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Relative abundance, size and age structure, and stock status of blue cod from the 2010 survey in Marlborough Sounds, and review of historical surveys

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EXECUTIVE SUMMARY

Beentjes, M.P.; Carbines, G.D. (2012). Relative abundance, size and age structure, and stock status of blue cod from the 2010 survey in Marlborough Sounds, and review of historical surveys.

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Marlborough Sounds 2010 blue cod potting survey

This report describes the 2010 Marlborough Sounds potting survey of relative abundance, population length and age structure, and stock status of blue cod for this area. Unlike previous surveys in this area the design included an experimental component, comparing random with fixed site sampling. This survey adheres to the terminology and analysis methods defined in the 2011 blue cod potting survey manual. Analyses of the 2010 survey catch rates, catch-at-age, total mortality (Z) and spawner-per-recruit (SPR) were carried out at the level of region (D'Urville, DUR; Pelorus Sound, PEL; Queen Charlotte Sound, QCH; and Cook Strait, CKST), and the level of management areas (closed, fished, closed-fished, outside) effective from 1 October 2008. Historical surveys of Marlborough Sounds (2001, 2004, and 2007) and Cook Strait (2008) were also analysed in the same way, and time series comparisons were made.

Eighty three sites (34 random and 49 fixed) were successfully surveyed in 13 strata between 20 September and 22 October 2010. At each site, 9 pots were set, using directed pot placement, resulting in 747 pots overall. A total of 1940 kg (4036 fish) of blue cod was taken.

Region –highest mean catch rates of all blue cod (fixed sites) by region were from DUR (3.82 kg.pot^{-1}, c.v. 7.7%), followed by PEL (2.90 kg.pot^{-1}, c.v. 12.6%), and QCH (2.09 kg.pot^{-1}, c.v. 17.8%), and for all random sites (including Maud) by region from DUR (4.75 kg.pot^{-1}, c.v. 17.3%), followed by PEL (2.17 kg.pot^{-1}, c.v. 19.1%) and CKST (1.06 kg.pot^{-1}, c.v. 22.5%). Sex ratios were dominated by males ranging from 1.8:1 to 6.8:1 (M:F). The scaled length and age frequency distributions for males and females were unimodal with mean ages (fixed sites) for males and females of 9.2 and 7.6 y (QCH), 8.4 and 6.8 y (PEL), 7.6 and 6.9 y (DUR), and 7.3 and 5.9 y for CKST random sites. The proportion of blue cod over the minimum legal size (30 cm and over) in fixed sites was 79% (PEL), 72% (QCH), 58% (DUR), and 50% in CKST random sites. Blue cod were larger and older in the inner sounds (QCH and PEL) than in the outer regions (DUR and CKST). Site type did not affect the population structure in DUR, but in PEL blue cod caught from random sites were slightly smaller and younger than those from fixed sites. The mortality estimates (*Z*) for fixed sites were 0.30 (QCH), 0.35 (PEL), 0.48 (DUR), and 0.50 for CKST random sites, where age at full recruitment was set to six years. Corresponding SPR ($F_{\%SPR}$) estimates were 38% (QCH), 32% (PEL), 23% (DUR), and 22% (CKST) using an M of 0.14.

Management area –Mean catch rates (fixed sites) by management area of all blue cod were similar in the closed, fished, and closed-fished areas (2.48, 2.43 and 2.46 kg.pot^{-1}, respectively), and highest in the outside area (3.40 kg.pot^{-1}).The proportions of blue cod over the minimum legal size (30 cm and over) were 77% (closed), 61% (fished), 72% (closed-fished), and 62% (outside). Male blue cod were larger and older in the closed compared to the fished and outside areas, but for females the difference was minor, although there was a higher proportion of larger and older females in the closed area compared to the other areas. The mortality estimates (*Z*) were 0.31 (closed), 0.47 (fished), 0.35 (closed-fished), and 0.46 (outside), where age at full recruitment = 6 years. Corresponding SPR ($F_{\%SPR}$) estimates were 37% (closed), 24% (fished), 32% (closed-fished) and 24% (outside) using an M of 0.14.

2008 Cook Strait blue cod potting survey

The 2008 blue cod potting survey of Cook Strait (trip_code jug0801) was analysed and documented as part of this project including preparation and age estimation from otoliths and presentation of

biological data. Twenty-two fixed sites were successfully surveyed in 3 strata between 9 and 15 September 2008. At each site, 9 pots were set, using directed pot placement, resulting in 198 pots overall. A total of 351 kg (683 fish) of blue cod was taken. Mean catch rate was 1.5 $kg.pot^{-1}$ with a cv of 15%. Sex ratio was dominated by males (7.4:1 M:F). The scaled length and age frequency distributions for males and females were unimodal with mean ages for males and females of 7.8 and 5.8 y. The proportion of blue cod over the minimum legal size (30 cm and over) was 66%. The mortality estimate (*Z*) was 0.39 where age at full recruitment was set to 6 years, and the corresponding SPR ($F_{\%SPR}$) estimate was 28% using an M of 0.14.

Time series

Temporal analyses of the 2001, 2004, 2007, 2008, and 2010 surveys show that the fished area (outer sounds) blue cod population structure was largely static until 2010 when there was a marked increase in average size, age, and abundance of blue cod from the closed area (inner sounds). The Z and SPR estimates also reflect these changes. The closure of the inner Sounds to all fishing two years before the 2010 survey suggests that this has had a dramatic effect on the population size, age, and numbers of fish inside the closed area. The 1995 and 1996 published catch rates were higher than those from 2001 to 2007, however, we recommend that these be re-estimated using standard methods.

2010 drift underwater video survey (DUV)

DUV transects were done concurrently with potting at 20 sites.. In total the video surveyed 62 km of transects covering a total area of 258 464 m^2, from which 2003 independent benthic habitat observations were made, and 861 blue cod and their associated habitat were recorded. Pots caught 936 blue cod. Pots had a higher proportion of blue cod from 29 to 40 cm and the implications of pot size selectivity are discussed. The observed density of blue cod from video transects had only a poor relationship with pot catches, and the variance was often high for both pots and the video. It appears that pots are attracting blue cod in from a distance greater than the area surveyed, and/or that that blue cod populations are highly clumped within the survey area. The relationship between pot catch and video count (i.e., catchability) was also highly variable among locations. The relationship between blue cod and benthic habitat structure is also examined.

1. INTRODUCTION

This report describes the 2010 Marlborough Sounds potting survey of relative abundance, population length/age structure and stock status of blue cod (*Parapercis colias*) continuing the time series that began in 1995. Unlike previous surveys in this area the 2010 survey included an experimental design component, comparing random sampling with the standard fixed site sampling. In addition, drift under-water video (DUV) surveying was carried out concurrently with the potting survey at selected sites to compare size structure and abundance between the two methods. A reanalysis of the catch rates of the 2001 to 2007 surveys was also carried out as well as analyses of catch-at-age, total mortality, and spawner-per-recruit, all compliant with the potting manual analytical methods (Beentjes & Francis 2011). There was also information available from a 2008 survey in Cook Strait for which there are no published analyses or results — for this survey we carried out complete analyses of biological data, prepared and aged otoliths, and finally produced catch-at-age, total mortality, and spawner-per-recruit outputs. Time series comparisons of abundance, size and age composition, and stock status were then made.

1.1 Blue cod potting surveys

Recreational blue cod stock status for stocks in the South Island are monitored using potting surveys that provide relative biomass indices. 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. In addition to the Marlborough Sounds, there are currently eight other areas surveyed, located in key recreational fisheries around the South Island, the aim being to repeat each survey about every four years: 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), Dusky Sound (Carbines & Beentjes 2003, 2011a) and Foveaux Strait, (Carbines & Beentjes 2012). In the Marlborough Sounds, potting surveys have been carried out in 1995, 1996, 2001, 2004, 2007 (Blackwell 1997, 1998, 2002, 2006, 2008), and in 2010 (current survey). There was also an unpublished 2008 survey outside of the sounds in Cook Strait which has been analysed and documented in this report.

The aim of blue cod potting surveys is to provide local abundance indices, and to monitor the size, age and sex structure of geographically separate blue cod populations. The surveys provide a means to evaluate the response of populations to changes in fishing pressure and to the implementation of management initiatives such as changes to the daily bag limit, minimum legal size, and/or area closures. Changes to the daily bag limit, minimum legal size and spatial management changes have occurred on five different occasions since 1986 in the Marlborough Sounds (Ministry for Primary Industries 2012). 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. 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 Marlborough Sounds

Blue cod (*Parapercis colias*) is the second most important recreational target species in the Marlborough Sounds and in Tasman/Golden Bay. The 2005–06 recreational catch estimates from QMA 7 of 148 t represent a slight decrease from previous estimates of 239 t in 1996, and 288 t in 2000. They still substantially exceed the small commercial fishery in QMA 7 (59 t in 2009–10),

which is essentially confined to the outer Sounds and Cook Strait (Davey et al. 2008, Ministry for Primary Industries 2012).

There has been a marked reduction in size of blue cod in the Marlborough Sounds from the late 1930s (Rapson 1956) to the mid 1990s when the potting survey time series began (Blackwell 1997). The Marlborough Sounds potting surveys show a decline in abundance of about 60% between 1995/1996 and 2007, and indicate that local depletion has occurred in the inner Sounds where blue cod catch rates have been lower and size smaller than the outer sounds. Tagging experiments suggest 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 blue cod in 1993 (Ministry for Primary Industries 2012). The minimum legal size (MLS) has ranged from 28 to 33 cm over this time, but since 2003 it has been 30 cm. On 1 October 2008, the inner Marlborough Sounds (Pelorus and Queen Charlotte Sounds) was closed to target blue cod fishing for four 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 2012). The 2010 Marlborough Sounds potting survey was carried out about two years after the closure took place. From October 2012 blue cod can be targeted in Marlborough Sounds, but there is a slot limit of 30 to 35 cm with MDL of 2 fish per person per day.

An objective for this project is to determine the status of Marlborough Sounds blue cod stocks using the spawner-per-recruit ($F_{\%SPR}$), an MSY-related proxy. The recommended Harvest Strategy Standard reference point for blue cod (a medium productivity stock) is $F_{40\%}$ (Ministry of Fisheries 2008). These are the first SPR estimates for blue cod in the Marlborough Sounds.

1.3 Drift underwater video (DUV)

The basic premise of this long-term monitoring programme is to use the passive capture method of potting to estimate the relative abundance and size structure of the Marlborough Sounds blue cod population. However, a review of the blue cod potting programme recommended that this method requires further validation (Stephenson et al. 2009). Different methods have different selectivity biases, and catch rates and size compositions from potting are known to differ from other methods such as line fishing (Carbines 1999, Blackwell 2002, 2006). Pot catches have also been shown to have a highly variable and largely unexplained relationship with direct counts of blue cod from diver transects (Cole et al. 2001). To investigate how reliable a proxy potting is for estimating blue cod abundance and population structure, direct *in situ* observations of blue cod populations from remote drift video transects (see Morrison & Carbines 2006, Carbines & Cole 2009) were compared with potting survey catches in the Marlborough Sounds.

1.4 Objectives

Overall Objective

1. To estimate relative abundance, maturity state, sex ratio, and age structure of blue cod (*Parapercis colias*) in the inner and outer 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 and the 2008 Tory Channel survey.

3. To determine stock status of blue cod populations in this area, and compare to other survey areas.

4. To undertake a Dropped Underwater Video (DUV) survey concurrently with potting survey to provide comparative estimates of biomass. (Subject to the success of this method currently being tested in BCO2009/02.)

5. To determine F_{msy} proxies for Marlborough Sounds blue cod.

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

2. METHODS

2.1 2010 Marlborough Sounds potting survey

2.1.1 Timing

A potting survey of the Marlborough Sounds area was carried out by NIWA between 20 September and 22 October 2010 consistent with the previous surveys and coinciding with a the time of year when spawning is known to occur in this region.

2.1.2 Survey area

The 2010 Marlborough Sounds potting survey included 13 strata (Table 1) from the inner and outer sounds, D'Urville (east and west of the Island), and Cook Strait. It did not include Separation Point (stratum 10) which was surveyed in 2004 and 2007 (Figure 1). Coastline length was measured using the ArcMap (GIS system) and recorded in kilometres. These replaced all previous coastline estimates reported in the 1995 to 2007 surveys as these were considered to be inaccurate. In the absence of specific habitat information or a clear understanding of the habitat requirements of blue cod, the area (km) within each stratum was taken as a proxy of available habitat for blue cod.

2.1.3 Survey design

The 2010 survey includes an experimental design component with the aim of comparing catch rates, size, and age composition from fixed sites used in the 1995 to 2007 surveys, and random sites in strata 4, 5, and 6 (EOPE, OPEL and DURE) (Table 1). Half of the total sites sampled in these three strata were allocated randomly and half were fixed sites. In addition, four sites were randomly allocated around Maud Island (three in stratum 8, and one in stratum 5), which encompasses the Department of Conservation scientific reserve around which there is a Ministry of Fisheries (now Ministry for

Primary Industries, MPI) no-take fishing zone. All sites in the Cook Strait region (strata 11 to 13, APAE, COOK, UNDW) were randomly allocated. The inshore working group agreed that with only one previous survey in Cook Strait (in 2008, using fixed sites), there was little concern about biasing the time series.

Fixed sites

The number of fixed sites used was optimised based on catch rates from previous surveys. From the full and larger list of fixed sites available, a number of sites per stratum were randomly selected to be surveyed in strata 1 to 9 (Figure 1). There was no phase 2 component to the fixed sites survey.

Random sites

In strata where random sites were used, the stratum coastline was divided into one kilometre blocks which were randomly selected. If two random sites were contiguous, or overlapped with a fixed site, then the next sites on the random list was selected ensuring that no sites were closer than one kilometre. There was no phase 2 component to the random sites survey.

2.1.4 Vessel and gear

The 2010 Marlborough Sounds survey was conducted from F.V. *Lady H.R*, a Picton based commercial vessel equipped to set and lift rock lobster and blue cod pots and skippered by Mr Craig Ashton. The vessel specifications are: 9.6 m length, 3.2 m breadth, and displacement of 10 t. It is powered by a 60 kilowatt Ford Diesel engine with propeller propulsion.

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 and replaced each day. The same pot design and bait type were used in all previous Marlborough sounds blue cod potting survey time series.

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

2.1.5 Sampling methods

Fixed sites

At each fixed site 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. The nine pots were set along the 1 km of coastline, at least 100 m apart to avoid pots competing for fish. Placement of the six pots was directed by the skipper using local knowledge and the vessel echo sounder to locate a suitable area of reef/cobble or biogenic habitat (i.e., directed placement). 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. The order that strata were surveyed depended on the prevailing weather conditions.

Pots do not have a unique identifiable code and are assumed to have equal catchability. 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. Immediately prior to each set of the pots, an acoustic doppler current profiler (ADCP) was deployed at the centre of each site 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 10 kg Merel motion compensating scales. The number of individuals of each species per pot was also recorded. Total length to the nearest centimetre below actual size, sex, and gonad maturity were recorded for all blue cod. Sagittal otoliths were removed from a representative size range of males and females (a target of up to five fish of each sex per 1 cm size class over the available length range across all survey strata) and weight of each fish was recorded to the nearest 10 g. Sex and maturity were determined by dissection and macroscopic examination of the gonads (Carbines 1998, Carbines 2004b). Gonads were recorded as one of five stages as follows: 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

Random sites

The only difference between sampling at random and fixed sites relates to the pot placement method. Pot placement in random sites used "systematic placement" as described in the potting manual, but was randomised with respect to depth over suitable rocky or cobbled substrate along a transect perpendicular to the shore. Transects were spaced about every 100 m within the 1 km length of coastline and at each transect one pot was placed at the random depth selected. This novel approach to pot placement was used to negate possible bias of depth and was approved by the Inshore Working Group before the survey commenced.

2.1.6 Data storage

The trip code for the survey is lhr1001. At the completion of the survey, data were entered into Ministry for Primary Industries (MPI) *trawl* and *age* databases in accordance with the business rules and the blue cod potting manual (Beentjes & Francis 2011). Fixed sites are entered into *trawl* table *t_station*_as attribute *stn_code* (concatenating strata number and site label, e.g., 1F, 2B etc.), whereas random sites are left blank in *stn_code*. Pot locations are entered in table *t_station* as attribute *station_no* (concatenating set number and pot number e.g., 11 to 19, or 31 to 39 etc.). In the *age* database the *sample_no* is equivalent to *station_no* in the *trawl* database. The comments entered into *t_trip_comm* were: "stratum 1 incorporates MAUD sites into strata 5 and 8 as per previous surveys. stratum2 gives option of including stratum 14, i.e., analysing MAUD as separate stratum. stratum2 stored in *t_station.other."*

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

2.1.7 Ageing

Otolith preparation

The thin section technique is used for ageing blue cod otoliths (Carbines 2004a). In this method the whole otolith is embedded in Araldite polymer resin, baked (50^{o} C 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 is then glued to a glass slide and a second cut is made resulting in a section of about 2 mm thickness. The resultant thin section on the slide is then coated with a slide mountant and sanded with 600-grit sandpaper to about 1 mm thickness before viewing. Sections were observed at x40 and x100 magnification under transmitted light with a compound microscope.

Otolith sections exhibit alternating opaque and translucent zones and age estimates are made by counting the number of annuli (opaque zones) from the core to the distal edge of the section, a technique previously validated and a protocol described for blue cod by Carbines (2004a).

Translucent zones are used to define each complete opaque zone, i.e., annuli are counted only if they have a translucent zone on both sides. The readability of each otolith was also graded from 1 (excellent) to 5 (unreadable) and grade 5 otoliths were removed from the analysis. Otoliths for the 2010 survey were read by three readers (Derek Kater, reader 1; Michael Stevenson, reader 2; Colin Sutton, reader 3). 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 (c.v.).

2.1.8 Analyses of data

For the 2010 survey, data analyses (catch rates, sex ratios, mean size, catch-at-age, Z estimates, and SPR) were conducted and presented at two geographical levels, i.e., first by region and then by management area.

Regional (QCH, DUR, PEL, CKST) analyses were carried out for fixed sites and for random sites (Table 1). All sites in QCH were fixed, all sites in CKST were random, and DUR and PEL contained a mix of fixed and random sites. For PEL region, all three random sites in stratum 8 (MPEL), and one of five in stratum 5 (OPEL), were set around Maud Island, a no-take area. Hence, for PEL region, two random site analyses are carried out, one including the Maud Island sites and one excluding them.

Management area (closed, fished, closed-fished, and outside) analyses were carried out using areas (Table 2, Figure 2) as follows:

Closed	(strata 1, 2, 5, 7, and 8 using data only from fixed sites).
Fished	(strata 3, 4, 6 using data only from fixed sites).
Closed-Fished	(combined closed and fished areas for fixed sites, strata 1 to 8).
Outside	(strata 11, 12, 13, and 9 comprising random sites in CKST and fixed sites in DURW).

Analyses of catch rates and coefficients of variation (c.v.s), length weight parameters, scaled length and age frequencies and c.v.s, sex ratios, mean length, and mean age, were carried out using the equations documented in the blue cod potting manual (Beentjes & Francis 2011).

2.1.8.1 Catch rates

For 2010, the catch rate (kg.pot^{-1}) estimates are pot-based and the c.v.s are set-based. Catch rates were estimated for all blue cod and recruited blue cod (30 cm and over which is equal to the MLS). Weights of individual blue cod that were not weighed during the 2010 survey were calculated from the length-weight relationship for that survey (see below). Derived individual fish weights were then used to determine catch rates and c.v.s of recruited blue cod. The revised coastline lengths (km) shown in Table 1 were used as the area of the stratum (A_t) when scaling catch rates (equations 3 and 5 in Beentjes & Francis 2011). Catch rates are presented by stratum, region, and management area. In addition, analyses of catch rates from fixed sites and random sites are compared for regions PEL and DUR.

2.1.8.2 Length-weight parameters

The length-weight parameters a_k, b_k from the 2010 survey were used in the equation

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

which calculates the expected weight (kg) 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 2010 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 Maturity

A logistic model of length on proportion mature was run for the 2010 survey data for each sex. Values of length-at-50% and -95% maturity (L_{50} and L_{95}) were converted to age-at-50% and -95% maturity (A_{50} and A_{95}) from the von Bertalanffy growth model from the same survey. These latter values were used to define maturity in the spawner-per-recruit analyses (see Section 2.1.8.8).

2.1.8.5 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 area of the strata, 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 on the survey are measured and if the actual weight of the catch is close to the estimated weight of the catch.

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 allow calculation of c.v.s 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 (regions or management areas), 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.

Regional analyses

For each of the four regions (CKST, DUR, PEL, QCH) catch-at-age in 2010 was estimated using the length and age data collected from that region, e.g., using the age length key (ALK) generated from QCH region applied to the length data from QCH region. The ALKs from PEL and DUR were used for both random and fixed sites within these respective regions. Separate analyses were carried out for fixed and random sites from DUR and PEL, and for PEL additional analyses were carried out excluding the Maud Island random sites. The coastline lengths (km) shown in Table 1 were taken as the area of the stratum (A_t) for scaling length and age (equation 8 in Beentjes & Francis, 2011). The length-weight parameters used for scaling were those from the 2010 survey for both sexes combined. Only 35 out of 4036 fish were not individually weighed during the survey. For each region, scaled length frequency

and age frequency proportions are presented together with coefficients of variation (c.v.) for each length and age class, and the mean weighted coefficients of variation (MWCV).

Management area analyses

The proportions-at-age from fixed sites for individual strata generated from regional catch-at-age analyses were recombined corresponding to the four different management areas (closed, fished, closed-fished, and outside). In this way, although we have combined strata across regions (e.g., QCH and PEL regions make up the closed area), the age data used is specific to the region-strata and hence applies the ALK to the stratum from which it was collected. For each management area, scaled length frequency and age frequency proportions are presented together with coefficients of variation (c.v.) for each length and age class, and the mean weighted coefficients of variation (MWCV).

2.1.8.6 Sex ratios, and mean length and age

For 2010, 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 LFs. Mean ages were calculated analogously from the scaled age frequencies. These outputs are presented by region (all sites, and separately for fixed and random sites) and by management area.

2.1.8.7 Total mortality estimates

Total mortality (Z) was estimated from catch-curve analysis using the Chapman Robson estimator (CR) (Chapman & Robson 1960). The CR method has been 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 ($M + F$). Implicit are the assumptions 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 y) using the maximum-likelihood estimator (equation 13 of Beentjes & Francis (2011)). Variance (95% confidence intervals) associated with Z was estimated under three different parameters of recruitment, ageing error, and Z estimate error (equations 14 to 18 of Beentjes & Francis (2011)). Catch-at-age distributions were estimated separately for males and females and then combined, hence providing a single Z estimate for the population.

For 2010, Z estimates were calculated by region (separately for fixed and random sites), and by management area.

2.1.8.8 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 determining 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 $F = 0$).

For 2010, $F_{\%SPR}$ was estimated by region (separately for random and fixed sites), and by management area.

Input parameters used in the SPR analysis

Growth parameters — von Bertalanffy growth parameters and length weight coefficients estimated from the 2010 survey (see below).

Parameter	Males	95% CI	Females	95% CI
K	0.118	0.098–0.139	0.128	0.098–0.158
t_0	-0.923	-1.522– -0.325	-0.989	-1.634– -0.345
L_∞	49.5	46.6–52.4	44.6	40.5–48.8
a	0.0013		0.0013	
b	3.0873		3.0873	

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 — age-at-maturity was estimated from the length-at-maturity logistic model values of the 2010 survey $L_{50\%}$ and $L_{95\%}$. The ages that corresponded to these parameters were estimated from the von Bertalanffy curves of the 2010 survey. Maturity was entered as a logistic function using age-at-50% maturity ($A_{50\%}$) and $Ato_{95\%}$ (age-at-95% maturity ($A_{95\%}$), minus $A_{50\%}$). The values of $A_{50\%}$ and $Ato_{95\%}$ were 4.8 and 4.6 years for females; the same values were also used for males because male length-at-95% maturity was unrealistic.

Selectivity — selectivity to the commercial fishery is described as knife-edge equal to age-at-MLS. Age 7 was used which corresponded to MLS of about 30 cm from the 2010 von Bertalanffy curves.

Fishing mortality (F) — fishing mortality is estimated from the results of the Chapman-Robson analyses and the assumed estimate of M (i.e., $F = Z–M$). The Z value is for an age-at-recruitment of 6 years.

Maximum age — Assumed to be 31 years.

Because this is a 'per-recruit' analysis, it does not matter what stock-recruit relationship is 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).

2.2 2008 Cook Strait blue cod potting survey

The 2008 blue cod potting survey of Cook Strait (trip_code jug0801) was analysed and documented as part of this project (objective 2), including presentation of biological data, preparation and age estimation from otoliths, catch at age, total mortality (Z), and spawner-per-recruit analysis. All at-sea sampling methods including pot design and deployment were the same as described above for the 2010 survey, however the vessel was the F.V. *Juggernaught*. Only one reader was used (reader 1, Derek Kater) to age the otoliths collected because of the large difference in age estimates among readers observed for the 2010 survey.

2.3 Analyses of historical surveys (1995, 1996, 2001, 2004, 2007, and 2008)

Historical surveys included those in Marlborough Sounds in 1995, 1996, 2001, 2004, and 2007 (trip_codes lhr0501, lhr0601, lhr0101, lhr0401, and lhr0701, respectively), and the 2008 survey of Cook Strait (jug0801). All these surveys used fixed sites. Catch rates were estimated for 2001, 2004, and 2007 by region (QCH, DUR, PEL), and stand-alone for the 2008 survey of Cook Strait (CKST). Catch rates were also analysed by management area as for the 2010 survey, except that the 2001 and 2004 surveys did not include stratum 9 (DURW) or strata 11 to 13 (Cook Strait), and hence there are no results

for "outside" management area for these surveys. The 2008 Cook Strait survey (strata 11, 12, and 13) was combined with the 2007 stratum 9 (DURW) for the analysis of the 2007 "outside" management area. Catch rates from the 1995 and 1996 surveys were interpreted from the data and figures in the published survey reports and presented by region and management area (Blackwell 1997, 1998)

For the 2001, 2004, and 2007 Marlborough Sounds surveys (DUR, PEL, QCH), and the 2008 survey of Cook Strait (CKST), catch-at-age was estimated using the length and age data collected from that region, for that survey. For example, using the age length key generated from QCH in 2001, applied to the length data from QCH in 2001. The 2010 survey length-weight parameters and areas of the strata (A_t) shown in Tab1e 1 were used in scaling catch-at-age. As for catch rates, the 2008 Cook Strait survey (strata 11, 12, and 13) were combined with the 2007 stratum 9 (DURW) for the analysis of the 2007 "outside" management area catch at age. For historical surveys, all fish were individually weighed. Historical survey catch-at-age results are presented only by management area. No catch at age was estimated for the 1995 and 1996 surveys because the otoliths collected from these surveys have not been prepared or aged.

For 2001, 2004, 2007, and 2008 Z and $F_{\%SPR}$ estimates are provided by region and management area. The 2010 survey growth parameters, maturity, selectivity, and maximum age were used in the spawner per recruit estimates. There are no Z and spawner per recruit estimates for 1995 and 1996 because there are no age data.

2.4 Drift underwater video (DUV)

To assess whether catch rates from potting surveys are proportional to actual abundance of blue cod, blue cod populations were assessed using drift underwater video (DUV) counts done concurrently at 20 sites.

2.4.1 Equipment used

The DUV system consists of a 35 kg bulb keel and tail fins which steady and orientate a forward and downward facing mounting platform fitted with a light sensitive camera and scaling lasers (Morrison & Carbines 2006, Carbines & Cole 2009). It was suspended beneath the F.V. *Lady H.R*, by a rope and a live-feed video cable so that location, time, depth and date were all burned in real time onto the recorded digital video footage using a video titler integrated with a surface Geographical Positioning System (GPS) and depth sounder.

2.4.2 Sample collection

The video system was deployed to a height of at least 1.5 m off the seabed, and once the speed of the surface vessel reached about one knot, the keel and tail fins would orient the camera platform forward and the video transect would begin recording for approximately 1200 m. Contact with the seabed was avoided by raising and lowering the system from the surface vessel throughout each transect and scaling lasers were used to back-calculate the size and variations of transect width. Transects were carried out between 0600 and 1500 hours, when the swell was less than 2 m, and when speed exceeded 0.8 $m.s^{-1}$ (to prevent fish being able to follow the camera and re-enter the video transect). Three replicate video transects were done (shallow/medium/deep) parallel to the shoreline at 20 sites directly prior to setting the pots.

2.4.3 Video analysis

Each video transect was analysed (read) twice. In the first reading, the number of blue cod per transect were counted and the transect dimensions were geo-referenced. Transects were also partitioned into gross general benthic habitat sections. All blue cod were geo-referenced and scaling lasers used to estimate fish length (Morrison & Carbines 2006), fish angle to the camera was also recorded (i.e., head-on, 45º, or 90º) as an estimate of measurement precision.

Habitat was characterised using the video records. During the first reading, at the location of each blue cod a fish based habitat quadrat was taken (approximately 5 m before and after each fish was observed). During the second reading, within each transect, each section of gross general habitat identified in the first reading (see above) was then sampled with at least five sequential points to record transect width from scaling-lasers and fish independent quadrat descriptions of benthic habitat (i.e., approximately 5 m before and after each sequential point). Both fish based and independent habitat quadrats recorded primary substrate (e.g., sand, bedrock, etc.), secondary habitat structure (e.g., macro-algae, sponge, shells) and percentage cover, topographic complexity (four categories), and actual counts of benthic species where possible.

All fish densities estimated by the area-swept drift video method were standardised by area, and the variance examined. A correlation was determined between the number of blue cod observed in video transects and caught by pots at each site (Cole et al. 2001). A comparison of blue cod length frequencies was also made between methods to examine size selectivity (Cole et al. 2001). Data on fish abundance by size class and *in situ* habitat data from the video are presented and a ratio of fish-based and independent habitat observations was used to determine features of the benthic environment disproportionally present (i.e., a ratio of more than 1) or absent (i.e., a ratio of less than 1) of blue cod.

3. RESULTS

3.1 2010 Marlborough Sounds blue cod potting survey

3.1.1 Sites surveyed

Eighty three sites were surveyed (9 pots per site, producing 747 pot lifts) from 20 September to 22 October 2010 from twelve strata throughout Marlborough Sounds and Cook Strait (Table 1, Figure 1). Of the 83 sites, 49 were fixed and 34 were random. Random sites were set only in DUR and PEL regions. Depth ranged from 3 to 32 m, and the mean soak time was 70 min (range 60 to 119 min, s.e. 2.57 min).

3.1.2 Catch

A total of 1940 kg of blue cod was taken on the 2010 Marlborough Sound survey, 1289 kg from fixed sites and 650 kg from random sites (Table 1).

The 1940 kg of blue cod comprised 4036 fish and accounted for 93% by number of the catch of all species on the survey (Table 3). Bycatch included 10 teleost fish, one shark, and one octopus species, as well as hagfish. The four most common bycatch species, by number, were triplefin (*Fosterygion varium* / *Grahamino capito*), scarlet wrasse (*Pseudolabrus miles*), leatherjacket (*Parika scaber*), and banded wrasse (*Notolabus fucicola*).

Of the 441 fixed site pots, 109 (25%) had zero catch of blue cod, compared with 127 of 306 pots from random sites (41%). Overall 31% of all pots set had zero blue cod.

3.1.3 Catch rates

Mean catch rates (kg.pot^{-1}) of blue cod (all sizes, and 30 cm and over) are presented by stratum, site type (fixed and random), and overall for each region (Tables 4 and 5, Figure 3). Catch rates for random sites are presented for sites both including and excluding those around Maud Island.

Mean catch rates (kg.pot^{-1}) of blue cod (all sizes, and 30 cm and over) are presented by stratum, site type (fixed and random), and overall for each management area (Tables 6 and 7, Figure 4). Catch rates for random sites are presented for sites both including and excluding those around Maud Island.

3.1.4 Biological and length frequency data

Cook Strait (CSKT random sites)

Of the 362 blue cod caught in the Cook Strait region, all but three fish were sexed and measured, and otoliths were taken from 128 fish across the available size range. The weighted sex ratio (M:F) ranged from 11.3:1 to 0.82:1 across the three strata and the overall weighted sex ratio was 5.2:1 (Table 8).

Size ranged from 19 to 48 cm for males and 14 to 35 cm for females, although this varied among strata. Mean length of males was between 3 and 5 cm greater than females among the three strata and overall weighted mean length was 30.5 cm for males and 25.6 cm for females (Table 8). The scaled length frequency distributions for strata 11, 12, and 13 were unimodal, although few fish were caught in stratum 13 and few females caught overall (Figure 5).

D'Urville (DUR fixed sites)

Of the 1346 blue cod caught in the D'Urville region from fixed sites, all but 9 fish were sexed and measured. The weighted sex ratio (M:F) range was similar for both strata and the overall weighted sex ratio was 1.8:1 (Table 9).

Size ranged from 15 to 48 cm for males and 19 to 40 cm for females, and was similar in the two strata. Overall weighted mean length was 31.3 cm for males and 28.7 cm for females (Table 9). The scaled length frequency distributions for strata 6 and 9 were unimodal (Figure 6).

D'Urville (DUR random sites)

Of the 538 blue cod caught in the D'Urville region stratum 6 from random sites, all but 10 fish were sexed and measured. The weighted sex ratio (M:F) was 3:1 (Table 10). Size ranged from 20 to 44 cm for males and 19 to 35 cm for females, and overall weighted mean length was 31.5 cm for males and 29.1 cm for females (Table 10). The scaled length frequency distributions for stratum 6 were unimodal (Figure 7).

Pelorus (PEL fixed sites)

Of the 780 blue cod caught in the Pelorus Sound region fixed sites, all but 31 fish were sexed and measured. The weighted sex ratio (M:F) ranged from 3.7:1 to 8.8:1 across the four strata and the overall weighted sex ratio was 6.8:1 (Table 11).

Size ranged from 17 to 43 cm for males and 18 to 34 cm for females, although this varied among strata. Mean length of males was between 3 to 6 cm greater than females among the four strata and overall weighted mean length was 32.8 cm for males and 28.3 cm for females (Table 11). The scaled length frequency distributions for all strata were unimodal, although female numbers are low (Figure 8).

Pelorus (PEL random sites including Maud Island)

Of the 494 blue cod caught in the Pelorus Sound region random sites including those around Maud Island, all but 23 fish were sexed and measured. The weighted sex ratio (M:F) ranged from 3.9:1 to 9.1:1 across the three strata and the overall weighted sex ratio was 5.4:1 (Table 12).

Size ranged from 18 to 43 cm for males and 10 to 35 cm for females, although this varied among strata. Mean length of males was between 5 to 6 cm greater than females among the three strata and overall weighted mean length was 32.1 cm for males and 27.2 cm for females (Table 12). The scaled length frequency distributions for all strata were unimodal (Figure 9).

Pelorus (PEL random sites excluding Maud Island)

Of the 394 blue cod caught in the Pelorus Sound region random sites, excluding those around Maud Island, all but 23 fish were sexed and measured. The weighted sex ratio (M:F) ranged from 3.1:1 to 5.8:1 across the two strata and the overall weighted sex ratio was 4.2:1 (Table 13).

Size ranged from 18 to 43 cm for males and 15 to 35 cm for females, although this varied between strata. Mean length of males was between 4 to 5 cm greater than females among the two strata and overall weighted mean length was 31.4 cm for males and 27.7 cm for females (Table 13). The scaled length frequency distributions for both strata were unimodal (Figure 10).

Queen Charlotte Sound (fixed sites)

Of the 506 blue cod caught in the Queen Charolotte Sound region fixed sites, all but 47 fish were sexed and measured, and otoliths were taken from 141 fish across the available size range. The weighted sex ratio (M:F) ranged from 2.1:1 to 4.1:1 across the three strata and the overall weighted sex ratio was 2.4:1 (Table 14).

Size ranged from 22 to 45 cm for males and 17 to 39 cm for females, although this varied among strata. Mean length of males was between 3 to 6 cm greater than females among the three strata and overall weighted mean length was 33.2 cm for males and 29.0 cm for females (Table 14). The scaled length frequency distributions lack the numbers in some strata to be able to describe size composition well, but in general appear to be unimodal (Figure 11).

Management area

The mean lengths and sex ratios are given by management area are in Table 15 together with other additional outputs described below.

3.1.5 Ageing and growth

Ages from 649 fish were used in estimating the population age structure from Marlborough Sounds in 2010. By region there were 128 aged fish from CKST, 198 from DUR, 182 from PEL, and 141 from QCH. Mean age-at-length for each region is shown in Appendix 2. Each regional data set was used to produce a single ALK for males and females. The all regions combined length-age data for 2010 are plotted and the von Bertalanffy model fits are shown for males and females separately (Figure 12). The growth parameters (K, t_0 and L_∞) are shown in the methods table of input data for the SPR analysis (Section 2.1.8.8). The growth parameters are similar for males and females except that males achieve a greater L_∞ than females (i.e., 49.5 cm for males and 44.6 cm for females).

Between reader comparisons are graphically presented in Figures 13 and 14. Reader 1 (Derek Kater) is the experienced reader having read otoliths from most blue cod potting surveys to date. The comparison between reader 1 and reader 2 indicates that the second reader is under-estimating age relative to reader 1 and this bias gets worse with increasing age (Figure 13). The bias is less between

reader 1 and reader 3, but for the older ages reader 3 is also under-estimating age relative to reader 1 (Figure 14). Given the large differences between reader 1 and the inexperienced readers (2 and 3), only ages from reader 1 were used in catch at age and von Bertalanffy estimates.

3.1.6 Maturity

Gonad stages of blue cod in Marlborough Sounds in September-October 2010 are presented by region for pre-recruited and recruited fish (Table 16). There was a clear indication of spawning activity during the survey period, particularly in DUR where over half the recruited and pre-recruited males were running ripe. The proportions in other regions indicate that spawning had not yet peaked. There appeared to be clear differences among regions in the timing of spawning, with a generally greater proportion of Stage 1 fish found in the Cook Strait strata (Table 16). However, the survey spanned over a month and the two sites surveyed in stratum 11 on 21 October were largely composed of stage 4 and 5 fish.

Curves of the logistic models of length against maturity by sex are shown in Figure 15. Lengths-at-50% and -95% maturity were 23 cm and 33 cm for females, and 23 cm and 40 cm for males, respectively. The female maturity length values were converted (using the von Bertalanffy curves of the 2010 survey) into ages-at-50% and -95% maturity ($A_{50\%}$ and $A_{95\%}$, 4.8 and 9.4 years) for use in the spawner-per-recruit analyses. The female maturity curve was used because for males the curve appears to be very flat and the length at 95% maturity was unrealistic.

3.1.7 Population length and age composition (region)

The scaled length frequency and age distributions for the 2010 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 16–22). The ALKs by sex are shown in Appendix 3 (3A to 3D). All fish lengths collected on the survey had at least one valid age reading in the four ALKs for both males and females for all catch-at-age analyses.

Cook Strait (random sites)

The scaled length frequency distribution for both males and females is unimodal with mean lengths of 30.5 cm and 25.6 cm respectively (Figure 16). The cumulative distribution plots of length frequency show clearly that males have a higher proportion of larger fish than females and also that the largest fish are males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 32% for males and 73% for females, indicating that males sampled in the survey provide a reasonable representation of the overall population, but not females because the sample size was low. Fish 30 cm and over comprise 50% of the scaled numbers (Table 15).

Age of blue cod ranged from 3 to 18 years for males and 2 to 9 years for females, but most males were between 5 and 10 years old and females between 5 and 7 years old (Figure 16). The estimated population age distributions are unimodal for both sexes with the peak at about 6 years for males, and 5 years for females. The cumulative distribution plots of age frequency show clearly that males have a higher proportion of older fish than females and also that the oldest fish are males. Further, mean age of males is greater than that of females (7.3 years for males and 5.9 years for females). The MWCVs around the age distributions are 35% for males and 50% for females, indicating that males sampled for age in the survey provide a reasonable representation of the overall population but less so for females where sample numbers were low.

D'Urville (fixed sites)

The scaled length frequency distribution for both males and females is unimodal with mean lengths of 31.3 cm and 28.7 cm respectively (Figure 17). The cumulative distribution plots of length frequency show clearly that males have a higher proportion of larger fish than females and also that the largest fish are males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 24% for males and 27% for females, indicating that fish sampled in the survey provide a reasonable representation of the overall population. Fish 30 cm and over comprise 58% of the scaled numbers (Table 15).

Age of blue cod ranged from 2 to 21 years for males and 2 to 13 years for females, but most males were between 5 and 9 years old and females between 6 and 9 years old (Figure 17). The estimated population age distributions were unimodal with the peak at 7 years for both sexes. The cumulative distribution plots of age frequency show clearly that males have a higher proportion of older fish than females and also that the oldest fish are males. Further, mean age of males is greater than that of females (7.6 years for males and 6.9 years for females). The MWCVs around the age distributions are 33% for males and 31% females, indicating that fish sampled in the survey for age provide a reasonable representation of the overall population.

D'Urville (random sites)

The scaled length frequency distribution for both males and females is unimodal with mean lengths of 31.5 and 29.1 cm respectively (Figure 18). The cumulative distribution plots of length frequency show clearly that males have a higher proportion of larger fish than females and also that the largest fish are males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 29% for males and 47% for females, indicating that males sampled in the survey provide a reasonable representation of the overall population, but less so for females where sample numbers were low. Fish 30 cm and over comprise 68% of the scaled numbers (Table 15).

Age of blue cod ranged from 4 to 16 years for males and 2 to 13 years for females, but most males and females were between 6 and 9 years old (Figure 18). The estimated population age distributions were unimodal with the peak at 7 years for both sexes. The cumulative distribution plots of age frequency show clearly that males have a higher proportion of older fish than females and also that the oldest fish are males. Further, mean age of males is greater than that of females (7.5 years for males and 7.0 years for females). The MWCVs around the age distributions are 35% for males and 40% females, indicating that fish sampled in the survey for age provide an imprecise representation of the overall population.

Pelorus (fixed sites)

The scaled length frequency distribution for both males and females is unimodal with mean lengths of 32.8 cm and 28.3 cm respectively (Figure 19). The cumulative distribution plots of length frequency show clearly that males have a higher proportion of larger fish than females and also that the largest fish are males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 21% for males and 50% for females, indicating that fish sampled in the survey provide a reasonable representation of the overall male population, but not the female population because the sample size was low. Fish 30 cm and over comprise 79% of the scaled numbers (Table 15).

Age of blue cod ranged from 2 to 18 years for males and 3 to 12 years for females, but most males were between 6 and 11 years old and females between 5 and 8 years old (Figure 19). The estimated population age distributions were unimodal for both sexes, but male ages are skewed to the right with the peak at 6 to 7 years for both sexes. The cumulative distribution plots of age frequency show clearly that males have a much higher proportion of older fish than females and also that the oldest fish are males. Further, mean age of males is greater than that of females (8.4 years for males and 6.8 years for females). The MWCVs around the age distributions are 38% for both sexes indicating that fish sampled in the survey for age provide an imprecise representation of the overall population.

Pelorus (random sites including Maud Island)

The scaled length frequency distribution for both males and females is unimodal with mean lengths of 32.1 cm and 27.2 cm respectively (Figure 20). The cumulative distribution plots of length frequency show clearly that males have a higher proportion of larger fish than females and also that the largest fish are males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 31% for males and 72% for females, indicating that fish sampled in the survey provide a reasonable representation of the overall male population, but not the female population because the sample size was low. Fish 30 cm and over comprise 72% of the scaled numbers (Table 15).

Age of blue cod ranged from 2 to 18 years for males and 1 to 15 years for females, but most males were between 6 and 11 years old and females between 5 and 8 years old (Figure 20). The estimated population age distributions were unimodal for both sexes, but male ages are skewed to the right with the peak at 6 to 7 years for both sexes. The cumulative distribution plots of age frequency show clearly that males have a much higher proportion of older fish than females and also that the oldest fish are males. Further, mean age of males is greater than that of females (8.0 years for males and 6.5 years for females). The MWCVs around the age distributions are 38% for males and 57% for females indicating that fish sampled in the survey for age provide an imprecise representation of the overall population.

Random sites (excluding Maud Island)

The scaled length frequency distribution for both males and females is unimodal with mean lengths of 31.6 cm and 27.2 cm respectively (Figure 21). The cumulative distribution plots of length frequency show clearly that males have a higher proportion of larger fish than females and also that the largest fish are males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 35% for males and 79% for females, indicating that fish sampled in the survey provide a reasonable representation of the overall male population, but not the female population because the sample size was low. Fish 30 cm and over comprise 69% of the scaled numbers (Table 15).

Age of blue cod ranged from 2 to 18 years for males and 1 to 15 years for females, but most males were between 6 and 11 years old and females between 5 and 8 years old (Figure 21). The estimated population age distributions were unimodal for both sexes, but male ages are skewed to the right with the peak at 6 to 7 years for both sexes. The cumulative distribution plots of age frequency show clearly that males have a much higher proportion of older fish than females and also that the oldest fish are males. Further, mean age of males is greater than that of females (7.6 years for males and 6.5 years for females). The MWCVs around the age distributions are 39% for males and 63% for females indicating that fish sampled in the survey for age provide an imprecise representation of the overall population.

Queen Charlotte Sound (fixed sites)

The scaled length frequency distribution for both males and females is bimodal with mean lengths of 33.2 cm and 29.0 cm respectively (Figure 22). The cumulative distribution plots of length frequency show clearly that males have a higher proportion of larger fish than females and also that the largest fish are males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 38% for males and 64% for females, higher than desired for the survey to provide a reasonable representation of the overall population. Fish 30 cm and over comprise 72% of the scaled numbers (Table 15).

Age of blue cod ranged from 5 to 16 years for males and 3 to 15 years for females, but most males were between 6 and 13 years old and females between 6 and 9 years old (Figure 22). The estimated population age distributions were unimodal for both sexes, but ages are skewed to the right with the peak at 8 years for both sexes. The cumulative distribution plots of age frequency show clearly that males have a much higher proportion of older fish than females and also that the oldest fish are males.

Further, the mean age of males is greater than that of females (9.2 years for males and 7.6 years for females). The MWCVs around the age distributions are 43% for males and 59% for females, higher than desired to provide a good representation of the overall population.

Comparison of length and age among regions

Cumulative plots of population length and age among the four regions with fixed sites in 2010 show that overall blue cod are clearly larger and older in Queen Charlotte Sound and Pelorus Sound than in the outer regions of D'Urville and Cook Strait, with the latter having the smallest and youngest fish for both sexes (Figure 23).

Comparison of length and age between fixed and random sites

Comparisons of the fixed site and random site length and age in the D'Urville region in 2010 shows no discernible difference indicating that survey site type in this region did not influence the estimated population structure (Figure 24).

In Pelorus Sound, four of the 12 random sites in 2010 were located around Maud Island, a no-take fishing zone (Figure 25). The results indicate that blue cod caught from random sites in Pelorus Sound were slightly smaller and younger than those from fixed sites and with only very minor difference between length and age structure between random sites that include those around Maud Island and those where they are excluded, i.e., there is some indication that larger males resided around Maud Island in 2010.

3.1.8 Population length and age composition (management area)

The scaled length frequency and age distributions for the 2010 survey are shown separately for each of the four management areas as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Figures 26–29). Only fixed sites length data are included in these analyses (see Table 2 for management area strata).

Closed area

The scaled length frequency distribution for both males and females is unimodal with mean lengths of 33.3 cm and 28.8 cm respectively and sex ratio of 3.9:1 (M:F) (Table 15, Figure 26). The cumulative distribution plots of length frequency show clearly that males have a higher proportion of larger fish than females and also that the largest fish are males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 24% for males and 46% for females, indicating that males sampled in the survey provide a reasonable representation of the overall population, but females do not because the sample size was low. Fish 30 cm and over comprise 77% of the scaled numbers (Table 15).

Age of blue cod ranged from 2 to 18 years for males and 3 to 15 years for females, but most males were between 6 and 13 years old and females between 6 and 8 years old (Figure 26). The estimated population age distributions are unimodal and skewed to the right for both sexes with the peak at about 7 years for both male and females. The cumulative distribution plots of age frequency show clearly that males have a higher proportion of older fish than females and also that the oldest fish are males. Further, the mean age of males is greater than that of females (8.9 years for males and 7.3 years for females). The MWCVs around the age distributions are 34% for males and 45% for females, indicating that fish sampled in the survey for age provide a reasonable representation of the overall population for males, but less so for females where sample numbers were low.

Fished area

The scaled length frequency distribution for both males and females is unimodal with mean lengths of 31.2 cm and 28 cm respectively and sex ratio of 2.6:1 (M:F) (Table 15, Figure 27). The cumulative

distribution plots of length frequency show clearly that males have a higher proportion of larger fish than females and also that the largest fish are males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 26% for males and 40% for females, indicating that males sampled in the survey provide a reasonable representation of the overall population, but not females because the sample size was low. Fish 30 cm and over comprise 61% of the scaled numbers (Table 15).

Age of blue cod ranged from 2 to 17 years for males and 3 to 13 years for females, but most males were between 6 and 9 years old and females between 5 and 8 years old (Figure 27). The estimated population age distributions are unimodal and skewed to the right for males with the peak at about 7 years for both sexes. The cumulative distribution plots of age frequency show clearly that males have a higher proportion of older fish than females and also that the oldest fish are males. Further, mean age of males is greater than that of females (7.6 years for males and 6.8 years for females). The MWCVs around the age distributions are 24% for males and 31% for females, indicating that fish sampled in the survey for age provide a reasonable representation of the overall population for both sexes.

Closed-Fished areas

The scaled length frequency distribution for both males and females is unimodal with mean lengths of 32.7 cm and 28.4 cm respectively and sex ratio of 3.3:1 (M:F) (Table 15, Figure 28). The cumulative distribution plots of length frequency show clearly that males have a higher proportion of larger fish than females and also that the largest fish are males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 19% for males and 36% for females, indicating that fish sampled in the survey provide a reasonable representation of the overall male population, but less so for the female population, where sample size was lower. Fish 30 cm and over comprise 72% of the scaled numbers (Table 15).

Age of blue cod ranged from 2 to 18 years for males and 3 to 15 years for females, but most males were between 6 and 13 years old and females between 6 and 8 years old (Figure 28). The estimated population age distributions are unimodal and skewed to the right for both sexes with the peak at about 7 years for both male and females. The cumulative distribution plots of age frequency show clearly that males have a higher proportion of older fish than females and also that the oldest fish are males. Further, mean age of males is greater than that of females (8.5 years for males and 7.1 years for females). The MWCVs around the age distributions are 27% for males and 32% for females, indicating that fish sampled in the survey for age provide a reasonable representation of the overall male population and less so for the female population where sample numbers were lower.

Outside area

The scaled length frequency distribution for both males and females is unimodal with mean lengths of 31.5 cm and 29 cm respectively and sex ratio of 2.4:1 (M:F) (Table 15, Figure 29). The cumulative distribution plots of length frequency show clearly that males have a higher proportion of larger fish than females and also that the largest fish are males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 22% for males and 29% for females, providing a reasonable representation of the overall population for both sexes. Fish 30 cm and over comprise 61% of the scaled numbers (Table 15).

Age of blue cod ranged from 3 to 21 years for males and 2 to 13 years for females, but most males were between 6 and 11 years old and females between 6 and 9 years old (Figure 29). The estimated population age distributions are unimodal and skewed to the right for males with the peak at about 7 years for both male and females. The cumulative distribution plots of age frequency show clearly that males have a higher proportion of older fish than females and also that the oldest fish are males. Further, mean age of males is greater than that of females (7.7 years for males and 7.0 years for females). The MWCVs around the age distributions are 37% for males and 39% for females,

indicating that fish sampled in the survey for age provide a poor representation of the overall population for both sexes.

Comparison among management areas

Cumulative plots of population length and age among the four management areas for fixed sites in 2010 show that overall male blue cod are clearly larger and older in the closed area compared to the fished and outside areas, while the combined closed-fished area is intermediate between the outside and the closed areas (Figure 30). For females there is very little difference in length among management areas, but there are slightly more older fish in the closed than the fished and outside areas (Figure 30).

3.1.9 Total mortality estimates (*Z*)

Region

Total mortality estimates (Z) and 95% confidence intervals for each region surveyed in the 2010 survey are given for a range of recruitment ages (5 to 10 y) in Table 17. For age-at-full recruitment of 6 years, mortality estimates were highest in Cook Strait (Z = 0.50), followed by D'Urville random sites (Z = 0.49), D'Urville fixed sites (Z = 0.48), Pelorus Sound random sites excluding Maud (Z = 0.48), Pelorus Sound random sites including Maud (Z = 0.39), Pelorus Sound fixed sites (Z = 0.35), and Queen Charlotte Sound (Z = 0.30).

Management area

Total mortality estimates (Z) and 95% confidence intervals for each management area surveyed in the 2010 survey are given for a range of recruitment ages (5 to 10 y) in Table 18. For age-at-full recruitment of 6 years, mortality estimates were highest in the fished (Z = 0.47), followed by outside (Z = 0.46), closed-fished (Z = 0.35), and closed areas (Z = 0.31).

3.1.10 Spawner-per-recruit analyses (SPR)

Region

The SPR curve is based on the relationship between %SPR and fishing mortality (Figure 31). The curve for the Marlborough Sounds 2010 survey is plotted for M = 0.14 (default value), and the relationship between F and %SPR for Queen Charlotte Sound in 2010 is shown on the curve as an example (Figure 31). Mortality parameters used, and the resulting $F_{\%SPR}$ values (where age-at-recruitment is 6 y), are shown in Table 19 for all regions. Based on the default M of 0.14, estimated fishing mortalities (F) and $F_{\%SPR}$ values in order from highest to lowest F values were from Cook Strait random sites (0.36, $F_{22.3\%}$), D'Urville random sites (0.35, $F_{22.7\%}$), D'Urville fixed sites (0.34, $F_{23.1\%}$), Pelorus random sites excluding Maud (0.34, $F_{23.1\%}$), Pelorus random sites including Maud (0.25, $F_{28.5\%}$), Pelorus fixed sites (0.21, $F_{32.0\%}$), and Queen Charlotte Sound fixed sites (0.16, $F_{38.1\%}$). This indicates that at the 2010 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit has been reduced to between 22% and 38% of the contribution in the absence of fishing.

Management area

Similarly, for management area in 2010, mortality parameters used and resulting $F_{\%SPR}$ values where age-at-recruitment is 6 y, are shown in Table 20. Based on the default M of 0.14, estimated fishing mortalities (F) and $F_{\%SPR}$ values ordered from of highest to lowest F values were fished (0.33, $F_{23.6\%}$), outside (0.32, $F_{24.1\%}$), closed-fished (0.21, $F_{32.0\%}$) and closed (0.17, $F_{36.7\%}$). This indicates that at the 2010 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit has been reduced to between 24% to 37% of the contribution in the absence of fishing.

3.2 Cook Strait blue cod potting survey

The complete results of the 2008 Cook Strait blue cod potting survey are shown in Appendix 4. Twenty-two fixed sites were successfully surveyed in three strata between 9 and 15 September 2008. At each site, 9 pots were set, using directed pot placement, resulting in 198 pots overall. A total of 351 kg (683 fish) of blue cod was taken. Mean catch rate was 1.5 $kg.pot^{-1}$ with a c.v. of 15%. Sex ratio was dominated by males (7.4:1 M:F). The scaled length and age frequency distributions for males and females were unimodal with mean ages for males and females of 7.8 and 5.8 y. The proportion of blue cod over the minimum legal size (30 cm and over) was 66%. The mortality estimate (*Z*) was 0.39 where age at full recruitment was 6 years, and the corresponding SPR ($F_{\%SPR}$) estimate was 28% using an M of 0.14 (Appendix 4).

3.3 Historical surveys

For the historical Marlborough Sounds surveys (1995, 1996, 2001, 2004, 2007, and 2008), catch rates are plotted by management area in Figure 32. Catch rates, catch-at-age, Z estimates, and SPR analyses by region and management area are provided for the 2001, 2004, and 2007 surveys in Appendices A to D as reference material, and 2008 in Appendix 4. Apart from 2008, no description of these outputs is provided in this results section. The results are, however, considered below in the discussion section under time series trends. The estimates of catch rates, catch-at-age, and Z presented in this report have all been carried out in accordance with the potting survey manual (Beentjes & Francis 2011). This has implications for catch rate c.v. estimation which changed from pot based to set based, although catch rates have remained pot based. Previously, total mortality was estimated using methods that differ slightly from that described in the manual. Finally, historical surveys were reanalysed using the same input parameters and software for all surveys making all results directly comparable. Hence, these results should be used in preference to those (where they are presented) in the standalone reports for these surveys.

3.4 Drift underwater video

Three replicate video transects were undertaken at 20 sites directly prior to sampling with nine replicate pots (Table 21, Figure 33). A total of 62 video transects and 180 pots were deployed at the 20 concurrently surveyed sites. The drift video surveyed 64 km of transects with an average transect width of 4.0 m (s.e. 3.5 m) covering a total area of 258 464 m^2. Within the area swept by the video method, 483 general habitat breaks were identified and 2003 fish-independent habitat quadrats were recorded within them. The video observed 861 blue cod and their associated fish based habitat quadrats, while the concurrent pots caught 936 blue cod (Table 21).

3.4.1 Species caught and observed

A total catch of 963 individuals was taken by pots at concurrently DUV surveyed sites, 97% of which were blue cod (Table 22). Bycatch from potting included 5 fish and 1 octopus species, these (ordered by numbers) were leatherjacket (*Parika scaber*), carpet shark (*Cephaloscyllium isabellum*), spotty (*Notolabrus celidotus*), octopus (*Octopus cordiformis*), red mullet (*Upeneichtys lineatus*) and tarakihi (*Nemadactylus macropterus*) (Table 22). By comparison, a total of 5033 individuals were observed in video transects, 76% of which were spotties (*Notolabrus celidotus*) and 17% were blue cod (Table 23). Nineteen other fish and one unidentified squid species were observed in the video transects, the five most common of which were butterfly perch (*Caesioperca lepidoptera*), jack mackerel

(*Trachurus* spp), snapper (*Pagrus auratus*), sweep (*Scorpis lineolatus*), and scarlet wrasse (*Pseudolabrus miles*) (Table 23).

3.4.2 Length frequency comparisons

The length frequency distributions from blue cod sampled concurrently by DUV and potting are shown in Figure 34. For the video method, the length frequency distribution is presented both for all blue cod, and for fish observed head-on to the camera excluded, so as to improve precision. The video method sampled considerably more blue cod below 29 cm (χ_1=294.0, P<0.001), but, while the sample size was low, also sampled more blue cod over 40 cm (χ_1=4.7, P=0.029), than were caught by pots (Figure 34). In contrast, pots caught proportionally more blue cod from 29–40 cm than were observed in the area sample by the drift video method (Figure 34).

3.4.3 Comparison of catch rates and counts

Blue cod densities (all fish) estimated by the area-swept drift video method were standardised to the mean number per 500 m^2 (for comparison) and plotted against the mean pot catch per site for all blue cod and for legal sized blue cod (at least 30 cm) (Figure 35). The variance was often high for both methods. The observed density of blue cod from video appeared to have little relationship with the pot catches at each site, with the relationship especially poor for recruited blue cod (Figure 35). Most sites had low observed video densities and high pot catch rates (e.g., sites 14 (MAUD) A-C, 5 (OPEL) C-J, 6 (DURE) F and M, and 7 (IPEL) D and G), while some had high video densities observed and low pot catch rates (e.g., 14 D). There were generally few recruited blue cod observed in video transects at any site outside of stratum DURE (Figure 35).

A correlation between the average density of blue cod observed per 100 m^2 and the equivalent site catch rate was only 0.27 for all and -0.19 for recruited blue cod (Figure 36). To provide better discrimination at the low end of the data, a natural log transformation is plotted in Figure 37 with subsequent correlation coefficients of 0.20 for all blue cod and -0.16 for recruited blue cod . However, when correlations are done by stratum, all are less than 0.28 except for stratum DURE (0.71 for all blue cod) and stratum IPEL (0.86 for all blue cod).

3.4.4 Benthic habitat descriptions and utilisation

The percentage of DUV observations associated with each primary substrate is shown for fish-based (blue cod by size class) and independent habitat observations in Figure 38. There were 16 primary substrate categories and 12 categories of secondary habitat structure recorded in the DUV survey (Figures 38 and 39). The most common primary substrate recorded at independent sequential video habitat quadrat observations were jagged bedrock/sand and shell grit/sand, whereas blue cod were observed proportionally more on jagged bedrock/sand/shell hash and jagged bedrock/sand (Figure 38). The most common secondary habitat structures recorded at independent observations were nothing (i.e., no structure), algal turf and macro algae, whereas blue cod were observed proportionally more frequently on tube worms, sponge, and macro algae (Figure 39).

The DUV data were further examined using the ratio of fish-based and independent habitat observations to determine whether blue cod were more commonly observed in association with certain features of the benthic environment. The most common primary substrate that fish were observed in association with for all size classes were jagged bedrock/sand and jagged bedrock/sand/shell hash (Figure 38), but it was jagged bedrock/sand/shell hash that was more frequently occupied by all size classes of blue cod (Figure 38), mainly because this category of

primary substrate was relatively uncommon in independent habitat observations. Smaller blue cod more frequently occupied patch reef/sand/shell hash and boulders/cobbles and, larger blue cod more frequently occupied shell grit/mud (Figure 38). In contrast, blue cod of all sizes were seldom associated with sand and cobbles (Figure 38).

Blue cod were most commonly observed with secondary habitat structures such as macro algae and sponge, and to a lesser extent with algal turf and bare substrate (i.e., no secondary structure). In comparison random habitat observations were predominantly bare substrate absent of secondary habitat structure (Figure 39). Using the ratio of fish-based and independent habitat observations blue cod were more frequently observed in association with macro algae, shell, sponge, and particularly tube worms (Figure 39). In contrast, blue cod of all size classes were observed less frequently in association with patch reef; rubble patches, shell hash and no structure (Figure 39).

Topographic complexity was recorded as one of four categories (flat to heavily undulating) and blue cod were most common observed in the moderately undulating category (Figure 40). In contrast, most random habitat observations were in the lowest category of topographic complexity (Figure 40). Using the ratio of fish-based and random habitat observations, both heavily and moderately undulating habitats were more frequently occupied by blue cod of all size classes in relation to their occurrence in random habitat observations, while flat and slightly undulating habitats were seldom utilised by all size classes of blue cod (Figure 40).

While the relief was generally flat throughout the Marlborough Sounds, rugosity decreased as the survey moved into the inner Sounds (Figure 41). In contrast, blue cod were most common in moderately undulating habitats, except in the stratum with the least complex habitat (IPEL) where blue cod were more common in heavily undulating habitats (Figure 41). The ratio of fish and independent habitat observations showed that heavily and moderately undulating habitats were more commonly occupied by blue cod in all strata, but that in IPEL heavily undulating habitats were extensively occupied by blue cod (Figure 41).

4. DISCUSSION

4.1 2010 Marlborough Sounds potting survey

The 2010 Marlborough Sounds blue cod potting survey is the sixth in the time series which began in 1995 (excluding the 2008 Cook Strait survey). The 2010 survey is the first of these to incorporate an experimental design to compare the effects of site type (fixed and random) on catch rates and population structure, as all previous surveys had used fixed sites. This survey is also the first to employ underwater video to estimate blue cod abundance and size structure. It is also unique in that it was carried out two years after the inner sounds were closed to fishing (closed area) and the take from the outer sounds was restricted to only three fish per person per day (fished area). Hence, the results of the 2010 survey can be compared to surveys before the closure to assess the effect of the closure on the blue cod population.

The 2010 survey was analysed by region and management area. The management areas (closed, fished, closed-fished and outside) are new and align with recent management interventions so analyses by management area for the historic surveys were *post hoc*.

In the discussion below, we deal initially with the results from the 2010 survey by region and management area, and then look at time series trends in catch rates, population structure, and stock status. Finally, we look at the effect of the 2008 closure on these population characteristics.

4.1.1 Catch rates

Region (fixed sites)

Overall the highest catch rates of all blue cod from fixed sites by region was from DUR, followed by PEL, and QCH, although there is considerable variation among strata within a region. The order was the same for the catch rates of recruited fish, but DUR and PEL were much closer (see Figures 1 and 3, Tables 4 and 5). Extremely low catch rates are found in stratum 13 in Cook Strait and stratum 1 in QCH, and high catch rates in stratum 9 at DUR.

Region (fixed and random sites)

The catch rates for all blue cod in DUR random sites were more than twice that in fixed sites from stratum 6 (DURE), and about three times as large for recruited blue cod (Figure 3, Tables 4 and 5) . In PEL the results were generally opposite, with higher catch rates in fixed sites than random sites for all blue and recruited blue cod in strata 4 and 5. However, catch rates were higher in the random sites in stratum 8 around Maud Island, the no-take area. The implication is that the Maud random sites may show slightly increased catch rates compared to those not in the no-take area. However, the entire inner sounds was a no-take area for two years before the survey, so this might explain why there are no significant differences between catch rates near Maud and those away from Maud. In south Otago the catch rates from random sites were about half those from fixed sites (Beentjes & Carbines 2011). The impact of fixed versus random sites on catch rates in Marlborough Sound will require further experimental survey work before any change to a fully random site survey can occur.

Management area (fixed sites)

Catch rates by management area are estimated using an alternative grouping of the strata (see Figure 4, Tables 6 and 7) and are highly variable among areas, but follow the same pattern for both all blue cod and recruited blue cod. For example, catch rates of all blue cod range from 0.6 to 3.9 kg.pot^{-1} in the closed area and 0.1 to 5.6 kg.pot^{-1} in the outside area. Overall, however, catch rates of all blue cod were similar in the closed and fished areas (2.48 kg.pot^{-1} and 2.43 kg.pot^{-1}, respectively), and highest in the outside area (3.40 kg.pot^{-1}) (see Table 6).

4.1.2 Sex and sex ratio

Sex ratios for all regions, site types, and management areas were male-dominated (Table 15) ranging from about 2:1 to 7:1 (M:F). 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 sex 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 the possible 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 the surveys before 2010 in Marlborough Sounds (Blackwell 1997, 1998, 2002, Beentjes & Carbines 2003, 2006, Blackwell 2006, Carbines & Beentjes 2006a, Blackwell 2008, Beentjes & Carbines 2009, Carbines & Beentjes 2009).

4.1.3 Population length and age structure

Region (fixed sites)

The results of the region based catch-at-age on fixed sites show that blue cod are clearly larger and older in Queen Charlotte Sound and Pelorus Sound than in the outer regions of D'Urville and Cook Strait, with the latter having the smallest and youngest fish (see Figure 23).

Region (fixed and random sites)

Comparisons of the 2010 fixed site and random site catch-at-age shows no discernible difference in the D'Urville region, indicating that survey site type does not affect the population structure (see Figure 24). However, blue cod caught from random sites in Pelorus Sound are slightly smaller and younger than those from fixed sites and with only very minor difference in length and age structure between random sites that include those around Maud Island and those where they are excluded, i.e., there is some indications that larger males resided around Maud Island in 2010 (see Figure 25). Off south Otago, site type had a significant influence on the length and age structure (Beentjes & Carbines 2011), but in Marlborough Sound this does not appear to be the case. One explanation for this may be that in Marlborough Sounds both random sites and fixed sites are, because of the methodology used, selected from coastline that is likely to contain blue cod habitat, whereas the south Otago strata are polygons and fixed site hotspots can have vastly different habitat than a random site within the same stratum.

Management area (fixed sites)

Results of the 2010 catch-at-age at fixed sites by management area, show that male blue cod are clearly larger and older in the closed, compared to the fished and outside areas (see Figure 30). For females, the difference is negligible, although there are higher proportions of larger and older females in the closed area compared to the other areas.

4.1.4 Stock status (*Z* and SPR)

The MPI *Harvest Strategy Standard* (Ministry of Fisheries 2008) specifies that a Fishery Plan should include a fishery target reference point, and this may be expressed in terms of biomass or fishing mortality. The more 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 2008). Based on this and recommendations from the Southern Inshore Working Group, blue cod is categorised as an exploited species with medium productivity and the recommended default proxy for F_{MSY} is $F_{40\%}$. We know, however, that the inner sounds are not closed systems and it seems likely that there has been some movement of blue cod between the inner and outer sounds. This may have changed the population age structure and the corresponding Z and SPR estimates. In addition, there have been a number of management changes in this area which will have changed the fishing mortality in the area over the lifetime of the fish in the sampled population. Estimates of total mortality are based on the assumption that recruitment and mortality are constant over the lifetime of the fish, which may not be the case within each region or within each management area. Analyses of Z and SPR were nevertheless carried out by region and management area and we discuss the implications of the results below with the understanding that these may be non-informative in some cases.

Region

The 2010 survey mortality estimates (*Z*) with age-at-full recruitment set at 6 years, are lower for Pelorus Sound and Queen Charlotte Sound than for Cook Strait and D'Urville, a reflection of the age structure derived from fixed sites in these regions in 2010 (Table 15). The corresponding SPR estimates using the default M value of 0.14 indicated that the expected contribution to the spawning biomass over the lifetime of an average recruit in Queen Charlotte Sound and Pelorus Sound regions

has been reduced to 38% and 32%, respectively, of the contribution in the absence of fishing. Similarly, for the Cook Strait and D'Urville regions, the SPR values were 22% and 23%, respectively (Table 15), and are less than the F_{MSY} target reference point of $F_{40\%}$. In contrast, for the Pelorus and Queen Charlotte Sounds, the level of exploitation is close to the target reference point of 40%. These results are consistent with the population recovering after closures of the inner Marlborough Sounds in 2008, where there has been no subsequent fishing mortality.

Management area

The expected contribution to the spawning biomass over the lifetime of an average recruit in the closed area is 37% compared to 24% in both the fished and outside areas (Table 15). Again these results are consistent with the population recovering after closures of the inner Marlborough Sounds in 2008. Indeed, within the closed area the SPR of 37% is close to the F_{MSY} target reference point of $F_{40\%}$.

4.2 Time series of catch rates

The catch rates from the 1995 to 2007 surveys are shown by region and management area in Appendix A and are plotted by management area, including 2010 catch rates, in Figure 32. From a fisheries management perspective we confine our discussion to the results by management area (Figure 32), but as mentioned, these management areas did not exist when the historic surveys (1995 to 2007) were carried out and hence the analyses by management area are *post hoc*. From 2001 to 2007, catch rates of all blue cod in the closed area were between about 0.5 and 0.8 kg.pot^{-1}, but they increased more than three-fold in 2010 to 2.48 kg.pot^{-1}. Catch rates from 1995 and 1996 were not reanalysed here, but the reports of these surveys indicate that catch rates in the closed area were about 1.8 kg.pot^{-1} (Blackwell 1997, 1998). We recommend caution in accepting the 1995 and 1996 published catch rates because the 1995 survey catch rates differ to those presented in the 1996 report and for consistency these should be estimated using the manual standards. In contrast, in the fished area, catch rates of all blue cod have declined gradually from 2001 to 2010 (3.34 kg.pot^{-1} to 2.43 kg.pot^{-1}), although there is no similar trend for recruited blue cod. For the 1995 and 1996 surveys the catch rate averaged about 4 kg.pot^{-1}, but the strata surveyed were not the same in each year. The outside area shows no trend in either all blue cod or recruited blue cod catch rates, but data are available from only three surveys (2007, 2008 and 2010).

In summary, it appears that catch rates in the closed area that corresponds to the inner sounds, declined from the mid 1990s to 2001, where they were low and stable until 2010 when they increased dramatically. The fished area showed a gradual decline in all blue cod, and the outside area showed no trends in catch rates over time.

4.3 Time series of catch at age

For the 2001, 2004, and 2007 surveys of the Marlborough Sounds, *post hoc* analyses of catch-at-age by management area clearly show that male and female blue cod were larger and older in the fished, compared to the closed management area (Appendices B4, B9, and B14). The 2004 and 2007 surveys also include catch-at-age from the outside management area; for 2007 this includes Cook Strait (2008 survey) and west of D'Urville Island (Appendix B14), and for 2004 only the latter (B9). In both 2004 and 2007 surveys, blue cod in the outside area were larger and older than those in the fished and closed areas.

Temporal trends in catch-at-age within each of the four management areas is described below.

Closed area –There was significant change in population size and age structure within the closed area between the historical surveys (2001, 2004, and 2007) and the 2010 survey, with blue cod of both sexes considerably larger and older in 2010 (Appendix C1). The 2010 survey was carried out two years after the closure of the inner Sounds and the marked changes in population size and age structure appear to be a result of the fishing ban in these areas since October 2008.

Fished area – The temporal changes are less straightforward in the fished area (Appendix C2). In 2010, blue cod are clearly larger and older than in 2001 and 2004, but the length distributions in 2007 and 2010 are virtually identical, despite there being many more young fish in 2007 than in any other year. This indicates that either growth was faster in 2007 and/or in the preceding years, or this anomaly is a result of ageing error (Appendix C2). The reduced daily limit of just three fish from the fished area may have contributed to larger size and age than previous surveys, although the data from 2007 is not consistent with this finding.

Closed-Fished area – The results for this area are a composite of the closed and fished areas. For both sexes, but especially males, there is a clear difference between 2010 and all surveys before, with larger and older fish present in 2010 (Appendix C3).

Outside area – There are three surveys that included strata corresponding to the outside area: 2004, 2007 and 2010. For both sexes the length distributions are similar between years but the age structure in 2004 and 2010 has many more older fish than in 2007 (Appendix C4). Again, this may be related to either growth differences or to ageing error. There have been no changes in the fishing regulations that apply to the outside area between these surveys and they are open access.

4.4 Time series of *Z* and SPR

The temporal trends in catch-at-age from 2001 through to 2010 by management area (Appendices B4, B9, B14) show clearly that before 2010, blue cod from the fished area were consistently larger and older than in those in the closed area. In contrast, in 2010 blue cod in the closed area are on average larger and older than those in the fished area (Figure 30). The fished area age structure has not changed to any degree over time and the change is a result of an increase in average size and age of blue cod in the closed area since its closure. Accordingly, the Z and SPR estimates reflect this change. For example, the Z estimate and SPR for the closed area in 2001 was 0.50 and 18% (Appendices D12–D14), compared to 0.31 and 37% in 2010 (Table 15).

4.5 Effect of the 2008 closure

The closure of the inner Sounds to all fishing between 1 October 2008 and December 2010 when the survey was carried out has clearly had a dramatic effect on the population size and age structure, and abundance inside the closed area. For the first time since 2001, and presumably for many years before this, blue cod are larger and more abundant within the inner, than the outer, Marlborough Sounds, suggesting that the management initiative has been successful in restoring a more natural population structure to the inner sounds. However, we do note that there is likely to have been movement of blue cod from the outer to the inner sounds which has contributed to the improved size and age structure and that the change is not necessarily strictly related to growth of individual fish resident within these areas.

4.6 Drift underwater video (DUV)

4.6.1 Comparisons between pot catch and DUV observation

For each blue cod potting survey, fishing gear, bait type and soak time are standardised (see Beentjes & Francis 2011), but other factors such as fish behaviour and environmental features can influence catchability and size selectivity in passive capture methods such as potting (Furevik 1994, Fogarty & Addison 1997, Robichaud et al. 2000). Cole et al. (2001) found blue cod catch rates unrelated to both time and tide in the Marlborough Sounds. However, when compared to diver transects, pots tended to under-sample small blue cod, being selective for fish over 15 cm (Cole et al. 2001, Cole et al. 2003). While there was a positive relationship between blue cod catch from pots (pot plan 1 from Beentjes & Francis 2011) and diver transects, it was weak and much of the variation remained unexplained (Cole et al. 2001).

In the 2010 Marlborough Sounds potting survey we used concurrent observations of blue cod abundance and habitat descriptions from the DUV method to investigate the relationship between count and size estimates of blue cod over a known area with catch rates and sizes of blue cod caught in survey pots (pot plan 1 in Beentjes & Francis 2011).

Does potting provide an index of fish community structure?

The DUV method observed about twice as many species as the pots caught in the 2010 Marlborough Sounds survey (Tables 22 and 23). Pots clearly select benthic carnivores and do not fully reflect community structure.

Does potting provide a representative size structure of blue cod populations?

Pots caught proportionately far more blue cod from 29 to 40 cm, and dramatically under sampled smaller blue cod compared to the DUV method (Figure 34). While few blue cod were observed or caught over 40 cm (18 observed and 11 caught in total), significantly (χ_1=4.7, P=0.029) more of these large fish were observed using the DUV than were caught in pots (Figure 34). This is more clearly illustrated by plotting the proportions of fish 29 cm and over (Figure 42).

The pots used in the Marlborough Sounds blue cod surveys (pot plan 1 from Beentjes & Francis 2011) demonstrated considerably more size selectivity than observed for pot plan 2 used in all other areas (Carbines & Beentjes 2012). As the pots are not designed to catch very small fish, it is clear that the results of potting surveys in the Marlborough Sounds are most effective for assessing trends for recruited blue cod (at least 30 cm) and that the results for these surveys should be interpreted accordingly. There is also potential size selectivity of pot plan 1 that may under-represent fish over 40 cm (Figure 42) and this should be investigated further.

Pots used in the Marlborough Sounds (pot plan 1) are different to those used in other survey areas (pot plan 2, Beentjes & Francis 2011). Most notably, pots based on plan 1 are not completely covered in a fine mesh (only the bottom is covered) and have a larger spacing between the bars of the entrance cones (necks) which would explain why small fish are not well retained in these pots. Pots based on plan 1 also have much smaller entrances and necks than plan 2 pots (which are based on a commercial BCO 5 design) and it is possible that these small entrances reduce the catchability of larger blue cod. To help resolve this we recommend that a future study compares the length frequency distributions from both pot types used concurrently in an area with abundant large fish.

Does potting provide an index of blue cod relative abundance?

The results of this study showed a very poor relationship between observed blue cod densities from video and pot catch rates; considerably worse than the relationship observed by Cole et al (2001) using SCUBA counts and pot catches (pot plan 1) of blue cod in the Marlborough Sounds. However,

considerably better correlation coefficients were observed between densities from DUV and pot catches (pot plan 2) of blue cod in Foveaux Strait (Carbines & Beentjes 2012).

In the Marlborough Sounds there were instances of high densities observed on video with concurrent low pot catch rates. This did not occur in Foveaux Strait (Carbines & Beentjes 2012). However, in both the Marlborough Sounds and Foveaux Strait there were several sites where fish were caught when few were observed on video (Figure 35). While it is possible that large blue cod were able to avoid detection in the video method, this seems unlikely as the video recorded proportionally more blue cod over 40 cm (Figure 42), and because larger blue cod are easier to detect by the video observer than are the more cryptic smaller fish (Figure 35). It therefore seems more likely that blue cod populations are either highly clumped within the survey area and missed by the video method's relatively narrow swath, or that pots are attracting blue cod in from a distance greater than the area surveyed by video. It is also clear that the relationship between pot catch and video count (i.e., catchability) is highly variable among locations. These effects are currently under investigation and will be reported elsewhere in the near future.

4.6.2 Importance of recording habitat for blue cod potting surveys

Using the ratios between benthic habitat categories observed adjacent to blue cod and those observed independently throughout the survey area it was possible to identify four primary substrate types and four secondary habitat structures that appear to be particularly important to blue cod in the Marlborough Sounds (Figures 38 and 39). Blue cod were more frequently observed in association with jagged bedrock/sand/shell hash and the secondary habitat structure tube worms (Figures 38 and 39), while blue cod were more frequently absent from areas of homogenous sand (all variations of) and areas without any secondary habitat structure (Figures 38 and 39). These results were mirrored by measures of topographic complexity (Figure 40) and highlighted the increasing importance of complex heterogeneous habitats in more homogonous areas such as IPEL (Figure 41).

In the Marlborough Sounds most of the benthic habitat is flat soft sediment devoid of structure, and there is only a narrow shallow band of heterogeneous primary substrate utilised by blue cod. Furthermore, secondary habitat structures important to blue cod, such as macro algae, sponges, and tube worms are fragile biogenic structures that are easily damaged both by physical impact and sedimentation (e.g., Lotze et al. 2006, Airoldi & Beck 2007) and require heterogeneous primary substrate (i.e., primary substrate and secondary habitat features are inter-related). The results presented here suggest that any form of homogenisation or other physical damage to these benthic environments in the Marlborough Sounds would be detrimental to blue cod populations.

Data on fish size and abundance from drift video and *in situ* habitat data increases our understanding of the physical factors driving blue cod distribution. It identifies benthic habitats and structures of particular importance (i.e., possible essential fish habitats) and allows the for the development of habitat maps which will be particularly important in terms of stratifying future surveys for more accurate scaling of relative abundance estimates (Stephenson et al. 2009). This also provides habitat information for assessing changes to the physical environment in the Marlborough Sounds and assessing other management approaches such as protection of critical habitat structures and zoning of activities.

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Table 1: Marlborough Sounds 2010 potting survey effort and catch summary by site type. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville; CKST, Cook Strait; 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 west; DURE, D'Urville east; APAE, Arapawa Island east; UNDW, Port Underwood, COOK, Cook Strait. *, includes three sites around Maud Island; **, includes one site at Maud Island.

									Depth (m)	
Region	Stratum	Stratum 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	5	45	52	26.9	11.1	6.4	20.3
QCH	2	OQCH	176.6	Fixed	5	45	214	115.1	12.3	6.4	28.9
QCH	3	EQCH	83.1	Fixed	7	63	240	118	10.9	2.9	29.3
PEL	4	EOPE	69.5	Fixed	4	36	276	127	14.6	6.4	29.3
PEL	5	OPEL	94.8	Fixed	4	36	255	139.1	11.2	5.5	16.5
DUR	6	DURE	105.1	Fixed	6	54	293	116	13.4	4.6	36.6
PEL	7	IPEL	100.1	Fixed	3	27	113	67.1	10.4	6.2	21.0
PEL	8	MPEL	72.3	Fixed	5	45	136	72.1	9.4	4.2	17.4
DUR	9	DURW	96.2	Fixed	10	90	1 054	508	18.4	7.3	33.8
Totals					49	441	2 633	1289			
PEL	4	EOPE	69.5	Random	4	36	206	88.6	8.5	3.1	22.0
PEL	5	OPEL	94.8	**Random	5	45	188	90.5	12.4	3.8	20.7
DUR	6	DURE	105.1	Random	6	54	548	256.4	16.7	5.5	42.1
PEL	8	MPEL	72.3	*Random	3	27	100	57.1	13.5	4.0	21.0
CKST	11	APAE	21.6	Random	4	36	124	58.2	15.1	6.0	23.8
CKST	12	COOK	30	Random	6	54	217	93.7	16.1	6.0	28.9
CKST	13	UNDW	34	Random	6	54	20	5.8	11.7	5.5	20.3
Totals					34	306	1 403	650.3			
Grand total					83	747	4 036	1 940			

Table 2: Location of blue cod potting survey strata (in surveys from 2001 to 2010) with respect to Marlborough Sounds management areas that were in place since 1 October 2008. The site type used on the surveys is also shown (see Appendix 1 for terminology). Closed = no-take area, fished = whole landed area, outside = all strata outside of fished or closed areas. See Figure 2 for management areas.

Survey (trip_code)	Management area	Strata	Site type
2001 (lhr0101)	Closed	1, 2, 5, 7, and 8	Fixed
	Fished	3, 4, and 6	Fixed
	Closed-fished	1 to 8	Fixed
	Outside	none	
2004 (lhr0401)	Closed	1, 2, 5, 7, and 8	Fixed
	Fished	3, 4, and 6	Fixed
	Closed-fished	1 to 8	Fixed
	Outside	9 and 10	Fixed
2007 (lhr0701)	Closed	1, 2, 5, 7, and 8	Fixed
	Fished	3, 4, and 6	Fixed
	Closed-fished	1 to 8	Fixed
	Outside	9 and 10	Fixed
2008 (jug0801)	Outside	11 to 13	Fixed
2010 (lhr1001)	Closed	1, 2, 5, 7, and 8	Fixed
	Fished	3, 4, and 6	Fixed
	Closed-fished	1 to 8	Fixed
	Outside	9	Fixed
	Outside	11 to 13	Random

Table 3: Total numbers of blue cod and bycatch species caught on the 2010 Marlborough Sounds potting survey.

Common name	Species	Species code	*N*	%
Blue cod	*Parapercis colias*	BCO	4 036	93.08
Triplefin	*Forsterygion varium/Grahamina capito*	TRP	63	1.45
Scarlet wrasse	*Pseudolabrus miles*	SPF	57	1.31
Leatherjacket	*Parika scaber*	LEA	47	1.08
Banded wrasse	*Notolabrus fucicola*	BPF	44	1.01
Tarakihi	*Nemadactylus macropterus*	TAR	25	0.58
Spotty	*Notolabrus celidotus*	STY	21	0.48
Octopus		OCT	14	0.32
Carpet shark	*Cephaloscyllium isabellum*	CAR	10	0.23
Sea perch	*Helicolenus percoides*	SPE	10	0.23
Conger eel	*Conger verreauxi*	CON	4	0.09
Goatfish	*Upeneichthys lineatus*	RMU	3	0.07
Marblefish	*Aplodactylus arctidens*	GTR	1	0.02
Hagfish	*Eptatretus cirrhatus*	HAG	1	0.02

Table 4: Mean blue cod catch rates for all blue cod caught from the 2010 Marlborough Sounds potting survey by region. Catch rates are pot-based, and s.e. and c.v. are set-based. s.e., standard error; c.v. coefficient of variation; QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville; CKST, Cook Strait. Random site catch rates in Pelorus are shown for sites including and excluding those around Maud Island.

Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
QCH	1	Fixed	45	0.60	0.31	51.4
	2	Fixed	45	2.56	0.63	24.5
	3	Fixed	63	1.87	0.21	11.3
	Overall	Fixed	153	2.09	0.37	17.8
PEL	4	Fixed	36	3.53	0.49	14.0
	5	Fixed	36	3.86	0.27	6.9
	7	Fixed	27	2.49	1.08	43.5
	8	Fixed	45	1.60	0.54	33.6
	Overall	Fixed	144	2.90	0.36	12.6
PEL	4	Random	36	2.46	1.03	41.8
	5	Random (incl. Maud)	45	2.01	0.37	18.3
	8	Random (incl. Maud)	27	2.11	0.80	38.0
	Overall	Random	108	2.17	0.42	19.1
PEL	4	Random	36	2.46	1.03	41.8
	5	Random (excl. Maud)	36	1.93	0.46	24.0
	8	Random (excl. Maud)	0	–	–	–
	Overall	Random	72	2.16	0.51	23.7
DUR	6	Fixed	54	2.15	0.24	11.2
	9	Fixed	90	5.64	0.55	9.8
	Overall	Fixed	144	3.82	0.29	7.7
DUR	6	Random	54	4.75	0.82	17.3
CKST	11	Random	36	1.62	0.73	45.1
	12	Random	54	1.74	0.42	24.0
	13	Random	54	0.11	0.09	88.2
	Overall	Random	144	1.06	0.24	22.5

Table 5: Mean blue cod catch rates for recruited blue cod (30 cm and over) caught during the 2010 Marlborough Sounds potting survey, by region. Catch rates are pot-based, and s.e. and c.v. are set-based. s.e., standard error; c.v. coefficient of variation; QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville; CKST, Cook Strait. Random site catch rates in Pelorus are shown for sites including and excluding those around Maud Island.

Region	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	c.v. (%)
QCH	1	Fixed	45	0.48	0.25	51.7
	2	Fixed	45	2.18	0.54	24.9
	3	Fixed	63	1.49	0.20	13.5
	Overall	Fixed	153	1.75	0.32	18.5
PEL	4	Fixed	36	2.81	0.36	12.9
	5	Fixed	36	3.55	0.26	7.2
	7	Fixed	27	2.24	0.97	43.4
	8	Fixed	45	1.38	0.42	30.3
	Overall	Fixed	144	2.54	0.32	12.6
PEL	4	Random	36	1.93	0.80	41.4
	5	Random (incl. Maud)	45	1.68	0.33	19.6
	8	Random (incl. Maud)	27	1.94	0.74	38.1
	Overall	Random	108	1.83	0.35	19.2
PEL	4	Random	36	1.93	0.80	41.4
	5	Random (excl. Maud)	36	1.56	0.40	25.3
	8	Random (excl. Maud)	0	–	–	–
	Overall	Random	72	1.72	0.41	23.8
DUR	6	Fixed	54	1.36	0.23	16.7
	9	Fixed	90	4.27	0.45	10.6
	Overall	Fixed	144	2.75	0.25	8.9
DUR	6	Random	54	3.76	0.73	19.4
CKST	11	Random	36	1.23	0.55	44.2
	12	Random	54	1.22	0.32	26.5
	13	Random	54	0.03	0.02	65.7
	Overall	Random	144	0.75	0.18	23.8

Table 6: Mean blue cod catch rates for all blue cod caught during the 2010 Marlborough Sounds potting survey by management area. Catch rates are pot-based, and s.e. and c.v. are set-based. s.e., standard error; c.v. coefficient of variation.

Management area	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	c.v. (%)
Closed	1	Fixed	45	0.60	0.31	51.4
	2	Fixed	45	2.56	0.63	24.5
	5	Fixed	36	3.86	0.27	6.9
	7	Fixed	27	2.49	1.08	43.5
	8	Fixed	45	1.60	0.54	33.6
	Overall		198	2.48	0.33	13.4
Fished	3	Fixed	63	1.87	0.21	11.3
	4	Fixed	36	3.53	0.49	14.0
	6	Fixed	54	2.15	0.24	11.2
	Overall		153	2.43	0.18	7.4
Closed-Fished	1	Fixed	45	0.60	0.31	51.4
	2	Fixed	45	2.56	0.63	24.5
	3	Fixed	63	1.87	0.21	11.3
	4	Fixed	36	3.53	0.49	14.0
	5	Fixed	36	3.86	0.27	6.9
	6	Fixed	54	2.15	0.24	11.2
	7	Fixed	27	2.49	1.08	43.5
	8	Fixed	45	1.60	0.54	33.6
	Overall		351	2.46	0.23	9.2
Outside	9	Fixed	90	5.64	0.55	9.8
	11	Random	36	1.62	0.73	45.1
	12	Random	54	1.74	0.42	24.0
	13	Random	54	0.11	0.09	88.2
	Overall		234	3.49	0.31	9.0

Table 7: Mean blue cod catch rates for recruited blue cod (30 cm and over) caught during the 2010 Marlborough Sounds potting survey by management area. Catch rates are pot-based, and s.e. and c.v. are set-based. s.e., standard error; c.v. coefficient of variation.

Management area	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	c.v. (%)
Closed	1	Fixed	45	0.48	0.25	51.7
	2	Fixed	45	2.18	0.54	24.9
	5	Fixed	36	3.55	0.26	7.2
	7	Fixed	27	2.24	0.97	43.4
	8	Fixed	45	1.38	0.42	30.3
	Overall		198	2.19	0.29	13.3
Fished	3	Fixed	63	1.49	0.20	13.5
	4	Fixed	36	2.81	0.36	12.9
	6	Fixed	54	1.36	0.23	16.7
	Overall		153	1.79	0.15	8.3
Closed-Fished	1	Fixed	45	0.48	0.25	51.7
	2	Fixed	45	2.18	0.54	24.9
	3	Fixed	63	1.49	0.20	13.5
	4	Fixed	36	2.81	0.36	12.9
	5	Fixed	36	3.55	0.26	7.2
	6	Fixed	54	1.36	0.23	16.7
	7	Fixed	27	2.24	0.97	43.4
	8	Fixed	45	1.38	0.42	30.3
	Overall		351	2.05	0.20	9.6
Outside	9	Fixed	90	4.27	0.45	10.6
	11	Random	36	1.23	0.55	44.2
	12	Random	54	1.22	0.32	26.5
	13	Random	54	0.03	0.02	65.7
	Overall		234	2.61	0.25	9.7

Table 8: Weighted mean lengths and weighted sex ratio (M:F) for all blue cod by stratum in the 2010 Marlborough Sounds survey (Cook Strait region – random sites).

			Length (cm)			
Stratum	Sex	N	Mean	Minimum	Maximum	Sex ratio M:F (% male)
11	m	112	30.6	19	40	11.3:1(91.9%)
	f	10	27.7	22	33	
	u	3	–	22	31	
12	m	180	30.5	19	48	4.8:1 (82.9%)
	f	37	25.6	14	35	
	u	0	–	–	–	
13	m	9	28.8	25	33	0.82:1 (45%)
	f	11	23.6	18	28	
	u	0	–	–	–	
Overall	m	301	30.5	19	48	5.2:1 (83.9%)
	f	58	25.6	14	35	
	u	3	–	22	31	

Table 9: Weighted mean lengths and weighted sex ratio (M:F) for all blue cod by stratum in the 2010 Marlborough Sounds survey (D'Urville region – fixed sites).

			Length (cm)			
Stratum	Sex	N	Mean	Minimum	Maximum	Sex ratio M:F (% male)
6	m	167	30.4	15	45	1.3:1 (56.8%)
	f	126	27.7	20	36	
	U	0	–			
9	m	709	31.8	19	48	2.1:1 (67.9%)
	f	335	29.3	19	40	
	U	9	–	23	35	
Overall	m	876	31.3	15	48	1.8:1 (64.2%)
	f	461	28.7	19	40	
	U	9	–	23	35	

Table 10: Weighted mean lengths and weighted sex ratio (M:F) for all blue cod by strata in the 2010 Marlborough Sounds survey (D'Urville region – random sites).

			Length (cm)			
Stratum	Sex	N	Mean	Minimum	Maximum	Sex ratio M:F (% male)
6	m	404	31.5	20	44	3:1 (75.2%)
	f	134	29.1	19	35	
	U	10	–	15	33	

Table 11: Weighted mean lengths and weighted sex ratio (M:F) for all blue cod by stratum in the 2010 Marlborough Sounds survey (Pelorus Sound region – fixed sites).

			Length (cm)			
Stratum	Sex	N	Mean	Minimum	Maximum	Sex ratio M:F (% male)
4	m	215	31.5	24	39	6.0:1 (85.7%)
	f	36	28.6	18	33	
	u	25		27	35	
5	m	227	33.0	17	40	8.2:1 (89.1%)
	f	28	28.7	21	32	
	u	0				
7	m	96	33.9	27	39	8.8:1 (89.8%)
	f	11	28.5	24	31	
	u	6		24	33	
8	m	107	33.1	21	43	3.7:1 (78.7%)
	f	29	27.2	20	34	
	u	0				
Overall	m	645	32.8	17	43	6.8:1 (87.1%)
	f	104	28.3	18	34	
	u	31		24	35	

Table 12: Weighted mean lengths and weighted sex ratio (M:F) for all blue cod by strata in the 2010 Marlborough Sounds survey (Pelorus Sound region – random sites including those around Maud Island).

			Length (cm)			
Stratum	Sex	N	Mean	Minimum	Maximum	Sex ratio M:F (% male)
4	m	156	31.2	22	41	5.8:1 (85.2%)
	f	27	27.6	20	33	
	u	23		25	36	
5	m	150	31.9	18	43	3.9:1 (79.7%)
	f	38	26.9	10	35	
	u	0				
8	m	90	33.6	20	41	9.1:1 (90.1%)
	f	10	27.1	21	33	
	u	0				
Overall	m	396	32.1	18	43	5.4:1 (84.3%)
	f	75	27.2	10	35	
	u	23		25	36	

Table 13: Weighted mean lengths and weighted sex ratio (M:F) for all blue cod by strata in the 2010 Marlborough Sounds survey (Pelorus Sound region – random sites excluding those around Maud Island).

			Length (cm)			
Stratum	Sex	N	Mean	Minimum	Maximum	Sex ratio M:F (% male)
4	m	156	31.2	22	41	5.8:1 (85.2%)
	f	27	27.6	20	33	
	u	23		26	36	
5	m	110	31.5	18	43	3.1:1 (75.5%)
	f	36	27.8	15	35	
	u	0				
Overall	m	266	31.4	18	43	4.2:1 (80.6%)
	f	63	27.7	15	35	
	u	23		26	36	

Table 14: Weighted mean lengths and weighted sex ratio (M:F) for all blue cod by strata in the 2010 Marlborough Sounds survey (Queen Charlotte Sound region – fixed sites).

			Length (cm)			
Stratum	Sex	N	Mean	Minimum	Maximum	Sex ratio M:F (% male)
1	m	35	33.2	22	40	2.3:1 (69.9%)
	f	15	27.3	19	35	
	u	2	–	32	33	
2	m	145	33.7	23	45	2.1:1 (68.1%)
	f	69	29.2	20	37	
	u	0	–	–	–	
3	m	157	32.1	24	45	4.1:1 (80.3%)
	f	38	28.6	17	39	
	u	45	–	26	35	
Overall	m	337	33.2	22	45	2.4:1 (71%)
	f	122	29.0	17	39	
	u	47	–	26	35	

Table 15: Marlborough Sounds 2010 survey summary of age, length, sex ratio, proportion recruited, total mortality (*Z*), $F_{\%SPR}$, and catch rates (all blue cod) by region (panel a) and management area (panel b). R, random sites; F, fixed sites; incl. M, including sites around Maud Island; excl. M, excluding sites around Maud Island. Estimate of $F_{\%SPR}$ is for age at recruitment of 6 years and M = 0.14.

(a)

Region	Mean age (y)		Mean length (cm)						
	Male	Female	Male	Female	30 cm & over (%)	Sex ratio (M:F)	*Z*	$F_{\%SPR}$	Catch rate (kg.pot^{-1}) (c.v. %)
CSKT (R)	7.3	5.9	30.5	25.6	50	5.2:1	0.51	22.3	1.06 (22.5)
DUR (F)	7.6	6.9	31.3	28.7	58	1.8:1	0.48	23.1	3.82 (7.7)
DUR (R)	7.5	7.0	31.5	29.1	68	3.1:1	0.49	22.7	4.75 (17.3)
PEL (F)	8.4	6.8	32.8	28.3	79	6.8:1	0.35	32.0	2.9 (12.6)
PEL (R incl. M.)	8.0	6.5	32.1	27.2	72	5.4:1	0.39	28.5	2.17 (19.1)
PEL (R excl. M)	7.5	6.6	31.4	27.7	67	4.2:1	0.48	23.1	2.16 (23.7)
QCH (F)	9.2	7.6	33.2	29.0	72	2.4:1	0.30	38.1	2.09 (17.8)

(b)

Management area	Mean age (y)		Mean length (cm)						
	Male	Female	Male	Female	30 cm & over (%)	Sex ratio (M:F)	Z	$F_{\%SPR}$	Catch rate (kg.pot^{-1}) (c.v. %)
Closed	8.9	7.3	33.3	28.8	77	3.9:1	0.31	36.7	2.48 (13.4)
Fished	7.6	6.8	31.2	28.0	61	2.6:1	0.47	23.6	2.43 (7.4)
Closed-fished	8.5	7.1	32.7	28.4	72	3.3:1	0.35	32.0	2.46 (9.2)
Outside	7.7	7.0	31.5	29.0	62	2.4:1	0.46	24.1	3.49 (9.0)

Table 16: Gonad stages of Marlborough Sounds blue cod in September-October 2010 by region. 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent; CKST, Cook Strait; DUR, D'Urville; PEL, Pelorus Sound; QCH, Queen Charlotte Sound.

Region	Size status	Sex	Gonad stage %					N
			1	2	3	4	5	
CKST	Pre-recruits (<30 cm)	Males	20.8	47.7	8.5	10.0	13.1	130
		Females	36.7	40.0	13.3	5.0	5.0	60
	Recruits (30 cm+)	Males	0.3	34.0	18.9	32.7	10.6	312
		Females	0.0	36.4	27.3	18.2	9.1	11
DUR	Pre-recruits (<30 cm)	Males	0.8	5.0	37.7	56.5	0.0	379
		Females	0.0	12.8	71.7	8.5	6.1	329
	Recruits (30 cm+)	Males	0.0	2.0	39.5	58.1	0.5	887
		Females	0.0	3.8	73.5	9.8	6.6	287
PEL	Pre-recruits (<30 cm)	Males	4.5	20.8	51.3	23.4	0.0	154
		Females	6.0	45.0	45.0	1.0	3.0	100
	Recruits (30 cm+)	Males	0.0	6.5	60.2	33.3	0.0	706
		Females	0.0	31.3	53.7	11.9	3.0	67
QCH	Pre-recruits (<30 cm)	Males	3.8	55.8	17.3	23.1	0.0	52
		Females	2.8	38.0	49.3	9.9	0.0	71
	Recruits (30 cm+)	Males	0.9	48.9	27.8	20.7	1.8	227
		Females	0.0	18.0	52.0	26.0	0.0	50

Table 17: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod from each region surveyed in the 2010 Marlborough Sounds potting survey. AgeR, age at full recruitment.

Region (site type)	ageR	*Z*	lowerCI	upperCI
D'Urville (fixed sites)	5	0.35	0.25	0.46
	6	0.48	0.33	0.66
	7	0.61	0.42	0.84
	8	0.57	0.38	0.8
	9	0.55	0.35	0.78
	10	0.50	0.31	0.73
D'Urville (random sites)	5	0.34	0.24	0.47
	6	0.49	0.32	0.69
	7	0.67	0.43	0.94
	8	0.70	0.43	1.05
	9	0.68	0.4	1.09
	10	0.57	0.29	0.95
Pelorus (fixed sites)	5	0.27	0.19	0.37
	6	0.35	0.25	0.48
	7	0.39	0.27	0.54
	8	0.38	0.26	0.53
	9	0.36	0.23	0.49
	10	0.42	0.27	0.61
Pelorus (random sites incl. Maud)	5	0.30	0.21	0.41
	6	0.39	0.27	0.54
	7	0.41	0.27	0.58
	8	0.39	0.26	0.56
	9	0.35	0.23	0.51
	10	0.41	0.25	0.61
Pelorus (random sites excl. Maud)	5	0.35	0.24	0.47
	6	0.48	0.33	0.66
	7	0.5	0.32	0.7
	8	0.47	0.29	0.69
	9	0.38	0.23	0.55
	10	0.41	0.24	0.62
Queen Charlotte Sound (fixed sites)	5	0.23	0.17	0.31
	6	0.30	0.21	0.4
	7	0.36	0.25	0.5
	8	0.40	0.27	0.56
	9	0.38	0.24	0.55
	10	0.38	0.24	56%
Cook Strait (random sites)	5	0.37	0.26	0.5
	6	0.50	0.33	0.7
	7	0.58	0.38	0.84
	8	0.69	0.43	1.03
	9	0.75	0.42	1.13
	10	0.82	0.42	1.35

Table 18: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod from each management area surveyed in the 2010 Marlborough Sounds potting survey. AgeR, age at full recruitment.

Management area	ageR	Z	lowerCI	upperCI
Closed	5	0.24	0.18	0.32
	6	0.31	0.22	0.4
	7	0.35	0.25	0.47
	8	0.37	0.26	0.5
	9	0.36	0.25	0.5
	10	0.41	0.27	0.56
Fished	ageR	Z	lowerCI	upperCI
	5	0.34	0.24	0.45
	6	0.47	0.34	0.65
	7	0.57	0.4	0.77
	8	0.55	0.38	0.74
	9	0.43	0.29	0.59
	10	0.4	0.26	0.57
Closed and Fished	ageR	Z	lowerCI	upperCI
	5	0.27	0.2	0.36
	6	0.35	0.25	0.46
	7	0.4	0.28	0.55
	8	0.4	0.29	0.55
	9	0.37	0.26	0.52
	10	0.41	0.27	0.56
Outside	ageR	Z	lowerCI	upperCI
	5	0.33	0.24	0.47
	6	0.46	0.32	0.64
	7	0.58	0.37	0.82
	8	0.56	0.33	0.86
	9	0.56	0.32	0.87
	10	0.52	0.3	0.82

Table 19: Mortality parameters (*Z*, *F*, and *M*) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* for each region surveyed in the 2010 Marlborough Sounds survey. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality. AgeR = 6.

Region (site type)	*M*	*Z*	*F*	$F_{\%SPR}$
D'Urville (fixed sites)	0.11	0.48	0.37	$F_{16.6\%}$
	0.14	0.48	0.34	$F_{23.1\%}$
	0.17	0.48	0.31	$F_{30.2\%}$
D'Urville (random sites)	0.11	0.49	0.38	$F_{16.3\%}$
	0.14	0.49	0.35	$F_{22.7\%}$
	0.17	0.49	0.32	$F_{29.6\%}$
Pelorus (fixed sites)	0.11	0.35	0.24	$F_{23.1\%}$
	0.14	0.35	0.21	$F_{32.0\%}$
	0.17	0.35	0.18	$F_{41.6\%}$
Pelorus (random sites incl. Maud)	0.11	0.39	0.28	$F_{20.5\%}$
	0.14	0.39	0.25	$F_{28.5\%}$
	0.17	0.39	0.22	$F_{37.0\%}$
Pelorus (random sites excl. Maud)	0.11	0.48	0.37	$F_{16.6\%}$
	0.14	0.48	0.34	$F_{23.1\%}$
	0.17	0.48	0.31	$F_{30.2\%}$
Queen Charlotte Sound (fixed sites)	0.11	0.30	0.19	$F_{27.6\%}$
	0.14	0.30	0.16	$F_{38.1\%}$
	0.17	0.30	0.13	$F_{49.4\%}$
Cook Strait (random sites)	0.11	0.50	0.39	$F_{16.0\%}$
	0.14	0.50	0.36	$F_{22.3\%}$
	0.17	0.50	0.33	$F_{29.0\%}$

Table 20: Mortality parameters (*Z*, *F*, and *M*) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of M for each management area surveyed in the 2010 Marlborough Sounds survey. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality. AgeR = 6.

Management area	*M*	*Z*	*F*	$F_{\%SPR}$
Closed	0.11	0.31	0.2	$F_{26.5\%}$
	0.14	0.31	0.17	$F_{36.7\%}$
	0.17	0.31	0.14	$F_{47.6\%}$
Fished	0.11	0.47	0.36	$F_{17.0\%}$
	0.14	0.47	0.33	$F_{23.6\%}$
	0.17	0.47	0.3	$F_{30.8\%}$
Closed-Fished	0.11	0.35	0.24	$F_{23.1\%}$
	0.14	0.35	0.21	$F_{32.0\%}$
	0.17	0.35	0.18	$F_{41.6\%}$
Outside	0.11	0.46	0.35	$F_{17.3\%}$
	0.14	0.46	0.32	$F_{24.1\%}$
	0.17	0.46	0.29	$F_{31.4\%}$

Table 21: Video transect and pot sample details. Note that stations are individual transects and pots. * = includes equivalent number of fish-based habitat quadrats (See Section 2.2.3). Blue cod numbers in brackets are the number at legal size (30 cm and over).

	Video	Pots
Sites	20	20
Stations	62	180
Habitat sections	483	-
Habitat quadrats	2003	-
Mean transect length	1033 m (± 44.2)	-
Mean transect width	4 m (± 3.5)	-
Total area swept	258 464 m^2	Unknown
Blue cod	861* (240)	936 (643)

Table 22: Pot catch, numbers of blue cod, bycatch species, and percentage of total numbers from the 20 videoed sites.

Common name	Scientific name	Total Number	Percent total catch
Blue cod	*Parapercis colias*	936	97.2
Leatherjacket	*Parika scaber*	18	1.9
Carpet shark	*Cephaloscyllium isabellum*	3	0.3
Spotty	*Notolabrus celidotus*	3	0.3
Octopus	*Octopus cordiformis*	1	0.1
Red mullet	*Upeneichtys lineatus*	1	0.1
Tarakihi	*Nemadactylus macropterus*	1	0.1
Total		963	100.0

Table 23: Video observations of the numbers of blue cod, bycatch species, and percentage of total numbers from the 20 videoed sites.

Common name	Scientific name	Total Number	Percent total catch
Spotty	*Notolabrus celidotus*	3 805	75.6
Blue cod	*Parapercis colias*	861	17.1
Butterfly Perch	*Caesioperca Lepidoptera*	145	2.9
Jack Mackerel	*Trachurus declivis*	36	0.7
Snapper	*Pagrus auratus*	32	0.6
Sweep	*Scorpis lineolatus*	23	0.5
Scarlet wrasse	*Pseudolabrus miles*	22	0.4
Warehou	*Seriolella brama*	18	0.4
Leatherjacket	*Parika scaber*	15	0.3
Carpet Shark	*Cephaloscyllium isabellum*	12	0.2
Trevally	*Pseudocaranx dentex*	10	0.2
Eagle ray	*Myliobatis tenuicaudatus*	4	0.1
Blue moki	*Latridopsis ciliaris*	4	0.1
Squid	Unknown	4	0.1
Smooth skate	*Raja innominata*	4	0.1
Banded wrasse	*Notolabrus fucicola*	3	0.1
Flat fish	*Rhombosolea* spp	3	0.1
Opal fish	*Hemerocoetes* spp	2	<0.1
Red mullet	*Upeneichtys lineatus*	2	<0.1
Sea perch	*Helicolenus* spp	2	<0.1
Longfinned boarfish	*Zanclistius elevatus*	1	<0.1
Porcupine fish	*Allomycterus jaculiferus*	1	<0.1
Unidentified		21	0.4
Total		5 033	100.0

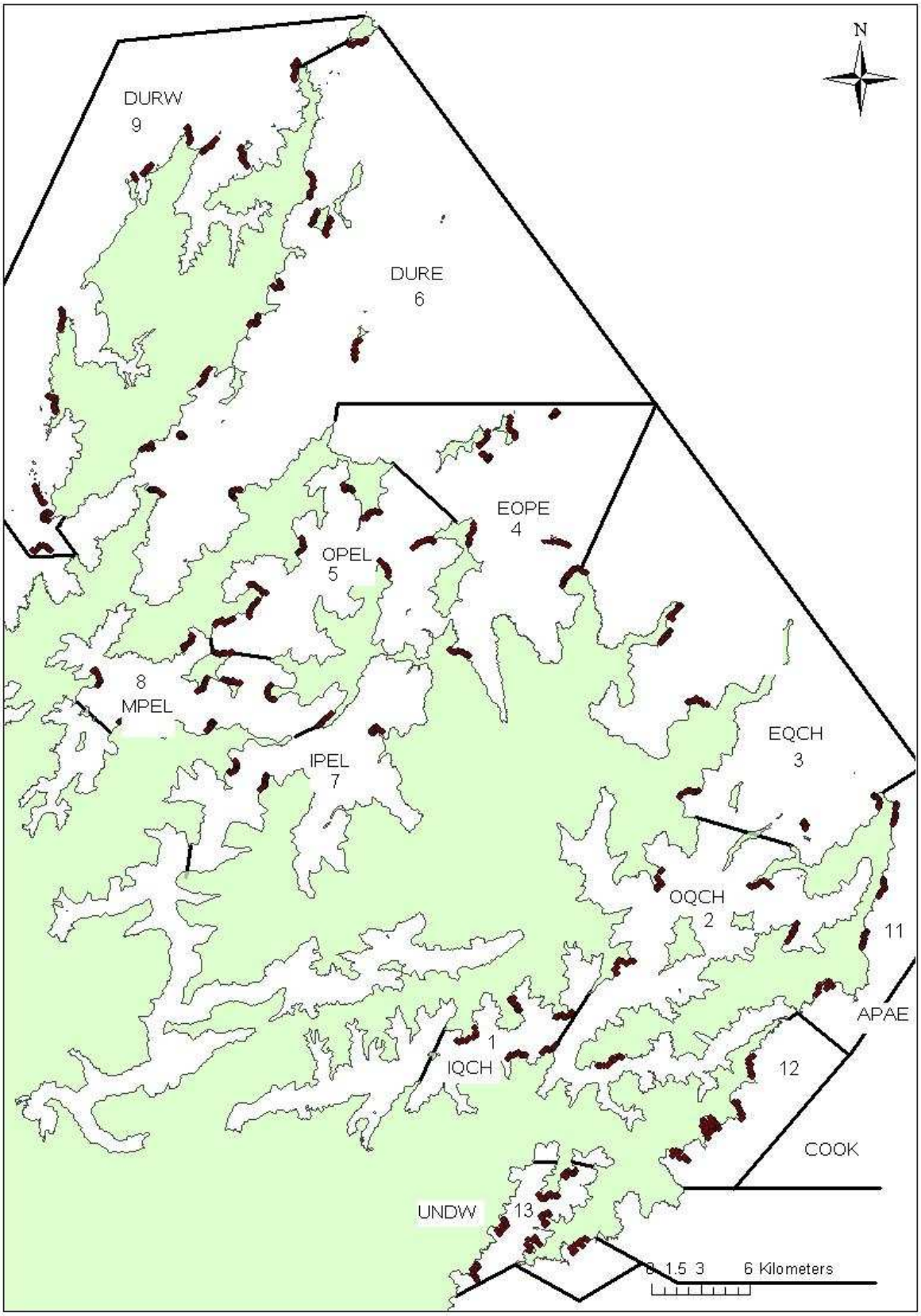


Figure 1: Map of Marlborough Sounds showing the stratum code, stratum number, and locations of all potting sites in the 2010 blue cod potting survey. Stratum 10 (SEP) is not shown on this figure and is located around the coast of Abel Tasman National Park, about 60 km east of D'Urville Island.

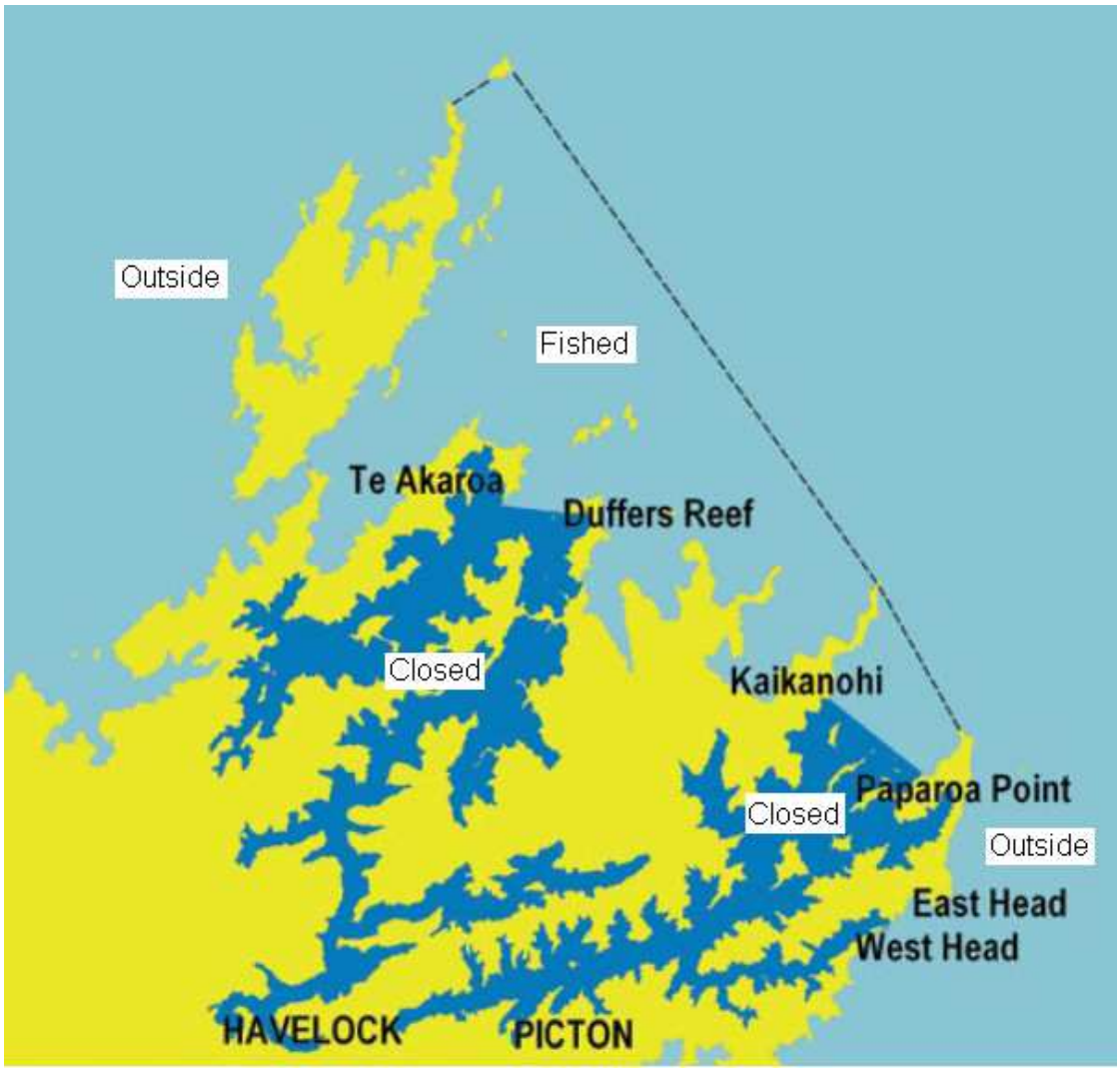


Figure 2: Map of Marlborough Sounds showing the three MPI blue cod management areas from 1 October 2008–1 October 2012. Closed area –closed to fishing (dark blue of inner sounds). Fished area – blue cod landed whole or gutted and the daily bag of three per person per day (between the closed area and the dashed line). Outside area – daily bag limit of ten per day. Figure is modified from that from MPI http://www.fish.govt.nz/NR/rdonlyres/AFFA8A90-BF46-4526-9DDF-1B20B3CDC394/0/MFishCodBroWeb.pdf

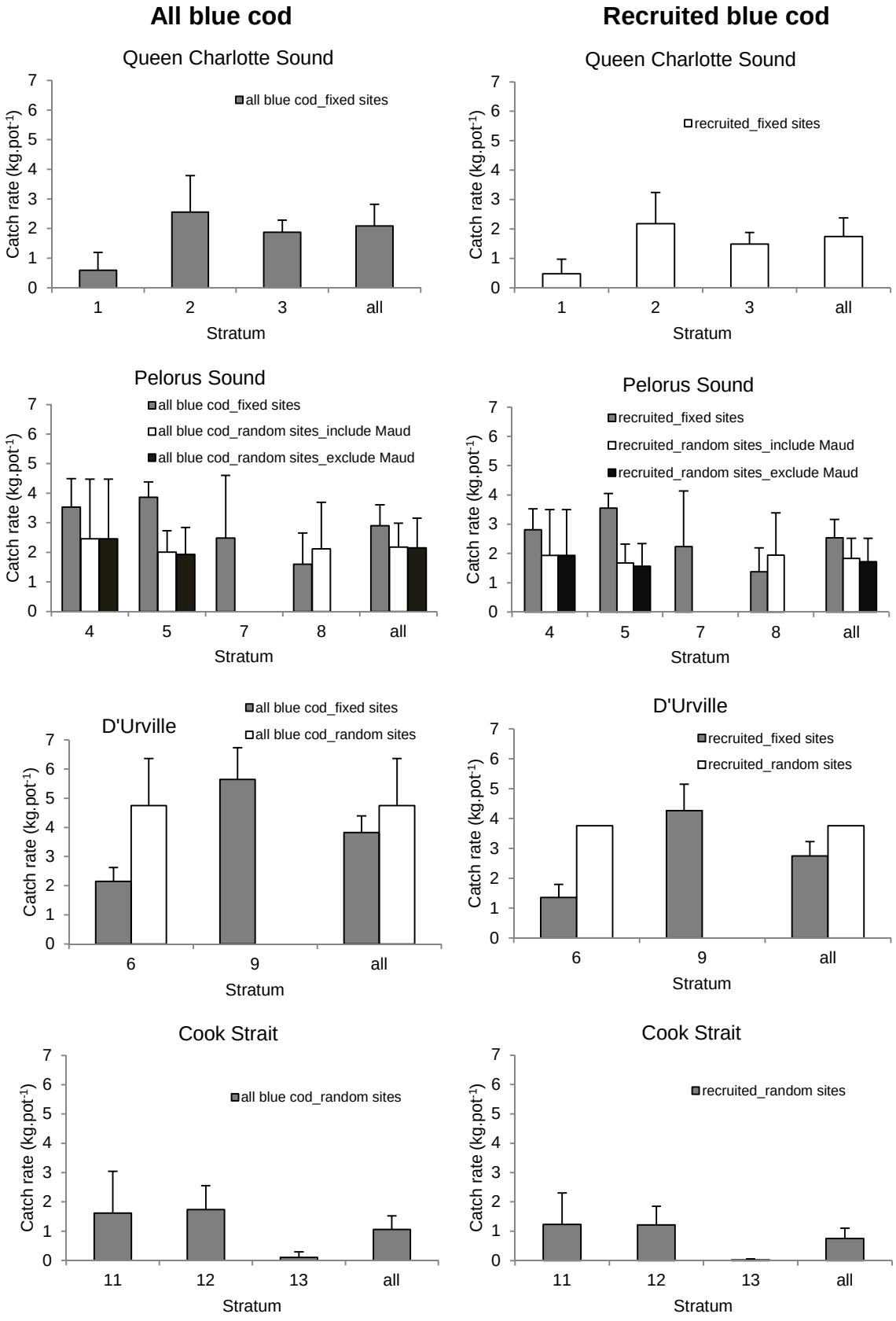


Figure 3: Marlborough Sounds 2010 potting survey catch rates of all blue cod and recruited blue cod (30 cm and over) by site type (fixed or random) for each region. Random site catch rates in Pelorus are shown for sites including and excluding those around Maud Island. Error bars are 95% confidence intervals.

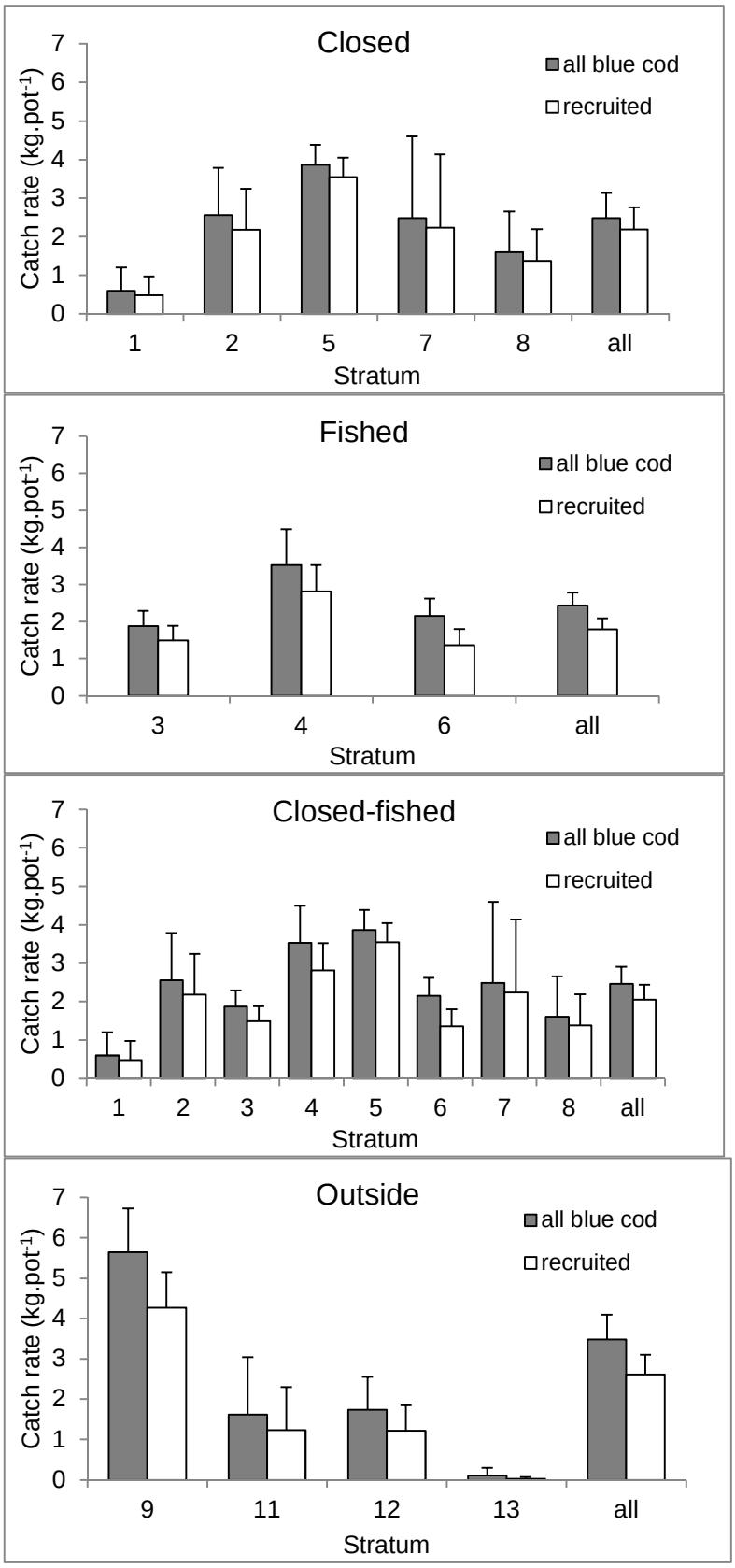


Figure 4: Catch rates of all blue cod and recruited blue cod (30 cm and over) from the 2010 Marlborough Sound potting survey. Catch rates are plotted by strata that fall within management areas, and overall. See Table 1 for stratum locations. All data are from fixed sites except strata 11 to 13 which are random sites in Cook Strait. Error bars are 95% confidence intervals.

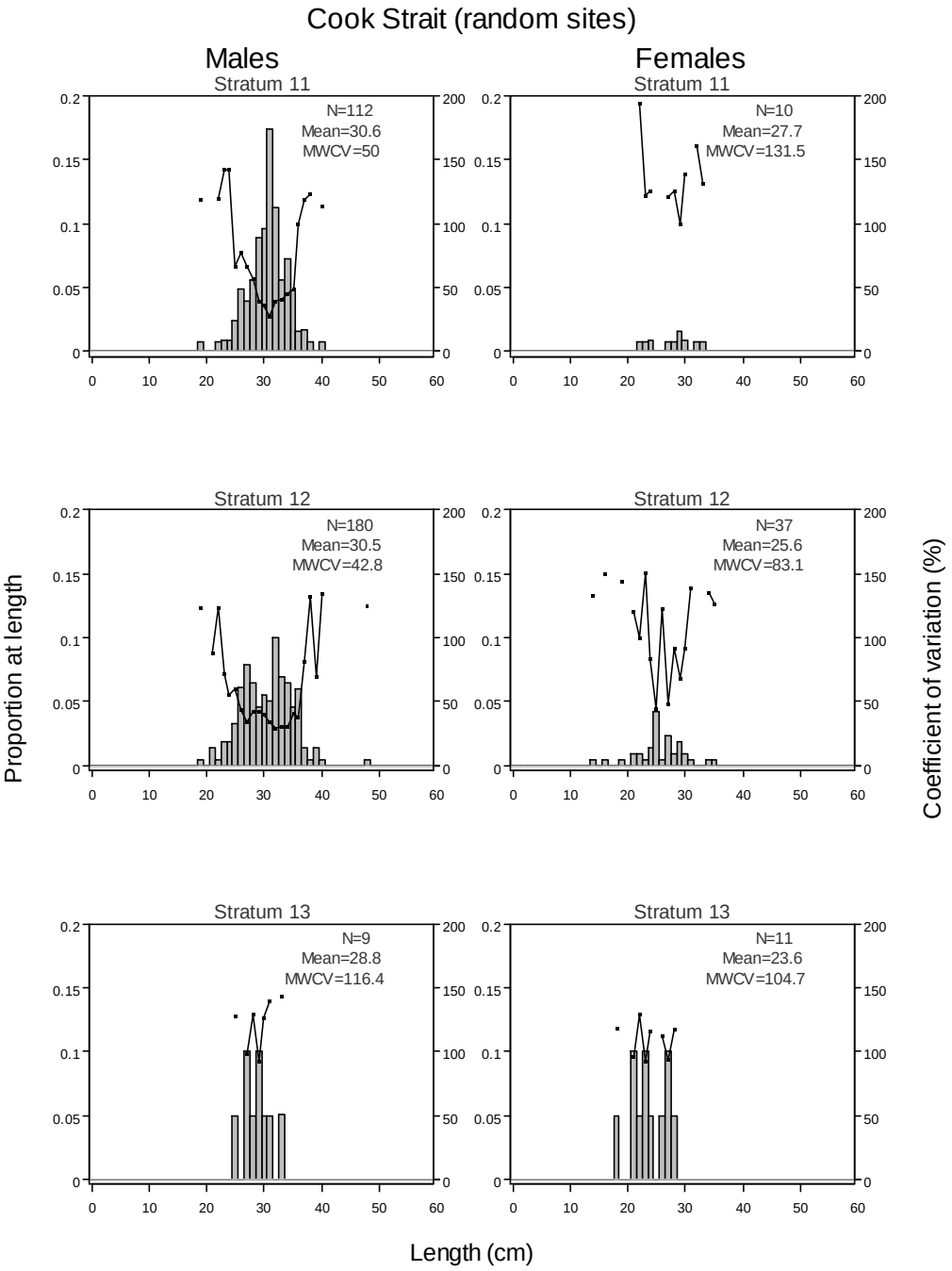


Figure 5: Scaled length frequency distributions of blue cod for each stratum in the 2010 survey of Marlborough Sounds (Cook Strait random sites).

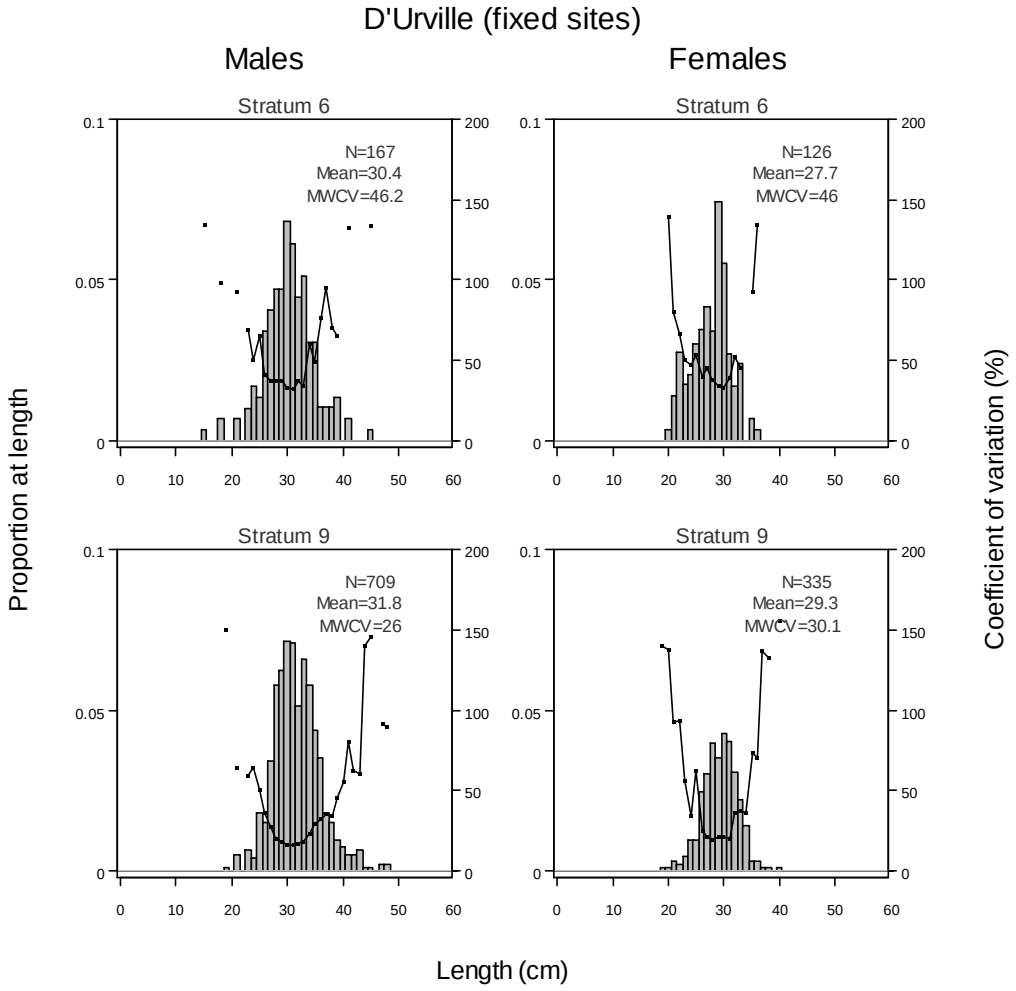


Figure 6: Scaled length frequency distributions of blue cod for each stratum in the 2010 survey of Marlborough Sounds (D'Urville fixed sites).

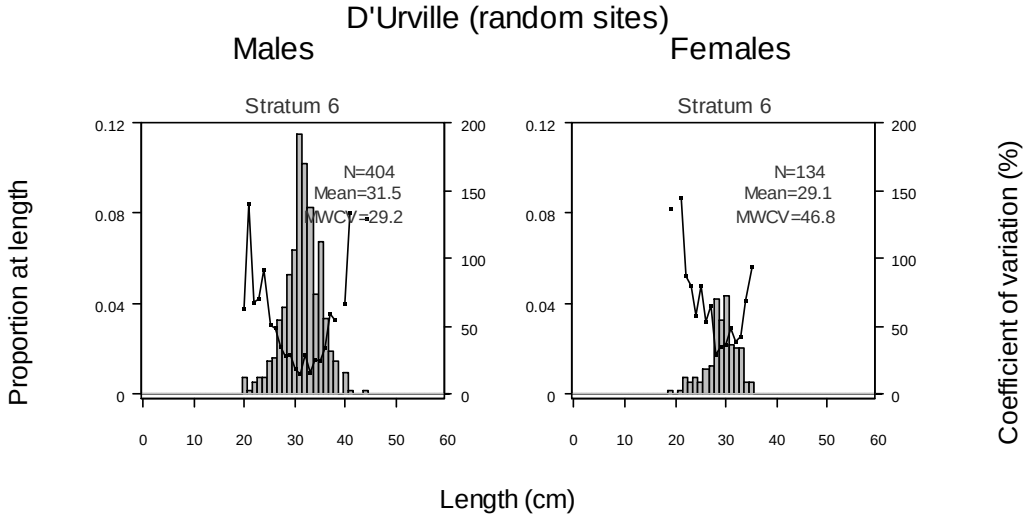


Figure 7: Scaled length frequency distributions of blue cod for the 2010 survey of Marlborough Sounds (D'Urville random sites).

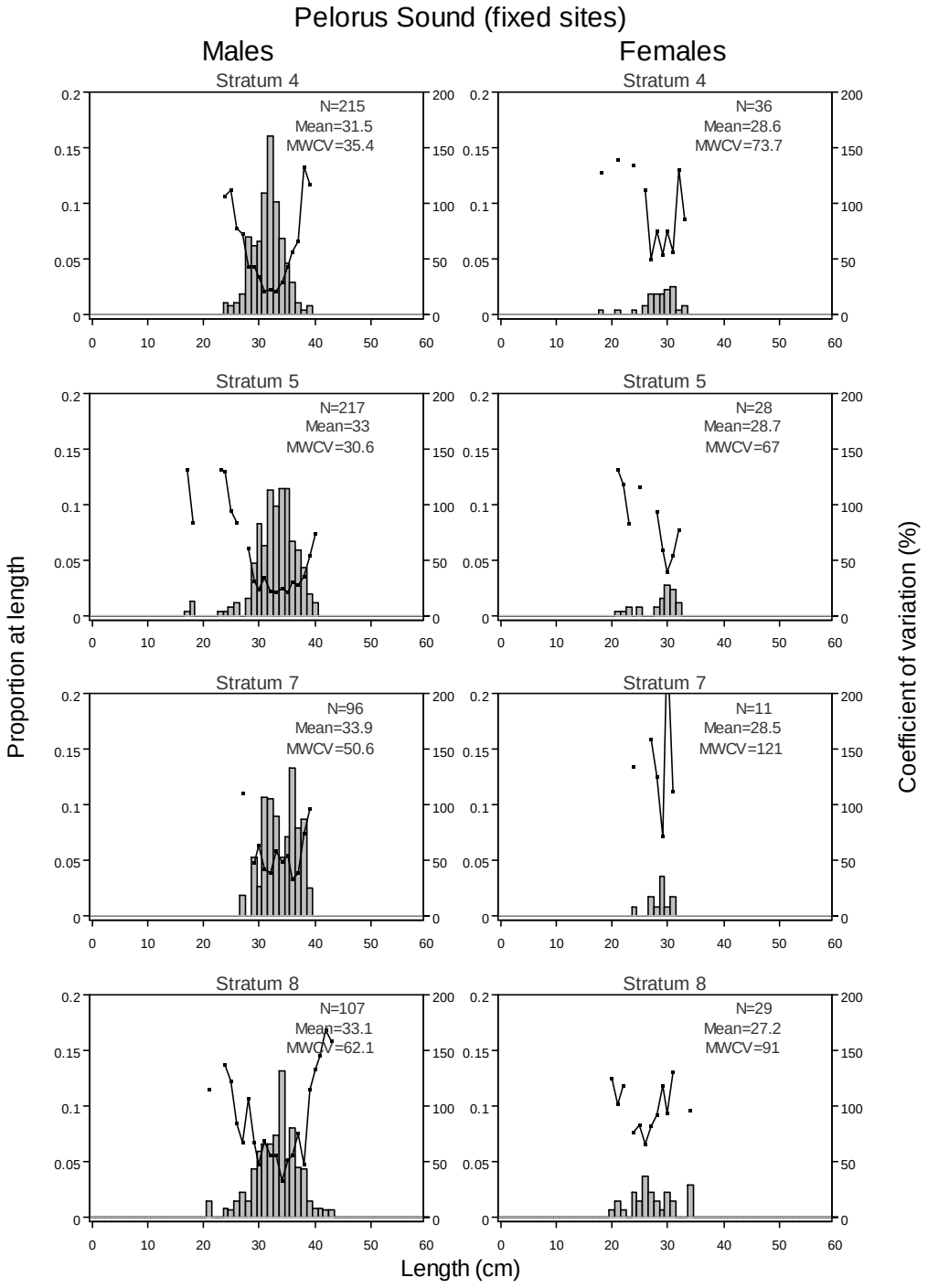


Figure 8: Scaled length frequency distributions of blue cod for each stratum in the 2010 survey of Marlborough Sounds (Pelorus Sound fixed sites).

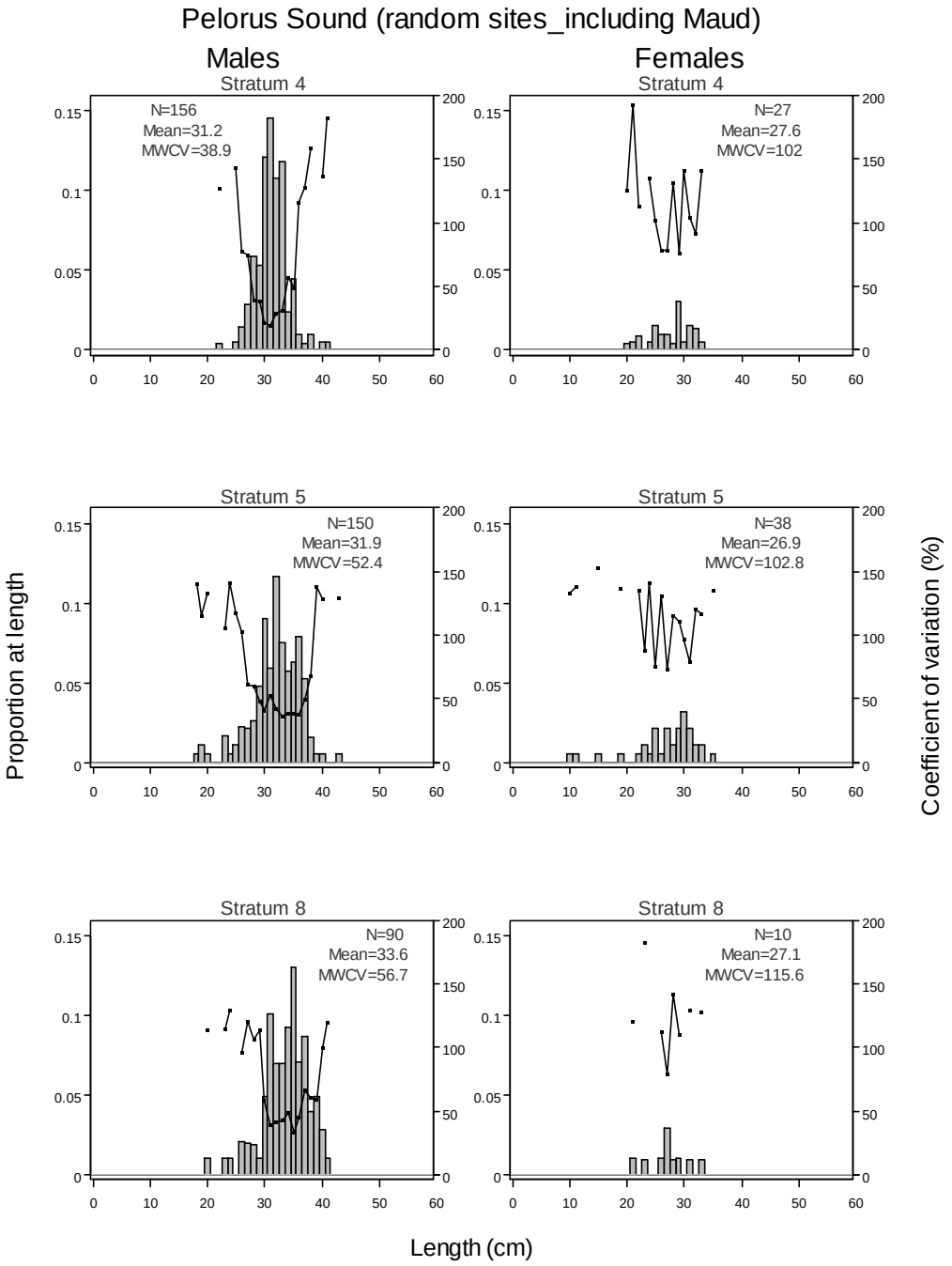


Figure 9: Scaled length frequency distributions of blue cod for each stratum in the 2010 survey of Marlborough Sounds (Pelorus Sound random sites including Maud Island).

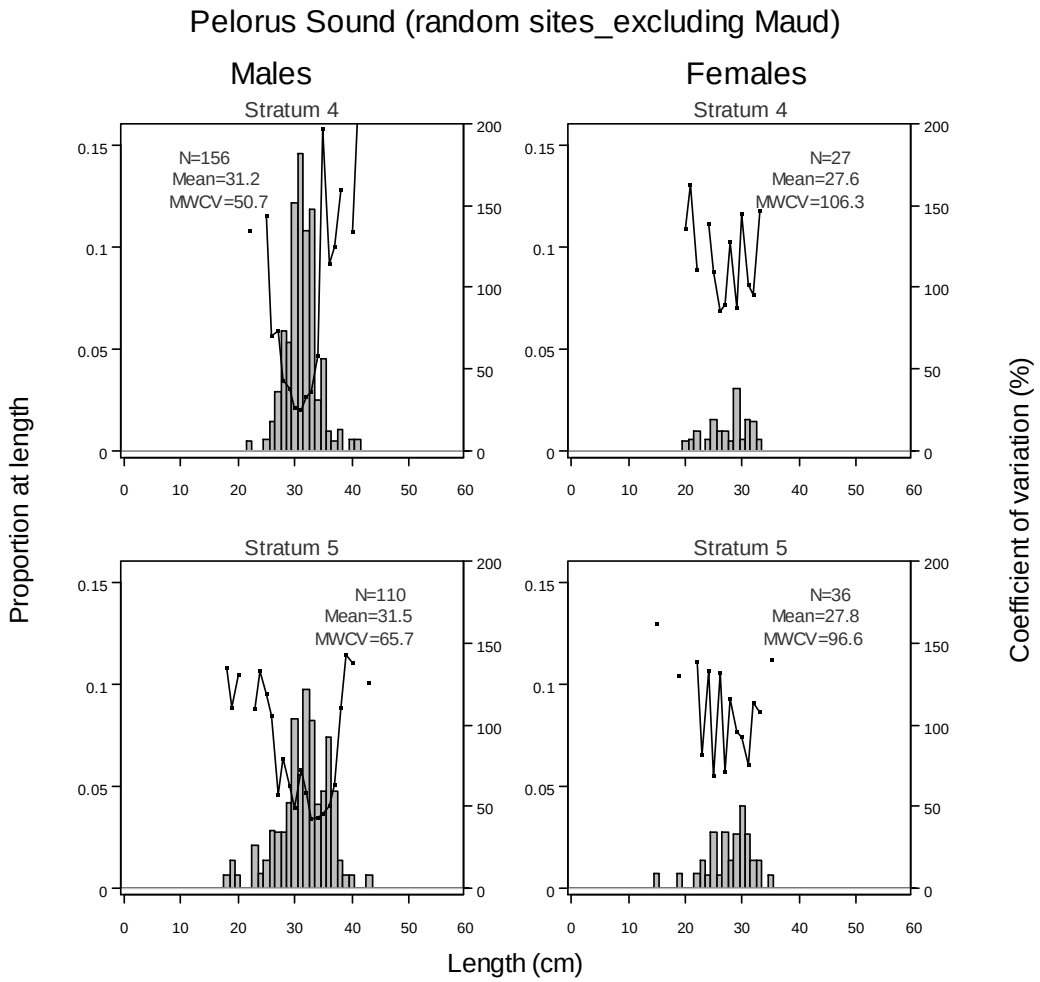


Figure 10: Scaled length frequency distributions of blue cod for each stratum in the 2010 survey of Marlborough Sounds (Pelorus Sound random sites excluding Maud Island).

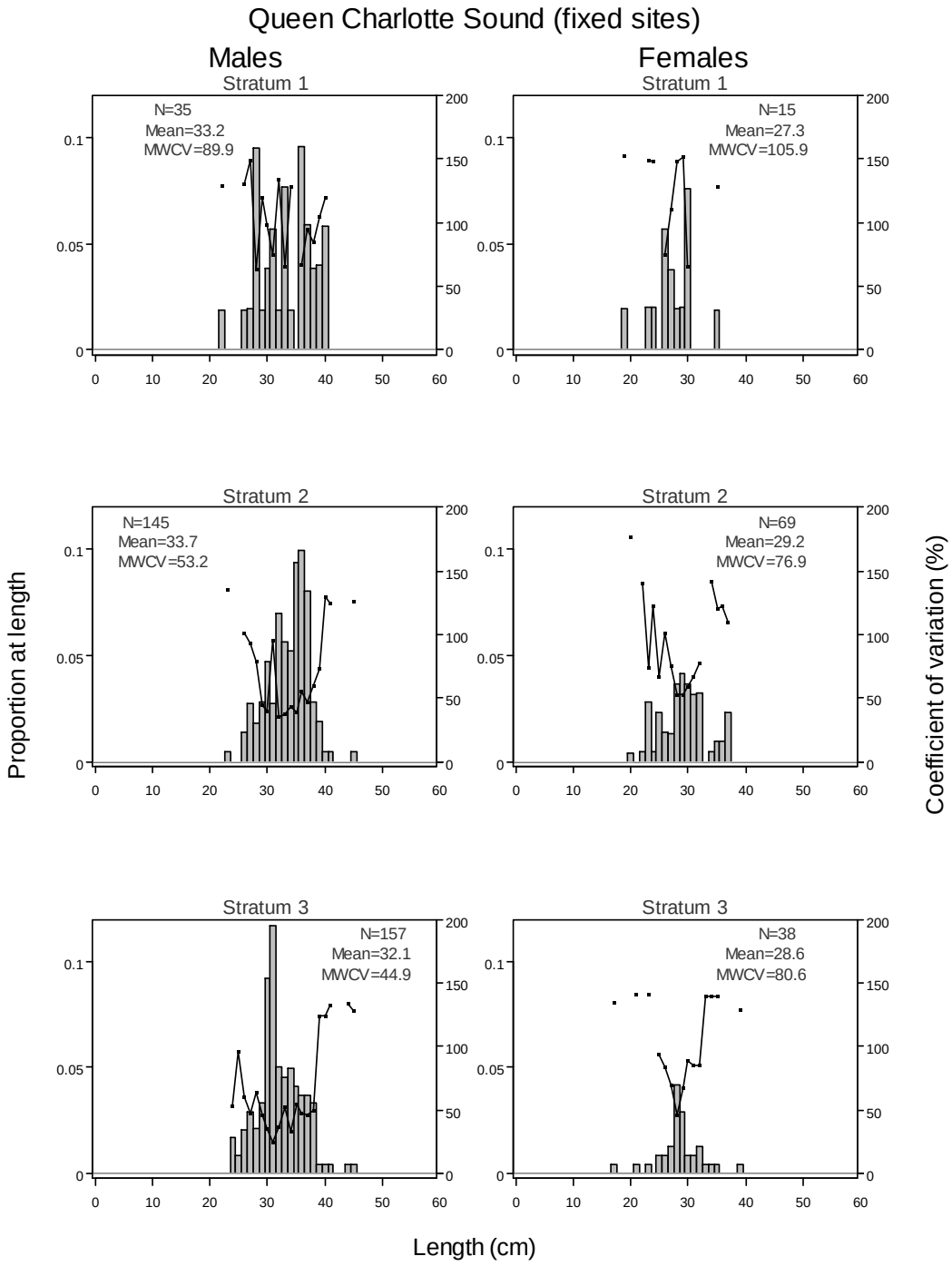


Figure 11: Scaled length frequency distributions of blue cod for each stratum in the 2010 survey of Marlborough Sounds (Queen Charlotte Sound fixed sites).

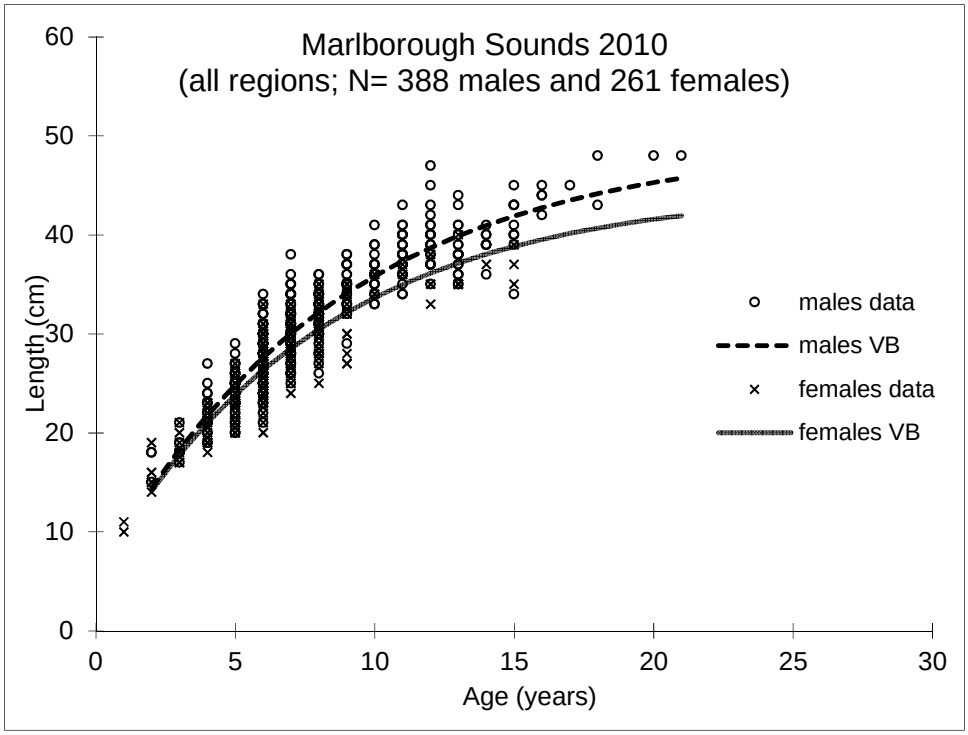


Figure 12: Observed age and length data by sex for the 2010 Marlborough Sounds survey (all regions combined) with von Bertalanffy growth models fitted to the data.

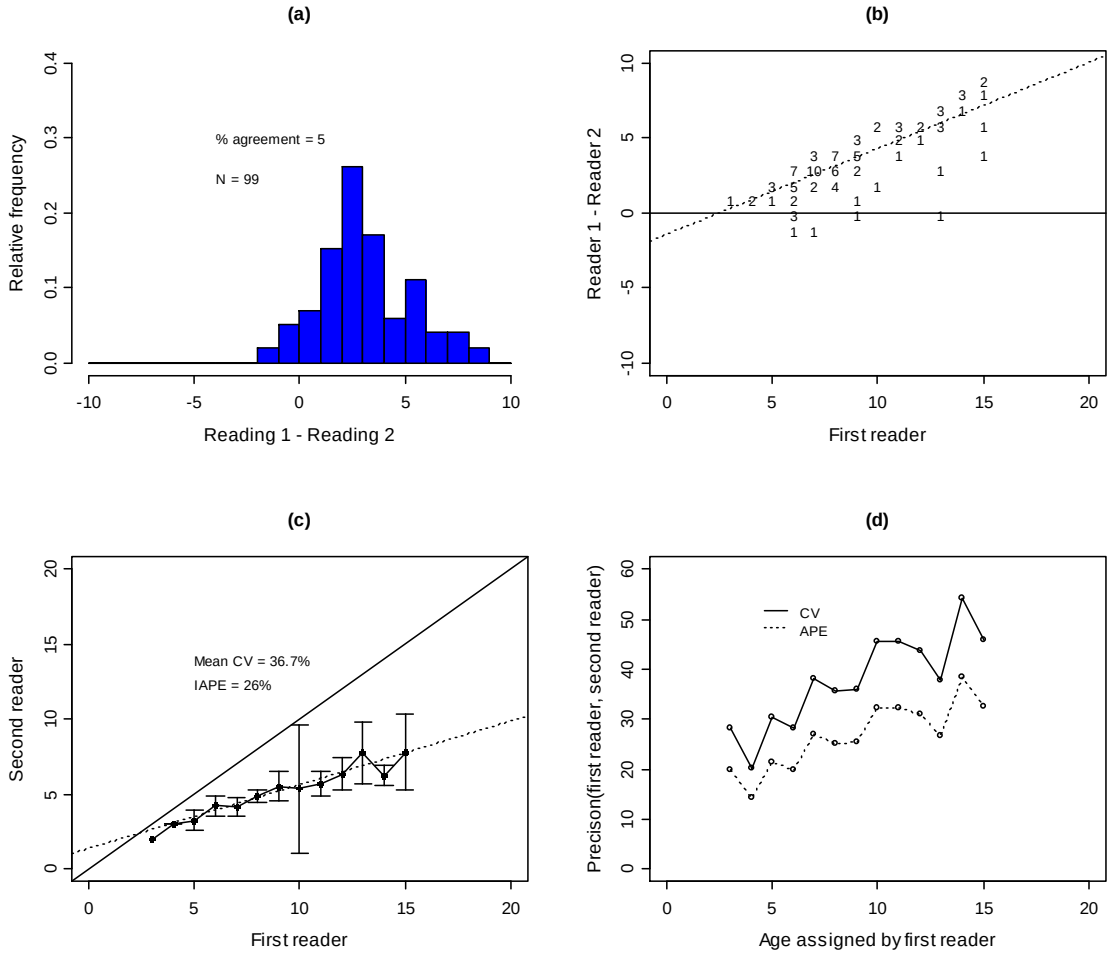


Figure 13: Blue cod age reader comparison plots between reader 1 and reader 2 for the 2010 Marlborough Sounds survey : (a) histogram of age differences between two readers; (b) Difference between reader 1 and reader 2 as a function of the age assigned by reader 1. The number of fish in each bin is plotted as the plot symbol; (c) Age bias plot, showing the correspondence of ages between reader 1 and reader 2 for all ages. Error bars indicate the c.v. of the ages for each age by reader 1; (d) Plot of the c.v. and the average percent error (APE) for each age as assigned by the first reader. In panels b and c, solid lines show perfect agreement, dashed lines show the trend of a linear regression of the actual data.

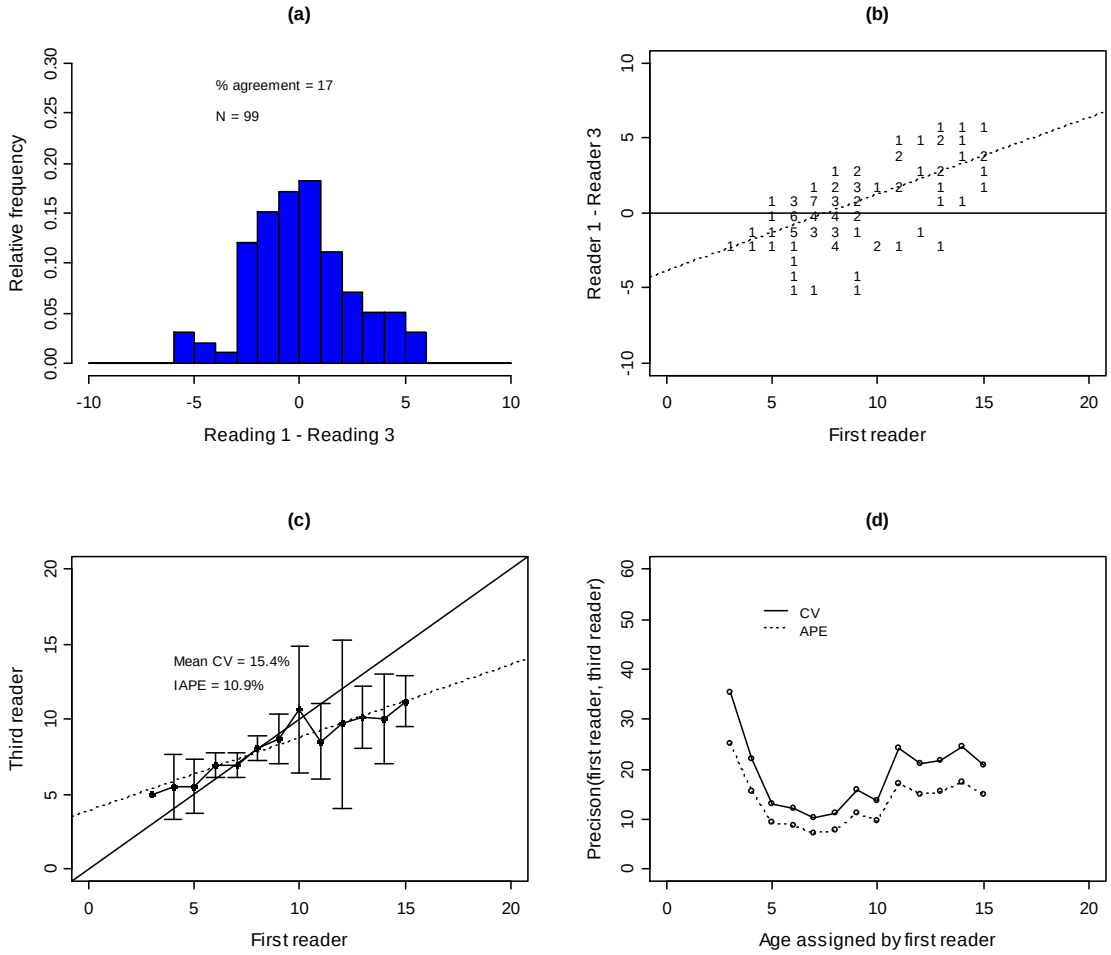


Figure 14: Blue cod age reader comparison plots between reader 1 and reader 3 for the 2010 Marlborough Sounds survey. See Figure 13 for explanation.

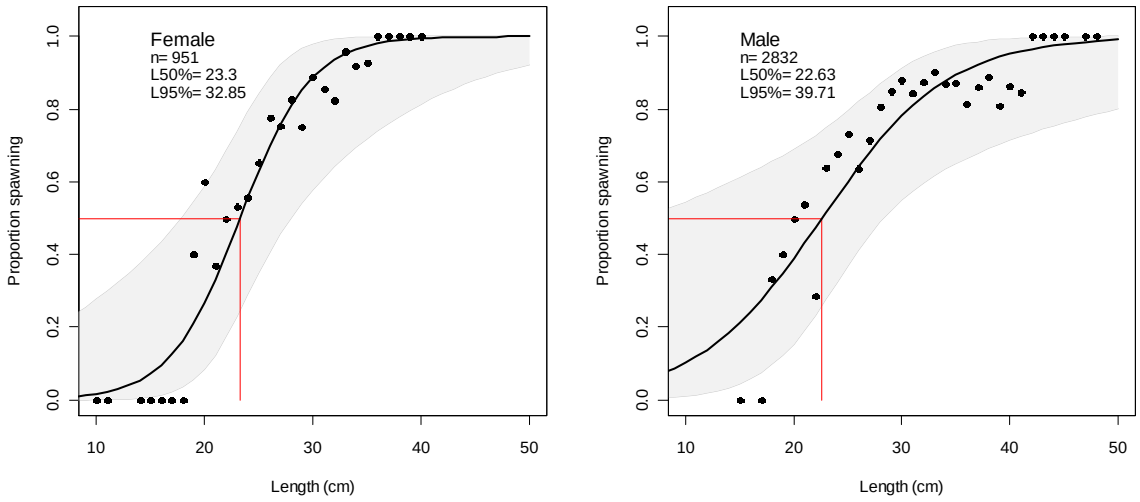


Figure 15: Length at maturity for female and male blue cod from the 2010 Marlborough Sounds cod potting surveys using stage 1 and 2 as immature and stages 3–5 as mature. Red lines indicate the $L_{50\%}$ maturity. Grey zones indicate the 95% confidence intervals for each ogive fit.

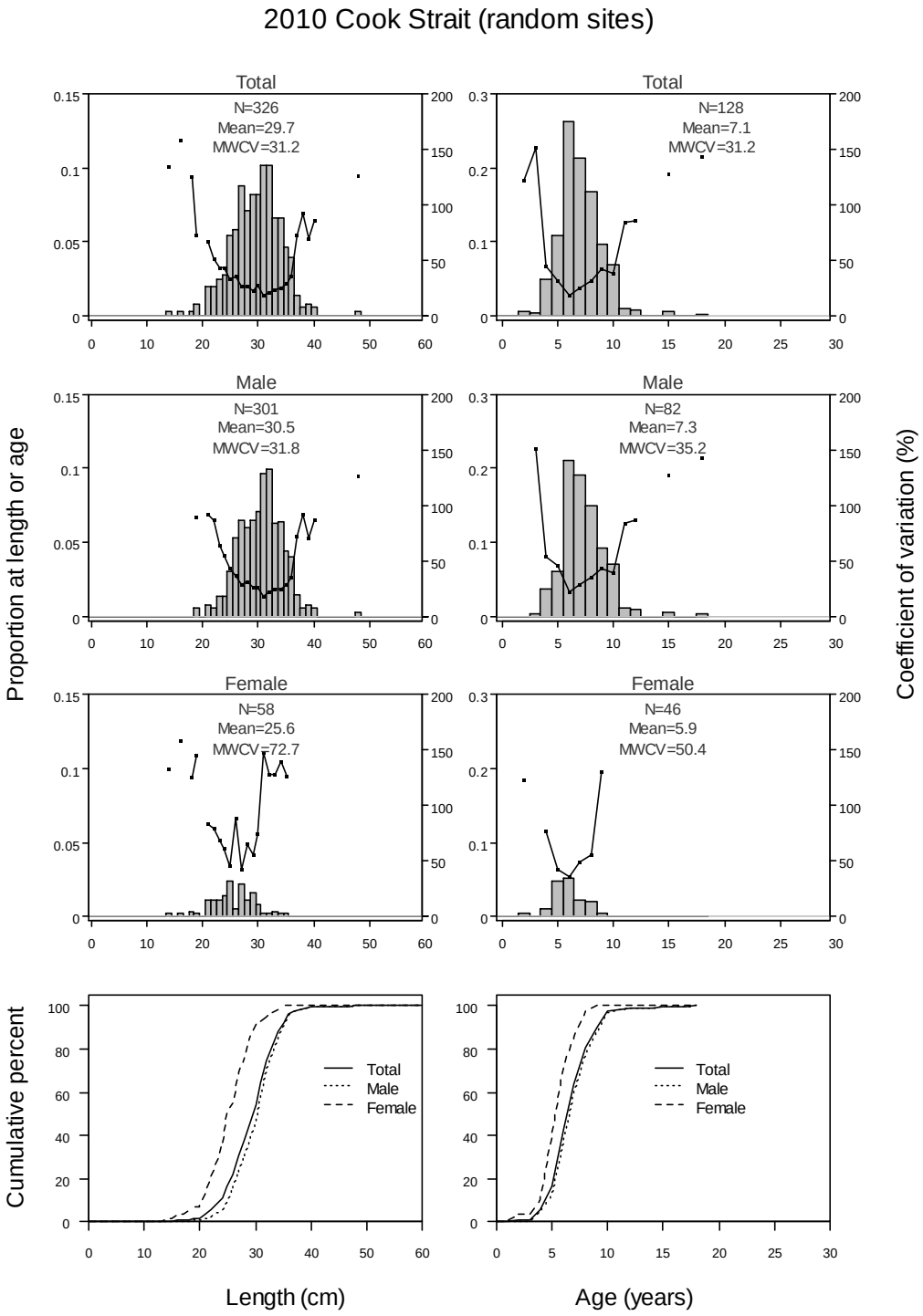


Figure 16: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (11–13) combined in Cook Strait region (random sites) for the 2010 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

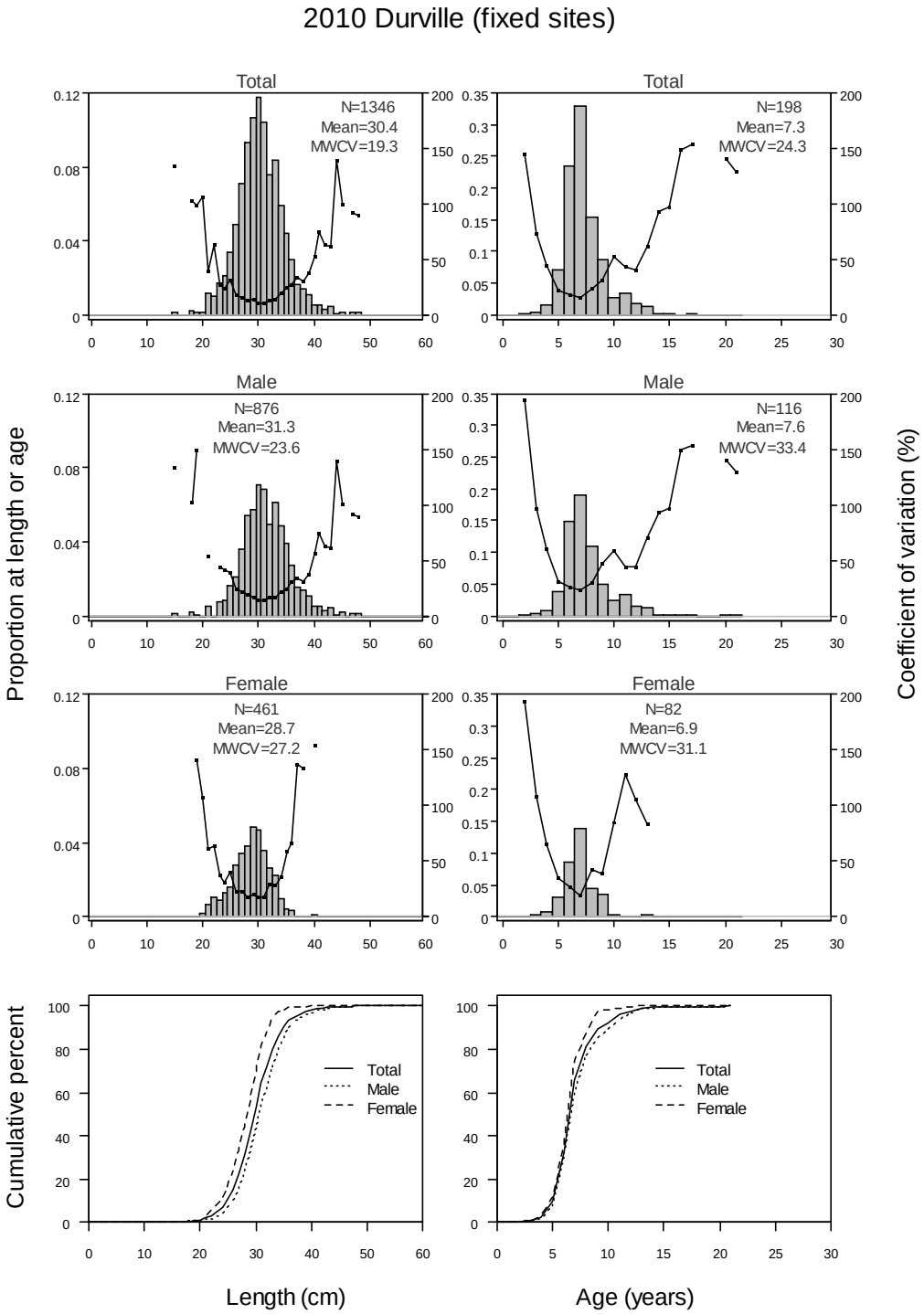


Figure 17: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for both strata (6 and 9) combined in D'Urville region (fixed sites only) for the 2010 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

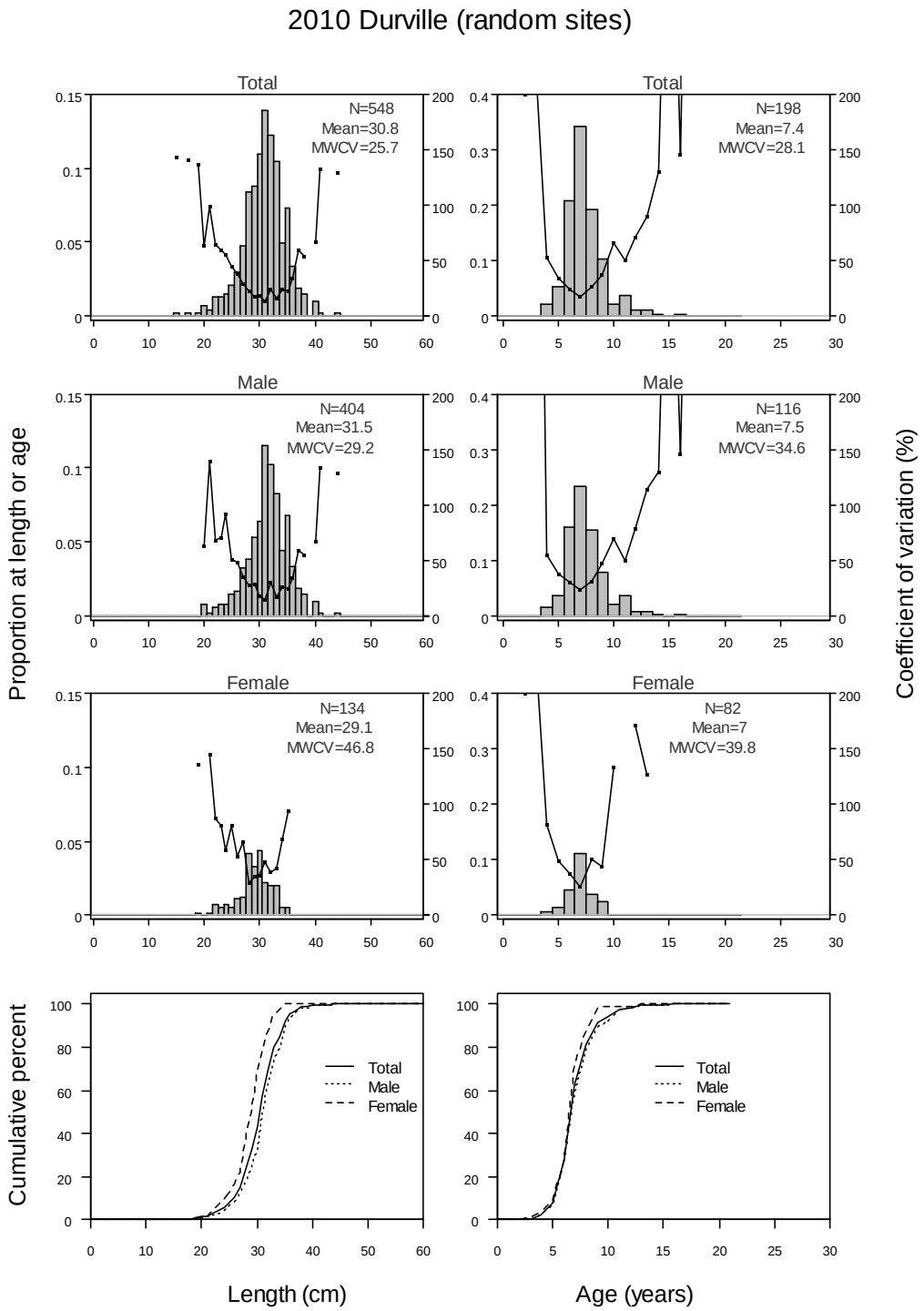


Figure 18: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for both strata (6 and 9) combined in D'Urville region (random sites only) for the 2010 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

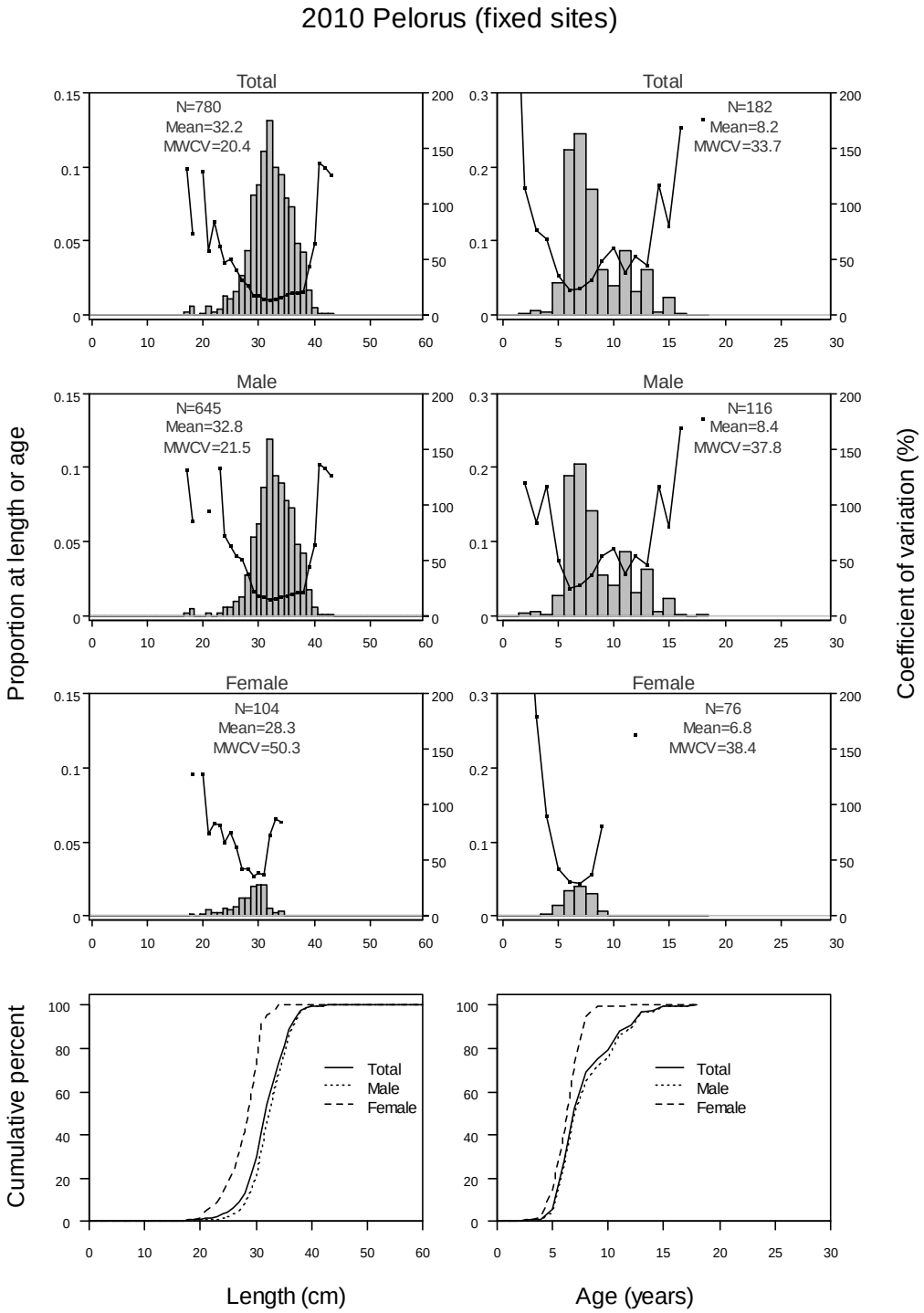


Figure 19: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (4, 5, 7, and 8) combined in Pelorus Sound region (fixed sites only) for the 2010 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

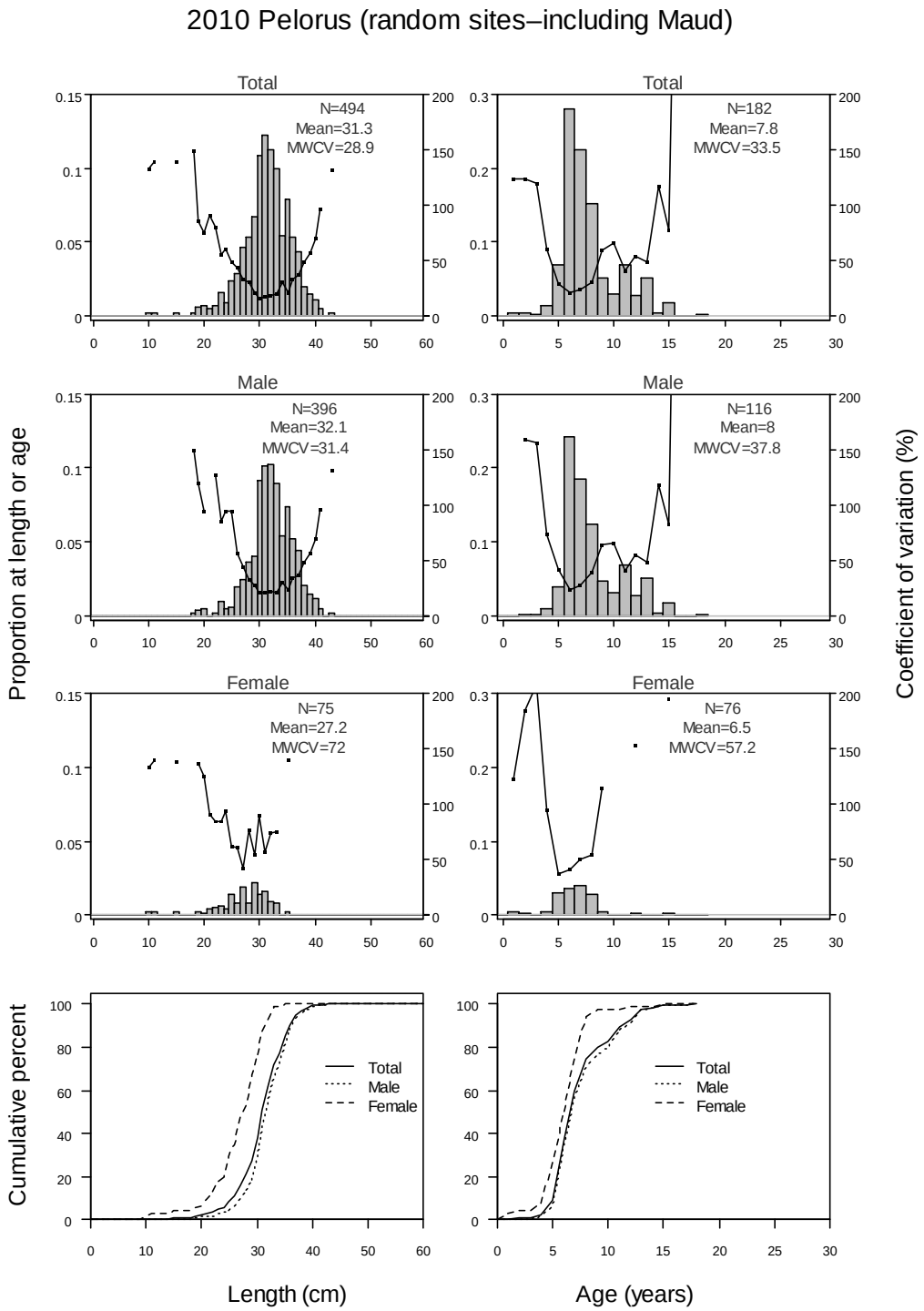


Figure 20: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for random sites from strata 4, 5, and 8 combined in Pelorus Sound region including those around Maud Island for the 2010 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

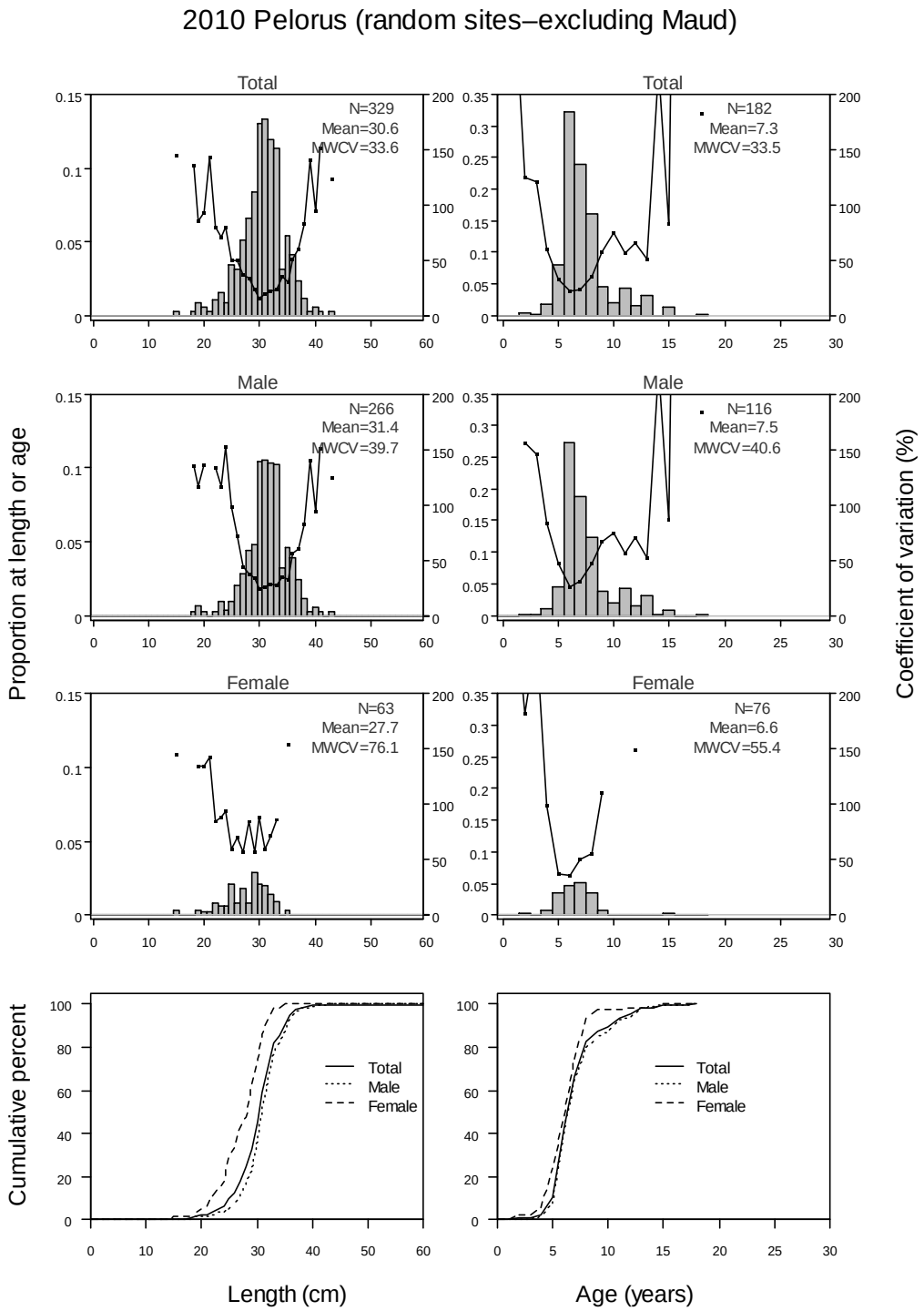


Figure 21: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for random sites from strata 4 and 5 combined in Pelorus Sound region, excluding those around Maud Island, for the 2010 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

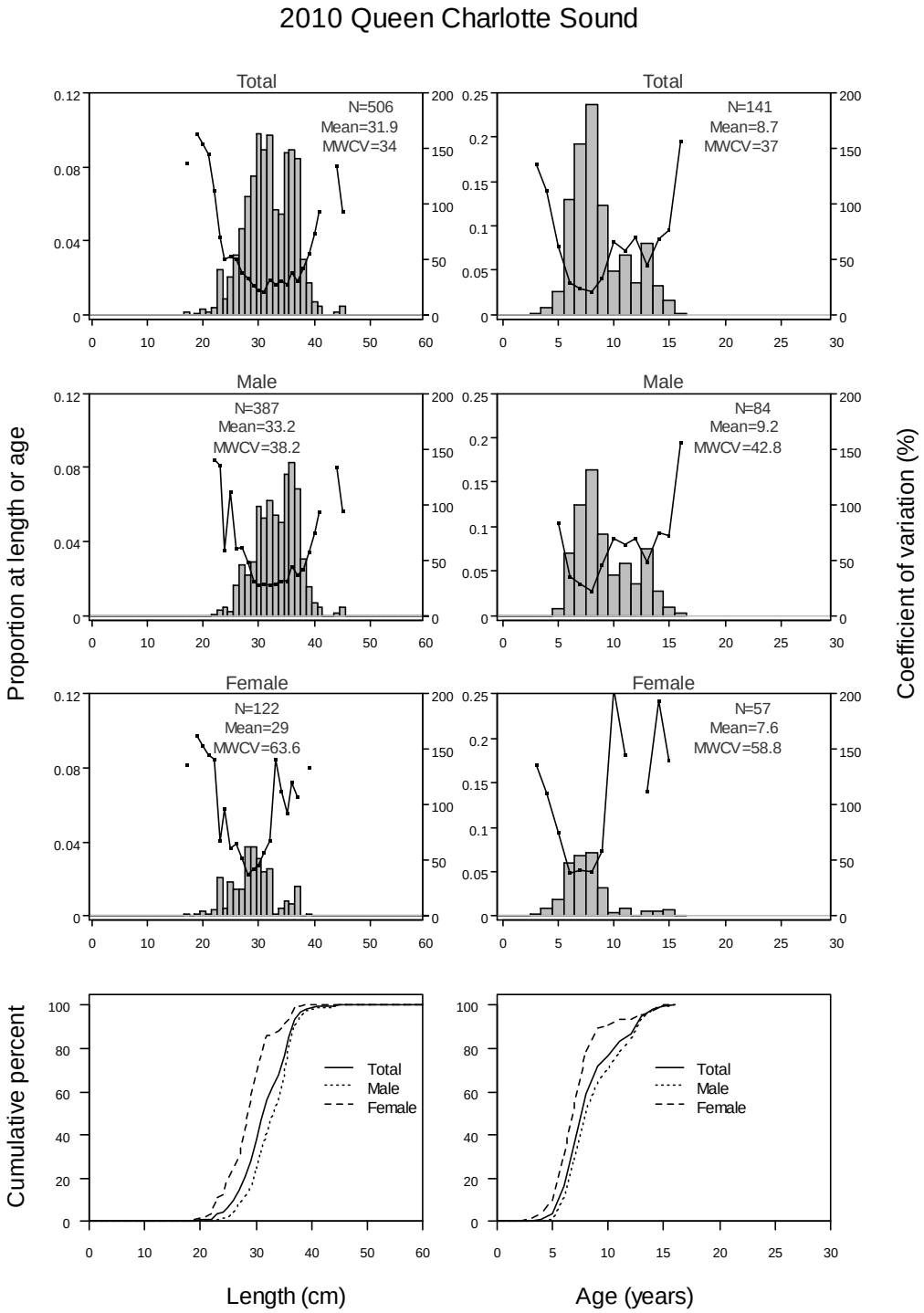


Figure 22: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (1–3) combined in Queen Charlotte Sound region (fixed sites) for the 2010 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

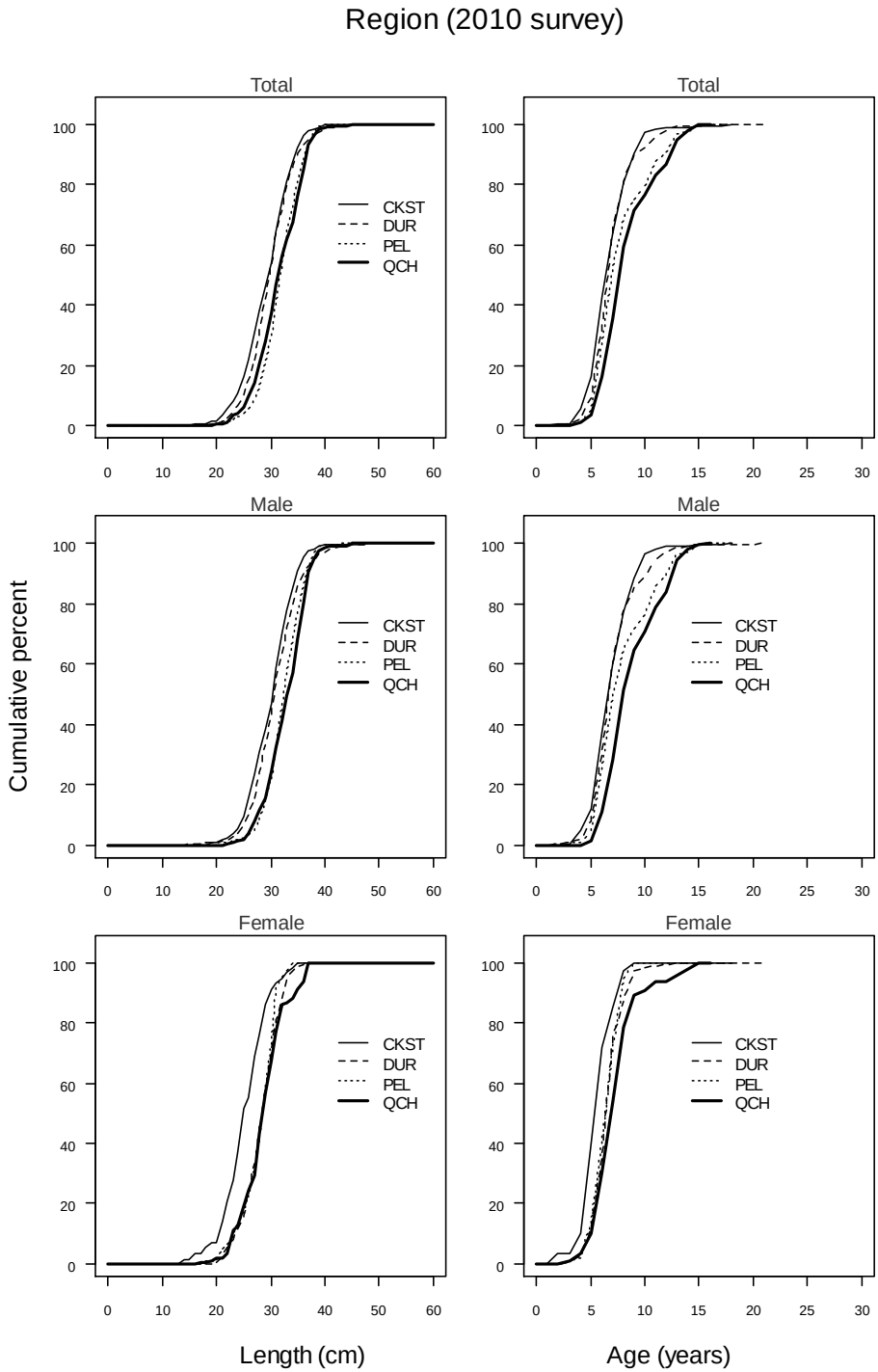


Figure 23: Cumulative distributions of scaled length and age frequencies for total, male and female blue cod for the four regions surveyed on the 2010 Marlborough Sounds blue cod potting survey. CKST, Cook Strait; DUR, D'Urville; PEL, Pelorus Sound; QCH, Queen Charlotte Sound. Only data from fixed sites are included in these plots.

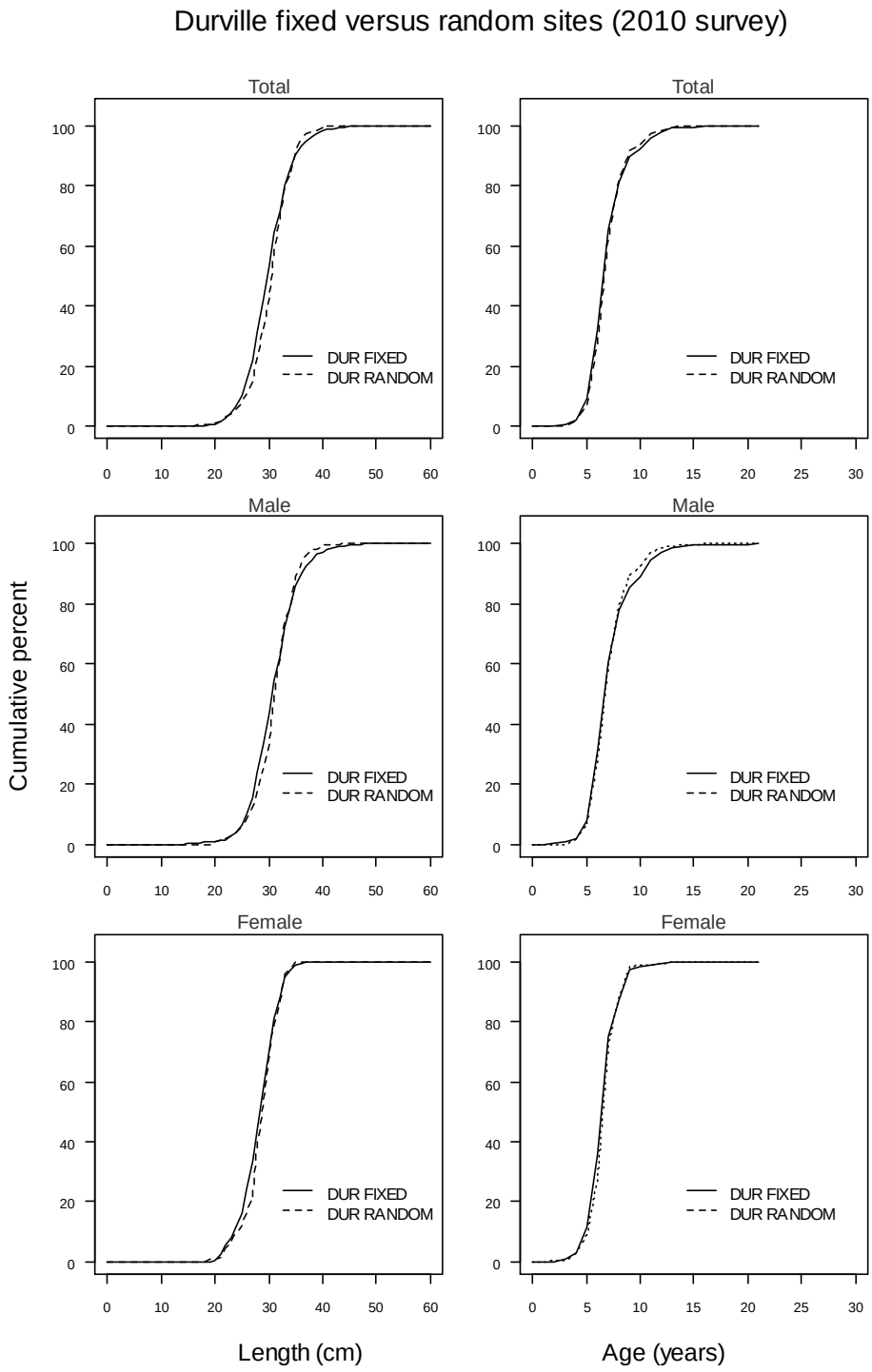


Figure 24: Cumulative distributions of scaled length and age frequencies for total, male, and female blue cod for the D'Urville region comparing fixed and random sites on the 2010 Marlborough Sounds blue cod potting survey.

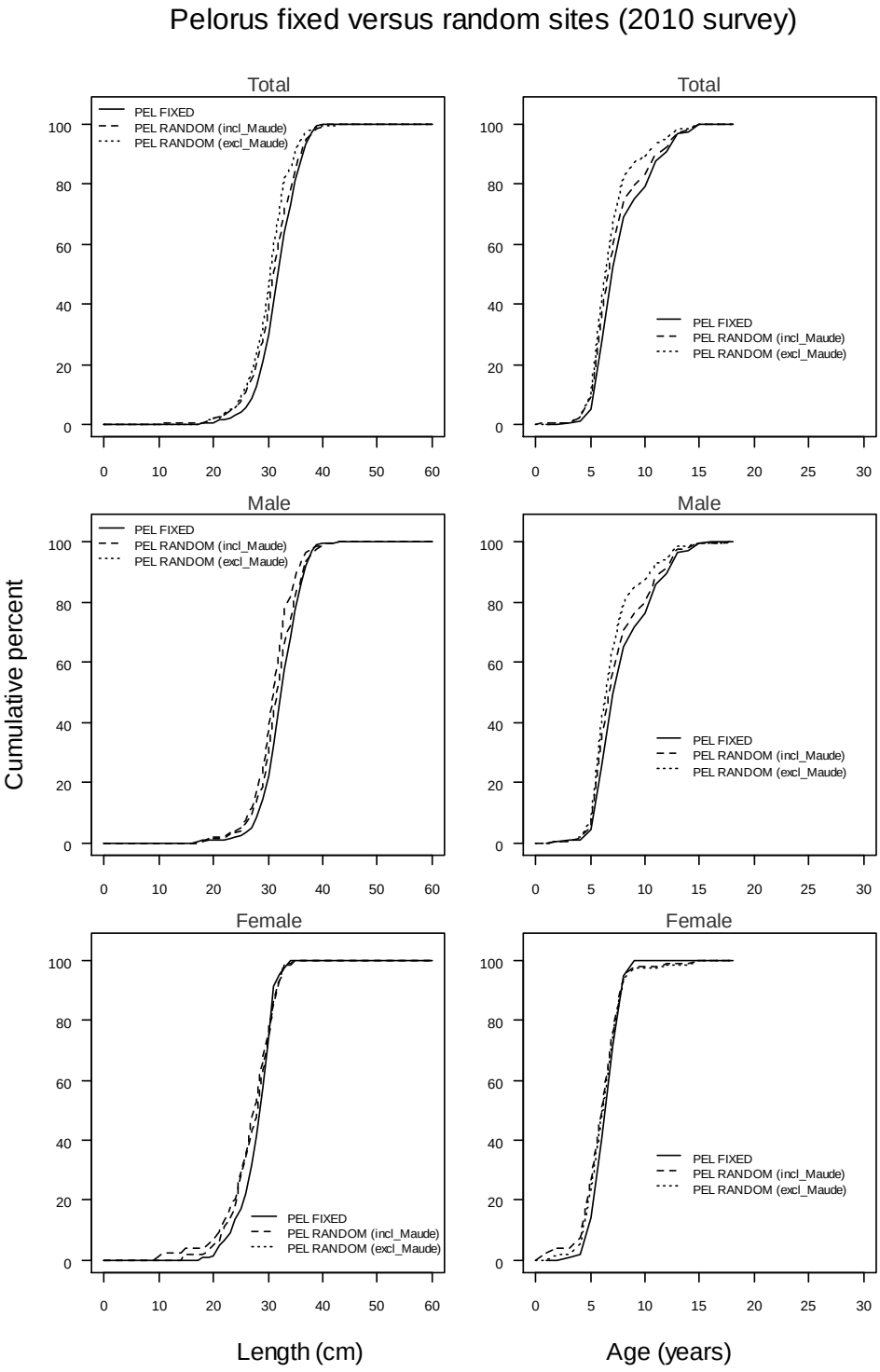


Figure 25: Cumulative distributions of scaled length and age frequencies for total, male, and female blue cod for the Pelorus region comparing fixed and random sites on the 2010 Marlborough Sounds blue cod potting survey. Random sites are shown as both including and excluding those around Maud Island.

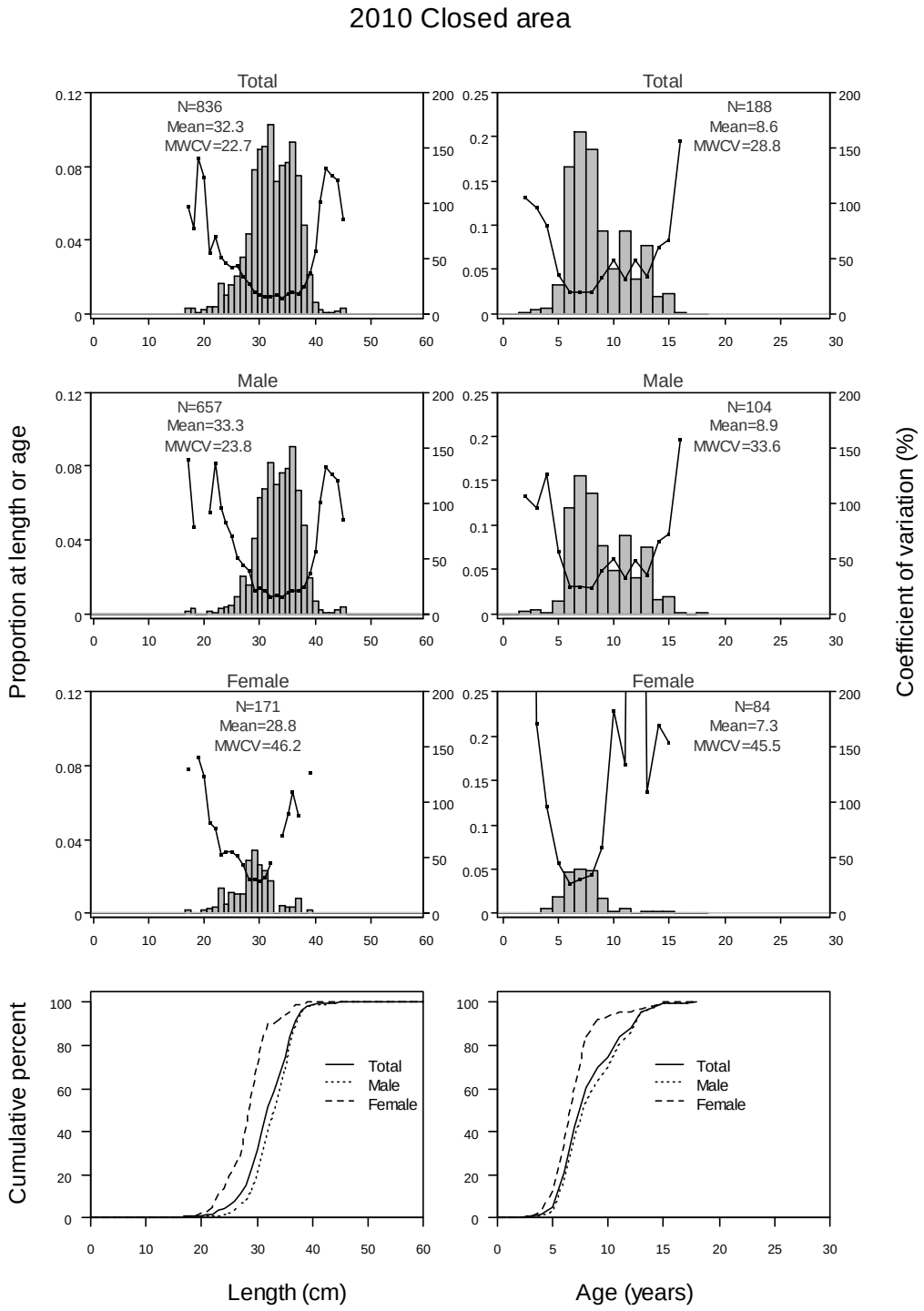


Figure 26: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (1, 2, 5, 7, and 8) combined in the closed management area (fixed sites only) for the 2010 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

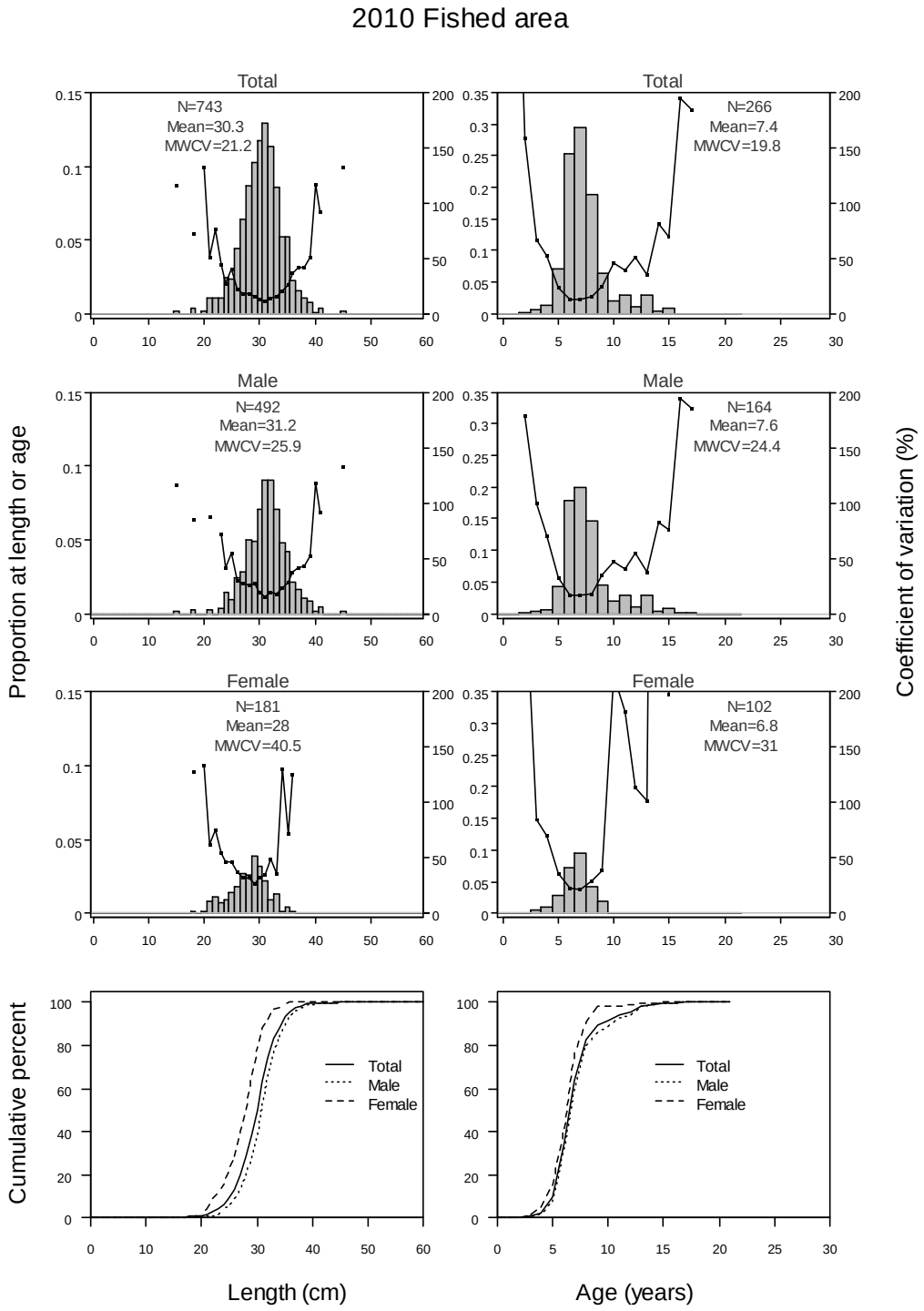


Figure 27: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (3, 4, and 6) combined in the fished management area (fixed sites only) for the 2010 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

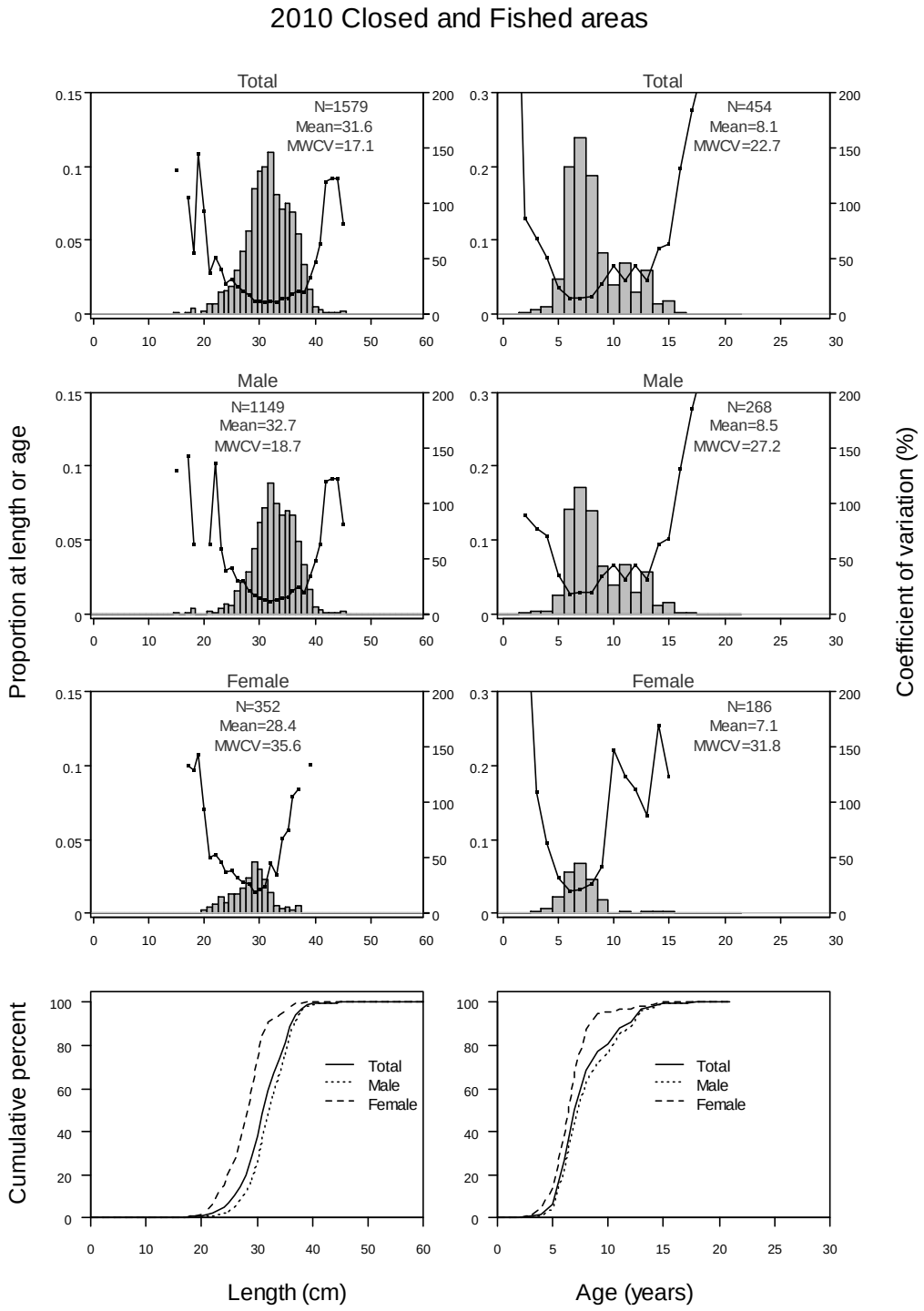


Figure 28: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (1, 2, 3, 4, 5, 6, 7, and 8) combined in the closed-fished combined management areas (fixed sites only) for the 2010 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

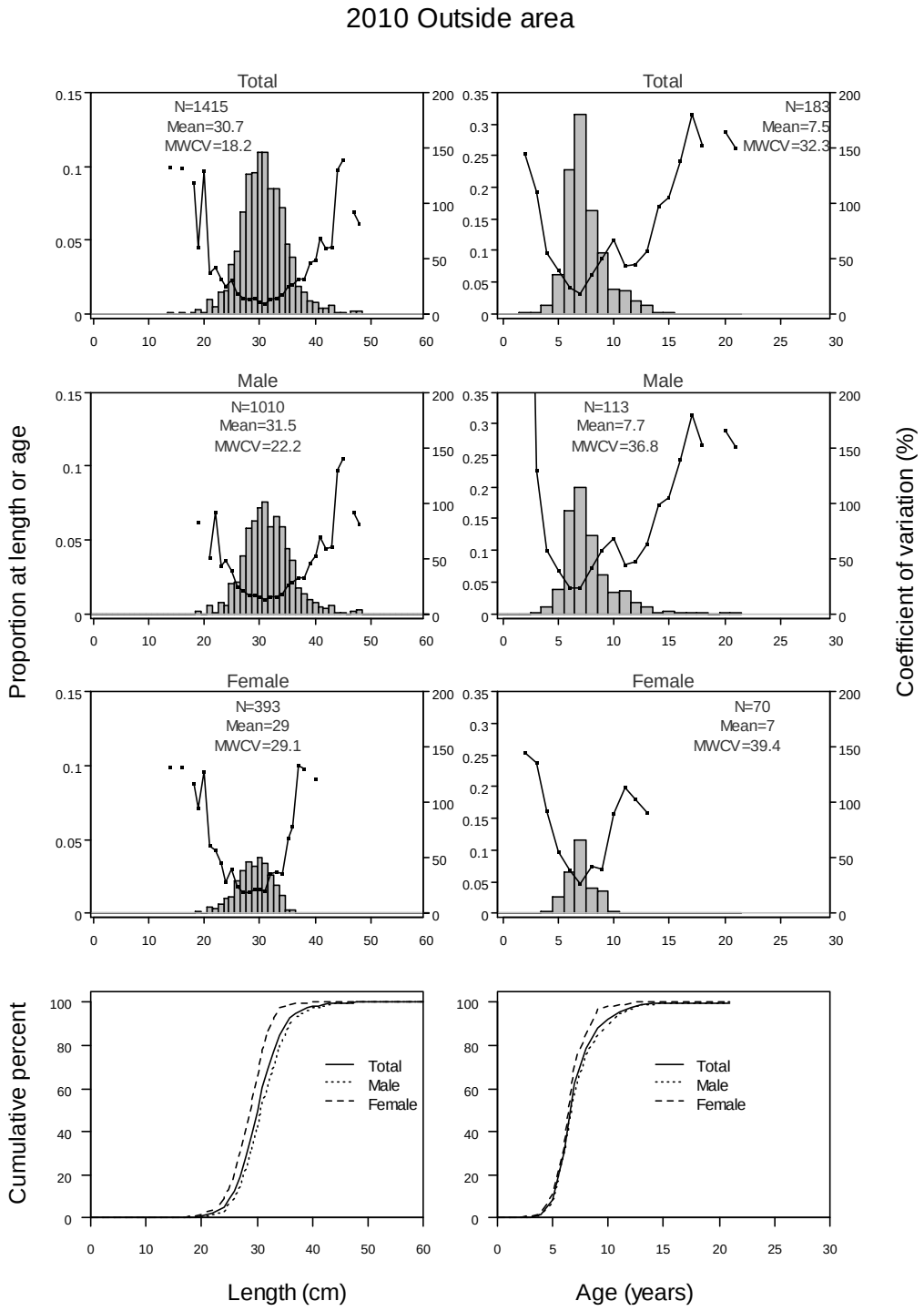


Figure 29: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (9, 11, 12, and 13) combined in the outside management area (fixed sites in stratum 9 and random sites in strata 11–13) for the 2010 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

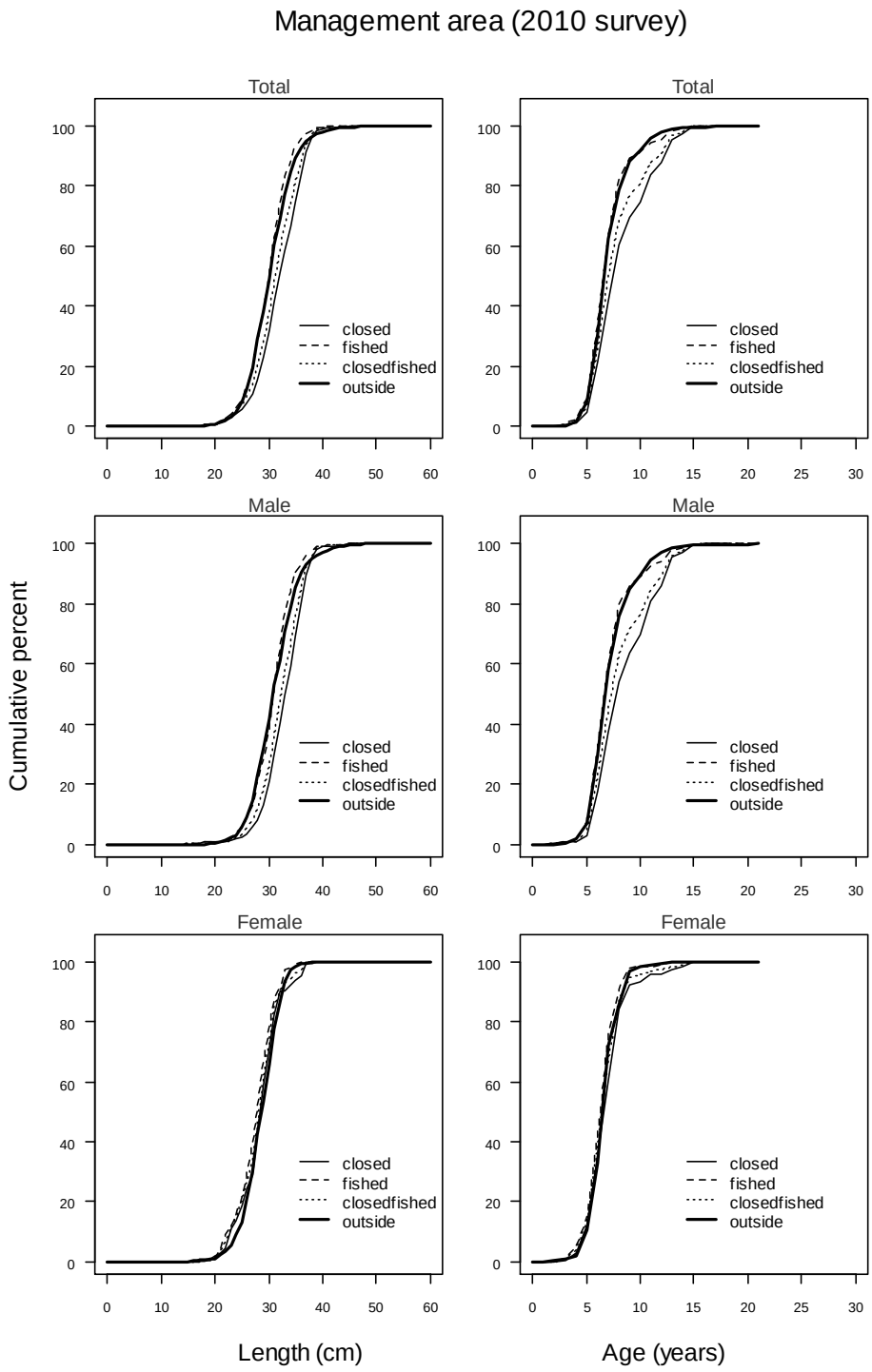


Figure 30: Cumulative distributions of scaled length and age frequencies for total, male, and female blue cod by management areas surveyed in the 2010 Marlborough Sounds blue cod potting survey. Only data from fixed sites are included in these plots.

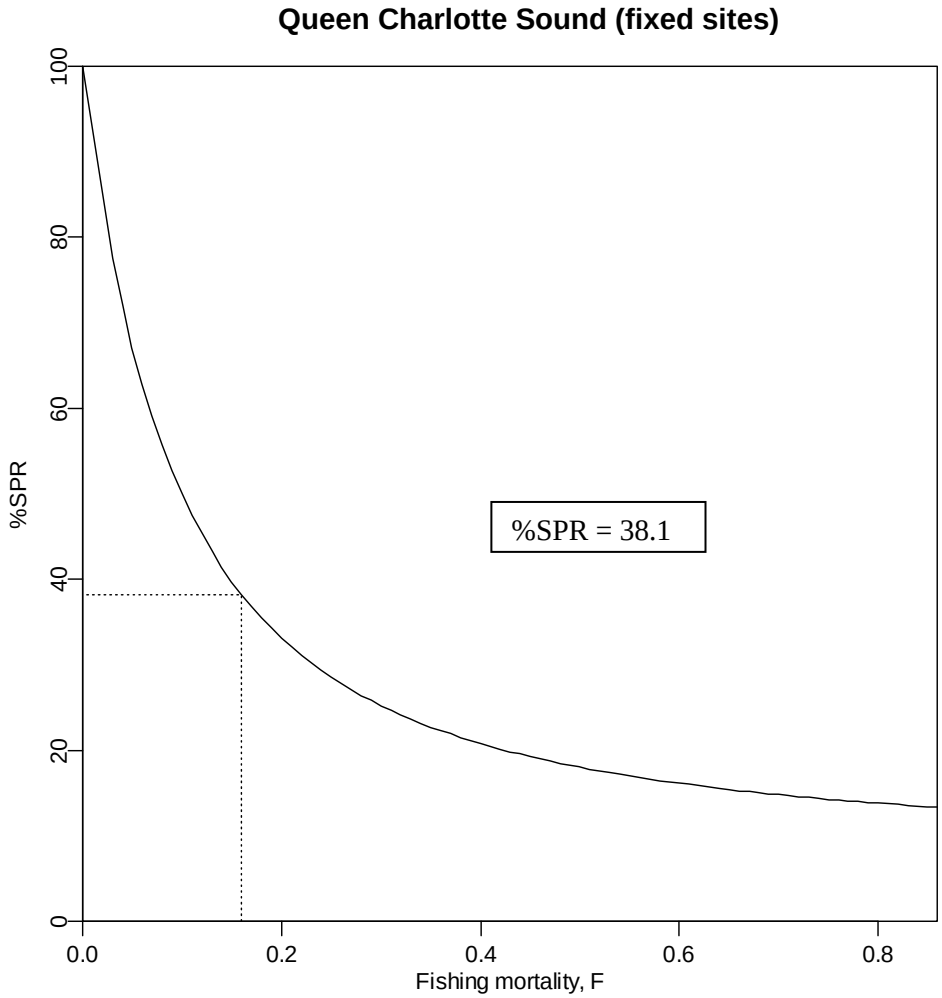


Figure 31: Spawner-per-recruit (SPR) curve as a function of fishing mortality (*F*) for 2010 Marlborough Sounds blue cod potting survey. The %SPR (38.1%) corresponding to the *F* value (0.16) for Queen Charlotte Sound is shown as an example. *M* = 0.14, and *F* value is for age of full recruitment equal to 6 years. *Z* estimates, fishing mortalities, and $F_{SPR\%}$ values for sensitivity analyses around *M* are given by region in Table 19, and by management area in Table 20.

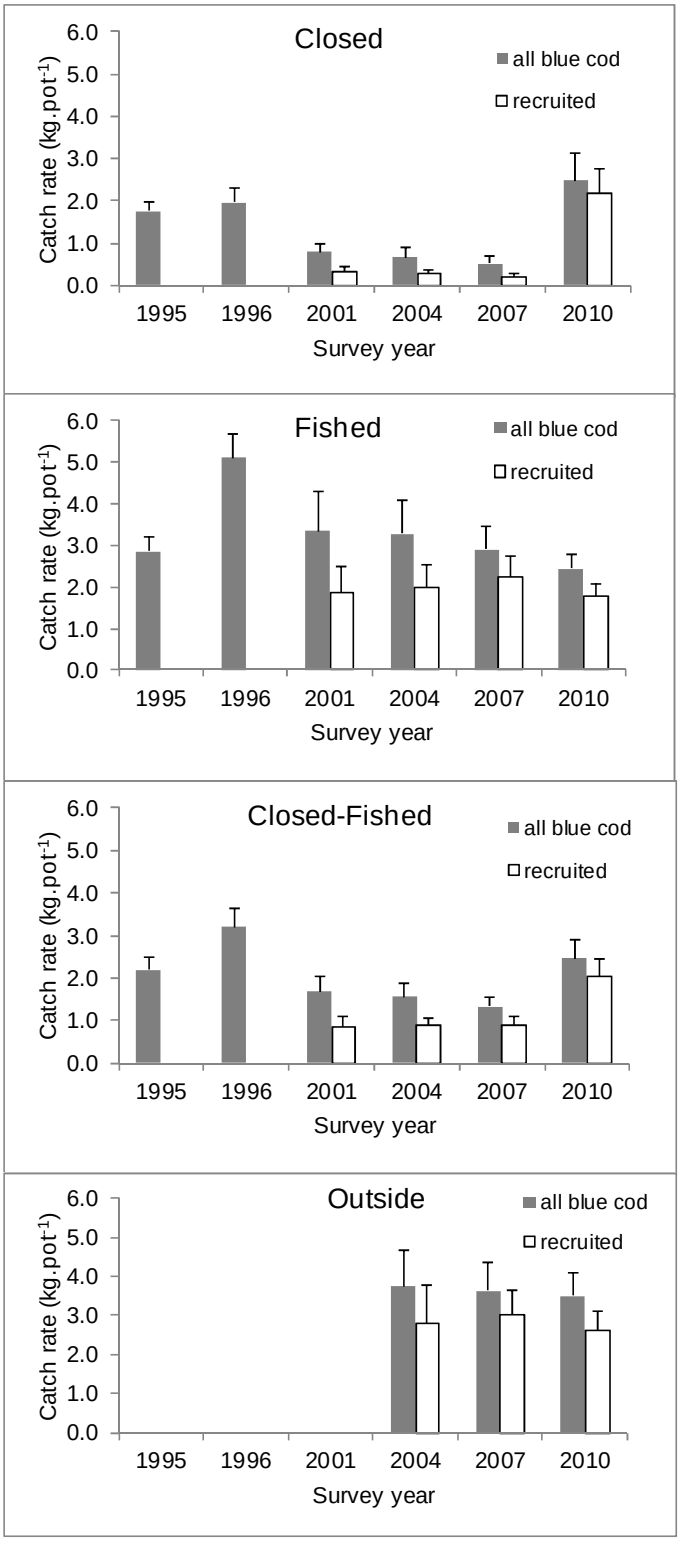


Figure 32: Catch rates of all blue cod and recruited blue cod (30cm and over) from the 1995, 1996, 2001, 2004, 2007, and 2010 Marlborough Sound potting surveys. Catch rates are plotted by management areas. Error bars are 95% confidence intervals. All sites were fixed except for 2010 outside which includes fixed sites from stratum 9 and random sites from strata 11–13. Outside 2007 includes the 2008 Cook Strait survey data. The 1995 and 1996 catch rates were interpreted from data in Blackwell 1997 and 1998, and not generated in this report.

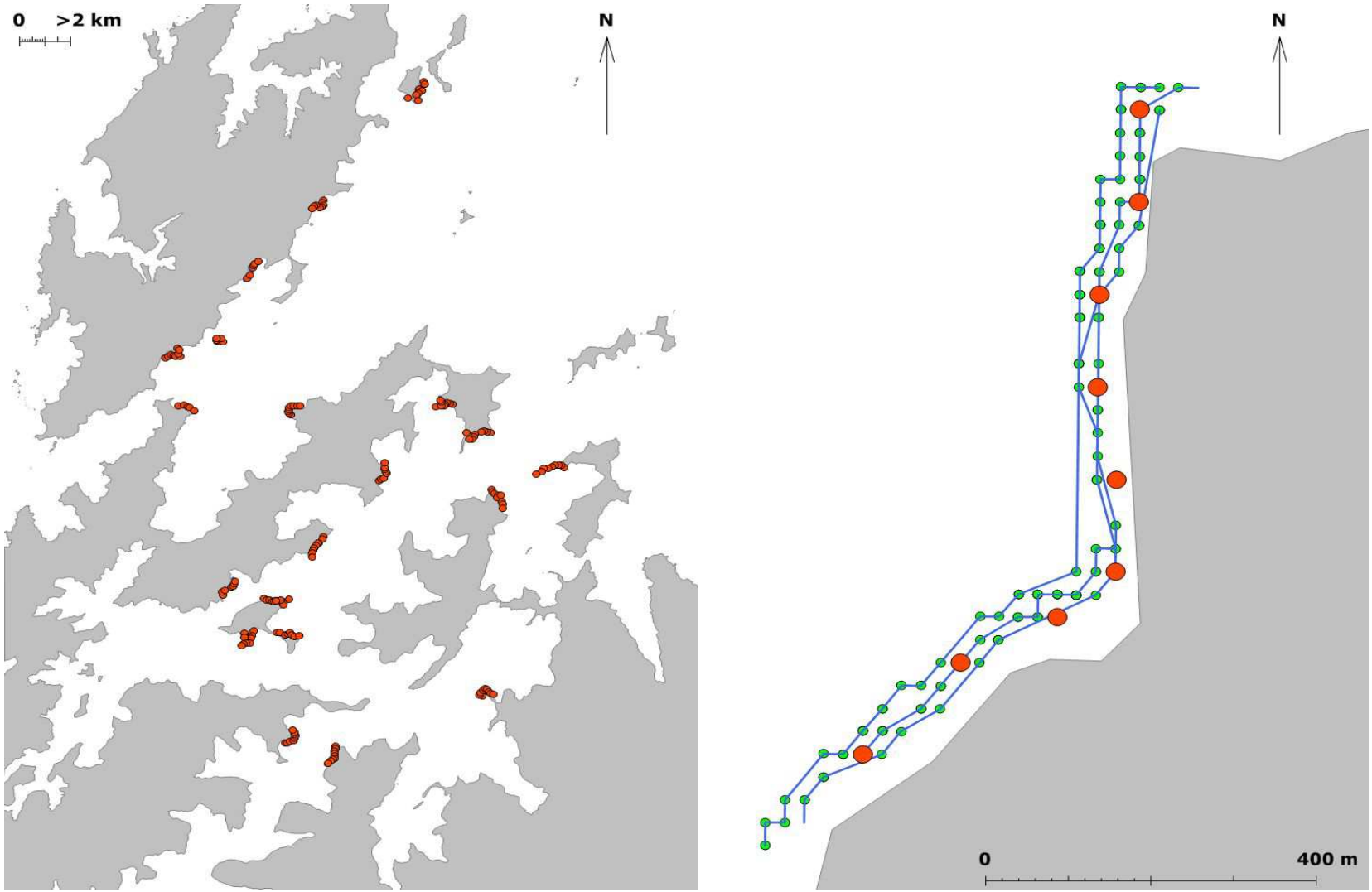


Figure 33: Drift underwater video (DUV) and potting sites. Left - the study area showing the 20 sites surveyed with 9 pots (dots) and 3 video transects. Right – an example site showing pots (large dots), video transects (lines), and habitat quadrats (small dots).

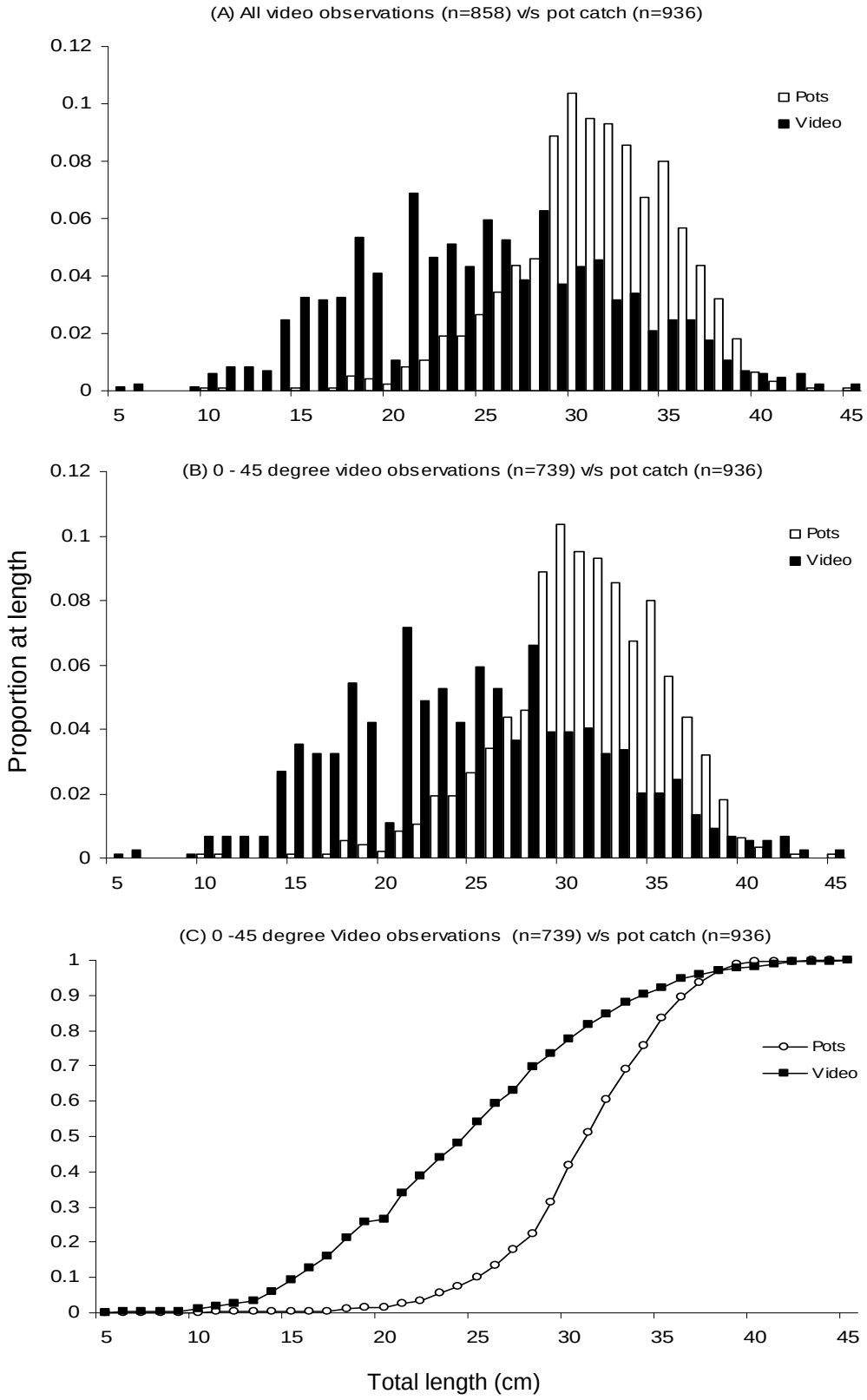


Figure 34: Top – length distribution of blue cod measured from video observations (white) plotted against concurrent pot catch (black). Middle – length distribution of blue cod observed by video excluding those with head-on body orientation to camera (white) plotted against pot catch (black). Bottom – cumulative frequency distribution of the data in the middle plot.

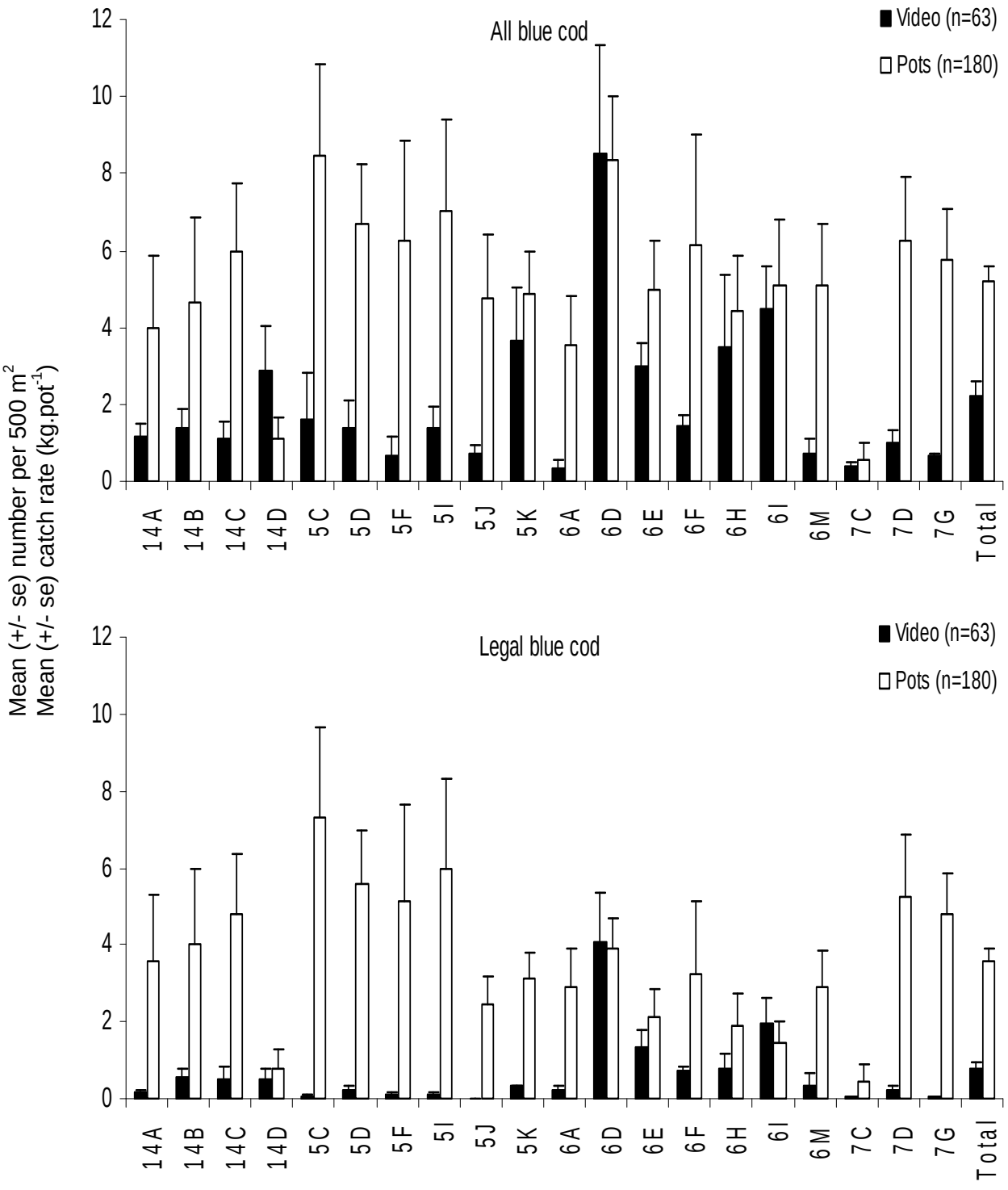


Figure 35: Mean site relative abundance (catch rates) from pots verses the equivalent mean site density estimates from the area swept video method for all blue cod (top) and legal sized (30 cm or more) blue cod (bottom). Strata codes are MAUD (14), OPEL (5), DURE (6), IPEL (7).

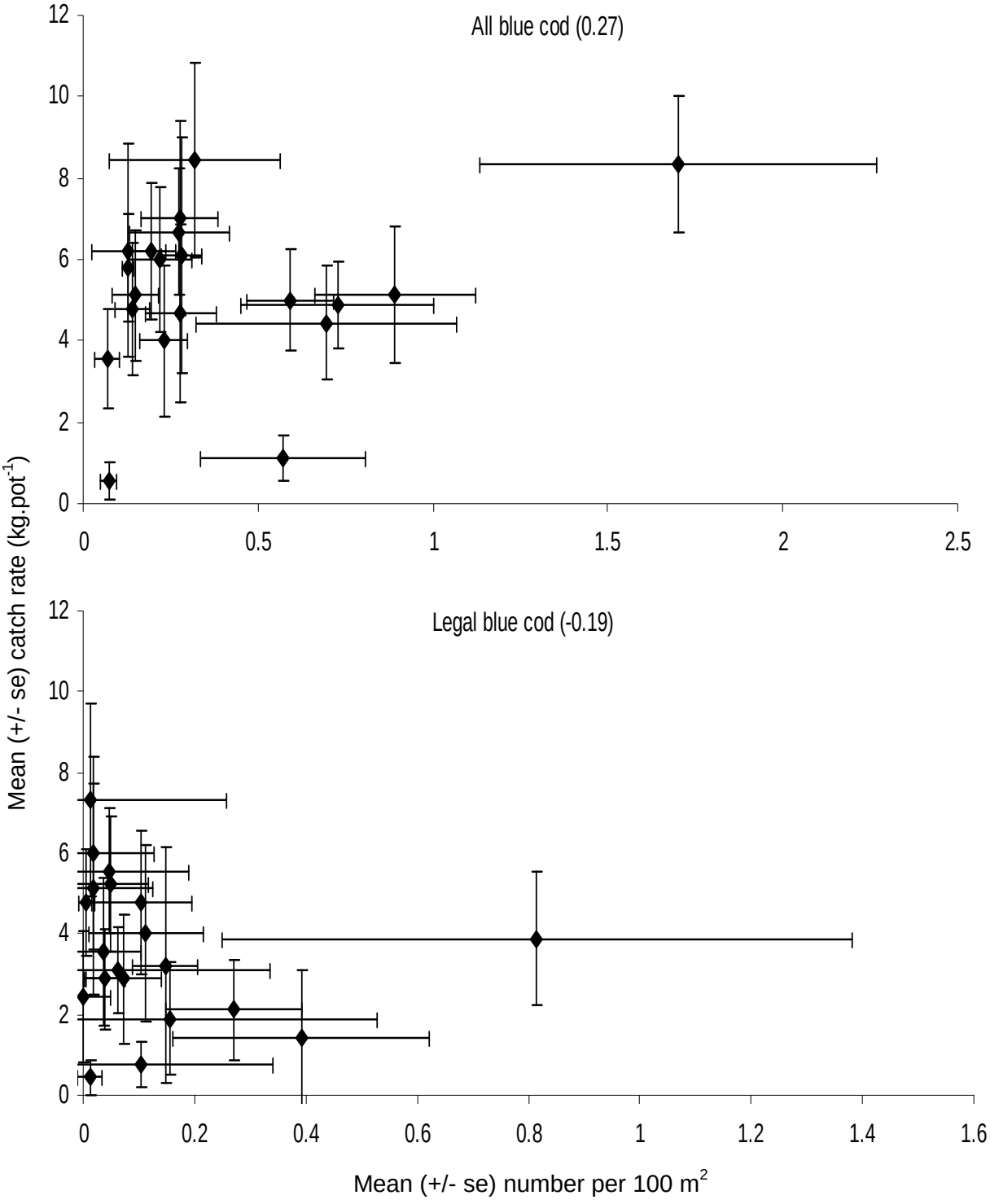


Figure 36: Mean density (from DUV) plotted against catch rate (from pots) of all (top) and legal size (30 cm or more) (bottom) blue cod surveyed concurrently with DUV and pots. The number in brackets is the correlation coefficient.

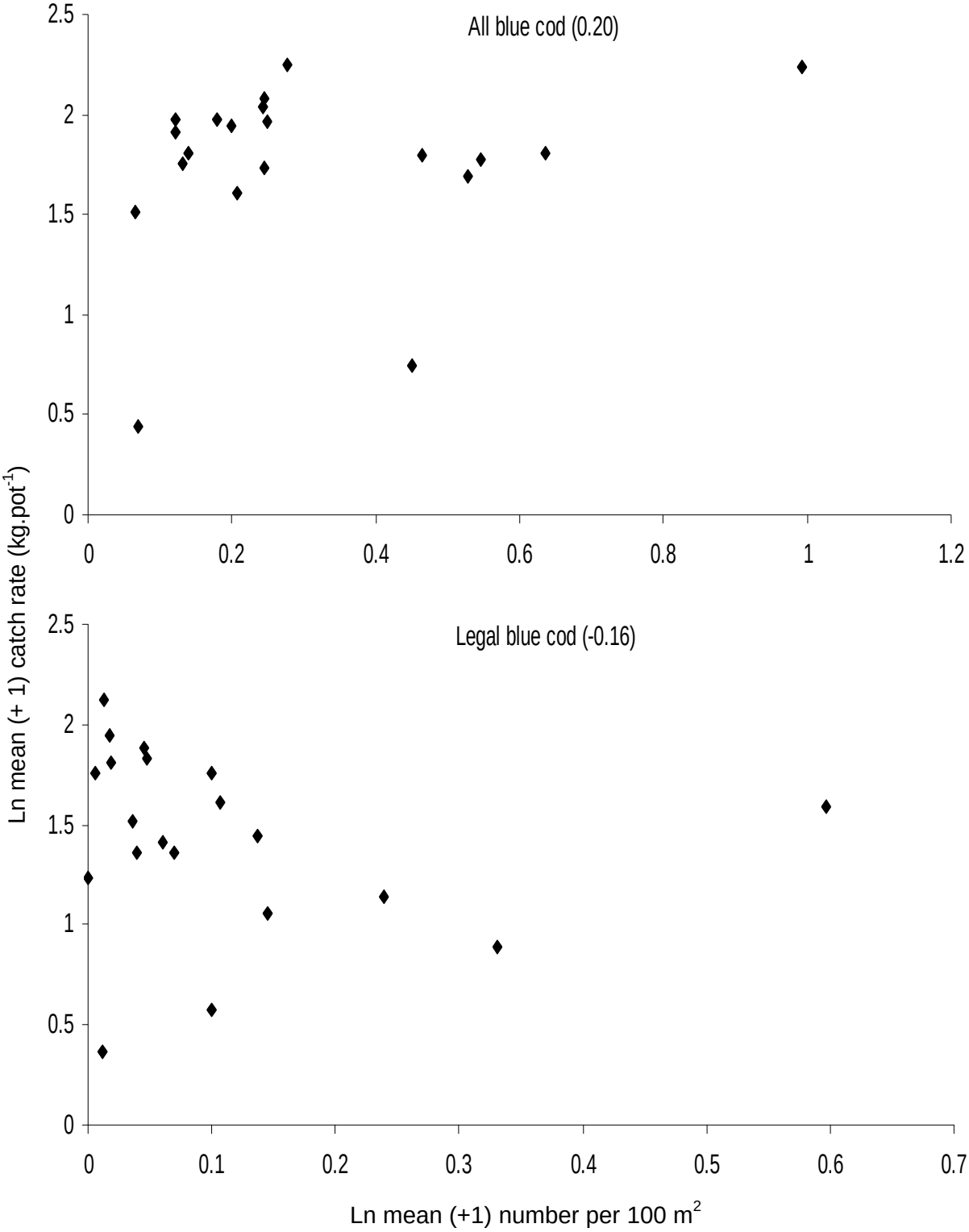


Figure 37: Mean (+1) natural log density (from DUV) plotted against the mean (+1) natural log catch rate (from pots) of all (top) and legal sized (bottom) blue cod surveyed concurrently with video and pots. The number in brackets is the correlation coefficient. The standard errors are not plotted for clarity of these graphs.

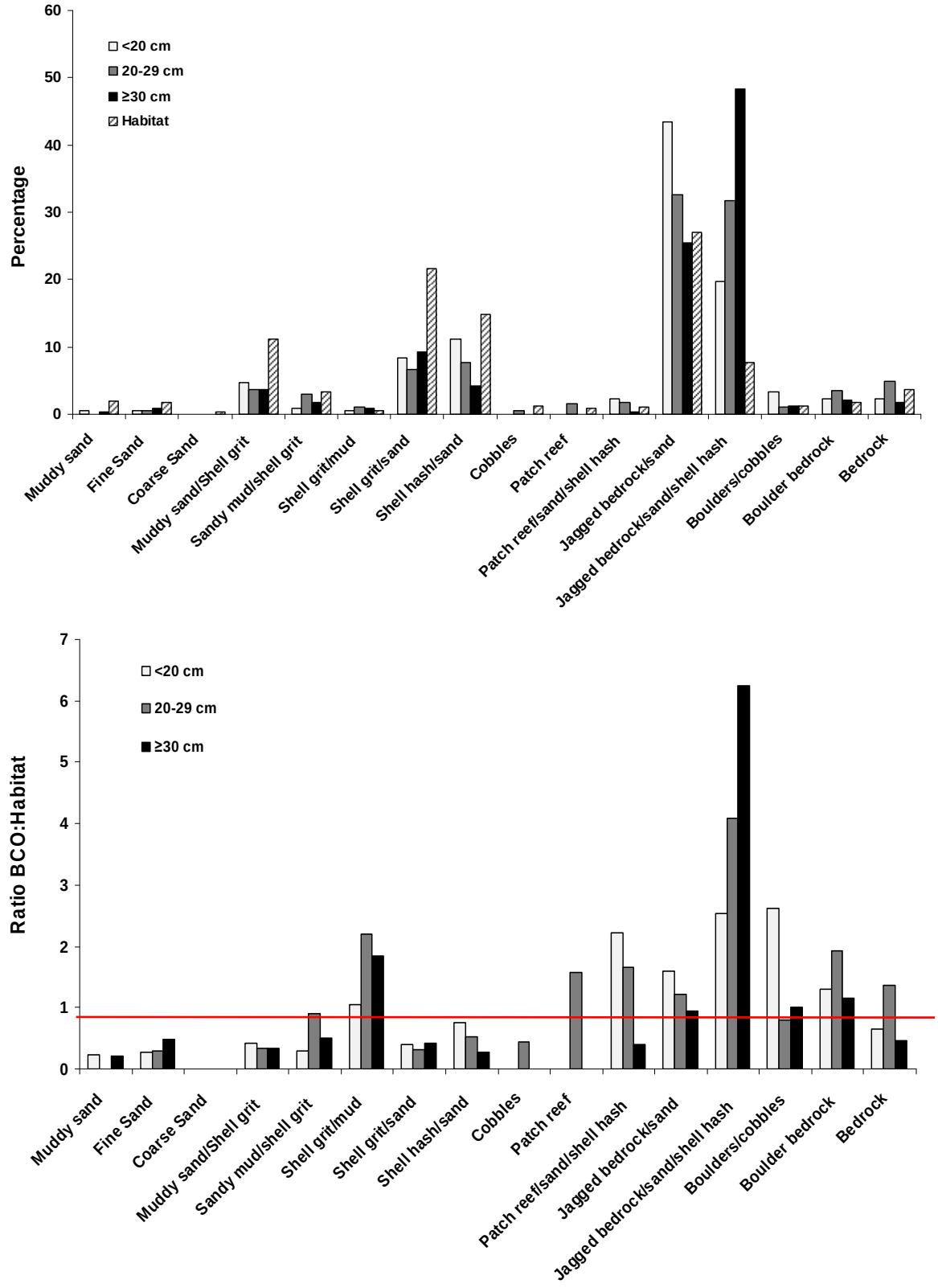


Figure 38: Percentage of primary substrate (top) observations associated with blue cod and independent video observations. The ratio of the percentages of blue cod associated primary substrate and the independent observations recorded by the video is shown in the bottom figure with a line drawn at a 1:1 ratio.

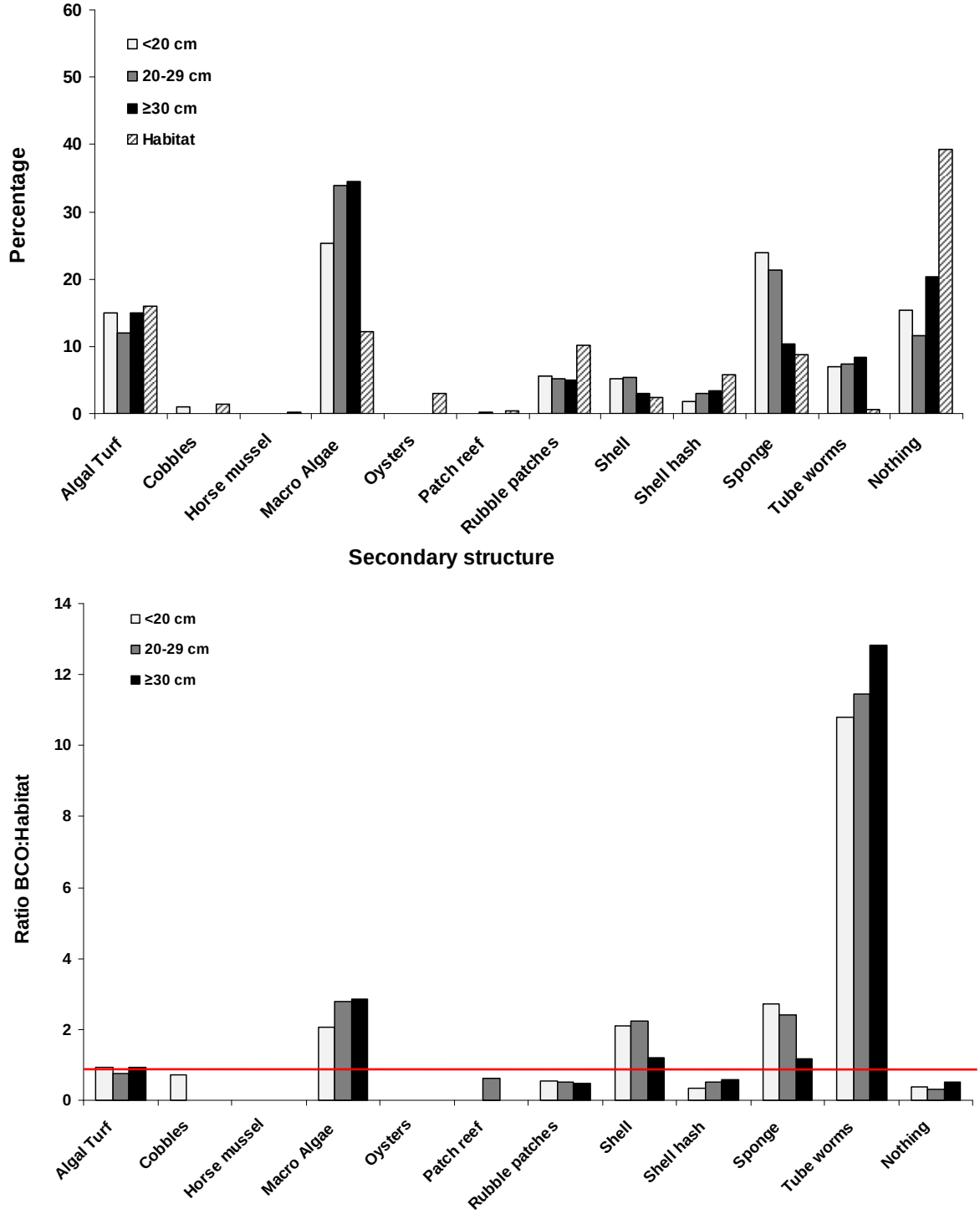


Figure 39: Percentage of secondary structure observations of blue cod and independent video observations. The ratio of the proportion of blue cod and the independent observation of secondary structure recorded by the video method is shown in the bottom figure. A horizontal line is drawn at a ratio of 1:1.

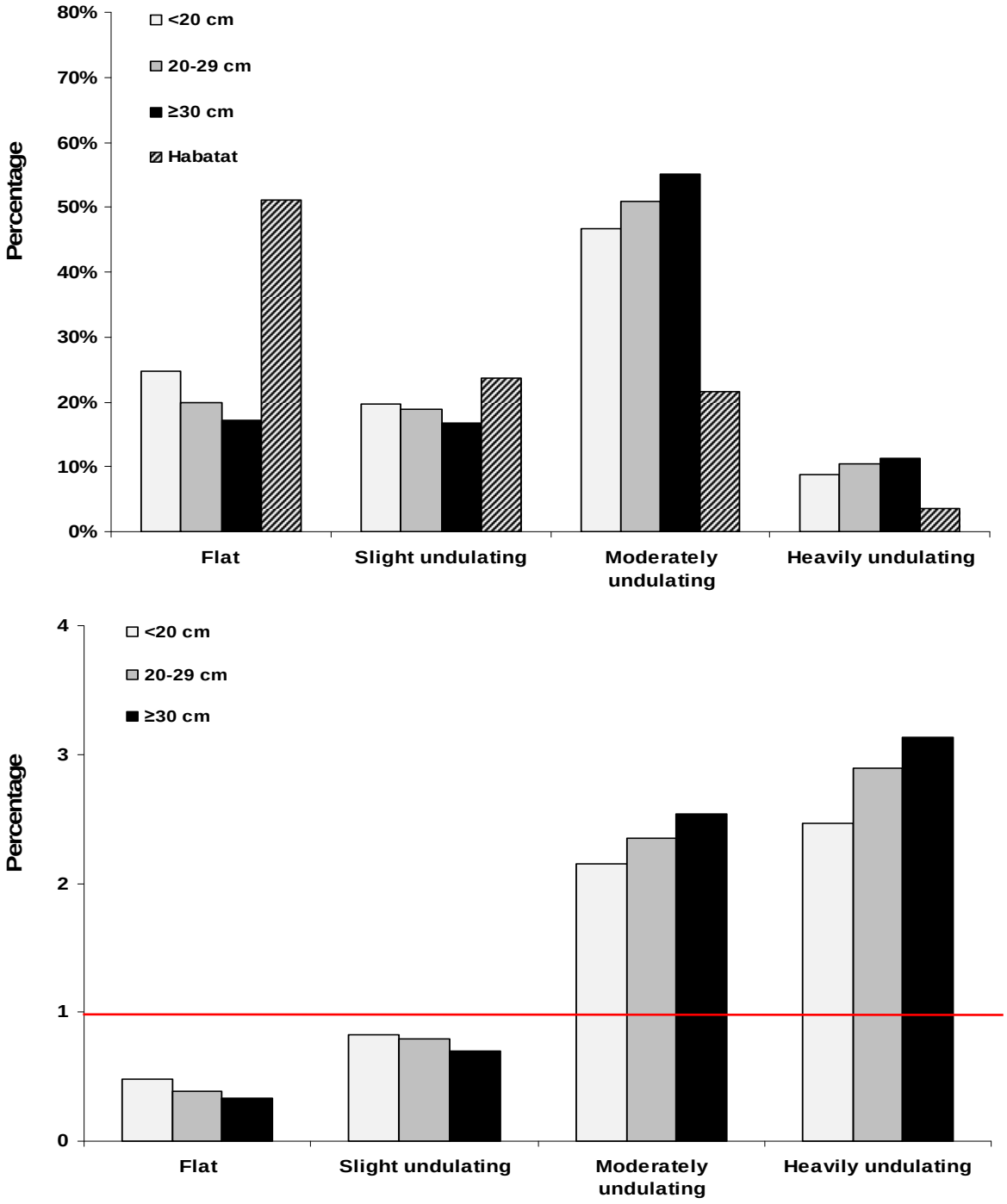


Figure 40: Percentage of topographic complexity observations of blue cod and independent video observations (top). The ratio of the proportion of blue cod and the independent observation of topographic complexity recorded by the video method is shown in the bottom figure. A horizontal line is drawn at a ratio of 1:1.

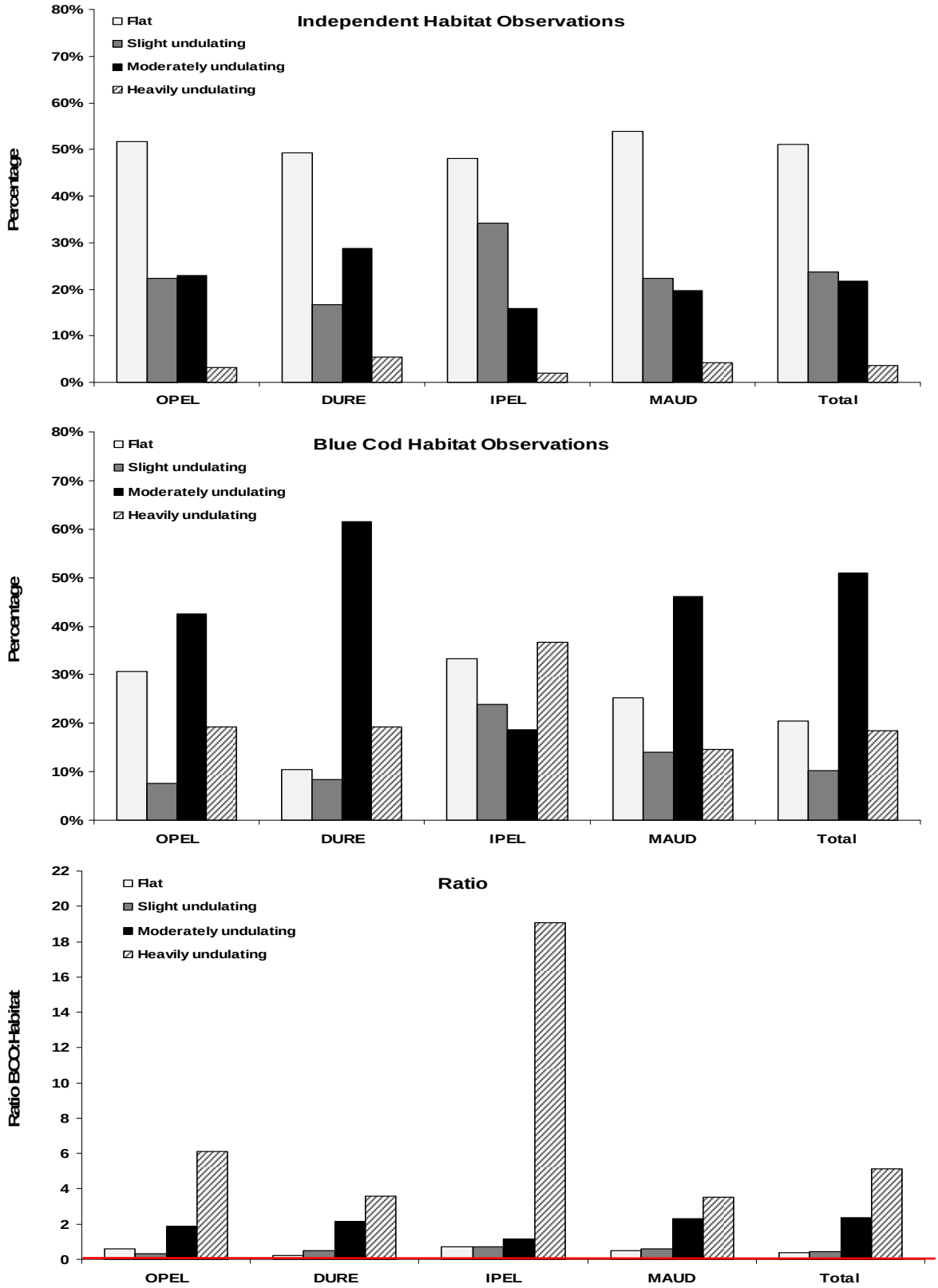


Figure 41: Percentage of topographic complexity observations of blue cod (top) and independent (mid) video observations for each stratum. The ratio of the proportion of blue cod and the independent video observations of topographic complexity is shown by strata in the bottom figure. A horizontal line is drawn at a ratio of 1:1.

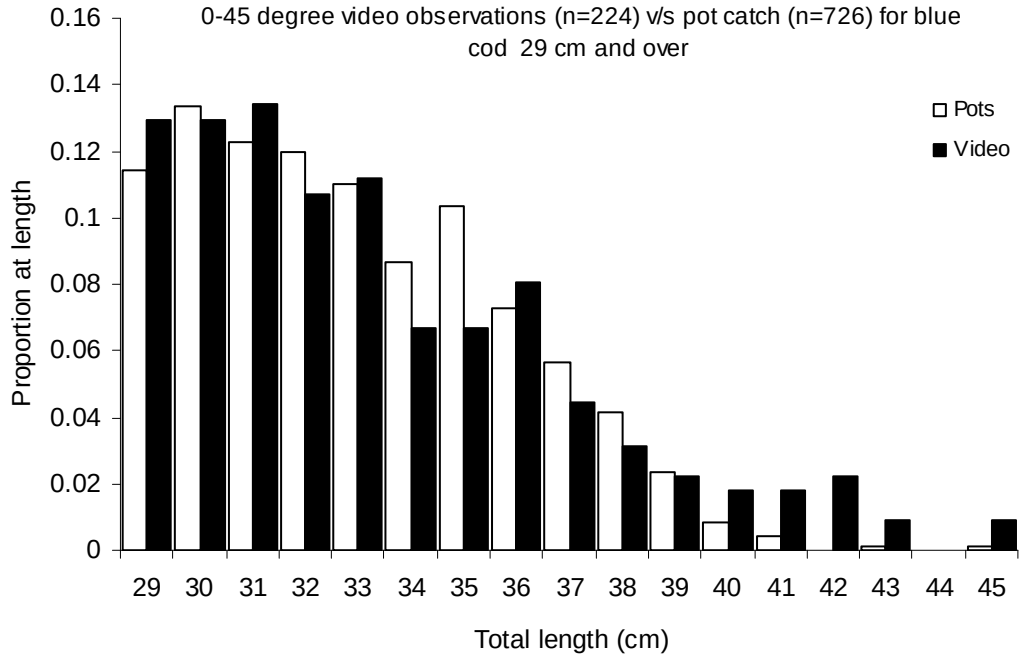


Figure 42: Proportional length frequency distribution of DUV observations (excluding those with head-on body orientation to camera) versus pot catch for blue cod 29 cm and over.

7. APPENDICES

Appendix 1: Glossary of terms used in this report (from Beentjes & Francis 2011).

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).
Fixed site	A predetermined site within a given stratum, that has a fixed location (single latitude and longitude or the centre point location of a section of coastline) and is available to be used repeatedly on subsequent surveys in that area. Which fixed sites are used in a particular survey is determined by random selection from all available fixed sites in each stratum. Fixed sites are sometimes referred to as index sites or fisher-defined sites**.**
Random site	A site that can have any location (single latitude and longitude) generated randomly from within a stratum, given the constraints of proximity to other selected sites for a specific survey.
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. Note that random sites do not have site labels.
Set	A group of pots deployed in the vicinity of a selected site in a specific survey. The pots are set in a cluster or linear configuration.
Set number	A number assigned to each set within a survey. Set numbers are defined sequentially in the order fished. Thus, any set within a survey is uniquely defined by a trip code and set number. Note that the set number is not recorded in the *trawl* database in isolation, but is entered as part of attribute *station_no* in table *t_station*.
Station	The position (latitude and longitude) at which a single pot (or other fishing gear) is deployed at a site during a survey, i.e. it is unique for the trip.
Pot number	Pots are numbered sequentially (1 to 6 or 1 to 9) in the order they are placed during a set.
Station number	A number which uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be station number 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.
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.

Appendix 2: Mean-age-at-length Marlborough Sounds 2010 survey by region.

Appendix 2A: Cook Strait.

	Males		Females	
Length (cm)	N	Mean age (y)	N	Mean age (y)
14			1	2.0
16			1	2.0
18			1	4.0
19	2	3.5	1	4.0
21	3	4.3	4	5.0
22	2	4.5	4	4.5
23	4	4.8	3	5.3
24	2	5.0	5	5.0
25	5	5.4	4	5.8
26	4	5.8	2	5.5
27	5	5.6	5	6.4
28	5	6.6	3	6.7
29	4	6.0	5	7.0
30	5	7.6	3	7.0
31	5	7.0	1	8.0
32	5	8.2	1	8.0
33	5	8.4		
34	5	7.8	1	9.0
35	5	8.6	1	8.0
36	5	10.0		
37	5	10.8		
38	1	7.0		
39	3	11.0		
40	1	15.0		
48	1	18.0		
Totals	82	7.4	46	5.8

Appendix 2B: D'Urville.

	Males		Females	
Length (cm)	N	Mean age (y)	N	Mean age (y)
15	1	2.0	1	2.0
17			1	3.0
18	2	3.0		
19	1	3.0	2	3.0
20	4	4.5	2	4.0
21	5	4.6	5	4.8
22	2	4.0	5	4.6
23	5	5.0	5	5.0
24	4	4.5	5	5.4
25	5	5.2	5	6.4
26	5	5.6	5	5.6
27	5	6.2	5	7.0
28	5	6.4	3	7.3
29	5	6.8	4	6.8
30	5	7.0	5	7.0
31	5	7.6	5	6.8
32	5	6.8	5	8.2
33	3	7.3	5	8.0
34	5	8.8	5	9.2
35	5	8.4	5	11.2
36	5	9.8	2	10.5
37	4	10.3		
38	5	10.8	1	12.0
39	3	11.7		
40	4	12.3	1	13.0
41	5	12.4		
42	1	12.0		
43	5	13.2		
44	2	16.0		
45	2	14.5		
47	1	12.0		
48	2	20.5		
Total	116	8.2	82	6.8

Appendix 2C: Pelorus Sound.

	Males		Females	
Length (cm)	N	Mean age (y)	N	Mean age (y)
10			1	1.0
11			1	1.0
15			1	2.0
17	1	3.0		
18	4	2.5	1	3.0
19	2	4.0	1	4.0
20	2	4.5	2	5.5
21	2	3.5	5	4.8
22	1	5.0	5	4.6
23	5	5.2	5	5.0
24	4	5.5	5	6.2
25	5	5.6	5	5.4
26	5	6.2	5	6.0
27	5	5.6	4	6.5
28	5	6.0	5	6.6
29	5	6.6	5	6.6
30	5	6.2	5	7.4
31	5	6.6	5	7.6
32	5	7.2	5	8.0
33	5	7.6	5	8.4
34	5	9.6	4	8.3
35	5	10.4	1	15.0
36	5	10.6		
37	5	11.0		
38	5	11.0		
39	4	13.3		
40	5	11.6		
41	3	11.3		
42	1	16.0		
43	2	16.5		
Total	106	7.9	76	6.3

Appendix 2D: Queen Charlotte Sound.

	Males		Females	
Length (cm)	N	Mean age (y)	N	Mean age (y)
17			1	3.0
19			1	3.0
20			1	4.0
21			1	5.0
22	1	6.0	1	5.0
23	1	5.0	4	5.3
24	3	5.7	1	6.0
25	1	5.0	4	6.3
26	5	6.8	5	6.0
27	5	6.6	5	6.6
28	5	7.0	5	7.6
29	5	6.6	4	7.3
30	5	7.2	5	7.2
31	5	7.6	4	8.0
32	5	7.4	5	8.0
33	5	8.6		
34	5	8.0	1	9.0
35	5	10.2	3	11.7
36	5	11.4	2	10.5
37	5	11.6	3	13.3
38	5	12.6		
39	4	12.8	1	15.0
40	5	13.8		
41	1	15.0		
44	1	13.0		
45	2	15.5		
Total	84	9.2	57	7.5

Appendix 3: Estimates of proportion of length at age for blue cod sampled from the Marlborough Sounds 2010 survey by region (age length key, ALK).

Appendix 3A: Cook Strait. N = 82 males 46 females.

Males

											Age (years)	
Length (cm)	3	4	5	6	7	8	9	10	11	12	15	18
19	0.5	0.5	0	0	0	0	0	0	0	0	0	0
21	0	0.67	0.33	0	0	0	0	0	0	0	0	0
22	0	0.5	0.5	0	0	0	0	0	0	0	0	0
23	0	0.5	0.25	0.25	0	0	0	0	0	0	0	0
24	0	0	1	0	0	0	0	0	0	0	0	0
25	0	0.2	0.4	0.2	0.2	0	0	0	0	0	0	0
26	0	0	0.25	0.75	0	0	0	0	0	0	0	0
27	0	0.2	0.2	0.4	0.2	0	0	0	0	0	0	0
28	0	0	0	0.6	0.2	0.2	0	0	0	0	0	0
29	0	0	0	1	0	0	0	0	0	0	0	0
30	0	0	0	0	0.4	0.6	0	0	0	0	0	0
31	0	0	0	0.2	0.6	0.2	0	0	0	0	0	0
32	0	0	0	0	0.2	0.4	0.4	0	0	0	0	0
33	0	0	0	0	0.2	0.4	0.2	0.2	0	0	0	0
34	0	0	0	0.2	0.4	0	0.2	0.2	0	0	0	0
35	0	0	0	0	0.2	0.2	0.4	0.2	0	0	0	0
36	0	0	0	0	0	0	0.2	0.6	0.2	0	0	0
37	0	0	0	0	0	0	0	0.6	0	0.4	0	0
38	0	0	0	0	1	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0.33	0.33	0.33	0	0
40	0	0	0	0	0	0	0	0	0	0	1	0
48	0	0	0	0	0	0	0	0	0	0	0	1

Females

						Age (years)	
Length (cm)	2	4	5	6	7	8	9
14	1	0	0	0	0	0	0
16	1	0	0	0	0	0	0
18	0	1	0	0	0	0	0
19	0	1	0	0	0	0	0
21	0	0	1	0	0	0	0
22	0	0.5	0.5	0	0	0	0
23	0	0	0.67	0.33	0	0	0
24	0	0	1	0	0	0	0
25	0	0	0.25	0.75	0	0	0
26	0	0	0.5	0.5	0	0	0
27	0	0	0	0.6	0.4	0	0
28	0	0	0	0.67	0	0.33	0
29	0	0	0	0.2	0.6	0.2	0
30	0	0	0	0.33	0.33	0.33	0
31	0	0	0	0	0	1	0
32	0	0	0	0	0	1	0
34	0	0	0	0	0	0	1
35	0	0	0	0	0	1	0

Appendix 3B: D'Urville. N = 116 males 82 females.

Males

																	Age (years)	
Length (cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	20	21
15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0.6	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0.8	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0.6	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0.8	0.2	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0.6	0.4	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0.4	0.4	0.2	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0.2	0.6	0.2	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0.4	0.6	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0.4	0.4	0.2	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0.33	0.33	0	0.33	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0.2	0.4	0	0.2	0.2	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0.2	0.2	0.6	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0.2	0.2	0	0.2	0.2	0	0.2	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0.25	0.25	0.5	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0.2	0	0.6	0.2	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0.33	0	0.33	0.33	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0.25	0.5	0	0.25	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0.2	0	0.2	0.4	0.2	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0.2	0.2	0.2	0	0.4	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0.5	0	0
47	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5

Females

											age (years)	
Length (cm)	2	3	4	5	6	7	8	9	10	11	12	13
15	1	0	0	0	0	0	0	0	0	0	0	0
17	0	1	0	0	0	0	0	0	0	0	0	0
19	0.5	0	0.5	0	0	0	0	0	0	0	0	0
20	0	0.5	0	0.5	0	0	0	0	0	0	0	0
21	0	0.2	0	0.6	0.2	0	0	0	0	0	0	0
22	0	0	0.6	0.2	0.2	0	0	0	0	0	0	0
23	0	0	0.2	0.6	0.2	0	0	0	0	0	0	0
24	0	0	0	0.6	0.4	0	0	0	0	0	0	0
25	0	0	0	0	0.6	0.4	0	0	0	0	0	0
26	0	0	0	0.4	0.6	0	0	0	0	0	0	0
27	0	0	0	0	0.4	0.4	0	0.2	0	0	0	0
28	0	0	0	0	0	0.67	0.33	0	0	0	0	0
29	0	0	0	0	0.5	0.25	0.25	0	0	0	0	0
30	0	0	0	0	0	1	0	0	0	0	0	0
31	0	0	0	0	0.2	0.8	0	0	0	0	0	0
32	0	0	0	0	0	0.2	0.4	0.4	0	0	0	0
33	0	0	0	0	0.2	0	0.4	0.4	0	0	0	0
34	0	0	0	0	0	0	0	0.8	0.2	0	0	0
35	0	0	0	0	0	0	0	0.4	0	0	0.2	0.4
36	0	0	0	0	0	0	0	0	0.5	0.5	0	0
38	0	0	0	0	0	0	0	0	0	0	1	0
40	0	0	0	0	0	0	0	0	0	0	0	1

Appendix 3C: Pelorus Sound. N = 116 males 76 females.

Males

															Age (years)	
Length (cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18
17	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0.2	0.4	0.4	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0.4	0.6	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0.8	0.2	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0.4	0.6	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0.2	0.6	0.2	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0.2	0	0.8	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0.8	0.2	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0.6	0.2	0.2	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0.2	0.4	0.4	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0.2	0.2	0.4	0.2	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0.4	0.2	0	0	0.2	0	0	0	0.2	0	0
35	0	0	0	0	0	0.2	0	0.2	0.2	0	0	0.4	0	0	0	0
36	0	0	0	0	0	0	0.2	0	0.2	0.4	0	0.2	0	0	0	0
37	0	0	0	0	0	0	0	0.2	0	0.4	0.4	0	0	0	0	0
38	0	0	0	0	0	0	0	0.2	0.2	0.2	0.2	0.2	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0.25	0	0.25	0.25	0.25	0	0
40	0	0	0	0	0	0	0	0	0	0.6	0.2	0.2	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0.67	0.33	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.5

Females

										Age (years)	
Length (cm)	1	2	3	4	5	6	7	8	9	12	15
10	1	0	0	0	0	0	0	0	0	0	0
11	1	0	0	0	0	0	0	0	0	0	0
15	0	1	0	0	0	0	0	0	0	0	0
18	0	0	1	0	0	0	0	0	0	0	0
19	0	0	0	1	0	0	0	0	0	0	0
20	0	0	0	0	0.5	0.5	0	0	0	0	0
21	0	0	0	0.2	0.8	0	0	0	0	0	0
22	0	0	0	0.4	0.6	0	0	0	0	0	0
23	0	0	0	0	1	0	0	0	0	0	0
24	0	0	0	0	0	0.8	0.2	0	0	0	0
25	0	0	0	0	0.6	0.4	0	0	0	0	0
26	0	0	0	0	0.2	0.6	0.2	0	0	0	0
27	0	0	0	0	0.25	0.25	0.25	0.25	0	0	0
28	0	0	0	0	0	0.6	0.2	0.2	0	0	0
29	0	0	0	0	0	0.4	0.6	0	0	0	0
30	0	0	0	0	0	0.2	0.4	0.2	0.2	0	0
31	0	0	0	0	0	0	0.4	0.6	0	0	0
32	0	0	0	0	0	0	0.2	0.6	0.2	0	0
33	0	0	0	0	0	0	0.4	0.4	0	0.2	0
34	0	0	0	0	0	0	0	0.75	0.25	0	0
35	0	0	0	0	0	0	0	0	0	0	1

Appendix 3D: Queen Charlotte Sound. N = 84 males 57 females.

Males

											Age (years)	
Length (cm)	5	6	7	8	9	10	11	12	13	14	15	16
22	0	1	0	0	0	0	0	0	0	0	0	0
23	1	0	0	0	0	0	0	0	0	0	0	0
24	0.33	0.67	0	0	0	0	0	0	0	0	0	0
25	1	0	0	0	0	0	0	0	0	0	0	0
26	0	0.4	0.4	0.2	0	0	0	0	0	0	0	0
27	0	0.6	0.2	0.2	0	0	0	0	0	0	0	0
28	0	0.2	0.6	0.2	0	0	0	0	0	0	0	0
29	0	0.8	0	0	0.2	0	0	0	0	0	0	0
30	0	0.2	0.4	0.4	0	0	0	0	0	0	0	0
31	0	0	0.4	0.6	0	0	0	0	0	0	0	0
32	0	0	0.6	0.4	0	0	0	0	0	0	0	0
33	0	0	0	0.6	0.2	0.2	0	0	0	0	0	0
34	0	0	0.2	0.6	0.2	0	0	0	0	0	0	0
35	0	0	0	0	0.4	0.2	0.2	0.2	0	0	0	0
36	0	0	0	0	0.2	0.2	0.2	0	0.2	0.2	0	0
37	0	0	0	0	0.2	0	0.2	0.2	0.4	0	0	0
38	0	0	0	0	0	0	0.2	0	0.8	0	0	0
39	0	0	0	0	0	0	0.25	0.25	0	0.5	0	0
40	0	0	0	0	0	0	0	0.2	0.2	0.2	0.4	0
41	0	0	0	0	0	0	0	0	0	0	1	0
44	0	0	0	0	0	0	0	0	1	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0.5	0.5

Females

										Age (years)	
Length (cm)	3	4	5	6	7	8	9	10	11	13	14	15
17	1	0	0	0	0	0	0	0	0	0	0	0
19	1	0	0	0	0	0	0	0	0	0	0	0
20	0	1	0	0	0	0	0	0	0	0	0	0
21	0	0	1	0	0	0	0	0	0	0	0	0
22	0	0	1	0	0	0	0	0	0	0	0	0
23	0	0.25	0.25	0.5	0	0	0	0	0	0	0	0
24	0	0	0	1	0	0	0	0	0	0	0	0
25	0	0	0.25	0.5	0	0.25	0	0	0	0	0	0
26	0	0	0.2	0.6	0.2	0	0	0	0	0	0	0
27	0	0	0	0.8	0	0	0.2	0	0	0	0	0
28	0	0	0	0	0.6	0.2	0.2	0	0	0	0	0
29	0	0	0	0	0.75	0.25	0	0	0	0	0	0
30	0	0	0	0.4	0.2	0.2	0.2	0	0	0	0	0
31	0	0	0	0	0	1	0	0	0	0	0	0
32	0	0	0	0	0.2	0.6	0.2	0	0	0	0	0
34	0	0	0	0	0	0	1	0	0	0	0	0
35	0	0	0	0	0	0	0.33	0	0	0.67	0	0
36	0	0	0	0	0	0	0	0.5	0.5	0	0	0
37	0	0	0	0	0	0	0	0	0.33	0	0.33	0.33
39	0	0	0	0	0	0	0	0	0	0	0	1

Appendix 4: Cook Strait 2008 blue cod survey results (trip_code jug0801).

Appendix 4A. Cook Strait 2008 potting survey effort and catch summary by strata. CKST, Cook Strait.

Region	Stratum	Stratum code	Area (km coastline)	Site type	*N* sets (sites)	*N* pots (stations)	No. blue cod	Catch (kg)	Depth (m) Mean	min	max
CKST	11	APAE	21.6	Fixed	7	63	492	262.1	23.2	12	46
CKST	12	COOK	30	Fixed	7	63	140	65.8	20.4	8	39
CKST	13	UNDW	34	Fixed	8	72	51	22.6	12.2	4	39
Totals					22	198	683	350.5			

Appendix 4B: Catch weights and total numbers of blue cod and bycatch species caught on the 2008 Cook Strait blue cod potting survey.

Common name	Scientific name	Species code	Catch (kg)	Number	Percent of total catch
Blue cod	*Parapercis colias*	BCO	351	684	83.0
Octopus	*Octopus sp.*	OCT	28.2	6	6.7
Banded wrasse	*Notolabrus fucicola*	BPF	26	56	6.1
Scarlet wrasse	*Pseudolabrus miles*	SPF	5.3	29	1.3
Spotty	*Notolabrus celidotus*	STY	2.8	8	0.7
Sea perch	*Helicolenus percoides*	SPE	1.4	4	0.3
Marblefish	*Aplodactylus arctidens*	GTR	1	1	0.2
Maori chief	*Paranotothenia augustata*	MCH	1	1	0.2
Red rock cod	*Scorpaena cardinalis*	SDL	1	5	0.2
Starfish		SFI	1	3	0.2
Tarakihi	*Nemadactylus macropterus*	TAR	1	4	0.2
Splendid perch	*Callanthias allporti*	SPP	0.8	2	0.2
Triplefin	*Gilloblennius* sp	GIL	0.6	12	0.1
Leatherjacket	*Parika scaber*	LEA	0.5	1	0.1
Brittle star	Ophiuroid	OPH	0.5	7	0.1
Trumpeter	*Latris lineata*	TRU	0.5	1	0.1
Nudibranch	Nudibranchia	NUD	0.1	1	0.0
Sea horse	*Hippocampus abdominalis*	SHO	0.1	1	0.0
Totals			422.8	826	100

Appendix 4C: Mean blue cod catch rates for all blue cod caught from the 2008 Cook Strait survey by stratum. Catch rates are pot-based, and s.e. and c.v. are set-based. s.e., standard error; c.v. coefficient of variation; CKST, Cook Strait.

Region	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	c.v. (%)
CKST	11	Fixed	63	4.2	0.76	18.1
CKST	12	Fixed	63	1.0	0.39	37.2
CKST	13	Fixed	72	0.3	0.10	31.1
	Overall	Fixed	198	1.5	0.24	15.4

Appendix 4D: Mean blue cod catch rates for recruited blue cod (30 cm and over) caught from the 2008 Cook Strait survey by stratum. Catch rates are pot-based, and s.e. and c.v. are set-based. s.e., standard error; c.v. coefficient of variation; CKST, Cook Strait.

Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
CKST	11	Fixed	63	3.48	0.73	20.9
CKST	12	Fixed	63	0.82	0.34	41.3
CKST	13	Fixed	72	0.21	0.07	34.7
	Overall	Fixed	198	1.25	0.22	17.6

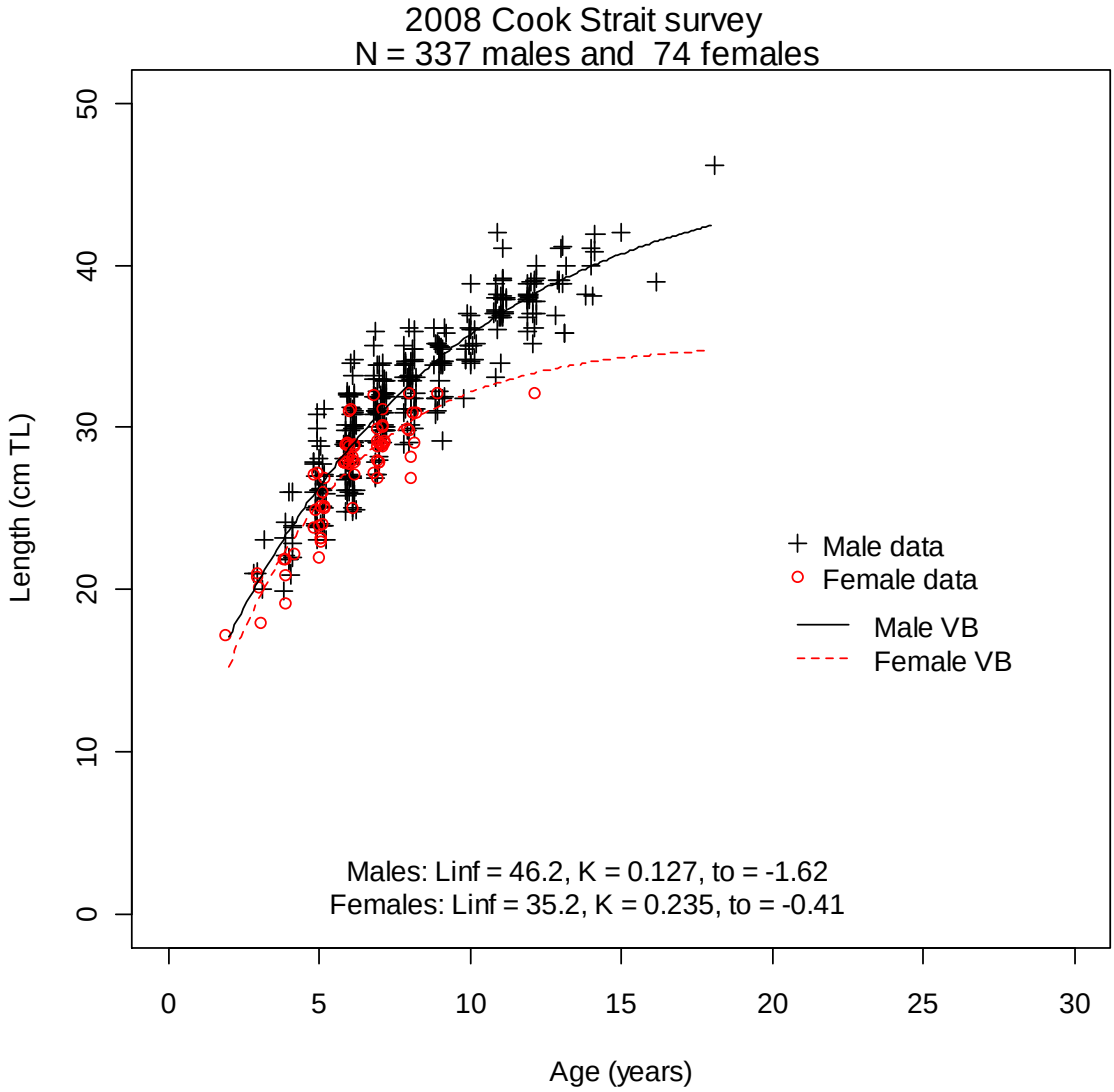
Appendix 4E: Weighted mean lengths and weighted sex ratio (M:F) for all blue cod by stratum in the 2008 Cook Strait survey.

			Length (cm)			
Stratum	Sex	N	Mean	Minimum	Maximum	Sex ratio M:F (% male)
11	m	448	32.2	20	46	10.1:1(91.0%)
	f	44	27.8	20	32	
	u	0	–	–	–	
12	m	117	31.5	23	42	5.1:1 (83.6%)
	f	23	24.9	18	32	
	u	1	22	22	22	
13	m	40	30.5	20	39	3.4:1 (77.3%)
	f	11	25.4	17	31	
	u	0	–	–	–	
Overall	m	605	31.9	20	46	7.4:1 (88.1%)
	f	78	26.4	17	32	
	u	1	22	22	22	

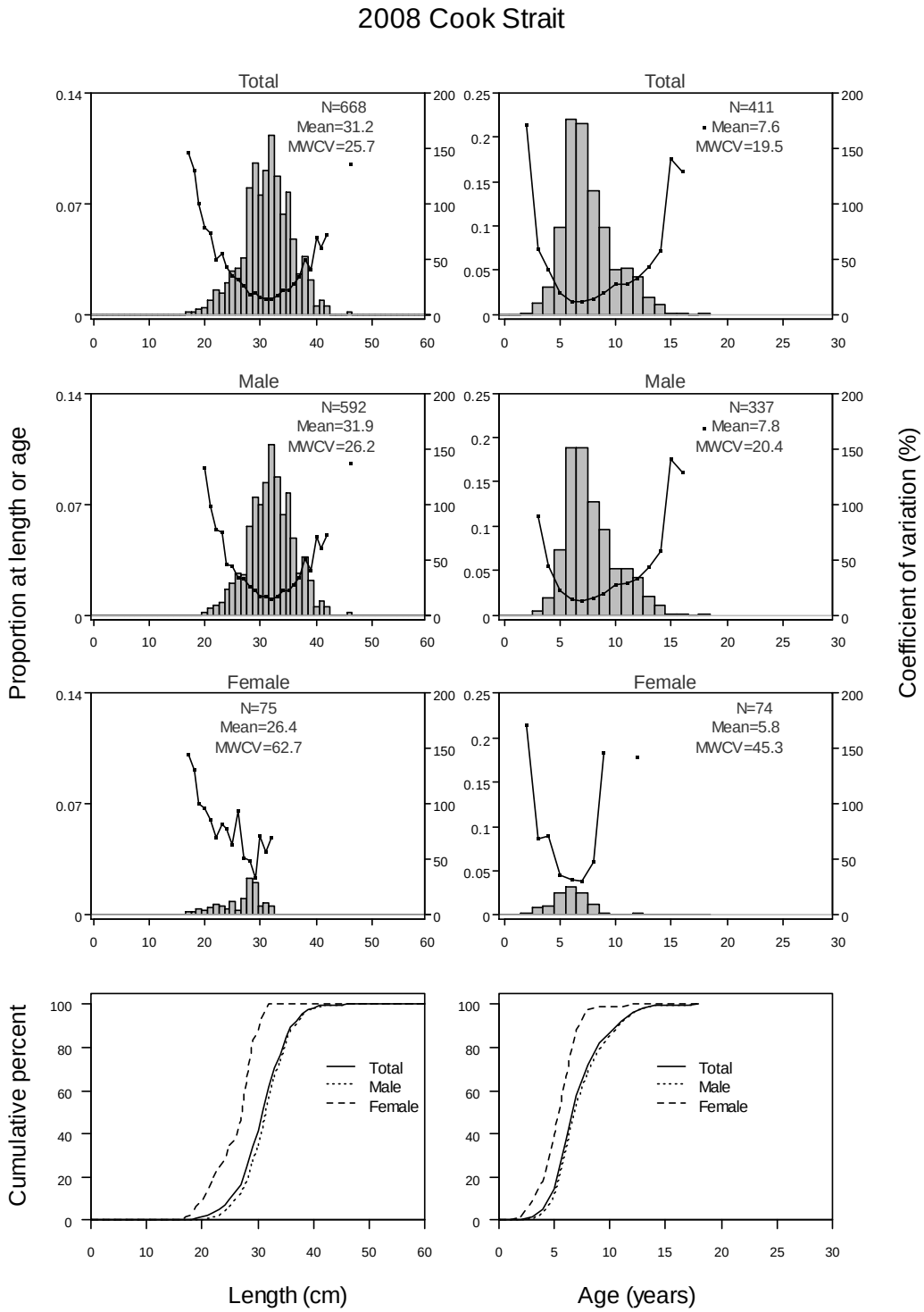
Appendix 4F: Gonad stages of 2008 Cook Strait survey 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent; CKST, Cook Strait.

			Gonad stage %				
Region	Size status	Sex	1	2	3	4	5
CKST	Pre-recruits (<30 cm)	Male	35.4	44.1	9.9	10.6	0
		Female	20.3	48.4	29.7	1.6	0
	Recruits (30 cm+)	Male	2.9	46.2	26.8	24.1	0
		Female	0.0	42.9	57.1	0.0	0

Appendix 4G: Observed age and length data by sex for the 2008 Cook Strait survey with von Bertalanffy growth models fitted to the data.



Appendix 4H: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (11, 12 and 13) combined (fixed sites) for the 2008 Cook Strait survey. N, sample size; MWCV, mean weighted coefficient of variation.



Appendix 4I: Estimates of proportion of length at age for blue cod sampled from the 2008 Cook Strait survey (age-length-key, ALK).

Males

															Age (y
Length (cm)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18
20	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0.67	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0.2	0.4	0.4	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0.3	0.7	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0.56	0.44	0	0	0	0	0	0	0	0	0	0	0
26	0	0.12	0.41	0.47	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0.29	0.5	0.21	0	0	0	0	0	0	0	0	0	0
28	0	0	0.29	0.5	0.21	0	0	0	0	0	0	0	0	0	0
29	0	0	0.06	0.71	0.13	0.06	0.03	0	0	0	0	0	0	0	0
30	0	0	0.04	0.39	0.43	0.13	0	0	0	0	0	0	0	0	0
31	0	0	0.06	0.19	0.48	0.19	0.06	0	0	0	0	0	0	0	0
32	0	0	0	0.19	0.45	0.13	0.19	0.03	0	0	0	0	0	0	0
33	0	0	0	0.05	0.32	0.55	0.05	0	0.05	0	0	0	0	0	0
34	0	0	0	0.08	0.12	0.28	0.28	0.2	0.04	0	0	0	0	0	0
35	0	0	0	0	0.05	0.16	0.47	0.26	0	0.05	0	0	0	0	0
36	0	0	0	0	0.07	0.14	0.21	0.21	0.07	0.14	0.14	0	0	0	0
37	0	0	0	0	0	0	0	0.12	0.62	0.19	0.06	0	0	0	0
38	0	0	0	0	0	0	0	0	0.45	0.45	0	0.1	0	0	0
39	0	0	0	0	0	0	0	0.07	0.27	0.33	0.27	0	0	0.07	0
40	0	0	0	0	0	0	0	0	0	0.33	0.33	0.33	0	0	0
41	0	0	0	0	0	0	0	0	0.2	0	0.4	0.4	0	0	0
42	0	0	0	0	0	0	0	0	0.33	0	0	0.33	0.33	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Females

								Age (years)	
Length (cm)	2	3	4	5	6	7	8	9	12
17	1	0	0	0	0	0	0	0	0
18	0	1	0	0	0	0	0	0	0
19	0	0	1	0	0	0	0	0	0
20	0	1	0	0	0	0	0	0	0
21	0	0.67	0.33	0	0	0	0	0	0
22	0	0	0.75	0.25	0	0	0	0	0
23	0	0	0	1	0	0	0	0	0
24	0	0	0	1	0	0	0	0	0
25	0	0	0	0.8	0.2	0	0	0	0
26	0	0	0	1	0	0	0	0	0
27	0	0	0	0.43	0.14	0.29	0.14	0	0
28	0	0	0	0	0.73	0.2	0.07	0	0
29	0	0	0	0	0.4	0.53	0.07	0	0
30	0	0	0	0	0	0.6	0.4	0	0
31	0	0	0	0	0.4	0.2	0.4	0	0
32	0	0	0	0	0	0.25	0.25	0.25	0.25

Appendix 4J: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod from the 2008 Cook Strait Sounds potting survey. AgeR, age at full recruitment.

Region	ageR	*Z*	lowerCI	upperCI
Cook Strait	5	0.31	0.23	0.41
	6	0.39	0.28	0.51
	7	0.44	0.32	0.58
	8	0.45	0.32	0.6
	9	0.48	0.33	0.67

Appendix 4K: Mortality parameters (*Z*, *F*, and *M*) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of M for the 2008 Cook Strait survey. F, fishing mortality; M, natural mortality; Z, total mortality. AgeR = 6.

Region	M	*Z*	F	$F_{\%SPR}$
Cook Strait	0.11	0.39	0.28	$F_{20.5\%}$
	0.14	0.39	0.25	$F_{28.5\%}$
	0.17	0.39	0.22	$F_{37.0\%}$

Appendix A: Historical surveys (1995, 1996, 2001, 2004, and 2007) effort details and catch rates.

Appendix A1: Marlborough Sounds potting survey effort and catch summary by site type from 2001, 2004, and 2007 surveys. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville; SEPR, Separation Point; CKST, Cook Strait.

2001 survey (trip code lhr0101)									Depth (m)		
Region	Stratum	Stratum 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	4	36	52	20.7	17.7	9	27
QCH	2	OQCH	176.6	fixed	7	63	253	84.3	20.2	7	45
QCH	3	EQCH	83.1	fixed	5	45	204	76.1	20.2	9	45
PEL	4	EOPE	69.5	fixed	5	45	216	65.7	14.1	5	29
PEL	5	OPEL	94.8	fixed	6	54	103	34.9	14.2	7	37
DUR	6	DURE	105.1	fixed	6	54	843	318.5	26.9	8	43
PEL	7	IPEL	100.1	fixed	4	36	29	6.7	10.4	5	16
PEL	8	MPEL	72.3	fixed	5	45	87	26.9	13.2	8	21
Totals					42	378	1787	633.8			

2004 survey (trip code lhr0401)									Depth (m)		
Region	Stratum	Stratum 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	4	36	39	12.7	17.9	4	37
QCH	2	OQCH	176.6	fixed	4	36	128	34.4	15.1	7	22
QCH	3	EQCH	83.1	fixed	4	36	207	72.4	18.2	7	33
PEL	4	EOPE	69.5	fixed	5	45	365	121.5	17.5	7	31
PEL	5	OPEL	94.8	fixed	8	72	284	67.6	16.5	4	33
DUR	6	DURE	105.1	fixed	12	108	1202	504.7	21.0	9	38
PEL	7	IPEL	100.1	fixed	3	27	34	5.5	11.9	7	18
PEL	8	MPEL	72.3	fixed	5	45	78	16.4	13.1	9	24
DUR	9	DURW	96.2	fixed	10	90	841	337.4	19.8	7	49
SEPR	10	SEPR	20	fixed	10	90	9	3.4	13.1	4	31
Totals					65	585	3187	1176			

2007 survey (trip code lhr0701)									Depth (m)		
Region	Stratum	Stratum 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	4	36	0	0	17.3	9	33
QCH	2	OQCH	176.6	fixed	4	36	75	23	17.4	9	43
QCH	3	EQCH	83.1	fixed	5	45	264	117	11.9	5	22
PEL	4	EOPE	69.5	fixed	8	72	569	233.3	19.6	7	43
PEL	5	OPEL	94.8	fixed	8	72	196	60.2	14.8	7	26
DUR	6	DURE	105.1	fixed	15	130	885	394.2	19.3	7	40
PEL	7	IPEL	100.1	fixed	3	27	29	7.6	11.4	7	18
PEL	8	MPEL	72.3	fixed	5	45	69	17.8	13.1	7	24
DUR	9	DURW	96.2	fixed	11	94	1059	524.1	18.4	7	34
SEPR	10	SEPR	20	fixed	12	105	19	7.9	11.9	5	32
Totals					75	662	3165	1385.1			

Appendix A2: Mean blue cod catch rates for all blue cod caught from the 1995, 1996, 2001, 2004, and 2007 Marlborough Sounds potting surveys by strata, region, and management area. Catch rates are pot based, and s.e. and c.v. are set-based, except 1995 and 1996 (potting survey manual, Beentjes & Francis 2011). s.e., standard error; c.v. coefficient of variation; QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville; SEPR, Separation Point; CKST, Cook Strait; Mgmt area, management area; Closed strata, (1, 2, 5, 7, 8); fished strata, (3, 4, 6); closed-fished strata, (1–8); outside strata, (6, 9, 11, 12, 13). The 1995 and 1996 survey data were not estimated as part of this report, but were interpreted from data in Blackwell 1997 and 1998 (catch rates, s.e. and c.v. are all pot based).

1995 survey (trip code lhr9501)

Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
All strata						
QCH	1	Fixed	72	0.64	0.07	10.9
QCH	2	Fixed	72	1.93	0.11	5.6
QCH	3	Fixed	72	2.42	0.17	7.0
PEL	4	Fixed	72	3.28	0.20	6.1
PEL	5	Fixed	72	2.71	0.21	7.7
	Overall	Fixed	360	–	–	–

Mgmt. area	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
Closed	1,2,5	Fixed	144	1.76	0.11	6.3
Fished	3,4	Fixed	216	2.85	0.18	6.6
Closed-Fished	1,2,3,4,5	Fixed	360	2.20	0.14	6.4

1996 survey (trip code lhr9601)

Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
All strata						
PEL	4	Fixed	36	2.7	0.10	3.7
PEL	5	Fixed	36	2.5	0.35	14.0
PEL	7	Fixed	36	0.9	0.04	4.4
PEL	8	Fixed	36	2.5	0.08	3.2
DUR	6	Fixed	36	7.5	0.50	6.6
	Overall	Fixed	180	–	–	–

Mgmt. area	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
Closed	5,7,8	Fixed	108	1.96	0.16	7.9
Fished	4,6	Fixed	72	5.1	0.30	5.9
Closed-Fished	4,5,6,7,8	Fixed	180	3.2	0.21	6.7

Appendix A2 – *continued*

2001 survey (trip code lhr0101)

Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
All strata						
QCH	1	Fixed	36	0.58	0.07	12.7
QCH	2	Fixed	63	1.34	0.24	18.2
QCH	3	Fixed	45	1.69	0.28	16.9
PEL	4	Fixed	45	1.46	0.27	18.6
PEL	5	Fixed	54	0.65	0.08	12.1

Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
DUR	6	Fixed	54	5.90	1.16	19.7
PEL	7	Fixed	36	0.19	0.06	29.7
PEL	8	Fixed	45	0.60	0.23	38.1
	Overall	Fixed	378	1.67	0.18	10.8
QCH	Overall	Fixed	144	1.33	0.16	12.3
PEL	Overall	Fixed	180	0.67	0.08	11.9
DUR	Overall	Fixed	54	5.90	1.16	19.7

Mgmt. area	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
Closed	Overall	Fixed	234	0.79	0.10	12.3
Fished	Overall	Fixed	144	3.34	0.49	14.6
Closed-Fished	Overall	Fixed	378	1.67	0.18	10.8

Appendix A2 – *continued*

2004 survey (trip code lhr0401)

Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
All strata						
QCH	1	Fixed	36	0.35	0.13	37.6
QCH	2	Fixed	36	0.96	0.31	32.0
QCH	3	Fixed	36	2.01	0.66	32.6
PEL	4	Fixed	45	2.70	0.39	14.6
PEL	5	Fixed	72	0.94	0.14	15.4
DUR	6	Fixed	108	4.67	0.82	17.6
PEL	7	Fixed	27	0.20	0.10	50.4
PEL	8	Fixed	45	0.36	0.15	42.2
DUR	9	Fixed	90	3.75	0.48	12.7
SEPR	10	Fixed	90	0.04	0.02	52.6
	Overall	Fixed	585	1.77	0.15	8.5

Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
All strata (excl. SEPR)	Overall	Fixed	495	1.82	0.15	8.5
QCH	Overall	Fixed	108	1.16	0.25	21.9
PEL	Overall	Fixed	189	0.96	0.10	10.6
DUR	Overall	Fixed	198	4.23	0.49	11.5

Mgmt. area	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
Closed	Overall	Fixed	216	0.66	0.12	18.1
Fished	Overall	Fixed	189	3.28	0.41	12.5
Closed-Fished	Overall	Fixed	405	1.57	0.16	10.4
Outside	Overall	Fixed	90	3.75	0.48	12.7

Appendix A2 – *continued*

2007 survey (trip code lhr0701)

Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
All strata						
QCH	1	Fixed	36	0.00	0.00	NA
QCH	2	Fixed	36	0.64	0.19	30.2
QCH	3	Fixed	45	2.60	0.41	15.8
PEL	4	Fixed	72	3.24	0.42	12.9
PEL	5	Fixed	72	0.84	0.21	25.5
DUR	6	Fixed	130	2.92	0.51	17.6
PEL	7	Fixed	27	0.28	0.15	51.8
PEL	8	Fixed	45	0.40	0.17	42.7
DUR	9	Fixed	94	5.49	0.69	12.5
SEPR	10	Fixed	105	0.07	0.04	48.7
	Overall	Fixed	662	1.77	0.12	6.9
All strata (excl. SEPR)	Overall	Fixed	557	1.81	0.13	6.9
QCH	Overall	Fixed	117	1.09	0.16	14.7
PEL	Overall	Fixed	216	1.07	0.12	11.1
DUR	Overall	Fixed	224	4.15	0.42	10.2

Mgmt. area	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
Closed	Overall	Fixed	216	0.51	0.09	17.7
Fished	Overall	Fixed	247	2.90	0.27	9.4
Closed-Fished	Overall	Fixed	463	1.34	0.11	8.3
Outside	Overall	Fixed	94	5.49	0.69	12.5
Outside (incl. CKST 2008 strata)	Overall	Fixed	292	3.6	0.38	10.5

Appendix A3: Mean blue cod catch rates for recruited blue cod (30 cm and over) caught from the 2001, 2004, and 2007 Marlborough Sounds potting surveys by strata, region, and management area. Catch rates are pot based, and s.e. and c.v. are set-based (potting survey manual, Beentjes & Francis 2011). s.e., standard error; c.v. coefficient of variation; QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville; SEPR, Separation Point; CKST, Cook Strait; Mgmt area, management area; Closed strata, (1, 2, 5, 7, 8); fished strata, (3, 4, 6); closed-fished strata, (1–8); outside strata, (6, 9, 11, 12, 13).

2001 survey (trip code lhr0101)

Region All strata	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	c.v. (%)
QCH	1	Fixed	36	0.30	0.02	8.3
QCH	2	Fixed	63	0.55	0.12	22.5
QCH	3	Fixed	45	0.90	0.24	26.4
PEL	4	Fixed	45	0.81	0.19	23.2
PEL	5	Fixed	54	0.31	0.03	9.9
DUR	6	Fixed	54	3.33	0.75	22.5
PEL	7	Fixed	36	0.07	0.04	63.0
PEL	8	Fixed	45	0.19	0.06	33.0
	Overall	Fixed	378	0.86	0.11	13.3
QCH	Overall	Fixed	144	0.61	0.10	15.9
PEL	Overall	Fixed	180	0.32	0.04	13.9
DUR	Overall	Fixed	54	3.33	0.75	22.5

Mgmt. area	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	c.v. (%)
Closed	Overall	Fixed	234	0.33	0.05	14.3
Fished	Overall	Fixed	144	1.87	0.32	17.1
Closed-Fished	Overall	Fixed	378	0.86	0.11	13.3

2004 survey (trip code lhr0401)

Region All strata	Stratum	Site type	Pot lifts (N)	Catch rate ($kg.pot^{-1}$)	s.e.	c.v. (%)
QCH	1	Fixed	36	0.21	0.09	43.9
QCH	2	Fixed	36	0.33	0.10	31.3
QCH	3	Fixed	36	1.08	0.49	45.1
PEL	4	Fixed	45	1.84	0.26	14.2
PEL	5	Fixed	72	0.47	0.10	20.5
DUR	6	Fixed	108	2.83	0.53	18.8
PEL	7	Fixed	27	0.09	0.02	23.8
PEL	8	Fixed	45	0.22	0.12	52.7
DUR	9	Fixed	90	2.80	0.51	18.1
SEPR	10	Fixed	90	0.02	0.01	71.0
	Overall	Fixed	585	1.07	0.10	9.7

Appendix A3 – *continued*

Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
All strata (excl. SEPR)	Overall	Fixed	495	1.10	0.11	9.7
QCH	Overall	Fixed	108	0.52	0.15	28.4
PEL	Overall	Fixed	189	0.59	0.07	11.2
DUR	Overall	Fixed	198	2.82	0.37	13.1

Mgmt. area	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
Closed	Overall	Fixed	216	0.28	0.05	16.4
Fished	Overall	Fixed	189	2.00	0.28	13.9
Closed-Fished	Overall	Fixed	405	0.88	0.10	11.5
Outside	Overall	Fixed	90	2.80	0.51	18.1

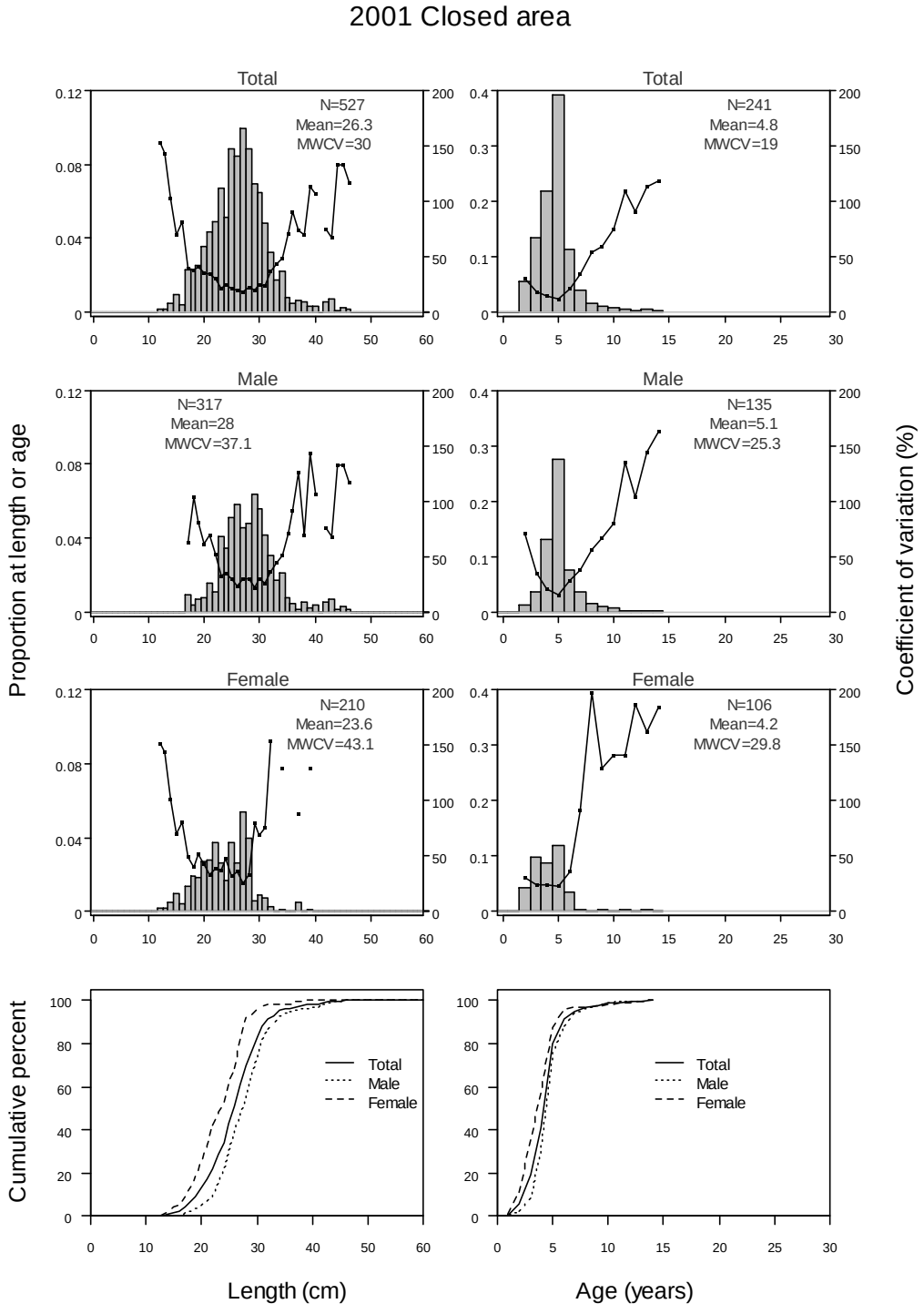
2007 survey (trip code lhr0701)

Region	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
All strata						
QCH	1	Fixed	36	0.00	0.00	NA
QCH	2	Fixed	36	0.19	0.06	33.1
QCH	3	Fixed	45	1.91	0.47	24.9
PEL	4	Fixed	72	2.42	0.34	14.2
PEL	5	Fixed	72	0.46	0.14	30.6
DUR	6	Fixed	130	2.37	0.43	18.2
PEL	7	Fixed	27	0.11	0.05	51.1
PEL	8	Fixed	45	0.21	0.12	57.1
DUR	9	Fixed	94	4.57	0.57	12.5
SEPR	10	Fixed	105	0.04	0.03	67.7
	Overall	Fixed	662	1.30	0.10	7.8
All strata (excl. SEPR)	Overall	Fixed	557	1.33	0.10	7.8
QCH	Overall	Fixed	117	0.63	0.13	21.3
PEL	Overall	Fixed	216	0.71	0.09	12.3
DUR	Overall	Fixed	224	3.42	0.35	10.3

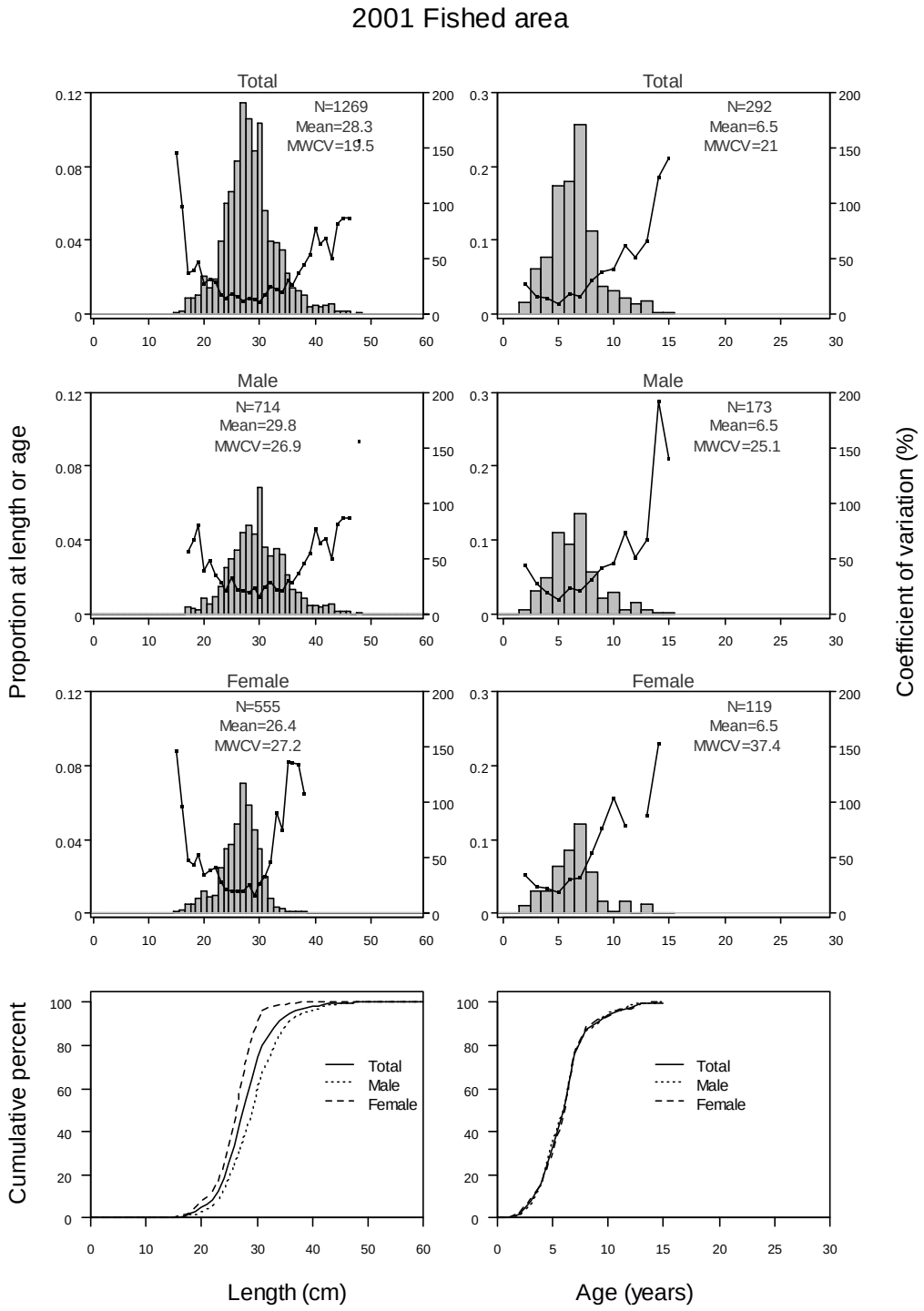
Appendix A3 – *continued*

Mgmt. area	Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	c.v. (%)
Closed	overal1	Fixed	216	0.21	0.04	19.6
Fished	Overall	Fixed	247	2.23	0.25	11.2
Closed-Fished	Overall	Fixed	463	0.91	0.09	10.0
Outside (stratum 9 only)	Overall	Fixed	94	4.57	0.57	12.50842
Outside (incl. CKST 2008 strata)	Overall	Fixed	292	3.01	0.32	10.6

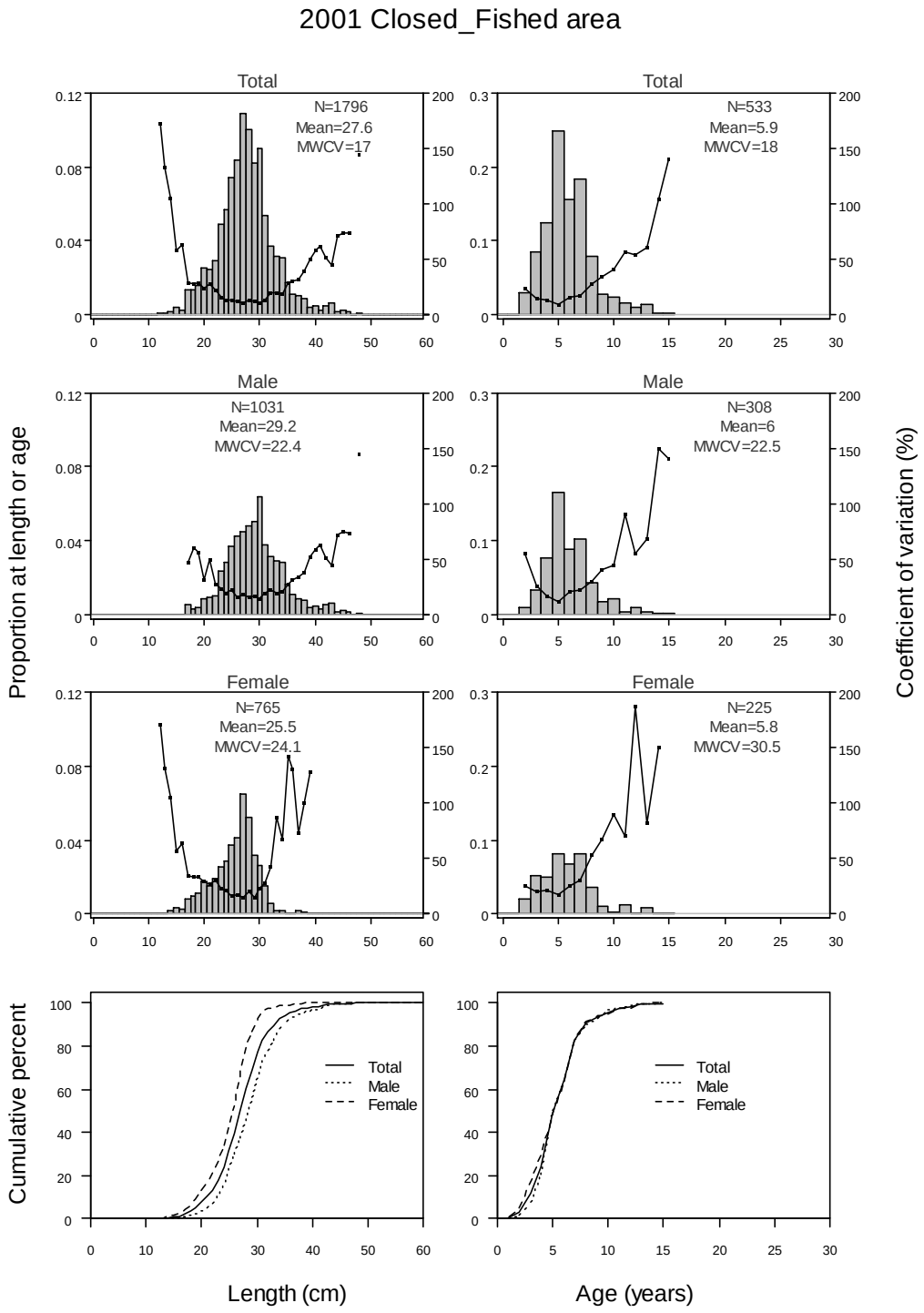
Appendix B. Catch-at-length and catch-at-age by management area (closed, fished, closed-fished and outside) for historical surveys of Marlborough Sounds (2001, 2004, 2007, and 2008).



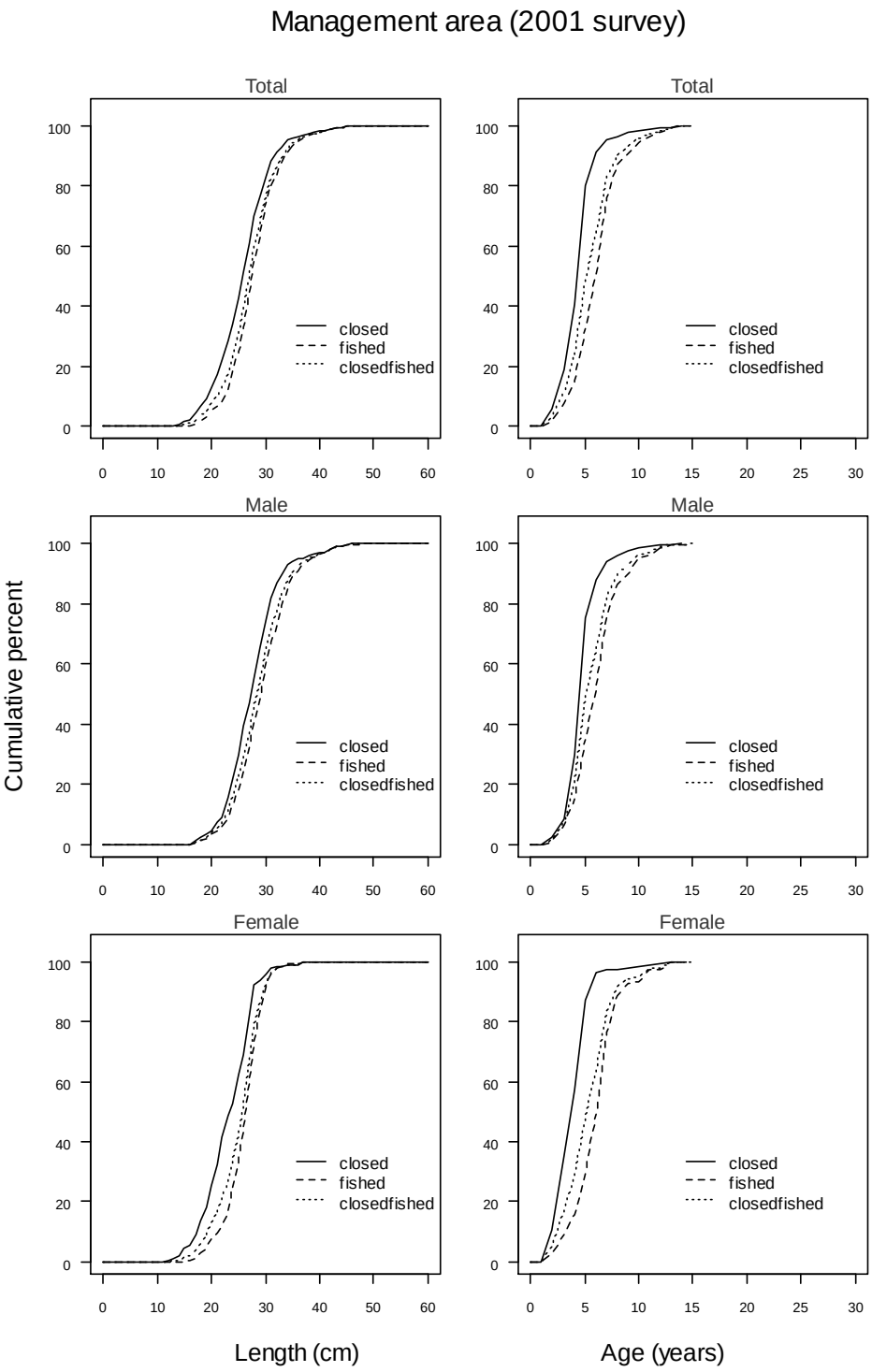
Appendix B1: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (1, 2, 5, 7, and 8) combined in the closed management area (fixed sites) for the 2001 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.



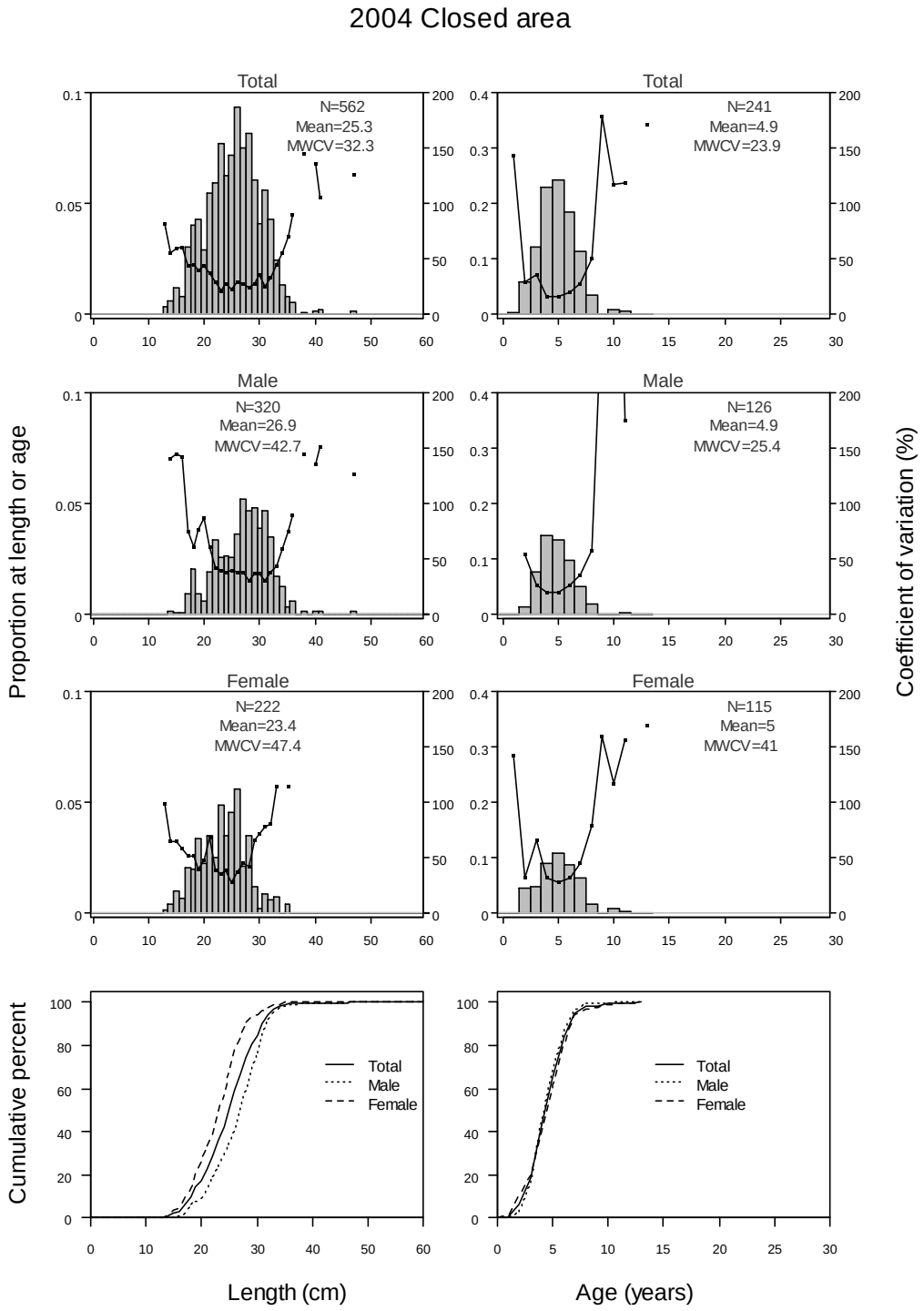
Appendix B2: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (3, 4, and 6) combined in the fished management areas (fixed sites) for the 2001 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.



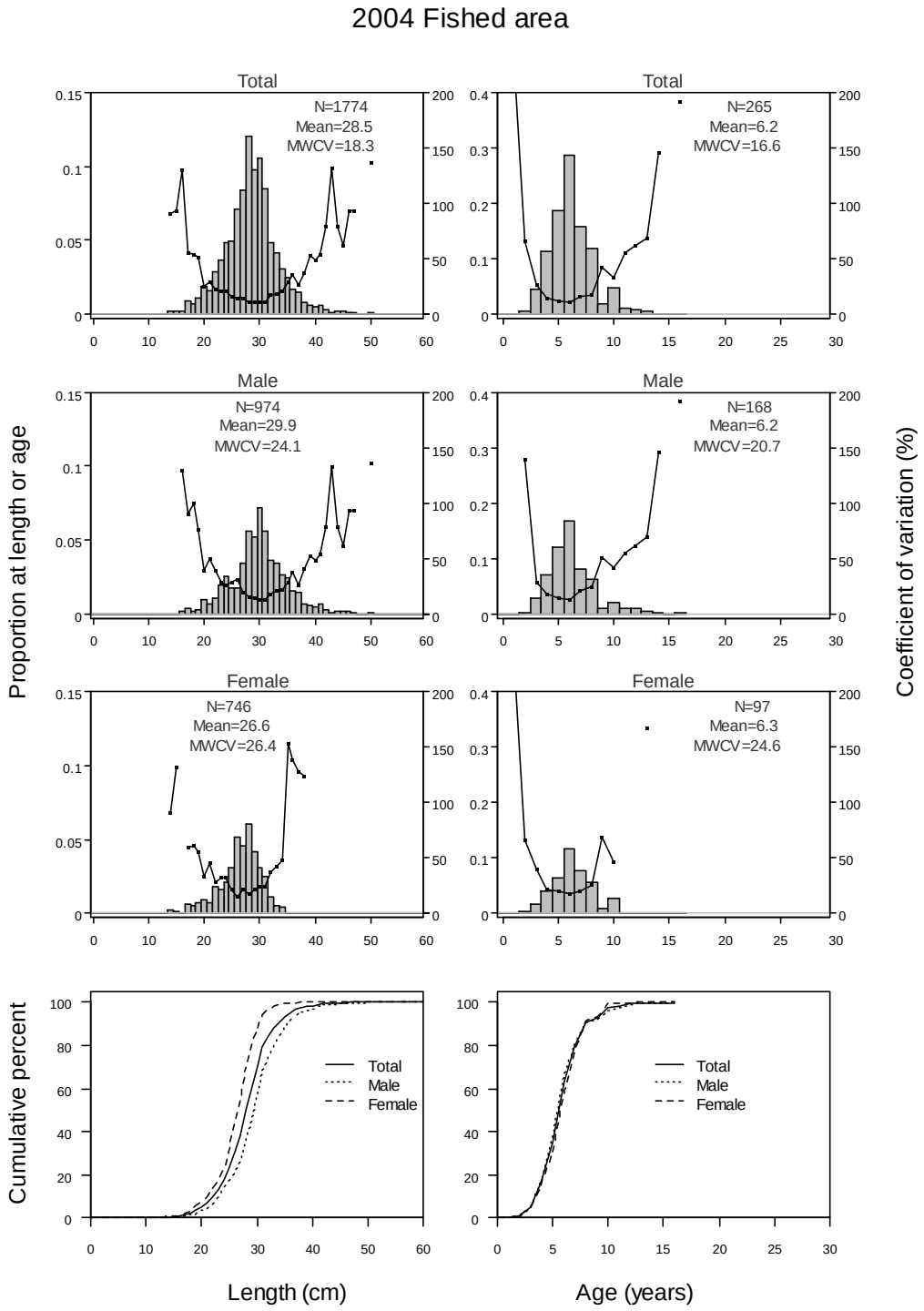
Appendix B3: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (1 to 8) combined in the closed-fished management area (fixed sites) for the 2001 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.



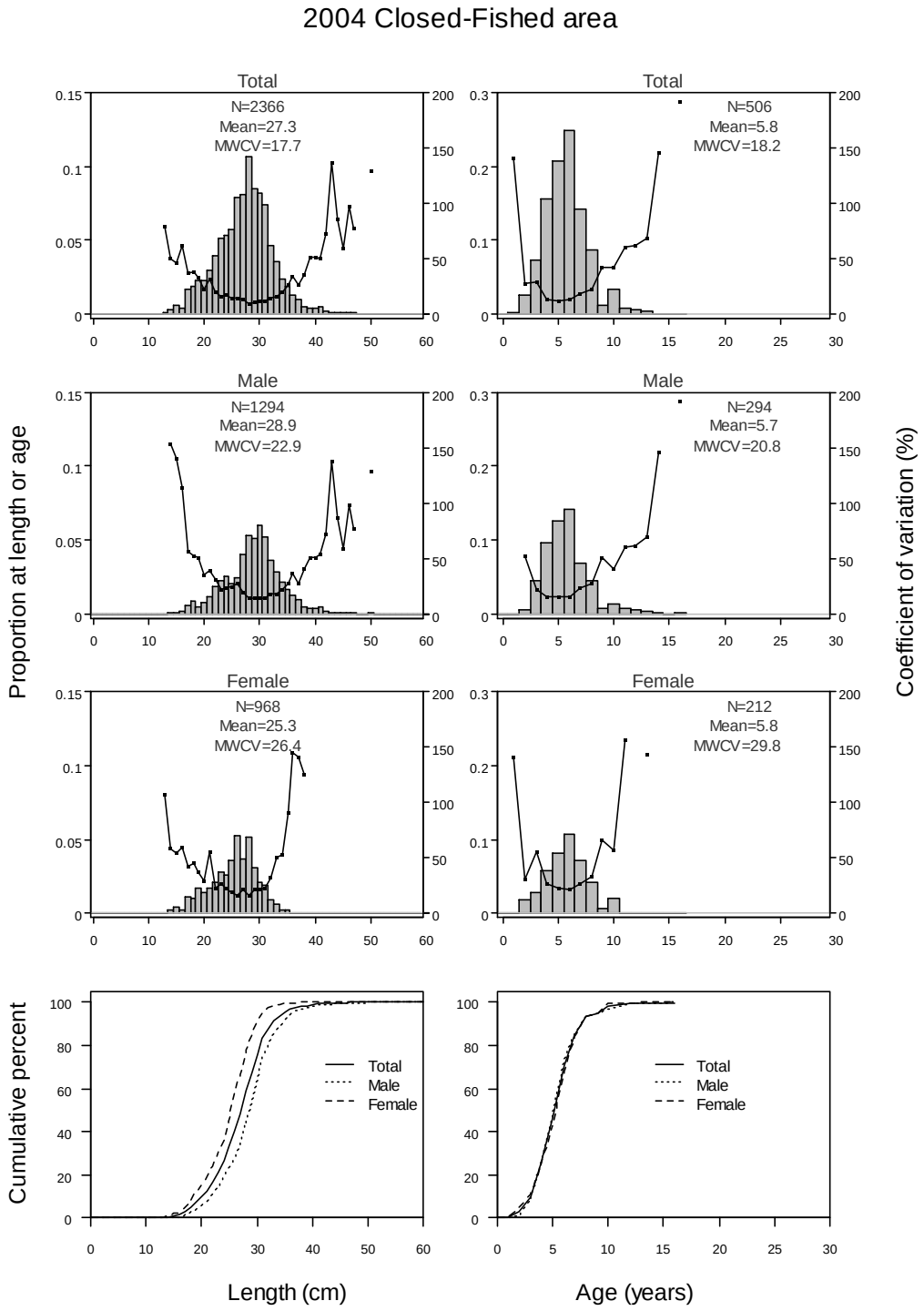
Appendix B4: Cumulative distributions of scaled length and age frequencies for total, male and female blue cod by management areas surveyed on the 2001 Marlborough Sounds blue cod potting survey.



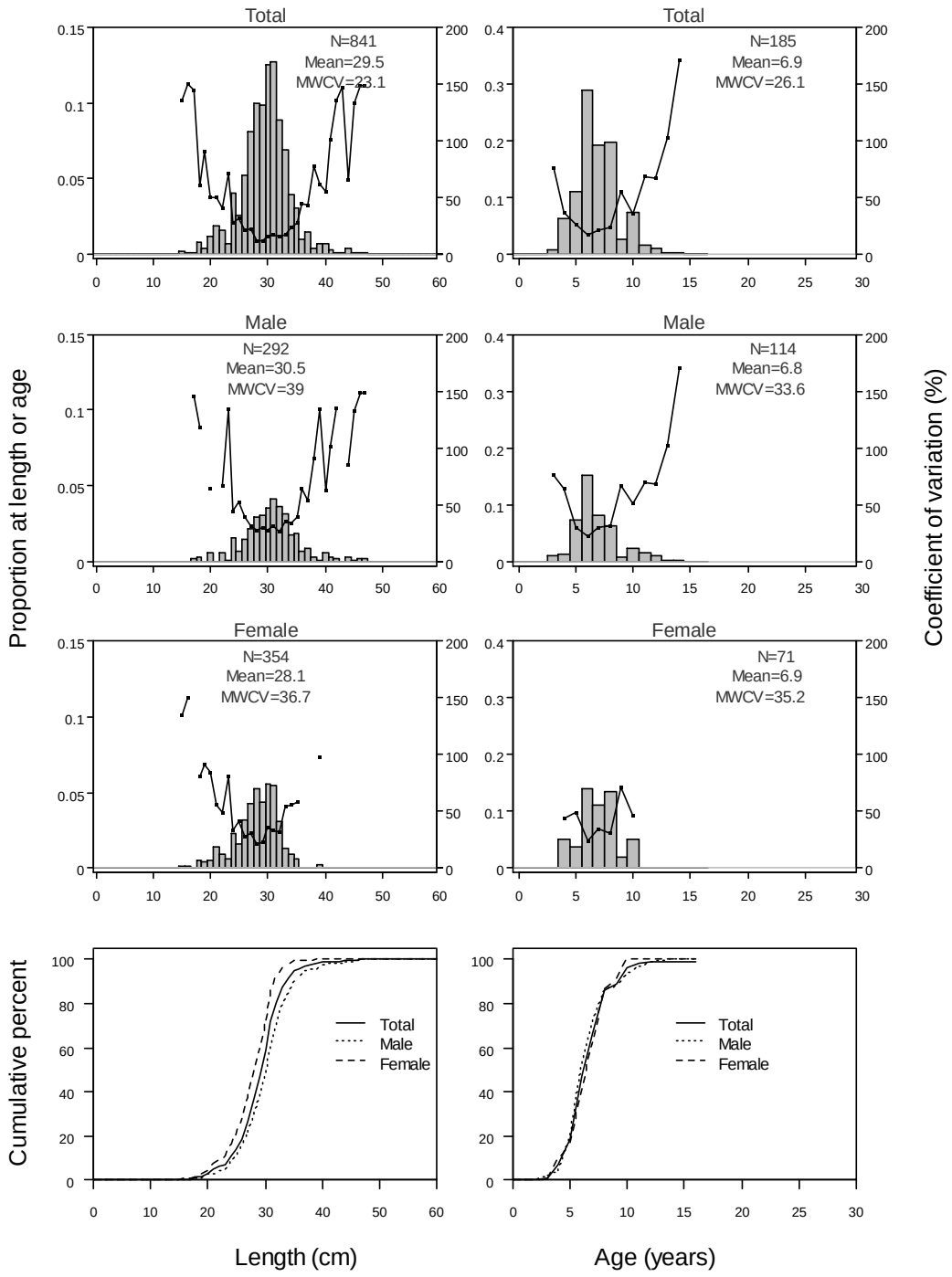
Appendix B5: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (1, 2, 5, 7, and 8) combined in the closed management area (fixed sites) for the 2004 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.



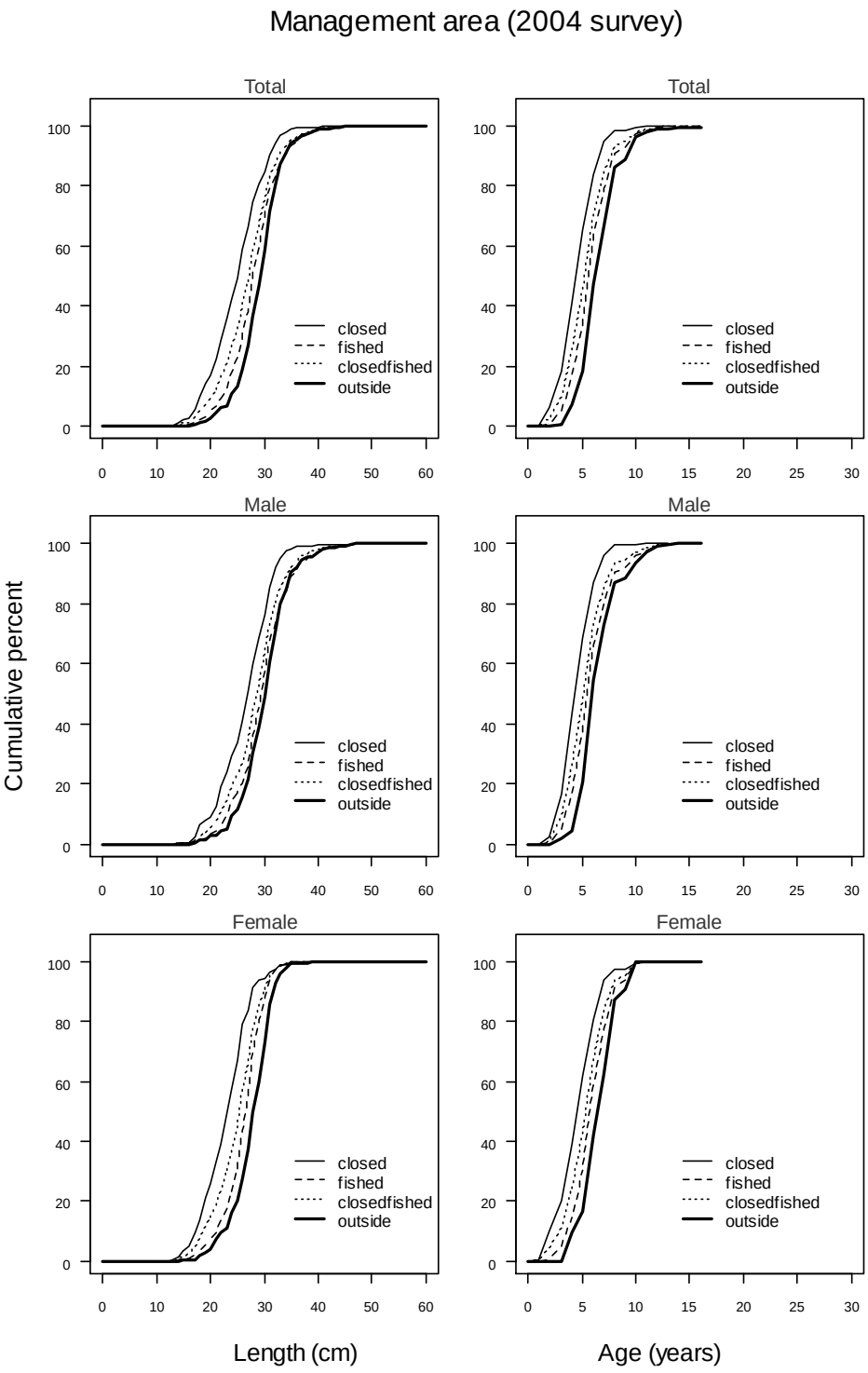
Appendix B6: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (3, 4, and 6) combined in the fished management areas (fixed sites) for the 2004 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.



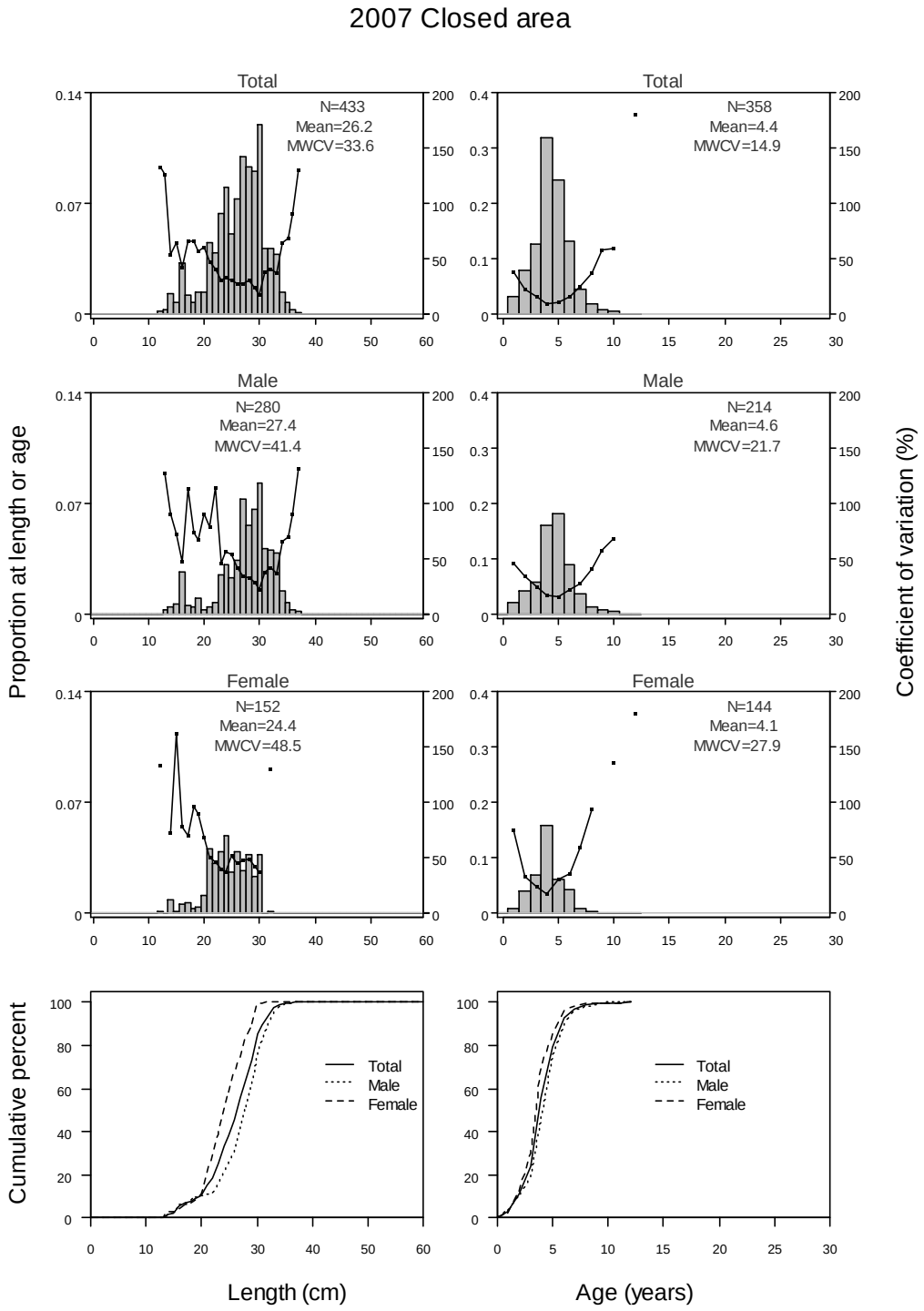
Appendix B7: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (1 to 8) combined in the closed-fished management area (fixed sites) for the 2004 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.



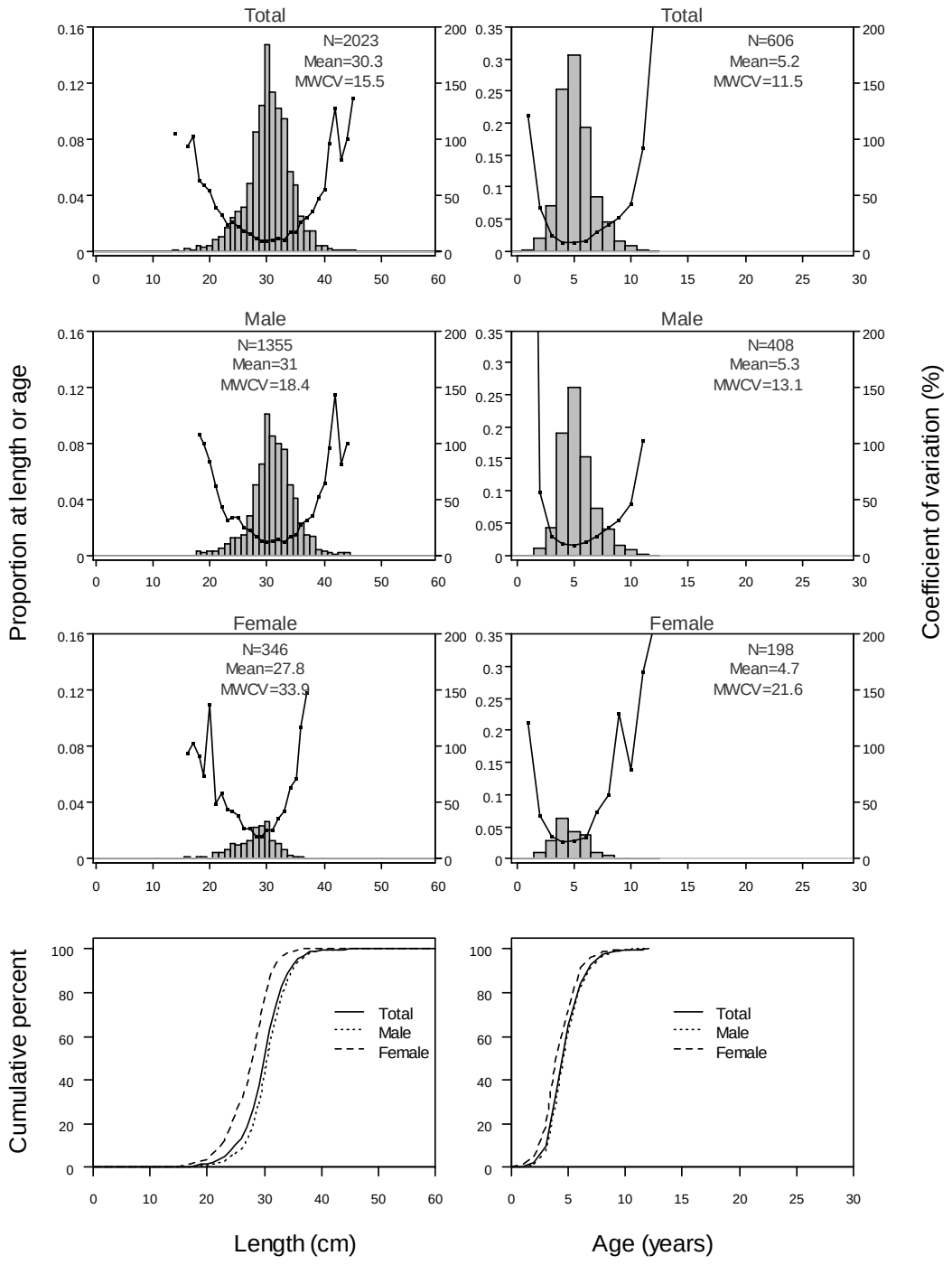
Appendix B8: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (1 to 8) combined in the outside management area (fixed sites) for the 2004 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.



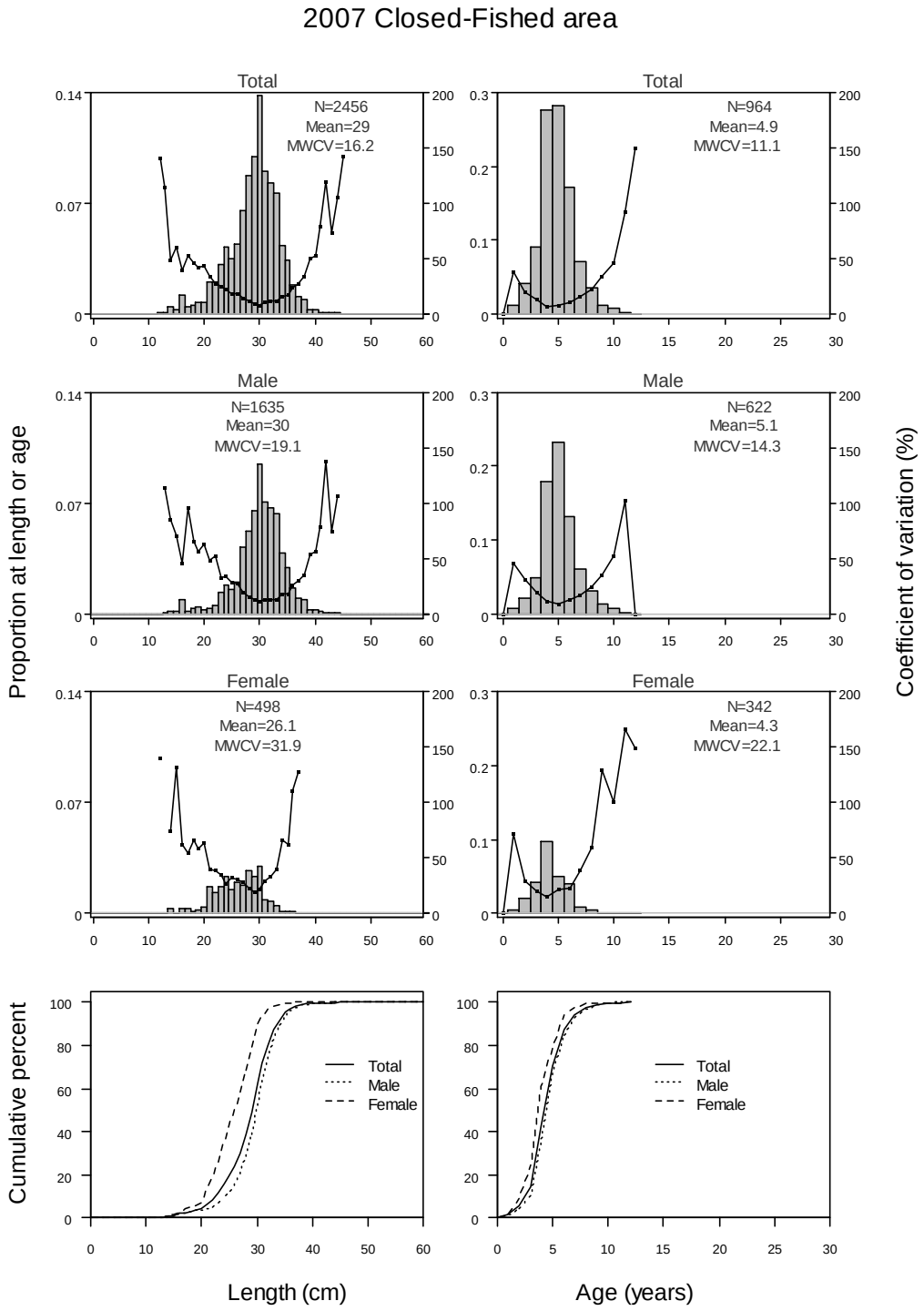
Appendix B9: Cumulative distributions of scaled length and age frequencies for total, male and female blue cod by management areas surveyed on the 2004 Marlborough Sounds blue cod potting survey.



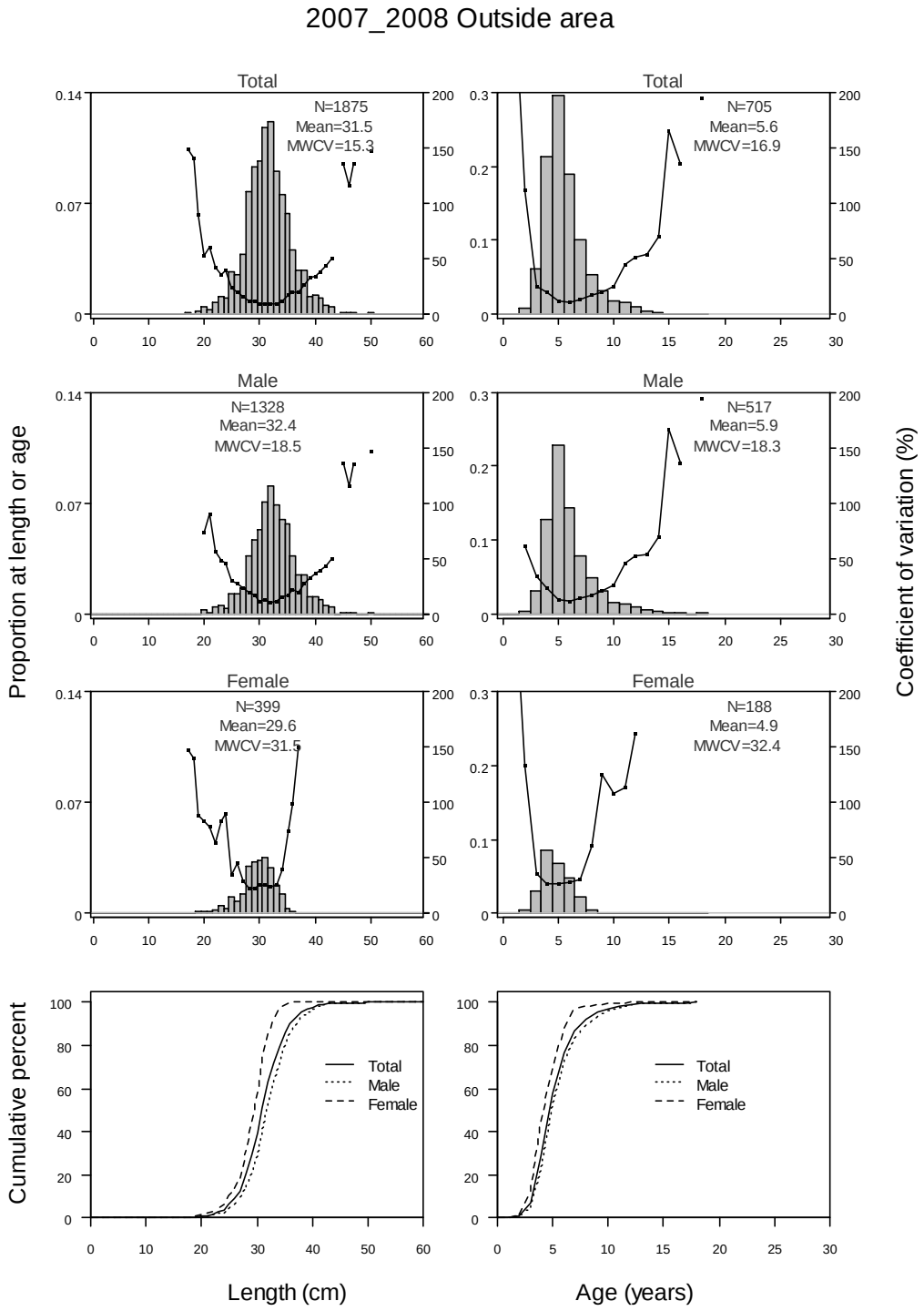
Appendix B10: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (1, 2, 5, 7, and 8) combined in the closed management area (fixed sites) for the 2007 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.



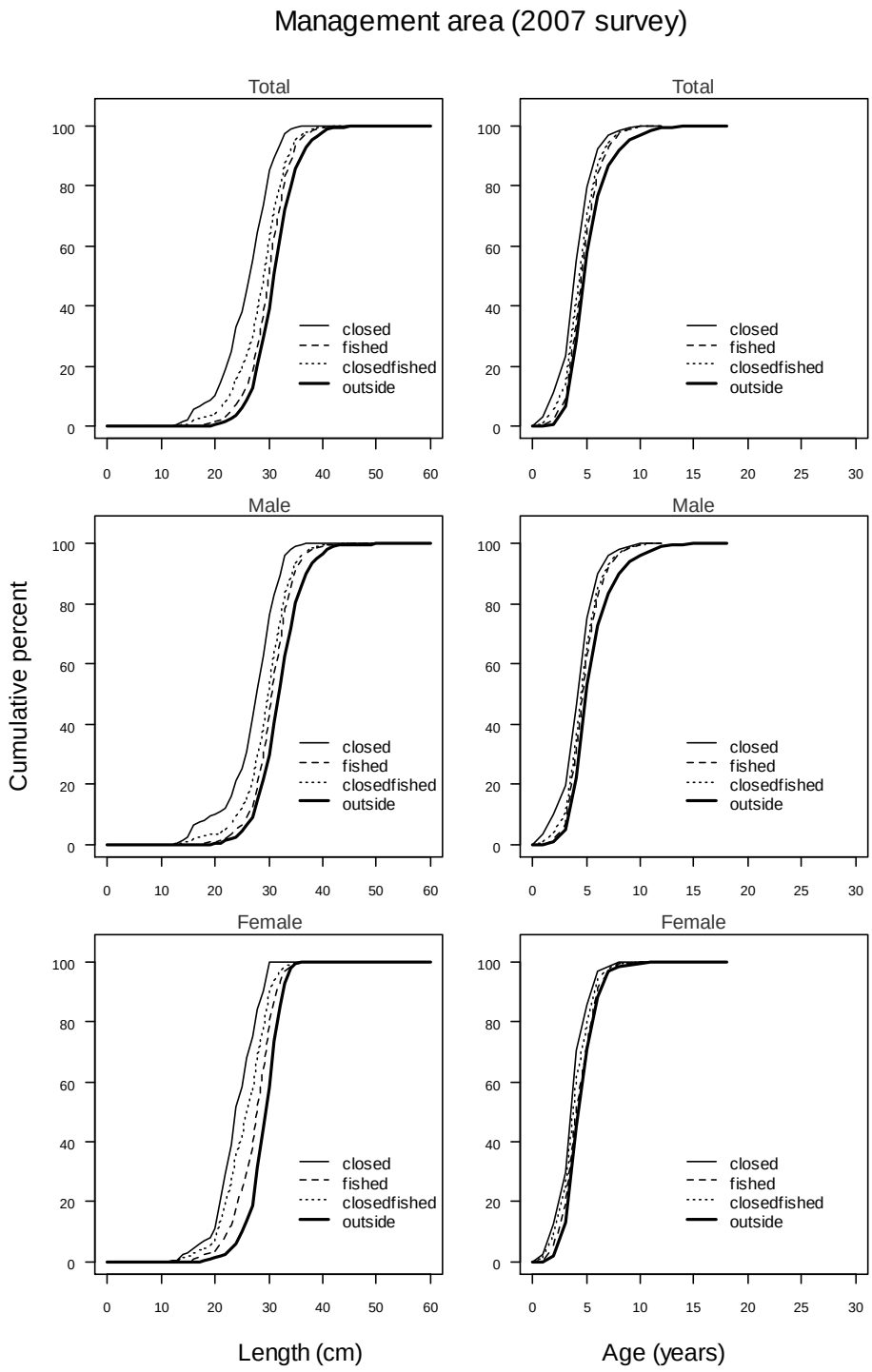
Appendix B11: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (3, 4, and 6) combined in the fished management areas (fixed sites) for the 2007 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.



Appendix B12: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (1 to 8) combined in the closed-fished management area (fixed sites) for the 2007 Marlborough Sounds survey. N, sample size; MWCV, mean weighted coefficient of variation.

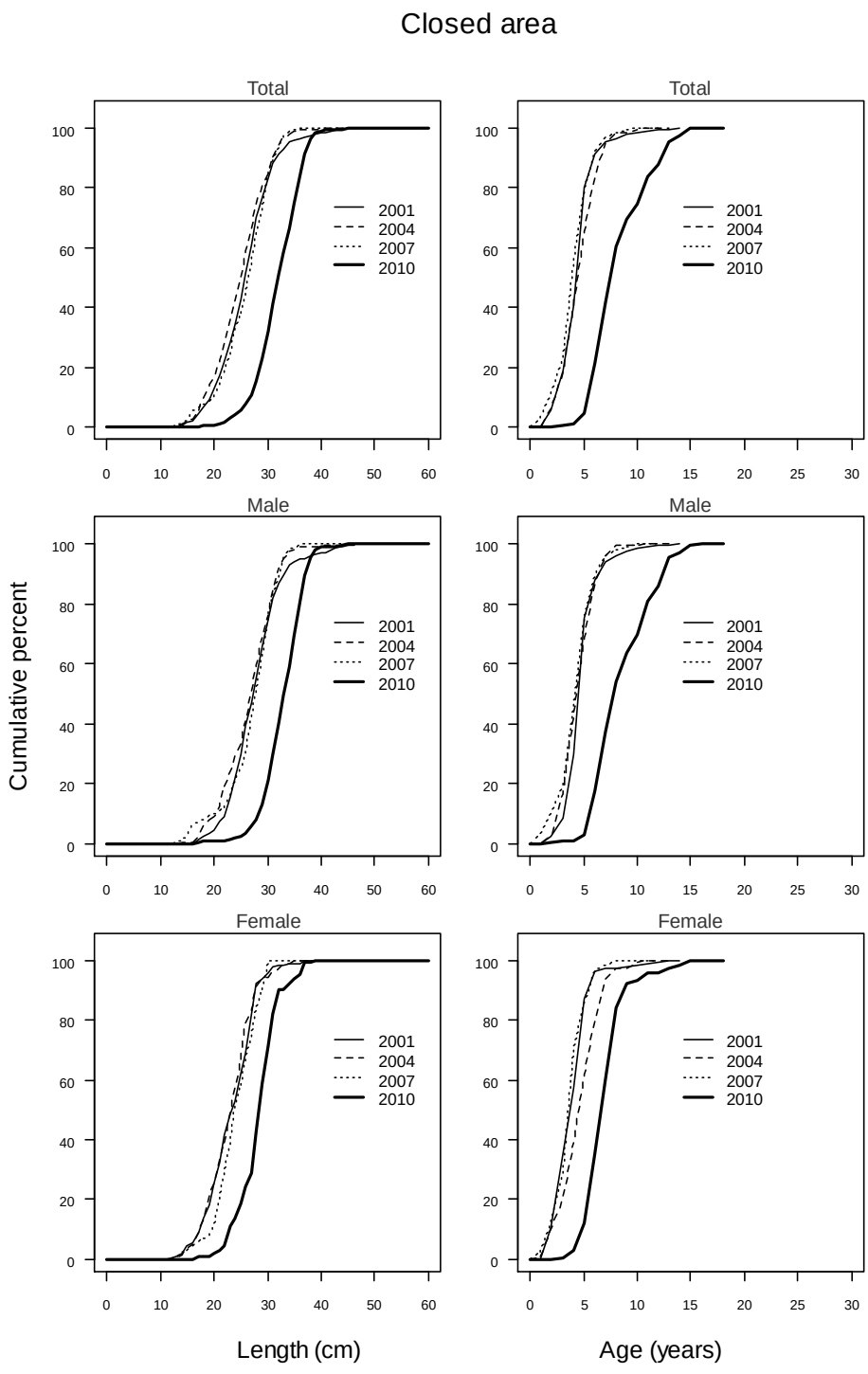


Appendix B13: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for the outside management area. Data are from stratum 9 (DURW) from the Marlborough Sounds 2007 survey and strata 11 to 13 from to 2008 Cook Strait (fixed sites). N, sample size; MWCV, mean weighted coefficient of variation.

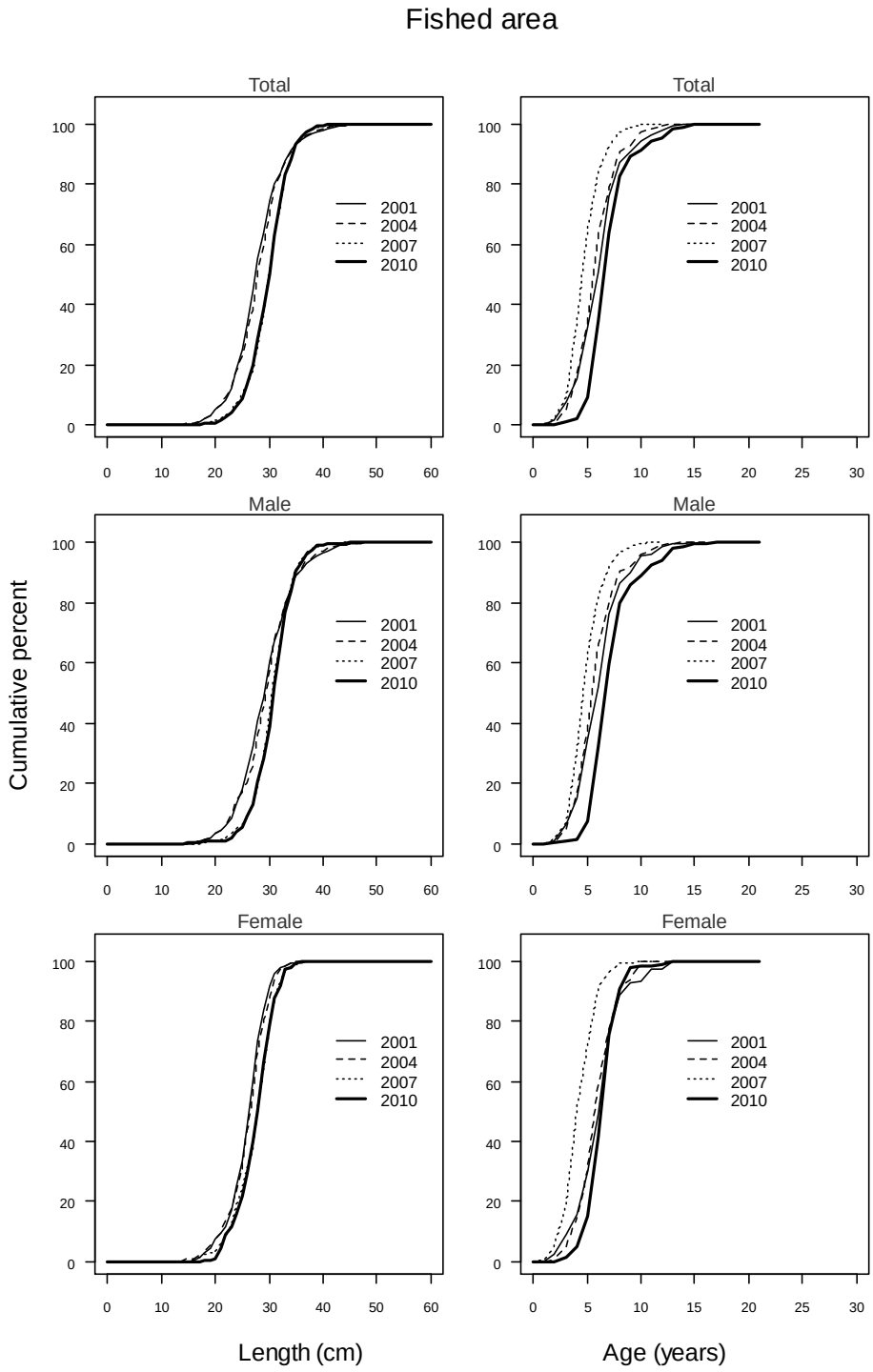


Appendix B14: Cumulative distributions of scaled length and age frequencies for total, male and female blue cod by management areas surveyed on the 2007 Marlborough Sounds blue cod potting survey.

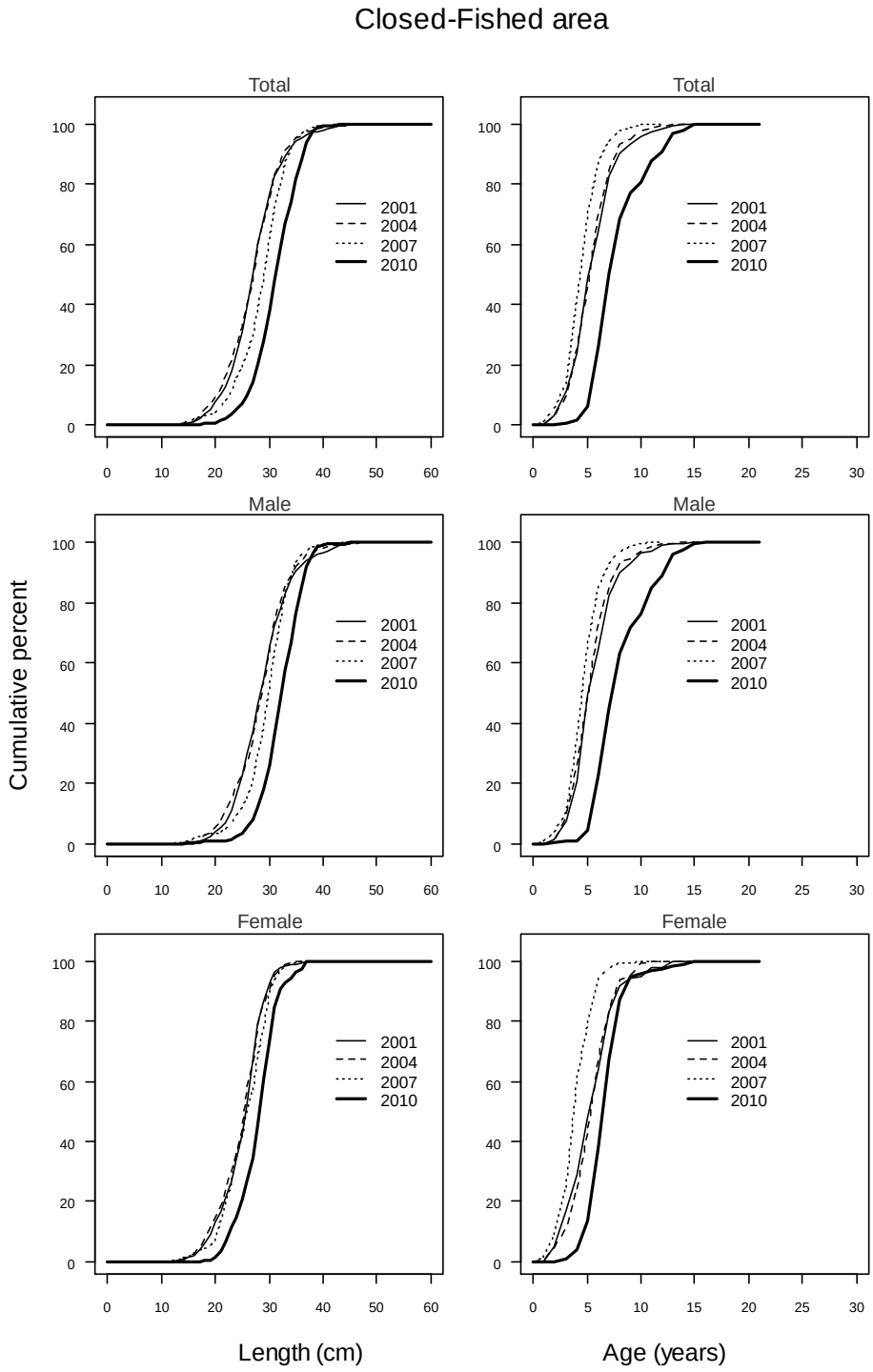
Appendix C: Cumulative distributions of scaled length and age frequencies for total, male, and female blue cod by management area for the 2001, 2004, 2007, 2008, and 2010 Marlborough Sounds blue cod potting surveys.



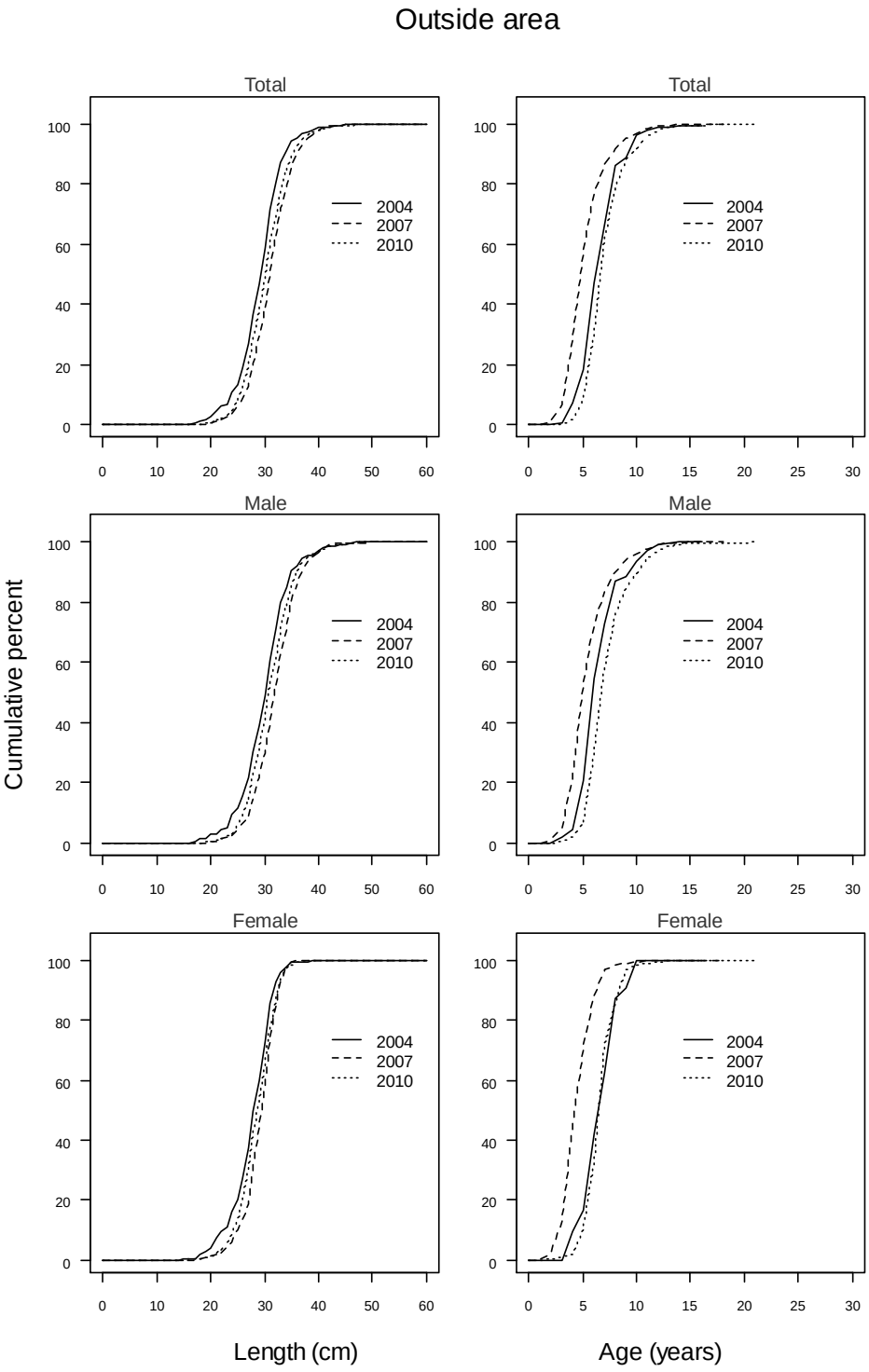
Appendix C1: Cumulative distributions of scaled length and age frequencies for total, male and female blue cod for the closed management area for Marlborough Sounds blue cod potting survey in 2001, 2004, 2007 and 2010.



Appendix C2: Cumulative distributions of scaled length and age frequencies for total, male and female blue cod for the fished management area for Marlborough Sounds blue cod potting survey in 2001, 2004, 2007, and 2010.



Appendix C3: Cumulative distributions of scaled length and age frequencies for total, male and female blue cod for the closed-fished management area for Marlborough Sounds blue cod potting survey in 2001, 2004, 2007, and 2010.



Appendix C4: Cumulative distributions of scaled length and age frequencies for total, male and female blue cod for the outside management area for Marlborough Sounds blue cod potting surveys in 2004, 2007, and 2010. In 2004 outside includes data from stratum 9 (DURW), and in 2007 from DURW in 2007 and strata 11 to 13 from the 2008 Cook Strait survey (fixed sites).

Appendix D: Z estimates and SPR results for historical Marlborough Sounds surveys 2001, 2004, and 2007 by region and management area.

Appendix D1: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod from each region surveyed in the 2001 Marlborough Sounds potting survey. AgeR, age at full recruitment.

Region	ageR	*Z*	lowerCI	upperCI
D'Urville	5	0.35	0.24	0.49
	6	0.48	0.32	0.66
	7	0.64	0.43	0.88
	8	0.55	0.34	0.85
	9	0.48	0.29	0.74
	10	0.59	0.33	0.94
Pelorus	5	0.91	0.6	1.27
	6	0.86	0.5	1.3
	7	0.89	0.47	1.46
	8	0.5	0.22	1
	9	0.56	0.22	1.01
	10	0.33	0.11	0.68
Queen Charlotte	5	0.81	0.53	1.12
	6	0.56	0.34	0.84
	7	0.44	0.27	0.67
	8	0.44	0.26	0.66
	9	0.48	0.27	0.78
	10	0.55	0.27	0.94

Appendix D2: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod from each region surveyed in the 2004 Marlborough Sounds potting survey. AgeR, age at full recruitment.

Region	ageR	*Z*	lowerCI	upperCI
D'Urville	5	0.39	0.28	0.52
	6	0.54	0.38	0.75
	7	0.57	0.39	0.8
	8	0.67	0.44	0.93
	9	0.57	0.34	0.84
	10	1.01	0.52	1.59
Pelorus	5	0.72	0.48	1
	6	0.82	0.51	1.21
	7	1.1	0.65	1.74
	8	1.15	0.53	2.33
	9	0.63	0.22	1.41
	10	0.5	0.15	1.16

Appendix D2 – *continued*

Queen Charlotte	5	0.62	0.41	0.89
	6	0.84	0.53	1.21
	7	1	0.59	1.6
	8	1.02	0.49	1.82
	9	0.75	0.29	1.69
	10	1.44	0.56	1.91

Appendix D3: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod from each region surveyed in the 2007 Marlborough Sounds potting survey. AgeR, age at full recruitment.

Region	ageR	*Z*	lowerCI	upperCI
D'Urville	5	0.84	0.58	1.14
	6	0.89	0.6	1.26
	7	0.85	0.57	1.2
	8	0.85	0.51	1.27
	9	0.93	0.52	1.43
	10	1.31	0.57	2.25
Pelorus	5	0.67	0.46	0.92
	6	0.75	0.49	1.05
	7	0.76	0.46	1.11
	8	0.8	0.45	1.26
	9	1.07	0.48	1.76
	10	2.21	1.03	2.54
Queen Charlotte	5	0.77	0.51	1.08
	6	0.96	0.6	1.39
	7	1.05	0.6	1.65
	8	1.67	0.77	2.29
	9	1.21	0.44	1.7

Appendix D4: Mortality parameters (*Z*, *F*, and *M*) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of M for each region surveyed in the 2001 Marlborough Sounds survey. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality. AgeR = 6.

Region	*M*	*Z*	*F*	$F_{\%SPR}$
D'Urville	0.11	0.48	0.37	$F_{16.6\%}$
	0.14	0.48	0.34	$F_{23.1\%}$
	0.17	0.48	0.31	$F_{30.2\%}$
Pelorus	0.11	0.86	0.75	$F_{10.4\%}$
	0.14	0.86	0.72	$F_{14.6\%}$
	0.17	0.86	0.69	$F_{19.2\%}$
Queen Charlotte	0.11	0.56	0.45	$F_{14.4\%}$
	0.14	0.56	0.42	$F_{20.1\%}$
	0.17	0.56	0.39	$F_{26.3\%}$

Appendix D5: Mortality parameters (*Z*, *F*, and *M*) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* for each region surveyed in the 2004 Marlborough Sounds survey. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality. AgeR = 6.

Region	*M*	*Z*	*F*	$F_{\%SPR}$
D'Urville	0.11	0.54	0.43	$F_{14.9\%}$
	0.14	0.54	0.4	$F_{20.8\%}$
	0.17	0.54	0.37	$F_{27.1\%}$
Pelorus	0.11	0.82	0.71	$F_{10.7\%}$
	0.14	0.82	0.68	$F_{14.8\%}$
	0.17	0.82	0.65	$F_{19.7\%}$
Queen Charlotte	0.11	0.84	0.73	$F_{10.5\%}$
	0.14	0.84	0.7	$F_{14.8\%}$
	0.17	0.84	0.67	$F_{19.4\%}$

Appendix D6: Mortality parameters (*Z*, *F*, and *M*) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* for each region surveyed in the 2007 Marlborough Sounds survey. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality. AgeR = 6.

Region	*M*	*Z*	*F*	$F_{\%SPR}$
D'Urville	0.11	0.89	0.78	$F_{10.2\%}$
	0.14	0.89	0.75	$F_{14.2\%}$
	0.17	0.89	0.72	$F_{18.7\%}$
Pelorus	0.11	0.75	0.64	$F_{11.4\%}$
	0.14	0.75	0.61	$F_{16.0\%}$
	0.17	0.75	0.58	$F_{21.0\%}$
Queen Charlotte	0.11	0.96	0.85	$F_{9.7\%}$
	0.14	0.96	0.82	$F_{13.6\%}$
	0.17	0.96	0.79	$F_{17.9\%}$

Appendix D7: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod from each management area surveyed in the 2001 Marlborough Sounds potting survey. AgeR, age at full recruitment.

Management area	ageR	*Z*	lowerCI	upperCI
Closed	5	0.88	0.58	1.24
	6	0.64	0.4	0.95
	7	0.5	0.3	0.76
	8	0.44	0.25	0.72
	9	0.49	0.24	0.88
	10	0.54	0.23	1.1
Fished	5	0.4	0.28	0.56
	6	0.49	0.34	0.69
	7	0.63	0.43	0.9
	8	0.55	0.35	0.8
	9	0.48	0.3	0.69
	10	0.58	0.33	0.89
Closed-Fished	5	0.46	0.33	0.64
	6	0.51	0.35	0.7
	7	0.62	0.41	0.87
	8	0.54	0.35	0.76
	9	0.48	0.3	0.69
	10	0.57	0.34	0.85

Appendix D8: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod from each management area surveyed in the 2004 Marlborough Sounds potting survey. AgeR, age at full recruitment.

Management area	ageR	*Z*	lowerCI	upperCI
Closed	5	0.69	0.46	0.98
	6	0.88	0.53	1.26
	7	1.08	0.57	1.8
	8	0.88	0.35	1.89
	9	0.54	0.18	1.4
	10	1.16	0.44	1.71
Fished	5	0.46	0.32	0.61
	6	0.61	0.42	0.83
	7	0.63	0.43	0.87
	8	0.69	0.47	0.97
	9	0.57	0.35	0.84
	10	0.94	0.53	1.54
Closed-Fished	5	0.51	0.35	0.69
	6	0.65	0.45	0.91
	7	0.69	0.45	0.95
	8	0.71	0.46	1.02
	9	0.57	0.35	0.85
	10	0.96	0.49	1.66
Outside	5	0.39	0.27	0.53
	6	0.54	0.38	0.74
	7	0.62	0.41	0.88
	8	0.78	0.48	1.17
	9	0.63	0.37	0.98
	10	1.17	0.54	1.89

Appendix D9: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod from each management area surveyed in the 2007 Marlborough Sounds potting survey. AgeR, age at full recruitment. Outside includes strata 11 to 13 surveyed in the 2008 Cook Strait survey.

Management area	ageR	*Z*	lowerCI	upperCI
Closed	5	0.86	0.57	1.19
	6	0.97	0.62	1.42
	7	0.9	0.55	1.34
	8	0.9	0.49	1.54
	9	0.98	0.43	2.09
	10	1.69	0.73	2.14

Appendix D9 – *continued*

Management area	ageR	*Z*	lowerCI	upperCI
Fished	5	0.72	0.51	0.99
	6	0.83	0.57	1.13
	7	0.87	0.57	1.21
	8	1.02	0.64	1.56
	9	1.08	0.58	1.69
	10	1.68	0.71	2.24
Closed-Fished	5	0.75	0.52	1.02
	6	0.86	0.58	1.19
	7	0.88	0.58	1.2
	8	0.99	0.61	1.53
	9	1.06	0.54	1.73
	10	1.68	0.72	2.26
Outside	5	0.55	0.39	0.76
	6	0.57	0.4	0.77
	7	0.55	0.38	0.75
	8	0.53	0.36	0.72
	9	0.55	0.37	0.78
	10	0.58	0.36	0.83

Appendix D10: Mortality parameters (*Z*, *F*, and *M*) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* for each management area surveyed in the 2001 Marlborough Sounds survey. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality. AgeR = 6.

Management area	*M*	*Z*	*F*	$F_{\%SPR}$
Closed	0.11	0.64	0.53	$F_{12.9\%}$
	0.14	0.64	0.5	$F_{18.0\%}$
	0.17	0.64	0.47	$F_{23.6\%}$
Fished	0.11	0.49	0.38	$F_{16.3\%}$
	0.14	0.49	0.35	$F_{22.7\%}$
	0.17	0.49	0.32	$F_{29.6\%}$
Closed-fished	0.11	0.51	0.4	$F_{15.7\%}$
	0.14	0.51	0.37	$F_{21.9\%}$
	0.17	0.51	0.34	$F_{28.5\%}$

Appendix D11: Mortality parameters (*Z*, *F*, and *M*) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* for each management area surveyed in the 2004 Marlborough Sounds survey. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality. AgeR = 6.

Management area	*M*	*Z*	*F*	$F_{\%SPR}$
Closed	0.11	0.88	0.77	$F_{10.2\%}$
	0.14	0.88	0.74	$F_{14.3\%}$
	0.17	0.88	0.71	$F_{18.9\%}$
Fished	0.11	0.61	0.5	$F_{13.4\%}$
	0.14	0.61	0.47	$F_{18.7\%}$
	0.17	0.61	0.44	$F_{24.5\%}$
Closed-fished	0.11	0.65	0.54	$F_{12.7\%}$
	0.14	0.65	0.51	$F_{17.8\%}$
	0.17	0.65	0.48	$F_{23.3\%}$
Outside	0.11	0.54	0.43	$F_{14.9\%}$
	0.14	0.54	0.4	$F_{20.8\%}$
	0.17	0.54	0.37	$F_{27.1\%}$

Appendix D12: Mortality parameters (*Z*, *F*, and *M*) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* for each management area surveyed in the 2007 Marlborough Sounds survey. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality. AgeR = 6. Outside includes strata 11 to 13 surveyed in the 2008 Cook Strait survey.

Management area	M	*Z*	F	$F_{\%SPR}$
Closed	0.11	0.97	0.86	$F_{9.6\%}$
	0.14	0.97	0.83	$F_{13.5\%}$
	0.17	0.97	0.8	$F_{17.8\%}$
Fished	0.11	0.83	0.72	$F_{10.6\%}$
	0.14	0.83	0.69	$F_{14.9\%}$
	0.17	0.83	0.66	$F_{19.6\%}$
Closed-fished	0.11	0.86	0.75	$F_{10.4\%}$
	0.14	0.86	0.72	$F_{14.6\%}$
	0.17	0.86	0.69	$F_{19.1\%}$
Outside	0.11	0.57	0.46	$F_{14.7\%}$
	0.14	0.57	0.43	$F_{19.8\%}$
	0.17	0.57	0.4	$F_{25.9\%}$