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Relative abundance, size and age structure, and stock status of blue cod in Dusky Sound, Fiordland in 2014

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EXECUTIVE SUMMARY

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This report describes the results of the 2014 blue cod (*Parapercis colias*) potting survey of Dusky Sound in Fiordland. Estimates are provided for population abundance, size and age structure, total mortality (*Z*), and spawner-per-recruit. This is the third survey in the Dusky Sound time series following surveys in 2002 and 2008 which were both fixed site surveys. In 2014, fixed site and random site surveys were carried out concurrently.

2014 fixed site survey

Simulations to determine the optimal allocation of fixed sites among the six Dusky Sound strata were carried out using catch rates from the 2002 and 2008 fixed site surveys and sites were randomly selected from the list of 124 available. The survey used a two-phase stratified random station design where 90% of sites were allocated to phase 1 with the remainder available for phase 2. Six pots (pot plan 2) were set along the shoreline extending away from the site position in both directions, but within 1.5 km of coastline. Pot placement for fixed sites was 'directed' with placement of each pot around the site determined by the skipper, with pots at least 100 m apart. Twenty-eight fixed sites (6 pots per site, producing 168 pot lifts) from six strata throughout Dusky Sound were surveyed from 11 to 29 October 2014.

A total of 645 kg of blue cod (966 fish) were caught and 19 pots (11%) had zero catch of blue cod. The mean catch rate of all blue cod, excluding the Marine Reserve (MR), was 3.2 kg.pot^{-1}, ranging from about 2 kg.pot^{-1} for the three inner strata to 9 kg.pot^{-1} for the outside strata, with a CV of 12%. Catch rates for recruited blue cod, (33 cm and over, minimum legal size), followed the same pattern as for all blue cod and were 2.3 kg.pot^{-1}, excluding the MR, with a CV of 12%. The MR catch rates for all blue cod and recruited blue cod were 3.8 kg.pot^{-1} (CV of 19%), and 3.41 kg.pot^{-1} (CV = 16%) respectively.

Of the 966 blue cod, 76 from the MR and 119 from outside the MR were unsexed. Outside the MR, total length range was 17–58 cm and weighted mean length was 35.2 cm for males, 32.6 cm for females and 32.7 for unsexed fish, with males larger than females in all strata. The weighted sex ratio of all blue cod was 39% male, and 46% male for recruited blue cod. Scaled length frequency distributions were unimodal, with a right hand tail more prominent in males. Recruited fish comprised 52% of the scaled numbers. Mean length of the 76 unsexed blue cod in the MR was 37.1 cm.

Otolith section ages from 150 males and 140 females collected from throughout the sound from fixed and random sites were used to estimate the population age structure with separate age length keys for males and females. Age estimates of blue cod were 2–17 years for males and 4–26 years for females, but most males and females were between four and eight years old, with peaks at 5 for both males and females. Females had a much higher proportion of older fish than males and the oldest fish were females. Mean ages were 6.8 years for males and 8.5 years for females. Marine Reserve blue cod from fixed sites were larger and older than elsewhere (mean length 37 cm and mean age 9 years).

Total mortality estimates (*Z*) for age-at-full recruitment of eight years were 0.24 (excluding the MR) and 0.22 for the MR. Based on the default *M* of 0.14, estimated fishing mortalities (*F*) and $F_{\%SPR}$ values were 0.10 and $F_{51.4\%SPR}$, excluding the MR, and 0.08 and $F_{57.0\%SPR}$, for the MR.

There was a clear indication of spawning activity during the survey period with 4 to 6 percent of all fish running ripe, and about a third ripening, indicating that the spawning period had not peaked (includes fixed and random sites data).

2014 random site survey

The timing and design of the random site survey was the same as for fixed sites except that 1) because this was the first random site survey, no simulations were carried out to allocate sites within strata and the number of sites assigned was similar to that for fixed sites; 2) random sites were generated by randomly selecting from 1 kilometre blocks of coastline from within each stratum; and 3) pot placement was 'systematic' with pots placed at random depths perpendicular to the coast between 5 and 80 m, 250 m apart.

Thirty four random sites were sampled (6 pots per site, 204 pot lifts) from six strata throughout Dusky Sound. A total of 572 kg of blue cod (883 fish) were caught and 40 pots (20%) had zero catch of blue cod. Mean catch rate of all blue cod, excluding the MR, was 2.6 kg.pot^{-1}, ranging from about 2 kg.pot^{-1} for the three inner strata to 5 kg.pot^{-1} for the outside strata, with a CV of 9%. Catch rates for recruited blue cod, followed the same pattern as for all blue cod and were 1.9 kg.pot^{-1}, excluding the MR, with a CV of 10%. The MR catch rates for all blue cod and recruited blue cod were 2.51 kg.pot^{-1} (CV = 49%), and 2.38 kg.pot^{-1} (CV = 49%), respectively.

Of the 833 blue cod caught, 56 from the MR and 218 from outside the MR were unsexed. Total length was 18–55 cm and weighted mean length was 33.8 cm for males, 32.3 cm for females, and 32.5 for unsexed fish, with males larger than females in all strata. The weighted sex ratio of all sexed blue cod was 52% male and for recruited blue cod was 55% male. Scaled length frequency distributions were unimodal, with a right hand tail more prominent in males. Recruited fish comprised 50% of the scaled numbers. Mean length of the 56 unsexed blue cod in the MR was 39.0 cm.

The age-length-key used for fixed sites was also used for random sites. Age estimates of blue cod were 2–17 years for males and 3–26 years for females, but most males and females were between four and eight years old with peaks at 4 or 5 for both males and females. Females had a much higher proportion of older fish than males and the oldest fish were females. Mean ages were 6.6 years for males and 7.9 years for females. Marine Reserve blue cod from random sites were larger and older than elsewhere (mean length 39 cm and mean age 9.9 years).

Total mortality estimates (Z) for age-at-full recruitment of eight years were 0.27 (excluding the MR) and 0.20 for the MR. Based on the default M of 0.14, estimated fishing mortalities (F) and $F_{\%SPR}$ values were 0.13 and $F_{44.8\%SPR}$, excluding the MR, and 0.06 and $F_{64.0\%SPR}$, for the MR.

Fixed and random site comparison

Catch rates of all blue cod were similar in fixed and random sites for the three inner strata, but were considerably higher in fixed sites for the outer two strata. The overall survey catch rate, excluding the MR, was also 23% higher in fixed than random sites. Survey precision around all blue cod catch rates was similar with CVs of 12% for fixed and 9% for random sites. Scaled length and age distributions were similar. Overall sex ratio favoured females in fixed sites (39% male), and was close to parity in random sites (52% male). Total mortality and SPR estimates were similar. MR catch rates were 52% larger in fixed than random sites.

Time series comparison (fixed sites)

The overall mean catch rate of all blue cod from fixed sites (outside the marine reserve) increased from 2002 to 2008 by 58%, followed by a 23% decline in 2014. The 2008 increase in catch rates was consistent with management measures in 2005 where bag limits in the inner sound were reduced and commercial fishing was prohibited. The reasons for the 2014 decline in catch rates are unknown. Marine Reserve catch rates were more than those in the inner sound but less than those from the outer strata and since it was established in 2005 there has been no increase in catch rates. Some movement of blue cod in and out of the reserve is likely. The sex ratio in Dusky Sound is skewed toward females with 43% of all blue cod being male in 2002, 44% in 2008, and 39% in 2014, with no trend overall.

Because ageing of the 2002 and 2008 surveys was carried out before the blue cod age determination protocol was developed, age compositions, total mortality (Z) and SPRs cannot validly be compared with the 2014 fixed site survey. There was a higher proportion of larger fish (both males and females) in the 2008 population compared to 2002, whereas in 2014 the male size distribution was similar to 2002 while the female distribution resembled 2008. Unlike 2008, there are no clear or obvious explanations for the shift in population length structure in 2014, as there have been no changes in management of Dusky Sound blue cod since 2005.

1. INTRODUCTION

This report describes the 2014 Ministry for Primary Industries (MPI) Dusky Sound potting survey of relative abundance, population length/age structure and stock status of blue cod (*Parapercis colias*). This is the third in the time series with previous surveys in 2002 and 2008 (Carbines & Beentjes 2003, 2011a).

1.1 Status of the Dusky Sound blue cod stock

Blue cod is a target and the species most frequently landed by recreational fishers off the South Island (Ministry for Primary Industries 2015). In the Southland Fisheries Management Area (FMA) BCO 5, recreational annual take was last estimated at 229 t during a 1999–2000 national telephone/diary survey (Ministry for Primary Industries 2015). Within Fiordland, recreational fishing is focused on Dusky and Doubtful Sounds, and off Preservation Inlet (Davey & Hartill 2008).

Dusky Sound is a key area for recreational fishing for blue cod, particularly since the closures of Doubtful and Milford Sound to target fishing for blue cod in 2005. Although MPI manage recreational fish stocks in Fiordland, 'Guardians of Fiordland' provide informed advice to MPI reflecting local view points and knowledge of the state of various fisheries and marine environment. At the time of the first Dusky Sound blue cod potting survey in 2002, Fiordland blue cod were managed as part of BCO 5 with open commercial access and a daily bag limit of 30 blue cod for recreational fishers. The Guardians of Fiordland subsequently developed the Fiordland Marine Area which was established by the Fiordland Marine Management Act in 2005. Since 2005 the daily bag limit in Dusky Sound was reduced to 20 blue cod in the outer fiords, with an end to daily bag limit accumulation. In the inner half of most fiords commercial fishing was prohibited and the daily bag limit for recreational fishes further reduced to only three blue cod, with no daily accumulation. The Taumoana (Five fingers) Marine Reserve in Dusky sound was the introduced at this time. The MLS is 33 cm for Dusky Sound, larger than the 30 cm for most other areas in New Zealand.

1.2 Blue cod potting surveys

South Island recreational blue cod stocks are monitored using potting surveys. These surveys take place predominantly in areas where recreational fishing is common, but in some areas there is substantial overlap between the commercial and recreational fishing grounds. The aim is to repeat each survey about every four years providing local relative 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 management initiatives such as changes to the daily bag limit, minimum legal size, and/or area closures. One method to investigate the status of blue cod stocks is to estimate spawner-per-recruit ($F_{\%SPR}$), an MSY-related proxy. The recommended Harvest Strategy Standard reference point for blue cod (a low productivity stock) is $F_{45\%SPR}$ (Ministry of Fisheries 2011).

In addition to Dusky Sound, there are currently eight other South Island areas surveyed, located in key recreational fisheries: Kaikoura (Carbines & Beentjes 2006a, 2009), Motunau (Carbines & Beentjes 2006a, 2009), Banks Peninsula (Beentjes & Carbines 2003, 2006, 2009), north Otago (Carbines & Beentjes 2006b, 2011b), south Otago (Beentjes & Carbines 2011), Paterson Inlet (Carbines 2007, Carbines & Haist 2014), Foveaux Strait (Carbines & Beentjes 2012), and the Marlborough Sounds (Blackwell 1997, 1998, 2002, 2006, 2008, Beentjes & Carbines 2012). While the aim is to repeat each survey about every four years, there are six years between surveys in Dusky Sound.

1.3 Previous Dusky Sound blue cod potting surveys

The 2002 and 2008 blue cod potting surveys of Dusky Sound were carried by NIWA on behalf of the Ministry for Primary Industries. In 2008 the Marine Reserve, then just three years old, was included at the request of the Guardians and permission to do so was granted by the Department of Conservation. All fish caught in the Marine Reserve were measured for length and released alive. Both these surveys used only fixed sites which are predetermined locations that can be used repeatedly between surveys (Beentjes & Francis 2011). The 2002 and 2008 surveys were reanalysed in 2012 updating catch-at-age, sex ratios, total mortality (Z) and spawner-per-recruit (SPR) estimates as prescribed by the potting survey standards and specifications (Beentjes 2012).

Subsequent to the 2008 survey, the South Island potting surveys were reviewed by an international expert panel in 2009, which recommended that blue cod would be more appropriately surveyed using random site potting surveys (Stephenson et al. 2009). A random site is any location (single latitude and longitude) generated randomly from within a stratum (Beentjes & Francis 2011). Since October 2014 random sites were used as the only site type, or in conjunction with fixed sites in all South Island blue cod surveys, with the exception of Dusky Sound. It is the intention of MPI to transition to a fully random survey design and the deployment of both fixed and random sites allows comparison of catch rates, length and age composition, and sex ratios between the site type survey designs in the interim.

Dusky Sound blue cod populations appear to be the ‘healthiest’ of all nine areas surveyed because fish are much larger, older, more abundant, and the sex ratio is female dominated (Carbines & Beentjes 2003, 2011a). There was also a clear increase in catch rates, size and age between 2002 and 2008, possibly reflecting the management changes implemented in 2005.

Both previous surveys were fixed site surveys, whereas in 2014, separate fixed site and random site surveys were conducted concurrently.

1.4 Objectives

Overall Objective

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

Specific objectives

1. To undertake a potting survey in Dusky Sound (BCO 5) to estimate relative abundance, size- and age-at-maturity, and sex ratio. Collect otoliths during the survey from pre-recruited and recruited blue cod.
2. To analyse biological samples collected from this potting survey.
3. To determine stock status of blue cod populations in this area, and compare this with other survey areas.
4. To determine F_{msy} proxies for Dusky sound blue cod

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

2. METHODS

2.1 2014 Dusky Sound blue cod survey

2.1.1 Timing

A potting survey of the Dusky Sound and outer coast was carried out by NIWA between 11 and 29 October 2014. The survey was consistent with the previous survey dates and coincided with the known spawning times in this region.

2.1.2 Survey area

Dusky Sound is in Fiordland National Park located at the most eastern part of New Zealand in the South Island between Puysegur Point and Doubtful Sound (Figure 1). The five strata (*inner, mid, outer, extreme outer, and open coast*) used in the 2002 Dusky Sound survey were originally defined as part of a blue cod tag and release study in 2001 (Carbines & McKenzie 2004) (Figure 2). Stratum size was determined at a scale at which blue cod might be expected to form distinct stocks, separated by natural boundaries where possible. The 2002 survey area and strata are identical to 2008, except that in 2008 stratum *outer* was subdivided into two strata; stratum *Marine Reserve* (Taumoana Marine Reserve) and stratum *outer* (remainder of the original *outer* stratum); For the 2014 survey the same (2008 survey) strata were used (Figure 2).

Available blue cod habitat within Dusky Sound often constitutes a narrow band/ledge of light foul extending out from the shore or exposed headland reefs, usually shallower than 50 m (Carbines & Beentjes 2003, Carbines & McKenzie 2004). Very few blue cod are ever caught along cliff faces or in deep trenches. This habitat band was assumed to be reasonably constraining and the length of the coastline and equivalent submerged areas supporting such habitat (measured by the length of the 50 m contour line from Chart NZ7653) was assumed to be proportional to the amount of blue cod habitat in each stratum (Table 1).

2.1.3 Survey design

Full fixed site and full random site surveys were carried out concurrently in Dusky Sound in 2014 (Table 1).

Allocation of sites to strata

Simulations to determine the optimal allocation of fixed sites among the six strata were carried out with catch rate data from the 2002 and 2008 fixed site surveys using NIWA's Optimal Station Allocation Program (*allocate*). Simulations were first carried out for fixed sites and constrained to have a minimum of three sites per strata and a CV (coefficient of variation) of no greater than 10%. Because there were no random sites surveyed in 2002 and 2008, random site allocation was nominally the same as for the fixed sites, but with one additional site added to each stratum because results from random site surveys indicate that random sites tend to have higher CVs than fixed sites (Table 1). The simulations indicated that 28 fixed sites and 34 random sites were required.

The survey used a two-phase stratified random station design (Francis 1984). For each survey (fixed and random) about 90% of sites were allocated to phase 1, with the remainder available for phase 2, with the Marine Reserve stratum excluded from phase two allocation (Table 1). Allocation of phase 2 stations was based on the mean pot catch rate (kg.pot.$^{-1}$) of all blue cod per stratum and optimised using the “area mean squared” method of Francis (1984). In this way, stations were assigned iteratively to the stratum in which the expected gain is greatest, where expected gain is given by:

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

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

Fixed sites
A fixed site has a fixed location (single latitude and longitude or the centre point location of a section of coastline) in a stratum and is available to be used repeatedly on subsequent surveys (Beentjes & Francis 2011). The fixed sites used in a particular survey are randomly selected from the list of all available fixed sites in each stratum. For the 2014 Dusky Sound survey, the 28 fixed sites were randomly selected from the full and larger list of 124 possible fixed sites. These sites were identified by local fishers as potential target fishing sites for blue cod and were used during the 2002 tagging study (Carbines & McKenzie 2004).

Pot configuration and placement for fixed sites is defined in the blue cod potting manual (Beentjes & Francis 2011). Six pots (pot plan 2) were set along the shoreline extending away from the site position in both directions, but within 1.5 km of coastline. Pot placement for fixed sites was ‘directed’ with placement of each pot around the site determined by the skipper using local knowledge and the vessel sonar to locate a suitable area of reef/cobble or biogenic habitat, and pots were at least 100 m apart.

Random sites
A random site has a location (single latitude and longitude) generated randomly within a stratum (Beentjes & Francis 2011). For each of the six Dusky Sound strata, the coastline was divided into 1 kilometre blocks (excluding coastline sections less than 1 km such as rocks or small islands) and a latitude and longitude at the centre of each block was assigned, giving a large number of potential random sites. From this list, the allocated number of random sites per stratum to be surveyed was randomly selected with the constraint that that they were not closer than 1 kilometre to an allocated fixed site (Table 1).

Pot configuration and placement for random sites is defined in the blue cod potting manual (Beentjes & Francis 2011). In systematic pot placement the position of each pot is arranged systematically around the site or along the site for a section of coastline as in the case in Dusky Sound where the habitat is generally confined to a narrow band along the shore. Following the recommendation of the Southern Inshore Working Group (SINSWG-2014/26), the first pot was set about 250 m from the centre of the 1 km length of coastline and then the remaining five pots placed in a line 100 m apart, moving towards and past the centre. Pots were then placed at random depths perpendicular to the coast between 5 and 80 m unless a drop off was encountered below 80 m in which case the pot was placed at a random depth between 5 m and the drop off depth.

2.1.4 Vessel and gear

The 2008 Dusky Sound potting survey was conducted from F.V. *Western Explorer* (registration number 9077), a Stewart Island based commercial vessel equipped to set and lift rock lobster and blue cod pots, and skippered by the owner Mr Andrew Hamilton. The vessel has a wooden hull, is 11.5 m in length, and is powered by a 180 horsepower diesel engine with propeller propulsion.

Nine custom designed and built cod pots were used to conduct the survey (Pot Plan 2 in Beentjes & Francis 2011). Pots were baited with paua viscera in “snifter pottles”. Bait was topped or replaced after every lift. The same pot design and bait type were used in all previous Dusky Sounds blue cod potting surveys.

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

2.1.5 Sampling methods

All sampling methods adhere strictly to the blue cod potting survey standards and specifications (Beentjes & Francis 2011).

At each site, six pots were set and left to fish (soak) for a target period of one hour during daylight hours. As each pot was placed, a record was made of sequential pot number (1 to 6) and the pot identification code (PP2A to PP2F), latitude and longitude from GPS, depth, and time of day. After each site was completed, the next closest site (either random or fixed) in the stratum was sampled. The ADCP was deployed at the centre of each site prior to the setting of pots and recovered after the last pot of each set was lifted. The order that strata were surveyed depended on the prevailing weather conditions, with the outer strata sampled in fine conditions.

Pots were lifted aboard using the vessel’s hydraulic pot lifter in the order they were set, and the time of each lift was recorded. Pots were then emptied and the contents sorted by species. Total catch weight per pot was recorded for each species to the nearest 10 g using 0–6/6–15 kg Marel motion compensating scales. The number of individuals of each species per pot was also recorded. Total length to the nearest centimetre below actual length, individual fish weight to the nearest 10 g, and sex and gonad maturity were recorded for blue cod. Sagittal otoliths were removed from a representative length range of blue cod males and females over the available length range across the five strata with the aim of taking two otolith pairs per size class for males and females from each stratum (Appendix 2). Sex and maturity were determined either by dissection and macroscopic examination of the gonads or ‘milking’(Carbines 1998, Carbines 2004). In the Marine Reserve all fish were released alive from the seven surveyed sites with limited information collected on the sex of measured fish. In six additional sites (three random and three fixed) outside the marine reserve in two strata (Extreme outer, Inner, Outer), sex was not recorded and all fish were released alive following instructions from MPI towards the end of the survey after concerns from Guardians of Fiordland over the numbers of fish being killed.

Blue cod gonad staging was undertaken using the five stage Stock Monitoring (SM) method used on previous surveys. Gonads were recorded as follows: 1, immature; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent; 6, resting.

2.1.6 Data storage (potting survey)

The trip code for the survey is WEX1401. At the completion of the survey, data were entered into the Ministry for Primary Industries (MPI) *trawl* and *age* databases in accordance with the business rules and the blue cod potting survey standards and specifications (Beentjes & Francis 2011). All analyses were carried out from data extracted from the *trawl* database. Fixed sites were entered into *trawl* table *t_station* in attribute *stn_code* (concatenating stratum number and site label, e.g., EO1, EO2 etc.). Similarly, random sites were entered into attribute *stn_code*, but were prefixed with R (e.g., REO1, REO2). Random site locations were also entered into *trawl* table *t_site*. Pot locations were entered in table *t_station* in attribute *station_no* (concatenating set number and pot number e.g., 11 to 16, or 31 to 36 etc.) with no distinction between fixed and random sites. In the *age* database the *sample_no* is equivalent to *station_no* in the *trawl* database. The complete list of all possible 124 fixed sites were archived in the trawl database in table *t_site* after this survey as this had not been carried out hitherto.

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

2.1.7 Age estimates

Otolith preparation and reading

A thin section technique was used for ageing blue cod otoliths. Although there is an Age Determination Protocol (ADP) report for blue cod this is not yet published, however, the methodologies used generally follow those outlined in ADP for trevally (Walsh et al. 2014).

1. Blue cod otolith thin-section preparations were made as follows: otoliths were individually marked on their distal faces with a dot in the centrum using a cold light source on low power to light the otolith from behind. Five otoliths (from five different fish) were then embedded in an epoxy resin mould and cured at 50 ºC. Thin sections were taken along the otolith dorso-ventral axis through the centrum of all five otoliths, using a Struers Accutom-50 digital sectioning machine, with a section thickness of approximately 350 µm. Resulting thin section wafers were cleaned and embedded on microscope slides using epoxy resin and covered with a coverslip. Finally, these slides were oven cured at 50ºC.
2. Otoliths were read using transmitted light under a compound microscope at a magnification of 40–100 times. Under transmitted light the wide opaque zone appears dark and the narrow translucent zone appears light. Translucent zones were counted. (Ageing of blue cod otolith thin sections prior to 2015 counted opaque zones to estimate age)
3. Two readers read all otoliths without reference to fish length.
4. Readers adhered to the SINSWG agreed blue cod protocols (blue cod protocol still unpublished) when interpreting zone counts. Both ventral and dorsal sides of the otolith were read, mainly from the core toward the proximal surface close to the sulcus.
5. The forced margin method was used, i.e., for otoliths collected in October, the margin was considered to be a wide translucent zone.
6. Where between-reader counts differed, the readers rechecked the count and conferred until agreement was reached, unless the section was a grade 5 (unreadable) or damaged (removed from the collection).
7. Between-reader ageing precision was assessed by the application of the methods and graphical techniques documented in Campana et al. (1995) and Campana (2001); including APE (average percent error) and coefficient of variation (CV).

2.1.8 Analyses of data

Analyses of catch rates, sex ratios, scaled length distribution, catch-at-age, Z estimates, and spawner-per-recruit were carried out and presented separately for fixed and random site surveys.

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

2.1.8.1 Catch rates

The catch rate (kg.pot^{-1}) estimates are pot-based and the CV estimates are set-based (Beentjes & Francis 2011). Catch rates and 95% confidence intervals (± 1.96 standard error) were estimated for all blue cod and for recruited blue cod (33 cm and over). The 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 and overall for fixed and random sites surveys. Catch rates were estimated for individual strata, all strata combined, and for all strata combined excluding the marine reserve.

2.1.8.2 Length-weight parameters

The length-weight parameters a_k, b_k from the 2014 Dusky Sound survey were used in the equation

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

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

2.1.8.3 Growth parameters

A von Bertalanffy growth model (von Bertalanffy 1938) was fitted to the 2014 survey length-age data by sex as follows:

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

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

2.1.8.4 Scaled length and age frequencies

Length and age compositions were estimated using the NIWA program Catch-at-age (Bull & Dunn 2002). The program scales the length frequency data by the area of the stratum, number of sets in each stratum, and estimated catch weight determined from the length-weight relationship of individual fish. The latter scaling should be negligible or very close to one if all fish caught during the survey were measured (which they were) and if the actual weight of the catch is close to the estimated weight of the catch.

The coastline length (in kilometres) shown in Table 1 was taken as the area of the stratum (A_t), and the length-weight parameter estimates were made from the 2014 survey data for males and females separately. Stratum coastline length rather than stratum area is used because blue cod habitat is confined to a narrow band along the coastline, mostly inside 50 m (see Section 2.12 Survey area).

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

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

Catch-at-age was estimated using a single age length key (ALK) applied to the length data from the entire survey area, and the same ALK was used for both random and fixed sites. For each survey, scaled length frequency and age frequency proportions are presented, together with CV for each length and age class, and the mean weighted coefficients of variation (MWCV).

Unsexed fish

Although blue cod sex is routinely recorded on Dusky Sound surveys outside the Marine Reserve, on the 2014 survey considerable numbers of fish were released alive without being assigned sex, potentially compromising the estimates of Z and SPR which depend, in part, on representative length frequency distributions by sex. This occurred later in the survey following a directive from MPI to release fish alive and affected almost exclusively strata EO (extreme outer) and OC (outer coast), in both fixed and random site surveys. To deal with this the SINSWG recommended combining sexed length data from both fixed and random sites in strata EO and OC and this be used to estimate catch-at-age, Z and SPR. Hence for both survey types, the length data used in the analyses include all fish from OC and EO, regardless if collected from fixed or random sites.

2.1.8.5 Sex ratios, and mean length and age

Sex ratios (expressed as percentage male) and mean lengths, for both the stratum or survey level, were calculated using equations 10 and 11 of Beentjes & Francis (2011) from the stratum or survey scaled LFs. Mean ages were calculated analogously from the scaled age frequencies. Sex ratios were also estimated for recruited blue cod (33 cm and over) and overall survey 95% confidence intervals around sex ratios were generated from the 300 LF bootstraps. Sex ratios were calculated separately for fixed and random sites without combining the length data in strata OC and EO as described above to deal with unsexed fish.

2.1.8.6 Total mortality estimates

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

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

2.1.8.7 Spawner-per-recruit estimates

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

Input parameters used in the 2014 SPR analysis

Growth parameters: von Bertalanffy growth parameters and length-weight coefficients were estimated from the 2014 Dusky Sound survey data (see below).

Parameter	Males	Females	Unsexed
K	0.222	0.129	–
t_0	0.638	-1.805	–
L_∞	50.3	46.7	–
a	0.00734	0.00787	0.01532
b	3.2089	3.1978	3.0184

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

Maturity: age-at-maturity was estimated from the length-at-maturity logistic model values of the 2008 survey $L_{50\%}$ and $L_{95\%}$. The ages that corresponded to these parameters were estimated from the von Bertalanffy curves of the 2008 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 5.25 and 3.45 years for females; the same values were also used for males because male length-at-95% maturity was unrealistic. These were also used for 2002 and 2008 surveys.

Selectivity: selectivity to the commercial fishery is described as knife-edge equal to age-at-MLS. Age corresponding to the MLS of about 33 cm from the 2014 von Bertalanffy curves was about 7 years.

Fishing mortality (F): fishing mortality was estimated from the results of the Chapman-Robson analyses and the assumed estimate of M (i.e., $F = Z–M$). The Z value was for an age-at-full recruitment (8 y for females).

Maximum age: assumed to be 31 years.

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

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

2.1.8.8 Analyses of 2002 and 2008 Dusky Sound surveys

As part of this report, catch rates were re-estimated for the 2002 and 2008 fixed site surveys using the potting survey standards and specifications equations in the potting manual (Beentjes & Francis 2011) so that they could be validly compared among the three Dusky Sound fixed site surveys. Time series graphical plots are provided for catch rates, and sex ratios.

3. RESULTS

3.1 2014 Dusky Sound fixed site blue cod potting survey

3.1.1 Fixed sites surveyed

Twenty eight fixed sites (6 pots per site, producing 168 pot lifts) from six strata throughout the Dusky Sound were surveyed from 11 to 29th October 2014 (Table 1, Figure 3). Depths sampled were 5–83 m (mean = 33 m). Twenty five sites were carried out in phase 1 and three in phase 2 in strata EO and INN (Table 1, Figure 4).

3.1.2 Catch (fixed sites)

A total of 644.7 kg of blue cod (966 fish) was taken comprising 90% by weight and 81% by number of the catch of all species on the survey (Table 2). Bycatch species included 12 teleost fishes, as well as octopus. The three most common bycatch species for fixed site surveys, by number, were scarlet wrasse (*Pseudolabrus miles*), girdled wrasse (*Notolabrus cinctus*), and banded wrasse (*Notolabrus fucicola*).

Of the 168 fixed site pots, 19 (11%) had zero catch of blue cod.

3.1.3 Blue cod catch rates (fixed sites)

Mean catch rates (kg.pot^{-1}) of blue cod (all lengths and 33 cm and over) from fixed sites are presented by stratum and overall (Table 3, Figure 5).

Mean catch rates of blue cod (all sizes) were about 2 kg.pot^{-1} for the three inner strata of Dusky Sound (INN, MID, OUT) and were about 5 and 9 kg.pot^{-1} for the outside strata, EO and OC respectively (Table 3, Figure 5). The overall catch rate, excluding the Marine Reserve, was 3.2 kg.pot^{-1} with a CV of 12%. Catch rates for recruited blue cod, 33 cm and over (minimum legal size), followed the same pattern as for all blue cod and overall were 2.3 kg.pot^{-1}, excluding the Marine Reserve, with a CV of 12%. The Marine Reserve catch rate was 3.8 kg.pot^{-1} and CV was 19%.

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

Of the 996 blue cod caught in fixed sites, 771 were sexed (77%) and all fish were measured for length (Table 4). Of the 771 sexed fish, 26 were released as sex was determined by milking (i.e., they were running ripe) and the remainder were killed to determine sex and, where required, to extract otoliths. Of the 195 unsexed fish, 76 (39%) were from the Marine Reserve where blue cod are always caught and released alive on these surveys. The other 119 unsexed fish were from strata EO and OC and were released alive following a directive from MPI towards the end of the survey (Table 4).

The weighted sex ratio was 32–49% male across the five strata and the overall weighted sex ratio was 39% male (Table 4). Length was 17–56 cm for males and 21–48 cm for females, although this varied among strata and the overall weighted mean length was 35.2 cm for males and 32.6 cm for females. The scaled length frequency distributions by strata lack the numbers to describe length composition well or compare among strata, but overall appear to be unimodal (Figure 6). There is no clear difference in the length distributions of sexed and unsexed fish in strata EO and OC (Figure 6).

3.1.5 Age and growth

Otolith section ages from 150 males and 140 females collected from fixed and random sites were used to estimate the population age structure from Dusky Sound in 2014 (Table 5). The length-age data are plotted and the von Bertalanffy model fits are shown for males and females separately (Figure 7). The growth parameters (K, t_0 and L_∞) are shown in the methods table of input data for the SPR analysis (Section 2.1.8.7). There is a large range in age at length for both sexes and although males grow faster and larger than females, the oldest fish are females.

Between-reader comparisons are presented in Figure 8. The two readers achieved agreement on 67% of read otoliths, and overall there was no bias between readers with a CV of 3.4% and average percent error (APE) of 2.4%.

3.1.6 Spawning activity

Gonad stages of blue cod sampled in the October 2014 Dusky Sound survey are presented for all lengths, and recruited fish (over 33 cm) from fixed and random sites combined (Table 6). There was a clear indication of spawning activity during the survey period with 4 to 6 percent of all fish running ripe, and about a third ripening, indicating that the spawning period had not peaked. Recruited fish showed a similar pattern, but with a slightly higher proportion of ripening and running ripe fish.

3.1.7 Population length and age composition (fixed sites)

Outside the Marine Reserve

The scaled length frequency and age distributions for the 2014 fixed site survey are shown for all strata combined, excluding the Marine Reserve, as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Figure 9). This includes the 216 unsexed fish, 106 males and 91 females from random sites strata EO and OC.

Scaled length frequency distributions for both males and females were unimodal with a right hand tail more prominent in males and mean lengths of 34.5 cm and 32.9 cm respectively (Figure 9**).** The cumulative distribution plots of length frequency show clearly that males had a higher proportion of larger fish than females and also that the largest fish were males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 34% for males and 33% for females. Recruited fish comprised 52% of the scaled numbers.

Age estimates of blue cod were 2–17 years for males and 4–26 years for females, but most males and females were between four and eight years old (Figure 9). The estimated population age distributions were unimodal or indistinct for both sexes, but ages were skewed to the right with the peak at four for males and five for females. The cumulative distribution plots of age frequency show clearly that females had a much higher proportion of older fish than males and also that the oldest fish were females. Further, the mean age of females was greater than that of males (6.8 for males and 8.5 years for females). The MWCVs around the age distributions were 33% for males and 40% for females, higher than desired to provide a good representation of the overall population age structure.

Marine Reserve

The scaled length and age distribution from fixed sites are shown for the Marine Reserve in Figure 10. Although there were only 76 fish caught in the Marine Reserve, the length and age distributions are generally similar in shape to those outside, except that mean fish size is larger (37.1 cm in the MR compared to 35.2 cm for males and 32.6 cm for females outside the MR). The age distribution reflects this difference with a higher proportion of older fish between 10 and 15 years of age. Ageing however, is based on ages of males and females from outside the Marine Reserve being assigned to unsexed fish and then applied to the length data, and hence there will be more uncertainty associated with the age distribution.

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

Fixed site total mortality estimates (*Z*) and 95% confidence intervals are given for a range of recruitment ages (5–10 y) in Table 7. For age-at-full recruitment (8 years as agreed by the SINSWG 2016-26), total mortality estimates were 0.24 (excluding the Marine Reserve) and 0.22 for the Marine Reserve.

Mortality parameters (Z, F, and M) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of M and age at full recruitment of eight years are shown in Table 8. Based on the default M of 0.14, estimated fishing mortalities (F) and $F_{\%SPR}$ values were 0.10 and $F_{51.4\%SPR}$, excluding the Marine Reserve; and 0.08 and $F_{57.0\%SPR}$ for the Marine Reserve. This indicates that at the 2014 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 51% of the contribution in the absence of fishing. Although fishing is not permitted in the Marine Reserve, an F value of 0.08 suggests that there may be some movement in and out of the reserve by blue cod; or that some illegal fishing has taken place.

3.2 2014 Dusky Sound random site blue cod potting survey

3.2.1 Random sites surveyed

Thirty four random sites (6 pots per site, 204 pot lifts) from six strata throughout the Dusky Sound were surveyed from 11 to 29th October 2014 (Table 1, Figure 3). Depths sampled were 5–63 m (mean = 27 m). Thirty-one sites were sampled in phase 1 and three in phase 2 in strata INN, OUT and EO (Table 1, Figure 4).

3.2.2 Catch (random sites)

A total of 572.3 kg of blue cod (883 fish) was taken comprising 91% by weight and 75% by number of the catch of all species on the survey (Table 2). Bycatch species included 7 teleost fishes, as well as hagfish. The three most common bycatch species for fixed site surveys, by number, were scarlet wrasse (*Pseudolabrus miles*), girdled wrasse (*Notolabrus cinctus*), and tarakihi (*Nemadactylus macropterus*).

Of the 204 fixed site pots, 40 (20%) had zero catch of blue cod.

3.2.3 Blue cod catch rates (random sites)

Mean catch rates (kg.pot^{-1}) of blue cod (all lengths and 33 cm and over) from random sites are presented by stratum and overall (Table 3, Figure 5).

Mean catch rates of blue cod (all sizes) were about 2 kg.pot^{-1} for the three inner strata of Dusky Sound (INN, MID, OUT) and were about 3 and 5 kg.pot^{-1} for the outside strata, EO and OC respectively (Table 3, Figure 5). The overall catch rate, excluding the Marine Reserve, was 2.6 kg.pot^{-1} with a CV of 9%. Catch rates for recruited blue cod, 33 cm and over (minimum legal size), followed the same pattern as for all blue cod and overall was 1.9 kg.pot^{-1}, excluding the Marine Reserve, with a CV of 10%. The Marine Reserve catch rate was 2.5 kg.pot^{-1} with a CV of 49%.

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

Of the 883 blue cod caught in random sites, 609 were sexed (69%) and all fish were measured for length (Table 4). Of the 609 sexed fish, 29 were released as sex was determined by milking (i.e., they were running ripe) and the remainder were killed to determine sex and, where required, to extract otoliths. Of the 274 unsexed fish, 56 (20%) were from the marine reserve where blue cod are always caught and released alive on potting surveys. Two fish in the Marine Reserve were sexed by milking. The other 218 unsexed fish were mainly from strata EO and OC, with two unsexed fish in OUT, and were released alive following a directive from MPI towards the end of the survey (Table 4).

The weighted sex ratio was 28–73% male across the five strata and the overall weighted sex ratio was 52% male (Table 4). Length was 18–55 cm for males and 18–52 cm for females, although this varied among strata and the overall weighted mean length was 33.8 cm for males and 32.3 cm for females. The scaled length frequency distributions by strata lack the numbers to describe length composition well or compare among strata, but overall appear to be unimodal (Figure 11). There is no clear difference in the length distributions of sexed and unsexed fish in strata EO and OC (Figure 11).

3.2.5 Age and growth

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

3.2.6 Blue cod spawning activity

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

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

Outside the Marine Reserve

The scaled length frequency and age distributions for the 2014 random site survey are shown for all strata combined, excluding the Marine Reserve, as histograms and as cumulative frequency line plots for males, females, and both sexes combined (Figures 12). This includes 119 unsexed fish, as well as the 171 males and 293 females from fixed sites strata EO and OC.

Scaled length frequency distributions for both males and females were unimodal with a right hand tail more prominent in males and mean lengths of 34.4 cm and 32.1 cm respectively (Figure 12**).** The cumulative distribution plots of length frequency show clearly that males had a higher proportion of larger fish than females, and also that the largest fish were males. The mean weighted coefficients of variation (MWCVs) around the length distributions are 41% for males and 36% for females. Fish 33 cm and over comprised 50% of the scaled numbers.

Age estimates of blue cod were 2–17 years for males and 3–26 years for females, but most males and females were between four and eight years old (Figure 12**).** The estimated population age distributions overall were unimodal or indistinct for both sexes, but ages were skewed to the right with the peak at four or five for both males and females. The unsexed fish age distribution appears to have characteristics of both the males and females. The cumulative distribution plots of age frequency show clearly that females had a much higher proportion of older fish than males and also that the oldest fish were females. Further, the mean age of females was greater than that of males (6.6 for males and 7.9 years for females). The MWCVs around the age distributions were 33% for males and 40% for females, higher than desired to provide a good representation of the overall population age structure.

Marine Reserve

The scaled length and age distribution from random sites are shown for the Marine Reserve in Figure 13. Although there were only 58 fish caught in the Marine Reserve the length and age distributions are generally similar in shape to those outside, except that mean fish size is larger (37.5 cm in the MR compared to 33.8 cm for males and 32.3 cm for females outside the MR). The age distribution reflects this difference with a higher proportion of older fish between 10 and 15 years of age. Ageing however, is based on ages of males and females from outside the Marine Reserve being assigned to unsexed fish and then applied to the length data, and hence there will be more uncertainty associated with the age distribution.

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

Random site total mortality estimates (*Z*) and 95% confidence intervals are given for a range of recruitment ages (5–10 y) in Table 7. For age-at-full recruitment (8 years as agreed by the SINSWG), total mortality estimates were 0.27 (excluding the Marine Reserve) and 0.20 for the Marine reserve.

Mortality parameters (*Z*, *F*, and *M*) and spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* and age at full recruitment of eight years are shown in Table 8. Based on the default *M* of 0.14 and age at full recruitment of eight years, estimated fishing mortalities (*F*) and $F_{\%SPR}$ values were 0.13 and $F_{44.8\%SPR}$, excluding the Marine Reserve, and 0.06 and $F_{64.0\%SPR}$, for the Marine Reserve (Figure 14). This indicates that at the 2014 levels of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit reduced to 45% of the contribution in the absence of fishing. Although fishing is not permitted in the Marine Reserve, an F value of 0.06 suggests some movement in and out of the reserve by blue cod; or that illegal fishing has taken place within the reserve.

3.3 Comparison of fixed site and random site surveys in 2014

Catch rates of all blue cod were similar in fixed and random sites for the three inner strata (INN, MID, OUT), but were considerably higher in fixed sites for the outer two strata EO and OC – particularly the open coast (OC), where they were nearly double (Table 3, Figure 15). The overall catch rate, excluding the Marine Reserve, was also 23% higher in fixed than random sites, but given the magnitude of confidence intervals, the difference is unlikely to be significant. The recruited fish (33 cm and over) catch rates exhibited the same pattern as for all blue cod. The large differences for the outer stratum OC may be partly a result of the placement of sites with fixed sites, on average, seven metres deeper than random sites (Table 1, Figure 3).

Cumulative plots of population length and age from the two surveys are presented in Figure 16. Overall there was little difference in scaled length and age distributions, although males are slightly larger in fixed than random sites, and this is also reflected in the age structure.

Sex ratios for fixed sites in all five strata favoured females, and overall was 39% male (see Table 4). Random site sex ratios were more variable (28 to 73% male) and overall the sex ratio was closer to parity at 52% male.

Total mortality and SPR estimates were very close for both fixed and random sites surveys with *Z* estimates of 0.24 and 0.27, and Spawner Biomass per Recruit ratios of $F_{51\%SPR}$ and $F_{45\%SPR}$, respectively, for age at recruitment of 8 years and M of 0.14. Marine Reserve SPR estimates were also similar at $F_{57\%SPR}$ and $F_{64\%SPR}$ for fixed and random sites, respectively (see Table 8).

3.4 Survey time series

3.4.1 Catch rates (fixed sites)

Mean catch rates ($kg.pot^{-1}$) for all blue cod and recruited blue cod (33 cm and over) from fixed sites are presented for each of the three surveys in the time series (Figure 17). Catch rates for the inner sound strata (INN, MID, OUT) all increased markedly in 2008 then declined in 2014, whereas the stratum EO is increasing over time, and the open coast (OC) is stable, but 2014 is the highest. Overall for all strata combined (excluding the Marine Reserve), catch rates increased markedly in 2008, then declined in 2014, and the magnitude of confidence intervals indicate that the 2008 increase and the 2014 decrease are significant The Marine Reserve catch rates have declined over time, but given the confidence intervals around the catch rates, this is unlikely to be significant. Catch rates for recruited fish (33 cm and over) display the same patterns (Figure 17).

3.4.2 Length distributions (fixed sites)

Because ageing of the 2002 and 2008 surveys was carried out before the age determination protocol was developed, age compositions, total mortality (Z) and SPR estimates cannot be compared with those from the 2014 fixed site survey. The scaled length frequency distributions from fixed sites among the three surveys were not consistent, with a clear and substantial increase in size between the 2002 and 2008 surveys for both males and females (Figure 18). In 2014 however, the male length distributions are very close to that of 2002, whereas those of females are similar to those of 2008.

3.4.3 Sex ratios (fixed sites)

The sex ratio among fixed site surveys for all blue cod was stable at about 40% male (Figure 19). The sex ratio for the 2014 random survey is shown for comparison at 52% male.

4. DISCUSSION

4.1 General

The 2014 Dusky Sound potting survey provides the third fixed site index in the time series of relative abundance and population structure of blue cod from Dusky Sound. In addition, for the first time, a random site survey was also carried out concurrently in 2014. Dual surveys are likely to continue until the overlapping time series of fixed and random sites is considered to be sufficient to enable any necessary corrections to parameters to be applied to earlier fixed site surveys and to move to a solely random site survey. For example catch rates, which are proxies for population abundance, may need correcting and the likely overlap period is three surveys, depending on the differences between survey types and the variability in outputs.

Survey sampling methods and strata were identical in the three surveys (2002, 2008 and 2014), except that stratum OUT was reduced in size after the 2002 survey because of the introduction of the Taumoana Marine Reserve in 2005. However, catch rates and other outputs from 2002 were re-estimated from the smaller stratum OUT, and hence the results of all three surveys outside the marine reserve are directly comparable. The 2014 survey was slightly compromised by the constraint to return fish alive towards the end of the survey resulting is reduced sample sizes by sex in the outer sound strata. However, there were no discernible differences in the length distributions of sexed and unsexed fish within strata and there appear to have been enough sexed fish to be representative of the populations of blue cod from these strata (see Table 4).

No target was specified for the survey but the he relative abundance CV was 12% for the fixed sites and 9% for the random sites survey, similar to values achieved for other blue cod surveys. Previous fixed site surveys achieved slightly lower CVs of 9% and 6% for 2002 and 2008 respectively, largely because of larger numbers of sets per survey which were nearly two fold greater than in 2014 (Carbines & Beentjes 2011a).

4.2 2014 fixed versus random site surveys

The overall CV for the 2014 random site survey of 9% was 3% less than that of the fixed site and is the first instance of achieving higher precision from the random survey design (Ministry for Primary Industries 2015). There were negligible differences in population size and age structure, Z, and SPR between fixed and random site surveys. However, catch rates were higher in fixed sites in the outer sound and also the overall sex ratio slightly favoured males in random sites (i.e., 39% male compared with 52% male) (see Table 4). The higher catch rates for fixed sites in the outer strata may be partly a result of the placement of fixed sites, on average, seven metres deeper than random sites (see Table 1 and Figure 3). It may also be plausible that as the fixed sites were selected as locations where blue cod were considered to be more abundant, hence on the open coast where abundance is much higher than the inner sounds, the fixed sites may have represented exceptionally good fishing spots. The reasons for differences in sex ratio between fixed and random sites is unclear. Sex ratios tend to be heavily skewed towards males in populations from the most heavily fished recreational blue cod fisheries in New Zealand such as Inner Banks Peninsula, Motunau and Marlborough Sound inner sounds (Beentjes & Carbines 2009, Carbines & Beentjes 2009).

4.3 Stock status

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

Random site surveys are considered by MPI to be superior to fixed sites surveys in design and precision, so estimates of *Z* and SPR from random site surveys are likely to be more representative of the population. The 2014 random site survey SPR estimate, for the default M value of 0.14, and age at full recruitment of 8 years (based on age to reach MLS for females), was $\mathrm{F_{45\%SPR}}$, indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit was reduced to 45% of the contribution in the absence of fishing (Figure 14). The level of exploitation (F) of Dusky Sound blue cod stocks approximates the F_{MSY} target reference point of $\mathrm{F_{45\%SPR}}$, indicating that fishing pressure is optimal. Inside the Marine Reserve, the random site $\mathrm{F_{\%SPR}}$ estimate was 64%, which is 19% better the target reference point. Within the Marine Reserve the spawner biomass per recruit ratio is about 15% greater than outside, which indicates that the restriction on fishing in this area since 2005 may have contributed to a partial rebuilding of the size and age structure.

4.4 Reproductive condition

All three fixed site surveys were carried out in October, so are comparable. During the 2002 survey most blue cod had resting and maturing gonads (some mature and only a few running ripe) indicating that spawning had only just begun (Carbines & Beentjes 2003). Gonad stages observed in 2008 were more developed than those observed in the 2002 survey, with about one quarter of blue cod in the running ripe condition (Carbines & Beentjes 2011a). The higher proportion of blue cod with gonads in the mature and running ripe phase in 2008 suggest that spawning had begun earlier than in 2002. In comparison, only 4 to 6% of gonads were in running ripe condition in 2014, more in line with the spawning cycle of 2002 (see Table 6).

4.5 Time series trends from Dusky Sound surveys

There are now three fixed site surveys in the time series, allowing a cautious attempt to identify and offer explanations for trends. The SINSWG noted, however, that the fixed site time series may not be valid given that fixed sites may be ‘hyperstable’ by virtue of their locations on fishing hot spots and that the meaningful time series should be based on random site surveys (14 April 2016). Also, because ageing of the 2002 and 2008 surveys was carried out before the age determination protocol was agreed upon, age compositions, total mortality (Z) and SPRs cannot be compared among the three fixed sites surveys.

4.5.1 Catch rates (fixed sites)

There were substantial changes in the catch rates of blue cod between 2002 and 2008 in Dusky Sound (Figure 17). The overall mean catch rate of all blue cod and of legal sized blue cod (33 cm and over) (outside the Marine Reserve) in 2008 increased by 58% and 75% respectively (Appendix 3). This increase in mean catch rate was consistent among all strata with the exception of the open coast stratum. The proportion of blue cod that were of legal size was also notably higher in the 2008 survey (55%) than in the 2002 survey (44%). In contrast, catch rates in the Marine Reserve in 2008 (compared to the same post-stratified area open to fishing in 2002) were remarkably similar. In 2014 catch rates in the inner sound were less than in 2008 and the overall catch rate was 23% and 39% less than in 2008 for all blue cod and legal sized fish (33 cm and over), respectively. Catch rates in the Marine Reserve also declined since 2008. Given the magnitude of the confidence intervals around the catch rate estimates, both the overall catch rate increase in 2002 and the decrease in 2014 are likely to be statistically significant.

Commercial fishers took, on average, 30.5 t of blue cod annually between 1989–90 and 2011–12 from Statistical Area 031 which includes Dusky Sound (Haist et al. 2013); but since 2005, commercial fishing has been restricted to the outer half of the fiords. Recreational fishing is permitted throughout Dusky Sound (excluding the Marine Reserve), with 90% of effort in the outer and coastal areas where commercial fishing also takes place, according to a 2008 characterisation of recreational fishing effort (Davey & Hartill 2008). The 2008 increase in catch rates from the inner sound and the relatively smaller mean size of blue cod from the open coast stratum in 2002 may reflect more intense fishing pressure in this area at this time (Carbines & Beentjes 2011a)(Appendix 3). The marked increase in both catch rates and mean size of blue cod from the inner half of Dusky Sound in 2008 were also consistent with the low levels of fishing pressure in this area. The 2014 overall decline in catch rates show the opposite pattern to 2008 with inner sound catch rates declining and those in the outer sound increasing (see Figure 5). Without information on recreational fishing effort, however, it is difficult to ascribe these changes to spatial distribution of fishing intensity.

In the Taumoana (Five Fingers Peninsula) Marine Reserve, where there has theoretically been no fishing pressure since 2005, the catch rates of all blue cod are higher than those in the inner sound, but lower than those from the outer strata. This indicates that the abundance of blue cod may be explained by the location of the strata. In 2002, when there was no Marine Reserve, the catch rates from sites within the Marine Reserve stratum were the highest in the time series and catch rates of all blue cod in the Marine Reserve have declined in both the 2008 and 2014 surveys after the reserve was established in 2005 (Figure 17). The small sample sizes and large catch rates confidence intervals for blue cod in the Marine Reserve suggest that the differences, however, may not be statistically significant. Blue cod from the Marine Reserve, however, are larger and older than elsewhere (see Figures 9 and 10), as expected from a no-take area. It is likely that fish move in and out of the Marine Reserve, as tagged blue cod in Dusky Sound, after up to three years at liberty, moved on average nearly 3 km. Of these 65% moved less than 1 km, and 13% crossed strata boundaries (Carbines & McKenzie 2004). Most movement was from outside to the inner sound.

4.5.2 Population length structure (fixed sites)

The length distributions are based on scaled length data that were weighted (scaled) by coastline length from each stratum in this survey. Scaling by area (coastline length in this case) assumes that the size of each stratum is directly proportional to the amount of blue cod habitat (i.e., it is assumed to be a proxy for habitat), however, this is probably not always the case given the discrete nature of areas of foul and biogenic habitat.

The scaled length frequency distributions for Dusky Sound blue cod in 2002 and 2008 are similar in shape, but there is a higher proportion of larger fish for both males and females in the 2008 population (Figure 18). The mean length increased for both males and females in 2008 compared to 2002 (35 to 38 cm for males and 30 to 32 cm for females) (Appendix 4). In 2014 male size distribution was similar to

2002 while the female distribution resembled that from 2008 (mean length in 2014 was 34.5 cm for males, and 33 cm for females). Unlike 2008, there are no clear or obvious explanations for the shift in population length structure in 2014 as there have been no changes in management of the sound since 2005.

4.5.3 Sex ratio (fixed sites)

The sex ratio in Dusky Sound is skewed toward females with 43% of all blue cod being male in 2002, 44% in 2008, and 39% in 2014, with no trend (Figure 19). Blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow (Carbines 2004). That males in Dusky Sound were larger on average than females and that the largest fish were males is consistent with sex structure in protogynous hermaphrodites.

In areas where fishing pressure is known to be high, such as Motunau, inshore Banks Peninsula, and the Marlborough Sounds, the sex ratios are skewed towards males which is contrary to an expected dominance of females resulting from selective removal of the larger final phase male fish (Beentjes & Carbines 2003, 2006, Carbines & Beentjes 2006a, Beentjes & Carbines 2012), Beentjes & 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, resulting in a higher rate (and possibly earlier onset) of sex change by primary females. With the exception of Foveaux Strait and offshore Banks Peninsula, Dusky Sound is the only survey where females dominate the population and 39% male is the lowest proportion of males recorded from blue cod surveys, suggesting that fishing pressure in Dusky Sound is less overall than in most blue cod fisheries.

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Table 1: Dusky Sound 2014 coastline area, site type, number of phase 1 and 2 stations, pot lifts, and depth.

Stratum				*N* sets (sites)					Depth (m)	
Name	Code	Area (km coastline)	Site type	Phase 1	Phase 2	*N* pots (stations)	No. blue cod	Catch (kg)	Mean	Range
Inner	INN	74.56	Fixed	5	1	36	129	91.5	30	6–60
Mid	MID	61.61	Fixed	4		24	81	58.3	28	9–61
Marine reserve	MR	19.9	Fixed	3		18	76	68.7	24	6–56
Outer	OUT	74.82	Fixed	6		36	97	67.2	43	13–83
Extreme outer	EO	44.22	Fixed	3	2	30	223	138.2	27	4–55
Open coast	OC	23.3	Fixed	4		24	360	220.8	40	21–60
Totals		298.41		25	3	168	966	644.7	33	5–83

Stratum				*N* sets (sites)					Depth (m)	
Name	Code	Area (km coastline)	Site type	Phase 1	Phase 2	*N* pots (stations)	No. blue cod	Catch (kg)	Mean	Range
Inner	INN	74.56	Random	6	1	42	111	85.6	31	7–62
Mid	MID	61.61	Random	5		30	118	74.4	29	8–60
Marine reserve	MR	19.9	Random	4		24	58	60.2	18	6–56
Outer	OUT	74.82	Random	7	1	48	183	106.5	24	5–60
Extreme outer	EO	44.22	Random	4	1	30	183	95.8	27	7–63
Open coast	OC	23.3	Random	5		30	230	149.8	33	16–61
Totals		298.41		31	3	204	883	572.3	27	5–63

Table 2: Total catch and numbers of blue cod and bycatch species caught on the 2014 Dusky Sound fixed site and random site potting surveys. Percent of the catch by weight is also shown.

		Fixed sites			
Common name	Species	Code	Catch (kg)	Number	% catch
Blue cod	*Parapercis colias*	BCO	644.7	966	89.99
Scarlet wrasse	*Pseudolabrus miles*	SPF	40.3	135	5.63
Girdled wrasse	*Notolabrus cinctus*	GPF	9.5	40	1.33
Banded Wrasse	*Notolabrus fucicola*	BPF	8.1	17	1.13
Octopus		OCT	4.5	1	0.63
Sea perch	*Helicolenus percoides*	SPE	4.1	13	0.57
Tarakihi	*Nemadactylus macropterus*	TAR	1.5	4	0.21
Spotty	*Notolabrus celidotus*	STY	0.9	9	0.13
Leatherjacket	*Meuschenia scaber*	LEA	0.6	2	0.08
Blue moki	*Latridopsis ciliaris*	MOK	0.6	1	0.08
Southern bastard cod	*Pseudophycis barbata*	SBR	0.6	1	0.08
Speckled sole	*Peltorhamphus latus*	SPS	0.6	2	0.08
Butterfly perch	*Caesioperca lepidoptera*	BPE	0.2	1	0.03
Dwarf scorpion fish	*Scorpaena papillosa*	RSC	0.2	1	0.03
Totals			716.4	1193	Totals

		Random sites			
Common name	Species	Code	Catch (kg)	Number	% catch
Blue cod	*Parapercis colias*	BCO	572.3	883	90.78
Scarlet wrasse	*Pseudolabrus miles*	SPF	34.4	191	5.46
Girdled wrasse	*Notolabrus cinctus*	GPF	10.8	48	1.71
Tarakihi	*Nemadactylus macropterus*	TAR	4	19	0.63
Butterfly perch	*Caesioperca lepidoptera*	BPF	3.4	8	0.54
Sea perch	*Helicolenus percoides*	SPE	2.8	13	0.44
Spotty	*Notolabrus celidotus*	STY	2.1	16	0.33
Hagfish	*Eptatretus cirrhatus*	HAG	0.3	1	0.05
Dwarf scorpion fish	*Scorpaena papillosa*	RSC	0.3	1	0.05
Totals			630.4	1180	

Table 3: Mean catch rates for all blue cod, and recruited blue cod (33 cm and over) caught from the 2014 Dusky Sound fixed site and random site potting surveys. Catch rates are pot-based, and s.e. and CV are set-based. See Table 1 for stratum names. s.e., standard error; CV coefficient of variation; Incl., including; excl., excluding. MR, Marine Reserve.

			Fixed sites survey					
			All blue cod			Recruited blue cod		
Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
INN	Fixed	36	2.54	1.04	41.0	2.09	0.81	39.0
MID	Fixed	24	2.43	0.48	19.7	1.92	0.49	25.4
MR	Fixed	18	3.82	0.72	18.8	3.41	0.54	15.8
OUT	Fixed	36	1.87	0.29	15.4	1.42	0.18	12.8
EO	Fixed	30	4.61	0.88	19.2	2.92	0.49	16.9
OC	Fixed	24	9.20	2.18	23.7	6.20	1.19	19.2
Overall (incl. MR)	Fixed	168	3.26	0.36	11.1	2.42	0.26	10.9
Overall (excl. MR)	Fixed	150	3.22	0.38	11.9	2.35	0.28	11.9

			Random sites survey					
			All blue cod			Recruited blue cod		
Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
INN	Random	42	2.04	0.33	16.1	1.69	0.23	13.8
MID	Random	30	2.48	0.52	21.1	1.74	0.47	27.0
MR	Random	24	2.51	1.24	49.5	2.38	1.16	48.7
OUT	Random	48	2.22	0.44	19.9	1.74	0.39	22.1
EO	Random	30	3.19	0.48	15.1	2.05	0.52	25.5
OC	Random	30	4.99	1.20	24.0	3.43	0.44	12.9
Overall (incl. MR)	Random	204	2.61	0.23	8.7	1.95	0.19	9.6
Overall (excl. MR)	Random	180	2.61	0.23	8.6	1.92	0.18	9.6

Table 4: Weighted mean lengths for the 2014 Dusky Sound fixed site and random site potting surveys for all blue cod. Weighted sex ratio (percent male) is given for all blue cod and recruited blue cod (33 cm and over). See Table 1 for strata names. m, male; f, female; u, unsexed. –, no data.

				Fixed site survey				
				Length (cm)			Percent male	
Stratum	Site type	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited
INN	Fixed	m	44	36.0	26	50	34.1	32.8
		f	85	34.3	25	48		
		u	0	–	–	–		
MID	Fixed	m	37	35.2	23	54	45.9	45.3
		f	44	33.3	21	47		
		u	0	–	–	–		
MR	Fixed	m	0	–	–	–	–	
		f	0	–	–	–		
		u	76	37.1	22	53		
OUT	Fixed	m	41	33.6	24	56	42.7	36.2
		f	56	33.2	21	47		
		u	0	–	–	–		
EO	Fixed	m	66	35.3	17	48	49.2	69.6
		f	67	30.9	23	44		
		u	90	31.8	23	58		
OC	Fixed	m	105	35.6	25	47	32.0	49.1
		f	226	31.3	22	44		
		u	29	37.0	28	53		
Overall (excl. MR)	Fixed	m	293	35.2	17	56	39.4	45.7
		f	478	32.6	21	48		
		u	119	32.7	22	58		

				Random site survey				
				Length (cm)			Percent male	
Stratum	Site type	Sex	N	Mean	Minimum	Maximum	All blue cod	Recruited
INN	Random	m	37	36.7	24	53	33.2	30.9
		f	74	35.0	25	50		
		u	0	–	–	–		
MID	Random	m	53	34.6	21	50	44.6	54.5
		f	65	31.9	19	50		
		u	0	–	–	–		
MR	Random	m	2	37.5	34	41	–	
		f	0	–	–	–		
		u	56	39.0	27	53		
OUT	Random	m	118	34.0	20	55	65.2	73
		f	63	29.8	18	52		
		u	2	42	39	45		

EO	Random	m	82	30.8	18	51	73	81.9
		f	30	28.3	19	52		
		u	71	31.9	22	44		
OC	Random	m	24	36.3	26	51	28.2	26.0
		f	61	34.5	24	42		
		u	145	32.8	24	51		
Overall (excl. MR)	Random	m	316	33.8	18	55	51.7	54.8
		f	293	32.3	18	52		
		u	218	32.5	22	53		

Table 5: Otolith raw unweighted ageing data used in the catch-at-age, Z estimates and SPR analyses for the 2014 Dusky Sound survey.

		Length of aged fish (cm)			Age (years)		
Survey	No. otos	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Total	290	34.2	17	56	8.1	2	26
Male	150	35.7	17	56	7.3	2	17
Female	140	32.6	18	50	8.8	3	26

Table 6: Gonad stages of Dusky Sound blue cod in October 2014 for all blue cod and recruited blue cod (33 cm and over). 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

		Gonad stage (%)					
Sex	Size range	1	2	3	4	5	N
Males	All sizes	26.4	28.8	36.6	5.6	2.6	607
Females		22.7	22.9	32.9	4.0	17.5	772
Males	Recruited (33 cm and over)	9.2	31.4	48.1	8.4	2.9	347
Females		7.0	20.9	50.0	5.6	16.5	358

Table 7: Total mortality estimates (*Z*) and 95% confidence intervals of blue cod for the fixed and random site 2014 Dusky Sound potting surveys. AgeR, age at full recruitment. excl.MR, excluding Marine Reserve.

	Fixed site survey			
			95% CIs	
Survey type	AgeR	*Z*	Lower	Upper
Fixed sites (excl. MR)	5	0.24	0.17	0.32
	6	0.23	0.17	0.31
	7	0.24	0.17	0.33
	8	0.24	0.18	0.32
	9	0.25	0.17	0.33
	10	0.26	0.18	0.34
Fixed sites (MR)	5	0.20	0.14	0.26
	6	0.20	0.14	0.27
	7	0.21	0.15	0.29
	8	0.22	0.15	0.29
	9	0.23	0.16	0.31
	10	0.25	0.17	0.33

	Random site survey			
			95% CIs	
Area (year)	AgeR	*Z*	Lower	Upper
Random sites (excl. MR)	5	0.27	0.20	0.36
	6	0.26	0.19	0.35
	7	0.27	0.19	0.37
	8	0.27	0.19	0.36
	9	0.27	0.19	0.36
	10	0.28	0.20	0.37
Random sites (MR)	5	0.18	0.13	0.24
	6	0.19	0.14	0.25
	7	0.19	0.13	0.25
	8	0.20	0.14	0.28
	9	0.21	0.15	0.30
	10	0.23	0.15	0.31

Table 8: Mortality parameters (*Z*, *F*, and *M*) and Spawner-per-recruit ($F_{SPR\%}$) estimates at three values of *M* and age at full recruitment of 8 years for blue cod from the 2014 Dusky Sound fixed and random site potting surveys. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality. AgeR, age at full recruitment. excl.MR, excluding Marine Reserve.

	Fixed site survey					
Survey type	Site type	AgeR	*M*	*Z*	*F*	$F_{\%SPR}$
Fixed sites (excl. MR)	Fixed	8	0.11	0.24	0.13	$F_{37.7\%}$
	Fixed	8	0.14	0.24	0.1	$F_{51.4\%}$
	Fixed	8	0.17	0.24	0.07	$F_{65.8\%}$
Fixed sites (MR)	Fixed	8	0.11	0.22	0.11	$F_{44.3\%}$
	Fixed	8	0.14	0.22	0.08	$F_{57.0\%}$
	Fixed	8	0.17	0.22	0.05	$F_{73.0\%}$
	Random site survey					
Survey type	Site type	ageR	*M*	*Z*	*F*	$F_{\%SPR}$
Random sites (excl. MR)	Random	8	0.11	0.27	0.16	$F_{32.9\%}$
	Random	8	0.14	0.27	0.13	$F_{44.8\%}$
	Random	8	0.17	0.27	0.1	$F_{57.4\%}$
Random sites (MR)	Random	8	0.11	0.20	0.09	$F_{47.0\%}$
	Random	8	0.14	0.20	0.06	$F_{64.0\%}$
	Random	8	0.17	0.20	0.03	$F_{81.9\%}$

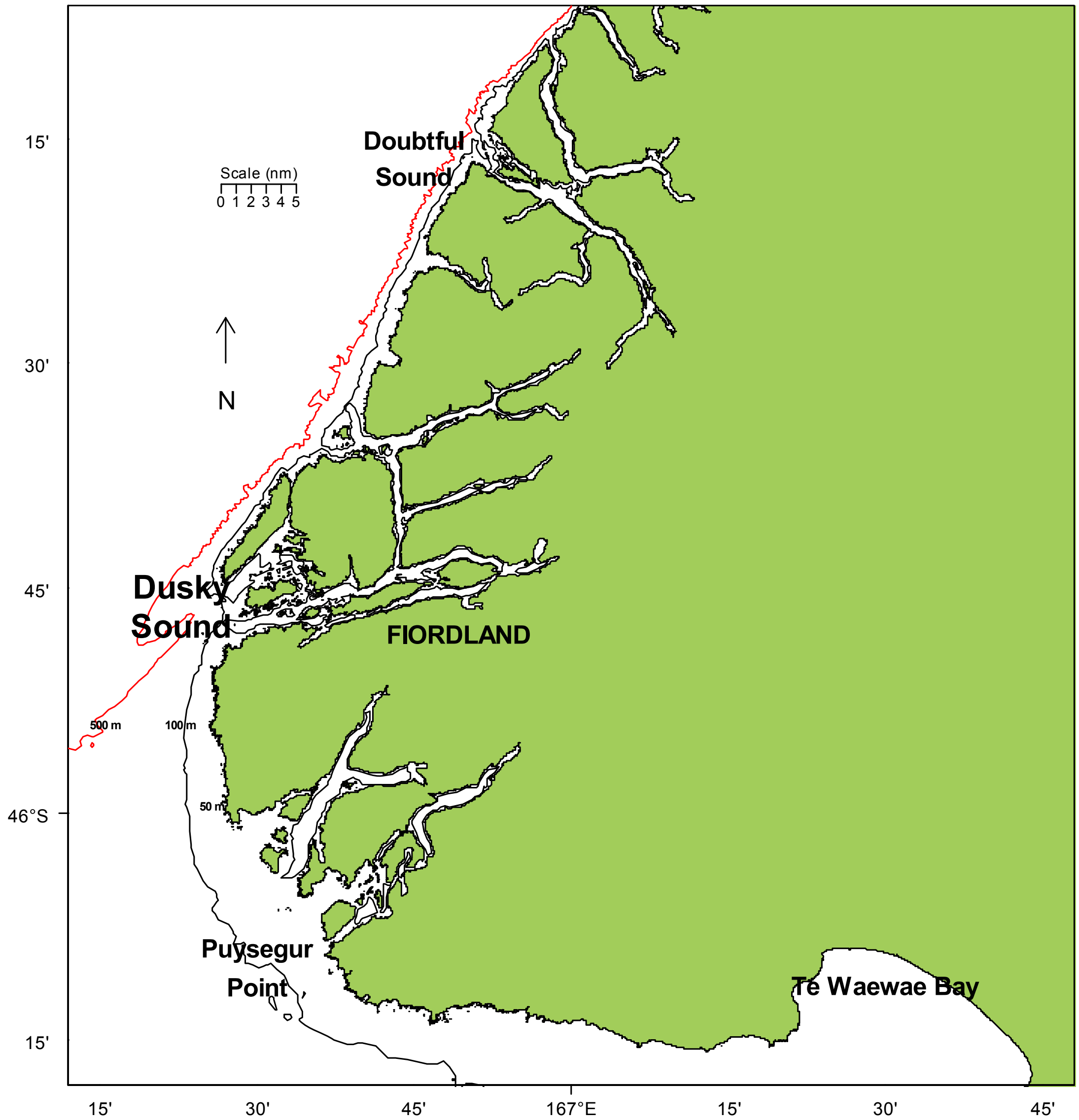

Figure 1: Map of Fiordland showing location of Dusky Sound. Depth contours are shown for 50 m, 100 m and 500 m.

Dusky Sound (strata)

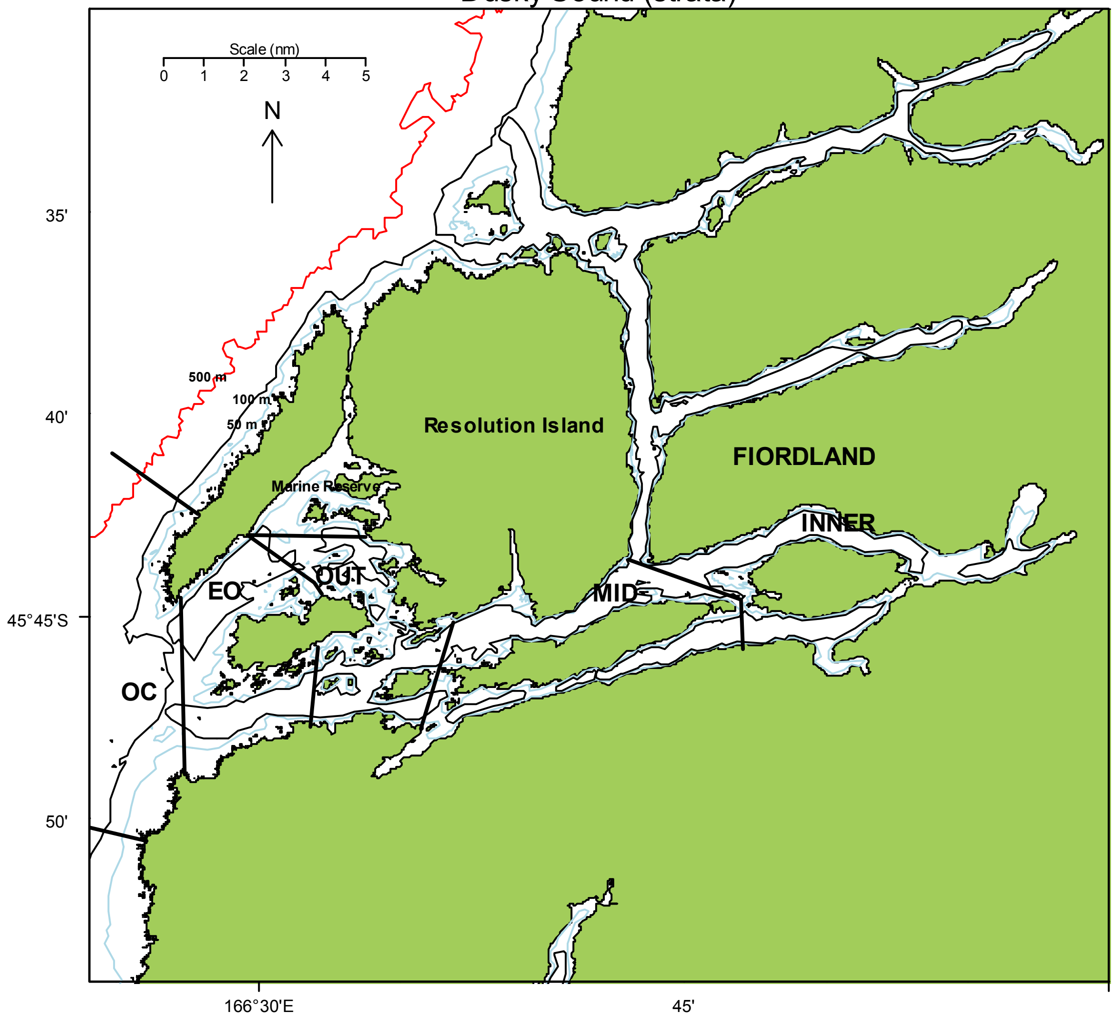

Figure 2: Map of Dusky Sound strata including the Marine Reserve. Depth contours are shown for 50 m, 100 m, and 500 m.

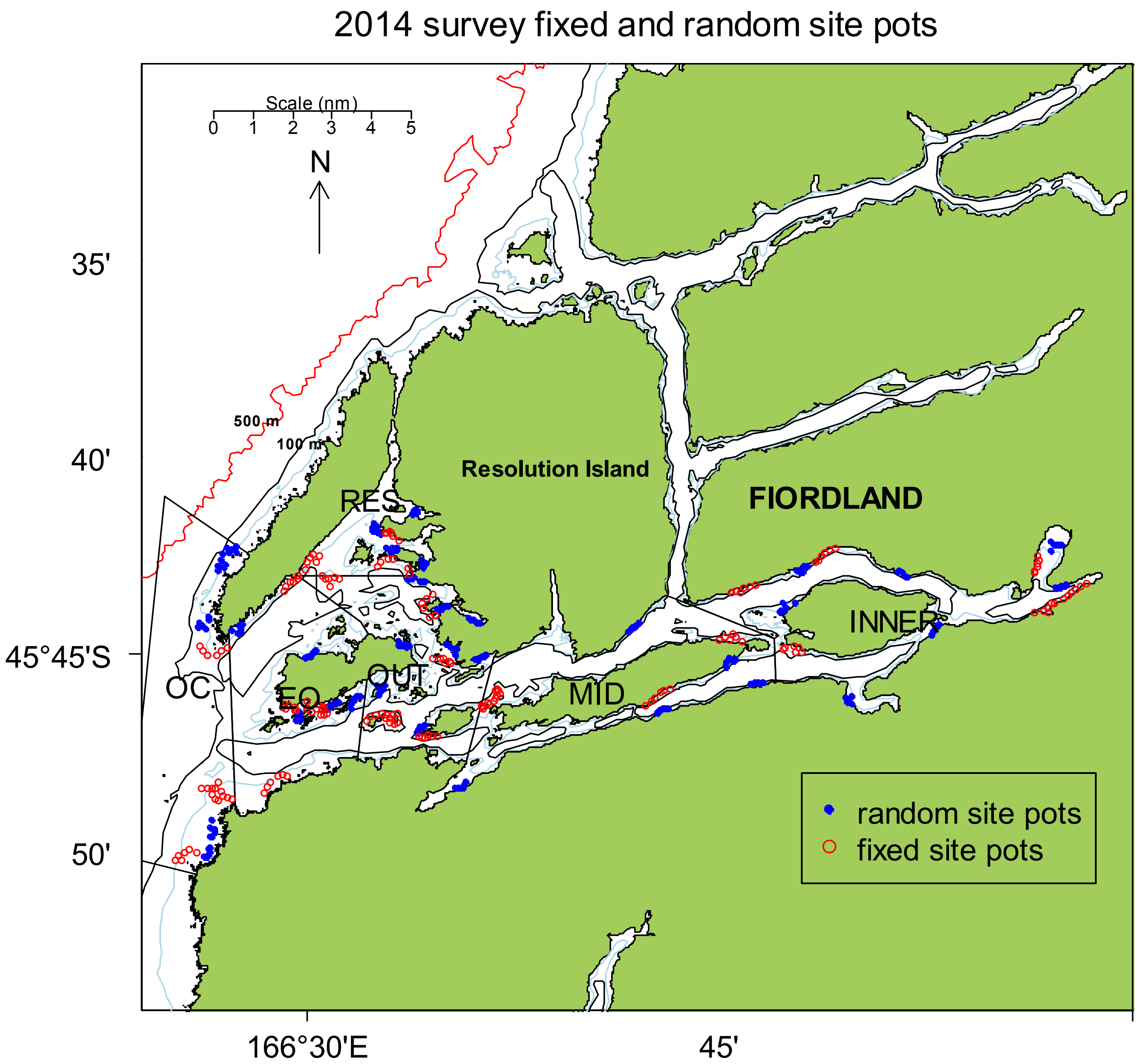

Figure 3: Map of Dusky Sound strata pot locations for the fixed and random sites surveys in 2014. Depth contours are shown for 50 m, 100 m, and 500 m.

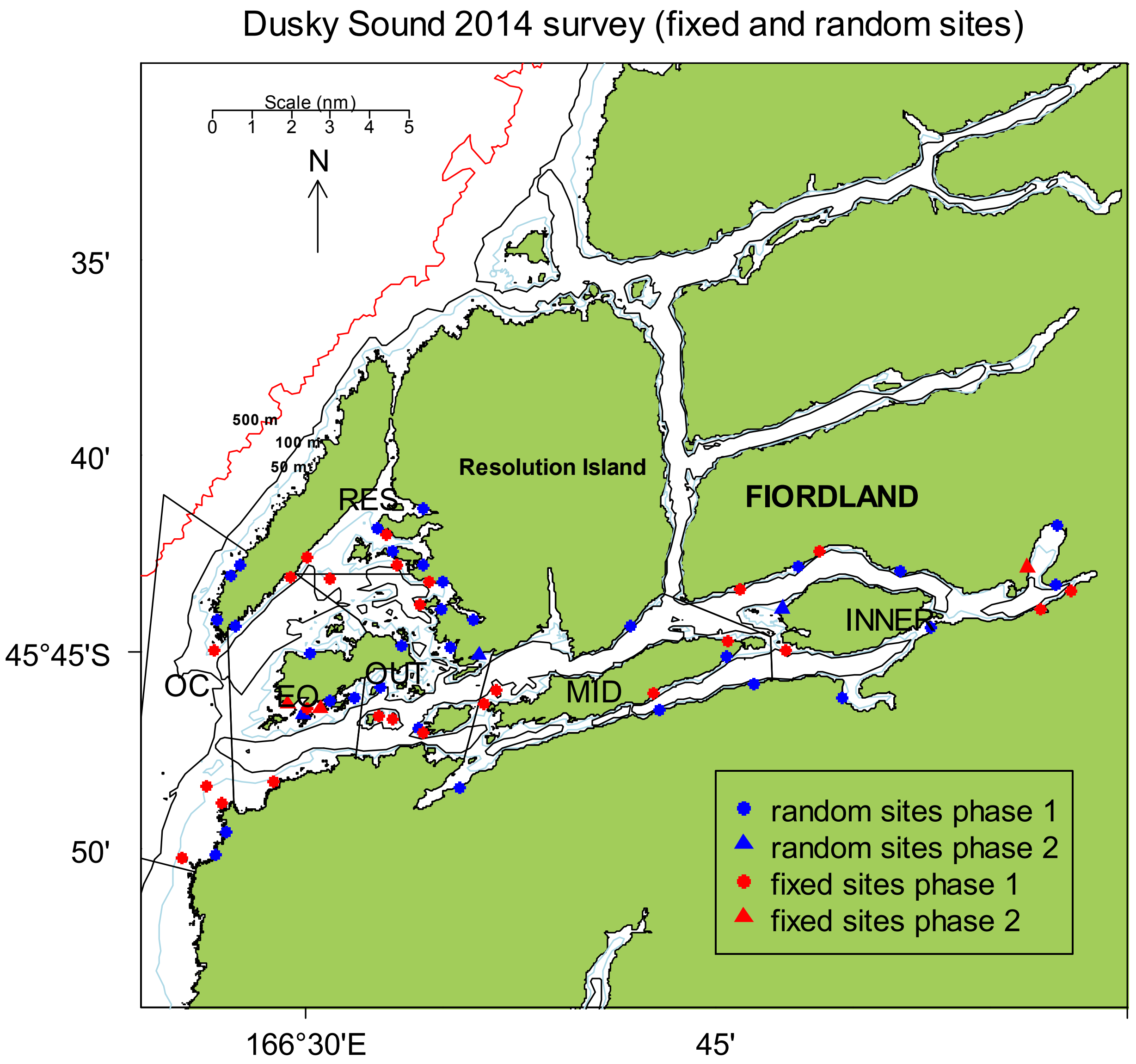

Figure 4: Map of Dusky Sound strata phase 1 and phase 2 sites for the fixed and random sites surveys in 2014. Depth contours are shown for 50 m, 100 m, and 500 m.

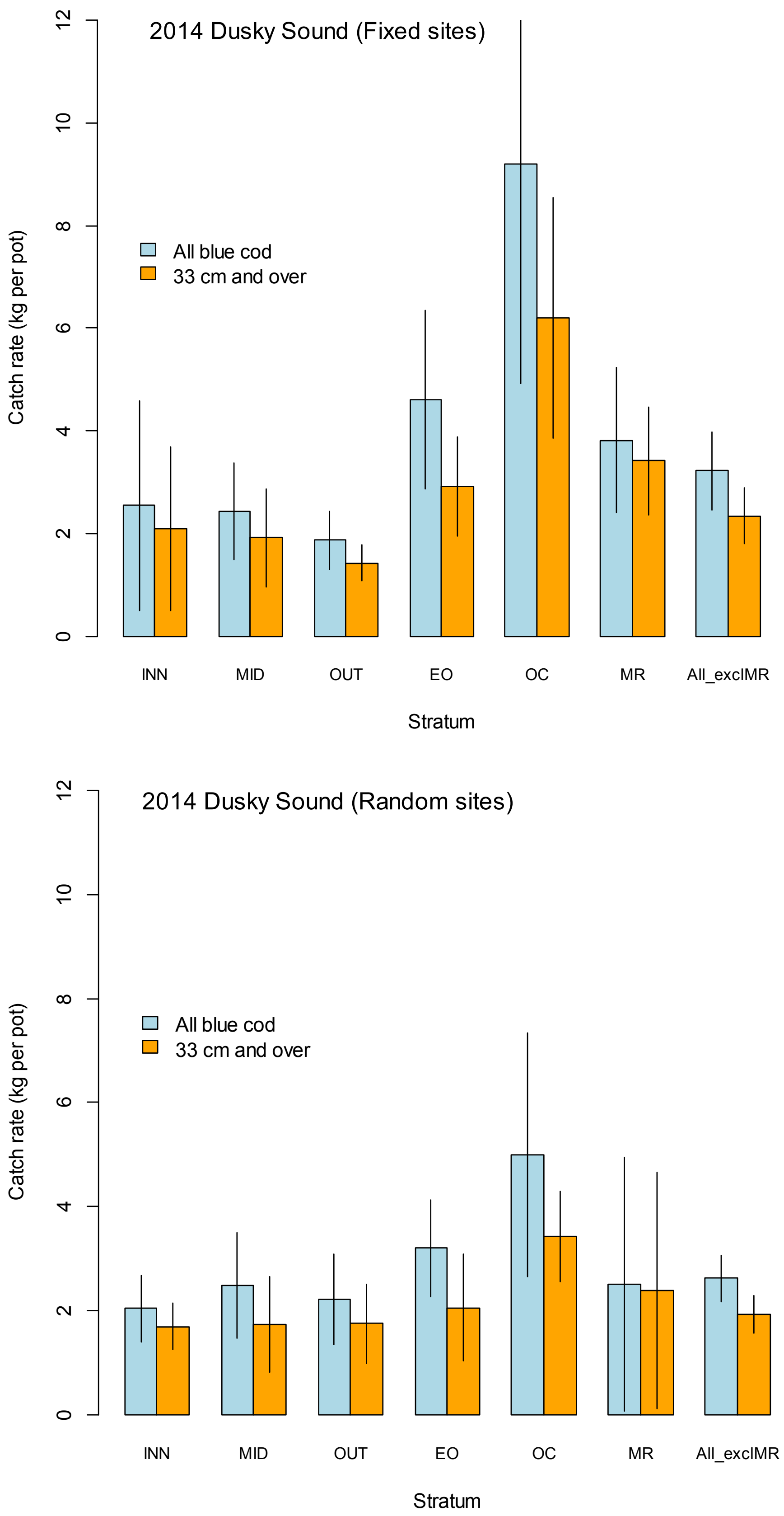

Figure 5: Catch rates (kg.pot^{-1}) of all blue cod and for recruited blue cod (33 cm and over) for the 2014 Dusky Sound fixed site (top panel) and random site (bottom panel) surveys. Error bars are 95% confidence intervals. See Figure 2 for location of strata. All_exclMR, overall survey catch rate excluding the Marine Reserve.

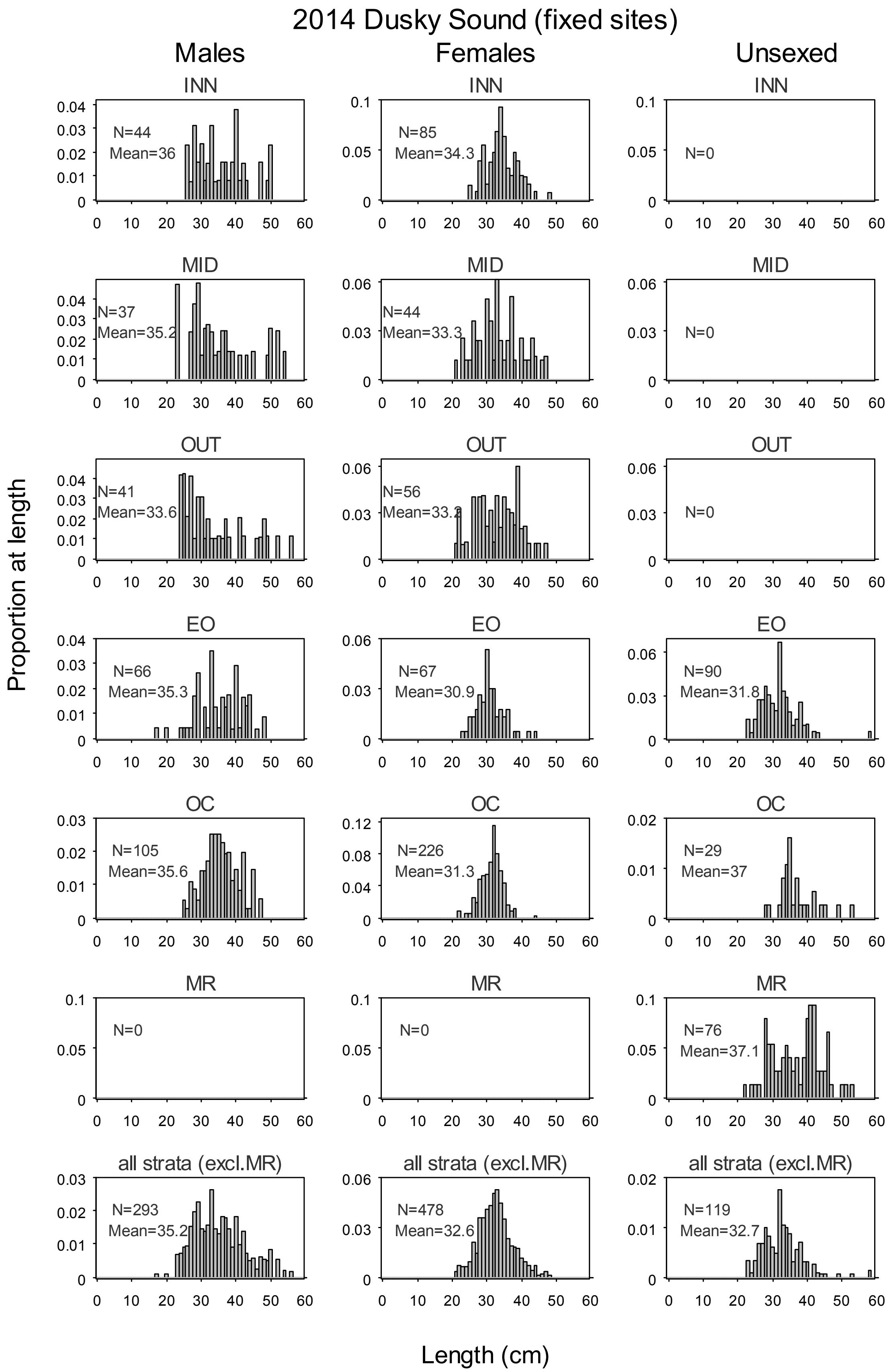

Figure 6: Scaled length frequency distributions by strata and overall for the 2014 Dusky Sound fixed site potting survey. excl.MR, excluding the Marine Reserve.

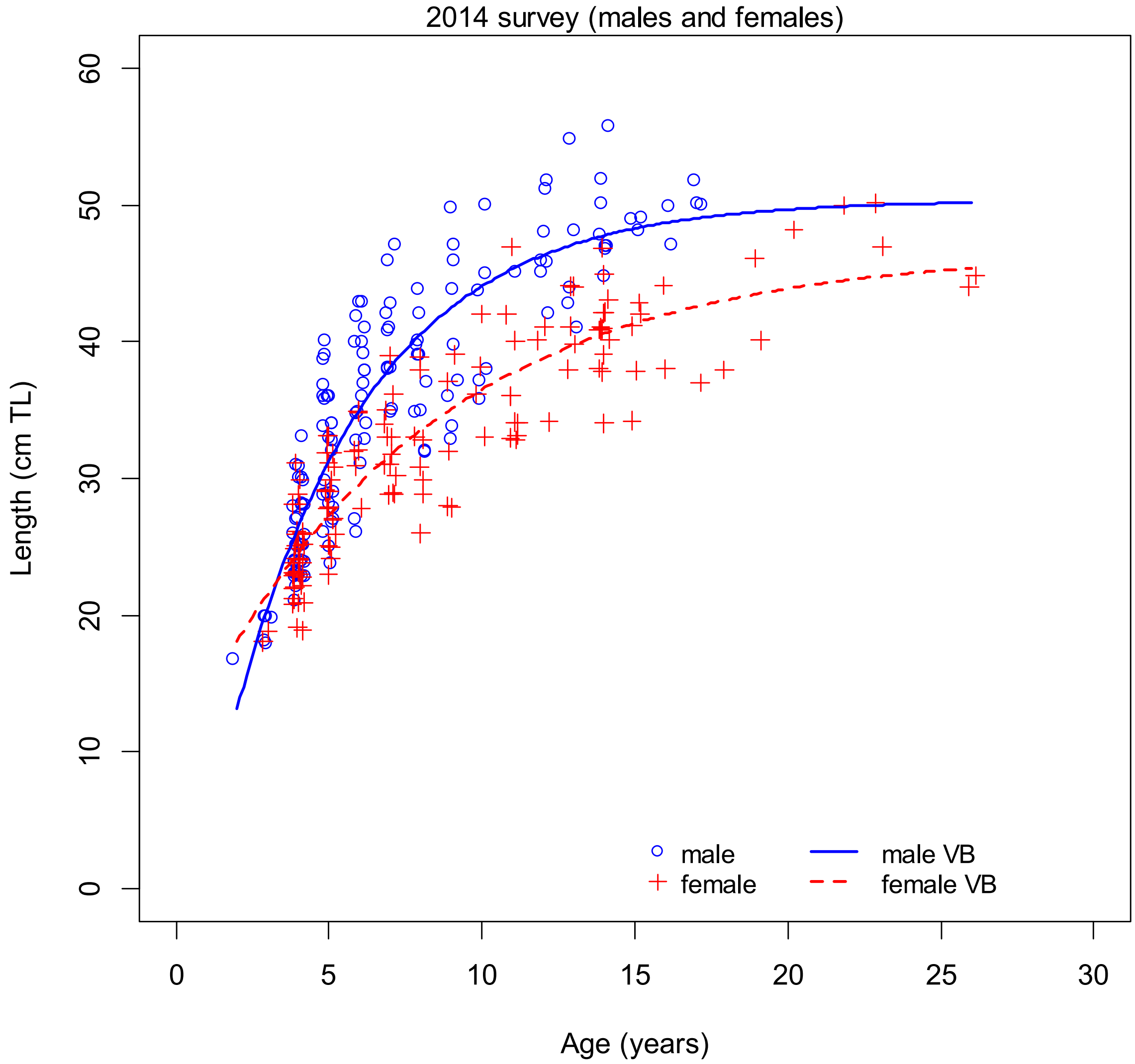

Figure 7: Observed blue cod age and length data by sex for the 2014 Dusky Sound survey with von Bertalanffy growth models fitted to the data. N= 150 males and 140 females. (see Section 2.1.8.7 Spawner-per-recruit, for von Bertalanffy parameters)

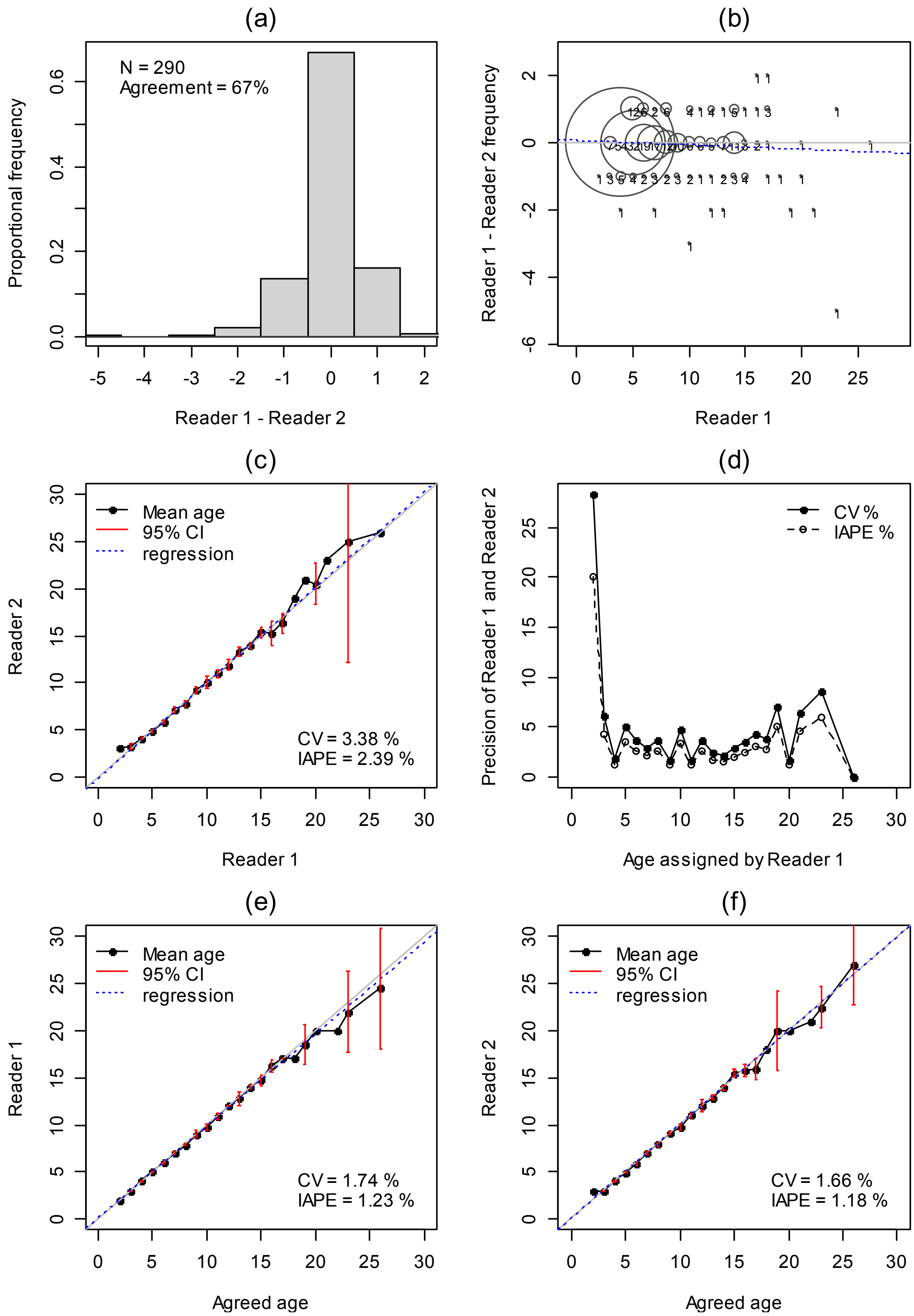

Figure 8: Blue cod age otolith reader comparison plots between reader 1 and reader 2 for the 2014 Dusky Sound survey: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age bin are annotated and proportional to circle size; (c) Age bias plot, showing the correspondence of ages between reader 1 and reader 2 for all ages; (e and f) reader age compared with agreed age. In panels b and c, solid lines show perfect agreement, dashed lines show the trend of a linear regression of the actual data.

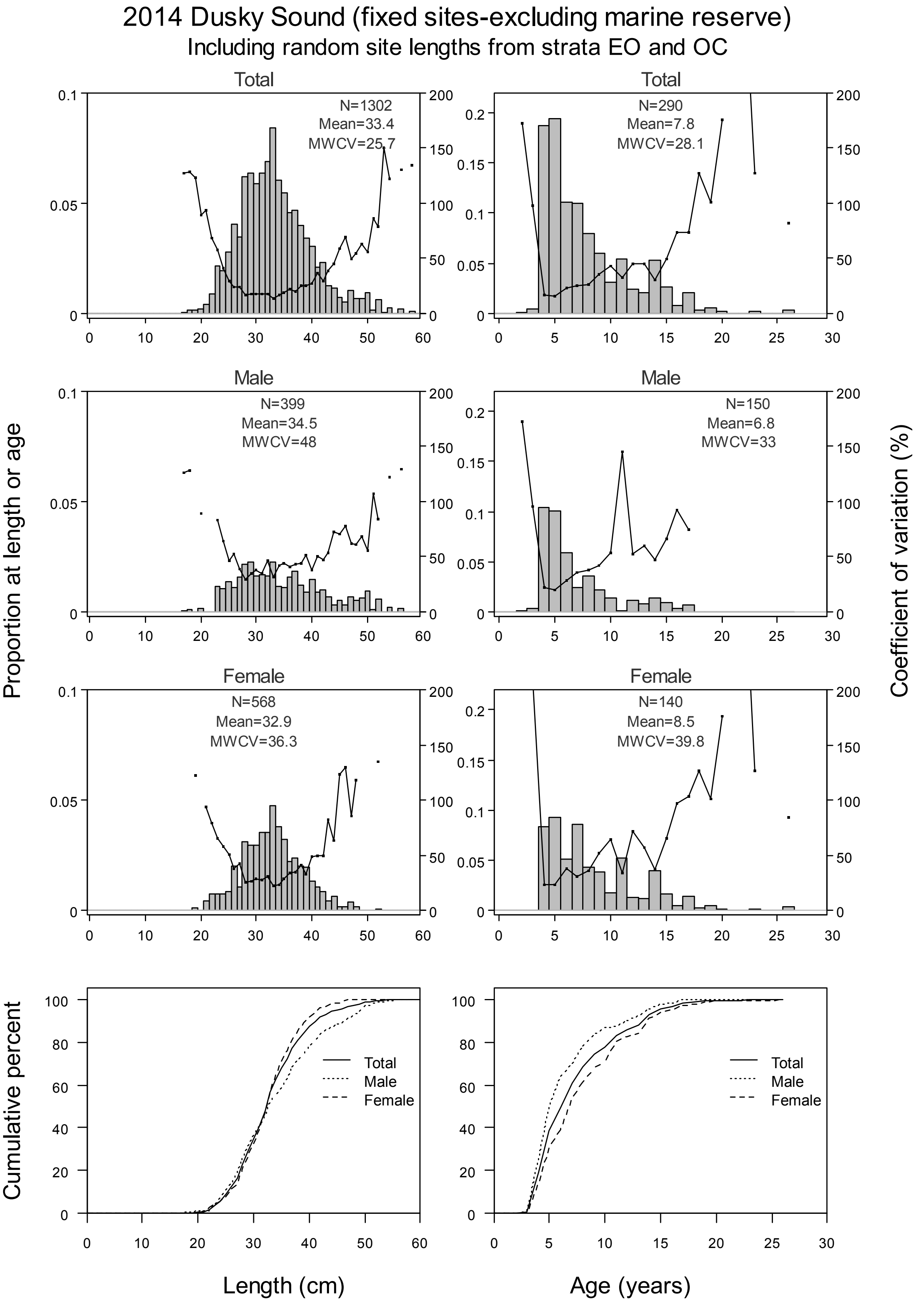

Figure 9: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2014 Dusky Sound fixed site blue cod potting survey (excluding the Marine Reserve), plus fish from random sites in strata EO and OC. N, sample size; MWCV, mean weighted coefficient of variation.

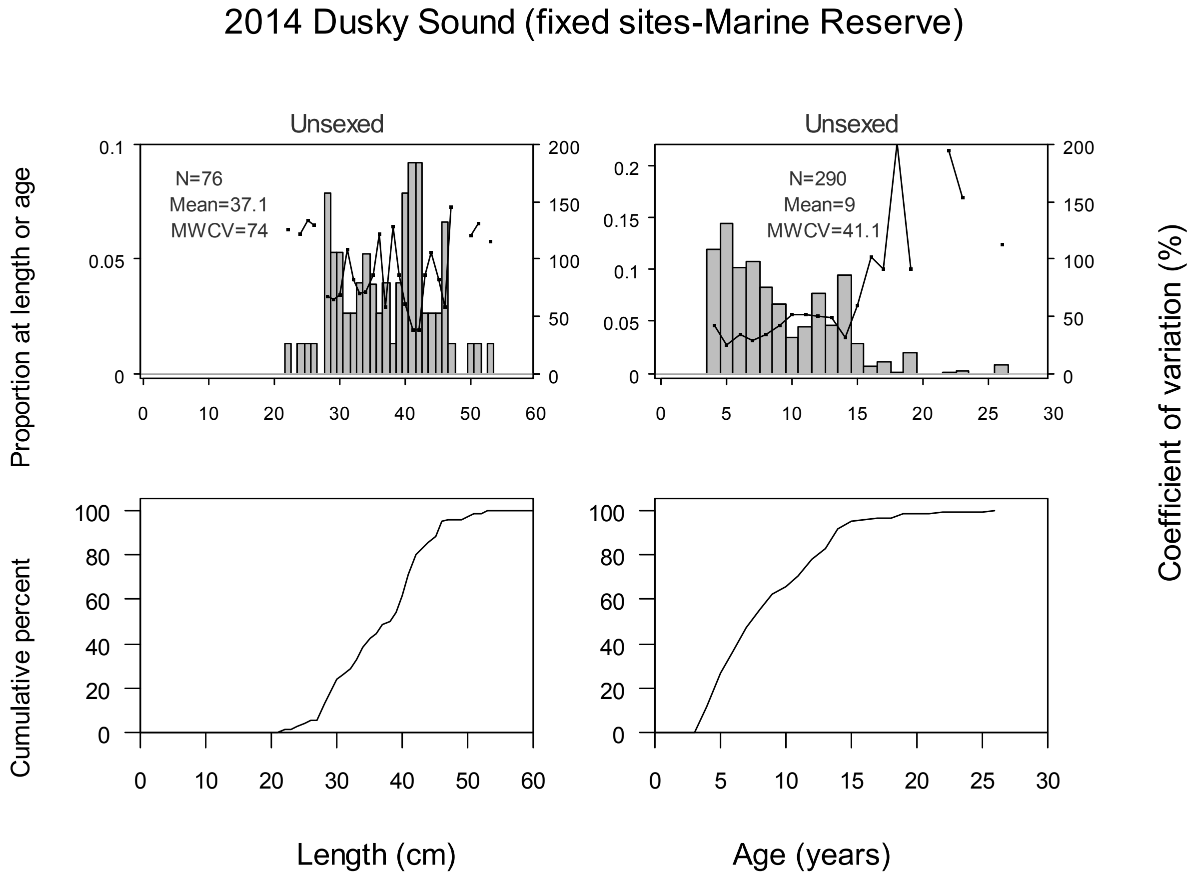

Figure 10: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2014 Dusky Sound fixed site blue cod potting survey inside the Marine Reserve. N, sample size; MWCV, mean weighted coefficient of variation.

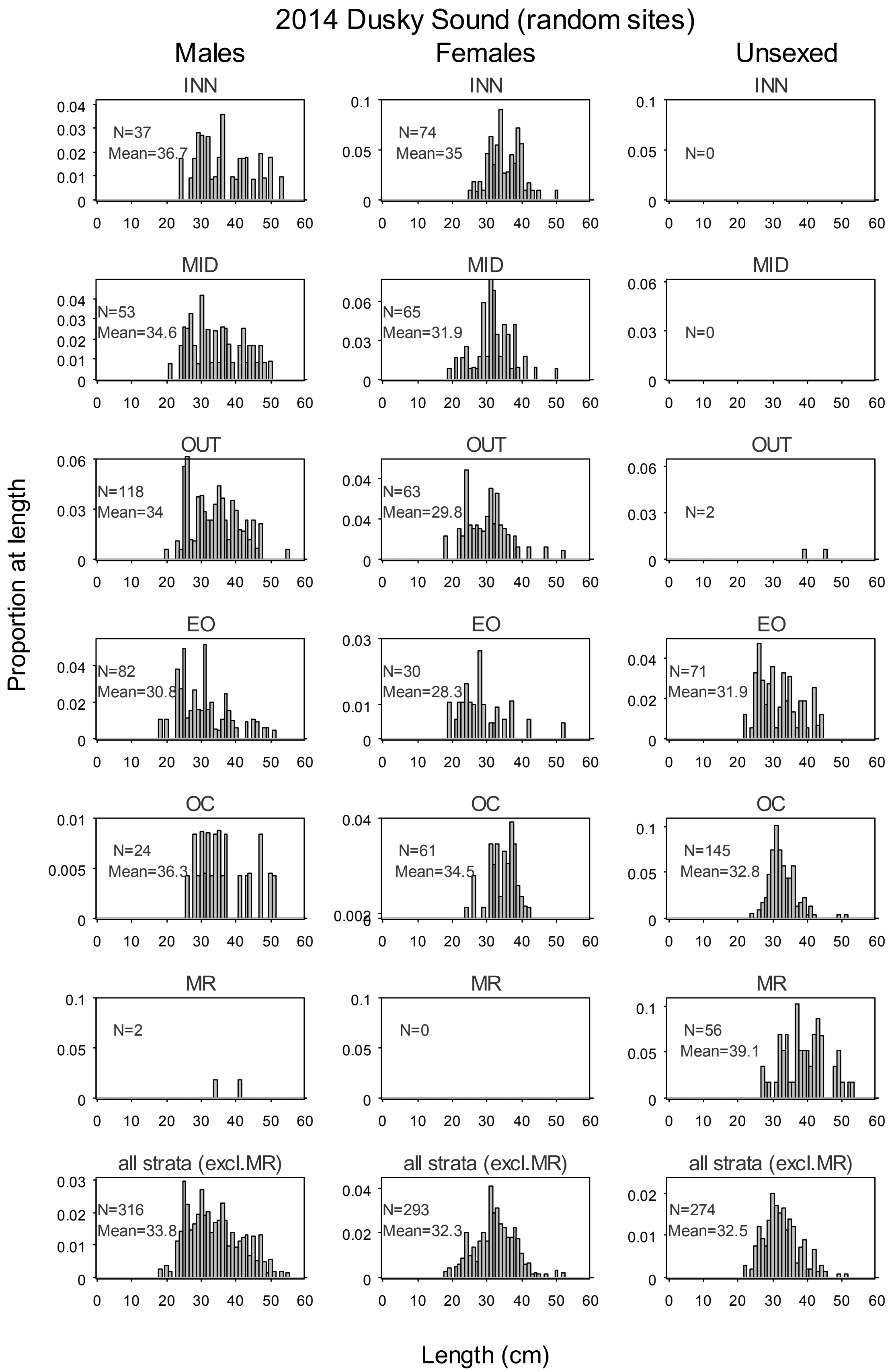

Figure 11: Scaled length frequency distributions by strata and overall for the 2014 Dusky Sound random site potting survey. excl.MR, excluding the Marine Reserve.

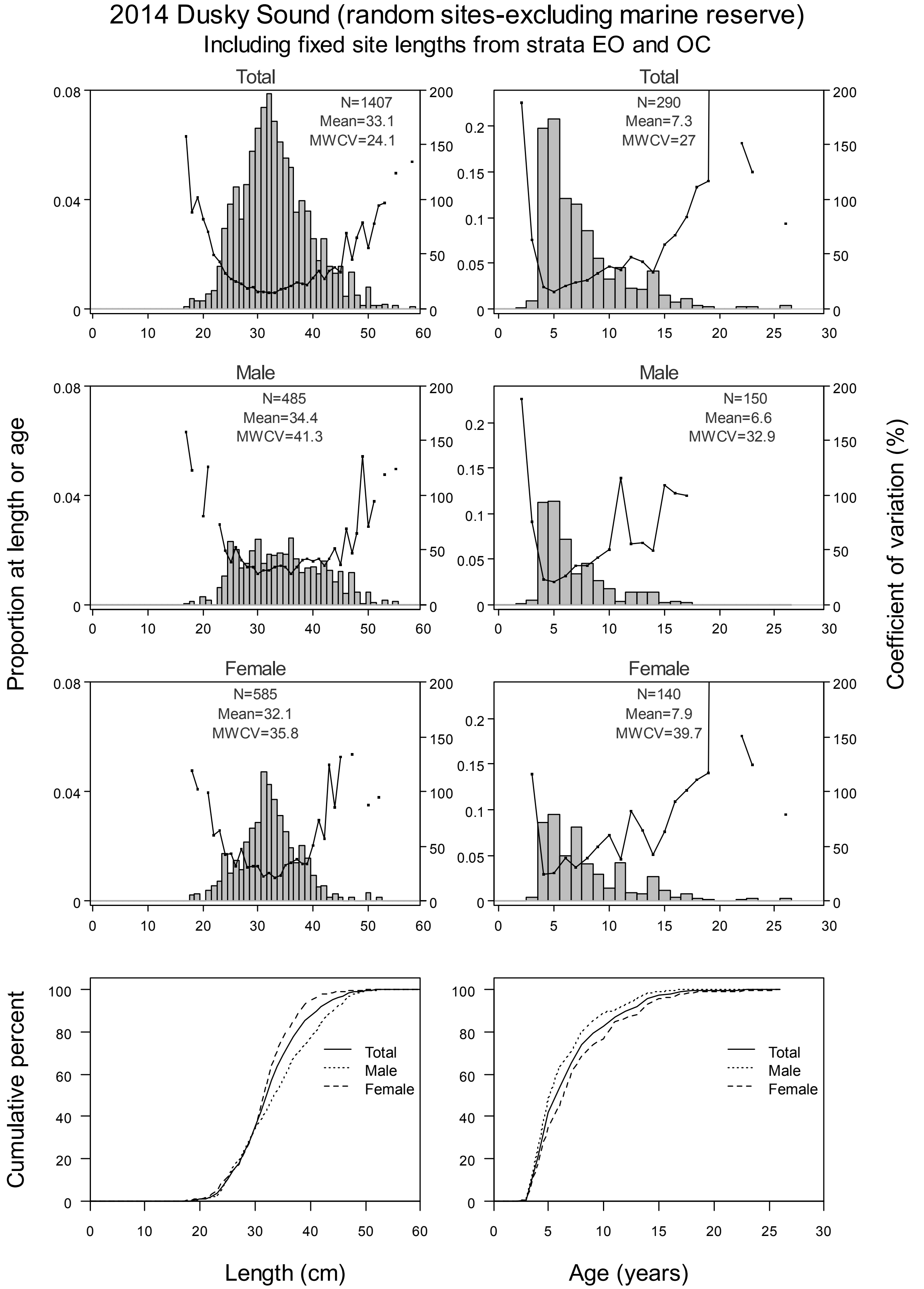

Figure 12: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2014 Dusky Sound random site blue cod potting survey (excluding the Marine Reserve), plus fish from fixed sites in strata EO and OC. N, sample size; MWCV, mean weighted coefficient of variation.

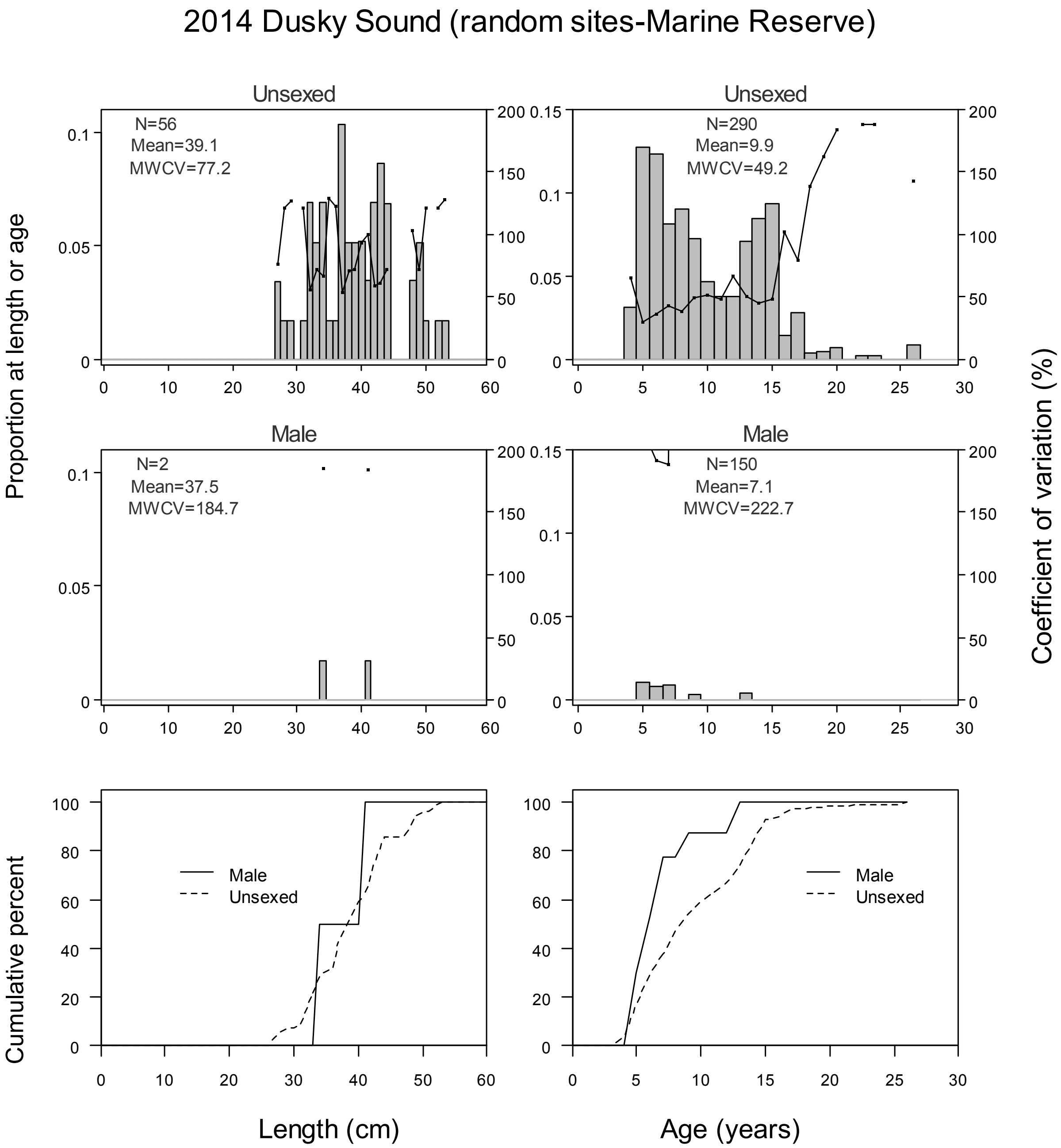

Figure 13: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata in the 2014 Dusky Sound random site blue cod potting survey inside the Marine Reserve. N, sample size; MWCV, mean weighted coefficient of variation.

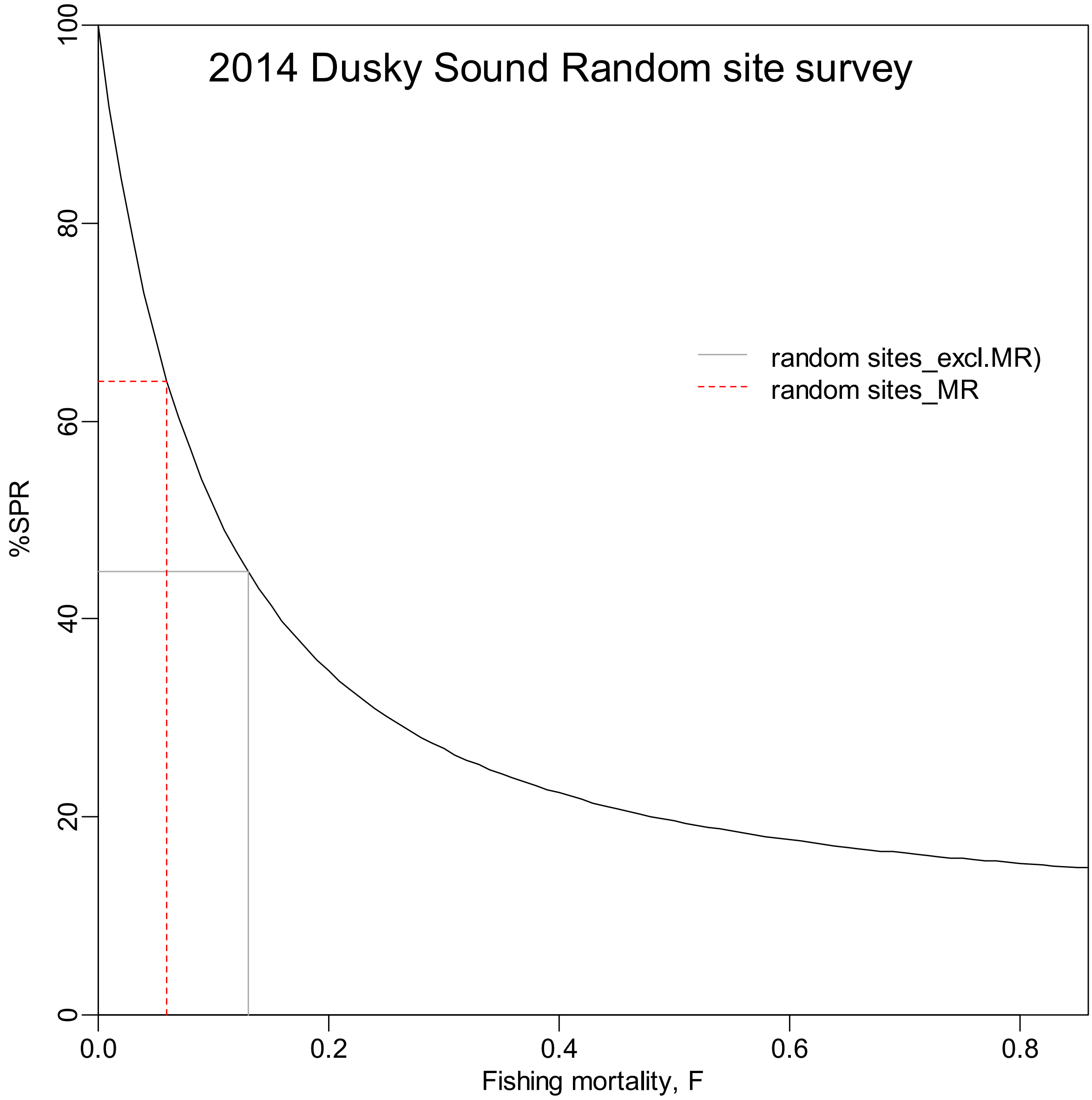

Figure 14: Spawner-per-recruit (SPR) as a function of fishing mortality (*F*) for 2014 Dusky Sound random blue cod potting survey. The %SPR (44.8%) corresponding to the *F* value of 0.13 is shown for sites outside the Marine Reserve (MR) and, as well as for the Marine Reserve (F =0.06, %SPR = 64%). In this plot *M* = 0.14, and *F* value is for age of full recruitment equal to 8 years for females.

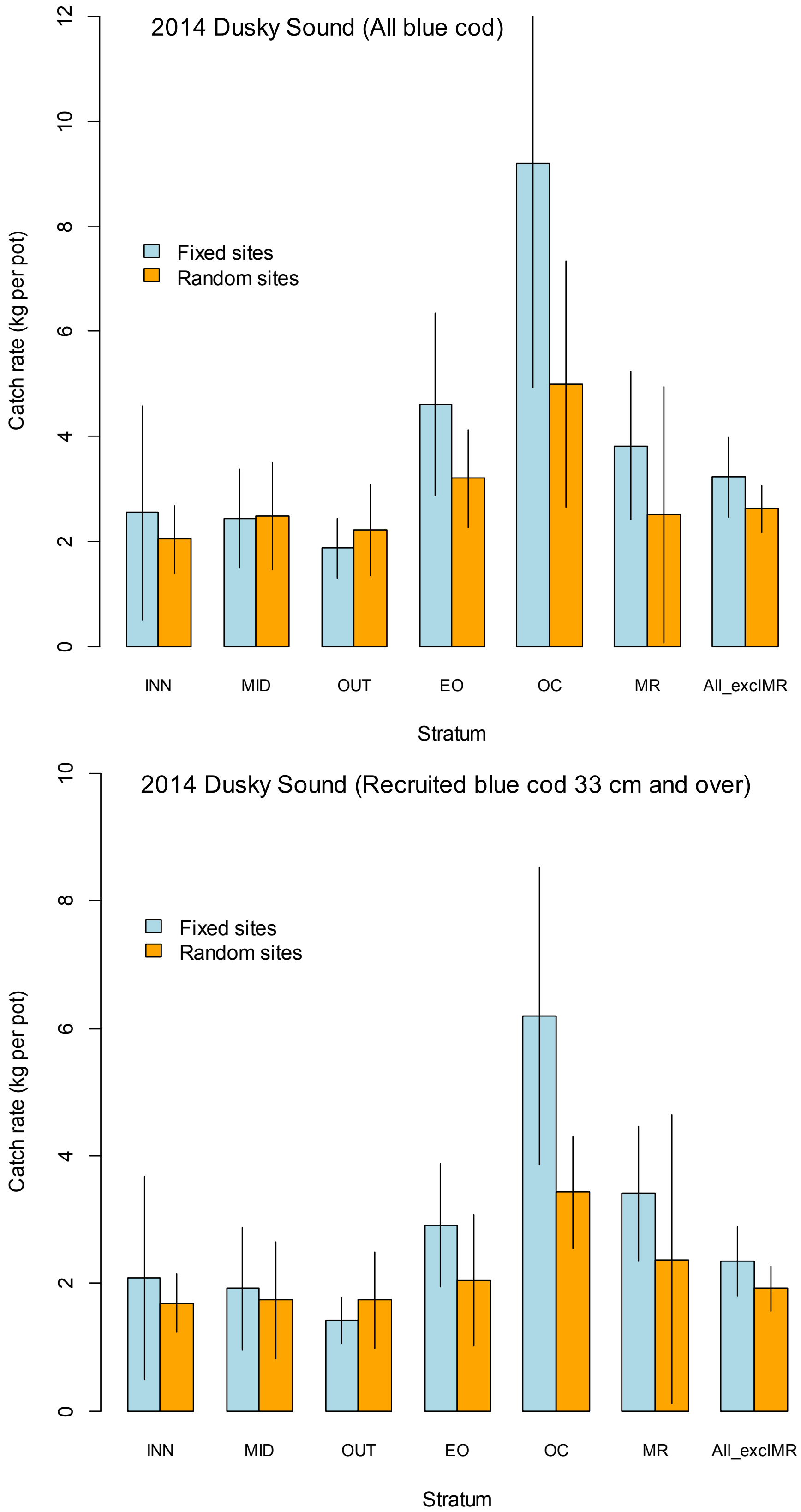

Figure 15: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and for recruited blue cod (33 cm and over) (bottom panel) for the 2014 Dusky Sound fixed and random site surveys. Error bars are 95% confidence intervals. See Figure 2 for location of strata. All_exclMR, overall survey catch rate excluding the Marine Reserve.

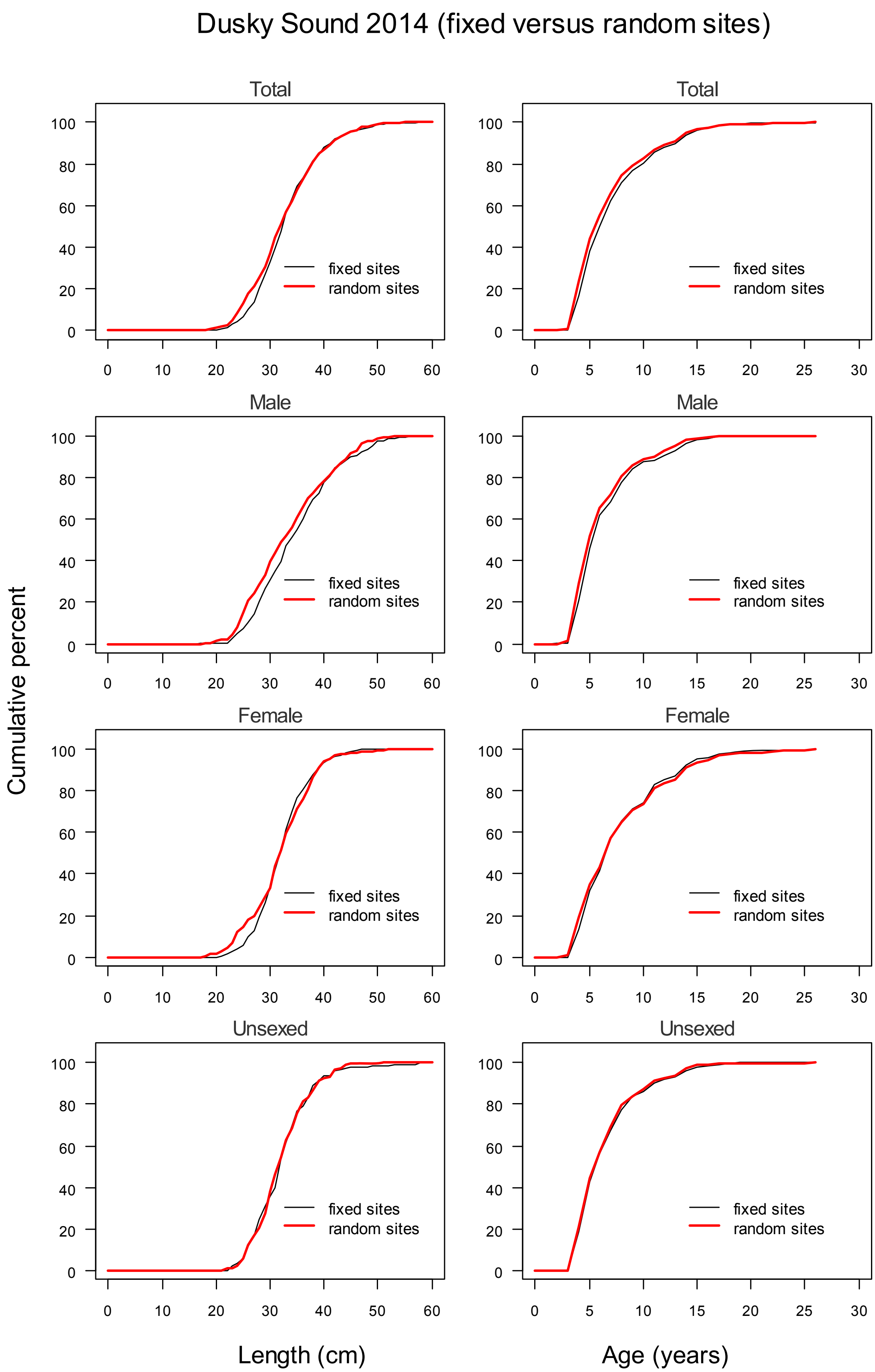

Figure 16: Cumulative distributions of scaled length and age frequencies for total, male, female, and unsexed blue cod from the 2014 Dusky Sound blue cod fixed site and random site potting surveys (excludes Marine Reserve fish). Numbers of measured fish were: Fixed sites – 293 males, 478 females and 195 unsexed; Random sites – 316 males, 293 females and 274 unsexed (See Table 4).

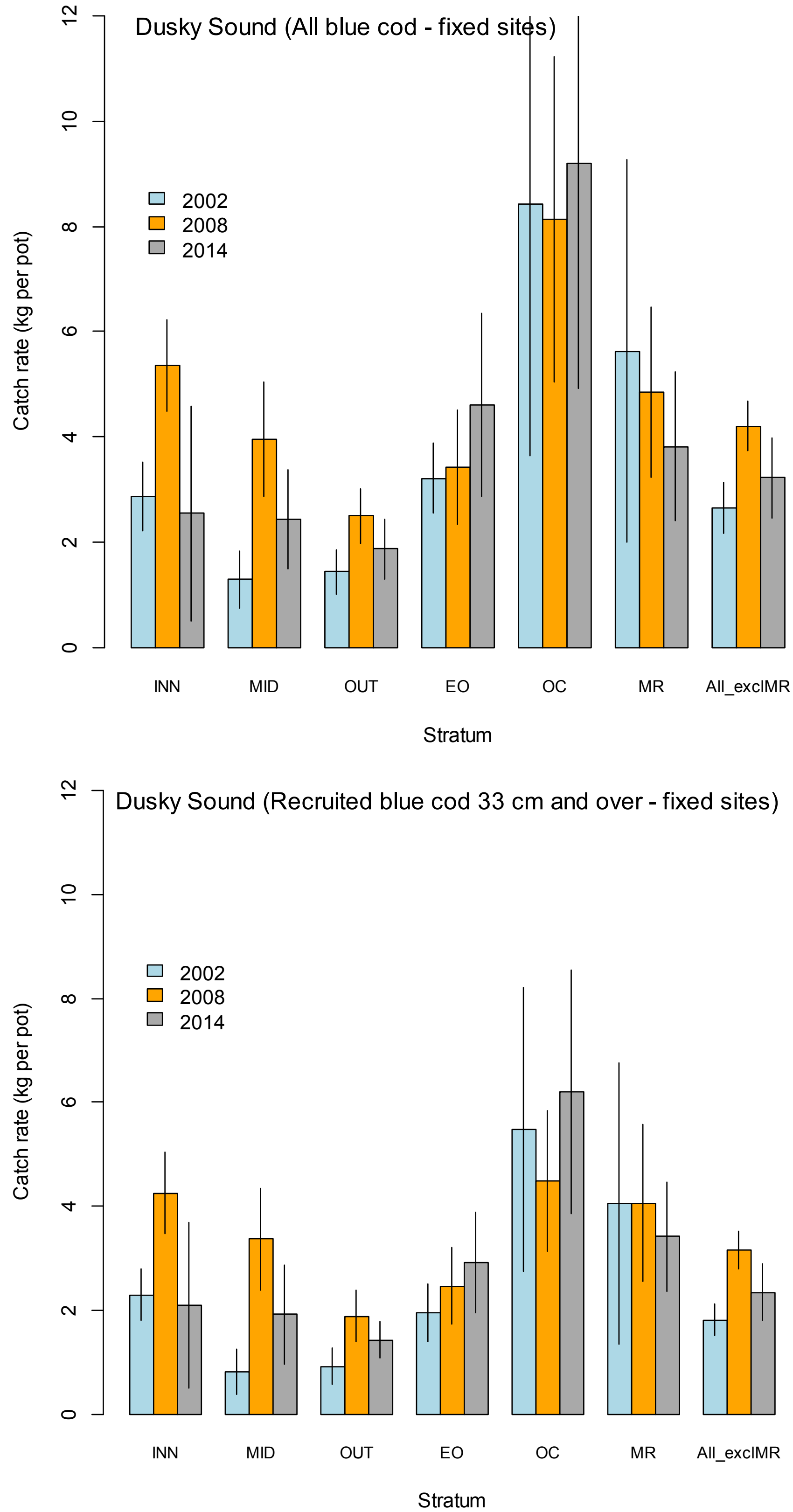

Figure 17: Catch rates (kg.pot^{-1}) of all blue cod (top panel) and for recruited blue cod (33 cm and over) (bottom panel) for the Dusky Sound fixed site potting surveys in 2002, 2008 and 2014. Error bars are 95% confidence intervals. See Figure 2 for location of strata. All_exclMR, overall survey catch rate excluding the Marine Reserve.

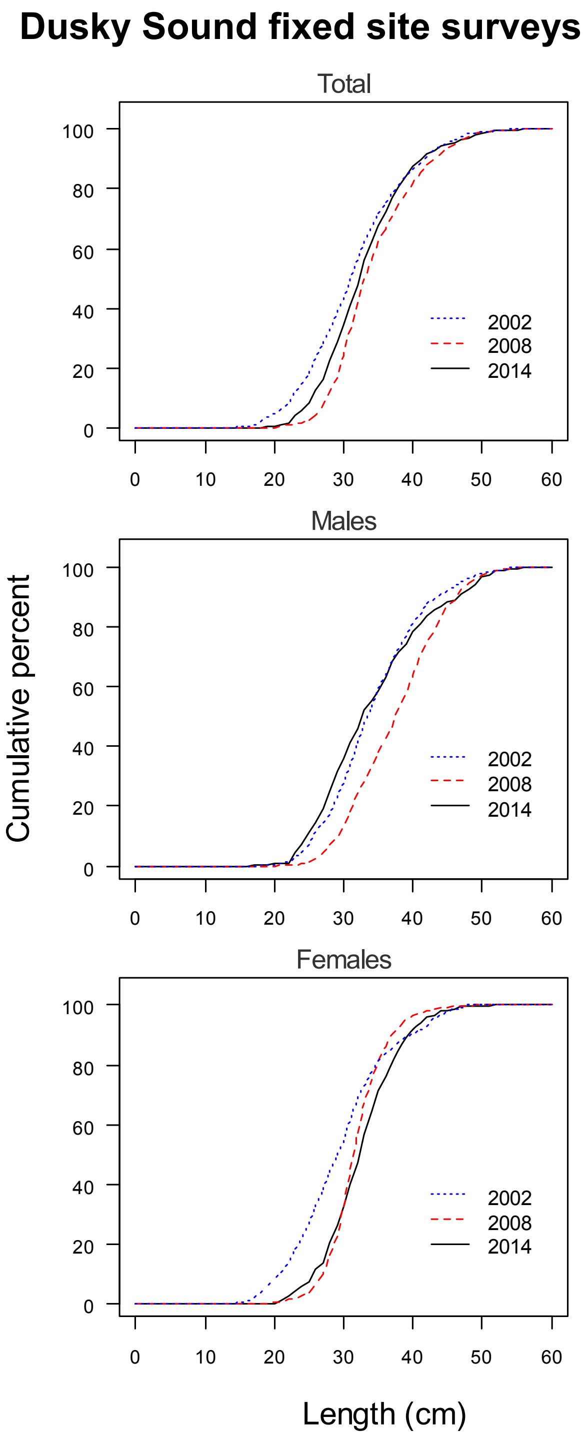

Figure 18: Cumulative distributions of scaled length and age frequencies for total, male, and female blue cod from Dusky Sound fixed site blue cod potting surveys in 2002, 2008, and 2014, excluding the Marine Reserve. The 2014 length and age plots include fish from random sites in strata EO and OC.

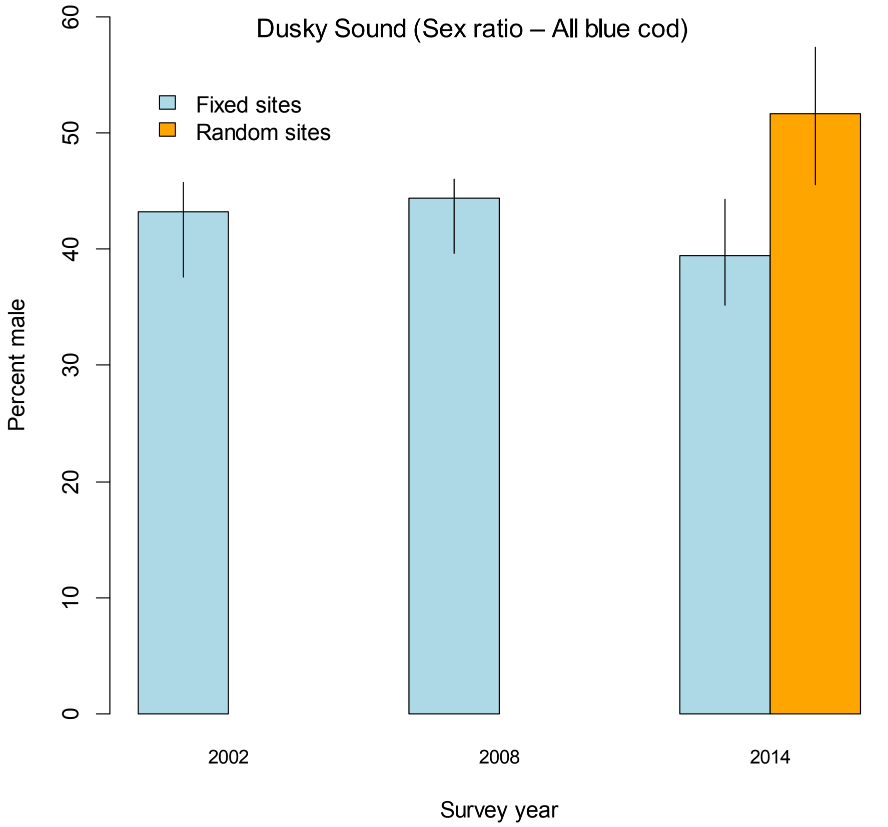

Figure 19: Sex ratio (percent male) of scaled length frequencies of all blue cod for Dusky Sound fixed site blue cod potting surveys in 2002, 2008, and 2014, and the random site survey in 2014. Error bars are 95% confidence intervals.

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

Fixed site	A site that has a fixed location (single latitude and longitude or the centre point location of a section of coastline) in a stratum and is available to be used repeatedly on subsequent surveys in that area. The fixed sites used in a particular survey are randomly selected from the list of all available fixed sites in each stratum. Fixed sites are sometimes referred to as index sites or fisher-defined sites and were defined at the start of the survey time series (using information from recreational and commercial fishers)
Pot number	Pots are numbered sequentially (1 to 6 or 1 to 9) in the order they are placed during a set. In the Marlborough Sounds nine pots are used.
Pot placement	There are two types of pot placement: **Directed**–the position of each pot is directed by the skipper using local knowledge and the vessel SONAR to locate a suitable area of reef/cobble or biogenic habitat. **Systematic**–the position of each pot is arranged systematically around the site or along the site for a section of coastline. For the former site, the position of the first pot is set 300 m to the north of the site location and remaining pots are set in a hexagon pattern around the site, at about 300 m from the site position.
Random site	A site that has the location (single latitude and longitude) generated randomly within a stratum, given the constraints of proximity to other selected sites for a specific survey.
Site	A geographical location near to which sampling may take place during a survey. A site may be either fixed or random (see below). A site may be specified as a latitude and longitude or a section of coastline (for the latter, use the latitude and longitude at the centre of the section).
Site label	An alphanumeric label of no more than four characters, unique within a survey time series. A site label identifies each fixed site and also specifies which stratum it lies in. Site labels are constructed by concatenating the stratum code with an alpha label (A–Z) that is unique within that stratum. Thus, sites within stratum 2 could be labelled 2A, 2B, and sites in stratum 3 could be labelled 3A, 3B etc. Site labels for random sites are constructed in the same way but prefixed with R (e.g., R4A, R4B etc).
Station	The position (latitude and longitude) at which a single pot (or other fishing gear such as ADCP) is deployed at a site during a survey, i.e., it is unique for the trip.
Station number	A number which uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be *station_no* 234. This convention is important in enabling users of the *trawl* database to determine whether two pots are from the same set. Note that the set numbers for potting surveys are not recorded anywhere else in the *trawl* database.

Appendix 2. Numbers of otoliths collected during the 2014 Dusky Sound survey for males and females, by strata and length class. Lgth, length.

	Males						Females					
	Strata						Strata					
Lgth (cm)	EO	INN	MID	OC	OUT	Male totals	EO	INN	MID	OC	OUT	Female totals
17	1					1						
18	2					2					1	1
19							2		1			3
20	3					3						
21			1			1	1		2		1	4
22			1			1	1				2	3
23	3		2		2	7	2		4		2	8
24	1	2	1		3	7	2		2	1	1	6
25	2				4	6	2	1	1	1	1	6
26	1	1	2			4		1	2	2	1	6
27		1	1	2	2	6	1			1		2
28	2	2	2	1		7	1		2	1	3	7
29		1	1	1		3	1	2	3	1	1	8
30	1	1	1		2	5			2	2		4
31	3					3	2	1		2	2	7
32			1	1	1	3	2	1	1	2		6
33		2		2	2	6		3	2	3	2	10
34	2		2	1		5		4	1	1		6
35		1		3	2	6	1	1		1	1	4
36	2	1	2	1	1	7			1	1	2	4
37	1	1		2	1	5	1		2			3
38	4			2	1	7		3	2	2	1	8
39	2		1		1	5				2	2	4
40	3	3				6		2	2	1		5
41	1		1	2		4		1	3	1	2	7
42	1	1	1	1		4	1	2		1	2	6
43		1	1	1	2	5		1	1			2
44	1		2	1		4			2	1	1	4
45	1	1	2			4		1			1	2
46	1		1		2	4			1			1
47		3	1	1	1	6			1		2	3
48	1	1	1		1	4		1				1
49	1	1			1	3						
50		4	1	1		6		1	1			2
51				1		1						
52			2		1	3						
53												
54												
55					1	1						
56					1	1						
Totals	40	28	31	24	32	155	20	26	39	27	31	143

Appendix 3: Mean catch rates for all blue cod, and recruited blue cod (33 cm and over) caught from the 2002 and 2008 Dusky Sound fixed site and random site potting surveys. Catch rates are pot-based, and s.e. and CV are set-based. See Table 1 for stratum names. s.e., standard error; CV coefficient of variation; Incl., including; excl., excluding. There was no Marine Reserve in 2002 and estimates for MR stratum in 2002 are for sites that were in the MR strata established in 2005.

			2002 fixed site survey					
			All blue cod			Recruited blue cod		
Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
INN	Fixed	48	2.87	0.34	11.7	2.30	0.25	10.9
MID	Fixed	48	1.29	0.28	21.8	0.81	0.22	27.4
MR	Fixed	24	5.63	1.86	33.0	4.05	1.38	34.0
OUT	Fixed	60	1.43	0.22	15.3	0.92	0.18	19.1
EO	Fixed	48	3.22	0.34	10.6	1.95	0.28	14.4
OC	Fixed	36	8.43	2.44	29.0	5.48	1.39	25.4
Overall (incl. MR)	Fixed	264	2.85	0.26	9.1	1.96	0.17	8.8
Overall (excl. MR)	Fixed	240	2.65	0.25	9.2	1.81	0.16	8.7

			2008 fixed site survey					
			All blue cod			Recruited blue cod		
Stratum	Site type	Pot lifts (N)	Catch rate (kg.pot^{-1})	s.e.	CV (%)	Catch rate (kg.pot^{-1})	s.e.	CV (%)
INN	Fixed	78	5.35	0.44	8.3	4.25	0.40	9.4
MID	Fixed	54	3.96	0.55	14.0	3.36	0.50	14.8
MR	Fixed	48	4.85	0.82	17.0	4.06	0.77	18.9
OUT	Fixed	48	2.50	0.26	10.5	1.88	0.25	13.3
EO	Fixed	48	3.43	0.56	16.3	2.46	0.38	15.2
OC	Fixed	48	8.13	1.57	19.4	4.48	0.69	15.5
Overall (incl. MR)	Fixed	324	4.25	0.23	5.5	3.21	0.18	5.7
Overall (excl. MR)	Fixed	276	4.20	0.24	5.8	3.15	0.19	5.9

Appendix 4: Weighted mean length and age, and weighted sex ratio for the 2002 and 2008 Dusky Sound fixed site potting surveys for all blue cod. m, male; f, female; u, unsexed. (data from Beentjes 2012).

Survey area	Year	Site type	Sex	*N*	Mean length (cm)	Mean age (years)	Percent male
Dusky Sound	2002	Fixed	m	657	34.7	7.7	43
			f	840	29.9	7.0	
			All	1497	32.0	7.3	
Dusky Sound (excl.MR)	2008	Fixed	m	773	37.9	10.1	44
			f	1149	32.2	7.9	
			All	1922	34.8	8.9	
Dusky Sound Marine Reserve	2008		U	285	35.9	9.6	–