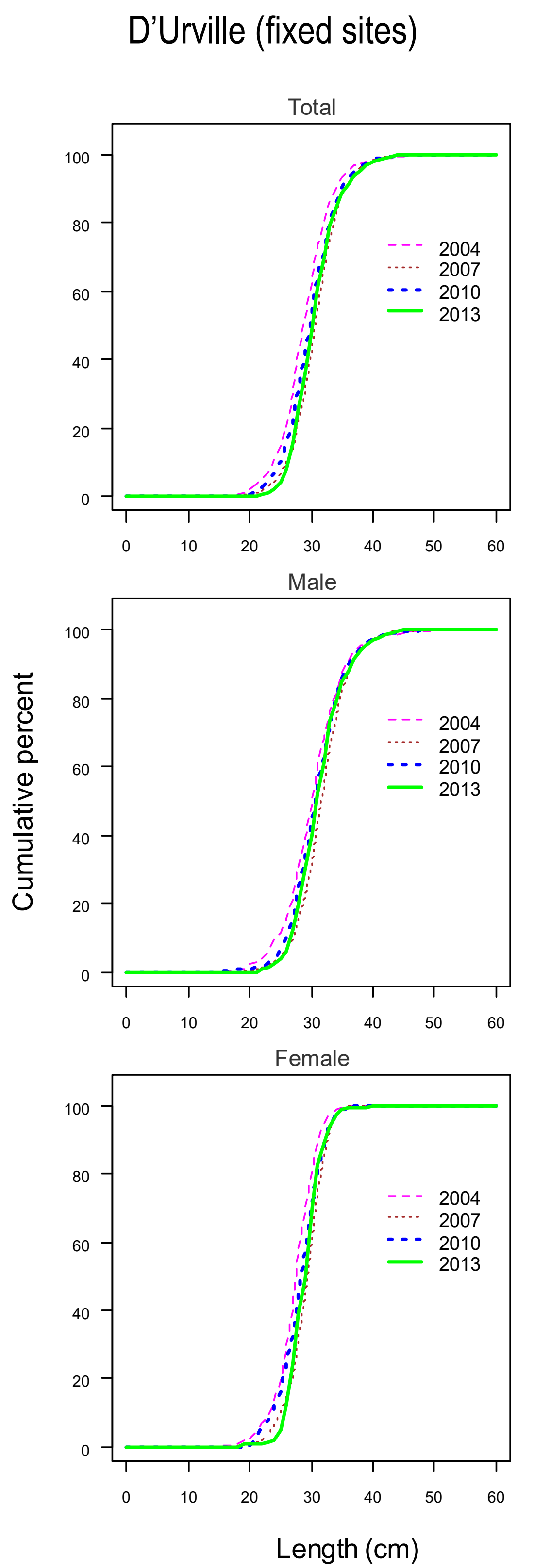


Figure 35: Cumulative distributions of scaled length frequencies for total, male, and female blue cod from D'Urville for the fixed-site potting surveys.

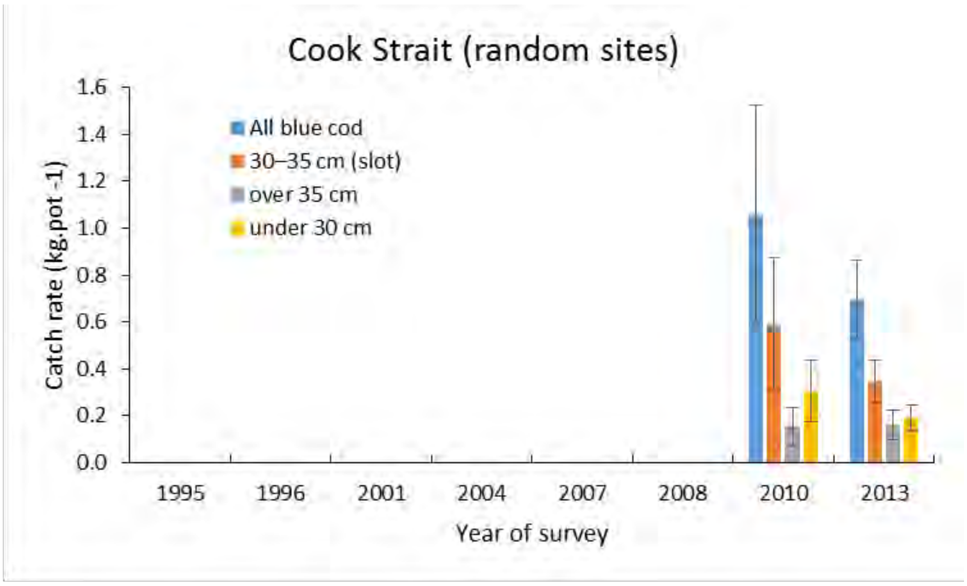


Figure 36: Marlborough Sounds potting survey (Cook Strait) catch rates of all blue cod and by size category for random sites by survey year. Error bars are 95% confidence intervals. See Figure 1 for location of Cook Strait (CKST).

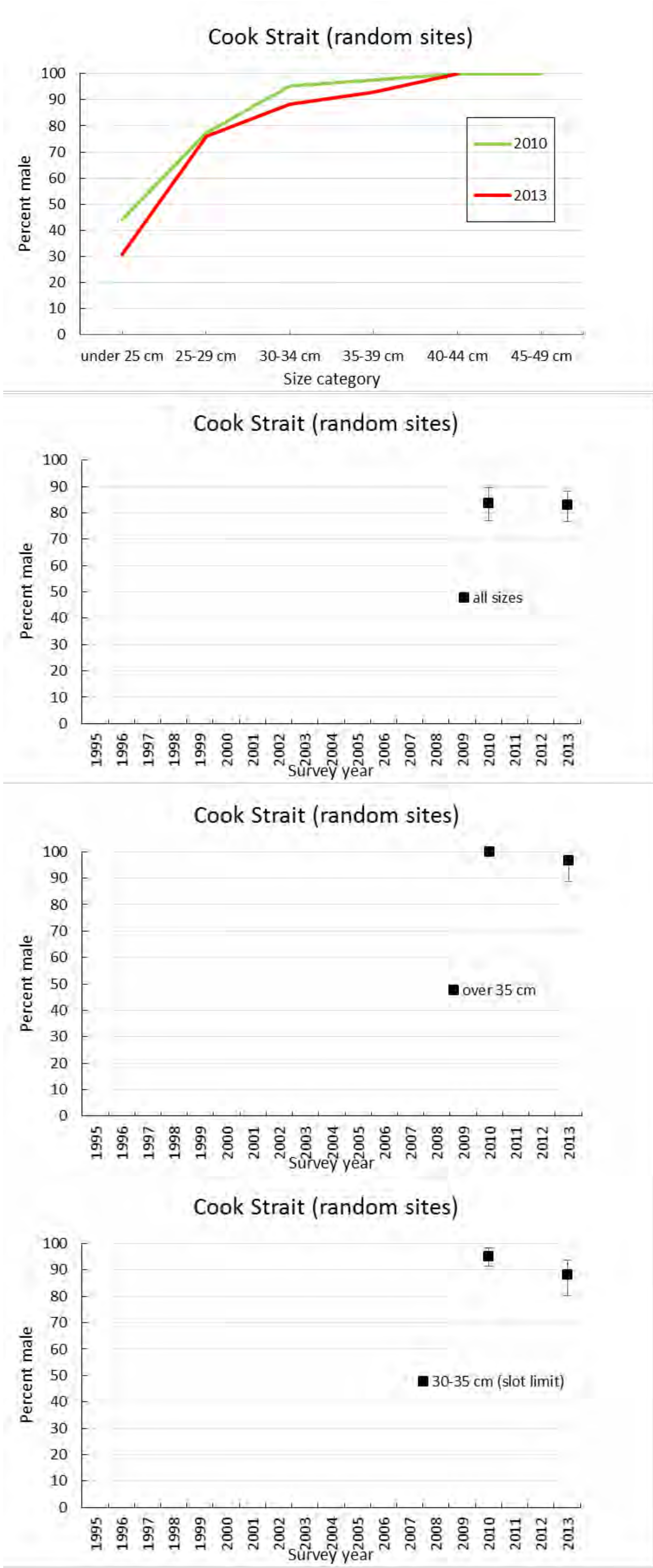


Figure 37: Cook Strait sex ratio (percent male) by size category for the Marlborough Sounds random-site potting surveys (top panel), and for three size categories across both surveys (bottom three panels). Error bars are 95% confidence intervals.

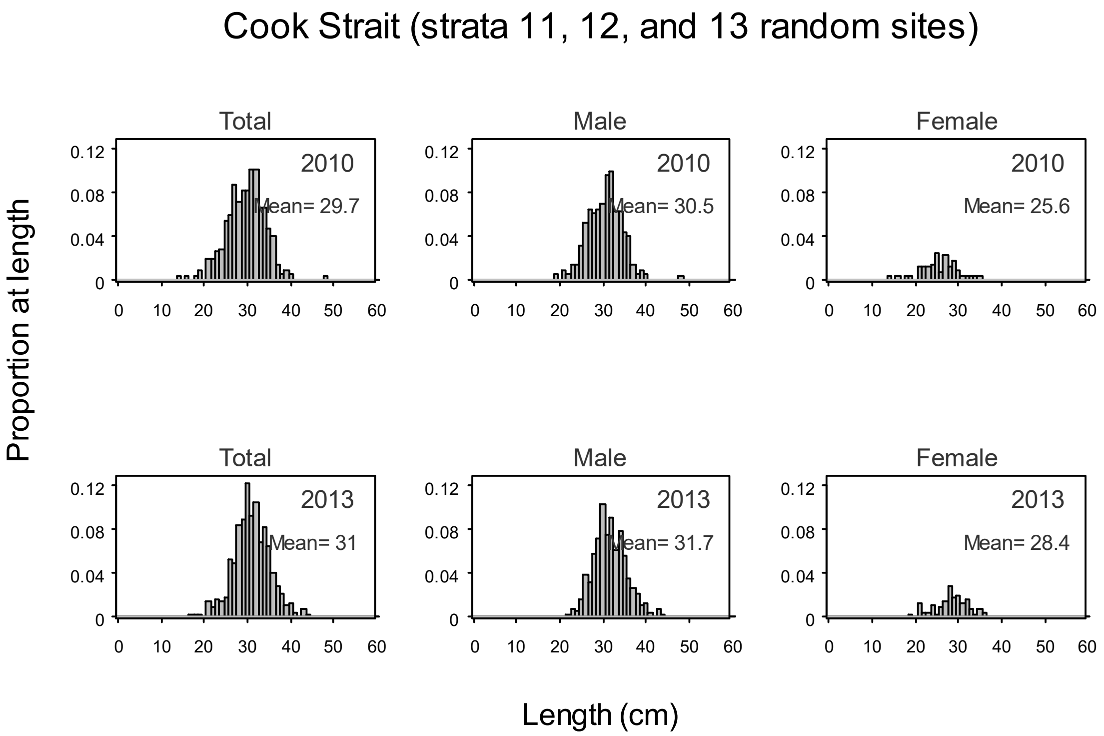


Figure 38: Scaled length distributions for total, male, and female blue cod from Cook Strait random-site potting surveys.

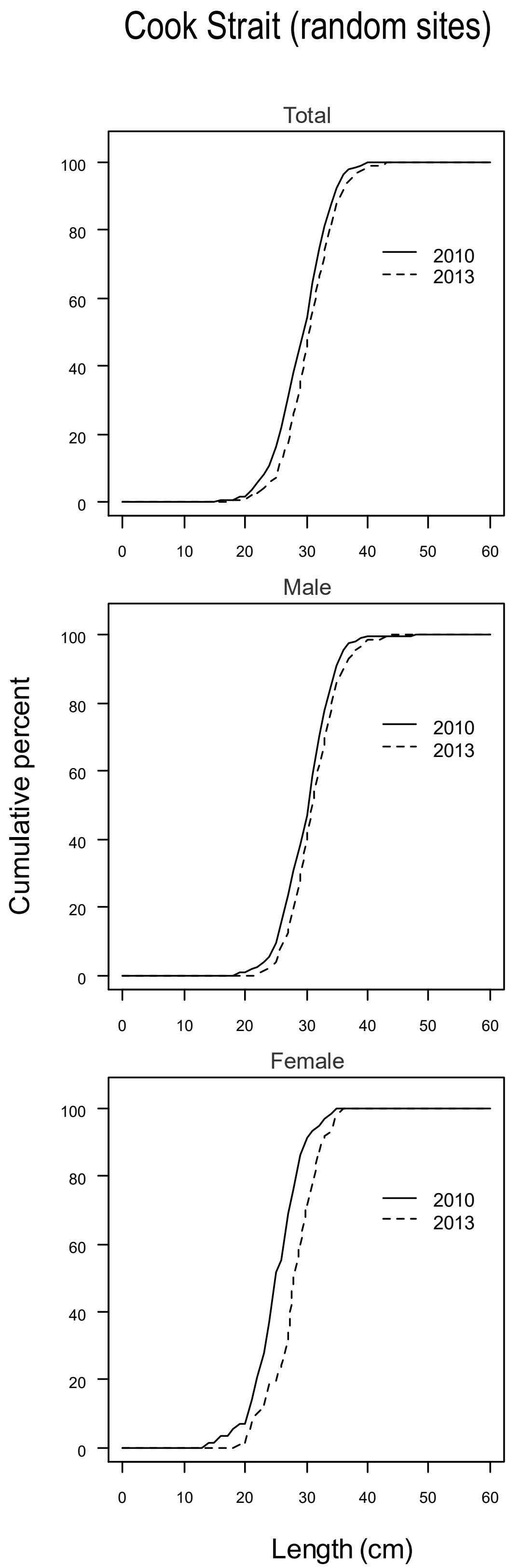


Figure 39: Cumulative distributions of scaled length frequencies for total, male, and female blue cod from Cook Strait random-site potting surveys.

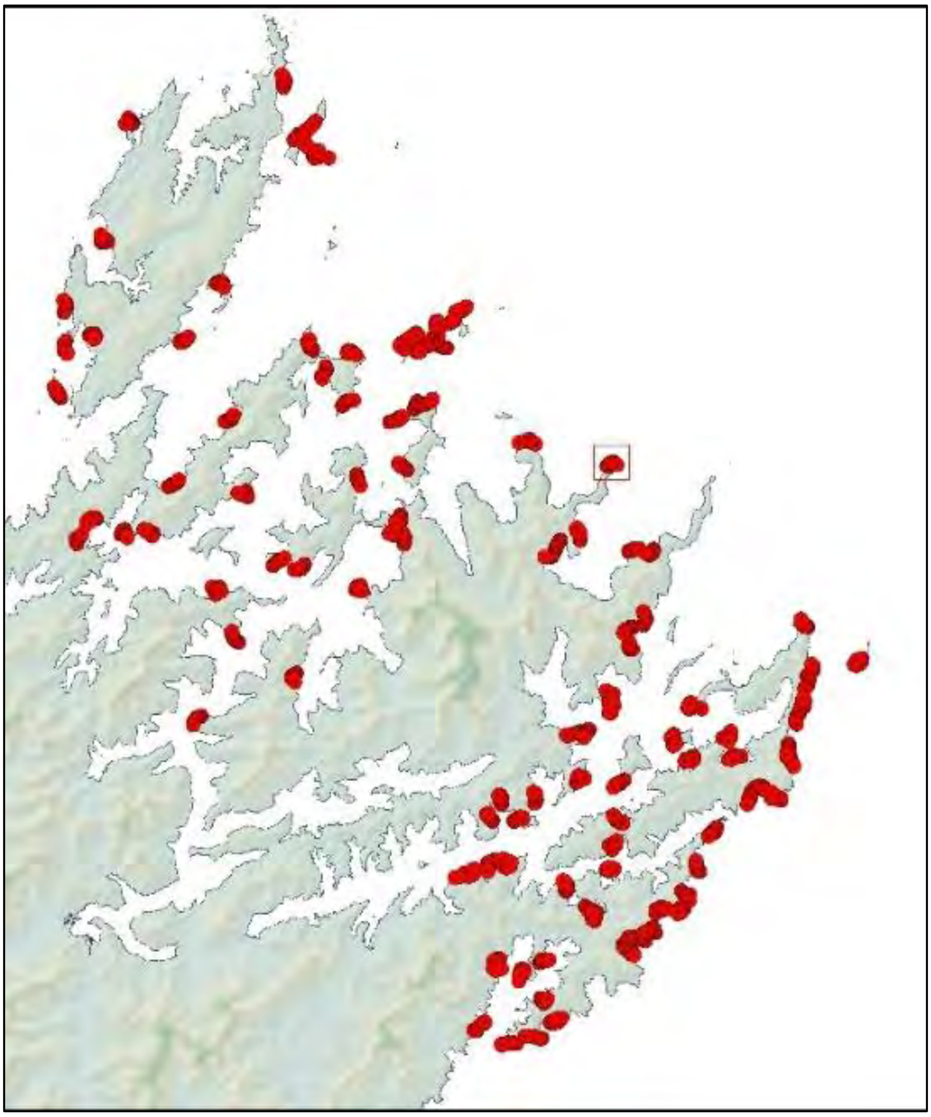


Figure 40: All pot sites (fixed and random) that were surveyed using multibeam echo-sounder in Marlborough Sounds in 2013. At each site the location of the nine pot stations is shown. The site in the box is fixed site 3E (western entrance to Port Gore), which was used in the following figures to illustrate habitat analyses that were carried out.

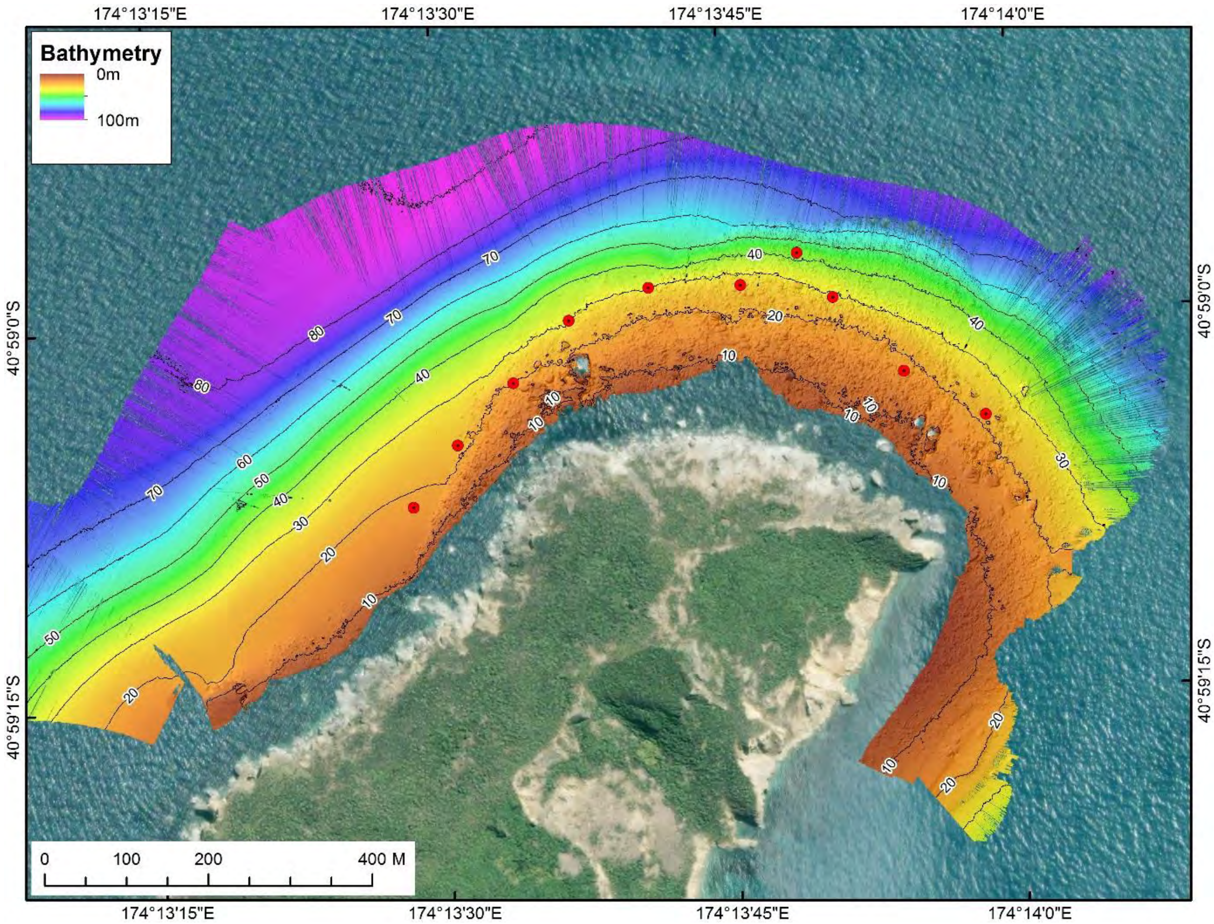


Figure 41: Bathymetry at fixed site 3E (western entrance to Port Gore) recorded from the multibeam echo-sounder on the 2013 Marlborough Sounds blue cod potting survey. The nine red dots in 30 m or less represent the pot location stations, and the outer red dot shows the location of the ADCP.

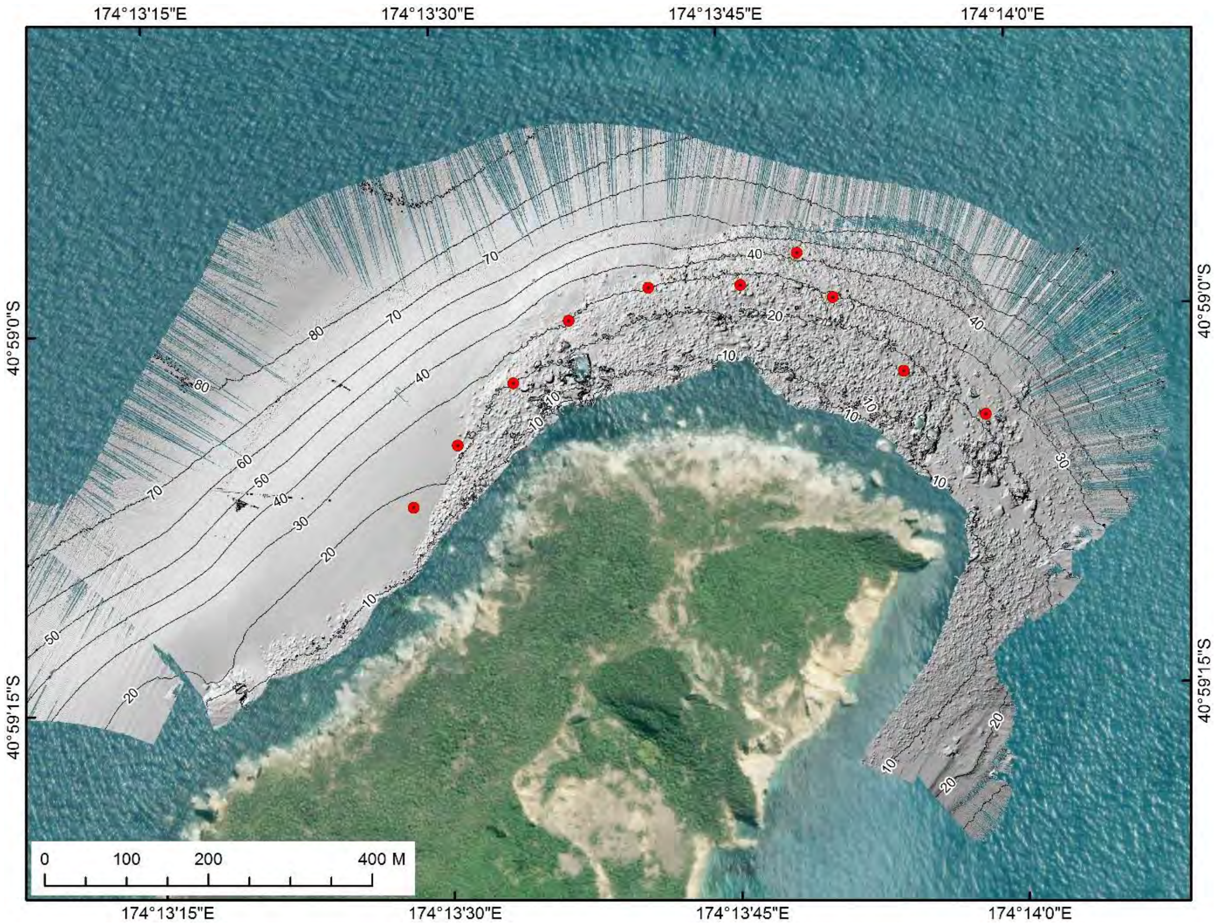


Figure 42: Hillshade map at fixed site 3E (western entrance to Port Gore) recorded from the multibeam echo-sounder on the 2013 Marlborough Sounds blue cod potting survey. The nine red dots in 30 m or less represent the pot location stations, and the outer red dot shows the location of the ADCP.

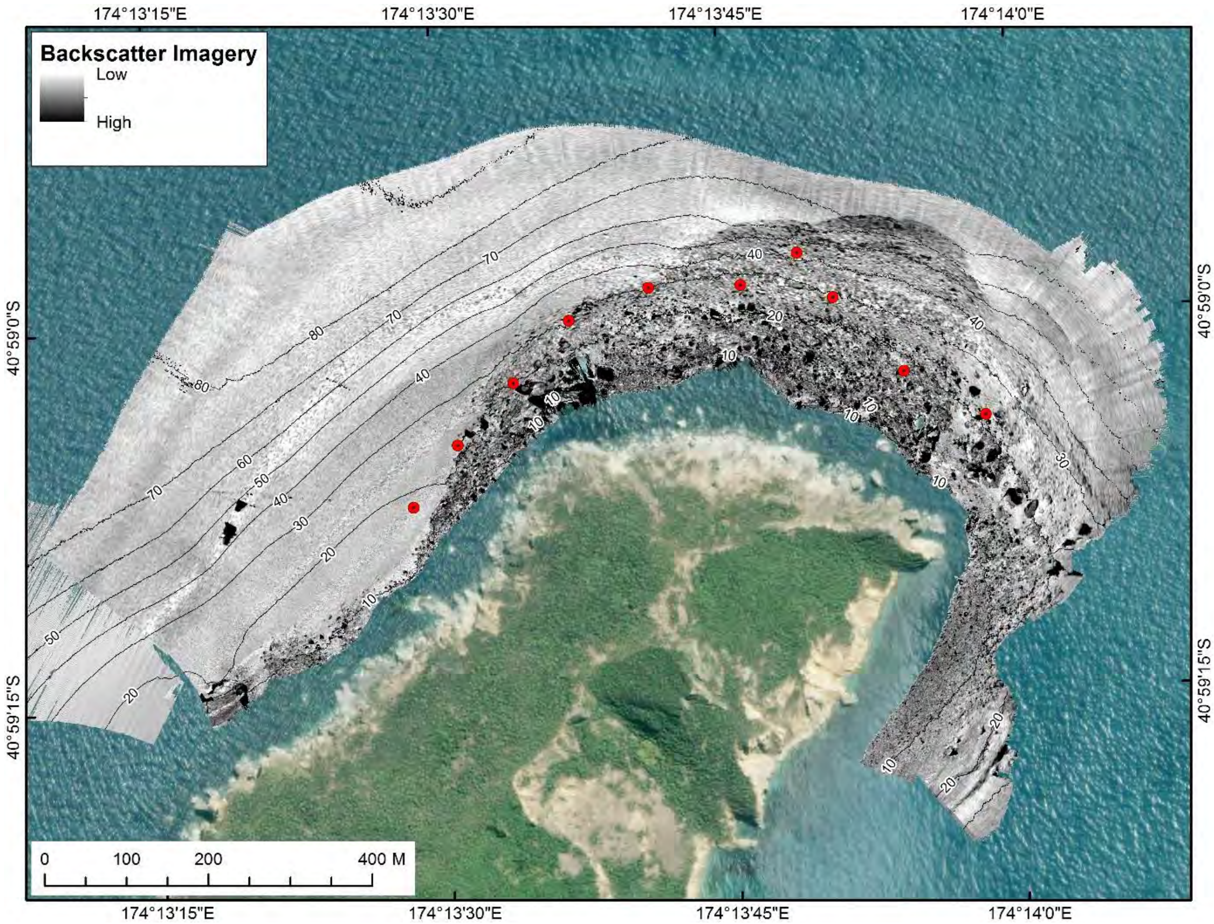


Figure 43: Backscatter map at fixed site 3E (western entrance to Port Gore) recorded from the multibeam echo-sounder on the 2013 Marlborough Sounds blue cod potting survey. High values usually indicate rock, gravel or compacted sediments, where low reflectivity indicates fine grained, soft sediments. The nine red dots in 30 m or less represent the pot location stations, and the outer red dot shows the location of the ADCP.

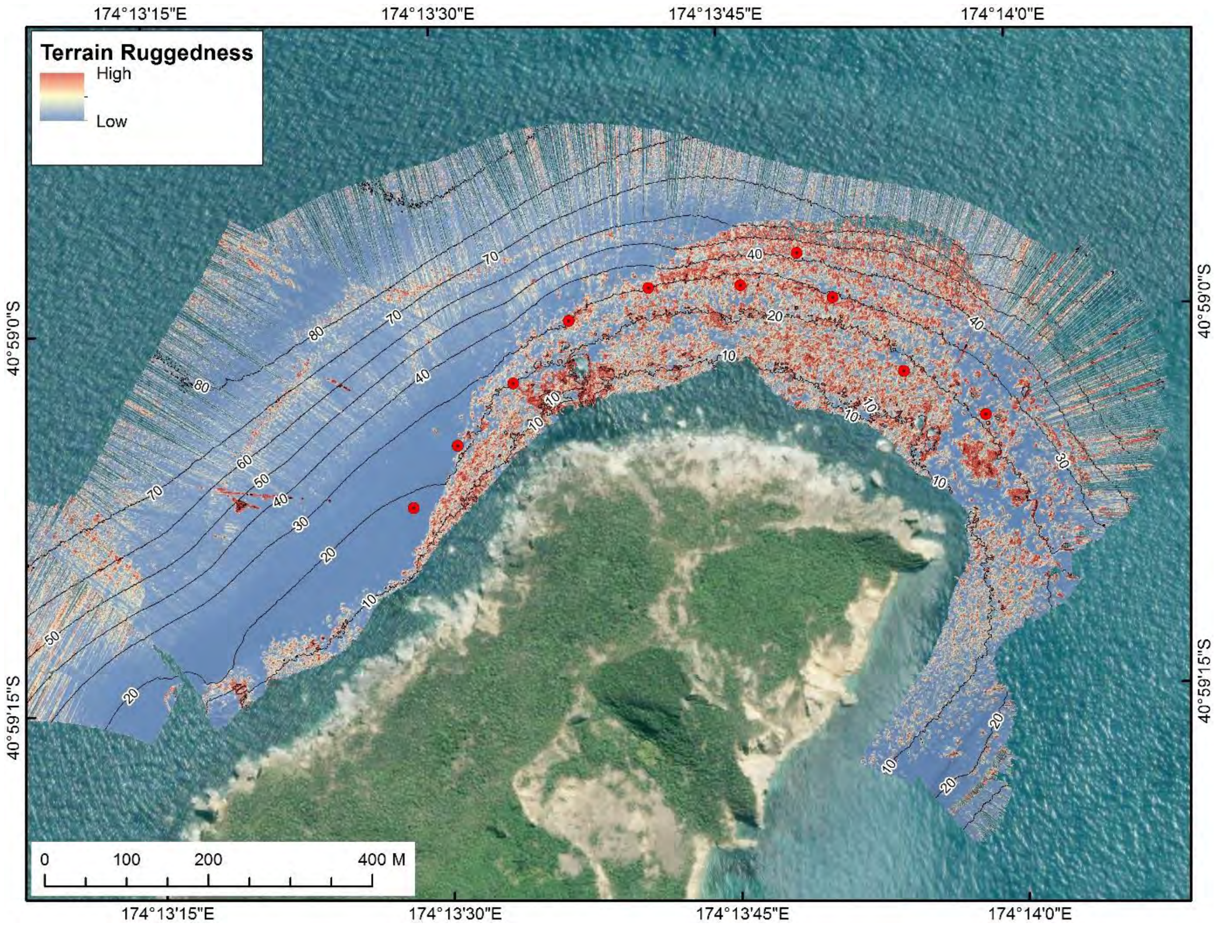


Figure 44: Terrain ruggedness (rugosity) map indicating the relation of actual surface area to the plan (flat) surface area of a given area at fixed site 3E (western entrance to Port Gore) recorded from the multibeam echo-sounder on the 2013 Marlborough Sounds blue cod potting survey. The nine red dots in 30 m or less represent the pot location stations, and the outer red dot shows the location of the ADCP.

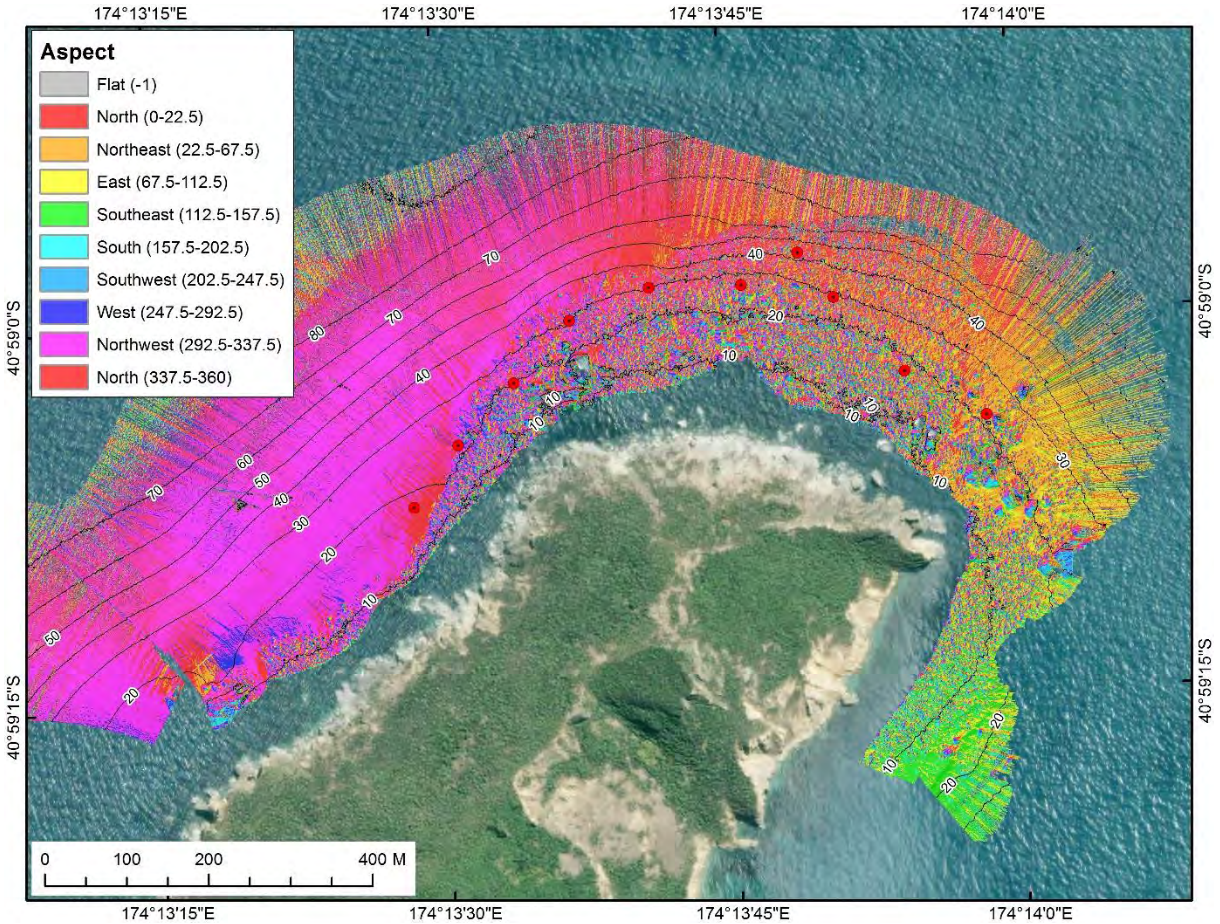


Figure 45: Aspect model in 22.5° segments showing the general direction of the seafloor slope at fixed site 3E (western entrance to Port Gore) recorded from the multibeam echo-sounder on the 2013 Marlborough Sounds blue cod potting survey. The nine red dots in 30 m or less represent the pot location stations, and the outer red dot shows the location of the ADCP.

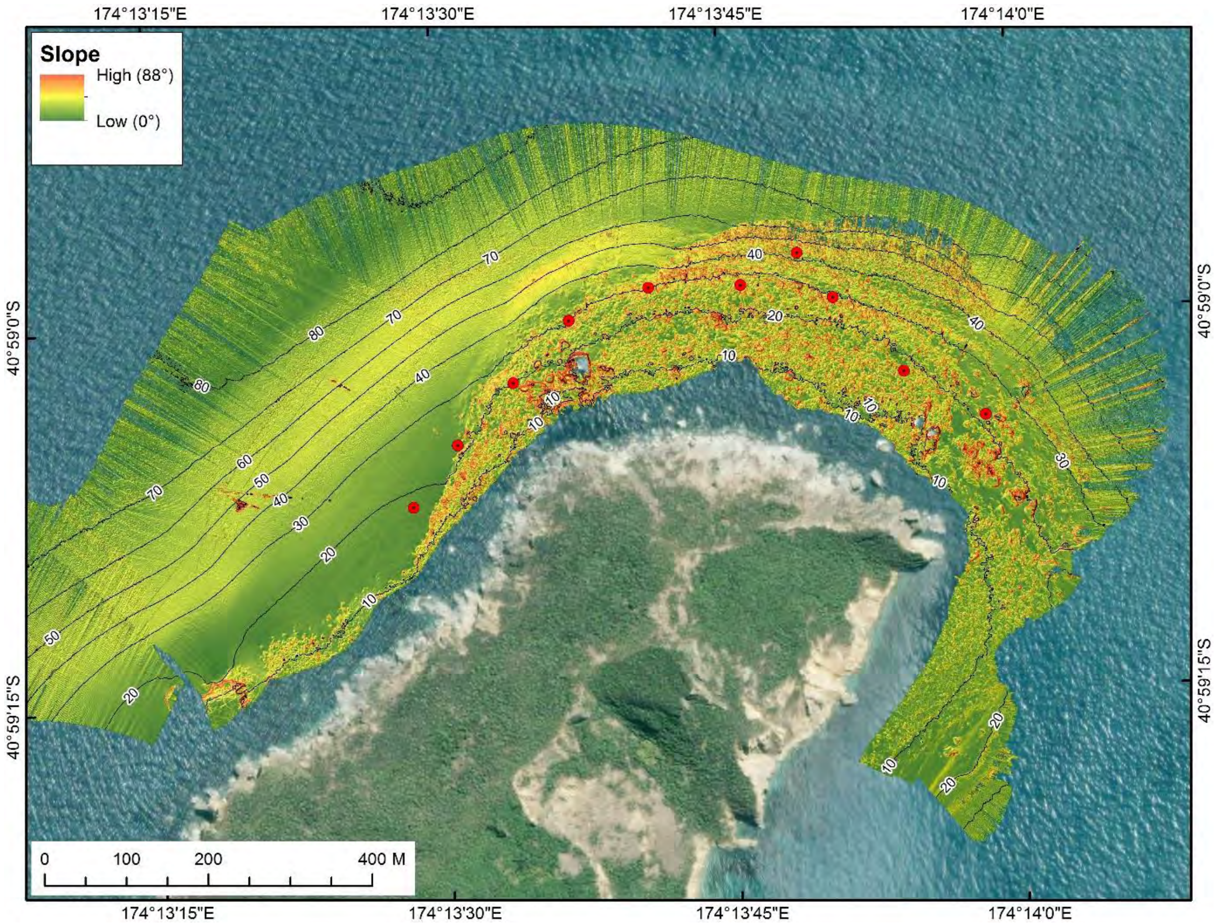


Figure 46: Slope model indicating slope in degrees at fixed site 3E (western entrance to Port Gore) recorded from the multibeam echo-sounder on the 2013 Marlborough Sounds blue cod potting survey. The nine red dots in 30 m or less represent the pot location stations, and the outer red dot shows the location of the ADCP.

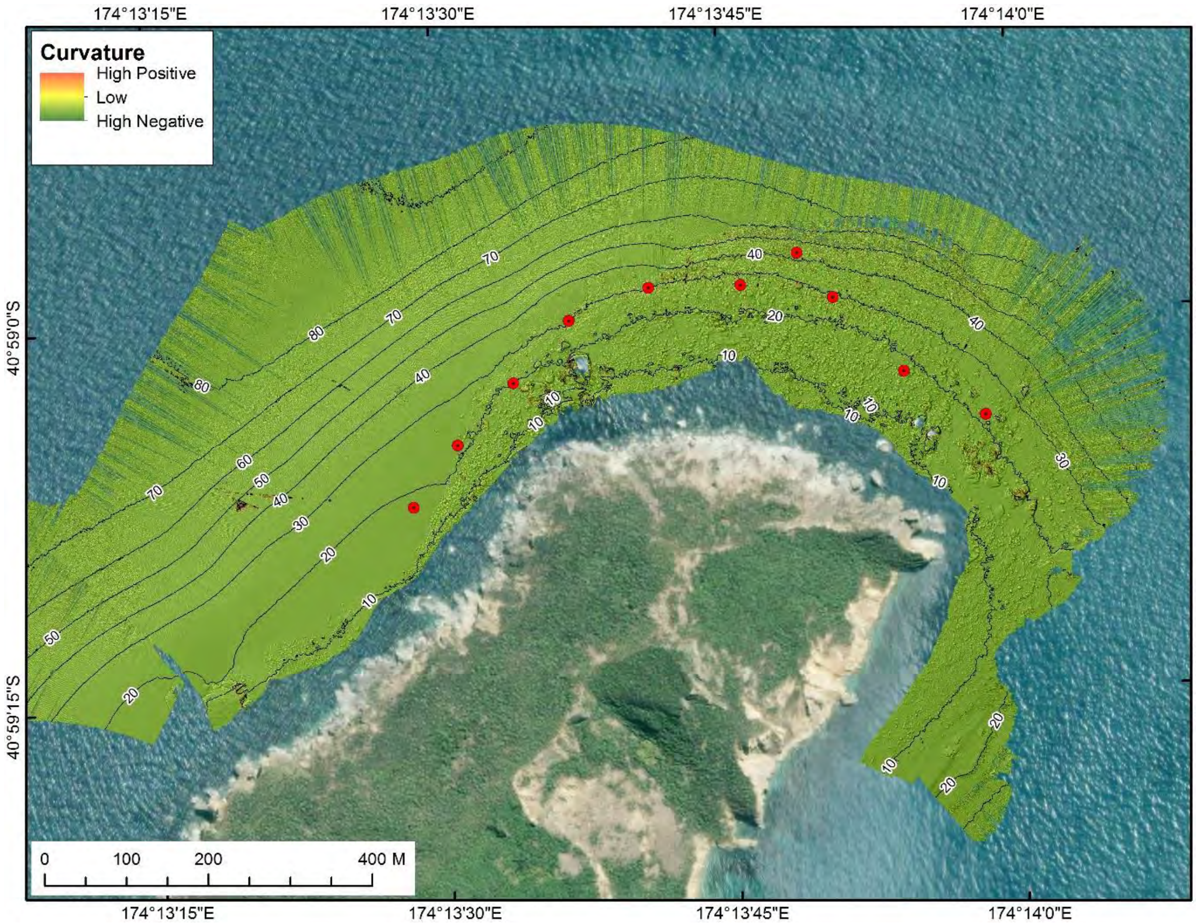


Figure 47: Curvature model indicating the change of slope at fixed site 3E (western entrance to Port Gore) recorded from the multibeam echo-sounder on the 2013 Marlborough Sounds blue cod potting survey. The nine red dots in 30 m or less represent the pot location stations, and the outer red dot shows the location of the ADCP.

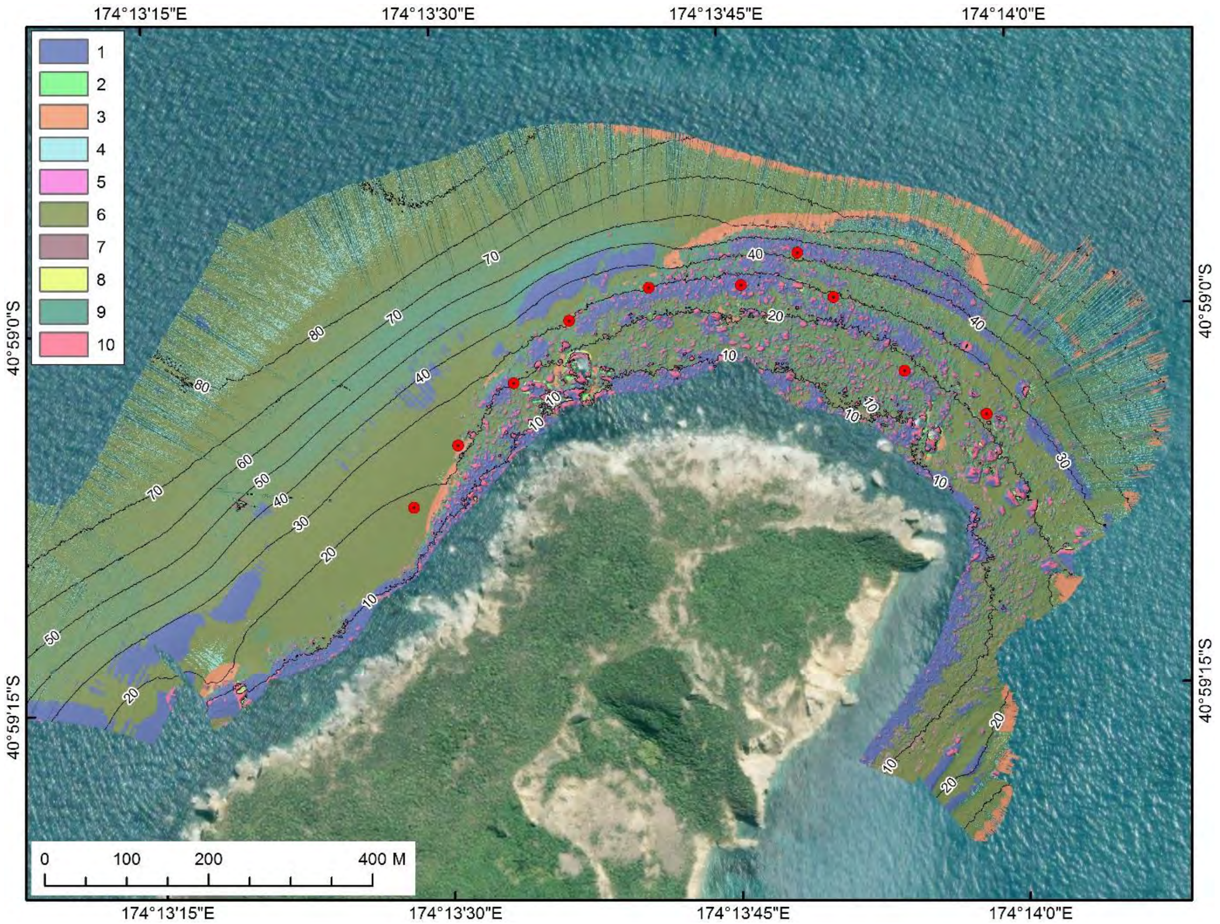


Figure 48: BTM classes map at fixed site 3E (western entrance to Port Gore) recorded from the multibeam echo-sounder on the 2013 Marlborough Sounds blue cod potting survey. The nine red dots in 30 m or less represent the pot location stations, and the outer red dot shows the location of the ADCP.

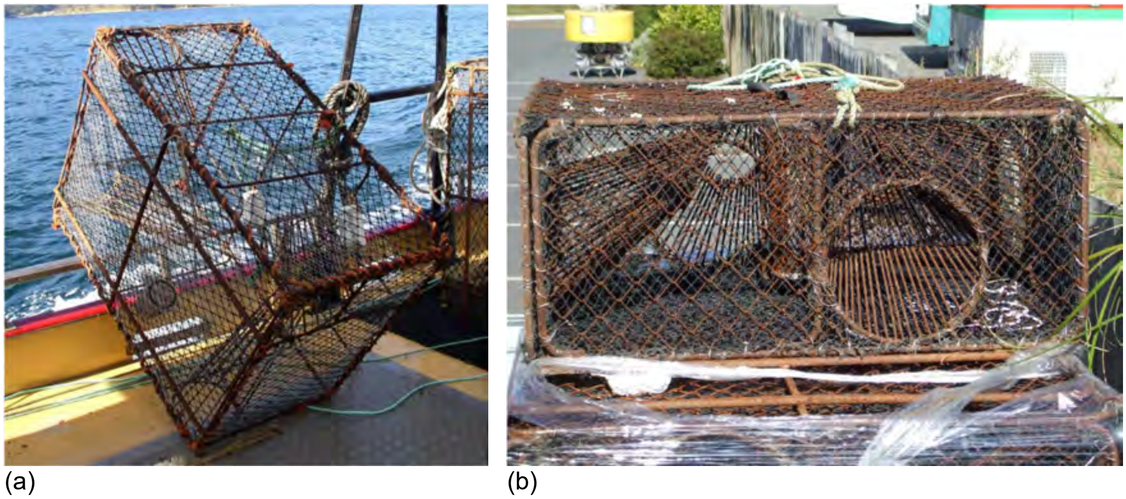


Figure 49: Photographs of (a) Pot Plan 1 from the Marlborough Sounds, and (b) Pot Plan 2 from other survey areas around the South Island. Photos are from Beentjes & Francis (2011).

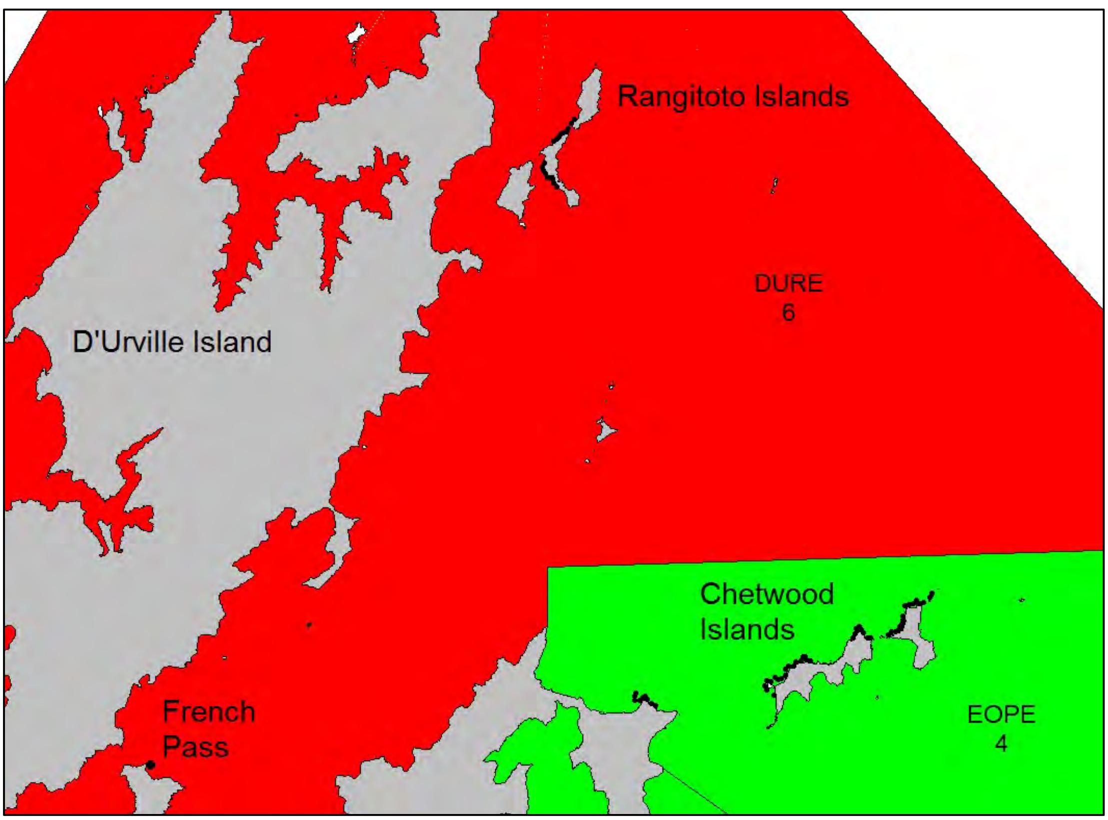


Figure 50: Locations of the 64 pots at eight sites used for the pot plan relative selectivity experiment. Dark circles show locations of individual pots. DURE, D'Urville Island east; EOPE, extreme outer Pelorus Sound.

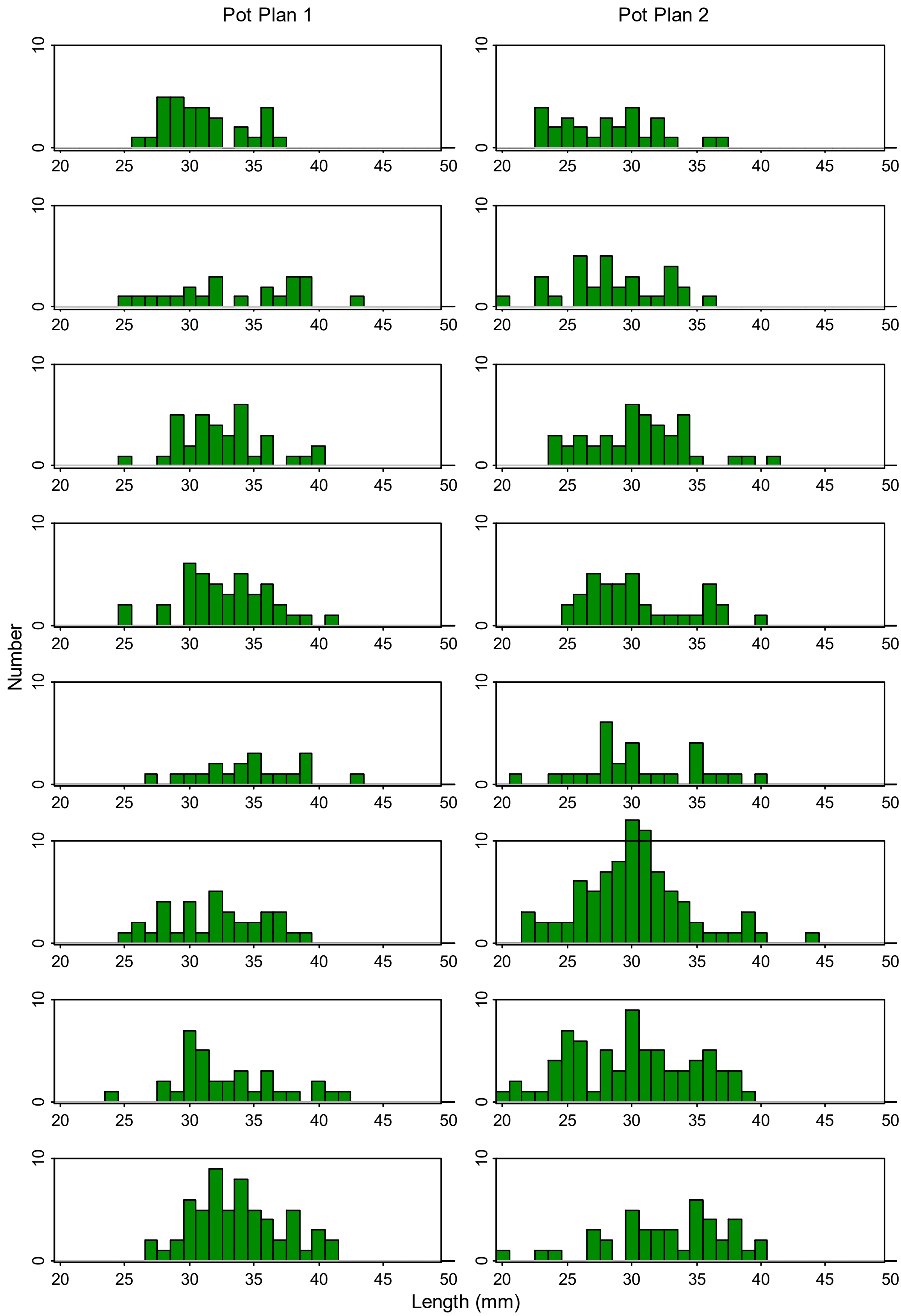


Figure 51: Length-frequency distribution of male blue cod for each pot plan and for each site fished.

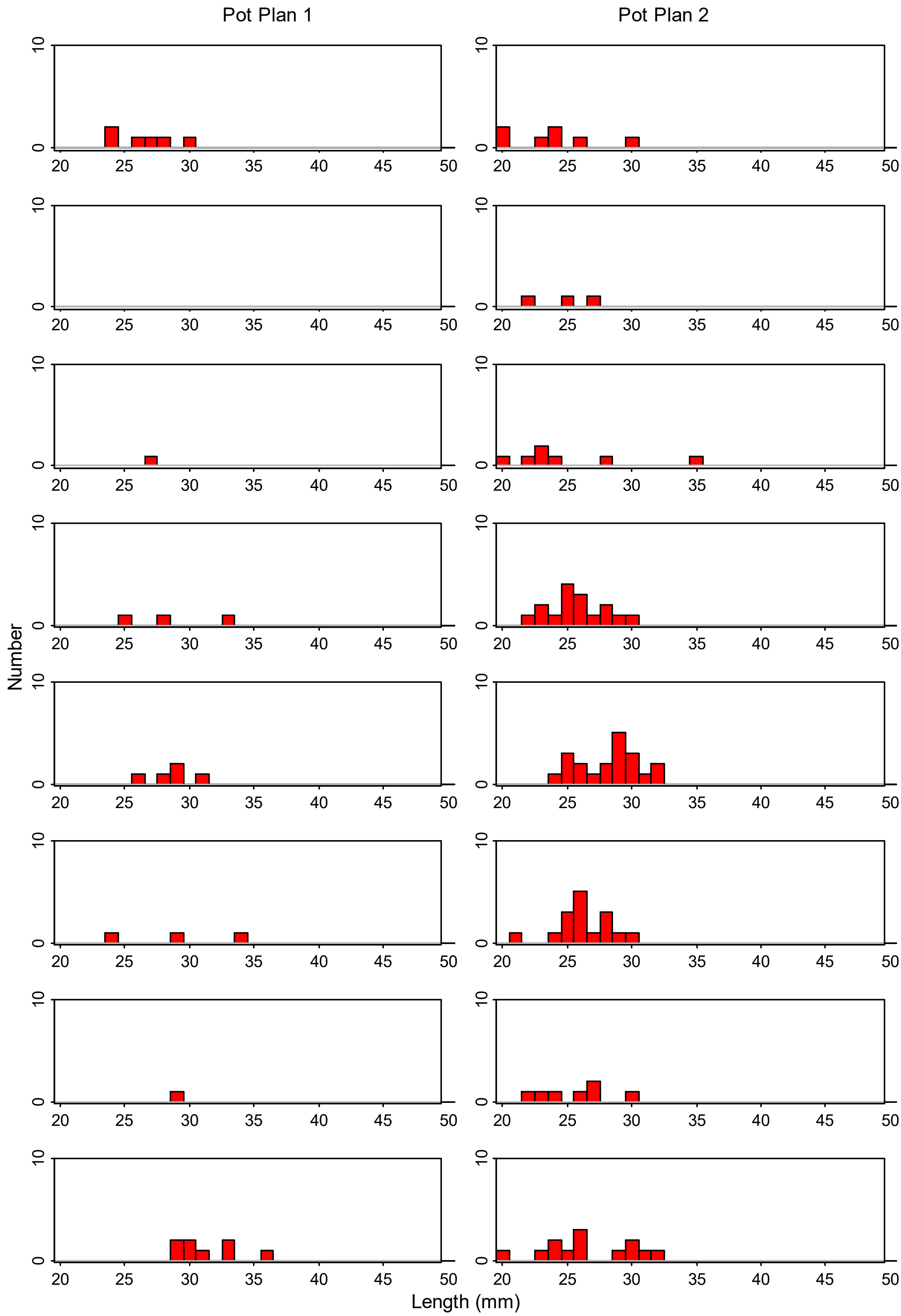


Figure 52: Length-frequency distribution of female blue cod for each pot plan and for each site fished.

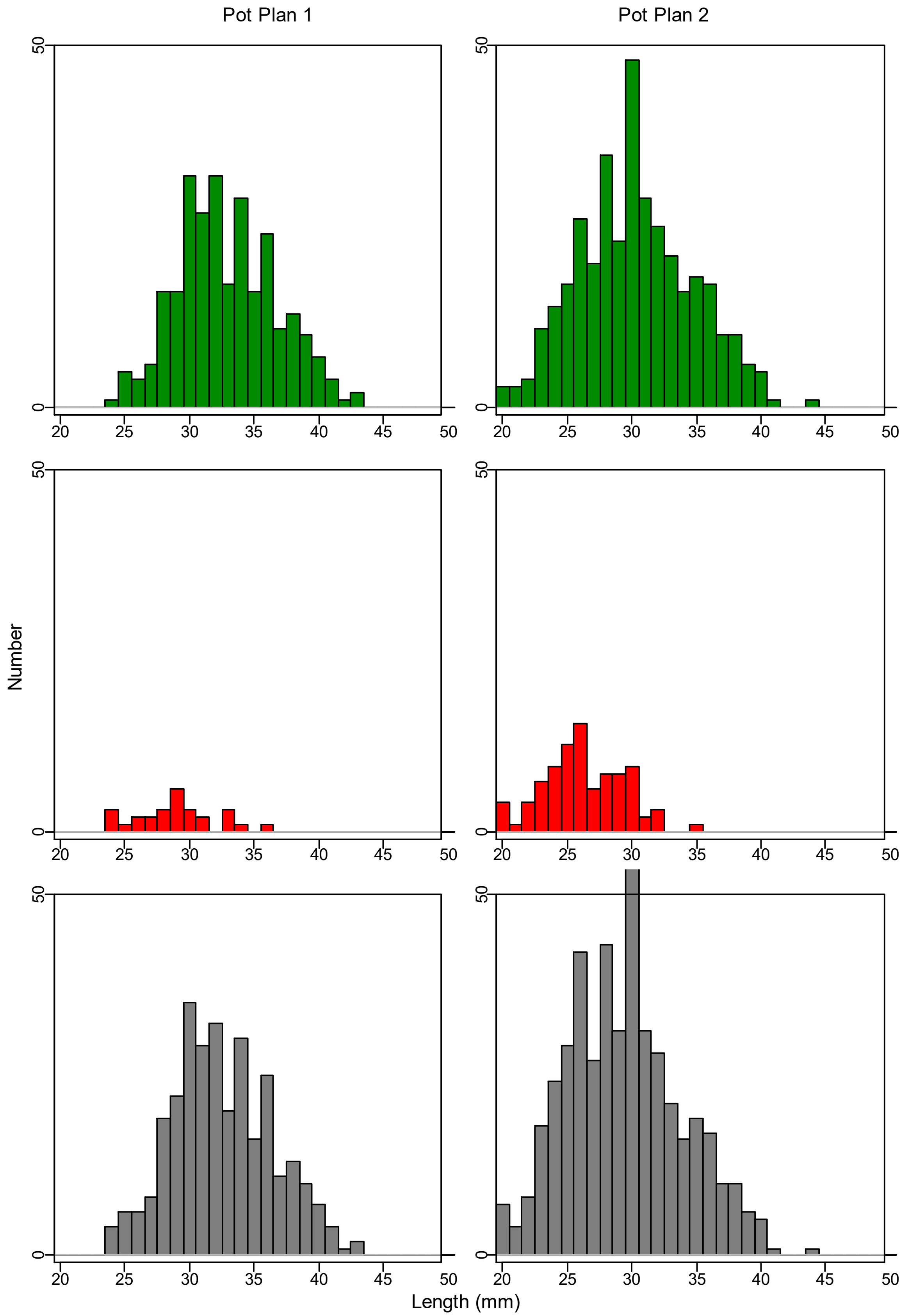


Figure 53: Pooled length-frequency distributions of male (top), female (middle), and combined (bottom) blue cod for combined catches from each pot plan.

a) b)

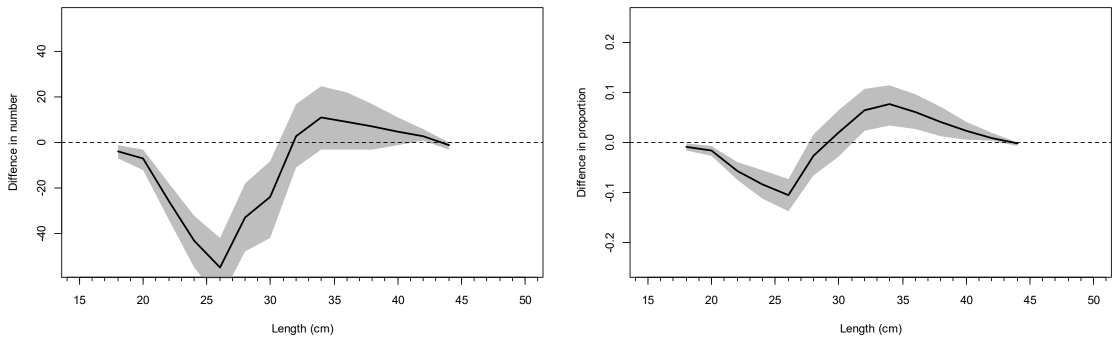


Figure 54: Relative selectivity by length in units of a) number and b) proportion of catch for pooled sexes between Pot Plan 1 and Pot Plan 2. The horizontal dashed line indicates a difference of zero. The black line indicates the mean relative selectivity, and the grey polygon indicates the 95% confidence interval of the difference, so lengths at which the polygon does not overlap the dashed horizontal line can be considered significantly different from zero. PP1 is more efficient above and PP2 below the dashed line.

a) b)

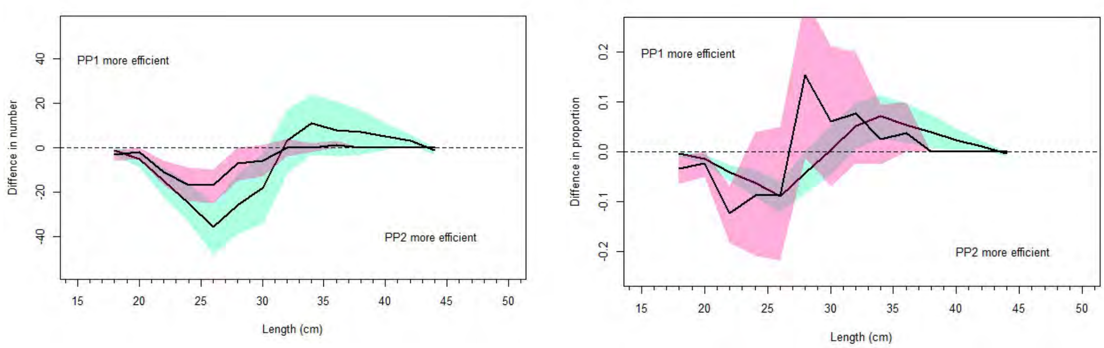


Figure 55: Relative selectivity by length for each sex in units of a) number and b) proportion of catch for pooled sexes between Pot Plan 1 and Pot Plan 2. The horizontal dashed line indicates a difference of zero. The black line indicates the mean relative selectivity, and the shaded polygons (pink = female, green = male) indicate the 95% confidence intervals of the differences, so lengths at which the polygons do not overlap each other can be considered significantly different from each other. PP1 is more efficient above and PP2 below the dashed line.

8. APPENDICES

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

Fixed site A site that has a fixed location (single latitude and longitude or the centre point location of a section of coastline) in a stratum and is available to be used repeatedly on subsequent surveys in that area. The fixed sites used in a particular survey are randomly selected from the list of all available fixed sites in each stratum. Fixed sites are sometimes referred to as index sites or fisher-defined sites and were defined at the start of the survey time series (using information from recreational and commercial fishers).

Pot number Pots are numbered sequentially (1 to 6 or 1 to 9) in the order they are placed during a set. In the Marlborough Sounds nine pots are used.

Pot placement There are two types of pot placement: **Directed –** the position of each pot is directed by the skipper using local knowledge and the vessel SONAR to locate a suitable area of reef/cobble or biogenic habitat. **Systematic –** the position of each pot is arranged systematically around the site or along the site for a section of coastline. For the former site, the position of the first pot is set 300 m to the north of the site location and remaining pots are set in a hexagon pattern around the site, at about 300 m from the site position.

Random site A site that has the location (single latitude and longitude) generated randomly within a stratum, given the constraints of proximity to other selected sites for a specific survey.

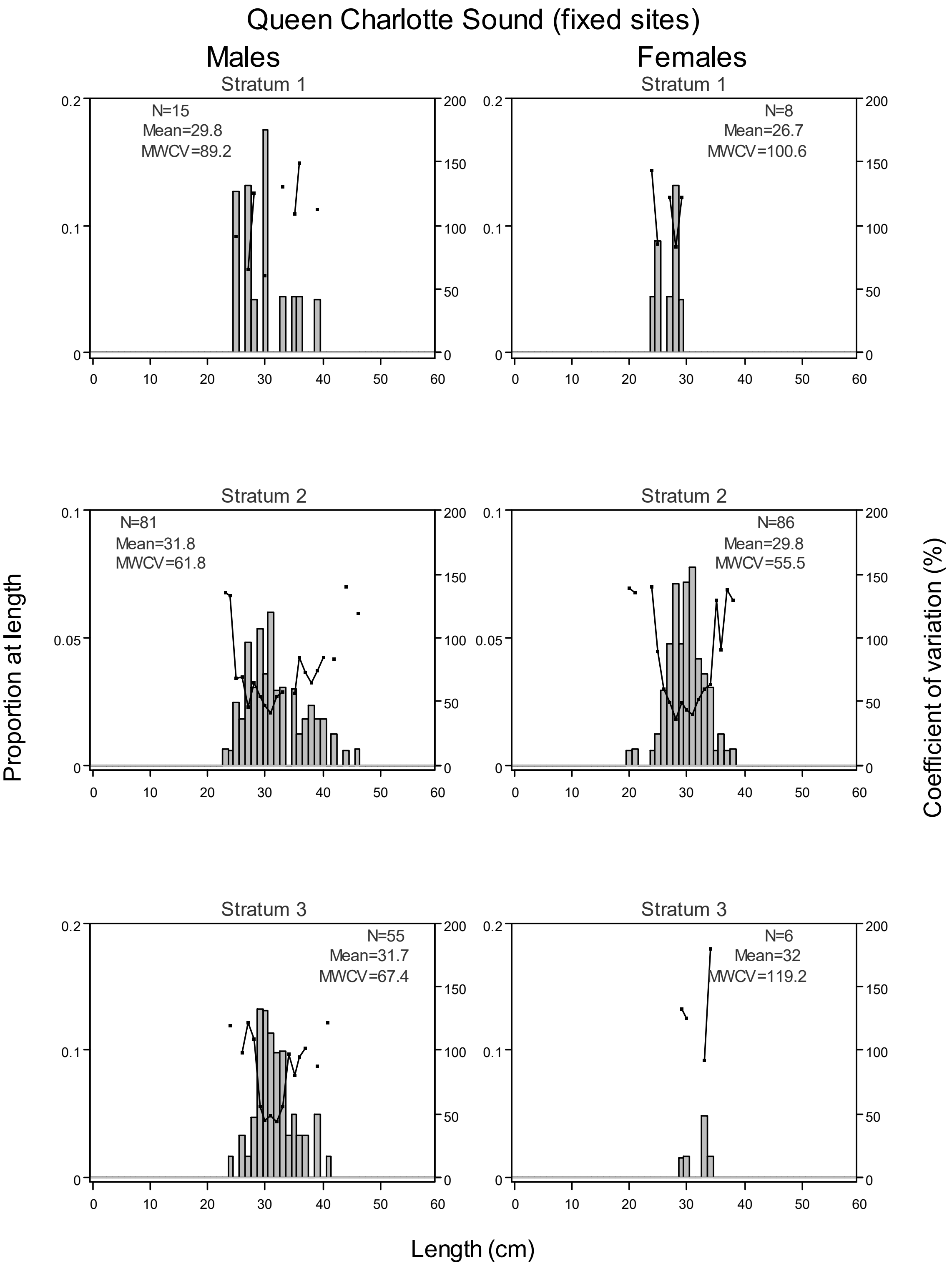
Site A geographical location near to which sampling may take place during a survey. A site may be either fixed or random (see below). A site may be specified as a latitude and longitude or a section of coastline (for the latter, use the latitude and longitude at the centre of the section).

Site label An alphanumeric label of no more than four characters, unique within a survey time series. A site label identifies each fixed site and also specifies which stratum it lies in. Site labels are constructed by concatenating the stratum code with an alpha label (A–Z) that is unique within that stratum. Thus, sites within stratum 2 could be labelled 2A, 2B, and sites in stratum 3 could be labelled 3A, 3B, etc. Site labels for random sites are constructed in the same way but prefixed with R (e.g., R4A, R4B, etc.).

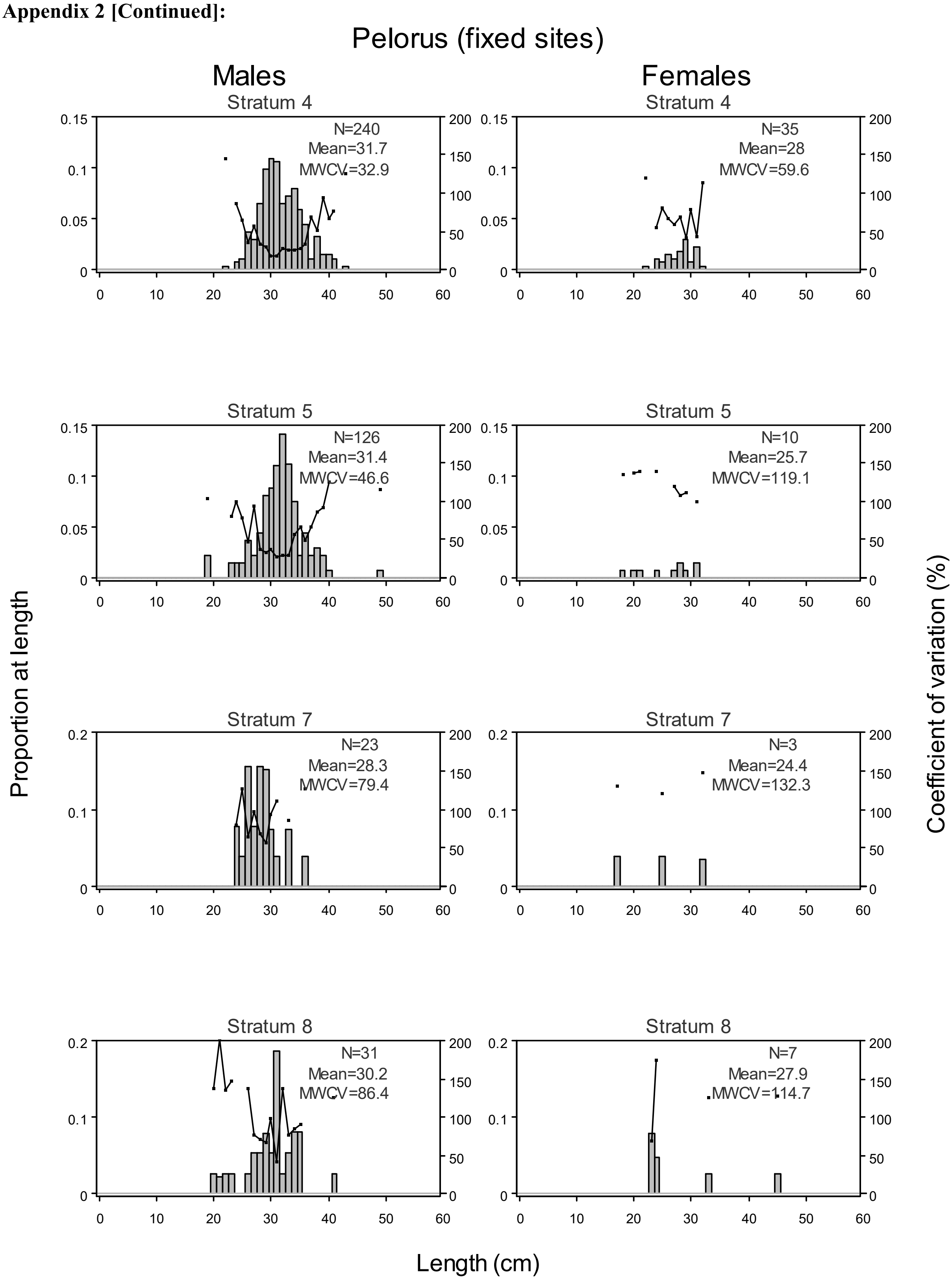
Station The position (latitude and longitude) at which a single pot (or other fishing gear such as ADCP) is deployed at a site during a survey, i.e., it is unique for the trip.

Station number A number that uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be *station_no* 234. This convention is important in enabling users of the *trawl* database to determine whether two pots are from the same set. Note that the set numbers for potting surveys are not recorded anywhere else in the *trawl* database.

Appendix 2: Raw length-frequency distributions of blue cod for each stratum in the 2013 fixed-site potting survey of Queen Charlotte Sound, Pelorus Sound and D'Urville Island. Stratum 1, IQCH; stratum 2, OQCH; stratum 3, EQCH; stratum 4, EOPE; stratum 5, OPEL; stratum 7, IPEL; stratum 8, MPEL; stratum 6, DURW; stratum 9, DURE; MWCV, mean weighted coefficient of variation. [Continued on next pages]



Appendix 2 [Continued]:



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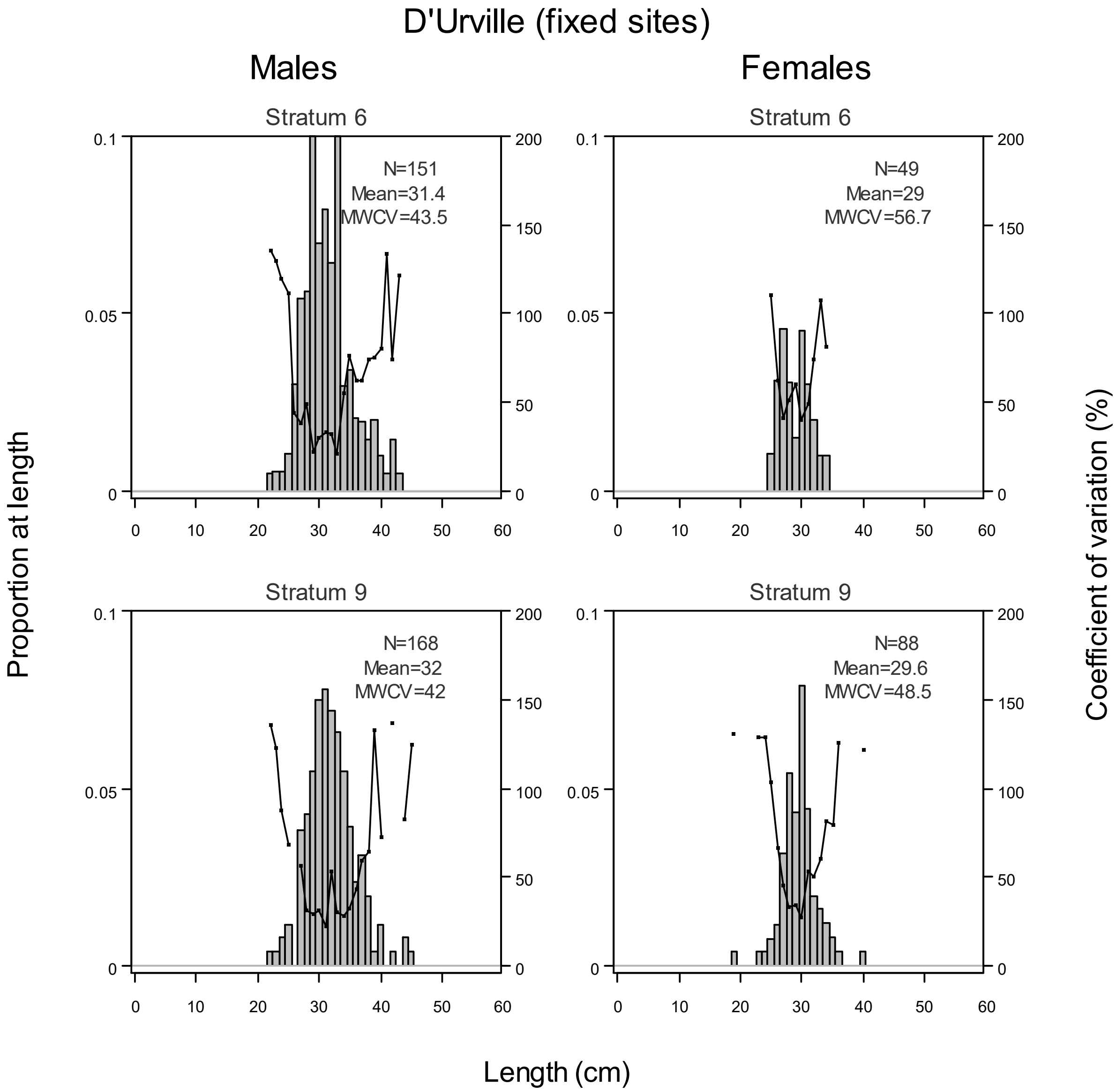


Appendix 3: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod for fixed- and random-site potting surveys from each region surveyed in the 2013 Marlborough Sounds. AgeR, age at full recruitment. **[Continued on next page]**

					Fixed-site survey
Region	Site type	ageR	*Z*	lowerCI	upperCI
QCH	Fixed	5	0.34	0.23	0.45
		6	0.33	0.23	0.45
		7	0.37	0.26	0.52
		8	0.36	0.25	0.49
		9	0.36	0.24	0.51
		10	0.46	0.30	0.66
PEL	Fixed	5	0.63	0.43	0.89
		6	0.63	0.42	0.87
		7	0.75	0.48	1.11
		8	0.62	0.37	0.96
		9	0.45	0.25	0.71
		10	0.55	0.3	0.87
DUR	Fixed	5	0.52	0.36	0.72
		6	0.64	0.44	0.86
		7	0.87	0.59	1.23
		8	0.7	0.44	1.04
		9	0.79	0.46	1.23
		10	0.52	0.30	0.83
					Random-site survey
Region	Site type	ageR	*Z*	lowerCI	upperCI
QCH	Random	5	0.33	0.22	0.45
		6	0.35	0.25	0.48
		7	0.40	0.28	0.54
		8	0.39	0.27	0.52
		9	0.38	0.25	0.53
PEL	Random	5	0.46	0.32	0.64
		6	0.52	0.35	0.72
		7	0.70	0.44	1.01
		8	0.56	0.34	0.84
		9	0.48	0.26	0.76
		10	0.66	0.31	1.16
DUR	Random	5	0.44	0.30	0.62
		6	0.54	0.37	0.75
		7	0.70	0.46	0.98
		8	0.59	0.37	0.88
		9	0.58	0.36	0.87
		10	0.52	0.30	0.79

Appendix 3 [Continued]:

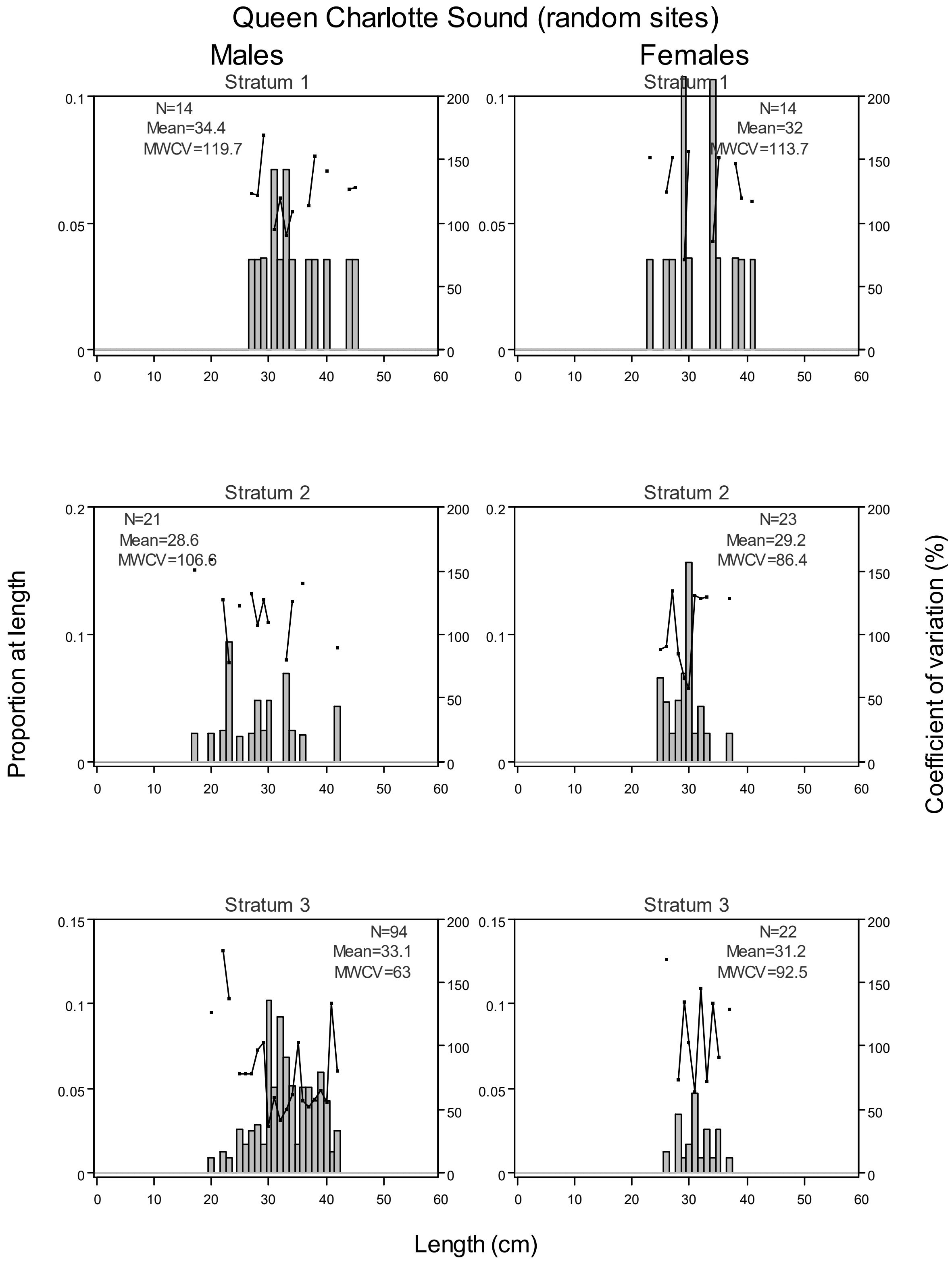
		Random-site survey			
Region	Site type	ageR	*Z*	lowerCI	upperCI
CKST	Random	5	0.71	0.48	0.99
		6	0.74	0.47	1.09
		7	0.62	0.37	0.99
		8	0.51	0.27	0.86
		9	0.49	0.26	0.85
		10	0.66	0.31	1.16

Appendix 4: Mortality parameters (*Z*, *F* and *M*) and spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* for blue cod from fixed- and random-site potting surveys from each region surveyed in the 2013 Marlborough Sounds. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality. AgeR = 6.

	Fixed-site survey				
Region	Site type	*M*	*Z*	*F*	$F_{\%SPR}$
QCH	Fixed	0.11	0.37	0.26	$F_{28.8\%}$
		0.14	0.37	0.23	$F_{37.1\%}$
		0.17	0.37	0.2	$F_{45.3\%}$
PEL	Fixed	0.11	0.75	0.64	$F_{15.8\%}$
		0.14	0.75	0.61	$F_{20.2\%}$
		0.17	0.75	0.58	$F_{24.7\%}$
DUR	Fixed	0.11	0.87	0.76	$F_{14.2\%}$
		0.14	0.87	0.73	$F_{18.2\%}$
		0.17	0.87	0.7	$F_{22.3\%}$

	Random-site survey				
Region	Site type	*M*	*Z*	*F*	$F_{\%SPR}$
QCH	Random	0.11	0.40	0.29	$F_{26.8\%}$
		0.14	0.40	0.26	$F_{34.3\%}$
		0.17	0.40	0.23	$F_{42.2\%}$
PEL	Random	0.11	0.7	0.59	$F_{16.6\%}$
		0.14	0.7	0.56	$F_{21.3\%}$
		0.17	0.7	0.53	$F_{26.0\%}$
DUR	Random	0.11	0.7	0.59	$F_{16.6\%}$
		0.14	0.7	0.56	$F_{21.3\%}$
		0.17	0.7	0.53	$F_{26.0\%}$
CKST	Random	0.11	0.62	0.51	$F_{18.3\%}$
		0.14	0.62	0.48	$F_{23.4\%}$
		0.17	0.62	0.45	$F_{28.6\%}$

Appendix 5: Raw length-frequency distributions of blue cod for each stratum in the 2013 random-site potting survey of Queen Charlotte Sound, Pelorus Sound, D'Urville and Cook Strait. Stratum 1, IQCH; stratum 2, OQCH; stratum 3, EQCH; stratum 4, EOPE; stratum 5, OPEL; stratum 7, IPEL; stratum 8, MPEL; stratum 6, DURW; stratum 9, DURE; stratum 11, APAE; stratum 12, COOK; stratum 13, UNDW; MWCV, mean weighted coefficient of variation. [Continued on next pages]



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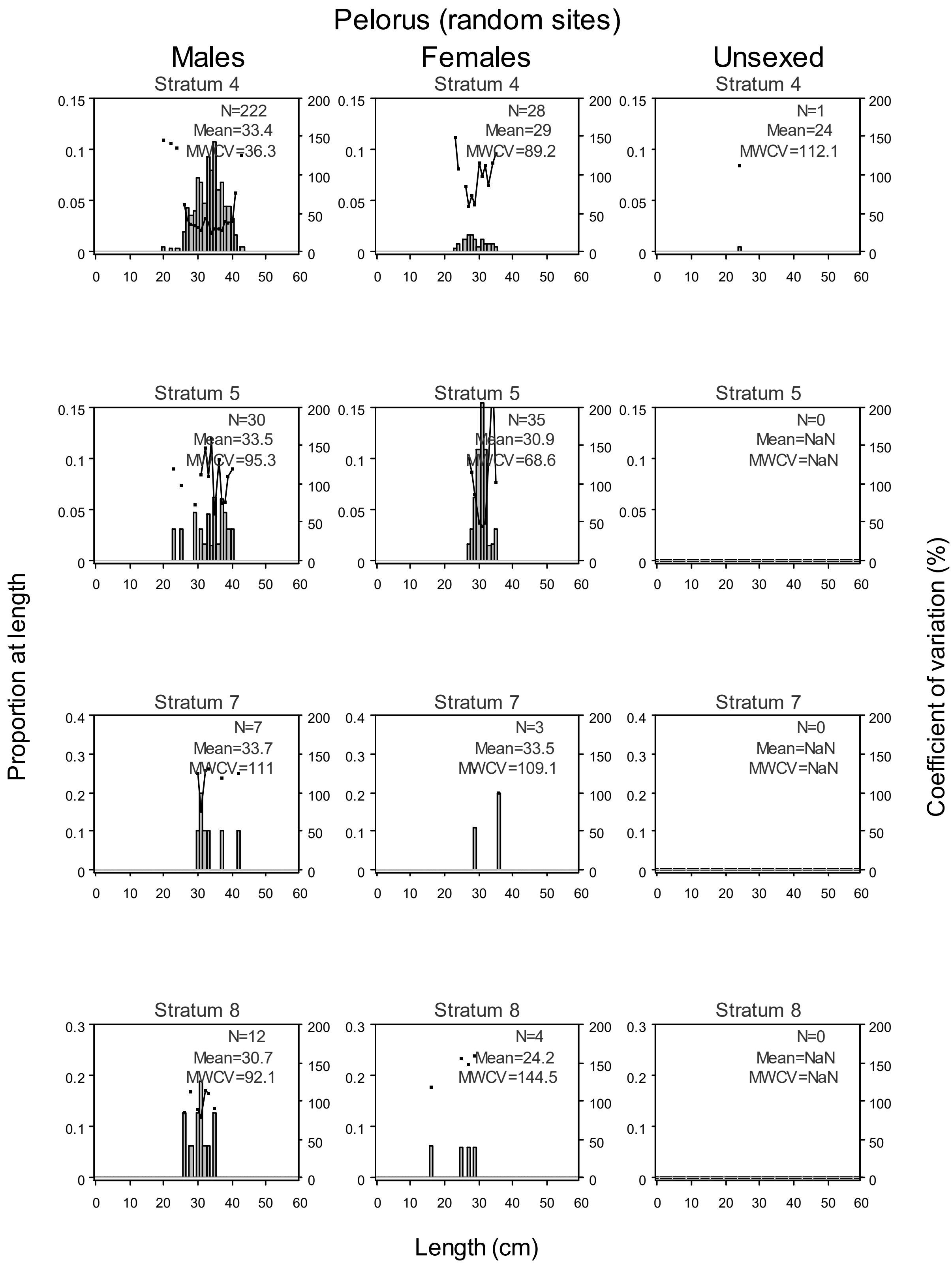
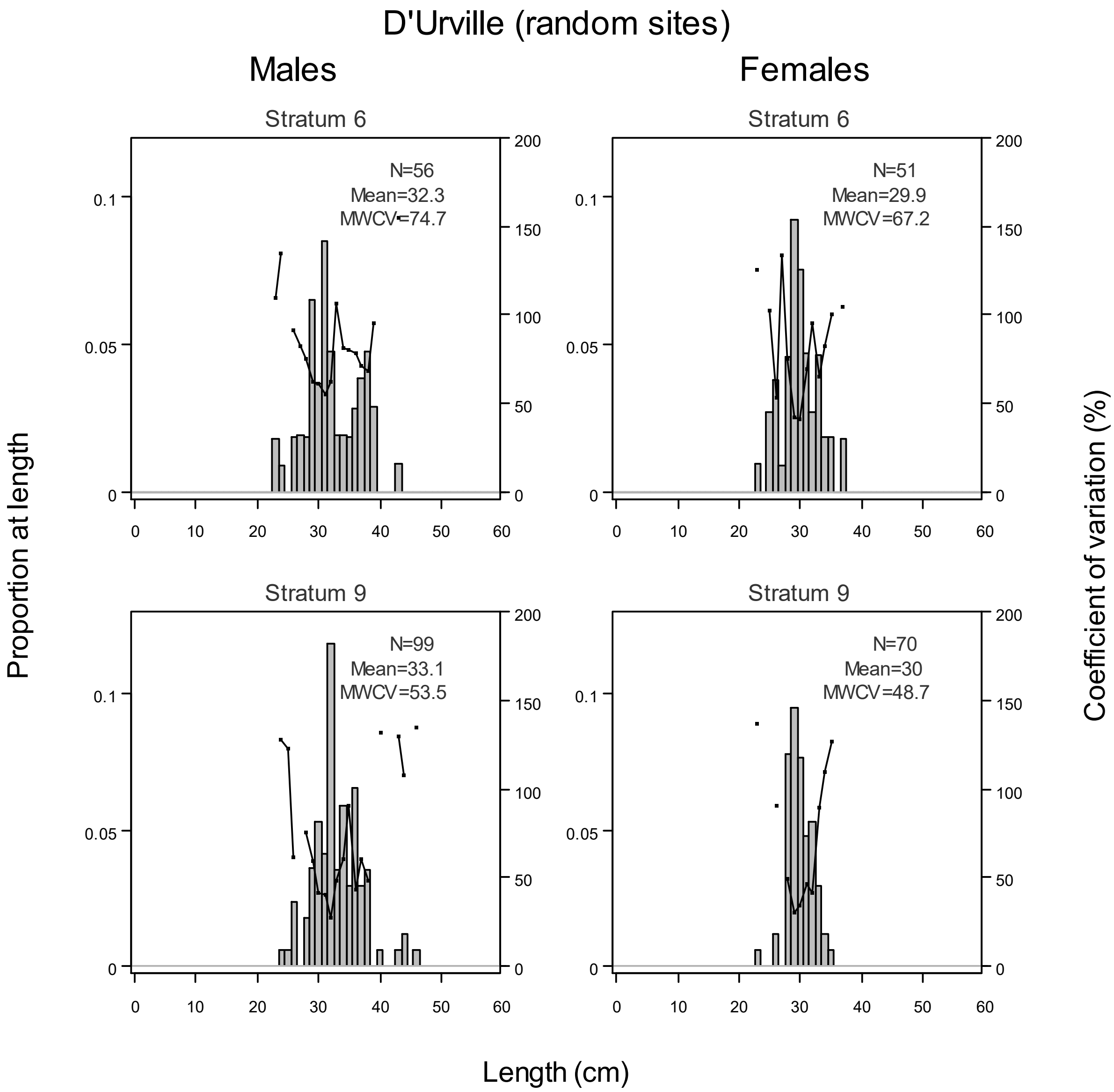
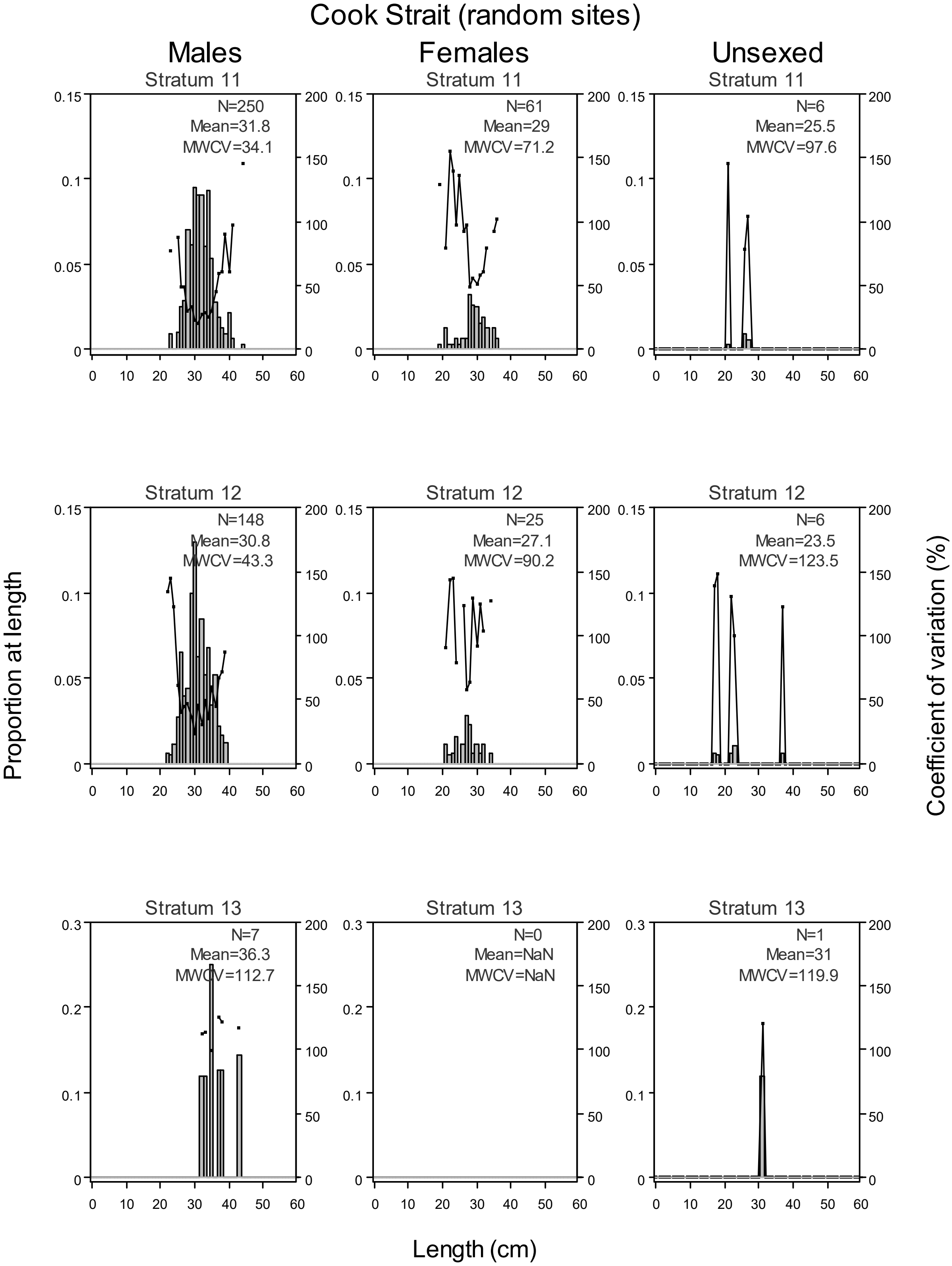


Appendix 5 [Continued]:



Appendix 5 [Continued]:



Appendix 6: Re-analysis of the Marlborough Sounds blue cod potting survey effort and catch summary by site type from the 1995 and 1996 surveys. All results determined as part of the 2013 survey analyses.

1995 survey (trip code lhr9501)

Region	Stratum	Stratum code	Area (km coastline)	Site type	*N* sets (sites)	*N* pots (stations)	No. blue cod	Catch (kg)
QCH	1	IQCH	43.2	Fixed	4	36	51	27
QCH	2	OQCH	176.6	Fixed	4	36	181	74
QCH	3	EQCH	83.1	Fixed	4	36	227	105
PEL	4	EOPE	69.5	Fixed	4	36	298	124
PEL	5	OPEL	94.8	Fixed	4	36	281	105
Totals					20	180	1 038	435

1996 survey (trip code lhr9601)

Region	Stratum	Stratum code	Area (km coastline)	Site type	*N* sets (sites)	*N* pots (stations)	No. blue cod	Catch (kg)
PEL	4	EOPE	69.5	Fixed	4	36	216	102
PEL	5	OPEL	94.8	Fixed	4	36	306	117
DUR	6	DURE	105.1	Fixed	4	36	750	342
PEL	7	IPEL	100.1	Fixed	4	36	99	35
PEL	8	MPEL	72.3	Fixed	4	36	283	98
Totals					20	180	1 654	694

Appendix 7: Re-analysis of the mean blue cod catch rates for all blue cod caught from the 1995 and 1996 Marlborough Sounds potting surveys by strata and overall. Catch rates were estimated as part of the 2013 survey analyses. Catch rates are pot based, and s.e. and CV are set-based. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville.

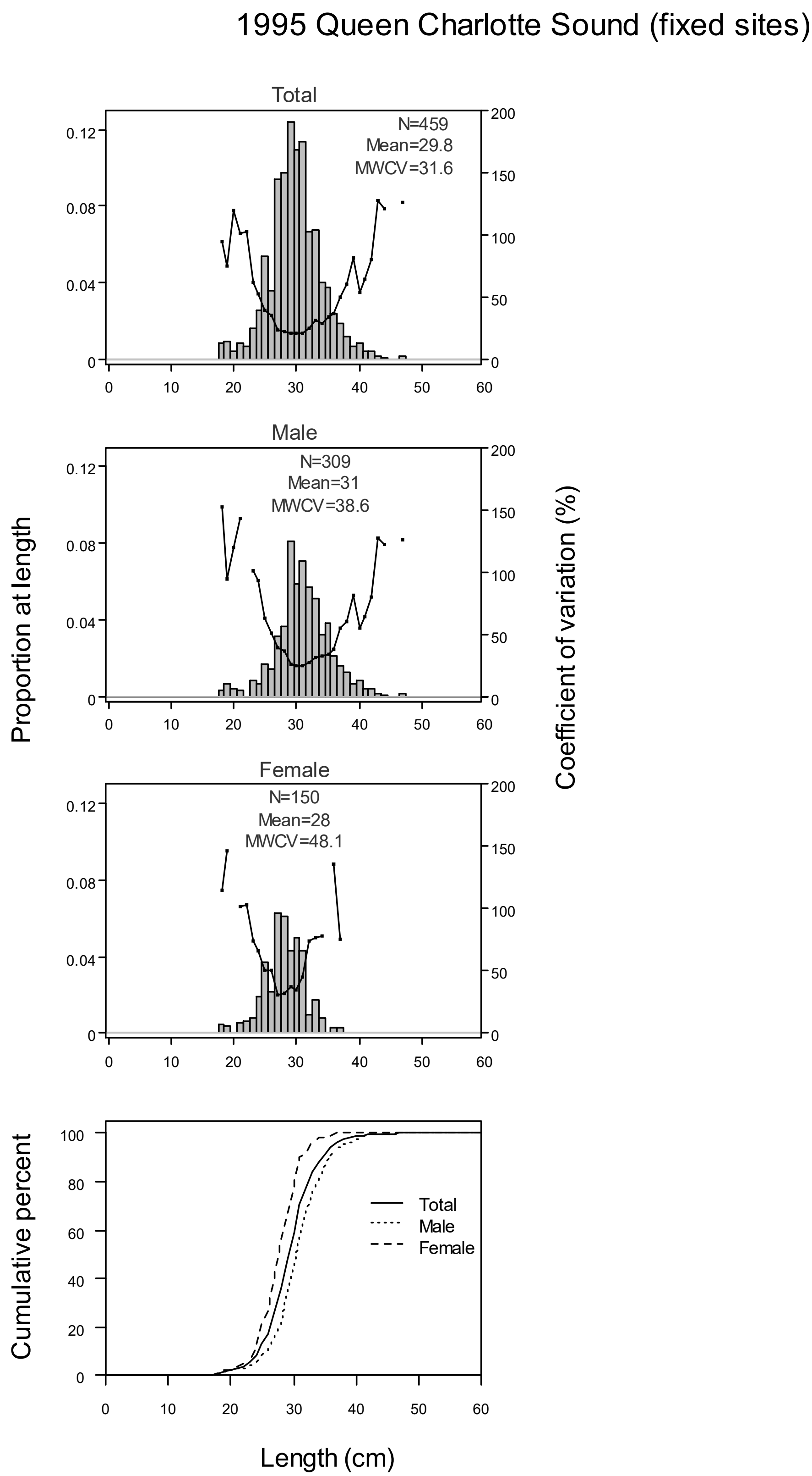
1995 survey (trip code lhr9501)

Region	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)
All strata						
QCH	1	Fixed	36	0.74	0.24	31.6
QCH	2	Fixed	36	2.04	0.35	17.1
QCH	3	Fixed	36	2.91	0.59	20.2
	Overall	Fixed	108	2.10	0.26	12.5
PEL	4	Fixed	36	3.5	0.20	5.7
PEL	5	Fixed	36	2.9	1.05	35.8
	Overall	Fixed	72	3.1	0.61	19.4

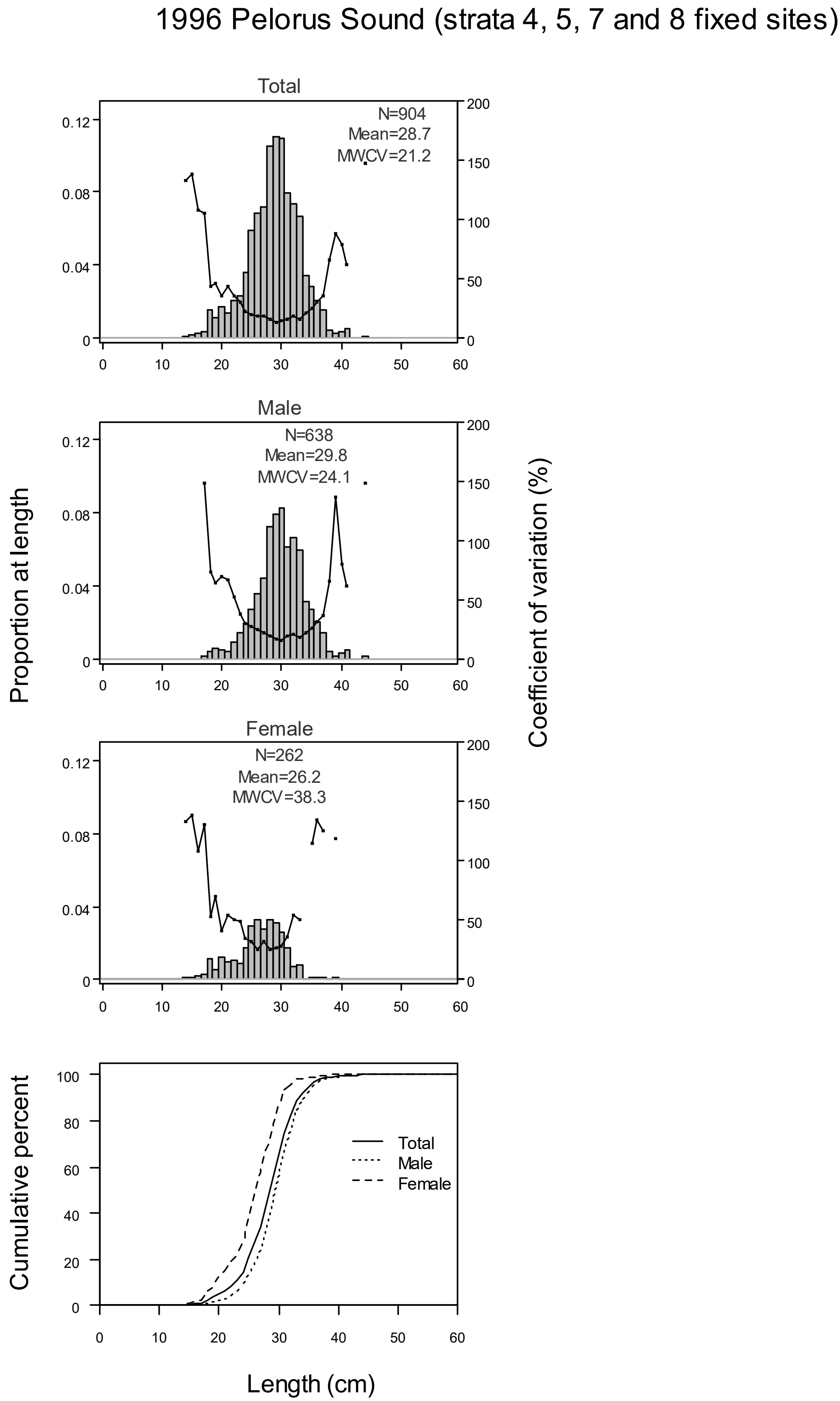
1996 survey (trip code lhr9601)

Region	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	CV (%)
All strata						
PEL	4	Fixed	36	2.8	0.41	14.6
PEL	5	Fixed	36	3.3	0.32	10.0
PEL	7	Fixed	36	1.0	0.26	26.8
PEL	8	Fixed	36	2.7	0.29	10.7
	Overall	Fixed	144	2.4	0.16	6.7
DUR	6	Fixed	36	9.50	0.58	6.1
	Overall	Fixed	36	9.50	0.58	6.1

Appendix 8: Scaled length-frequency, and cumulative distributions for total, male, and female blue cod for all strata (1 to 3) combined in Queen Charlotte Sound (fixed sites) for the 1995 Marlborough Sounds potting survey. N, sample size; MWCV, mean weighted coefficient of variation.



Appendix 9: Scaled length-frequency, and cumulative distributions for total, male, and female blue cod for all strata (4, 5, 7 and 8) combined in Pelorus Sound (fixed sites) for the 1996 Marlborough Sounds potting survey. N, sample size; MWCV, mean weighted coefficient of variation.



Appendix 10: Number of blue cod gonad samples preserved, by length (cm) and sex.

Length (cm)	Male	Female	Unidentified	Total
16	0	2	0	2
17	0	1	0	1
18	0	0	1	1
19	0	2	0	2
20	2	1	0	3
21	1	2	1	4
22	0	1	1	2
23	4	5	1	10
24	5	6	1	12
25	14	5	2	21
26	21	4	1	26
27	25	11	1	37
28	29	14	0	43
29	32	13	0	45
30	34	20	0	54
31	49	15	1	65
32	44	12	0	56
33	31	2	0	33
34	27	4	0	31
35	13	2	0	15
36	20	0	0	20
37	14	2	0	16
38	16	1	0	17
39	11	0	0	11
40	6	0	0	6
41	2	0	0	2
42	4	0	0	4
43	1	0	0	1
45	1	0	0	1
48	1	0	0	1
Total	407	125	10	542

Appendix 11: Numbers of blue cod with gonad samples preserved, by sex and gonad stage.

	1	2	3	4	5	6	Total
Male	29	75	38	50	185	30	407
Female	1	5	36	6	76	1	125
Unidentified	9	0	0	0	0	0	9
Total	39	80	74	56	261	31	541