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Relative abundance, population structure, and stock status of blue cod in the Foveaux Strait in 2014. Experimental evaluation of pot catchability and size selectivity.

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This report describes the results of the 2014 Foveaux Strait blue cod (*Parapercis colias*) potting survey. This is the second fully random site allocation potting survey to be undertaken in the time series for Foveaux Strait. An experimental evaluation of size selectivity and catchability of survey pots was also done at the conclusion of the 2014 survey.

The 2014 potting survey used a two-phase stratified random site design with six sites per stratum randomly allocated for phase 1. Between 11 February and 17 March 2014, 53 potting sites were surveyed (6 pots per site = 318 pot lifts) from 8 strata throughout Foveaux Strait. During phase 1, 288 pot lifts were completed (91%) with 30 in phase 2. The total blue cod catch was 2888 kg, consisting of 6668 blue cod. Most fish had gonads in the early maturing stages with some running ripe and spent, indicating the survey was at the latter stage of spawning.

Stratum catch rates for blue cod of all sizes ranged from 0.3 to 16.2 kg per pot (per hour) with an overall mean catch rate of 7.6 kg per pot and coefficient of variation (CV) of 11.6%. Stratum catch rates of legal-sized blue cod (33 cm and over) ranged from 0.2 to 6.5 kg per pot, with an overall mean catch rate of 3.1 kg per pot and a CV of 8.5%. Catch rates were highest in the western entrance of Foveaux Strait and off the northern coast of Stewart Island, and lowest in the large sandy area of the eastern stratum surrounding Ruapuke the North Islands. Thirty-one percent of blue cod caught exceeded the minimum legal size (MLS = 33 cm and over).

Total length ranged from 9 to 46 cm. Length-frequency distributions using raw data show that strata had similar size structures with few blue cod over 40 cm. Males were larger than females in all strata and overall mean length was 30.4 cm for males and 27.9 cm for females. Overall sex ratio for all fish was 1:1.1 (M:F), but skewed in favour of males (1:0.3) for legal-sized fish. Otoliths were prepared and read for 116 males and 106 females, these were then used to construct age-length keys applied to the scaled length-frequency distributions to estimate the population age structure for each sex. Age ranged from 0 to 14 years, but most fish were between 4 and 6 years for males and 3 and 7 years for females. Mean age was 5.3 years for males and 5.4 years for females. Total mortality estimates (Z) for age at recruitment from 5 to 9 years ranged between 0.59 and 0.87, respectively.

The 2014 Foveaux Strait survey spawner (biomass) per recruit (SPR) using the default M value of 0.14 was $F_{20\%}$, indicating that at the current level of fishing mortality the expected contribution to the spawning biomass over the lifetime of an average recruit has been reduced to 20% of the contribution in the absence of fishing. This level of exploitation (F) is well below the Ministry for Primary Industries target reference point of $F_{45\%}$ for blue cod, and indicates that the current level of fishing is too high for this stock.

Survey comparison

Since the initial random site potting survey of Foveaux Strait in 2010 (56 sites, 336 pot lifts) the overall catch rates for all and legal-sized blue cod had increased by 77% and 67%, respectively, in the 2014 survey. There was an increase in catch rates over almost the entire survey area (apart from the north-eastern coast of Stewart Island). The overall increase in catch rates was driven by the central Foveaux Strait stratum, the western Foveaux Strait strata, and the eastern strata. The overall CVs for the 2014 survey catch rates were marginally higher than the overall CVs from the 2010 survey.

The percent of blue cod caught that exceeded the MLS in the 2014 survey (31%) had increased 5% since the 2010 survey (26%). However, the maximum size of blue cod (46 cm) had reduced by 10 cm

since the 2010 survey (56 cm) with proportionately fewer fish over 45 cm caught in the 2014 survey. Overall mean length and sex ratio for all fish remained stable between the 2010 and 2014 surveys, although the sex ratio of legal-sized fish had become more skewed towards males in 2014.

The age range was reduced by 14 years in the 2014 survey (0–14 years), however, a change in ageing protocols between the 2010 and 2014 surveys prevents comparisons of age. In 2014 an allowance was made for a juvenile check in the otolith that was previously counted as the first annuli for the 2010 survey, which largely explains the decline in mean age by 1.8 years for males and 1.5 years for females between the surveys. However, a doubling of *Z* estimates between surveys was predominantly driven by a marked reduction in the proportion of older fish in the 2014 survey (over 8 years). The SPR ($M = 0.14$) subsequently reduced by 15% between surveys to a level ($F_{20\%}$) that suggests fishing pressure continues to be too high in Foveaux Strait.

Catchability and size selectivity of survey pots

At eight selected sites, five flown drop underwater video (DUV) transects were conducted immediately prior to setting type 1 (n = 3) and type 2 (n = 3) pots for comparisons of size selectivity and catchability. The DUV system surveyed a total area of 95 577 m^2, and 1555 blue cod (5–46 cm) were recorded. Type 1 pots subsequently caught 531 blue cod (20–43 cm), and type 2 pots caught 960 blue cod (11–44 cm). Both caught similar numbers of fish over 30 cm, but type 1 pots caught very few below 27 cm. Compared to the DUV, the type 1 pots had proportionately more blue cod over 28 cm and fewer under 26 cm, while type 2 pots caught proportionately more blue cod over 25 cm and fewer under 22 cm.

The estimated density of blue cod from video transects had a stronger relationship with both type 1 and type 2 pot catches of blue cod in the current experimental study, suggesting that fishing at ‘slack water’ maximises catchability and strengthens the relationship between what is observed in situ and what is subsequently caught in pots. However, the obvious size selectivity bias, and weaker relationships between in situ observations and standard potting survey catches from larger studies done at all tidal phases, creates uncertainty in the ability of these potting surveys to reliably describe the ‘relative’ abundance and structure of blue cod populations, especially for pre-recruited blue cod, regardless of the type of pot used.

1. INTRODUCTION

Blue cod (*Parapercis colias*) is a particularly desirable finfish caught easily by line or pot from small vessels fishing over reef edges. Most blue cod have a restricted home range (Rapson 1956, Mace & Johnston 1983, Mutch 1983, Carbines & McKenzie 2001, 2004, Carbines 2004a), and stocks of this species largely consist of many independent sub-stocks within each Fisheries Management Area (FMA) (Carbines 2004a). Due to this philopatric behaviour, blue cod can be susceptible to localised depletion within sub-areas of FMAs in response to local fishing pressure.

Blue cod is the species most frequently landed by South Island recreational fishers, and an important species for Māori customary fishers (Ministry for Primary Industries 2017). Southland is New Zealand's largest commercial blue cod fishery (BCO 5) with 1099 t landed 2015–16, and a much smaller amount of blue cod landed annually by recreational fishers (approximately 44 t, Ministry for Primary Industries 2017). The commercial catch from BCO 5 is almost exclusively taken by a target pot fishery operating mainly within Foveaux Strait, around Stewart Island and southern Fiordland (Starr & Kendrick 2009, 2011). The Southland recreational blue cod catch is taken mainly by line fishing from northern Stewart Island (including Paterson Inlet, James et al. 2004), throughout Foveaux Strait (Warren et al. 1997) and in Fiordland (Davey & Hartill 2008). Recreational blue cod landings are managed through bag limit strategies with a variety of minimum size limits being applied throughout the South Island FMAs (Ministry for Primary Industries 2017). Commercial blue cod landings are managed through the same MLS, a pot mesh size restriction, and the Quota Management System's total allowable catch commercial catch (TACC) within each FMA (Ministry for Primary Industries 2017).

Prior to the allocation of the Southland blue cod annual quota in 1986 (BCO 5 = 1190 t), commercial catches historically ranged from 626 t to 954 t (1983–86). The Quota Appeal Authority further increased the TACC in BCO 5 to 50% higher than historical catches (1536 t) with no evidence the take was sustainable (Warren et al. 1997). Over time, catches gradually increased until the TACC was reached for the first time in 2003–04, after which commercial landings have continued to decline while effort has increased (Starr & Kendrick 2009, 2011). In 2011 the TACC for BCO 5 was cut by 20% and the recreational bag limit (30 per day) was reduced by 33% (Ministry for Primary Industries 2017). In 2013 a stock assessment of blue cod indicated that Statistical Areas 025 (effectively Foveaux Strait), 027 and 030 were all close to the biomass target of 40% B_0, with slightly lower abundance in Statistical Area 025 than in the others (Haist et al. 2013). However, it was considered that fishing mortality rates were below the F_{msy} limit and that the current TACC was sustainable (Haist et al. 2013).

Historical catch rates and length-frequency data of blue cod in the Foveaux Strait were derived retrospectively from fine mesh pots used in the potting phase of a tagging programme in 1998 (Carbines & McKenzie 2001) and compared to a 2009 fine mesh potting survey that re-sampled 42 selected fixed sites to describe changes in population structure and standardised catch rates of blue cod (Carbines 2009). The two comparable surveys indicated clear differences in the catch rates of blue cod between 1998 and 2009. Catch rates of pre-recruits had increased, and sites in the central and eastern coastal areas of Foveaux Strait had maintained consistent catch rates of legal-sized blue cod (33 cm tail length and over). However, catch rates of legal-sized fish in the most productive areas at the western entrance of Foveaux Strait and around Ruapuke Island had declined to about half the levels recorded in 1998. Comparisons of length-frequency data also showed a dramatic decline in the proportion of legal-sized blue cod since 1998. The decline in the proportion of legal-sized blue cod was most apparent around Ruapuke Island and the western entrance to Foveaux Strait. In summary, comparisons between potting surveys using standardised methods suggested that major changes in blue cod population size and structure had occurred between 1998 and 2009 (Carbines 2009).

Ministry for Primary Industries potting surveys

To monitor South Island blue cod populations, the Ministry for Primary Industries undertakes a quadrennial series of potting surveys to generate relative biomass estimates in key recreational fisheries within all three South Island FMA, these include the Marlborough Sounds, north Canterbury, Banks Peninsula, north and south Otago, Dusky Sound and Paterson Inlet (Ministry for Primary Industries 2017). These surveys provide relative abundance indices as well as information on population size/age structure, mortality estimates, and sex ratio used to monitor blue cod stocks. In addition to catch rate information, monitoring age structure provides a possible means of evaluating the response of a population to changes in fishing pressure. Otoliths collected during potting surveys are used to calculate the age structure of blue cod throughout the South Island. Subsequent estimates of total mortality (Z) for each survey are based on catch curve analysis (Ricker 1975) of the age distributions derived specifically for each survey; thus it is possible to determine stock status using an MSY-related proxy. For blue cod there is insufficient information to estimate B_{MSY}, in part because recreational catches have not been estimated reliably, and may represent a significant proportion of the total catch. F_{MSY} is a more appropriate reference point for blue cod and the most widely used proxy for F_{MSY} currently is from spawner per recruit analyses ($F_{\%SPR}$). Hence, we are interested in where fishing mortality, derived from the catch curve analysis (Z) and estimates of M, lies in relation to the recommended $F_{45\%SPR}$ reference point for blue cod. This is documented in the Ministry of Fisheries 'Operational Guidelines for New Zealand's Harvest Strategy Standard' (Ministry of Fisheries 2011).

Foveaux Strait time series

The 1998 and 2009 fine mesh potting surveys of Foveaux Strait used a fixed site design (i.e., surveying known blue cod 'hotspots', which have a number of potential biases (Stephenson et al. 2009). Consequently, the Ministry for Primary Industries established a new random site allocation potting survey design in 2010 (Carbines & Beentjes 2012). This was the first fully random site allocation blue cod potting survey to be undertaken in New Zealand and began a new time series for Foveaux Strait. The 2010 random site survey used a two-phase stratified random site design with six sites per stratum randomly allocated for phase 1. Between 10 February and 16 June 2010, 56 potting sites were surveyed (6 pots per site = 336 pot lifts) from 8 strata throughout Foveaux Strait (Figure 1). The total blue cod catch was 1868 kg, consisting of 4340 blue cod. Overall catch rates ranged from 1.2 to 14.1 $kg.pot^{-1}$ with an overall mean rate of 4.8 $kg.pot^{-1}$ and coefficient of variation (CV) of 11.3%. Catch rates of legal-sized blue cod ranged from 0.46 to 5.1 kg per pot, with an overall mean of 2.1 $kg.pot^{-1}$ and a CV of 10.9%. Catch rates were highest in the western entrance of Foveaux Strait and off the northern coast of Stewart Island, and lowest in the large stratum around Ruapuke Island (Figure 1).

In the 2010 survey the total length of fish sampled ranged from 11 to 56 cm, and 26% of blue cod caught exceeded the minimum legal size (MLS). Scaled length-frequency distributions show that strata had similar size structures, with few blue cod over 40 cm, apart from the stratum on the east coast of Stewart Island, which had some large fish. The combined length distributions were unimodal with the male peak at about 34 cm and the female at 30 cm. Males were larger than females in all strata and overall mean length was 30.5 cm for males and 27.8 cm for females. Overall sex ratio for all fish was 1:1.2 (M:F), but skewed in favour of males (1:0.5) for fish above the MLS. Age ranged from 1 to 28 years, with most fish between 4 and 9 years for males and 4 and 10 years for females. Mean age was 7.1 years for males and 6.9 years for females. Total mortality estimates (Z) for age-at-recruitment from 5 to 8 years ranged between 0.34 and 0.46 (both sexes combined). The spawner (biomass) per recruit (SPR) of the 2010 Foveaux Strait survey was $F_{35\%}$, indicating that at that level of fishing, the expected contribution to the spawning biomass over the lifetime of an average recruit had been reduced to 35% of the contribution in the absence of fishing. This level of exploitation (F) was outside the Ministry for Primary Industries target reference point of $F_{45\%}$ for this stock.

This report describes the 2014 blue cod potting survey of the Foveaux Strait, the second in the time series since the initial random site potting survey in 2010 (Carbines & Beentjes 2012).

1.1 Catch vs. count

The basic premise of potting surveys as long-term monitoring programmes is to use the passive capture method of potting to estimate the actual abundance and size structure of blue cod populations. However, a review of the blue cod potting programme recommended that this premise requires further validation (Stephenson et al. 2009).

Different methods have different size selectivity and catch rates, and size composition from potting can differ both between pot types (Beentjes & Carbines 2012, Carbines & Beentjes 2012) and when compared to other methods such as line fishing (Carbines 1999, 2008). Pot catches can also have a highly variable and largely unexplained relationship with counts from diver transects (Cole et al. 2001). Continuous video recordings of blue cod entries and exits from pots also show that less than 8% of approaches lead to entries, and that local topography can constrain pot entries in some situations (Cole et al. 2004). To further investigate the relationship between potting survey catch rates (relative abundance) and size structure with direct observations of blue cod, the 2010 Foveaux Strait potting survey also employed fish counts from remote flown drop underwater video (DUV) transects done at 12 random potting sites immediately prior to potting (Carbines & Beentjes 2012). Five additional fixed sites (at hot spots) were also surveyed with the DUV in 2010 to increase the range of fish densities for comparative purposes. At least five replicate DUV transects were undertaken at each site directly prior to potting (type 2 pots; see Section 2.4 and Beentjes & Francis 2011 for description), and in total 85 video transects and 102 pots were deployed. The video surveyed a total area of 233 608 m^2 and counted 1525 blue cod, while the concurrent type 2 pots caught 2452 blue cod.

In Foveaux Strait the DUV showed a higher proportion of small blue cod than type 2 pots, and the correlations between the average densities and catch rates were only 0.50 for all and 0.54 for blue cod 20 cm or more (Carbines & Beentjes 2012). A Marlborough Sounds DUV survey showed an even higher proportion of small blue cod than type 1 pots, and the correlations between the average densities and catch rates were only 0.27 for all and -0.19 for blue cod 30 cm or more (Beentjes & Carbines 2012). The relationship between catch and count (i.e., catchability) seems to be highly variable over time and/or location (Cole et al. 2001, Beentjes & Carbines 2012, Carbines & Beentjes 2012, Carbines & Haist 2014, 2017). Following the 2014 random site potting survey of Foveaux Strait, a further comparison of DUV transects and subsequent catches of type 1 and type 2 pots (see Beentjes & Francis 2011) was undertaken at eight selected sites.

Overall objective

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

Specific objectives

1. To undertake a potting survey in the Foveaux Strait to estimate relative abundance, size- and age-at-maturity, sex ratio and to collect otoliths from pre-recruited and recruited blue cod.

2. To analyse biological samples collected from this potting survey in specific objective 1.

3. To determine stock status of blue cod populations in the Foveaux Strait.

4. To undertake a drop underwater video (DUV) survey concurrently with the potting survey to provide comparative estimates of biomass.

5. To test the gear selectivity of Pot Plan 1 vs. Pot Plan 2.

2. METHODS

In this report we use only the terms and methods defined in the blue cod potting survey manual (Beentjes & Francis 2011), but note that surveys carried out before this manual was written may have used different and inconsistent terminology (see Appendix 1).

2.1 Timing

The previous random site survey for the Foveaux Strait was done mainly in January–April 2010, although prolonged bad weather delayed surveying the last site until early June 2010 (Carbines & Beentjes 2012). To continue the random site survey time series for the Foveaux Strait with minimal temporal (seasonal) variability between surveys, the 2014 Foveaux Strait potting survey began on 11 February and due to good weather was completed on 17 March 2014. The experimental comparison of pot types (Objective 5) with concurrent flown video transects (Objective 4) was done 21–25 March 2014, following the biomass survey (Objective 1).

2.2 Survey area

Foveaux Strait is a shallow body of water at the southern tip of New Zealand, separating the South Island and Stewart Island. It is about 80 km long and 23–53 km wide (Figure 1). The seafloor is principally alluvial gravel, locally overlaid with sand, sloping gently from 20 m deep in the east to 50 m deep in the west. Islands and reefs extend northwards across Foveaux Strait's shallow eastern entrance, north-east of Stewart Island. As the Foveaux Strait separates the Tasman Sea from the South Pacific Ocean, it is subject to extremely strong tidal flows. It is also subject to the influence of the Tasman and Southland currents from west to east (Houtman 1966, Heath 1972, 1981).

The strong tidal flows in the Foveaux Strait support a rich variety of filter feeding benthic organisms such as bryozoans, bivalves, sponges and tunicates that stabilise the seabed by forming large biogenic reefs (Fleming 1952, Cranfield et al. 1999), which have associated fish communities (Cranfield et al. 2001, Carbines & Cole 2009). The Foveaux Strait area also has a high variety of rocky reef assemblages and a high diversity of macroalgal species (Kettles et al. 2017). Regional patterns in algal species composition, macroalgal community structure, benthic community structure and mobile macroinvertebrate species assemblages generally reflect broadscale differences in exposure to prevailing south-westerly swells, which dominate the physical setting in this region. Foveaux Strait forms part of a unique Stewart Island bioregion within the Southern New Zealand biogeographic province (Shears et al. 2008).

The 2010 Foveaux Strait random site potting survey area was originally defined after discussions with local fishers, the Ministry for Primary Industries, and the South Marine Recreational Fisheries Forum. The survey area was divided arbitrarily into 10 strata throughout the greater Foveaux Strait area (Figure 1). However, due to high variability in catch rates during the 2010 survey, the areas of strata 6 and 7 were re-drafted based on a local LINZ multi-beam survey and commercial fishers advice into two seabed habitat types (stratum 7 = foul, and stratum 8 = sand; see Figure 2). In the absence of more specific habitat information for the wider survey area, the area (km^2) within each stratum was taken as a proxy of available habitat for blue cod.

2.3 Survey design

The 2014 random site Foveaux Strait potting survey used a two-phase stratified design, using six pots per site (Figure 3) and sites at least 1000 m apart (Figure 2). Six sites per stratum (n = 48 sites, 288 pot lifts) were allocated to eight strata for phase one (Table 1). An additional five sites (30 pot lifts) were allocated to three strata in phase two (10.4%).

Allocation of phase 2 sites was based on the mean 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, phase 2 sites were assigned iteratively to the stratum in which the expected gain is greatest, where expected gain is given by:

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

where for the *i*th stratum, $mean_i$ is the mean catch rate, $area_i$ is the area, and n_i is the number of sets in phase 1. In the iterative application of this equation, n_i is incremented by 1 each time a phase 2 set is allocated to stratum *i*. Pots were always allocated in groups of six, which equates to one set (see Figure 3).

2.4 Vessels and gear

The 2014 Foveaux Strait random site potting survey was conducted from F.V. *Francis*, a Stewart Island-based commercial vessel equipped to set and lift rock lobster and blue cod pots. The vessel was charted by Saltwater Science Ltd and skippered by the owner Mr Brett Hamilton. The vessel specifications are: 10.5 m length, 3.6 m breadth, 6.5 t, fibreglass monohull, powered by a 430 hp diesel engine with propeller propulsion. The trip code for the survey was fra1401.

Six custom designed and built cod pots were used to conduct the survey (Objective 1). Pot specifications were: length 1200 mm, width 900 mm, depth 500 mm, 30 mm diameter synthetic inner mesh, 50 mm cyclone wire outer mesh, entrances 4 (Pot Plan 2 in Beentjes & Francis 2011). Pots were marked with a number from 1 to 6, and baited with paua guts in 'snifter pottles'. Bait was topped up after every lift and replaced each day. The same pot design and bait type were used in all previous South Island blue cod potting survey time series except Marlborough Sounds, where the pots used are of different dimensions and construction (Pot Plan 1 in Beentjes & Francis 2011).

A high-performance, 3-axis (3D) acoustic doppler current profiler (RDI – 1200 kHz) was deployed at each site. The ADCP records current flow and direction in 5 m depth bins.

2.5 Sampling methods

The ADCP was initially deployed at the random point generated, and around this central point, six pots were set sequentially in a fixed hexagon pattern with each point (pot) approximately 300 m from the centre and 300 m from adjacent pots (Figure 3). The six pots were set blind (i.e., not targeted by sonar) in the fixed grid pattern determined from an initial starting point approximately 300 m north of the random site location occupied by the ADCP (Figure 3).

Pots were left to fish (soak) for approximately 1 hour during daylight hours. After each site was completed (six pot lifts) the next closest site in the stratum was sampled. While it was not logistically possible to standardise for time of day or tides, each stratum was usually surveyed throughout the day, collectively giving each stratum roughly equal exposure to all daily tidal and time regimes. The order that strata were surveyed depended on the prevailing weather conditions, as exposed strata could only be surveyed during calm conditions.

As each pot was set, a record was made on customised forms (see Beentjes & Francis 2011) of pot number, latitude and longitude, depth, time of day, and standard trawl survey physical oceanographic data, including wind direction, wind force, air temperature, air pressure, cloud cover, sea condition, sea colour, swell height, swell direction, bottom type, bottom contour, sea surface temperature, sea bottom temperature, wind speed, and water visibility (secchi depth). The ADCP was deployed at the centre of each site to record current speed and direction throughout the pot sets.

After 1 hour, pots were lifted aboard using the vessel's hydraulic pot lifter, emptied, and the contents sorted by species. Total weight per pot was recorded for each species to the nearest 10 g using 10 kg Merel motion compensating scales. The number of individuals of each species was also recorded per pot. Total length down to the nearest centimetre, sex, and gonad maturity were recorded for all blue cod, and the sagittal otolith removed from a representative size range of males and females, from which the weight of each fish was recorded to the nearest 10 g. Otoliths were removed from a target of five fish of each sex per 1 cm size class over the available length range collected throughout the entire survey area.

All blue cod were sexed by dissection and direct examination of the gonads (Carbines 2004a). Gonads were also recorded as one of five stages as follows: 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent (see Beentjes & Francis 2011).

2.6 Otolith preparation and reading

Due to the small size and cryptic banding pattern of blue cod otoliths, the best method for ageing them is to use a thin section mounted on a slide and viewed through a microscope (Carbines 2004b). Once removed by dissection, otoliths were rinsed with water, air-dried, and stored in a plastic pipette within a paper envelope. These were later embedded in a polymer resin, baked (50°C for at least 3 hours), and sectioned transversely with a diamond-tipped cut-off wheel. The thin section was then glued with resin onto a slide and sanded with 600-grit sandpaper to about 0.25 mm thickness before viewing. Sections were observed at ×40 and ×100 magnification under reflected light with a compound microscope (Walsh 2017).

Otoliths from the 2010 Foveaux Strait survey were read under transmitted light counting all opaque zones (as per Carbines 2004b). However, a new MPI ageing protocol (Walsh 2017) recommends reading blue cod otoliths under reflected light (see Appendix 2). Otolith sections exhibit alternating opaque and translucent zones, and age estimates were made by counting the number of annuli (opaque zones) from outside of the juvenile zone to the distal edge of the section (see Appendix 2, Figure A). The readability of each otolith was also graded from 1 (excellent) to 5 (unreadable). Otoliths were read independently by two readers (G. Carbines and P. VanKampen), and where counts differed the readers consulted to resolve the final age estimate. Otoliths given a grade 5 (unreadable) or damaged were removed from the analysis.

2.7 Data analysis

The data analyses follow the methods and equations described in the blue cod potting survey standards and specification document (Beentjes & Francis 2011).

CPUE for fish of minimum legal size

The potting survey manual does not provide equations for calculating catch rates of fish greater than the minimum legal size (MLS), however the approach that has been used in recent years is an extension of the equations for calculating catch rates for the entire catch. For blue cod potting surveys, individual fish weights are measured for only a subset of the sampled fish, and catch rates for fish greater than or equal to the MLS are based on the predicted weight of individual fish based on their length. The set-specific CPUE (kg.pot^{-1}) for fish greater than the MLS is,

$$C_{st}^{legal} = \left(\sum_{p} \sum_{k=1,2} \sum_{l \geq MLS} f_{lkpst} \, a_k \, l^{b_k} \right) \Big/ m \qquad (1)$$

Where f_{lkpst} is the number of fish of length l and sex k (k = 1 for males and k = 2 for females) caught in pot p of set s of stratum t, m is the number of pot lifts in set s, and a_k and b_k are sex-specific length-weight parameters (described below). Note that the above equation assumes that all fish have been measured for length.

The sex-specific length-weight parameters a_k, b_k are calculated by fitting (maximum likelihood) the following equation to all samples where length, weight, and sex were recorded:

$$w_{ki} = a_k \left(l_{ki} \right)^{b_k} \, \varepsilon_{ki} \qquad (2)$$

where w_{ki} and l_{ki} are the weight and length of fish i of sex k and the ε_{ki} are normally distributed. The equations for calculating the stratum and survey catch rates and CVs for fish greater than or equal to the MLS follow those in the potting survey manual (equations 2–5 of Beentjes and Francis 2011), replacing $\bar{C}_{st}$ with C_{st}^{legal}.

Length-frequency, age-frequency and total mortality estimates

Calculation of survey-level length frequency (LF), age frequency (AF), and total mortality (Z) follow the equations described in the potting survey manual (Beentjes and Francis 2011). Uncertainty in the LF, AF and Z estimates were calculated using the bootstrap procedures described in the survey manual. The LF and AF CVs were based on 300 bootstrap replicates and the Z confidence limits were based on 1000 replicates.

Growth parameters

Von Bertalanffy growth models were fitted (maximum likelihood) to the sex-specific length-age data:

$$l_{ki} = L_k^{\infty}\left(1 - \exp\left(K_k\left(t_{ki} - t_k^0\right)\right)\right) + \varepsilon_{ki} \qquad (3)$$

where l_{ki} and t_{ki} are the length (cm) and age of fish i of sex k, respectively, L_k^{∞}, K_k, and t_k^0 are parameters of the growth model for sex k, and the ε_{ki} are normally distributed.

The estimated growth parameters L_k^{∞}, K_k, and t_k^0 were used in the spawning biomass per recruit analyses.

Spawning biomass per recruit calculations

Spawning biomass per recruit (SPR, Ministry of Fisheries 2011) analysis estimates the impact of fishing on the reproductive capacity of the stock. SPR is a deterministic calculation, dependent on population growth, natural and fishing mortality, maturation, and fishing selectivity. For blue cod, the calculations are based on age- and sex-specific dynamics and spawning biomass is summed over male and female fish. The following equations give the number of fish at age a and sex k (N_{ka}) and the spawning biomass per recruit (S_F) for a given F:

$$N_{ka} = \begin{cases} 0.5 & a = 0 \\ N_{k,a-1}\exp\left(-s_{k,a-1}F - M\right) & 1 \geq a < mage \\ N_{k,a-1}\exp\left(-s_{k,a-1}F - M\right) \Big/ 1 - \exp\left(-s_{k,a-1}F - M\right) & a = mage \end{cases} \qquad (4)$$

$$S_F = \sum_k \sum_a \left(m_a a_k \left(l_{ka}\right)^{b_k} N_{ka}\right) \qquad (5)$$

where M is the natural mortality rate, s_{ka} is the selectivity for age a and sex k, m_a is the maturity for age a, l_{ka} is the mean length for age a and sex k, $mage$ is the maximum age (50) and a_k and b_k are the length-weight parameters for sex k (see equation 2). $F_{\%SPR}$ is the fishing mortality (F) at a given spawning biomass per recruit (%SPR) relative to the spawning biomass per recruit in the absence of fishing $\left(\text{i.e. } S_f / S_0\right)$.

Population parameters are either estimated based on survey data (s_{ka} , l_{ka} , a_k and b_k) or fixed at default values as specified in the potting survey manual: the instantaneous natural mortality rate is assumed to be 0.14, with sensitivities conducted for *M* values of 0.11 and 0.17; the maturation ogive assumes fish under age 3 are all immature, proportions mature of 0.1, 0.4 and 0.7 for ages 4, 5 and 6, respectively, and 100% maturity for fish aged 7 and older; and fishery selectivity is assumed to be knife-edge at the age at MLS. The estimate of current fishing mortality (*F*) is equal to *Z*-*M*, and the Southern Inshore Working Group determined that the age of recruitment for the *Z* calculations would be the age where both male and female blue cod were at or above the MLS. *Z* and SPR results are also provided for ages at recruitment from 5 through 9.

Note that the above equations assume that the surveys that generate the length-age data (and von Bertalanffy growth curves) occur at the time of spawning so that a fish aged 3 is exactly 3 years old. Also, knife-edged fishery selectivity is interpreted to mean that age classes become fully selected when they reach the birthday where their mean length-at-age is greater than or equal to the MLS. Alternative interpretations of knife-edge selectivity are possible – for example, assuming full selectivity at the exact age where the mean length is equal to the MLS (i.e., full selectivity at some mid-point in the year).

2.8 Gear selectivity of Pot Plan 1 vs. Pot Plan 2

Eight selected fixed sites offering a range of blue cod abundance and sizes were used for the comparison of survey pot types (Pot Plan 1 vs. Pot Plan 2, see Beentjes & Francis 2011). Drop underwater video (DUV, see Section 2.9) transects were used in conjunction with the pot type comparison to describe the in situ blue cod population from which fish were captured by the two pot types.

Equipment

Three of the pots used in Objective 1 (Pot Plan 2) were set concurrently with three of the Marlborough Sounds design pots (Pot Plan 1). Pot plan specifications are described in detail in Beentjes and Francis (2011). Pots were marked with a number from 1 to 6, and baited with paua guts as per Objective 1. To qualitatively record blue cod behaviour in and around pots a small underwater camera (GoPro – 8x4x4 cm) was mounted inside one of each of the two pot types (n = 2 cameras).

Experimental design

To compare the catchability of the two pot types, eight fixed sites were selected over a range of blue cod abundance and size (avoiding areas of extremely low density). Three replicate pots of each design (i.e., Pot Plans 1 & 2) were set together (alternately) within each site immediately following DUV transects (see Section 2.9).

Timing

The pot type comparison was done at the conclusion of the 2014 random site potting survey (Objective 1) and in conjunction with flown DUV transects (see Section 2.9) over five consecutive days from 21 to 25 March 2014.

Sampling methods

The sampling methods used in the pot type comparison remained consistent with the potting survey (see Objective 1). At each site, six pots were set and left to fish (soak) for 1 hour during daylight hours. The six pot locations were systematically set in a fixed hexagon pattern with each point (pot) approximately 300 m from the central fixed site location (marked by the ADCP) and 300 m from adjacent pots (Figure 3). However, in the pot type comparison, the two pot types were set alternately in the hexagon grid so that both pot types had an equivalent opportunity to attract fish at each site.

Sampling was undertaken during settled weather (below 12 knots wind speed and 1 m swell height), during daylight hours, and at the conclusion of the tidal flow (‘slack water’). For each individual pot, the pot number, latitude and longitude (GPS), depth and time of day were recorded as it was set. After 1 hour pots were lifted aboard using the vessel's hydraulic pot lifter, emptied, and all blue cod measured (total length rounded down to the nearest centimetre).

Data analysis

Between pot type comparisons were based on the absolute catch-at-length, as the same number of pots were fished at the same sites together. Proportional length-frequency distributions and catch (as a proxy for relative abundance) were examined in relation to abundance estimates from video transect (see Section 2.9) to compare the catchability and size selectivity of the two survey pot types. Where possible, correlations were made between catch rates of each pot type.

2.9 Drop underwater video (DUV)

Catch from potting surveys are used as a proxy for actual abundance and size structure, but it is unknown how these relative measures relate to the actual in situ abundance and size structure of blue cod (Stephenson et al. 2009). To address this, we estimated blue cod abundance and size structure using flown drop underwater video (DUV) transects at the eight fixed sites used in the comparison of pot types (see Section 2.8).

Equipment

The DUV consists of a 35 kg bulb keel and tail fins that steady and orient a forward and downward facing mounting platform, fitted with a low-light camera and scaling lasers (Morrison & Carbines 2006, Carbines & Cole 2009, Carbines & Haist 2014, 2017, Compton et al. 2012). It was suspended beneath a moving vessel by a rope and a live-feed video cable so that location, time, depth and date were all burned in real time onto the recorded digital video footage integrated with a surface Geographical Positioning System (GPS) and depth sounder.

Experimental design

To compare the catchability of the two pot designs, eight fixed sites over a range of blue cod abundance and size were used. Five replicate DUV transects were done throughout each site (Table 10) immediately prior to potting (see Section 2.8).

Timing

Flown DUV transects were done in conjunction with the pot type comparison (see Section 2.8) over five consecutive days of fine weather from 21 to 25 March 2014.

Sampling methods

The DUV was deployed at a height of at least 1.5 m off the seabed as the vessel drifted through the site area. Once the speed of the surface vessel exceeds that of the deployed video, the keel and tail fins orient the platform forward, and the video records a transect of approximately 800 m in length. Contact with the seabed was avoided by lifting and lowering the DUV from the surface vessel throughout each transect and scaling lasers were used to back-calculate the size and variations of transect width. Transects were carried out between 0700 and 1600 hours, when the swell was no more than 1 m, and when speed exceeded 0.8 $m.s^{-1}$ (to prevent fish being able to follow the video and re-enter the video transect). Five replicate video transects were done at each site during the flow of the tidal cycle directly prior to sampling with six pots (as described in Section 2.8) once the current speed dropped below 0.8 $m.s^{-1}$.

Video analysis

Blue cod were geo-referenced and scaling lasers were used to estimate fish length (Morrison & Carbines 2006, Carbines & Usmar 2013). A correlation was calculated between the density of blue cod counted at each site and the number caught in each pot type.

To increase precision of blue cod length estimates from the single camera DUV system, fish length estimates were not used if they were derived from fish observed off the bottom or at an angle of more than 45 degrees to the camera (Carbines & Usmar 2013).

Data analysis

Abundance estimates from DUV transects were examined in relation to catch so as to compare the catchability of the two survey pot types. Where appropriate, correlations were made between abundance and catch, and proportional length frequencies were then compared between these methods to examine size selectivity (Cole et al. 2001).

3. RESULTS

3.1 Sites surveyed

Fifty-three random sites (6 pots per site, 318 pot lifts) were surveyed over 15 fishable days from 11 February to 17 March 2014 (Table 1, Figure 2 and Appendix 3). The survey used 48 sites in phase 1 (6 per stratum) with 5 allocated to phase 2, depth ranged from 7 to 63 m (Table 1). Environmental data recorded throughout the 2014 Foveaux Strait survey are presented in Appendix 4 and are stored on the Ministry for Primary Industries database *trawl*. The ADCP data are archived in a spreadsheet with the Research Data Manager, NIWA, Greta Point, Wellington.

3.2 Catch

A total of 3295 kg of catch was taken during the 2014 Foveaux Strait random site survey, of which 2888 kg (88%) was blue cod, consisting of 6668 fish (Table 2). Bycatch included 11 fish species, an octopus species and a crab species (Table 2). The five most common bycatch species by weight were leather jackets (*Parika scaber*), scarlet wrass (*Pseudolabrus miles*), octopus (*Octopus cordiformis*), banded wrasse (*Notolabrus fucicola*), and maori chief (*Paranotothenia angustata*) (Table 2).

The mean catch rates of blue cod (all sizes) ranged from 0.32 kg.pot^{-1} for the sandy stratum 8 at the eastern entrance of the Foveaux Strait, to 16.22 kg.pot^{-1} in stratum 1 on the northern coast of Stewart Island at the western entrance of the Foveaux Strait (Table 3, Figure 4). Overall mean catch rate and CV were 7.57 kg.pot^{-1} and 11.60%. For blue cod 33 cm and over (local minimum legal size) the highest catches also came from stratum 1 (16.22 kg.pot^{-1}) and the lowest catch rates were also from stratum 8 (0.32 kg.pot^{-1}). Overall mean catch rate and CV for legal-sized fish were 3.06 kg.pot^{-1} and 8.5% (Table 4, Figure 4).

3.3 Biological and length-frequency data

All of the 6668 blue cod caught during the 2014 Foveaux Strait random site survey were measured for length and sexed (Figure 5).

Sex ratio

For all blue cod the sex ratio ranged from 1:0.6 (M:F) in the central Foveaux Strait stratum 5 to 1:1.6 in the eastern Stewart Island coastal stratum 10, and overall were 47% male (1:1.1) (Table 5). The sex ratio for blue cod 33 cm and over (local minimum legal size) ranged from 1:0.1 (M:F) in strata 7 and 5 to 1:0.6 (M:F) in stratum 2, and was overall 76% males (1:0.3) (Table 5). The size of blue cod ranged from 9 to 43 cm for females and 14 to 46 cm for males (Table 5).

Length frequency

The length-frequency distributions were bimodal in strata 4, 5 and 6, but unimodal in strata 1, 2, 7 and 8 (Figure 5). Twenty-three percent of the blue cod caught were of legal size.

Biological data

Of the 6668 blue cod examined in the 2014 Foveaux Strait random site survey, 86% of the males and 84% of the females had early maturing gonads, while 11.6% of males and 14.8% of females were either spawning or spent (Table 16).

Otoliths and individual fish weights were taken from 292 blue cod selected across the available size range throughout the entire survey. The survey length-weight relationship analysis included 136 females (range 9–43 cm) and 153 males (range 14–66 cm). Using the derived model $W = aL^b$, the length-weight parameters for Foveaux Strait in 2014 were males: a = 0.016612, b = 2.9977; females: a = 0.028437, b = 2.8355.

3.4 Ageing (between-reader analyses)

From 292 otoliths collected during the 2014 Foveaux Strait survey, 70 were rejected as unreadable or damaged, leaving 222 otoliths (116 males 14–46 cm, 106 females 9–43 cm (Table 7)). These otoliths were collected across all strata (Appendix 5).

Initial independently derived reader estimates of otolith age class are compared in Figure 6 and show 55% agreement between the two readers, with reader 2 generally estimating slightly lower age classes than reader 1 (tabulated in Appendix 6). When the differences between age class estimates were resolved by agreement between the readers, reader 1 was 78% consistent with the agreed age class and reader 2 was 69% consistent with the agreed age classes (Figure 6, Appendix 7).

3.5 Growth

The fitted von Bertalanffy growth models for the 2014 Foveaux Strait survey are shown in Figure 7, and the growth parameters (K, t_0 and L_{inf}) shown below. Male and female size-at-age is similar until about age 5, after which males grow a little faster and achieve a slightly larger L_{inf} than females.

Parameter	Males	Females
K	0.0874	0.1191
T_0	-1.5402	-1.2706
L_{inf}	58.9	45.5

3.6 Length and age composition

The scaled length and age distributions for all strata combined are shown for males and females in Figure 8. Length-frequency distributions were unimodal, males were larger than females and had a peak centred at about 30 cm, while females peaked at around 28 cm (Figure 8).

Age ranged from 0 to 14 years (Table 7), but with very few fish older than 10 years. For males and females the dominant age class was 5 years (Figure 8). The mean weighted coefficients of variation (MWCVs) around the survey age distributions are moderate (less than 30%) indicating that fish sampled in the 2014 Foveaux Strait potting surveys provide a fair representation of the overall population. The age-length-keys (ALKs) by sex are shown in Appendices 8 and 9, mean-age-at-length is shown in Appendix 10.

3.7 Total mortality (Z) estimates

Total mortality estimates (Z) for the 2014 Foveaux Strait potting survey, calculated using the Chapman-Robson estimator, are given in Table 8, with 95% confidence intervals for these estimates based on a bootstrap procedure. Estimates of Z increase with the assumed age-at-recruitment to the fishery from 0.59 at 5 years to 0.87 at 9 years (Table 8). For comparison, Z estimates from catch curve analysis are also presented in Table 8. Note that there were no age 13 fish in the age composition so this age class was not included in the catch curve analysis. The catch curve Z estimates are somewhat higher than the Chapman-Robson estimates, but there is no indication that strong cohorts may be biasing estimates (Figure 9).

3.8 Spawner per recruit analyses

The age- and sex-specific values for fish size, maturity and selectivity used in the SPR analysis are given in Appendix 11.

Spawning biomass per recruit analyses are plotted as %SPR vs. fishing mortality rate (Figure 9). Mortality parameters used in the analyses, and resulting %SPR values, are shown in Table 9. Based on the default M value of 0.14 and a fully-selected age of 8 years (both males and females fully selected in fisheries, based on growth curves and the MLS), the fishing mortality estimate was 0.57, corresponding to a spawner biomass per recruit ratio of 20% at M = 0.14. This indicates that at recent levels of fishing mortality, the expected contribution to the spawning biomass over the lifetime of an average recruit has been reduced to about 20% of the contribution in the absence of fishing. $F_{\%SPR}$ estimates for M values of 0.11 and 0.17 ranged from 15% to 26% (Table 9).

3.9 Gear selectivity of Pot Plan 1 vs. Pot Plan 2

Eight fixed sites were selected and experimentally surveyed over five consecutive days from 21 to 25 March 2014 (Figure 10). Four sites were located in survey stratum 4, and four sites were located in survey stratum 7, all within 3 km of the Stewart Island coast (Figure 10). The experiment used three type 1 and three type 2 pots set alternately within each site (n = 48 pot lifts, Table 10).

From the eight selected sites, 531 blue cod were caught in type 1 pots, and 960 blue cod were caught in type 2 pots (Table 11). Because the same number of pots was fished concurrently at the same sites, the two pot types were compared based on the absolute catch-at-length (Figure 11). Both pots caught equivalent numbers of fish over 30 cm, but type 2 pots also caught similar numbers of fish below 30 cm, which type 1 pots almost entirely missed (Figure 11).

The size range of blue cod caught in type 1 pots (20–43 cm) was more constrained than the size range from type 2 pots (11–44 cm), while the average size of blue cod from type 1 pots (31.6±0.1 cm) was 4 cm larger than those from type 2 pots (Table 11, Figure 11). Consequently, type 1 pots also caught more males (67%) than type 2 pots (49%) because males are generally larger (see Section 3.6).

The mean catch rates of blue cod at each site are shown in Figure 12. For type 1 pots, the mean catch rate of all sized blue cod ranged from 7.5±3.7 fish.pot^{-1} for site D, to 36.3±11.4 fish.pot^{-1} for site A. For type 2 pots, the mean catch rate of all blue cod ranged from 6.3±2.0 fish.pot^{-1} for site F, to 149.7±19.6 fish.pot^{-1} for site A. The correlation between the average catch rates of blue cod from the two pot types was 0.72 for fish 20–32 cm, but -0.54 for fish 33 cm and over (Figure 13). No fish below 20 cm were caught by type 1 pots.

3.10 Drop underwater video

Video counts vs. pot catches

Five drop underwater video (DUV) transects were undertaken at each of eight selected sites along the north-east coast of Stewart Island (Figure 10) directly prior to sampling with type 1 and type 2 pots (see Section 3.9). A total of 40 DUV transects and 48 pot lifts were deployed (Table 11). The DUV surveyed 30 km of transects with an average transect width of 3.2 m (s.e. ± 0.1 m) covering a total area of 95 577 m^2. A total of 1555 blue cod were observed using DUV, while the concurrent pots caught 1491 blue cod (Table 11).

Length-frequency comparisons

Fish observed either off the bottom or at a camera angle over 45 degrees were removed (n = 162) to improve precision (Carbines & Usmar 2013), and the resulting proportional length-frequency distribution showed that the DUV sampled a considerably greater proportion of blue cod below 20 cm than did either type of pot (Figure 11). Larger blue cod were also caught disproportionately more in pots than observed, with type 1 pots proportionally sampling more blue cod over 27 cm and type 2 pots sampling proportionally more blue cod over 22 cm (Figure 11). The cumulative distribution plots of length frequency confirm that the video observations had a higher proportion of smaller fish than pots (Figure 11).

Comparison of catch rates and counts

Fish densities estimated by the area-swept DUV method for three size classes of blue cod are shown in Figure 12. At site D, few fish were observed or caught, and high densities observed at sites A and B preceded high catch rates from both pot types. However, relatively high densities of fish observed at sites E and H preceded only moderate catches, and low densities observed at site G preceded moderate catch rates in both pot types. Furthermore, moderate densities observed at site F preceded both high catch rates in type 1 pots and low catch rates in type 2 pots (Figure 12).

Type 1 pots did not catch any fish below 20 cm, but the correlation between the average density and catch rate was 0.68 for fish 20–32 cm, and -0.62 for fish 33 cm and over (Figure 14). The correlation between observed density and catch rates from type 2 pots was 0.43 for fish less than 20 cm, 0.86 for fish 20–32 cm, and 0.71 for fish 33 cm and over (Figure 15).

Blue cod behaviour in and around pots

Sixteen hours of video was viewed qualitatively from the cameras placed inside one of each of the two pot types. The camera placed inside the type 1 pot showed that all blue cod can exit via the entry cones at all times, and that it is only the bait that retains fish in the pots. Most blue cod were also able to pass through the larger top external trawl mesh (60x40 mm) section of type 1 pots (for specifications, see Beentjes & Francis 2011). When the type 1 pot was disturbed during lifting, many fish were able to vacate the pot through this larger mesh portion before being pinned to the bottom of the pot by water flow during lifting. The camera placed inside the type 2 pot also showed that all blue cod can exit via the entry cones at all times, and that it is bait that retains fish in the pots. However, blue cod were less able to pass through the smaller internal trawl mesh (30x30 mm) of type 2 pots.

4. DISCUSSION

4.1 Survey time series

The 2014 blue cod potting survey was the second full random site survey done in the Foveaux Strait (Figure 4). The overall catch rates of all blue cod (Table 3) and legal-sized blue cod (at least 33 cm, Table 4) increased 77% and 67%, respectively, since those recorded in the initial 2010 random site potting survey (see Figure 4). In 2014, there was an increase in catch rates over almost the entire survey area (except stratum 4) for all blue cod and legal-sized blue cod (except strata 4 and 6). This increase was primarily driven by increases in the catch rates of blue cod in the central Foveaux Strait stratum 5, the western strata 1 and 2, and the eastern strata 7 and 10 (Figure 4). There was a dramatic decline in catch rates in the central coastal Stewart Island stratum 4 (down 38% for all blue cod and down 31% for legal-sized blue cod, Figure 4). The overall CVs for the 2014 survey catch rates were 12.8% for all blue cod and 11.2% for legal-sized blue cod (Tables 3 and 4), which were marginally higher than the overall CVs from the previous 2010 survey (Carbines & Beentjes 2012).

4.2 Reproductive condition

Observations of gonad stages in 2014 were mainly in the early maturing stage, but with some running ripe and spent gonads (Table 6). This indicates that the timing of the survey (late summer/autumn) was at the conclusion of the spawning season and was consistent with the previous survey done at a similar time of year (Carbines & Beentjes 2012). This repeated observation of running ripe and spent gonads at this time of year further suggests a longer spawning period than thought previously (Carbines 2004a). However, as the 2014 potting survey was undertaken outside the main spawning period it was not possible to determine size of age-at-maturity.

4.3 Size and sex ratio

The overall sex ratio (1:1.1 M:F, 47% male) was relatively even for all blue cod in most strata except strata 2 and 10 that were 66% and 60% female, respectively. In contrast, stratum 5 was 62% male (Table 5). For legal-sized blue cod (33 cm and over) all stratum catches were biased towards males, with the bias most pronounced in strata 5 and 7, with 89% and 93% males, respectively (Table 5). Blue cod are protogynous hermaphrodites with some (but not all) females changing into males as they grow (Carbines 2004a). The finding that males were larger on average than females and that the largest fish were males (Table 5) is consistent with the sex structure in a protogynous hermaphrodite population. However, the male skewed sex ratios of legal-sized blue cod in some strata are contrary to an expected dominance of females resulting from selective fishing (MLS) removing the larger terminal sex males. Carbines (2004a), and subsequently Beentjes and Carbines (2005), hypothesise that the shift towards a higher proportion of males in heavily fished blue cod populations may be caused by removal of the inhibitory aggressive behavioural effects of large males resulting in a higher rate (and possibly earlier onset) of sex change by the remaining primary females (e.g., Kobayashi et al. 1993a, 1993b). This hypothesis is supported by the predominance of males in most areas known to be heavily fished, such as the Marlborough Sounds (Beentjes & Carbines 2012). However, in Foveaux Strait (where the MLS is 10% larger) the numbers of males and females are more balanced despite relatively heavy fishing pressure from the largest commercial blue cod fishery in the country (Starr & Kendrick 2011).

4.4 Population length and age structure

Length-frequency distributions were similar for most strata, with few fish over 40 cm present except for strata 7 and 10 (Figure 5). The overall average size of blue cod in the 2014 Foveaux Strait survey (Table 5) was virtually unchanged since the 2010 survey (Carbines & Beentjes 2012). Within strata, the average size of blue cod had increased slightly in strata 2 and 4, but it had declined by over 9% in strata 5 and 10. While the proportion of legal-sized (33 cm and over) blue cod caught on the 2014 Foveaux Strait survey (31%) had risen by 5% since the 2010 survey (26%), there were fewer large fish (over 40 cm) and the maximum size had declined from 56 cm in 2010 (Carbines & Beentjes 2012) to 46 cm in 2014 (Table 5).

The age distributions, and total mortality estimates are based on scaled length data that were weighted (scaled) by stratum area. Scaling by area assumes that the size of each stratum is directly proportional to the amount of blue cod habitat, i.e., area is assumed to be a proxy for habitat; however, this is probably not the case given the discrete nature of areas of foul and possible biogenic habitat (Carbines & Cole 2009). With improving seabed habitat mapping, in future it may be possible to scale catch data to more detailed estimates of the actual areas of suitable blue cod habitat within each stratum – as was recommended by the expert review panel following a workshop on blue cod potting surveys in April 2009 (Stephenson et al. 2009). However, as area is currently the only available proxy for blue cod habitat it was used for scaling.

The scaled length-frequency distribution for the 2014 Foveaux Strait survey shows few large blue cod throughout Foveaux Strait (Figure 8). The resulting population age structure shows a steep decline on the right-hand limb and a low proportion of fish older than 8 years. The 2010 Foveaux Strait survey had notably more blue cod over 40 cm and older than 8 years (Carbines & Beentjes 2012).

A change in ageing protocols between the 2010 (Carbines & Beentjes 2012) and 2014 (Walsh 2017) Foveaux Strait potting surveys prevents comparisons of age between surveys. In 2014 an allowance was made for a juvenile check in the otolith that was previously counted as the first annuli in the 2010 survey (Carbines 2016). This largely explains the decline in mean age by 1.8 years for males and 1.5 years for females between the surveys.

4.5 Total mortality (*Z*)

Mortality estimates (*Z*) from the 2014 Foveaux Strait survey are considerably higher than equivalent estimates from the 2010 Foveaux Strait survey (Carbines & Beentjes 2012). However, as the current survey used a different aging protocol (Walsh 2017) to the 2010 survey (Carbines & Beentjes 2012) it will have resulted in biased comparisons of Z and $F_{\%SPR}$ estimates.

4.6 Stock status (spawning biomass per recruit ratio analyses)

The Ministry of Fisheries 'Operational Guidelines for New Zealand's Harvest Strategy Standard' (Ministry of Fisheries 2011) specifies that a Fishery Plan should include a fishery target reference point, and this may be expressed in terms of biomass or fishing mortality. The more appropriate target reference point for blue cod is F_{MSY}, which is the amount of fishing mortality that results in the maximum sustainable yield. The recommended proxy for F_{MSY} is the level of spawner per recruit $F_{\%\mathrm{SPR}}$. The 'Harvest Strategy Standard' includes the following table of recommended default values for F_{MSY} (expressed as $F_{\%\mathrm{SPR}}$ levels from spawning biomass per recruit analysis), and also for B_{MSY} (expressed as $\%B_0$).

Productivity level	$\%B_0$	$F_{\%SPR}$
High productivity	25%	$F_{30\%}$
Medium productivity	35%	$F_{40\%}$
Low productivity	40%	$F_{45\%}$
Very low productivity	≥ 45%	≤ $F_{50\%}$

Based on the 'Harvest Strategy Standard' and recommendations from the Southern Inshore Working Group, blue cod is categorised as an exploited species with low productivity (on account of complications related to sex change) and hence the recommended default proxy for F_{MSY} is $F_{45\%}$. Our SPR estimates for the default M value of 0.14 were $F_{20\%}$ for Foveaux Strait in 2014, indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit has been reduced to 20% of the contribution in the absence of fishing. Further, the level of exploitation (F) of Foveaux Strait blue cod stocks is greater than the F_{MSY} target reference point (Table 9, see Figure 9) and fishing pressure in Foveaux Strait has resulted in an $F_{\%SPR}$ estimate that is 20% outside of the Ministry for Primary Industries specified target.

Sensitivity analyses using M values of 0.11 and 0.17 (20% below and above the default of 0.14) resulted in substantial differences in the $F_{\%SPR}$ from the default M value (Table 9, see Figure 9). A higher natural mortality (0.17) increased spawning biomass contribution to 26%. Conversely, lower mortality (0.11) decreased the spawning biomass contribution by a similar amount. However, the estimated fishing mortality rate (F) is above the target reference point of $F_{40\%}$ for all estimates of M (Figure 9).

Catch rates have increased between the 2010 and 2014 Foveaux Strait potting surveys while the average size of blue cod has remained stable. However, a reduction in larger (over 40 cm) fish is of concern to the potential reproductive capacity of Foveaux Strait blue cod. In the Southland quota stock BCO 5, the commercial pot mesh size has been restricted to 48 mm since 1994 to avoid the mortality of undersized fish (Warren et al. 1997). As the vast majority of the fishing mortality in Southland (96% commercial landings according to Ministry for Primary Industries 2017) has constrained the associated mortality of undersized fish (pots vs. hooks, see Carbines 1999), the average size of blue cod in the greater Foveaux Strait area has remained stable between 2010 and 2014 in spite of relatively high fishing pressure (Starr & Kendrick 2011). Southland commercial fishers have subsequently increased the commercial pot mesh size in 2017 to 50 mm in an attempt to increase the average size of fish taken by the commercial sector.

4.7 Comparison of pot catches and video observations

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

During the 2010 Marlborough Sounds potting survey concurrent observations of blue cod abundance from a flown drop underwater video (DUV) was also used at 20 survey sites to investigate the relationship between observed density and sizes of blue cod and subsequent catch in nine type 1 pots (Pot Plan 1 in Beentjes & Francis 2011). The DUV had a much higher proportion of small blue cod than the type 1 pots, and a correlation between average density and catch was 0.27 for all and -0.19 for blue cod 30 cm or larger (Beentjes & Carbines 2012). During the 2010 Foveaux Strait potting survey concurrent observations of blue cod abundance from a DUV were also used (at 12 survey sites and 5 fixed sites) to investigate the relationship between observations and catch of blue cod caught in six type 2 pots (Pot Plan 2 in Beentjes & Francis 2011). The DUV again had a higher proportion of small blue cod than the type 2 pots, and a correlation between average density and catch was 0.5 for all and 0.54 for blue cod 20 cm or larger (Carbines & Beentjes 2012). The correlations between blue cod observed by video and the subsequent catch in the current study (Section 3.10) were considerably stronger for both type 1 and type 2 pots (n = 8 sites) than those observed in similar studies in both the Marlborough Sounds (type 1 pots at 20 sites, Beentjes and Carbines 2012) and the Foveaux Strait (type 2 pots at 17 sites, Carbines and Beentjes 2012). Environmental conditions that maximise catchability strengthen the relationship between what is observed in situ and what is subsequently caught, and during the current study blue cod were all observed during the tidal flow and caught at slack water. The two previous studies set pots over a variety of tidal phases, but the current study set pots only at slack water, a time considered to maximise catchability in Foveaux Strait (Warren et al. 1997). Consequently, the stronger relationship between catch and count observed in the current study is likely to represent something closer to maximum catchability.

The two pot types seem generally similar in their catchability of blue cod 30 cm or larger, but have obvious differences with smaller blue cod (Figure 13). Consequently, catch rates and mortality estimates should not be compared between surveys using different pot types. In the current experimental study type 1 pots caught proportionately more blue cod over 28 cm and fewer under 26 cm than the DUV, while type 2 pots caught proportionately more blue cod over 25 cm and fewer under 22 cm (Figure 11). When considered in conjunction with previous larger-scale comparisons of both type 1 (Beentjes & Carbines 2012, Cole et al. 2001) and type 2 pots (Carbines & Beentjes 2012, Carbines & Haist 2014), the obvious size selectivity bias and repeatedly weak relationships between in situ observations and subsequent potting survey catches suggest that neither pot type is particularly suitable for estimating the density of fish less than 30 cm (especially type 1 pots, see Figure 11).

The size selectivity of all three methods appears to be similar for fish over 30 cm, and the relationship between catch and count (i.e., catchability) appears to improve for larger fish in the current study. However, there has been sufficient variation in catchability over time and/or location for both pot types in other studies (Cole et al. 2001, Beentjes & Carbines 2012, Carbines & Beentjes 2012, Carbines & Haist 2014, 2017) to question the consistency of blue cod catchability and consequently the reliability of potting surveys as a relative index for blue cod abundance and population structure (Stephenson et al. 2009).

The poor relationships between relative abundance for pots and the abundance estimates from in situ observations are often the result of catch from pots not increasing to the same degree as the abundance estimates (Cole et al. 2001, Beentjes & Carbines 2012, Carbines & Beentjes 2012, Carbines & Haist 2014, 2017) and suggests possible hyperstability for the pot indices. Video footage from the cameras placed inside each of the two pot types showed that blue cod can exit via the entry cones at all times, and that it is only the bait that retains fish in both pot types. This observation supports the conclusion of Cole et al. (2004) that a shorter set duration might greatly improve the efficiency of pots, and consequently future potting surveys should record bait depleted to determine if there is a relationship between bait loss and catch rates.

5. ACKNOWLEDGMENTS

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Table 1: Foveaux Strait 2014 survey stratum area, number of phase 1 and 2 sites, pot lifts, and depth of sites.

	Size of strata *	Number of selected sites (0)		Number of pot lifts (0)	Depth (m)	
Stratum	Area (km^2)	Phase 1	Phase 2	Total	Mean	Range
1	221.8	6	1	42	47.0	27–58
2	245.0	6	1	42	39.8	31–52
4	160.0	6		36	31.5	7–40
5	248.6	6		36	33.9	21–36
6	261.8	6		36	25.5	11–37
7	367.6	6	3	54	24.4	9–49
8	590.7	6		36	45.3	24–57
10	238.8			36	42.9	12–63
Total	2 334.3	48	5	318	35.8	7–63

Table 2: Catch weights, numbers of blue cod, bycatch species, and percentage of total weight from the 2014 Foveaux Strait random sites survey (n = 53).

Common name	Scientific name	Catch (kg)	Number	Percent of total catch
Blue cod	*Parapercis colias*	2 887.7	6 668	87.63
Leather jacket	*Parika scaber*	333.0	1 010	10.11
Scarlet wrasse	*Pseudolabrus miles*	21.7	41	0.66
Octopus	*Octopus cordiformis*	21.4	5	0.65
Banded wrasse	*Notolabrus fucicola*	15.4	32	0.47
Maori chief	*Paranotothenia angustata*	4.0	3	0.12
Trumpeter	*Latris lineata*	3.0	6	0.09
Blue moki	*Latridopsis ciliaris*	2.3	5	0.07
Tarakihi	*Nemadactylus macropterus*	2.2	9	0.07
Girdled wrasse	*Notolabrus cinctus*	1.4	3	0.04
Sand shark	*Odontaspis ferox*	1.3	1	0.04
Red cod	*Pseudophycis bachus*	0.9	1	0.03
Spotty	*Notolabrus celidotus*	0.6	1	0.02
Paddle crab	*Ovalipes catharus*	0.3	3	0.01
Total		3 295.2	7 788	100.00

Table 3: Mean catch rates for all blue cod caught in the 2014 Foveaux Strait random site survey (see Figure 2). Catch rates are expressed as kg.pot^{-1} and s.e. and CV are set-based estimates. s.e., standard error, CV, coefficient of variation. For strata 7 and 8 the results are also provided (in italics) using the 2010 stratification (see Figure 2).

Stratum	Sites	Pot lifts (N)	Mean (kg/pot)	s.e.	CV (%)
1	7	42	16.22	3.58	22.08
2	7	42	15.41	2.22	14.41
4	6	36	5.48	3.00	54.78
5	6	36	9.42	4.13	43.88
6	6	36	3.16	1.41	44.53
7	9	54	11.45	1.98	17.27
7 (2010 stratum)	*7*	*42*	*9.92*	*2.99*	*30.08*
8	6	36	0.32	0.19	58.67
8 (2010 stratum)	*8*	*48*	*4.44*	*2.08*	*46.87*
10	6	36	7.76	4.80	61.84
Total	53	318	7.57	0.88	11.60
(2010 stratum)	*53*	*318*	*8.48*	*1.09*	*12.85*

Table 4: Mean catch rates for blue cod 33 cm and over (MLS in BCO 5) caught in the 2014 Foveaux Strait random site survey (see Figure 2). Catch rates are expressed as kg.pot^{-1} and s.e. and CV are set-based estimates. s.e., standard error, CV, coefficient of variation. For strata 7 and 8 the results are also provided (in italics) using the 2010 stratification (see Figure 2).

Stratum	Sites	Pot lifts (N)	Mean (kg/pot)	s.e.	CV (%)
1	7	42	6.50	0.99	15.21
2	7	42	5.88	0.87	14.80
4	6	36	2.62	1.19	45.31
5	6	36	3.34	1.33	39.71
6	6	36	1.72	0.75	43.58
7	9	54	5.35	0.53	9.93
7 (2010 stratum)	*7*	*42*	*4.09*	*0.95*	*23.24*
8	6	36	0.23	0.17	72.27
8 (2010 stratum)	8	48	2.62	1.11	42.58
10	6	36	1.93	0.87	45.05
Total	53	318	3.06	0.26	8.49
(2010 stratum)	*53*	*318*	*3.50*	*0.39*	*11.26*

Table 5: Mean lengths of blue cod in the 2014 Foveaux Strait random site survey, by strata and sex: m, males; f, female. The sex ratio is shown as the number of females per male, and the percent of males (shown in brackets) is also given for all blue cod and those over the MLS (33 cm).

			Length (cm)			Sex ratio M:F (% male)	
Strata	Sex	N	Mean	Minimum	Maximum	All blue cod	≥33 cm
1	M	647	31.0	19	44	1:1.3(43.5)	1:0.5(66.8)
	F	842	29.2	17	41		
2	M	471	31.6	21	44	1:2.0(33.3)	1:0.6(62.5)
	F	942	29.4	20	39		
4	M	260	30.2	17	44	1:0.9(53.3)	1:0.2(83.7)
	F	228	26.2	15	41		
5	M	508	28.7	15	42	1:0.6(62.3)	1:0.1(88.5)
	F	307	24.2	13	38		
6	M	163	28.7	17	42	1:0.7(57.8)	1:0.5(65.4)
	F	119	27.1	16	43		
7	M	802	31.1	16	46	1:0.8(56.6)	1:0.1(93.0)
	F	615	26.8	18	37		
8	M	16	29.8	19	37	1:1.2(45.7)	1:0.3(75.0)
	F	19	18.7	9	36		
10	M	276	29.9	14	46	1:1.6(37.9)	1:0.4(70.8)
	F	453	27.6	19	35		
Overall (un-weighted)	M	3 143	30.4	14	46	1:1.1(47.1)	1:0.3(75.5)
	F	3 525	27.9	9	43		

Table 6: Gonad stages of Foveaux Strait blue cod in 2014 random sites. 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 (%)					
	1	2	3	4	5	N
Males	1.8	86.4	0.2	9.5	2.1	3 143
Females	0.8	83.7	0.8	10.5	4.3	3 525

Table 7: Otolith raw data used in the catch-at-age, *Z* estimates, and SPR analyses for 2014 Foveaux Strait random sites.

	No.	Length of aged fish (cm)			Age (years)		
Survey	otoliths	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Total	222	28.9	9	46	5.4	0	14
Male	116	30.5	14	46	5.4	1	14
Female	106	27.1	9	43	5.4	0	11

Table 8: Blue cod total mortality estimates (*Z*) with 95% confidence intervals and corresponding spawning biomass per recruit ratios (assuming *M* = 0.14) for ages of recruitment (AgeR) from 5 to 9 for the 2014 Foveaux Strait random site survey.

	Chapman-Robson Z				Catch curve Z
		Confidence intervals			
AgeR	*Z*	Lower	Upper	%SPR	Z
5	0.59	0.40	0.88	23%	0.81
6	0.67	0.46	1.03	21%	0.87
7	0.69	0.46	1.13	21%	0.92
8	0.71	0.44	1.19	20%	0.99
9	0.87	0.48	1.57	18%	1.11

Table 9: Mortality rates and spawning biomass per recruit ratios, assuming an age of recruitment of 8, at three values of *M* (natural mortality) for the 2014 Foveaux Strait random site survey. *Z* = total mortality.

M	*Z*	%SPR
0.11	0.71	15%
0.14	0.71	20%
0.17	0.71	26%

Table 10: Experimental design used to compare pot types.

Level	N
Sites	8
Designs (Pot Plans 1 & 2)	2
Pots (replicates)	3
Total pots set	48

Table 11: Drop underwater video (DUV) and pot sample details. Note that stations are individual transects and pots.

	DUV	Type 1	Type 2
Sites	8	8	8
Stations	40	24	24
Total transects length	29.6 km		
Mean transect length	740.6 m (± 22.5)		
Mean transect width	3.2 m (± 0.1)		
Total area swept	95 576.8 m^2		
Blue cod			
Total	1555	531	960
Male		353	466
Female		178	494
M:F ratio		1:0.5	1:1.1
% male		66.5%	48.5%
length range cm	5–46	20–43	11–44
Mean length ± se	23.2±0.2	31.6±0.1	27.6±0.1

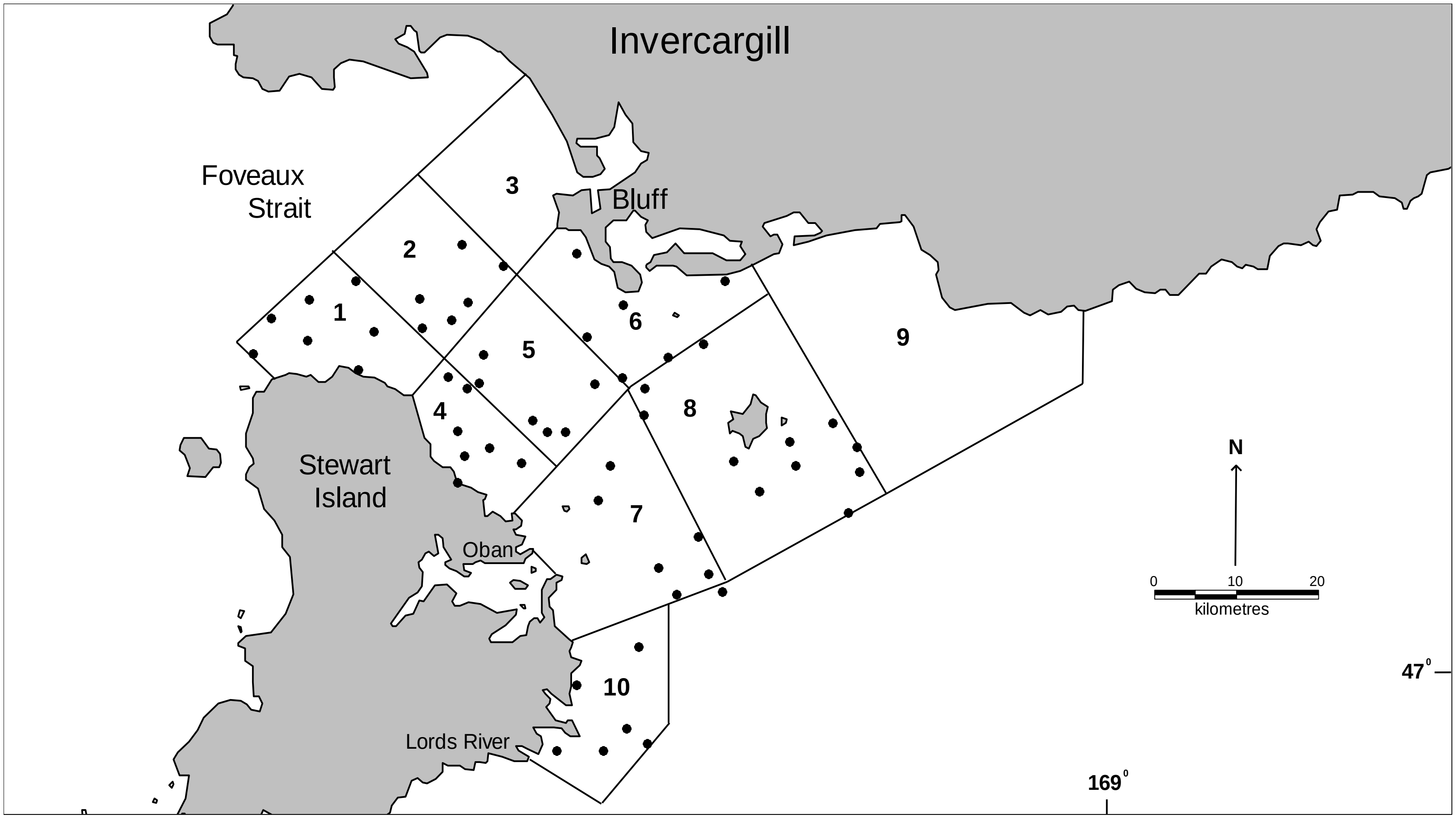


Figure 1: Sites surveyed in the 2010 Foveaux Strait survey. Strata 3 and 9 were not surveyed in 2010 (Carbines & Beentjes 2012).

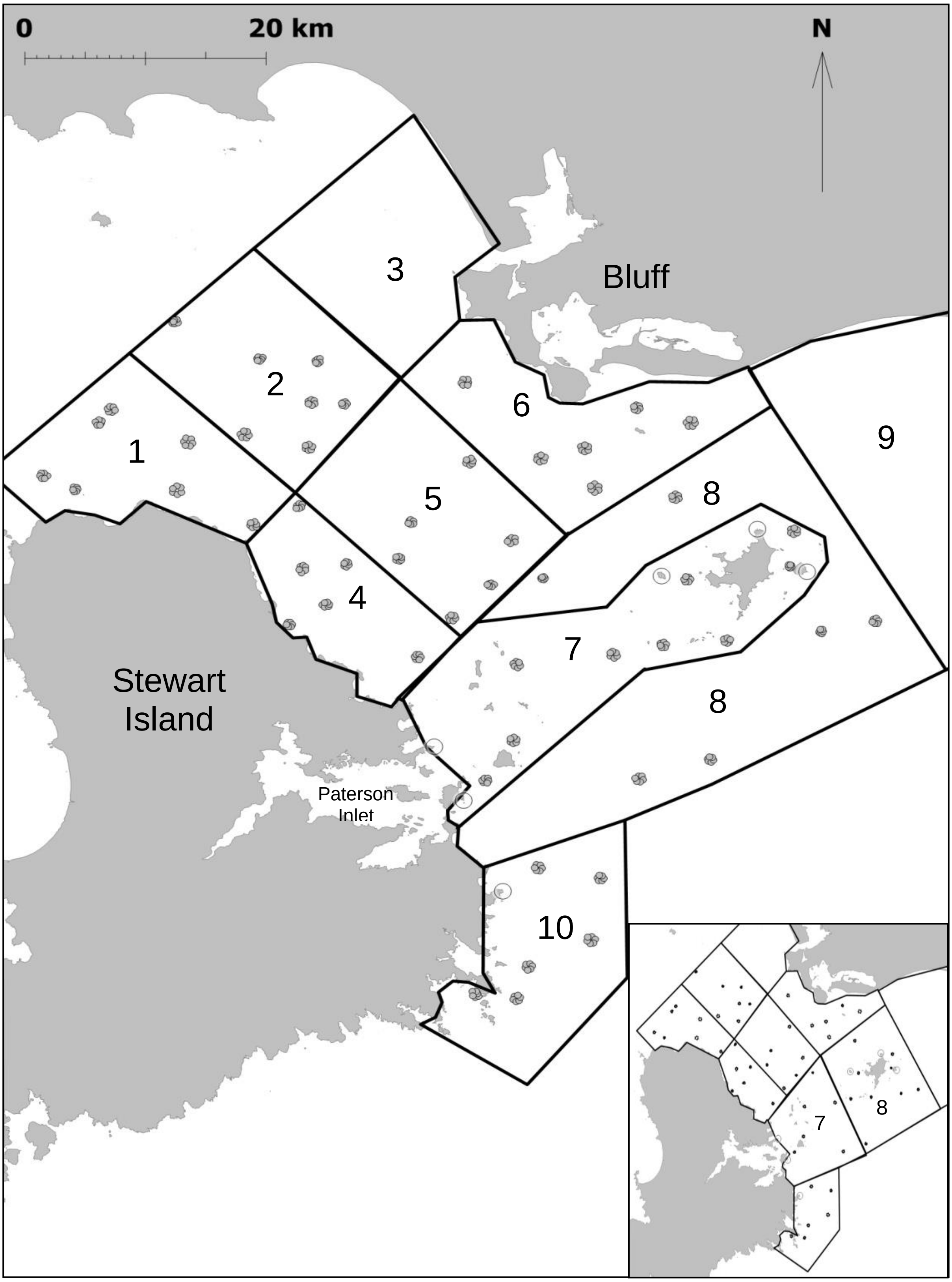


Figure 2: Strata polygons and sites (with pot locations shown) surveyed in the 2014 Foveaux Strait survey. Strata 3 and 9 were not surveyed in either 2010 or 2014. The areas of strata 7 and 8 were redrafted based on seabed habitat type in 2014, the original 2010 stratification is shown in the bottom right insert.

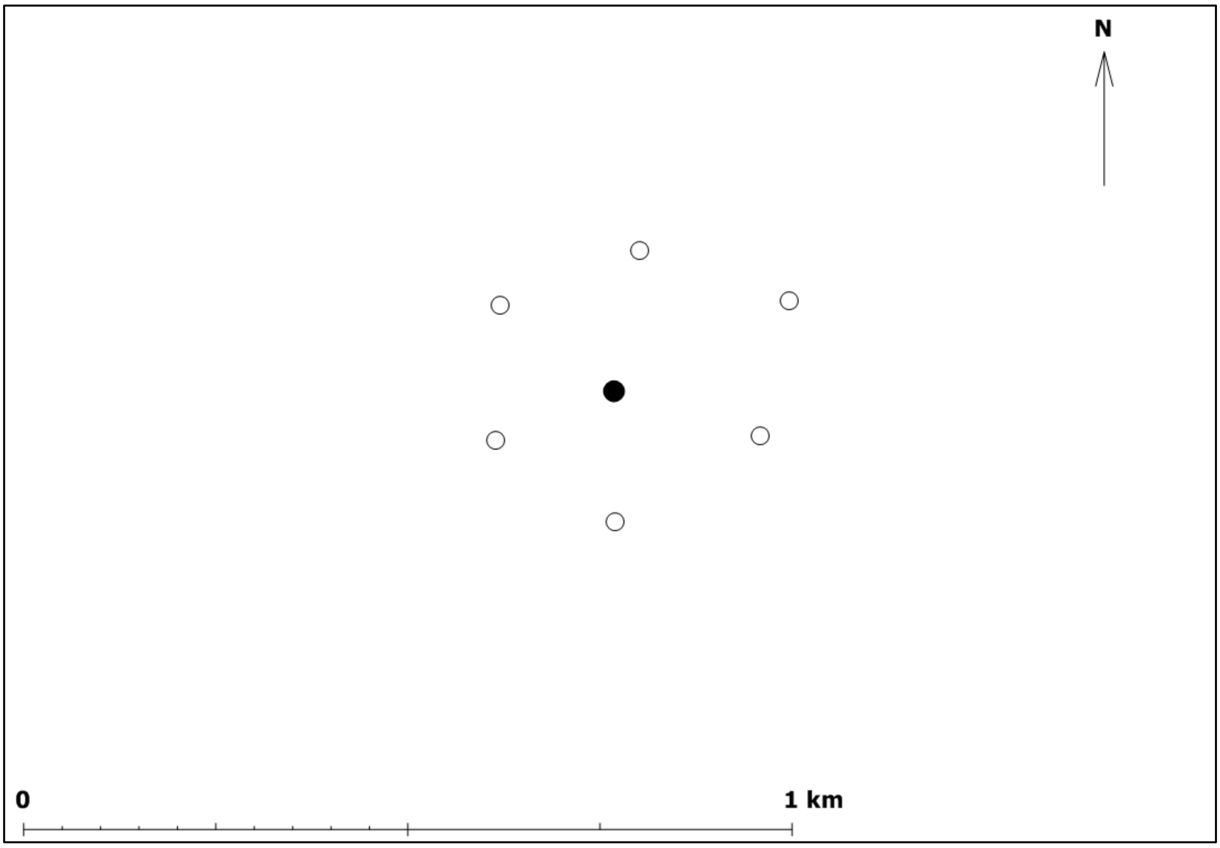
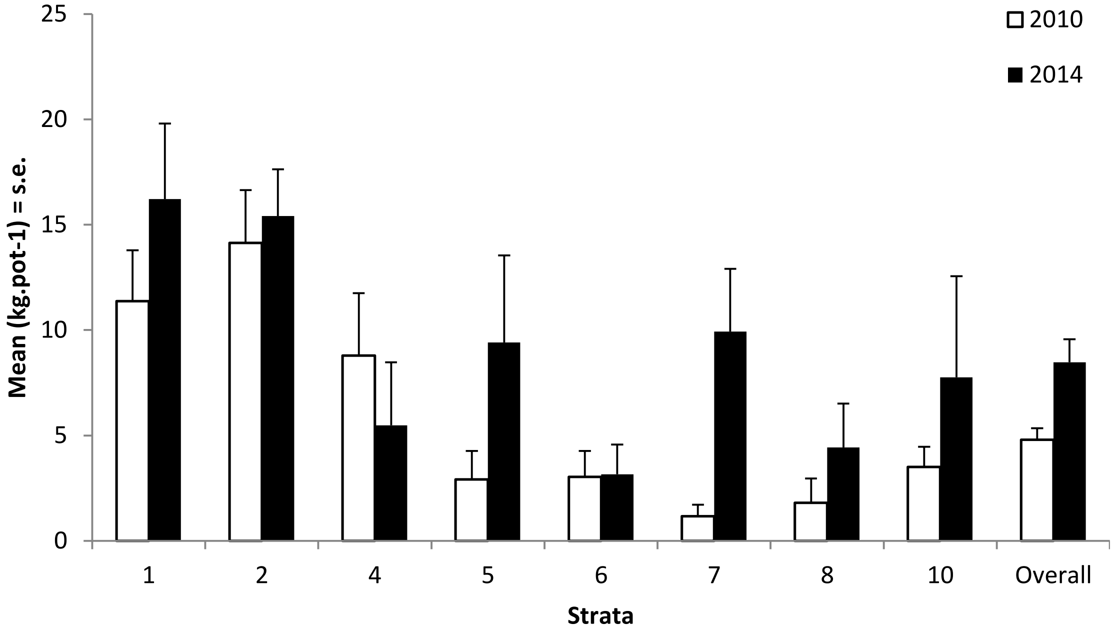


Figure 3: A typical random site with the ADCP (●) placed central to pots (○) set in a fixed hexagon pattern approximately 300 m apart.



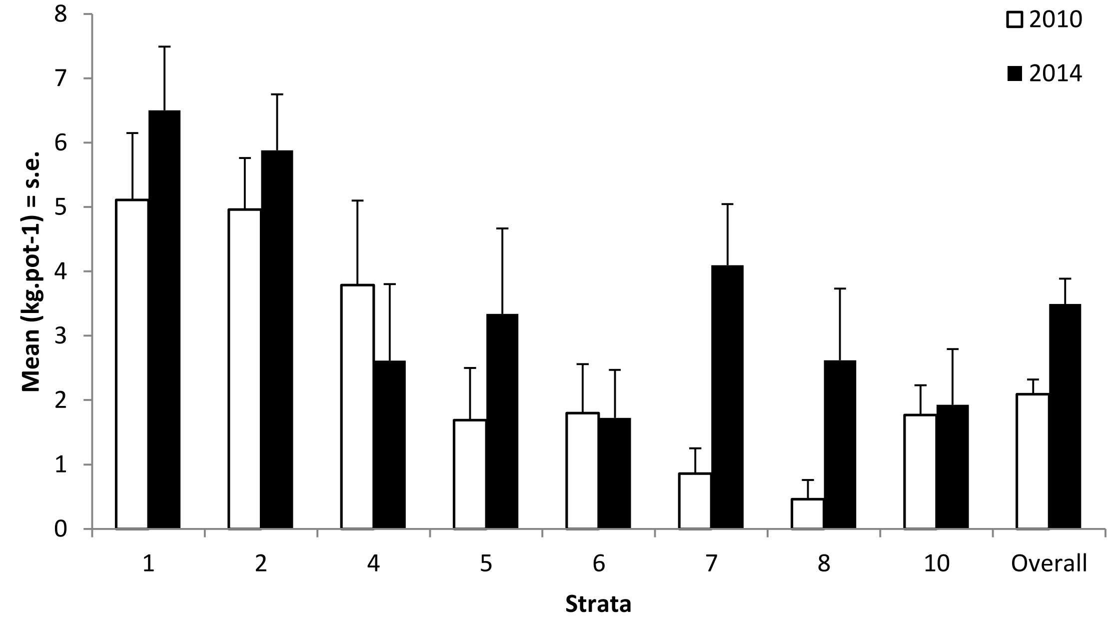


Figure 4: Catch rates (kg.pot^{-1}) and 95% confidence intervals for all blue cod (above) and those 33 cm and over (below) from the 2010 and 2014 Foveaux Strait random site surveys. Strata and sites are shown in Figure 2.

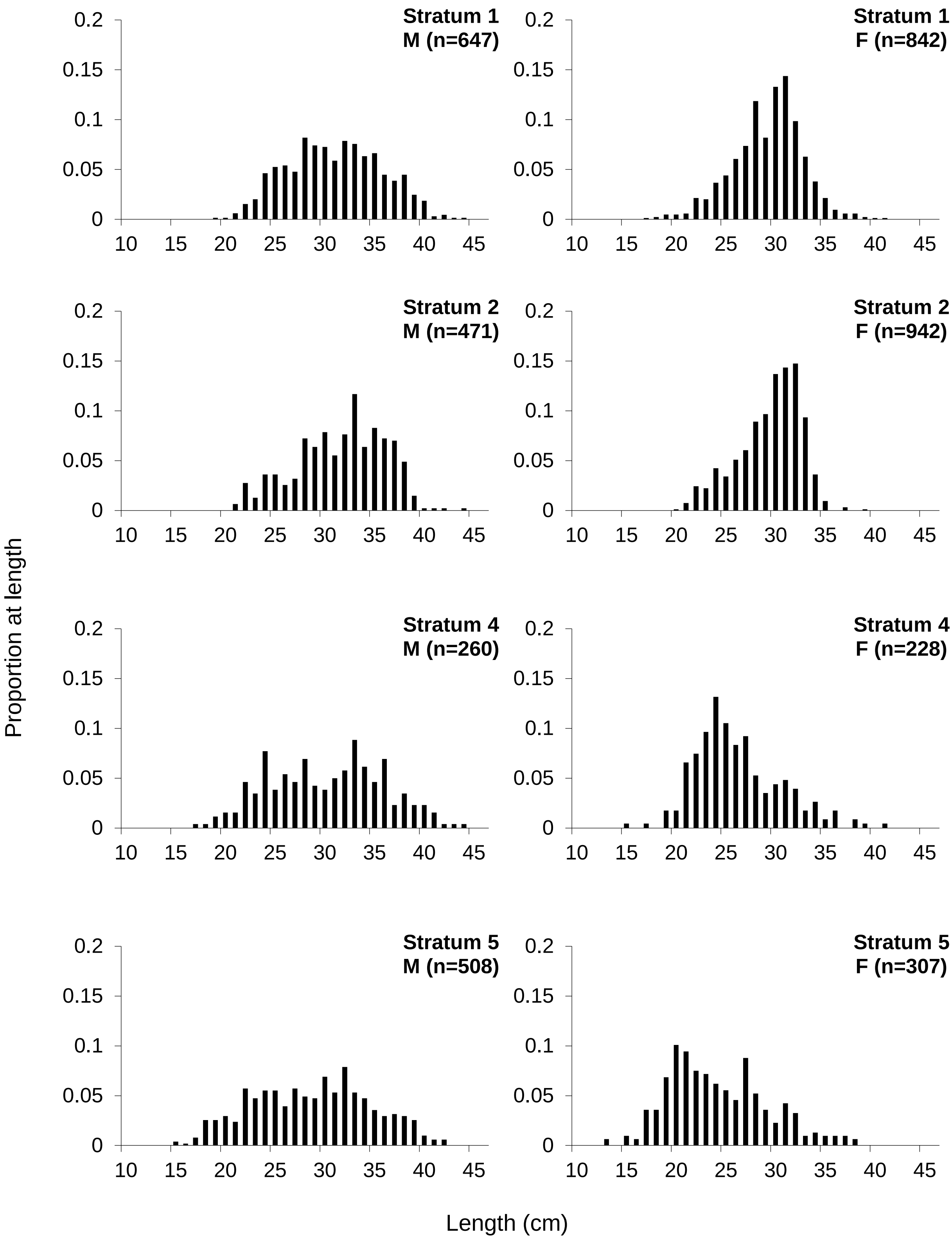


Figure 5: Unscaled proportion length-frequency distributions by sex within stratum for the 2014 Foveaux Strait survey, cumulative length-frequency distributions by sex for both the 2010 and 2014 Foveaux Strait surveys (all strata). Proportions for each sex within each stratum sum to 1. Strata are shown in Figure 2. [Continued on next page]

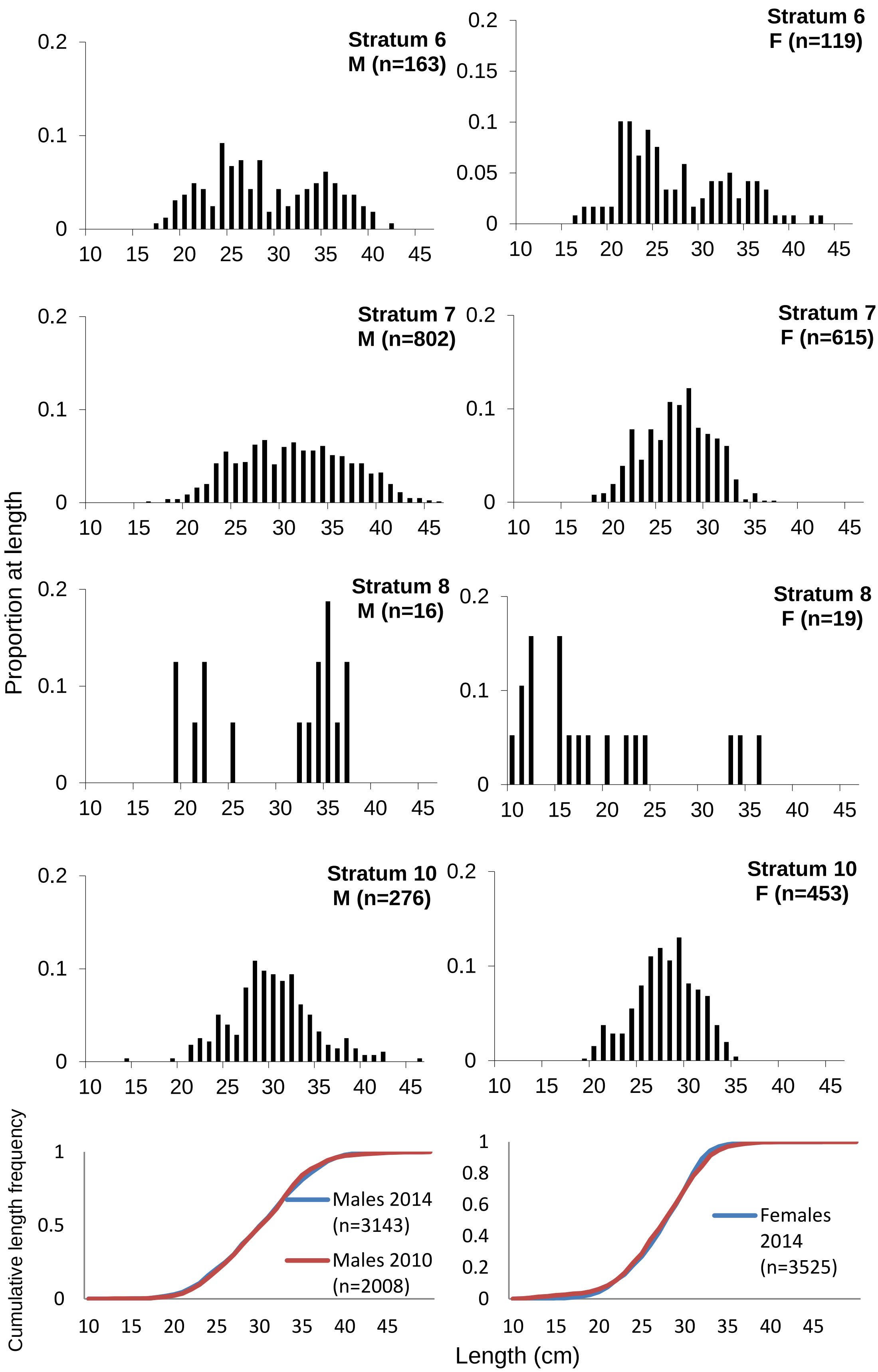


Figure 5 [Continued]: Unscaled proportion length-frequency distributions by sex within stratum for the 2014 Foveaux Strait survey, cumulative length-frequency distributions by sex for both the 2010 and 2014 Foveaux Strait surveys (all strata). Proportions for each sex within each stratum sum to 1. Strata are shown in Figure 2.

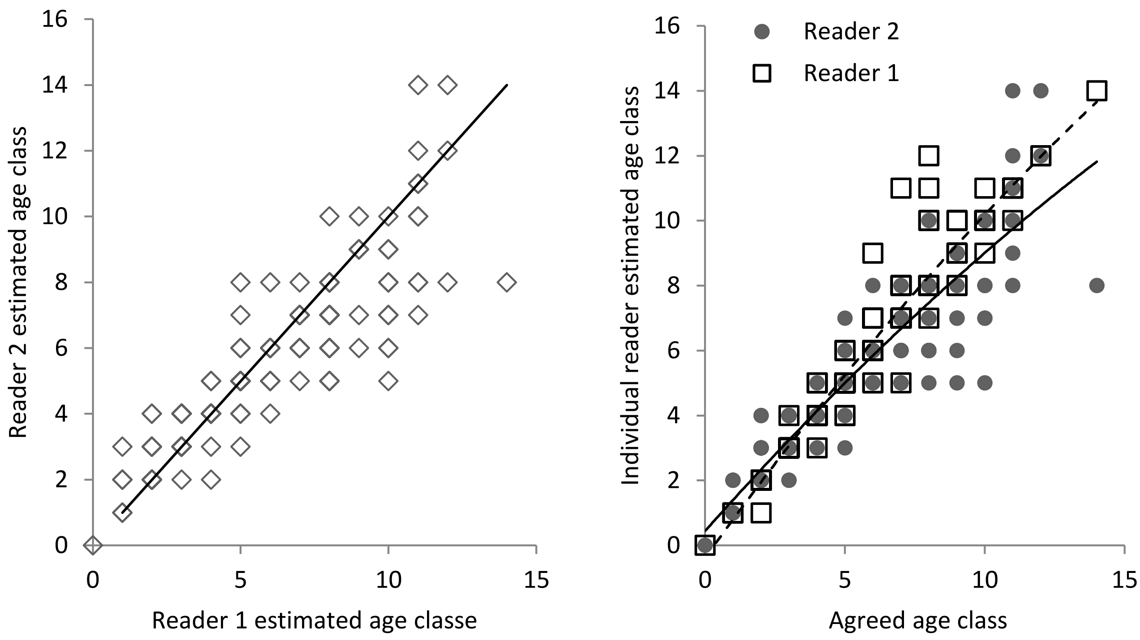


Figure 6: Foveaux Strait 2014 survey comparison of individual reader age class estimates from otoliths (n = 222), on the right plotted against each other and on the left with the 1:1 line (solid) fitted, as well as the mean for each age recorded by reader 2 for each age recorded by reader 1 (dashed polynomial trend line fitted).

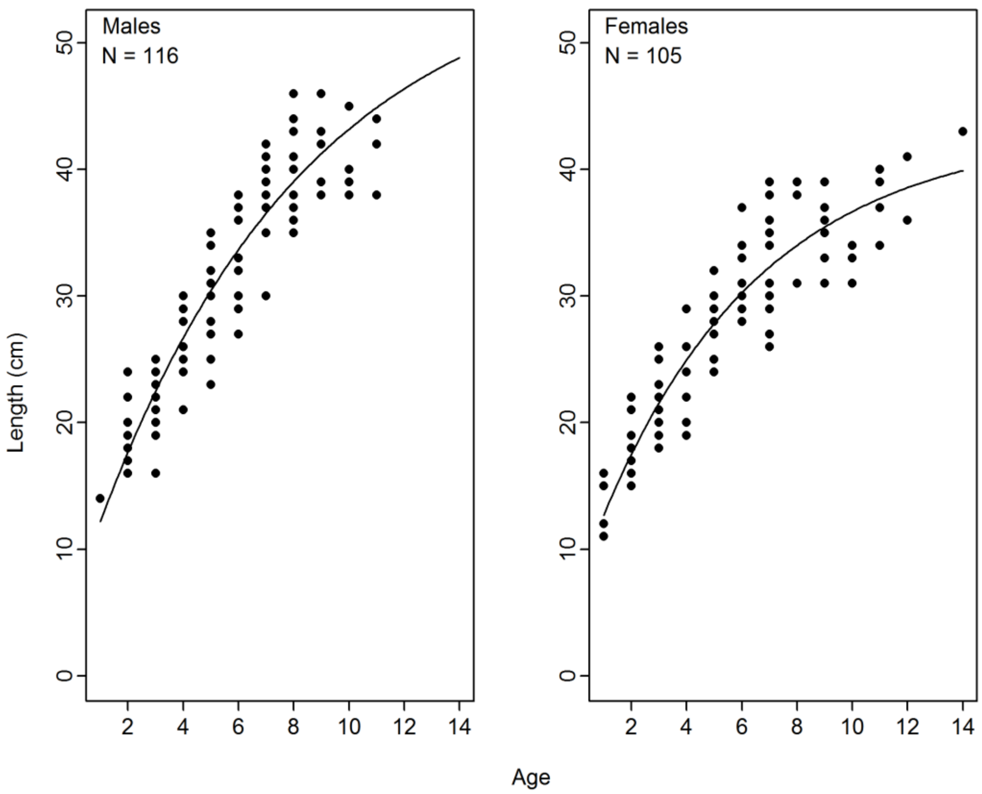


Figure 7: Observed length-at-age data and fitted von Bertalanffy growth models by sex for the 2014 Foveaux Strait survey. See Table 7 for description of biological samples.

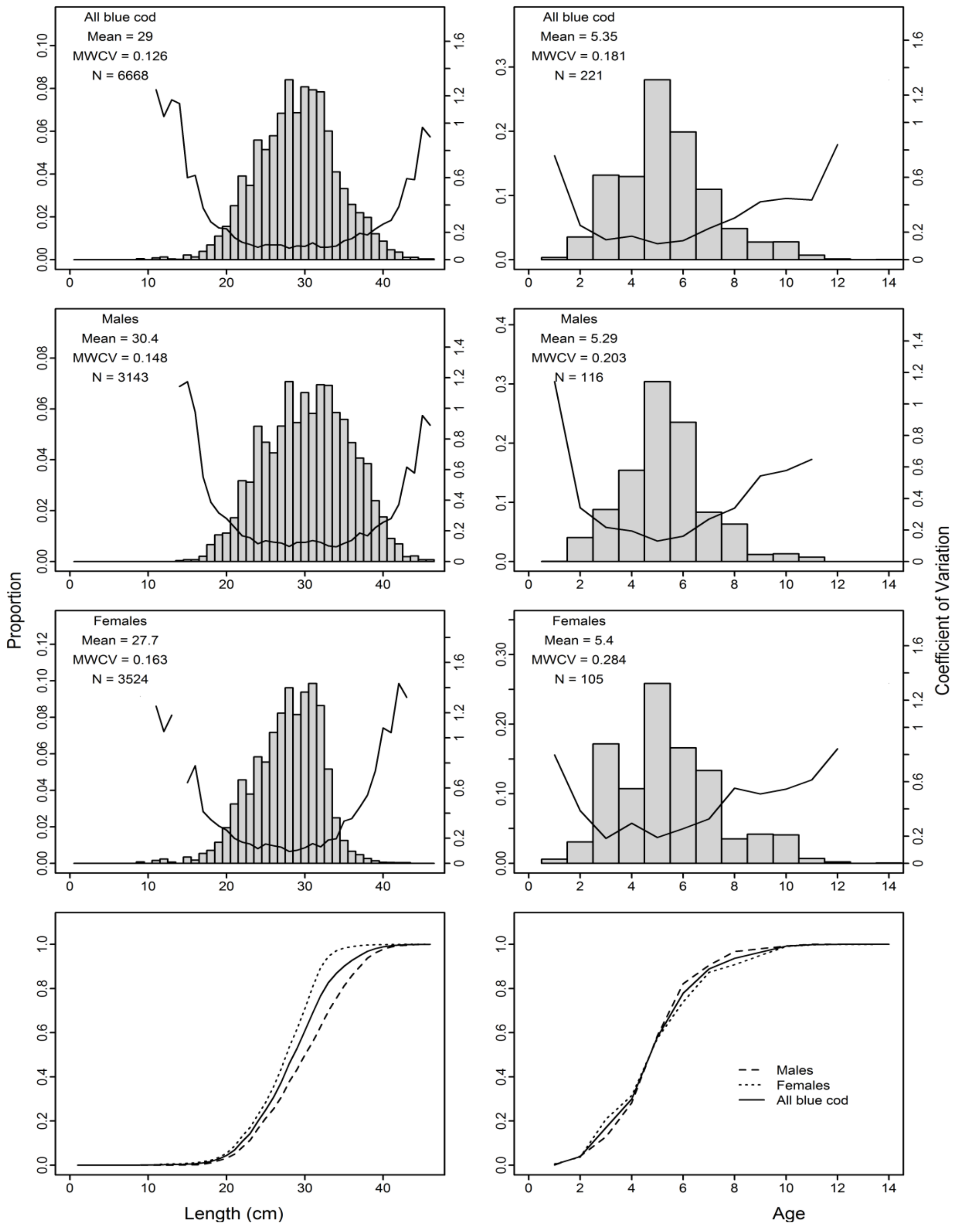
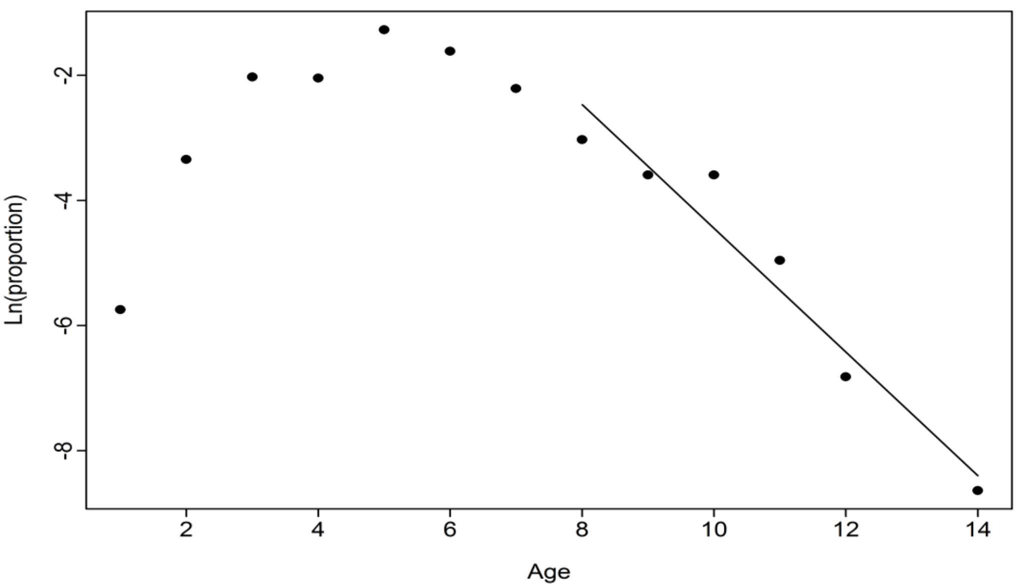


Figure 8: Scaled length-frequency, age-frequency, and cumulative distributions for total, male and female blue cod for the 2014 Foveaux Strait random site potting survey. N, sample size; MWCV, mean weighted coefficient of variation.



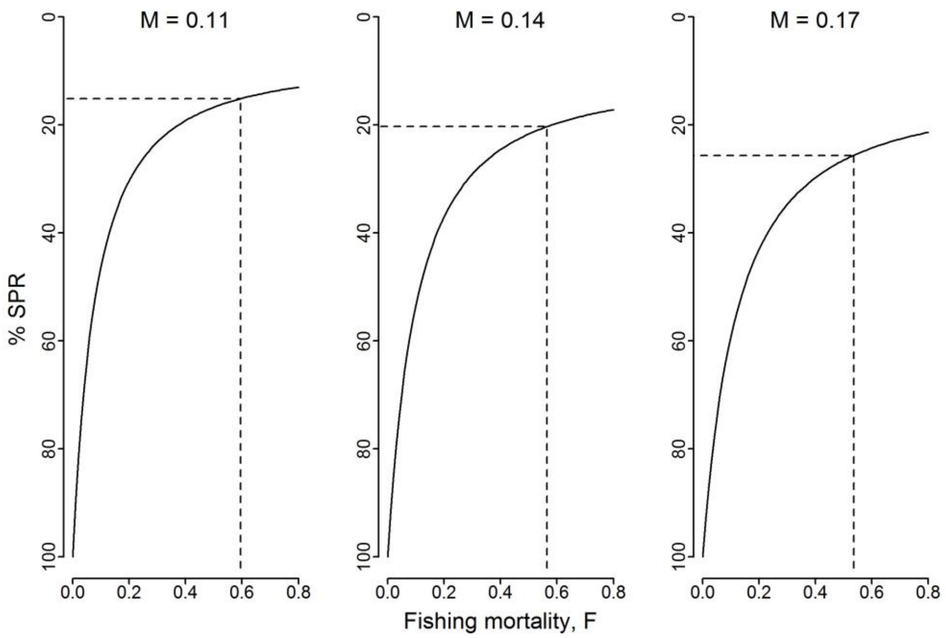


Figure 9: [Top] The natural log of proportions-at-age (sexes combined) for the 2014 Foveaux Strait survey. The line shows the regression fit of the log of proportions vs. age, fitted to ages 8 through 14 (slope = --0.99). Note that there were no fish aged 13 so these are not included in the fit. [Bottom] Plot of spawner per recruit (SPR) relative to unfished SPR (%SPR) as a function of fishing mortality for the 2014 Foveaux Strait random site potting survey at three values of *M* (0.11, 0.14, 0.17). The dashed line shows the survey estimate of *F* and resulting %SPR, assuming an age at recruitment of 8. The y-axis has been inverted because a low fishing mortality corresponds to a high %SPR.

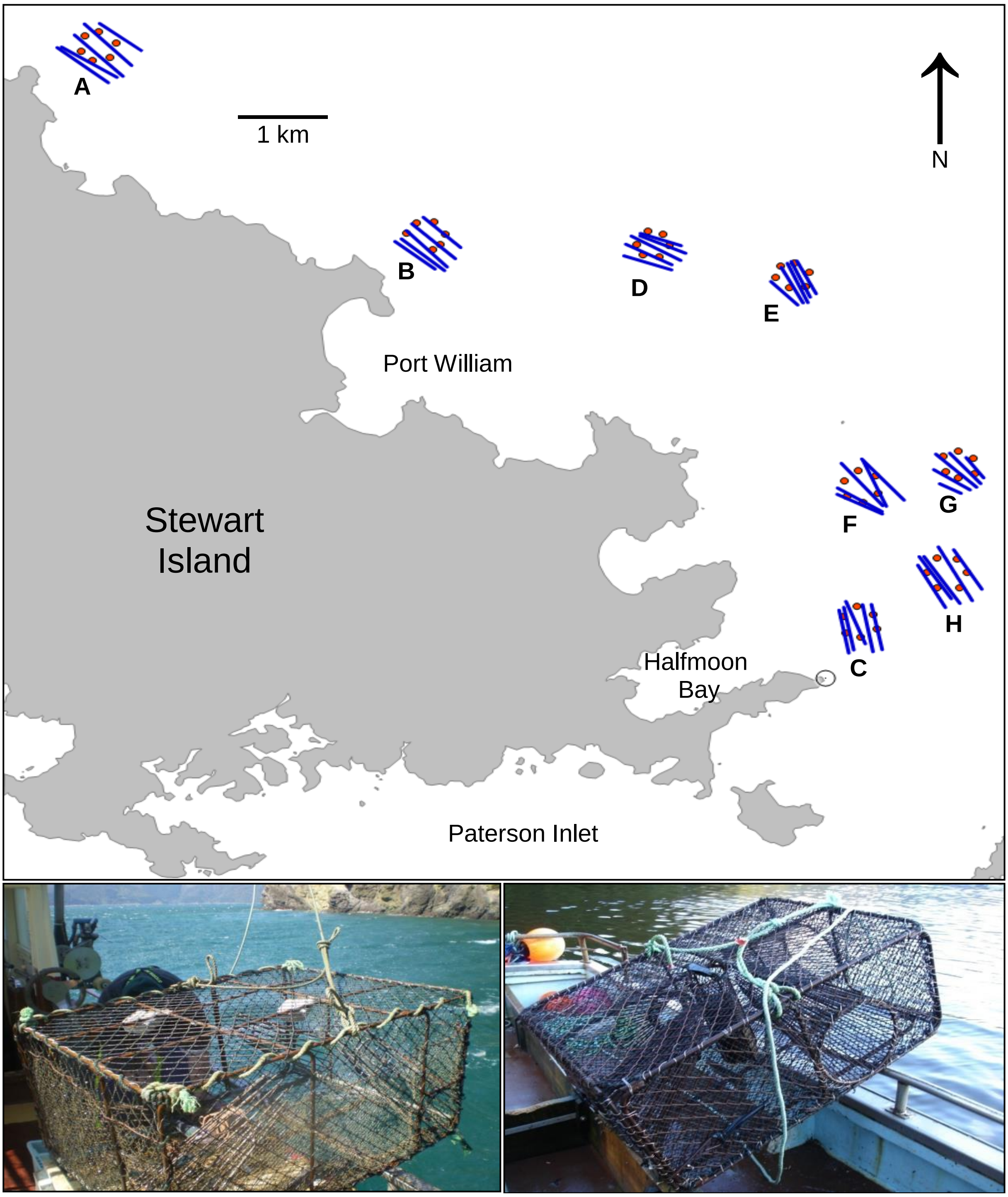


Figure 10: Top eight selected sites used for pot type comparisons (n = 24 type 1 pot sets; n = 24 type 2 pot sets – red dots) and DUV transects (n = 40 – blue lines) surveyed prior to pots. Below left is a photo of a type 1 pot, and below right is a photo of a type 2 pot (n = 3 of each pot type per site). A full description of the two blue cod survey pot types is given by Beentjes & Francis (2011). Photos are author's own.

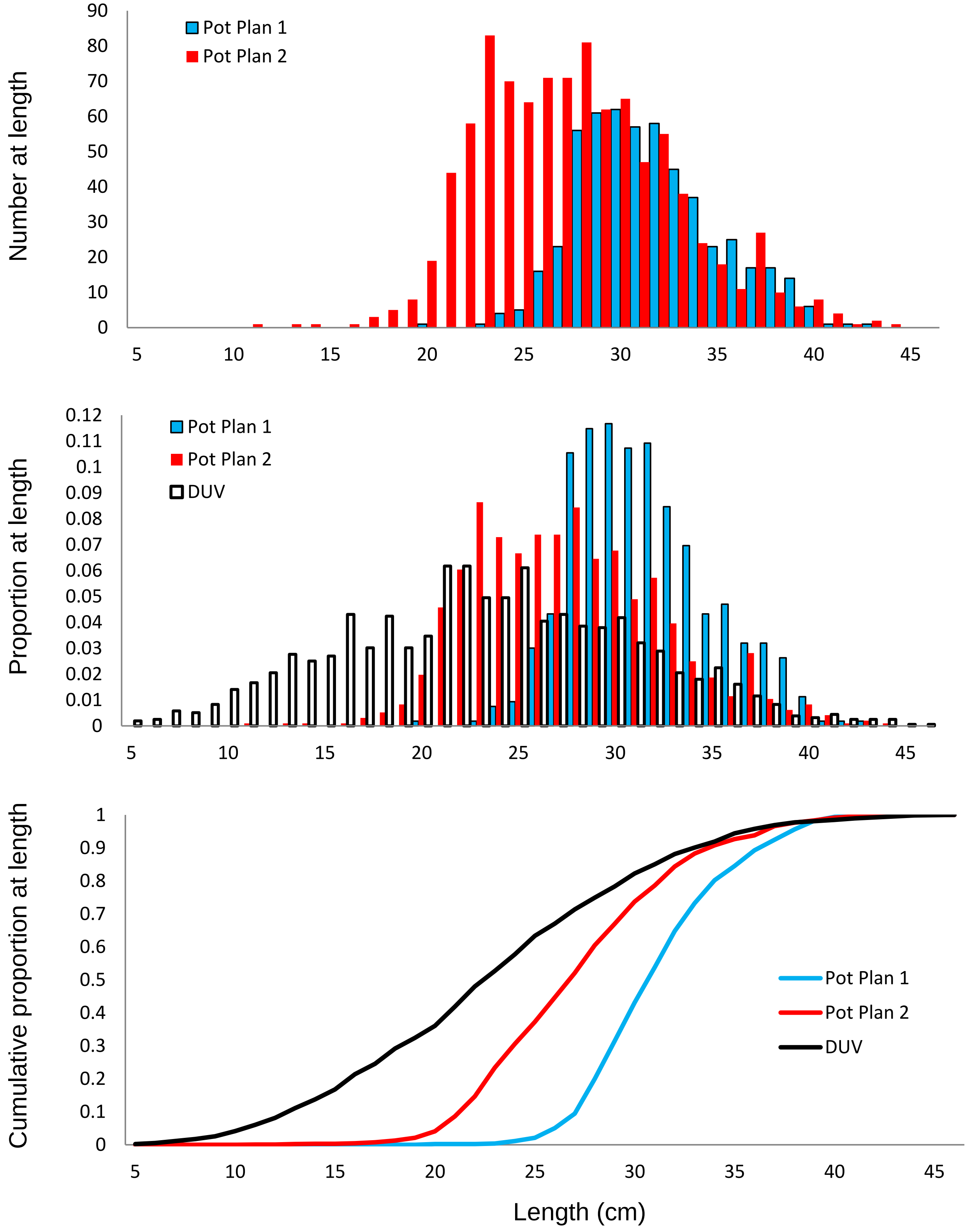


Figure 11: [Top] Absolute catch-at-length for blue cod from concurrent pot type 1 (n = 531) and type 2 (n = 960). [Middle] Proportion-at-length of blue cod video observation size estimates (n = 1393) plotted against concurrent pot type catches. [Bottom] Cumulative proportion-at-length of video observations against pot type catches.

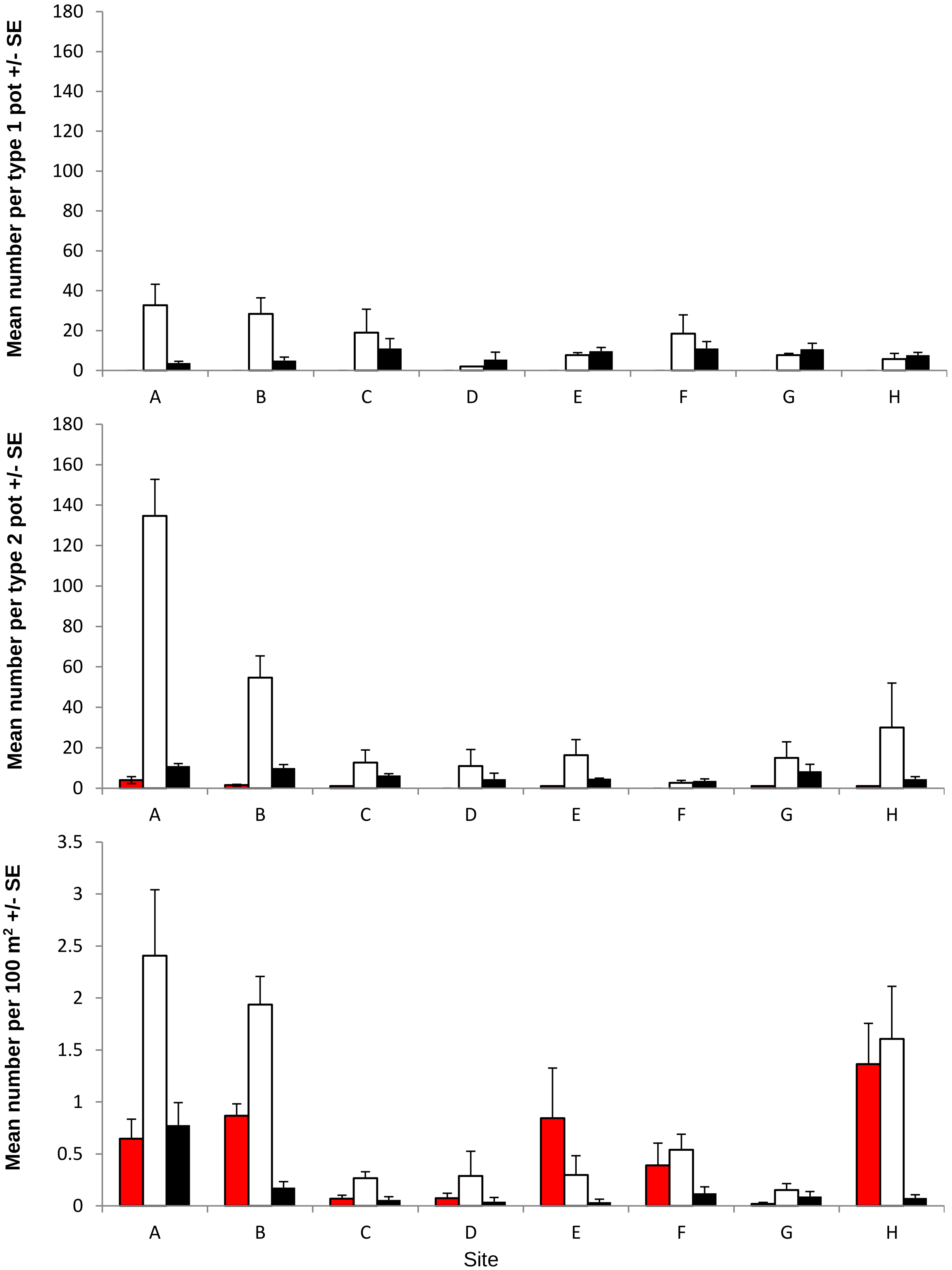


Figure 12: [Top] Mean site relative abundance for three size classes of blue cod from type 1 pots. [Middle] Mean site relative abundance for three size classes of blue cod from type 2 pots. [Bottom] Mean site density estimates from the area swept video method (DUV) for three size classes of blue cod. Error bars are ± one standard error, site locations are shown in Figure 10. Size classes are <20 cm (red), 20–32 cm (white), and ≥33 cm (black).

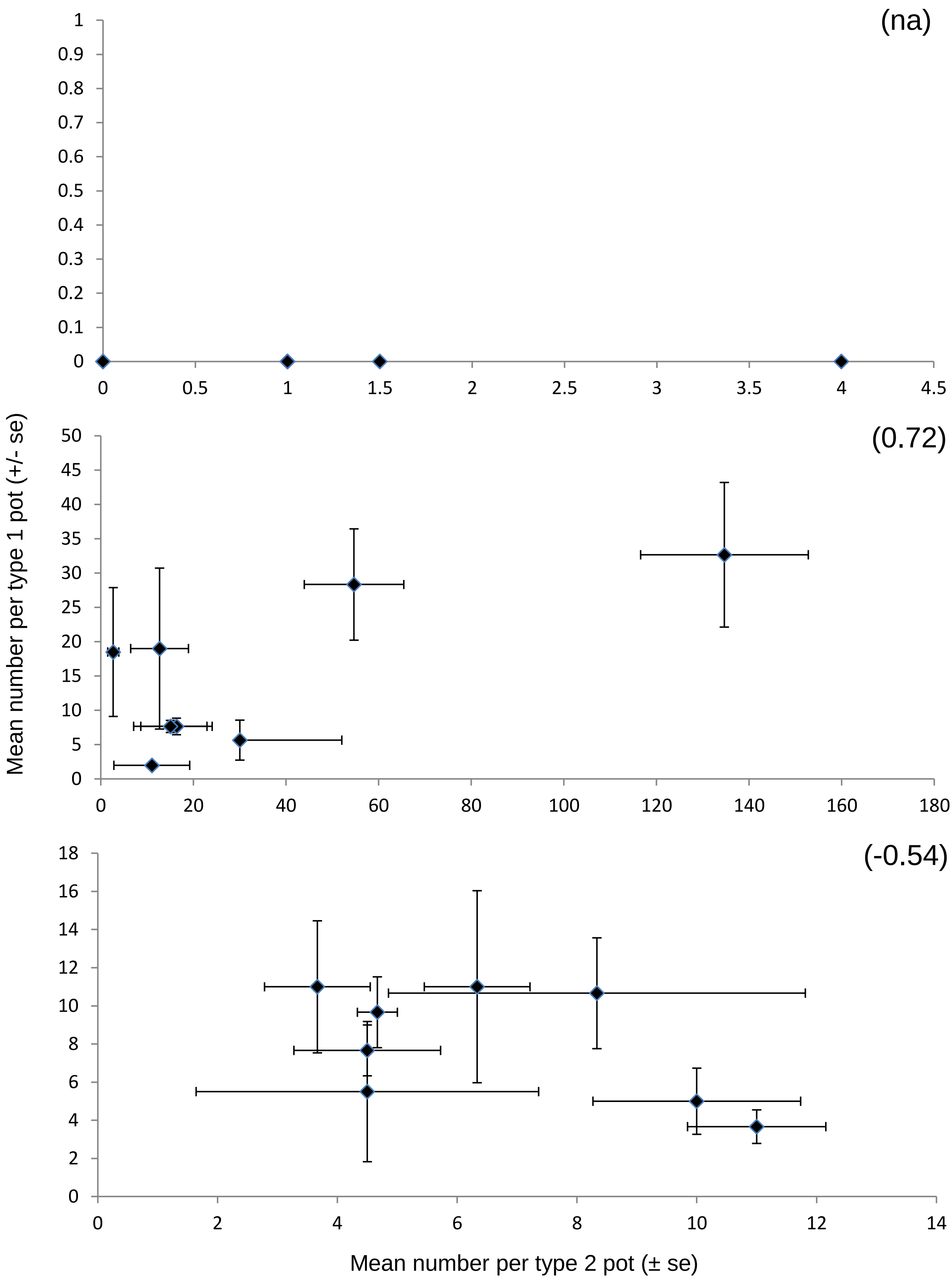


Figure 13: Mean catch rate for three size classes of blue cod (<20 cm (top), 20–32 cm (middle), ≥33 cm (bottom)) dual surveyed with type 1 and type 2 pots, error bars are ± one standard error. The correlation coefficient is shown in brackets for each graph.

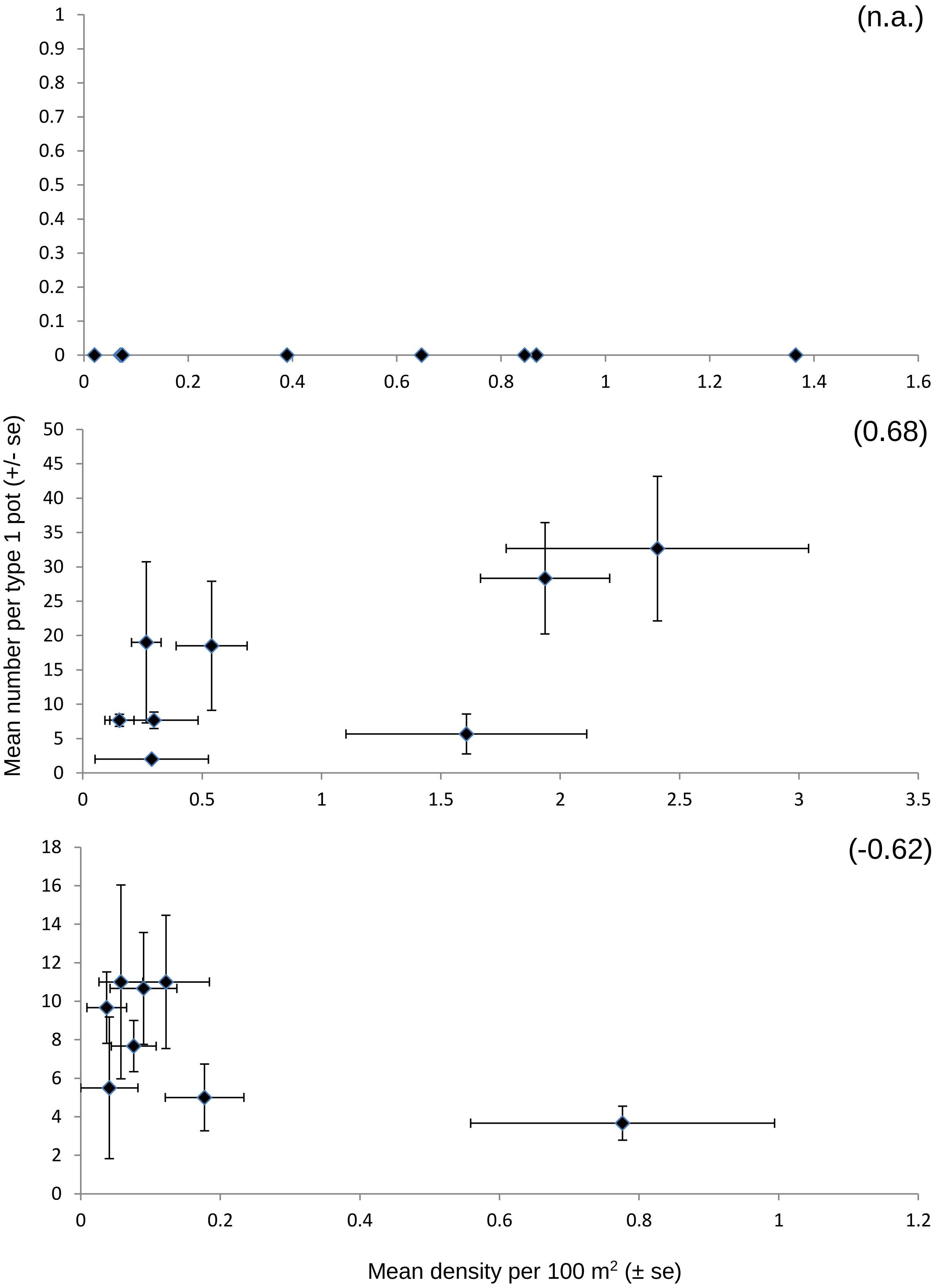


Figure 14: Mean density vs. catch rate for three size classes of blue cod (<20 cm (top), 20–32 cm (middle), ≥33 cm (bottom)) dual surveyed with DUV and type 1 pots, error bars are ± one standard error. The correlation coefficient is shown in brackets for each graph.

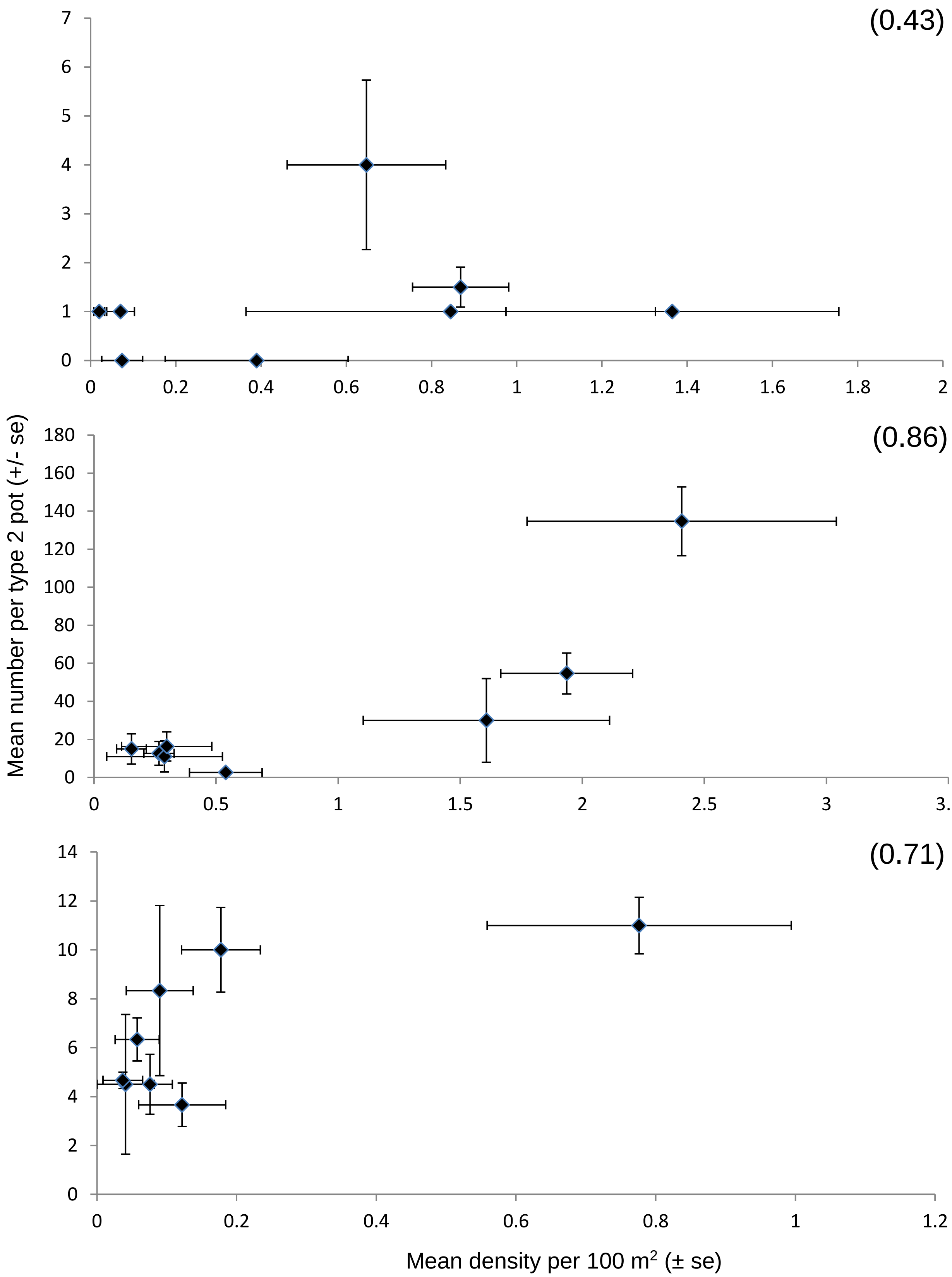


Figure 15: Mean density vs. catch rate (number.pot^{-1}) for three size classes of blue cod (<20 cm (top), 20–32 cm (middle), ≥33 cm (bottom)) dual surveyed with DUV and type 2 pots, error bars are ± one standard error. The correlation coefficient is shown in brackets for each graph.

APPENDIX 1:

Terminology used in potting surveys. In this report we use the terms defined in the blue cod potting survey manual (Beentjes & Francis 2011).

Site	A geographical location near to which sampling may take place during a survey. A site may be either fixed or random (see below). A site may be specified as a latitude and longitude or a section of coastline (for the latter, use the latitude and longitude at the centre of the section).
Fixed site	A predetermined site within a given stratum, that has a fixed location (single latitude and longitude or the centre point location of a section of coastline) and is available to be used repeatedly on subsequent surveys in that area. Fixed sites are known fishing spots identified by local fishers. Which fixed sites are used in a particular survey is determined by random selection from all available fixed sites in each stratum. Fixed sites are sometimes referred to as an index site or a fisher-selected site**.**
Random site	A site that can have any location (single latitude and longitude) generated randomly from within a stratum, given the constraints of proximity to other selected sites for a specific survey.
Site label	An alphanumeric label of no more than 4 characters unique within a survey time series. A site label identifies each site and also specifies which stratum it lies in. Fixed site labels are constructed by concatenating the stratum code with an alpha label (A–Z) that is unique within that stratum. Thus, sites within stratum 2 could be labelled 2A, 2B, and sites in stratum 3 could be labelled 3A, 3B etc. Note that fixed site labels remain constantly fixed to that location for all surveys. In contrast, random sites are regenerated for each survey and use a numeric label based on the order in which they were randomly generated, followed by the letter R and then concatenated with the stratum code. Thus, sites within stratum 2 could be labelled 2R1, 2R3, and sites in stratum 3 could be labelled 3R1, 3R2 etc.
Set	A group of pots deployed in the vicinity of a selected site in a specific survey. The pots are set in a cluster or linear configuration.
Set number	A number assigned to each set within a survey. Set numbers are defined sequentially in the order fished. Thus, any set within a survey is uniquely defined by a trip code and set number. Note that the set number is not recorded in the *trawl* database in isolation, but is entered as part of attribute *station_no* in table *t_station*.
Station	The position (latitude and longitude) at which a single pot (or other fishing gear) is deployed at a site during a survey, i.e., it is unique for the trip.
Pot number	Pots are numbered sequentially (1 to 6) in the order they are placed during a set.
Station number	A number that uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be station number 234. This convention is important in enabling users of the *trawl* database to determine whether two pots are from the same set.
Pot placement	There are two types of pot placement: 1) Directed, where 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 (this is how pots are set at fixed sites); 2) Systematic, where the position of each pot is determined from a fixed pattern set systematically around a site centre point. The pots are set blind with no knowledge of the bottom type (this is how pots are set at random sites).

APPENDIX 2:

Change of ageing method between the 2010 and 2014 surveys.

Otoliths from the 2010 Foveaux Strait random site potting survey (Carbines & Beentjes 2012) were read under transmitted light counting all opaque (dark) zones as per Carbines (2004b). However, a new validation study shows that the fist opaque zone, previously counted as the first annuli, is in fact a juvenile check (Carbines 2016). Furthermore, a new ageing protocol recommends reading blue cod otoliths under reflected light (where opaque zones appear light and translucent zones appear dark), and counting only translucent (dark) zones beyond the juvenile portion of the otolith (Figure A). Otoliths from the 2014 Foveaux Strait random site potting survey were read under the reflected light as per the new ageing protocol as it better distinguished the banding patterns and allowed for a previously unknown juvenile check.

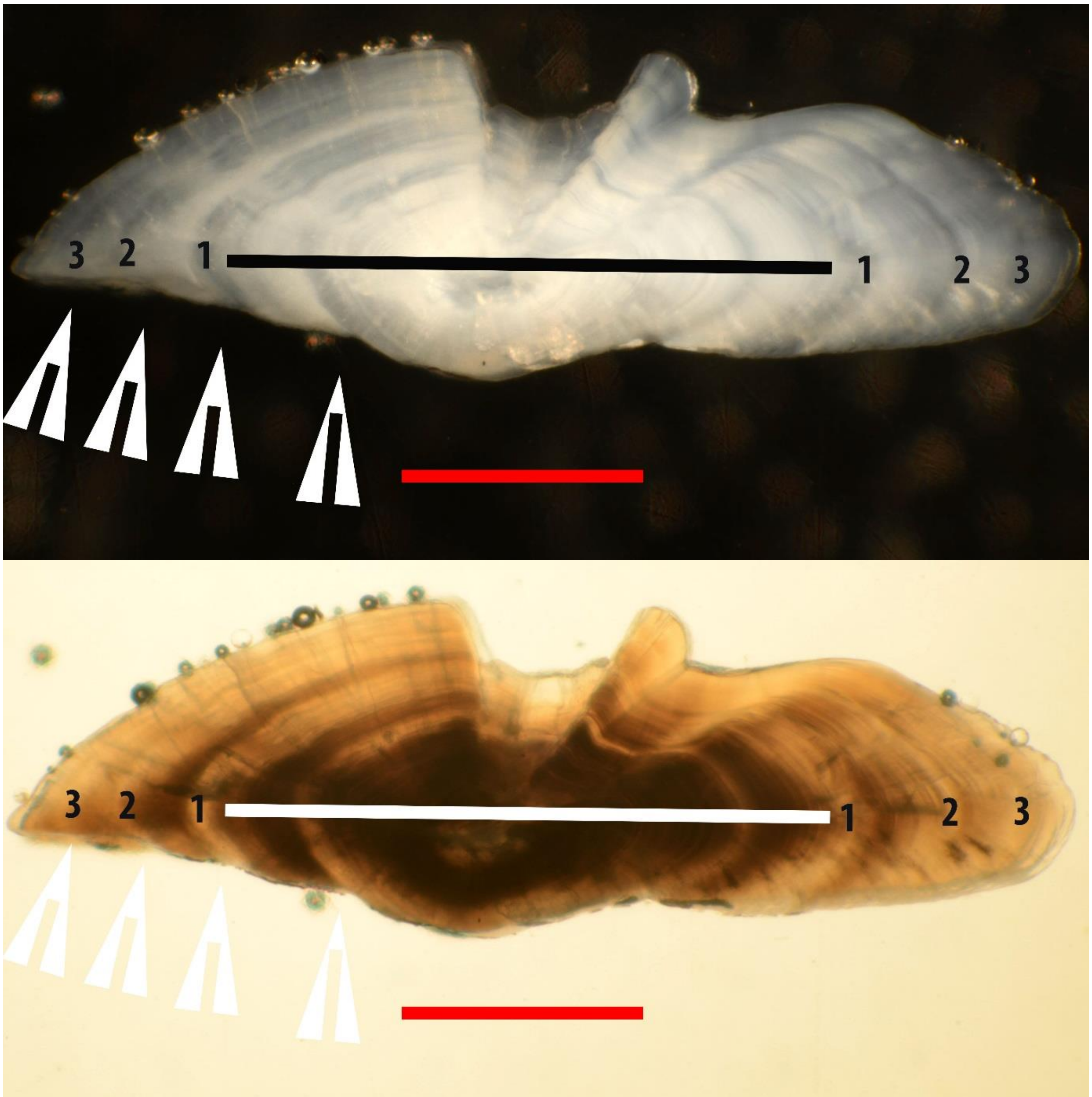


Figure A: Sectioned otolith from a three plus blue cod shown in (A) reflected light (B) transmitted light. The area of the zero plus portion of the otolith is shown by the black/white bar and the annuli are marked. The red scale bar is 0.5 mm, and arrows show the notches on the dorsal distal edge marking the juvenile check and annuli (numbered). Figure from Carbines (2016).

APPENDIX 3:
Summary of survey pot lift station data, Foveaux Strait 2014.

								Catch of blue cod	
Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	(kg)	Number
1	11-Feb-14	1	5	5	5	6:30	1	6.9	13
1	11-Feb-14	1	5	5	5	6:40	2	6.2	22
1	11-Feb-14	1	5	5	5	6:50	3	6.8	14
1	11-Feb-14	1	5	5	5	7:00	4	7.1	11
1	11-Feb-14	1	5	5	5	7:10	5	4.3	28
1	11-Feb-14	1	5	5	5	7:20	6	7.6	22
2	11-Feb-14	1	8	5	5	9:35	6	0	0
2	11-Feb-14	1	8	5	5	9:40	5	0	0
2	11-Feb-14	1	8	5	5	9:45	4	0	0
2	11-Feb-14	1	8	5	5	9:50	3	0	0
2	11-Feb-14	1	8	5	5	9:55	2	0	0
2	11-Feb-14	1	8	5	5	10:00	1	0	0
3	11-Feb-14	1	5	3	3	11:42	1	0	0
3	11-Feb-14	1	5	3	3	11:47	2	0.7	1
3	11-Feb-14	1	5	3	3	11:53	3	1	1
3	11-Feb-14	1	5	3	3	11:58	4	0	0
3	11-Feb-14	1	5	3	3	12:04	5	0	0
3	11-Feb-14	1	5	3	3	12:09	6	0	0
4	11-Feb-14	1	5	2	2	14:12	6	1.5	10
4	11-Feb-14	1	5	2	2	14:17	5	7.3	12
4	11-Feb-14	1	5	2	2	14:22	4	2.3	6
4	11-Feb-14	1	5	2	2	14:27	3	5.5	17
4	11-Feb-14	1	5	2	2	14:32	2	51.5	14
4	11-Feb-14	1	5	2	2	14:38	1	2.5	4
5	12-Feb-14	1	2	2	2	6:56	1	11.7	20
5	12-Feb-14	1	2	2	2	7:01	2	11.8	22
5	12-Feb-14	1	2	2	2	7:06	3	8.8	17
5	12-Feb-14	1	2	2	2	7:11	4	13.7	38
5	12-Feb-14	1	2	2	2	7:16	5	25.5	49
5	12-Feb-14	1	2	2	2	7:21	6	26.3	55
6	12-Feb-14	1	2	3	3	9:46	6	*26.2*	58
6	12-Feb-14	1	2	3	3	9:51	5	4.6	8
6	12-Feb-14	1	2	3	3	9:56	4	5.1	11
6	12-Feb-14	1	2	3	3	10:01	3	7.9	16
6	12-Feb-14	1	2	3	3	10:06	2	10.5	22
6	12-Feb-14	1	2	3	3	10:11	1	8.7	20
7	12-Feb-14	1	2	1	1	12:13	1	23.5	52
7	12-Feb-14	1	2	1	1	12:18	2	22.5	43
7	12-Feb-14	1	2	1	1	12:23	3	16.6	28
7	12-Feb-14	1	2	1	1	12:28	4	17.5	31
7	12-Feb-14	1	2	1	1	12:33	5	28	60
7	12-Feb-14	1	2	1	1	12:38	6	16.5	34
8	13-Feb-14	1	5	5	5	5:51	6	38	112
8	13-Feb-14	1	5	5	5	5:56	5	32	78
8	13-Feb-14	1	5	5	5	6:01	4	23.5	62

[Continued]:

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Catch of blue cod Number
8	13-Feb-14	1	5	5	5	6:06	3	23	61
8	13-Feb-14	1	5	5	5	6:11	2	25	70
8	13-Feb-14	1	5	5	5	6:16	1	30	85
9	13-Feb-14	1	5	1	1	9:38	1	3	11
9	13-Feb-14	1	5	1	1	9:42	2	3.1	17
9	13-Feb-14	1	5	1	1	9:47	3	7.2	16
9	13-Feb-14	1	5	1	1	9:52	4	10.3	15
9	13-Feb-14	1	5	1	1	9:57	5	1	4
9	13-Feb-14	1	5	1	1	10:02	6	11	55
10	13-Feb-14	1	4	5	5	11:42	6	1.1	1
10	13-Feb-14	1	4	5	5	11:47	5	1	1
10	13-Feb-14	1	4	5	5	11:52	4	4.8	5
10	13-Feb-14	1	4	5	5	11:57	3	1	1
10	13-Feb-14	1	4	5	5	12:02	2	2.2	3
10	13-Feb-14	1	4	5	5	12:07	1	1	1
11	13-Feb-14	1	4	2	2	13:31	1	19.5	60
11	13-Feb-14	1	4	2	2	13:36	2	5.9	16
11	13-Feb-14	1	4	2	2	13:41	3	0.1	1
11	13-Feb-14	1	4	2	2	13:46	4	23	30
11	13-Feb-14	1	4	2	2	13:51	5	2.3	5
11	13-Feb-14	1	4	2	2	13:56	6	23	68
12	14-Feb-14	1	1	5	5	6:25	6	13.5	31
12	14-Feb-14	1	1	5	5	6:30	5	11.2	35
12	14-Feb-14	1	1	5	5	6:35	4	15	26
12	14-Feb-14	1	1	5	5	6:40	3	9.5	22
12	14-Feb-14	1	1	5	5	6:45	2	13.5	38
12	14-Feb-14	1	1	5	5	6:50	1	11.5	38
13	14-Feb-14	1	4	6	6	8:51	1	23.5	65
13	14-Feb-14	1	4	6	6	8:56	2	19.5	56
13	14-Feb-14	1	4	6	6	9:01	3	18	42
13	14-Feb-14	1	4	6	6	9:06	4	12.7	39
13	14-Feb-14	1	4	6	6	9:11	5	17.5	44
13	14-Feb-14	1	4	6	6	9:16	6	11.5	33
14	14-Feb-14	1	4	1	1	11:29	6	0	0
14	14-Feb-14	1	4	1	1	11:34	5	**1**	1
14	14-Feb-14	1	4	1	1	11:39	4	0	0
14	14-Feb-14	1	4	1	1	11:44	3	0	0
14	14-Feb-14	1	4	1	1	11:49	2	0	0
14	14-Feb-14	1	4	1	1	11:54	1	0	0
15	14-Feb-14	1	4	3	3	13:16	1	0	0
15	14-Feb-14	1	4	3	3	13:21	2	0	0
15	14-Feb-14	1	4	3	3	13:26	3	0	0
15	14-Feb-14	1	4	3	3	13:31	4	0	0
15	14-Feb-14	1	4	3	3	13:36	5	0	0
15	14-Feb-14	1	4	3	3	13:41	6	0	0
16	15-Feb-14	1	7	2	2	6:00	6	9.5	21
16	15-Feb-14	1	7	2	2	6:05	5	19.3	43

[Continued]:

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Catch of blue cod Number
16	15-Feb-14	1	7	2	2	6:10	4	19.2	45
16	15-Feb-14	1	7	2	2	6:15	3	13.6	38
16	15-Feb-14	1	7	2	2	6:20	2	10	16
16	15-Feb-14	1	7	2	2	6:25	1	16.7	39
17	15-Feb-14	1	7	1	1	8:05	1	27.3	65
17	15-Feb-14	1	7	1	1	8:10	2	14	37
17	15-Feb-14	1	7	1	1	8:15	3	12.5	39
17	15-Feb-14	1	7	1	1	8:20	4	9.6	21
17	15-Feb-14	1	7	1	1	8:25	5	1.8	11
17	15-Feb-14	1	7	1	1	8:30	6	28	61
18	15-Feb-14	1	8	6	6	10:45	6	0	0
18	15-Feb-14	1	8	6	6	10:50	5	0.1	1
18	15-Feb-14	1	8	6	6	10:55	4	0	0
18	15-Feb-14	1	8	6	6	11:00	3	0	0
18	15-Feb-14	1	8	6	6	11:05	2	0.2	4
18	15-Feb-14	1	8	6	6	11:10	1	0	0
19	15-Feb-14	1	8	3	3	12:45	1	0	0
19	15-Feb-14	1	8	3	3	12:50	2	6.5	9
19	15-Feb-14	1	8	3	3	12:55	3	0	0
19	15-Feb-14	1	8	3	3	13:00	4	0.5	1
19	15-Feb-14	1	8	3	3	13:05	5	0	0
19	15-Feb-14	1	8	3	3	13:10	6	0	0
20	16-Feb-14	1	1	1	1	6:42	6	26.5	50
20	16-Feb-14	1	1	1	1	6:47	5	3.1	5
20	16-Feb-14	1	1	1	1	6:52	4	4.2	6
20	16-Feb-14	1	1	1	1	6:57	3	19.6	29
20	16-Feb-14	1	1	1	1	7:02	2	32	56
20	16-Feb-14	1	1	1	1	7:07	1	3	4
21	16-Feb-14	1	1	3	3	8:53	1	23.8	43
21	16-Feb-14	1	1	3	3	8:58	2	33.8	69
21	16-Feb-14	1	1	3	3	9:02	3	55	146
21	16-Feb-14	1	1	3	3	9:08	4	34.2	65
21	16-Feb-14	1	1	3	3	9:13	5	36.6	66
21	16-Feb-14	1	1	3	3	9:18	6	28.5	64
22	16-Feb-14	1	1	4	4	11:45	6	34.5	98
22	16-Feb-14	1	1	4	4	11:50	5	8.2	20
22	16-Feb-14	1	1	4	4	11:55	4	9.1	22
22	16-Feb-14	1	1	4	4	12:00	3	8.9	19
22	16-Feb-14	1	1	4	4	12:05	2	7.4	15
22	16-Feb-14	1	1	4	4	12:10	1	33.5	101
23	16-Feb-14	1	1	6	6	14:14	1	1.5	2
23	16-Feb-14	1	1	6	6	14:19	2	11.3	19
23	16-Feb-14	1	1	6	6	14:24	3	51	94
23	16-Feb-14	1	1	6	6	14:29	4	1	1
23	16-Feb-14	1	1	6	6	14:34	5	1.5	1
23	16-Feb-14	1	1	6	6	14:39	6	0	0
24	16-Feb-14	1	1	2	2	16:00	6	0.2	1

[Continued]:

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Number
24	16-Feb-14	1	1	2	2	16:05	5	9	14
24	16-Feb-14	1	1	2	2	16:10	4	3.9	9
24	16-Feb-14	1	1	2	2	16:15	3	5.3	14
24	16-Feb-14	1	1	2	2	16:20	2	10	24
24	16-Feb-14	1	1	2	2	16:25	1	1.5	3
25	17-Feb-14	1	2	6	6	7:00	1	17.7	50
25	17-Feb-14	1	2	6	6	7:05	2	10	19
25	17-Feb-14	1	2	6	6	7:10	3	6.3	14
25	17-Feb-14	1	2	6	6	7:15	4	12.3	30
25	17-Feb-14	1	2	6	6	7:20	5	32.2	72
25	17-Feb-14	1	2	6	6	7:25	6	9.9	27
26	17-Feb-14	1	2	5	5	9:21	6	2.9	5
26	17-Feb-14	1	2	5	5	9:26	5	4.6	9
26	17-Feb-14	1	2	5	5	9:31	4	5.1	9
26	17-Feb-14	1	2	5	5	9:36	3	2.5	4
26	17-Feb-14	1	2	5	5	9:41	2	4.5	6
26	17-Feb-14	1	2	5	5	9:46	1	24.1	62
27	17-Feb-14	1	2	4	4	11:09	1	39.7	76
27	17-Feb-14	1	2	4	4	11:14	2	31.3	68
27	17-Feb-14	1	2	4	4	11:19	3	52	133
27	17-Feb-14	1	2	4	4	11:24	4	6.5	12
27	17-Feb-14	1	2	4	4	11:29	5	9	18
27	17-Feb-14	1	2	4	4	11:34	6	9	15
28	17-Feb-14	1	6	6	6	14:05	6	11.8	25
28	17-Feb-14	1	6	6	6	14:10	5	9.6	36
28	17-Feb-14	1	6	6	6	14:15	4	9.1	19
28	17-Feb-14	1	6	6	6	14:20	3	8.7	22
28	17-Feb-14	1	6	6	6	14:25	2	4.5	18
28	17-Feb-14	1	6	6	6	14:30	1	11	38
29	19-Feb-14	1	8	1	1	6:56	1	0.8	1
29	19-Feb-14	1	8	1	1	7:01	2	0	0
29	19-Feb-14	1	8	1	1	7:06	3	0	0
29	19-Feb-14	1	8	1	1	7:11	4	0	0
29	19-Feb-14	1	8	1	1	7:16	5	0.2	1
29	19-Feb-14	1	8	1	1	7:21	6	0.2	1
30	19-Feb-14	1	8	4	4	8:48	6	0	0
30	19-Feb-14	1	8	4	4	8:53	5	0	0
30	19-Feb-14	1	8	4	4	8:58	4	0	0
30	19-Feb-14	1	8	4	4	9:03	3	0	0
30	19-Feb-14	1	8	4	4	9:08	2	0	0
30	19-Feb-14	1	8	4	4	9:13	1	0	0
31	19-Feb-14	1	7	3	3	10:05	1	2	6
31	19-Feb-14	1	7	3	3	10:10	2	12.3	32
31	19-Feb-14	1	7	3	3	10:15	3	8.4	17
31	19-Feb-14	1	7	3	3	10:20	4	10.4	16
31	19-Feb-14	1	7	3	3	10:25	5	10.6	13
31	19-Feb-14	1	7	3	3	10:30	6	6.5	7

[Continued]:

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Number
32	19-Feb-14	1	7	4	4	12:54	6	0	0
32	19-Feb-14	1	7	4	4	12:59	5	26.1	44
32	19-Feb-14	1	7	4	4	13:04	4	16	18
32	19-Feb-14	1	7	4	4	13:09	3	11.6	17
32	19-Feb-14	1	7	4	4	13:14	2	1.8	2
32	19-Feb-14	1	7	4	4	13:19	1	0	0
33	20-Feb-14	1	6	2	2	7:30	1	1.2	2
33	20-Feb-14	1	6	2	2	7:35	2	3.4	7
33	20-Feb-14	1	6	2	2	7:40	3	2.2	9
33	20-Feb-14	1	6	2	2	7:45	4	0.8	1
33	20-Feb-14	1	6	2	2	7:50	5	8.1	17
33	20-Feb-14	1	6	2	2	7:55	6	3.6	4
34	20-Feb-14	1	6	1	1	9:40	6	0	0
34	20-Feb-14	1	6	1	1	9:45	5	0.2	1
34	20-Feb-14	1	6	1	1	9:50	4	4.7	9
34	20-Feb-14	1	6	1	1	9:55	3	1.2	5
34	20-Feb-14	1	6	1	1	10:00	2	0	0
34	20-Feb-14	1	6	1	1	10:05	1	1.4	1
35	20-Feb-14	1	6	5	5	11:35	1	0	0
35	20-Feb-14	1	6	5	5	11:41	2	1	2
35	20-Feb-14	1	6	5	5	11:46	3	0.2	1
35	20-Feb-14	1	6	5	5	11:51	4	0	0
35	20-Feb-14	1	6	5	5	11:56	5	0.7	1
35	20-Feb-14	1	6	5	5	12:01	6	0.5	1
36	21-Feb-14	1	6	4	4	6:35	6	0	0
36	21-Feb-14	1	6	4	4	6:40	5	0	0
36	21-Feb-14	1	6	4	4	6:45	4	0	0
36	21-Feb-14	1	6	4	4	6:50	3	0.4	1
36	21-Feb-14	1	6	4	4	6:55	2	0	0
36	21-Feb-14	1	6	4	4	7:00	1	0	0
37	21-Feb-14	1	6	3	3	8:28	1	0	0
37	21-Feb-14	1	6	3	3	8:33	2	6.5	16
37	21-Feb-14	1	6	3	3	8:38	3	16.9	38
37	21-Feb-14	1	6	3	3	8:43	4	1.4	2
37	21-Feb-14	1	6	3	3	8:48	5	4.6	6
37	21-Feb-14	1	6	3	3	8:53	6	0	0
38	21-Feb-14	1	8	2	2	10:25	6	0	0
38	21-Feb-14	1	8	2	2	10:30	5	0.3	3
38	21-Feb-14	1	8	2	2	10:35	4	0	0
38	21-Feb-14	1	8	2	2	10:40	3	0.5	8
38	21-Feb-14	1	8	2	2	10:45	2	1.4	2
38	21-Feb-14	1	8	2	2	10:50	1	0.7	4
39	21-Feb-14	1	5	4	4	13:15	1	5	12
39	21-Feb-14	1	5	4	4	13:20	2	4.2	9
39	21-Feb-14	1	5	4	4	13:25	3	9.1	28
39	21-Feb-14	1	5	4	4	13:30	4	0.2	1
39	21-Feb-14	1	5	4	4	13:35	5	2.3	4

[Continued]:

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Number
39	21-Feb-14	1	5	4	4	13:40	6	0	0
40	21-Feb-14	1	4	4	4	15:05	6	0.7	1
40	21-Feb-14	1	4	4	4	15:10	5	6.4	12
40	21-Feb-14	1	4	4	4	15:15	4	1.1	2
40	21-Feb-14	1	4	4	4	15:20	3	0.3	1
40	21-Feb-14	1	4	4	4	15:25	2	0	0
40	21-Feb-14	1	4	4	4	15:30	1	0	0
41	25-Feb-14	1	10	3	3	5:54	1	24.2	69
41	25-Feb-14	1	10	3	3	5:59	2	39.4	106
41	25-Feb-14	1	10	3	3	6:04	3	22	64
41	25-Feb-14	1	10	3	3	6:09	4	30.8	85
41	25-Feb-14	1	10	3	3	6:14	5	37.8	104
41	25-Feb-14	1	10	3	3	6:19	6	22.4	64
42	25-Feb-14	1	10	1	1	7:54	6	0	0
42	25-Feb-14	1	10	1	1	7:59	5	0	0
42	25-Feb-14	1	10	1	1	8:04	4	0	0
42	25-Feb-14	1	10	1	1	8:09	3	0	0
42	25-Feb-14	1	10	1	1	8:14	2	0	0
42	25-Feb-14	1	10	1	1	8:19	1	0	0
43	25-Feb-14	1	10	6	6	9:57	1	0	0
43	25-Feb-14	1	10	6	6	10:02	2	0	0
43	25-Feb-14	1	10	6	6	10:07	3	0	0
43	25-Feb-14	1	10	6	6	10:12	4	0	0
43	25-Feb-14	1	10	6	6	10:17	5	6	8
43	25-Feb-14	1	10	6	6	10:22	6	0	0
44	25-Feb-14	1	7	5	5	12:41	6	0	0
44	25-Feb-14	1	7	5	5	12:46	5	20	21
44	25-Feb-14	1	7	5	5	12:51	4	4.7	7
44	25-Feb-14	1	7	5	5	12:56	3	4.6	8
44	25-Feb-14	1	7	5	5	13:01	2	0	0
44	25-Feb-14	1	7	5	5	13:06	1	11.6	53
45	25-Feb-14	1	7	6	6	14:39	1	25.6	57
45	25-Feb-14	1	7	6	6	14:44	2	25	57
45	25-Feb-14	1	7	6	6	14:49	3	26.4	53
45	25-Feb-14	1	7	6	6	14:54	4	26.2	64
45	25-Feb-14	1	7	6	6	14:59	5	0.1	1
45	25-Feb-14	1	7	6	6	15:04	6	4.2	6
46	26-Feb-14	1	10	2	2	6:41	6	10.1	29
46	26-Feb-14	1	10	2	2	6:46	5	16	38
46	26-Feb-14	1	10	2	2	6:51	4	19.6	45
46	26-Feb-14	1	10	2	2	6:56	3	18.8	40
46	26-Feb-14	1	10	2	2	7:01	2	9.1	16
46	26-Feb-14	1	10	2	2	7:06	1	6.7	25
47	26-Feb-14	1	10	5	5	8:35	1	0	0
47	26-Feb-14	1	10	5	5	8:40	2	6.3	16
47	26-Feb-14	1	10	5	5	8:45	3	0.7	1
47	26-Feb-14	1	10	5	5	8:50	4	4	11

[Continued]:

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Number
47	26-Feb-14	1	10	5	5	8:55	5	2.1	3
47	26-Feb-14	1	10	5	5	9:00	6	2.6	3
48	26-Feb-14	1	10	4	4	10:30	6	0.1	1
48	26-Feb-14	1	10	4	4	10:35	5	0	0
48	26-Feb-14	1	10	4	4	10:40	4	0	0
48	26-Feb-14	1	10	4	4	10:45	3	0.8	1
48	26-Feb-14	1	10	4	4	10:50	2	0	0
48	26-Feb-14	1	10	4	4	10:55	1	0	0
49	27-Feb-14	2	7	9	9	7:46	1	33.9	102
49	27-Feb-14	2	7	9	9	7:51	2	13.8	50
49	27-Feb-14	2	7	9	9	7:56	3	12	27
49	27-Feb-14	2	7	9	9	8:01	4	33.4	95
49	27-Feb-14	2	7	9	9	8:06	5	10.3	37
49	27-Feb-14	2	7	9	9	8:11	6	16.6	53
50	16-Mar-14	2	1	7	7	7:41	1	*9.8*	21
50	16-Mar-14	2	1	7	7	7:46	2	*9.7*	16
50	16-Mar-14	2	1	7	7	7:51	3	*25.5*	60
50	16-Mar-14	2	1	7	7	7:56	4	*9.2*	22
50	16-Mar-14	2	1	7	7	8:01	5	*8.9*	17
50	16-Mar-14	2	1	7	7	8:06	6	*46.0*	103
51	16-Mar-14	2	2	7	7	10:36	6	*33.3*	89
51	16-Mar-14	2	2	7	7	10:41	5	*4.0*	18
51	16-Mar-14	2	2	7	7	10:46	4	*0.4*	1
51	16-Mar-14	2	2	7	7	10:51	3	*13.4*	28
51	16-Mar-14	2	2	7	7	10:56	2	*17.8*	37
51	16-Mar-14	2	2	7	7	11:01	1	*13.4*	27
52	17-Mar-14	2	7	7	7	7:10	1	0	0
52	17-Mar-14	2	7	7	7	7:15	2	0	0
52	17-Mar-14	2	7	7	7	7:20	3	7	24
52	17-Mar-14	2	7	7	7	7:25	4	17.1	34
52	17-Mar-14	2	7	7	7	7:30	5	7.3	13
52	17-Mar-14	2	7	7	7	7:35	6	21.7	33
53	17-Mar-14	2	7	8	8	9:05	6	0	0
53	17-Mar-14	2	7	8	8	9:10	5	2.5	3
53	17-Mar-14	2	7	8	8	9:15	4	0	0
53	17-Mar-14	2	7	8	8	9:20	3	2.7	3
53	17-Mar-14	2	7	8	8	9:25	2	2.8	5
53	17-Mar-14	2	7	8	8	9:30	1	1.7	3

APPENDIX 4:

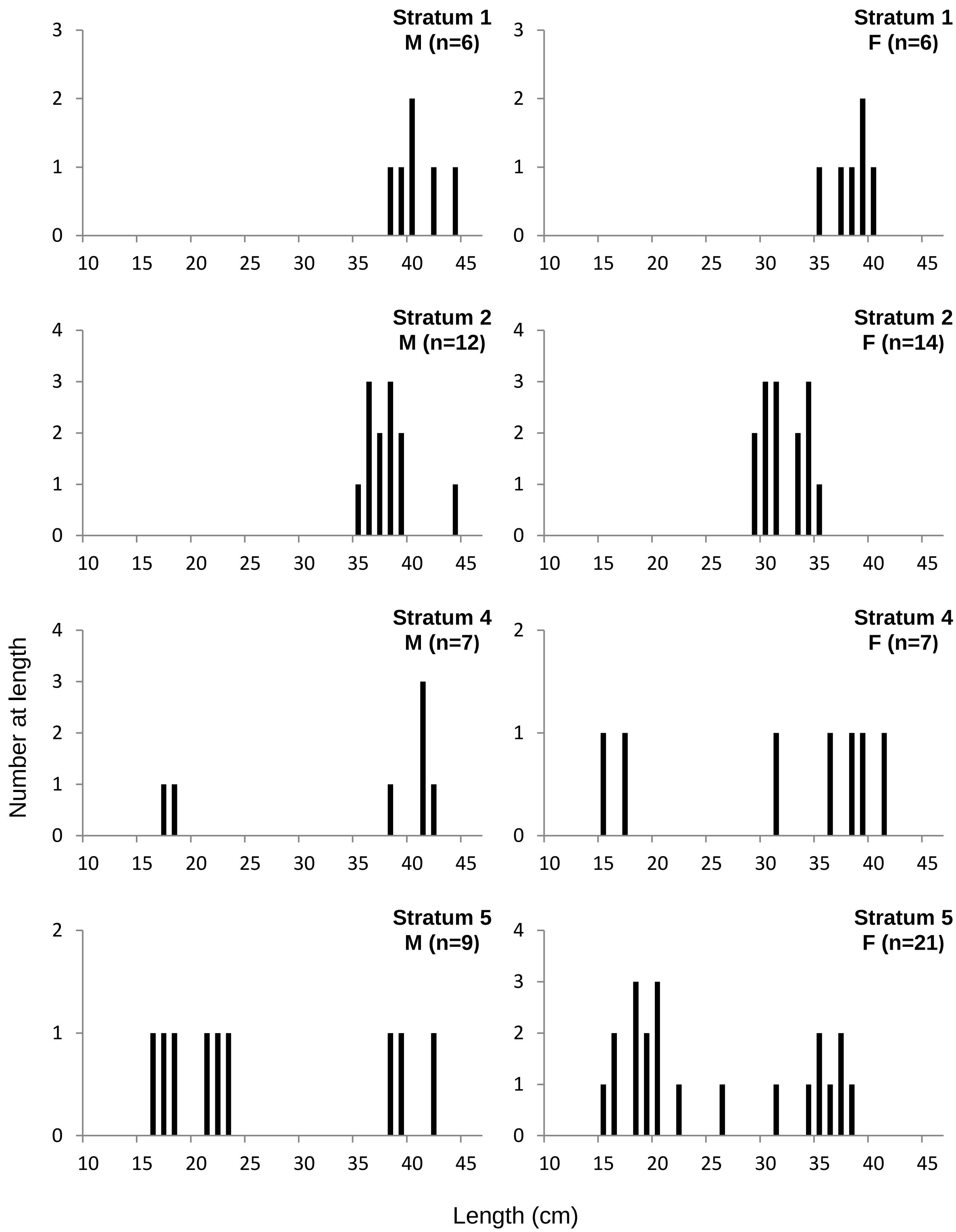
Summary of the Foveaux Strait 2014 survey oceanographic environmental station data recorded in the format of the trawl data base. Depths are measured in meters, directions in compass degrees (999 = nil), wind force in the Beaufort scale, temperatures in degrees centigrade, air pressure in millibars, cloud cover in oktas, sea condition in the Douglas scale, sea colour in a categorical scale from 1 (deep blue) to 8 (yellow green), swell height in meters, bottom type in a categorical scale from 1 (mud or ooze) to 13 (sponge beds), bottom contour in a categorical scale from 1 (smooth/flat) to 5 (very rugged), and wind speed in metres per second.

Set	ADCP depth	Wind direction	Wind force	Air temp	Air pressure	Cloud cover	Sea condition	Sea colour	Swell height	Swell direction	Bottom type	Bottom contour	Surface temp	Bottom temp	Wind speed	Secchi depth
1	30.7	220	4	18.6	998	8	2	7	1	280	12	2	14		5.6	20
2	30.5	270	4	18.1	998	8	2	7	1	280	4	1	14		6.3	22.6
3	33.8	120	1	18.4	998	8	2	7	1	090	4	2	14		1.2	4.2
4	36.2	190	4	21.4	998	7	2	7	1.5	240	4	2	14.1		6.3	22.5
5	36.0	330	3	18.1	998	8	2	6	2.5	280	12	2	15		3.9	14.2
6	51.8	270	3	16	998	8	2	6	3	275	12	2	14.5		5.0	18
7	39.7	220	4	19.2	1 000	5	1	6	2	240	12	2	15		6.2	22.2
8	33.6	240	4	14.5	997	7	2	7	1	260	12	2	13.5		7.1	25.5
9	35.5	260	3	14.5	998	8	2	7	1	230	4	2	14		5.0	18.1
10	39.5	195	3	17.3	998	8	2	7	0.5	270	4	2	14.3		4.8	17.1
11	35.3	270	3	15.4	999	7	2	7	0.5	270	4	2	14.2		5.1	18.5
12	56.5	320	5	12.1	997	6	2	7	2	240	12	2	14.2		9.0	32.4
13	36.6	275	5	14.5	997	6	3	7	2	240	12	2	14.3		10.7	38.6
14	36.6	300	2	15.3	998	7	2	7	0.5	340	6	3	14.2		3.7	13.2
15	8.6	005	2	16.2	999	8	1	7	0	999	3	1	14.3		2.3	8.4
16	24.0	270	3	16.8	1 005	8	1	7	0.5	285	7	4	14.1		3.7	13.2
17	21.8	300	3	17.2	1 001	8	1	7	0.5	285	7	4	14.1		4.0	14.3
18	54.9	130	4	14.4	1 001	8	2	7	1.5	190	4	1	14.1		5.4	19.4
19	53.6	140	4	14.8	1 000	7	2	7	1.5	150	4	1	14		6.8	24.5
20	31.1	060	2	14.5	1 010	5	1	1	0.5	050	9	3	14		2.0	7.2
21	45.7	050	3	19.6	1 010	4	1	1	0.5	050	12	2	14		4.0	14.5
22	54.7	120	4	16	1 012	3	1	4	1.5	200	12	3	14		7.3	26.1
23	53.9	040	4	17.5	1 014	2	2	4	2	240	4	3	14		6.0	21.5
24	39.1	050	5	21.4	1 013	2	2	4	2	240	7	5	14		8.4	30.1
25	43.3	040	1	16.5	1 007	8	1	7	0.5	070	10	2	14		1.1	4.1

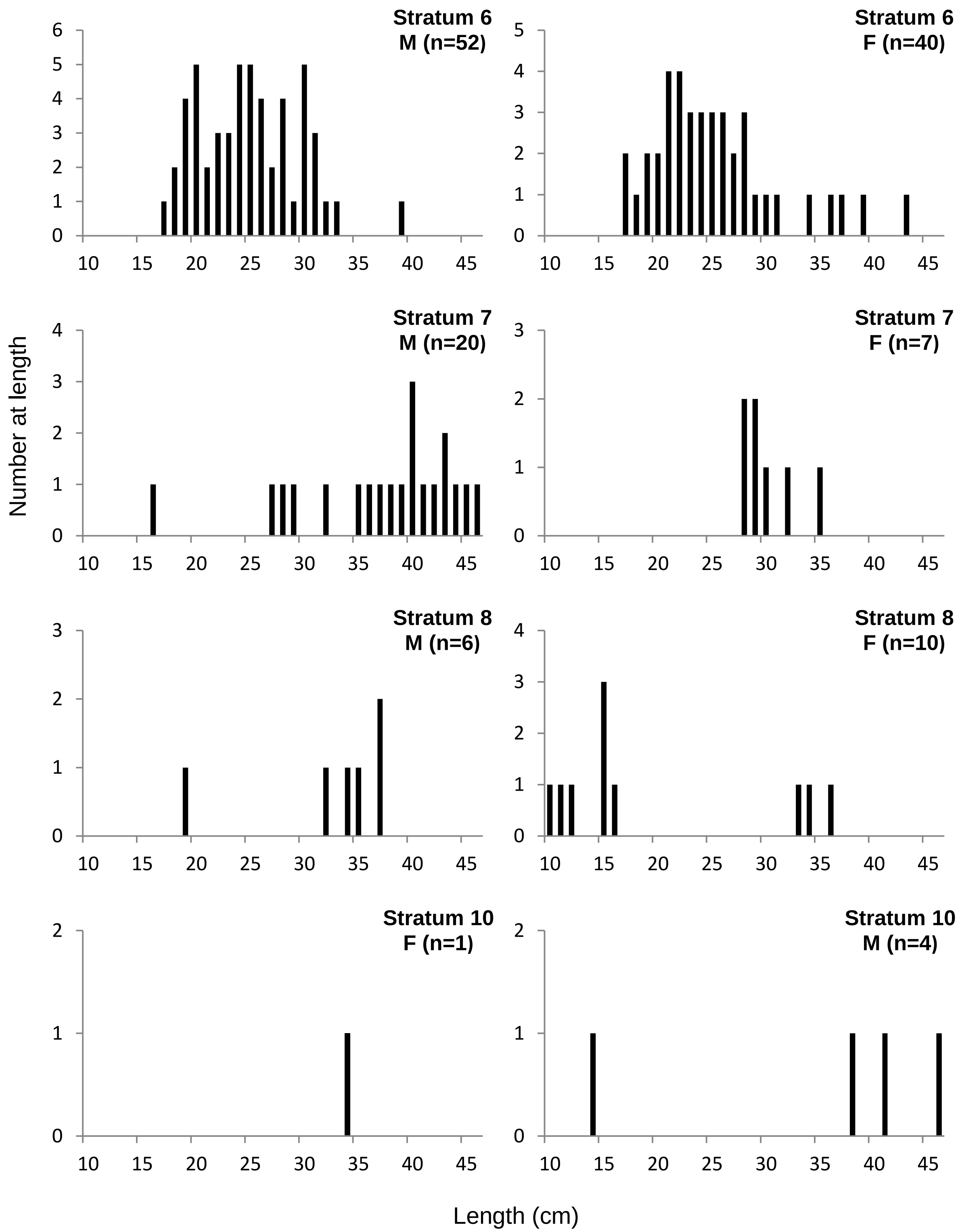
[Continued]:

Set	ADCP depth	Wind direction	Wind force	Air temp	Air pressure	Cloud cover	Sea condition	Sea colour	Swell height	Swell direction	Bottom type	Bottom contour	Surface temp	Bottom temp	Wind speed	Secchi depth
26	32.0	040	3	16.5	1 005	8	1	7	0.5	070	5	1	14.5		3.5	12.6
27	39.3	060	4	15.1	1 006	8	1	7	0.5	070	10	2	14.1		6.1	21.9
28	36.6	060	3	17.7	1 004	8	1	7	0.5	090	8	2	14.7		4.3	15.3
29	56.7	070	4	14.7	1 016	8	2	7	0.5	180	3	1	14		6.5	23.5
30	53.0	090	2	14.9	1 016	8	2	7	0.5	180	3	1	14		2.0	7.2
31	17.4	040	1	18.6	1 016	8	1	7	0.5	060	3	1	14		1.4	5.2
32	11.9	060	3	21.4	1 015	7	1	7	0.5	060	7	3	14		3.6	12.8
33	31.1	999	0	17.8	1 018	6	0	5	0.25	100	4	1	14.7		0.0	0
34	27.8	999	0	23.5	1 020	3	0	5	0.25	100	4	1	14.8		0.0	0
35	28.3	999	0	23.8	1 020	3	0	5	0.5	100	4	1	14.7		0.0	0
36	13.9	330	1	17.1	1 015	4	0	5	0.25	120	3	2	14.8		1.4	4.9
37	17.2	300	2	19.4	1 015	4	0	5	0.5	120	6	2	14.7		2.8	10.2
38	24.7	260	3	19.5	1 014	7	0	5	0.25	120	3	1	14.7		3.4	12.1
39	35.1	180	2	18.3	1 012	8	1	7	0.25	001	5	1	14.1		2.8	10.1
40	35.8	999	0	18.4	1 009	8	0	7	0.25	001	5	1	14.2		0.0	0
41	42.8	200	4	11.7	1 014	8	2	6	2	160	7	4	13		6.3	22.5
42	60.0	240	3	11.3	1 014	6	2	5	2	160	3	1	13.1		4.8	17.4
43	63.1	240	4	13.3	1 014	4	2	5	2	160	4	1	14		6.7	24.2
44	38.4	240	4	15.7	1 014	4	2	6	0.5	240	4	2	14.3		7.9	28.5
45	20.1	240	4	17.6	1 014	5	2	6	0.5	240	7	2	14.3		7.9	28.4
46	33.1	280	2	12.4	1 014	4	1	5	1.5	210	7	2	13.1		2.3	8.1
47	19.2	330	2	21.7	1 015	0	0	5	0.5	105	7	3	13		1.7	6.1
48	50.3	060	3	16.2	1 016	0	1	5	1	210	4	2	13.2		4.0	14.4
49	41.5	330	4	16.2	1 010	7	2	6	1	340	7	3	13.1		6.1	22.1
50	53.8	060	4	15.2	1 012	8	2	7	2.5	240	4	2	14		7.9	28.3
51	38.4	060	2	18.5	1 014	6	1	7	1.5	240	4	2	14		3.7	13.4
52	27.1	330	2	16.1	1 001	4	2	5	2	090	7	2	13.5		2.1	7.5
53	21.4	330	1	17.5	1 003	4	1	5	1	090	4	1	13.5		1.5	5.5

APPENDIX 5:
Unscaled length-frequency distributions of blue cod for each stratum from which otoliths were used in the Foveaux Strait 2014 age-length-keys.



[Continued]:



Stratum 6 M (n=52)
Stratum 6 F (n=40)
Stratum 7 M (n=20)
Stratum 7 F (n=7)
Stratum 8 M (n=6)
Stratum 8 F (n=10)
Stratum 10 F (n=1)
Stratum 10 M (n=4)
Number at length
Length (cm)

APPENDIX 6:

Between-reader comparisons (using first independent readings only) for otolith data collected in Foveaux Strait 2014.

Reader two									Age class (reader one)							
difference	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
-6															1	1
-5											1					1
-4											2	1	1			4
-3									4	1	3	2				10
-2					1	1	1	1	5	1	3					13
-1				1	1	3	5	9	9		3	2				33
0	1	3	19	24	15	17	12	14	7	5	1	3	1			122
1		3	6	11	3	3		1		1		1				29
2		1	2			1	1		1				1			7
3						1						1				2
Total	1	7	27	36	20	26	19	25	26	8	13	10	3	0	1	222
% agreement	100	43	70	67	75	65	63	56	27	63	8	30	33		0	55

APPENDIX 7:

Independent reader comparisons with agreed age from otolith data collected in Foveaux Strait 2014.

Reader one difference	Agreed age class 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
-2								1								1
-1			1		1	2	2		1	2	1	1				11
0	1	6	27	35	17	20	15	18	13	6	6	7	2		1	174
1				1	3	4	6	11		4	1					30
2									2							2
3							1		1							2
4								1	1							2
Total	1	6	28	36	21	26	24	31	18	12	8	8	2	0	1	222
% agreement	100	100	96	97	81	77	63	58	72	50	75	88	100		100	78

Reader two difference	Agreed age class 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
-6															1	1
-5											1					1
-4										1						1
-3									1	1	2	1				5
-2						1		3	4	2	2	1				13
-1				2	1	1	2	5	3	1		1				16
0	1	3	19	24	19	22	21	21	9	7	3	3	1			153
1		3	7	10	1	1		2				1				25
2			2			1	1		1				1			6
3												1				1
Total	1	6	28	36	21	26	24	31	18	12	8	8	2	0	1	222
% agreement	100	50	68	67	90	85	88	68	50	58	38	38	50		0	69

APPENDIX 8:

The proportion of fish at age and length and the total number at length and at age for male blue cod sampled from the 2014 Foveaux Strait (age-length-key, ALK).

Len (cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
16	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	2
17	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
18	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4
19	0	0.8	0.2	0	0	0	0	0	0	0	0	0	0	0	5
20	0	0.4	0.6	0	0	0	0	0	0	0	0	0	0	0	5
21	0	0	0.67	0.33	0	0	0	0	0	0	0	0	0	0	3
22	0	0.25	0.75	0	0	0	0	0	0	0	0	0	0	0	4
23	0	0	0.75	0	0.25	0	0	0	0	0	0	0	0	0	4
24	0	0.2	0.2	0.6	0	0	0	0	0	0	0	0	0	0	5
25	0	0	0.2	0.4	0.4	0	0	0	0	0	0	0	0	0	5
26	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4
27	0	0	0	0	0.67	0.33	0	0	0	0	0	0	0	0	3
28	0	0	0	0.2	0.8	0	0	0	0	0	0	0	0	0	5
29	0	0	0	0.5	0	0.5	0	0	0	0	0	0	0	0	2
30	0	0	0	0.2	0.4	0.2	0.2	0	0	0	0	0	0	0	5
31	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3
32	0	0	0	0	0.33	0.67	0	0	0	0	0	0	0	0	3
33	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
34	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
35	0	0	0	0	0.33	0	0.33	0.33	0	0	0	0	0	0	3
36	0	0	0	0	0	0.75	0	0.25	0	0	0	0	0	0	4
37	0	0	0	0	0	0.4	0.2	0.4	0	0	0	0	0	0	5
38	0	0	0	0	0	0.25	0.25	0.12	0.12	0.12	0.12	0	0	0	8
39	0	0	0	0	0	0	0.67	0	0.17	0.17	0	0	0	0	6
40	0	0	0	0	0	0	0.6	0.2	0	0.2	0	0	0	0	5
41	0	0	0	0	0	0	0.4	0.6	0	0	0	0	0	0	5
42	0	0	0	0	0	0	0.5	0	0.25	0	0.25	0	0	0	4
43	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	2
44	0	0	0	0	0	0	0	0.67	0	0	0.33	0	0	0	3
45	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
46	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	2
Total	1	16	15	13	17	13	16	13	5	4	3	0	0	0	116

APPENDIX 9:

The proportion of fish at age and length and the total number at length and at age for female blue cod sampled from the 2014 Foveaux Strait survey (age-length-key, ALK). The zero age class is not included (n = 1).

Len (cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
15	0.4	0.6	0	0	0	0	0	0	0	0	0	0	0	0	5
16	0.33	0.67	0	0	0	0	0	0	0	0	0	0	0	0	3
17	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3
18	0	0.25	0.75	0	0	0	0	0	0	0	0	0	0	0	4
19	0	0.25	0.5	0.25	0	0	0	0	0	0	0	0	0	0	4
20	0	0	0.8	0.2	0	0	0	0	0	0	0	0	0	0	5
21	0	0.25	0.75	0	0	0	0	0	0	0	0	0	0	0	4
22	0	0.2	0.6	0.2	0	0	0	0	0	0	0	0	0	0	5
23	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3
24	0	0	0	0.67	0.33	0	0	0	0	0	0	0	0	0	3
25	0	0	0.67	0	0.33	0	0	0	0	0	0	0	0	0	3
26	0	0	0.25	0.5	0	0	0.25	0	0	0	0	0	0	0	4
27	0	0	0	0	0.5	0	0.5	0	0	0	0	0	0	0	2
28	0	0	0	0	0.6	0.4	0	0	0	0	0	0	0	0	5
29	0	0	0	0.2	0.2	0.4	0.2	0	0	0	0	0	0	0	5
30	0	0	0	0	0.2	0.6	0.2	0	0	0	0	0	0	0	5
31	0	0	0	0	0	0.17	0.17	0.33	0.17	0.17	0	0	0	0	6
32	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
33	0	0	0	0	0	0.33	0	0	0.33	0.33	0	0	0	0	3
34	0	0	0	0	0	0.14	0.43	0	0	0.29	0.14	0	0	0	7
35	0	0	0	0	0	0	0.6	0	0.4	0	0	0	0	0	5
36	0	0	0	0	0	0	0.5	0	0.25	0	0	0.25	0	0	4
37	0	0	0	0	0	0.25	0	0	0.25	0	0.5	0	0	0	4
38	0	0	0	0	0	0	0.33	0.67	0	0	0	0	0	0	3
39	0	0	0	0	0	0	0.25	0.25	0.25	0	0.25	0	0	0	4
40	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
41	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
43	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Total	5	12	21	8	9	11	15	5	7	4	5	2	0	1	105

APPENDIX 10:

Mean age-at-length for the 2014 Foveaux Strait survey.

	Males		Females		All fish	
Length (cm)	N	Mean age	N	Mean age	N	Mean age
11	0	0	1	1	1	1
12	0	0	1	1	1	1
14	1	1	0	0	1	1
15	0	0	5	1.6	5	1.6
16	2	2.5	3	1.67	5	2
17	3	2	3	2	6	2
18	4	2	4	2.75	8	2.38
19	5	2.2	4	3	9	2.56
20	5	2.6	5	3.2	10	2.9
21	3	3.33	4	2.75	7	3
22	4	2.75	5	3	9	2.89
23	4	3.5	3	3	7	3.29
24	5	3.4	3	4.33	8	3.75
25	5	4.2	3	3.67	8	4
26	4	4	4	4.5	8	4.25
27	3	5.33	2	6	5	5.6
28	5	4.8	5	5.4	10	5.1
29	2	5	5	5.6	7	5.43
30	5	5.4	5	6	10	5.7
31	3	5	6	8	9	7
32	3	5.67	1	5	4	5.5
33	1	6	3	8.33	4	7.75
34	1	5	7	8.29	8	7.88
35	3	6.67	5	7.8	8	7.38
36	4	6.5	4	8.75	8	7.62
37	5	7	4	9.25	9	8
38	8	8	3	7.67	11	7.91
39	6	7.83	4	8.75	10	8.2
40	5	7.8	1	11	6	8.33
41	5	7.6	1	12	6	8.33
42	4	8.5	0	0	4	8.5
43	2	8.5	1	14	3	10.3
44	3	9	0	0	3	9
45	1	10	0	0	1	10
46	2	8.5	0	0	2	8.5
Total	116	5.41	105	5.49	221	5.44

APPENDIX 11:

Parameter values used in the 2014 Foveaux Strait SPR analyses.

	Males				Females			
Age	Length (cm)	Weight (kg)	Selectivity	Maturity	Length (cm)	Weight (kg)	Selectivity	Maturity
1	12.2	0.030	0	0	12.7	0.038	0	0
2	17.7	0.091	0	0	17.5	0.095	0	0
3	22.5	0.188	0	0	21.5	0.172	0	0
4	26.7	0.314	0	0.1	25.0	0.261	0	0.1
5	30.4	0.464	0	0.4	27.8	0.355	0	0.4
6	33.7	0.630	1	0.7	30.3	0.450	0	0.7
7	36.5	0.804	1	1	32.3	0.541	0	1
8	39.1	0.981	1	1	34.0	0.626	1	1
9	41.3	1.157	1	1	35.5	0.705	1	1
10	43.2	1.327	1	1	36.7	0.776	1	1
11	44.9	1.490	1	1	37.7	0.839	1	1
12	46.4	1.644	1	1	38.6	0.895	1	1
13	47.7	1.787	1	1	39.3	0.943	1	1
14	48.8	1.919	1	1	39.9	0.986	1	1
15	49.9	2.040	1	1	40.4	1.022	1	1
16	50.7	2.151	1	1	40.9	1.054	1	1
17	51.5	2.251	1	1	41.2	1.081	1	1
18	52.2	2.342	1	1	41.5	1.104	1	1
19	52.8	2.424	1	1	41.8	1.124	1	1
20	53.3	2.497	1	1	42.0	1.140	1	1
21	53.8	2.562	1	1	42.2	1.155	1	1
22	54.2	2.621	1	1	42.4	1.167	1	1
23	54.6	2.673	1	1	42.5	1.177	1	1
24	54.9	2.719	1	1	42.6	1.186	1	1
25	55.1	2.760	1	1	42.7	1.193	1	1
26	55.4	2.797	1	1	42.8	1.199	1	1
27	55.6	2.829	1	1	42.8	1.204	1	1
28	55.8	2.857	1	1	42.9	1.209	1	1
29	55.9	2.882	1	1	42.9	1.213	1	1
30	56.1	2.905	1	1	43.0	1.216	1	1
31	56.2	2.924	1	1	43.0	1.218	1	1
32	56.3	2.941	1	1	43.0	1.221	1	1
33	56.4	2.957	1	1	43.1	1.222	1	1
34	56.5	2.970	1	1	43.1	1.224	1	1
35	56.6	2.982	1	1	43.1	1.225	1	1
36	56.6	2.992	1	1	43.1	1.227	1	1
37	56.7	3.001	1	1	43.1	1.228	1	1
38	56.8	3.009	1	1	43.1	1.228	1	1
39	56.8	3.017	1	1	43.1	1.229	1	1
40	56.8	3.023	1	1	43.1	1.230	1	1
41	56.9	3.028	1	1	43.2	1.230	1	1
42	56.9	3.033	1	1	43.2	1.230	1	1
43	56.9	3.037	1	1	43.2	1.231	1	1
44	57.0	3.041	1	1	43.2	1.231	1	1
45	57.0	3.044	1	1	43.2	1.231	1	1

[Continued]:

	Males				Females			
Age	Length	Weight	Selectivity	Maturity	Length	Weight	Selectivity	Maturity
46	57.0	3.047	1	1	43.2	1.232	1	1
47	57.0	3.050	1	1	43.2	1.232	1	1
48	57.0	3.052	1	1	43.2	1.232	1	1
49	57.0	3.054	1	1	43.2	1.232	1	1
50	57.0	3.055	1	1	43.2	1.232	1	1