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Relative abundance, size and age structure, and stock status of blue cod in Paterson Inlet of BCO 5 in 2010

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This report describes the results of the 2010 Paterson Inlet blue cod (*Parapercis colias*) potting surveys. These were concurrent fixed and random site surveys, the second fixed site survey since 2006, and the first random stratified site survey in Paterson Inlet. Both surveys used two-phase stratified designs, with six sites per stratum allocated for phase 1. Between 23 November and 11 December 2010, sixty-four sites were surveyed (6 pots per site, 384 pot lifts) from six strata throughout Paterson Inlet. The catch of each pot was weighed, and the length and sex of blue cod was recorded. Otoliths were read from 282 blue cod collected from both random and fixed sites representatively selected throughout Paterson Inlet (except the marine reserve). The resulting age-length keys were applied to the scaled length frequency distributions of both fixed and random stratified site surveys to estimate the population age structures.

Fixed site survey

The fixed site survey used 25 phase 1 sites, with three additional sites allocated in phase 2. Total blue cod catch was 828 kg, consisting of 1506 fish. For blue cod catch rates by stratum ranged from 1.5 to 8.4 $kg.pot^{-1}$, with an overall mean catch rate of 4.8 $kg.pot^{-1}$ and coefficient of variation (CV) of 9.3%. Catch rates of legal size blue cod (at least 33 cm) ranged from 1.4 to 6.2 $kg.pot^{-1}$, with an overall mean catch rate of 3.1 $kg.pot^{-1}$ and CV of 10.4%. Catch rates were highest in the Ulva Island/Te Wharawhara Marine Reserve stratum, and lowest in the Big Glory Bay stratum. At fixed sites outside of the marine reserve 38% of blue cod caught were of legal size, compared to 56% inside the reserve.

Total lengths recorded at fixed sites ranged from 15 to 51 cm. The length frequency distributions were mainly unimodal, with few fish below 22 cm or over 45 cm. Males were larger than females in all strata and overall mean length was 32 cm for males and 28 cm for females. Overall sex ratios for all and for legal sized fish were 1:0.3 (M:F) and 1:0.1 respectively. Age ranged from 2 to 25 years, with most blue cod between 5 and 12 years for males and 4 and 9 years for females. The mean weighted coefficients of variation (MWCVs) around the age distributions (about 30%) indicate that fish sampled in the 2010 surveys provided a reasonable representation of the overall population. The total mortality estimate (Z) was 0.37, assuming age-at-recruitment to the fishery at 8 years. The spawning biomass per recruit ($F_{\%SPR}$) estimate indicates that the expected contribution to the spawning biomass over the lifetime of an average recruit has been reduced to 40% of the contribution in the absence of fishing, and this level of exploitation (F) is of some concern as it is equal to the Ministry of Primary Industries target reference point of $F_{40\%}$.

Most gonads were in the mature stage with 11% of individuals running ripe.

Temporal comparisons between fixed site surveys

The overall catch rates from the 2010 fixed site survey were remarkably similar to those recorded in the 2006 fixed site survey. While there was a 38% increase in the catch rates of blue cod within the marine reserve, this had been offset by a 21% decline in the larger stratum 4 where most recreational fishing occurs. When the marine reserve was not included in the overall catch rates, there had been a 12% decline in the fishable part of Paterson Inlet. The overall CVs from the 2010 survey catch rates are similar to the 2006 survey (12%), and gonad observations were also consistent with the previous survey.

Random-stratified survey

The random-stratified survey used 33 phase 1 sites, with another three sites allocated in phase 2. Total blue cod catch was 224 kg, consisting of 639 fish. For legal sized blue cod, catch rates by stratum ranged from 0.2 to 2.5 $kg.pot^{-1}$ with an overall mean catch rate of 1.1 $kg.pot^{-1}$ and coefficient of

variation (CV) of 21%. Catch rates of legal size blue cod by stratum ranged from 0.2 to 1.2 $kg.pot^{-1}$ with an overall mean catch rate of 0.5 $kg.pot^{-1}$ and CV of 21%. Catch rates were highest in the marine reserve stratum, and lowest in the Big Glory Bay stratum. However, at random sites outside of the marine reserve 26% of blue cod caught were of legal size, compared to only 22% inside the reserve.

Total lengths recorded at random sites ranged from 11 to 45 cm. The length frequency distributions were mainly unimodal, with few fish below 17 cm or over 40 cm. Males were larger than females in all strata, and overall mean length was 29 cm for males and 26 cm for females. Overall sex ratios for all and for legal sized blue cod were 1:0.4 (M:F) and 1:0.2 respectively. Age ranged from 1 to 20 years, with most fish between 3 and 12 years for males and 3 and 9 years for females. The MWCV of the age distributions (about 40%) indicates that fish sampled in the 2010 random-stratified survey provided only a fair representation of the overall populations. The Z estimate was 0.43, assuming an age-at-recruitment of 8 years. The $F_{\%SPR}$ estimate indicates that the spawning biomass has been reduced to 37%, which should be of concern as this level of exploitation (F) is beyond the Ministry of Primary Industries target reference point of $F_{40\%.}$

The majority of gonads were in the mature stage with 24% running ripe.

Comparison between survey designs

The rank order of catch rates among strata was consistent between the 2010 fixed site and random-stratified survey. However, the catch rates at random sites were generally less than a fifth of the catch rates at fixed sites. The overall CVs of the catch rates from the random-stratified survey (over 23%) were more than twice the size of the CVs from the fixed site survey (11%). It appears that the random-stratified survey may not have had sufficient effort to constrain the variance of the catch rates and that more effort (i.e., sites) may be required in future random surveys of Paterson Inlet.

The proportion of fish less than 28 cm was notably lower in the fixed site survey than in the random stratified survey. The mean lengths of both male and female blue cod were higher at fixed sites, yielding proportionately more older fish and resulting in Z estimates from the fixed site survey that were slightly lower than those derived from the random-stratified survey. It may therefore be inappropriate to compare mortality estimates between random-stratified and fixed site surveys. The higher proportion of running ripe fish at random sites may be a result of fine spatial scale variability in the onset of spawning between coastal and offshore areas within Paterson Inlet, as the random site survey had more offshore sites than the fixed site survey which was largely concentrated on the coastline.

Environmental data

Significant relationships were found between the survey relative abundance estimates ($kg.pot^{-1}$) and some of the covariates related to the environmental conditions recorded from the 2010 Paterson Inlet potting surveys. Higher catch rates were observed with biogenic and rocky bottom types, greater depths, fixed-site locations, and locations with more westerly and northerly current directions.

Drop underwater video (DUV)

DUV transects were conducted concurrently with pots at 22 sites directly prior to potting. The DUV system surveyed 47 km of transects covering a total area of 194 175 m^2, from which 1109 independent benthic habitat observations were made, and 590 blue cod and their associated habitat features were recorded. Pots caught 918 blue cod, but with a higher proportion of legal size fish and proportionately fewer fish below 20 cm than the DUV observed. The estimated density of blue cod from video transects had only a weak relationship with pot catches, and the variance was often high for both pots and the video. The relationship between blue cod and benthic habitat structure was also examined.

1 INTRODUCTION

Blue cod (*Parapercis colias*) is a particularly desirable finfish caught by line or pot from small vessels fishing over reef edges on shingle/gravel or sandy seabed. Tagging experiments show that 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 may be especially susceptible to localised depletion within sub-areas of FMAs, and in response to local fishing pressure, managed bag limit strategies with a variety of upper limits have been applied within all South Island FMAs (Ministry of Fisheries 2010).

Blue cod is the species most frequently landed by South Island recreational fishers, and an important species for Maori customary fishers (Ministry of Fisheries 2010). The largest commercial blue cod fishery is the Southland FMA quota BCO 5, with 1391 t landed in 2008–09 (Ministry of Fisheries 2010). The Southland commercial blue cod catch is almost exclusively taken by a target pot fishery operating mainly within Foveaux Strait, around Stewart Island and in southern Fiordland (Starr & Kendrick 2008). The Southland recreational blue cod catch is taken mainly by line fishing from Foveaux Strait, Paterson Inlet and greater Fiordland (Davey & Hartill 2008, 2011, James et al. 2004, Warren et al. 1997).

In an aerial survey of Stewart Island, James et al. (2004) found that most of the recreational fishing trips were in Paterson Inlet (Figure 1) and trip reports showed that most fishers on Stewart Island targeted blue cod. Paterson Inlet has long been prized for its fisheries, and blue cod has always been the main finfish species harvested (Elvy et al. 1997) with most recreational fishing trips in Paterson Inlet targeting blue cod (Carbines 1998). Historically, Paterson Inlet supported a commercial hand-line fishery from dinghies from the 1920s to the 1950s (Warren et al. 1997), but since 1992 commercial fishing has been prohibited (Elvy et al. 1997). Due to the level of recreational fishing the Paterson Inlet Working Group reduced the local daily bag limit for blue cod from 30 to 15 fish per person per day in 1994 (Elvy et al. 1997). In 2004 Paterson Inlet was declared Te Whak̲a ä Te Wera Mätaitai Reserve and Tangata Tiaki/Kaitiaki further reduced the daily bag limit for blue cod from 15 to 10 fish per person per day in 2006 (Te Rûnanga o Ngâi Tahu 2007). The no-take Ulva Island/Te Wharawhara Marine Reserve was also established in Paterson Inlet around Ulva Island in 2004 (Figure 1).

In the 2000–01 Sustainability Round, the Ministry undertook to work with stakeholders in the Southland area to monitor blue cod populations. A relative biomass estimate based on potting surveys was initiated with a view to repeating surveys every three to four years. With the cooperation of the Te Whak̲a ä Te Wera Mätaitai Reserve Tangata Tiaki, an initial standardised potting survey of Paterson Inlet was conducted in November 2006 (Carbines 2007). With the cooperation of the Department of Conservation, it was also possible to include the Ulva Island/Te Wharawhara Marine Reserve as an unfished "control" area to monitor blue cod within the reserve, and over time assess and compare the impact of fishing on fish in the remainder of Paterson Inlet. The Department of Conservation has also conducted regular line fishing surveys throughout Paterson Inlet since 1994 (Chadderton & Davidson 2003), although this catch data has a much higher variance than the 2006 potting survey (Carbines 2007).

In addition to catch rate information, monitoring age structure provides a means of evaluating the response of a population to changes in fishing pressure. Otoliths collected during potting surveys are now 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 in Paterson Inlet there is insufficient information to estimate B_{MSY} since recreational catches in most areas have not been estimated reliably and are expected to represent a large 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 obtained 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 $F_{40\%SPR}$ 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).

The previous Paterson Inlet potting survey used a selected fixed site design surveying known fishing spots (Carbines 2007), however, this type of survey has a number of potential biases and the catch indices cannot be extrapolated to the whole survey area as the samples are not representative. In a review of all blue cod potting surveys, Stephenson et al. (2009) suggested using a more statistically robust random-stratified survey, but acknowledged the need for some continuity with previous survey data. Consequently, for a comparison of these methods the 2010 Paterson Inlet potting survey began a new random-stratified survey concurrently with a second fixed site survey.

1.1 Catch versus count

The use of a passive capture method such as pots to reliably estimate the actual abundance and size structure of blue cod populations requires further validation (Stephenson et al. 2009). Different methods have different selectivity bias and catch rates, and size composition from potting can differ compared to other methods such as line fishing (Carbines 1999, 2008). Pot catches can also have a highly variable and a largely unexplained relationship with counts from diver transects (Cole et al. 2001). To further investigate the relationship between potting survey catch rates (relative abundance – $kg.pot^{-1}$) and size structure with direct observations of blue cod, the 2010 Paterson Inlet potting survey also employed fish counts from remote video transects (see Morrison & Carbines 2006, Carbines & Cole 2009) done at potting sites prior to potting. This report therefore describes both the concurrent fixed and random-stratified potting surveys of the greater Paterson Inlet area, with comparisons of concurrently undertaken flown video transects.

Overall objective

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

Specific objectives

1. To undertake a potting survey in Paterson Inlet (BCO 5) to estimate relative abundance, size- and age at-maturity, sex ratio and collect otoliths from pre-recruited and recruited blue cod.

2. To analyse biological samples collected from the potting survey and produce a training reference photo library of blue cod otoliths.

3. To determine stock status of blue cod populations in this area.

4. To undertake a Dropped Underwater Video (DUV) survey concurrently with the potting survey to provide comparative estimates of biomass.

5. To determine F_{MSY} proxies for Paterson Inlet blue cod.

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. The main point of difference between the terms shown below and those used for surveys completed prior to 2010 is that the term station is now used to refer to a pot rather than a site (see Appendix 1).

2.1 Timing

To continue the fixed site survey time series for Paterson Inlet with minimal temporal (seasonal) variability between surveys, the 2010 Paterson Inlet fixed and random-stratified potting surveys were carried out concurrently between 11 November and 10 December 2010.

2.2 Survey area

Paterson Inlet is a shallow enclosed body of water on the northern end of Stewart Island at the southern tip of New Zealand (Figure 1). The seafloor is principally alluvial gravel overlaid with sand and shallow patches of rocky ground. Areas of potential blue cod habitat range throughout the Inlet at depths of only a few meters in the inner parts of the Inlet (strata 1 and 5) to over thirty meters in the outer stratum 4 (Figure 1, Carbines 2007). There were no detailed habitat maps available for Paterson Inlet.

The survey area used in the 2006 survey was defined after discussions with the Ministry of Fisheries (now Ministry for Primary Industries) Recreational Fishing Forum, local fishers, and the Mataitai Tangata Tiaki. 52 possible fixed sites were identified from a previous recreational diary (Carbines 1998) and flyover survey (James et al. 2004) of Paterson Inlet. The survey area boundary was defined as inside a line from Ackers Point to Bullers Point and the Inlet was divided arbitrarily into five strata, including Big Glory Bay and the marine reserve around Ulva Island (Figure 1).

The area of the five strata was chosen to contain roughly equal distributions of possible potting sites, and the area of each stratum was taken as a proxy measure of available habitat for blue cod. The same survey area and strata were used for the 2010 random-stratified survey of Paterson Inlet, but with stratum 5 subdivided on the basis of depth (i.e., above and below 24 m deep).

2.3 Survey design

Both the random and fixed site 2010 Paterson Inlet potting surveys used a two-phase stratified design, using six pots per site (Figure 2) and ensuring that sites were at least 300 m apart. The fixed site survey consisted of 28 sites[1] (168 pot lifts) allocated to strata 1–5, and the random survey consisted of 36 sites (216 pot lifts) allocated to strata 1–6 (Figure 3). For the fixed site survey, five sites per strata (n=25 sites, 150 pot lifts) were allocated to phase 1 and three sites (10.7%) were allocated to phase 2 (Table 1). For the random-stratified survey, five or six sites (depending on strata size) per strata (n=33 sites, 198 pot lifts) were allocated to phase 1 and three sites (8.3%) were allocated to phase 2 (Table 2). 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 ith 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.

[1] Fixed sites are randomly selected from a pool of 52 possible fixed fishing sites identified in 2006.

2.4 Vessels and gear

The Paterson Inlet survey was conducted from F.V. *Western Explorer*, a Stewart Island based commercial vessel equipped to set and lift rock lobster and blue cod pots and skippered by Mr Andrew Hamilton. The vessel specifications are: 11.5 m length, 3.8 m breadth, 15 t, wooden monohull, powered by a 180 hp Daewoo diesel engine with propeller propulsion.

Six custom designed and built cod pots were used to conduct the survey. 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

At each random site an acoustic doppler current profiler (ADCP) was first deployed. Around this central point, six pots were set sequentially in a fixed hexagon pattern with each point (pot) approximately 200 m from the centre and 200 m from adjacent pots. The six pots were set blind (i.e., not targeted by sonar) in the fixed grid pattern determined from an initial starting point approximately 200 m north of the random site location occupied by the ADCP (Figure 2).

In Paterson Inlet, fixed sites were adjacent to the coastline or submerged rocks (See Figure 1). The ADCP was initially deployed central to each fixed site, and the six pots were set in clusters, separated by at least 100 m. Once on site, the position of each of the six pots was determined by the skipper using local knowledge and the vessel sounder to locate an area of foul ground (Figure 2).

At both random and fixed sites pots were left to fish (soak) for approximately one 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 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 from GPS, 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 and was recovered after the last pot of each set was lifted.

After one 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 weight of each fish was recorded to the nearest 10 g. Otoliths were removed from a target of five fish of each sex per one centimetre size class over the available length range collected representatively throughout the inlet (excluding the marine reserve).

No blue cod could be harmed in the marine reserve (stratum 3) and Te Whaka ä Te Wera Mätaitai Reserve Kaitiaki restricted biological samples (i.e., killing fish) to 300 blue cod throughout the Mätaitai (strata 1, 2, and 4). Fortunately blue cod were spawning during the potting survey and it was possible to determine sex and maturity of almost all blue cod by “milking” (nonlethal) rather than by lethal dissection and direct examination of the gonads (Carbines 1998, 2004a). Any blue cod that could not be sexed by “milking’ were sexed through dissection, and all blue cod selected for otolith sampling were both “milked” and dissected for a comparison of sexing methods. For both “milking” and direct macroscopic observations, 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 paper envelopes. These were later embedded in a polymer resin, baked (50° C for at least three hours), and sectioned transversely about 1 mm either side of the nucleus 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 1 mm thickness before viewing. Sections were observed at ×40 and ×100 magnification under transmitted light with a compound microscope.

Otolith sections exhibit alternating opaque and translucent zones and age estimates were made by counting the number of annuli (opaque zones) from the core to the distal edge of the section (See Appendix 2, Figure 2.A), a technique previously validated for blue cod and a protocol described by Carbines (2004b). Translucent zones are used to define each complete opaque zone, i.e., annuli are counted only if they have a translucent zone on both sides. The readability of each otolith was also graded from 1 (excellent) to 5 (unreadable). Otoliths were read independently by two readers (G. Carbines and N. Usmar), 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 Otolith reference collection

Potting surveys now routinely estimate age of blue cod throughout the South Island of New Zealand; consequently Stephenson et al. (2009) recommended establishing reference collections of prepared otoliths and their associated digital images and documented interpretations. The reference collection is used to ensure consistency of age estimation through time by preventing long-term drift in interpretation by experienced readers. It also acts as a training tool for inexperienced readers.

From the 2010 Paterson Inlet collection, 100 otoliths were selected over the available age range including both sexes and a variety of otolith readability grades (See Section 2.6). The reference collection included some otoliths that were considered unreadable so as to ensure readers are suitably trained to identify these. Otoliths were photographed at ×40 and ×100 magnification under transmitted light with a compound microscope using a Nikon D7000 16.2 Mp digital camera. Two images were stored for each otolith; one image unmarked, the other annotated with the agreed interpretations of the two readers. Each annotated image contains relevant markings of the core (primordium) and the opaque zones (Appendix 2, Figure 2.A).

2.8 Data analysis

The data analyses follow the methods and equations described in the blue cod potting survey standards and specification document (Beentjes & Francis 2011), with exceptions noted here. Modifications of the standard analytical methods were required because fish sampled in the Patterson Inlet surveys were not all sexed. The equations for calculating catch rates of fish greater than the minimum legal size (MLS) and for calculating scaled length frequencies (LFs) need to be modified to account for the unsexed fish.

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 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. If not all fish have length measurements, expansion of the number with measurements is required as described in equation 4.

In the case where not all fish have been sexed, the above equation is extended to include unsexed fish (k=4):

$$C_{st}^{legal} = \left(\sum_{p} \sum_{k=1,2,4} \sum_{l \geq MLS} f_{lkpst} \, a_k \, l^{b_k} \right) \Big/ m \, . \qquad (2)$$

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:

$$w_{ki} = a_k \left(l_{ki} \right)^{b_k} \; \varepsilon_{ki} \qquad (3)$$

where w_{ki} and l_{ki} are the weight and length of fish i of sex k and the ε_{ki} are normally distributed. To obtain length-weight parameters for unsexed fish (k=4), the above equation is fitted to the combined male and female length-weight data.

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} .

Calculating scaled length frequency when not all fish are sexed

If the sexed (and measured) fish are a random sample of the catch, the recommended formula for calculating scaled length frequencies (LFs) is appropriate (Equations 7 and 7´, Beentjes & Francis 2011), however this is not the case for the Patterson Inlet surveys (see Section 2.6 and Appendix 3). A two-step procedure is adopted for calculating scaled LFs in this situation. The first step adjusts for fish that did not have length measured and the second step adjusts for fish that were not sexed. The first step follows equation 7´ in the survey manual, which scales the number of fish sampled relative to the total number caught. An alternative approach, Equation 7, scales the weight of fish sampled relative to the total weight of fish caught. For blue cod potting surveys, all fish are counted but not all fish are individually weighed so adjustment based on number is a more direct approach, consistent with how the data is collected.

For set s in stratum t, let N_{st} be the number of blue cod caught, and let f_{lkst} be the number of blue cod of length l and sex class k in the length sample from the catch. Then the sex class length frequency $\left(f'_{lkt}\right)$ for stratum t, which represents the expected number at length and sex class in a set from this stratum, is given by

$$f'_{lkt} = (1/n_t)\sum_s^{\mathrm{LF}}\left[f_{lkst}\left(\frac{N_{st}}{\sum_{l',k'} f_{l'k'st}}\right)\left(\frac{\sum_{s'} N_{s't}}{\sum_{s'}^{\mathrm{LF}} N_{s't}}\right)\right] \qquad \text{for } k = 1,2,4 \tag{4}$$

where $\sum_s^{\mathrm{LF}}$ denotes a summation restricted to those sets for which there is a length sample, and the sex classes include 1 (males), 2 (females), and 4 (unsexed). Equation (4) allows for the possibility that not all blue cod caught in a survey were measured. The third term inside the square brackets adjusts for sets that were not sampled for length and the second term adjusts for sets where not all fish were measured.

The second step of the LF scaling accounts for fish that were not sexed (ie. k=4), and requires calculation of one or more sex-length keys. Sex-length keys could be calculated at the stratum or survey level, depending on the specifics of the sex sampling. A survey-level sex-length key may be preferred because this will minimize the number of length bins for which there are no sexed fish. However, if there are strata where the sex ratio at length may be biased (e.g. the marine reserve where "milking" only was used to sex fish) sexed fish from these strata should be not be included in the sex-length key. For the Patterson Inlet surveys, a survey-wide sex-length key, excluding the marine reserve), was calculated.

For each length class l, the proportion at sex k is:

$$S_{lk} = \frac{\sum_t^{SL}\sum_s^{LF} f'_{lkt}}{\sum_t^{SL}\sum_s^{LF}\sum_{k=1}^{k=2} f'_{lkt}} \qquad \text{for } k = 1,2 \tag{5}$$

Where $\sum_t^{SL}$ denotes a summation over strata to be included in the sex-length key. Then, the strata- and sex-specific LF $\left(f_{lkt}\right)$ is given by:

$$f_{lkt} = f'_{lkt} + S_{lk} f'_{l,4,t} \qquad \text{for } k = 1,2 \tag{6}$$

Length frequency, age frequency and total mortality estimates

Calculation of survey-level length frequency (LFs), age frequency (AFs), and total mortality (Z) follow the equations described in the potting survey manual (Beentjes and Francis 2011). Uncertainty in the LFs, AFs 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.

For the Patterson Inlet survey, fish sampled in the marine reserve were not included in calculating the survey level LFs, AFs and total mortality (Z) as the sex data may not be representative. Also, this area is closed to fishing and the objective of the survey Z estimates is to monitor the effects of fishing.

Growth parameters

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

$$l_{ki} = L_k^{\infty}\left(1-\exp\left(K_k\left(t_{ki}-t_k^0\right)\right)\right)+\varepsilon_{ki} \tag{7}$$

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* ($F_{\%SPR}$) is the ratio of spawning biomass per recruit at a given level of fishing mortality (*F*) relative to the spawning biomass per recruit in the absence of fishing. *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*:

$$N_{ka} = \begin{cases} 0.5 & a = 0 \\ N_{k,a-1}\exp\left(-s_{k,a-1}F - M\right) & 1 \geq a < mage \\ N_{k,a-1}\exp\left(-s_{k,a-1}F - M\right) \Big/ 1-\exp\left(-s_{k,a-1}F - M\right) & a = mage \end{cases} \tag{8}$$

$$S_F = \sum_k \sum_a \left(m_a\, a_k \left(l_{ka}\right)^{b_k} N_{ka}\right) \tag{9}$$

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*.

Population parameters (l_{ka}, a_k and b_k) are either estimated based on survey data 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, 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 SINS working group determined that an age of recruitment of 8 would be the basis for the Patterson Inlet *SPR* analysis. *SPR* results are also provided for ages at recruitment from 5 through 11.

Note that the above equations assume that the surveys which generate the length-age data (and vB growth curves) occur at the time of spawning, such 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 (ie. full selectivity at some mid-point in the year).

Re-analysis of 2006 Patterson Inlet survey data

Two elements of the 2006 Patterson Inlet potting survey are re-analyzed using the methods described here so that comparisons with the 2010 survey are based on equivalent methods (See Appendix 4). The method for calculating survey CPUE CVs has changed from that used for previous blue cod surveys (Beentjes & Francis, 2011). Also, a different method was used to estimate Z for the 2006 survey: treating all survey data as unsexed, assuming the age-length key was not constructed by sex, and using a regression approach (Carbines, 2007). Estimates of Z presented in Appendix 4 use the standard methods, including the method to scaled unsexed fish LFs. Additionally, stratum areas are used to scale stratum CPUE and LFs, rather than the stratum coastline lengths used previously.

GLM for the 2010 environmental data

General linear model (GLM) analyses were conducted to ascertain if there were significant relationships between the 2010 Patterson Inlet catch rates and the associated environmental and ADCP data. The response variables were the natural logarithm of catch (either in weight or in numbers) averaged across each set, and 0 observations were replaced with a small constant (0.001). Continuous variables were considered as either linear, quadratic, or 3rd order polynomials. The Akaike Information Criteria, with correction for finite sample sizes (AICc, Burnham & Anderson 2002) was used to select the best (most parsimonious) model:

$$AICc = 2k - 2\ln(L) + \frac{2k(k+1)}{n-k-1}$$

where k is the number of parameters in the model, n is the sample size, and L is the maximum likelihood for the model.

The following variables were considered in the GLM analyses:

Variable	Continuous (c) or factorial (f)
Set characteristics	
Stratum number	f
Random or fixed	f
Environmental measures	
Wind speed (wind_spd)	c
Secchi	c
Air pressure (air_press)	c
Bottom temperature (bot_temp)	c
Surface temperature (surf_temp)	c
Bottom contour (bot_cont)	c
Bottom type (bot_type)	f
Sea condition (sea_cond)	c
Sea colour (sea_col)	c
Cloud cover (cloud_cov)	c
Average depth (avg. depth)	c
Air temperature (air_temp)	c
Wind force (wind_force)	c
Wind direction (wind_dir)	c
ADCP (current)	
Average direction (av_direction)	c
Average speed (av_speed)	c
Minimum degrees (min_deg)	c

Maximum degrees (max_deg)	c
Current variation (Variation)	c

The 2006 Patterson Inlet potting survey data was not included in the analysis because ADCP data was not available for that survey.

2.9 Drop underwater video (DUV)

Catch rates (kg.pot^{-1}) from potting surveys are used as a proxy for actual abundance, but it is unknown how this measure of relative abundance is related to the actual abundance of blue cod (Stephenson et al. 2009). To address this we estimated blue cod populations using drop under water video (DUV) counts conducted concurrently at a sub-sample of 11 random and 11 fixed sites.

Sample collection

The DUV consists of a 35 kg bulb keel and tail fins which 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). 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.

The video camera was deployed at a height of at least 1.5 m off the seabed as the vessel steamed through the site area. Once the speed of the surface vessel exceeds that of the deployed video, the keel and tail fin orient the platform forward, and the video records a transect of approximately 600 m length. Contact with the seabed is avoided by lifting and lowering the DUV from the surface vessel throughout each transect and scaling lasers are used to back-calculate the size and variations of transect width. Transects were carried out between 0700 and 1630 hours, when the swell was less than 2 m, and when speed exceeded 0.8 m.s^{-1} (to prevent fish being able to follow the video and re-enter the video transect). At least three replicate video transects were done at each site directly prior to sampling with six replicate pots (as described in Section 2.5).

Video analysis

Each video transect was processed (viewed) twice. On the first viewing, transect dimensions were geo-referenced and partitioned into gross general benthic habitat sections. All blue cod were geo-referenced and scaling lasers were used to estimate fish length (Morrison & Carbines 2006). At the location of each blue cod, a benthic habitat sub-transect was sampled (approximately 5 m before and after the fish observed). During the second viewing, each section of general habitat was sampled with at least five sequential sub-transects to record transect width from scaling-lasers and provide fish independent descriptions of benthic habitat. Both fish-dependent and fish-independent habitat sub-transects recorded primary (geological) substrata (categories based on grain size from sand to bedrock) and secondary habitat structure (categories of overlaying organic or geological benthic habitat), percentage cover (e.g., shells, sponges, macro-algae, etc.) topographic complexity and actual counts of benthic species where possible.

A correlation was calculated between the number of blue cod counted and caught at each site, and a comparison of blue cod length frequencies made between these methods to examine size selectivity (Cole et al. 2001). Data on fish abundance by size class from video and habitat data are presented separately for random and fixed sites, and a ratio of fish-dependent and fish-independent habitat observations was used to determine features of the benthic environment that were disproportionally utilised or absent of blue cod.

3 RESULTS

3.1 Sites surveyed

Twenty-eight fixed sites (6 pots per site, 168 pot lifts) and thirty-six random sites (6 pots per site, 216 pot lifts) were surveyed over twenty fishable days from 11 November to 10 December 2010 (Tables 1 and 2, Figure 3, Appendix 5). Of the 28 fixed sites, 25 were carried out in phase 1 (5 per stratum) with 3 allocated to stratum 4 in phase 2 (Table 1); of the 36 random sites, 33 were carried out in phase 1 (5 or 6 per stratum) and 3 allocated to stratum 4 in phase 2 (Table 2). Depth ranged from 3 to 26 m, and the mean soak time was 1 hour (range 59 to 71 min, s.e. = 4 sec). Environmental data recorded throughout the Paterson Inlet survey are presented in Appendix 6 and are stored on the Ministry for Primary Industries database *trawl*. The ADCP data is archived in a spreadsheet with the Research Data Manager, NIWA, Greta Point, Wellington.

3.2 Catch

A total of 1500 kg of catch was taken on the 2010 Paterson Inlet fixed and random-stratified surveys, of which 1052 kg (70%) was blue cod, consisting of 2145 fish. However, the fixed site survey caught 70% of the total blue cod, with blue cod accounting for 78% of catch in the fixed site survey (Table 3) compared to only 51% of the catch in the random-stratified survey (Table 4).

Bycatch included 10 fish species in the fixed site survey (Table 3), but only 5 fish and 1 octopus species in the random-stratified survey (Table 4). For the fixed site survey the five most common bycatch species by weight were spotty (*Notolabrus celidotus*), banded wrasse (*Notolabrus fucicola*), trumpeter (*Latris lineata*), conger eels (*Conger verreauxi*), and leather jackets (*Parika scaber*) (Table 3). For the random-stratified survey by far the most common bycatch species both by weight (48%) and by numbers (79%) was spotty (Table 4).

In the fixed site survey the mean catch rates of blue cod (all sizes) ranged from 1.54 kg.pot^{-1} for the Big Glory Bay stratum to 8.36 kg.pot^{-1} for the marine reserve (Table 5, Figure 4). Overall mean catch rate and CV were 4.21 kg.pot^{-1} and 11.1%. For blue cod 33 cm and over (local minimum legal size) the highest catches also came from the marine reserve (6.17 kg.pot^{-1}) and the lowest catch rates were also from Big Glory Bay (1.40 kg.pot^{-1}). Overall mean catch rate and CV for fish of at least 33 cm from the fixed site survey were 2.59 kg.pot^{-1} and 11.3% (Table 6, Figure 4).

In the random-stratified survey catch rates were lower, and the mean catch rates of blue cod (all sizes) ranged from 0.24 kg.pot^{-1} for the coastal Big Glory Bay stratum to 2.53 kg.pot^{-1} for the marine reserve (Table 7, Figure 5). Overall mean catch rate and CV were 0.82 kg.pot^{-1} and 24.2%. For blue cod 33 cm and over the highest catches also came from the marine reserve (1.24 kg.pot^{-1}) and the lowest catch rates were again from coastal Big Glory Bay (0.22 kg.pot^{-1}). Overall mean catch rate and CV for blue cod 33 cm and over from the random-stratified survey were 0.40 kg.pot^{-1} and 23.2% (Table 8, Figure 5).

3.3 Biological and length frequency data

Of the 2145 blue cod caught on the 2010 Paterson Inlet fixed and random-stratified surveys, all were measured for length and 97% were sexed, otoliths were taken throughout the inlet (except from stratum 3, the marine reserve) and read from 282 fish across the available size range (Appendix 7).

For all blue cod from the fixed site survey (excluding the marine reserve where 13% of fish could not be sexed) the sex ratio ranged from 1:0.4 (M:F) in stratum 5 to 1:0.2 (M:F) in stratum 1, and overall were 75% male at 1:0.3 (M:F) (Table 9). The sex ratio for blue cod 33 cm and over (local minimum legal size) ranged from 1:0.3 (M:F) in stratum 5 to 1:less than 0.1 (M:F) in stratum 4, and was overall heavily skewed towards males (1:0.1) (Table 10). The size of blue cod at fixed sites ranged from 15 to 45 cm for females and 15 to 51 cm for males, although size varied among strata.

For the random-stratified survey, all blue cod (excluding the marine reserve where 7% of fish could not be sexed) the sex ratio ranged from 1:0.5 (M:F) in stratum 4 to 1:3.0 (M:F) in stratum 5, and overall were 60% male at 1:0.4 (M:F) (Table 11). The sex ratio for blue cod 33 cm and over all ranged from 1:less than 0.1 (M:F) in stratum 4 to 1:3.0 (M:F) in stratum 5, but overall were skewed towards males (1:0.2) (Table 9). The size of blue cod at random sites ranged from 11 to 44 cm for females and 15 to 45 cm for males, but also varied among strata.

The length frequency distributions were mainly unimodal for most strata in both the fixed and random-stratified surveys, although strata 2 and 3 from the random-stratified survey tended to be more bimodal in distribution (Figure 6). Fish taken in the random-stratified survey were noticeably smaller than those from the fixed site survey in all strata except stratum 5 where sample sizes were very low (Tables 9 and 10, Figure 6).

For the fixed site survey, small blue cod (less than 20 cm) were uncommon, caught mainly in strata 3 and 4 close to the entrance of Paterson Inlet (Figure 6). In contrast, the largest blue cod taken in the fixed site survey came from strata 1 and 2 deeper inside the Inlet. Mean lengths of males were 4–6 cm more than females in all strata except for stratum 5 where the difference was much smaller, but overall (excluding the marine reserve) the mean male length was 31.9 cm and mean female length was 27.5 cm (Table 9). The proportion of legal sized blue cod caught on the 2010 fixed site survey was 38% outside the marine reserve and 56% inside the marine reserve.

The random-stratified survey caught more small blue cod (less than 20 cm) than the fixed site survey, mainly in strata 2, 3 and 4 in central north to outer areas of Paterson Inlet (Table 10, Figure 6). The largest blue cod caught in the random-stratified survey came from strata 5 and 6 in Big Glory Bay. Mean lengths of males were 3–6 cm more than females in all strata and overall mean male length was 29.3 cm and mean female length 26.3 cm (Table 10), 2.6 cm and 1.2 cm smaller than male and females respectively in the fixed site survey (Table 9). The proportion of legal sized blue cod caught on the 2010 Paterson Inlet random-stratified survey was 26% outside the marine reserve and 22% within the marine reserve.

Because the number of blue cod that could be killed for dissection during the 2010 Paterson Inlet potting survey was restricted (See Section 2.5), a comparison of sexing methods was made using 303 biological samples sexed and staged by non-lethal “milking” (See Section 2.5) and then by dissection. These methods showed identical results, thus validating the use of milking as a reliable sexing method for this survey. Of 1454 blue cod able to be examined in the fixed site survey, most had gonads in the late maturing phase. Fourteen-percent of males and 2% of females were in the running ripe stage, and only one male had spent gonads (Table 11). Of the 821 blue cod able to be examined in the random-stratified survey, most were in the late maturing phase, with 26% of males and 20% of females in the running ripe stage, and none with spent gonads (Table 12). The smallest fish observed in the running ripe stage were 18 cm for both males and females, with running ripe fish becoming common among males over 20 cm and females over 22 cm.

The combined survey length-weight relationship analysis included 138 females (range 11–45 cm) and 165 males (range 15–51 cm). Using the derived model $W = aL^b$, the length-weight parameters for Paterson Inlet were: males – a = 0.00663, b = 3.2469, females – a = 0.00663, b = 3.2469.

3.4 Ageing (between reader analyses)

From 303 otoliths collected during the 2010 Paterson Inlet surveys, 21 were rejected as unreadable or damaged, leaving 282 otoliths (153 males 15–51 cm, 129 females 11–45 cm (Table 13)). These otoliths were collected across all strata except the marine reserve (Appendix 7).

Initial independently derived reader estimates of age class are compared in Figure 7 (tabulated in Appendix 8) and show 72% agreement between the two readers, with reader 2 generally estimating lower age classes than reader 1 for fish over 30 cm. When the differences between age class estimates were resolved by agreement between the readers, reader 1 was 86% consistent with the agreed age class estimates compared to reader 2 who was 80% consistent with the agreed age classes (Figure 7, Appendix 9).

3.5 Otolith reference collection

Potting surveys now routinely estimate age of blue cod throughout the South Island of New Zealand; consequently Stephenson et al. (2009) recommended establishing reference collections of prepared otoliths and their associated digital images and documented interpretations. The reference collection is used to ensure consistency of age estimation through time by preventing long-term drift in interpretation by experienced readers. It also acts as a training tool for inexperienced readers.

From the 2010 Paterson Inlet otolith collection, 100 otoliths were selected and digital images recorded for each otolith to establish an reference collection (See Appendix 2). Digital images and details of the 2010 Paterson Inlet otolith reference collection are held by the MPI data manager.

3.6 Growth

The fitted von Bertalanffy growth models for the 2010 survey are shown in Figure 8, and the growth parameters (K, t_0 *and* L_{inf}) shown below. Male and female size-at-age is similar until about age 7, after which males grow faster and achieve a greater maximum length (L_{inf}) than females.

Parameter	Males	Females
K	0.0703	0.1086
T_0	-2.0046	-1.4415
L_{inf}	63.74	47.31

3.7 Length and age composition

The scaled length and age distributions for all strata combined (with the exception of the marine reserve) are shown for males, females, and both sexes combined for the 2010 Patterson Inlet fixed site (Figure 9) and random-stratified (Figure 10) surveys. For comparison, the same summary is presented for the 2006 Patterson Inlet fixed site survey (Figure 11).

The scaled length frequency distributions tend to be unimodal, with males larger than females. The frequency of smaller fish, less than 28 cm, was much greater in the stratified random survey than in the fixed-site survey (Figure 12). Comparing the 2006 and 2010 fixed-site surveys, the male mean length was smaller (32.2 cm compared to 32.8 cm) and the female mean length was larger (27.5 cm compared to 26.9 cm) for the 2010 survey.

Age of blue cod ranged from 1 to 25 years (Table 13), but there were few fish older than 15. For males, the dominant age-classes were 5, 6, 7, 8, 10 and 11, while for females the dominant age-classes were from 4 to 9 (Figure 9 and Figure 10). The mean age of males was higher in the fixed-site survey (8.5 compared to 7.1) as was the mean age of females (6.8 compared to 6.2). Mean ages by sex were also higher for the 2010 fixed-site survey than for the 2006 fixed-site survey by about 0.5 years.

The mean weighted coefficients of variation (MWCVs) around the age distributions are moderate (about 30%) indicating that fish sampled in the 2010 surveys provide a fair representation of the overall populations.

The age-length-keys (ALKs) by sex are shown in Appendices 10 and 11 and mean-age-at-length is shown in Appendix 12. For both males and females, all lengths measured on the survey had at least one valid age reading in the age-length-keys.

3.8 Total mortality (Z) estimates

Total mortality estimates (Z) and 95% confidence intervals for the 2010 Paterson Inlet fixed site and random-stratified surveys (excluding the marine reserve) are given in Tables 14 and 15, respectively. Z estimates increase with the assumed age-at-recruitment to the fishery, and are slightly higher for the random-stratified survey than for the fixed site survey. For the fixed site survey, Z estimates range from 0.25 to 0.56 for ages-at-recruitment of 5 and 11. For the random-stratified survey, Z estimates range from 0.31 to 0.59 for ages-at-recruitment of 5 and 11. Estimates of Z were somewhat higher for the 2006 fixed site survey, ranging from 0.32 to 0.85 for ages-at-recruitment of 5 and 10 (Appendix Table 4.C).

3.9 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 13.

Spawning biomass per recruit analyses for the random stratified survey is plotted as $F_{\%SPR}$ versus fishing mortality rate (Figure 13). Mortality parameters used in the analyses, and resulting $F_{\%SPR}$ values are shown in Tables 16 and 17. Based on the default value of M of 0.14 and age at recruitment of 8 years, the fishing mortality estimated for the 2010 Patterson Inlet random stratified was 0.29 which corresponds to an $F_{\%SPR}$ of 36.9%. 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 36.9% of the contribution in the absence of fishing. $F_{\%SPR}$ estimates for M values of 0.11 and 0.17 were 27.2% and 46.6%, respectively (Table 17). $F_{\%SPR}$ estimates were slightly higher for the fixed-site survey (Table 16)

3.10 GLM for environmental data

When individual environmental variables were offered to the GLM model, bottom type explained the highest proportion of the variability in catch rates at 42% and 39% for the weight-based and numbers-based response variable, respectively (Table 18). This was followed by set type (random or fixed), which explained 32% and 26% of the variability in weight-based and numbers-based catch rates. The remainder of the variables offered in the GLM had relatively little explanatory power.

When a full GLM was fitted, the order in which variables entered the models was the same when catch rates were weight-based as when numbers-based, but with 2 additional environmental variables significant in the numbers-based model, according to the AICc criterion (Table 18). The order in which environmental variables entered the model was: bottom type, depth, random or fixed-site set, current direction, air pressure (numbers model only), and wind direction (numbers model only). For the final models, the environmental variables explained 57.7% and 62.6% of the variation in catch rates for the weight- and numbers- based models, respectively (Table 18).

Higher catch rates were observed at biogenic and rocky bottom types, greater depths, fixed-site stations and with higher values for current direction (i.e., more west and northerly, Figure 14).

3.11 Drop underwater video

Video counts versus pot catch

At least three drop underwater video (DUV) transects (shallow/mid/deep water) were undertaken at 11 random and 11 fixed sites directly prior to sampling pots (see Table 19, Figure 15). A total of 72 DUV transects and 132 pots were deployed at the 22 sites surveyed with both methods. The DUV surveyed 47 km of transects with an average transect width of 4.2 m (s.e. ± 0.2 m) covering a total area of 194 175 m^2. Within the area swept by the DUV, 252 general habitat breaks were identified and 1109 fish-independent habitat transects were recorded within them (Figure 15). A total of 590 blue cod were observed using DUV, while the concurrent pots caught 918 blue cod (Table 19).

Species caught and observed

A total catch of 1107 individuals was taken by pots at concurrently DUV surveyed sites, 61% of which were blue cod (Table 20). Fixed sites caught 72% blue cod and random sites caught 29% blue cod (Table 20). At the DUV surveyed sites bycatch from potting included ten fish and one octopus species. The five most common bycatch species from potting (by numbers) were spotty *(Notolabrus celidotus*), banded wrasse (*(Notolabrus fucicola*), trumpeter (*Latris lineata*), leather jackets (*Parika scaber*), and scarlet wrasse (*Pseudolabrus miles*).

A total of 2713 individuals was observed in DUV transects (not including 4982 unidentified individuals – mainly *Triperygiidae*), 19% of which were blue cod (Table 21). At fixed sites 16% of the observed fish were blue cod and at random sites 35% were blue cod (Table 21). Eighteen other fish species were observed in DUV transects, the five most common of which were spotty *(Notolabrus celidotus*), southern pigfish (*Congiopodus leucopaecilus*), Tarakihi (*Nemadactylus macropterus*), banded wrasse (*Notolabrus fucicola*), and butterfly perch (*Caesioperca lepidoptera*).

Length frequency comparisons

The length frequency distributions from the DUV surveyed sites are shown in Figure 16. Both the length frequency distributions for all blue cod observed, and only those observed without a camera head-on position (to improve precision) showed that the DUV sampled considerably more blue cod below 20 cm than pots (Figure 16). Because there were few large blue cod caught or observed it is less obvious whether pots proportionally sample more blue cod over 38 cm (Figure 16). The cumulative distribution plots of length frequency confirm that the video has a higher proportion of smaller fish than pots do (Figure 16).

Comparison of catch rates and counts

All fish densities estimated by the area-swept DUV method were standardised to the mean number per 1500 m^2 and plotted against the mean pot catch per site for all blue cod and for blue cod of at least 20 cm (to reduce pot size selectivity) in Figure 17. However, there were few blue cod below 20 cm and there was little difference between the two figures, with the variance often high for both pots and the video (Figure 17). Generally where no fish were seen, none or only a few were caught; and where large densities were observed catch rates were high. However, there were several sites with low observed densities and high catch rates (e.g., sites 2D, 3D, 3I, and 4I respectively), and an instance of high densities observed and low catch rates (site 4R5, Figures 17). The correlation between the average density and catch rate of all blue cod was 0.39 (Figure 18), similar to that observed by Cole et al. (2001) (Figure 19).

Benthic habitat descriptions and utilisation

Benthic habitat data from the DUV method are presented for fixed and random sites, and a ratio of fish-dependent and fish-independent habitat observations was used to determine which primary substrata and secondary habitat structures (as defined in Section 2.9) blue cod are more commonly associated with, within the benthic environment.

Primary substrate
Using the DUV fish-independent habitat observations, the main primary substrate at fixed sites were muddy sand/shell grit, sand/shell grit and sand (Figure 20), while homogeneous sand was more commonly observed at random sites (Figure 21). Blue cod were observed mostly with sand/shell grit, sand/shell/gravel and muddy sand/shell at fixed sites (Figure 20), and among sand/shell gravel and muddy sand/shell gravel at random sites (Figure 21).

The main primary substrates observed in fish-dependent habitat observations for fixed sites were various forms of sand and grit (Figure 20). However, using a ratio of the substrate category proportions observed between fish-dependent verses fish-independent habitat observations (i.e., substrate category occupancy in proportion to its availability), showed that blue cod at fixed sites were highly associated with jagged bedrock/sand (Figure 20). At random sites the main substrate observed in fish-dependent habitat observations were sand/shell gravel and muddy sand/shell gravel, although the above ratio showed that all sized blue cod were most associated with jagged bedrock/sand and associated with homogeneous jagged bedrock (Figure 21).

Secondary habitat structures
The main secondary habitat structures observed independently of fish at fixed sites were macroalgae and "no structure" (Figure 22). Blue cod of all size classes were observed most frequently with macroalgae and bedrock/macroalgae, and were seldom observed in areas with no structure (Figure 22). Fish-independent observations at random sites were also mostly of macroalgae and "no structure", but showed proportionately more sponge than at fixed sites (Figure 23). Larger blue cod at random sites were observed with mainly bedrock/macroalgae while smaller blue cod were mainly observed with sponge (Figure 23).

The main secondary habitat structure observed with both blue cod and fish-independent habitat observations at fixed sites was macroalgae (Figure 22). However, using the ratio of fish-dependent and fish-independent secondary habitat categories, shows that larger blue cod at fixed sites were most associated with bedrock, bedrock/macroalgae and sponge on boulders, while smaller blue cod were most associated with boulders/macroalgae and sponge (Figure 22). At random sites blue cod were observed mainly with bedrock/macroalgae and sponge, while fish-independent habitat observations were mainly of macroalgae, sponge and "no structure" (Figure 23). Using the above ratio showed that larger blue cod at random sites were more often associated with bedrock/macroalgae, while smaller blue cod were more associated with sponge (Figure 23).

4 DISCUSSION

The 2010 Paterson Inlet blue cod potting survey was the first comparison of a full fixed and full random-stratified site survey design. This was the first random-stratified survey and the second fixed site survey (Carbines 2007) done in Paterson Inlet.

4.1 Fixed site survey design time series

For the fixed site survey, the overall catch rates of all blue cod (Table 5) and legal sized blue cod (at least 33 cm, Table 6) were remarkably similar to those recorded in the 2006 survey (See Figure 4 and Appendix 4). While there was an increase in catch rates in the marine reserve (stratum 3 - up 38% for all blue cod and up 24% for legal sized blue cod), this was offset by a decline in stratum 4 catch rates - down 21% for all blue cod and down 24% for legal sized blue cod (Figure 4). Consequently, since 2006 the rank order of catch rates among strata (i.e., 4, 3, 2, 1, 5) has changed, with the marine reserve now having the highest catch rates in 2010 (i.e., 3, 4, 2, 1, 5, see Figure 4).

Diary, aerial, and boat ramp recreational fishing surveys have all concluded that the majority of fishing within Paterson Inlet occurs within stratum 4 (Carbines 1998, James et al. 2004, Davey & Hartill

2011), while fishing has been prohibited within the marine reserve since 2004. When the marine reserve is not included in the overall catch rates (i.e., only the fishable part of Paterson Inlet is included), catch rates of both all, and legal sized, blue cod have declined by 12% (Figure 4).

The overall CV for the 2010 fixed site survey catch rates was 11.1% for all blue cod and 11.3% for legal sized blue cod (Tables 5 and 6) which were very similar to the overall CV from the previous 2006 fixed site survey (11.9% for all blue cod and 12.3% for legal sized blue cod (Tables 4.A and 4.B in Appendix 4)).

4.2 Comparisons of catch rates between survey designs

For the random-stratified survey, the rank order of catch rates among strata was consistent with the 2010 fixed site survey (i.e., strata 3, 4, 2, 1, 5), but overall catch rates of all and legal sized blue cod (Tables 7 and 8) were only 19% and 15% respectively of the catch rates from the concurrent fixed site survey (Figure 5). This level of reduced catch in the random-stratified survey was reasonably consistent among strata for both all and legal sized blue cod (Figure 5).

The overall CVs of the catch rates from the random-stratified survey (over 23% - Tables 7 and 8) were more than twice the size of the CVs from the fixed site survey (11% - Tables 5 and 6). This suggests that the random-stratified survey effort may not have been sufficient to constrain the variance of the catch rates in Paterson Inlet. However, catch rates and CVs from a random-stratified survey of three strata off Otago (also using six phase 1 sites per strata) had about half the catch rate and similar CVs to concurrently surveyed fixed sites (Table 22). In another comparison of potting survey designs conducted in Pelorus Sound as part of the 2010 Marlborough Sounds survey, both catch rates and CVs were similar for fixed and random sites (Table 22). The 2010 Foveaux Strait random-stratified blue cod survey (directly outside Paterson Inlet) also used a similar level of sampling effort to the 2010 Paterson Inlet random-stratified survey, but the CVs of catch rates in Foveaux Strait were considerably lower (Table 22). Clearly there is no simple relationship between random and fixed site survey catches as these appear to be quite area specific and are possibly related to the blue cod population size and the heterogeneity of benthic habitat in each survey area.

4.3 Reproductive condition

Observations of gonad stages were similar between fixed and random sites with most individuals in the mature stage, some running ripe and one spent gonad found (Tables 11 and 12). This indicates that the timing of the survey (late spring) was during the early part of the spawning season and was consistent with the previous survey done at a similar time in 2006 (Carbines 2007). However, the proportion of running ripe phase individuals was about twice as high at random sites (24%) than at fixed sites (11%) suggesting that there may be some fine scale variability in the onset of spawning as fixed sites tended to be along the coast compared to the more off shore nature of random sites (see Figure 3). Without histological samples taken throughout the year it is difficult to accurately determine the size/age-at-sexual maturity (see Carbines 2004a), but with running ripe fish being relatively common among males over 20 cm and females over 22 cm it is appears that sexual maturity in Paterson Inlet is attained at 3 to 4 years old. However, while blue cod in Paterson Inlet may be spawning at this small size, their fecundity is likely to be low and larger fish may contribute disproportionately to the total egg production (Beer et al. 2013).

4.4 Size and sex ratio

As not all fish in the marine reserve could be sexed, stratum 3 was not included in the analysis of sex ratios (see Section 2.5 and Appendix 3). At fixed sites about 75% of fish were males, and for all blue cod the sex ratio was relatively consistent in most strata (1:0.3 – 1:0.4, M:F), except stratum 1 where it was 1:0.2 (Table 9). Ninety-one percent of legal sized blue cod from fixed sites were male and all strata were heavily biased towards males, particularly in stratum 4 (Table 9). However, at random sites only 60% of all blue cod were male and the sex ratio was skewed in favour of females in strata 1, 5 and 6 (Table 10) Eighty-one percent of legal sized blue cod from fixed sites were male and all strata were biased towards males except stratum 5 (where only seven fish were caught, see Table 10). The most pronounced male bias for both all and legal sized blue cod at random sites was in stratum 4 (Table 10).

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 (Tables 9 and 10) is consistent with the sex structure in a protogynous hermaphrodite. However, the male skewed sex ratios of legal sized blue cod in almost all strata are contrary to an expected dominance of females resulting from selective removal of the larger terminal sex males. Beentjes & Carbines (2005) suggested that the shift towards a higher proportion of males in heavily fished blue cod populations may be caused by removal of the 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 higher predominance of males at the fisher identified fixed sites (see Section 2.2) and in stratum 4 generally (Tables 9 and 10) as this is where fishing pressure is highest (Carbines 1998, James et al. 2004, Davey & Hartill 2011) and catch rates have reduced by 24% for legal sized blue cod since the 2006 fixed site survey (Figure 4).

4.5 Population length and age structure

Length frequency distributions were generally similar for most strata in fixed and random-stratified surveys, although blue cod taken from random sites were on average 2–3 cm smaller than those taken from fixed sites (Tables 9 and 10, Figure 6). The random-stratified survey also caught more small blue cod (over 20 cm) than the fixed site survey, particularly in the outer areas of Paterson Inlet, while the largest fish from both surveys came from deeper within the inlet.

The proportion of legal sized blue cod caught (33 cm and over) from fixed sites outside the marine reserve was 38% (down from 40% in 2006), which is comparatively low in comparison to the 2008 Dusky Sound survey (55%, Carbines & Beentjes 2011), but dramatically higher than the 2009 fixed site potting survey in the adjacent Foveaux Strait (17%, Carbines 2009). However, the proportion of legal sized blue cod caught in 2010 from the Paterson Inlet random-stratified survey outside the marine reserve was 26%, which is the equivalent proportion of legal sized blue cod caught in the 2010 Foveaux Strait random-stratified potting survey (Carbines & Beentjes 2012). However, comparing proportions of legal sized blue cod across years or areas is difficult because they are affected by both recruitment and fishing mortality.

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., stratum area is assumed to be a proxy for habitat; however, this is probably not the case given that the habitat types where blue cod are most frequently found are unevenly distributed in the DUV analysis (Section 3.10). 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).

The scaled length frequency distributions show more clearly that at random sites proportionately more small fish and fewer larger fish are caught than at fixed sites (Figures 9 and 10). There are few fish over 40 cm at either fixed or random sites, and the resulting population age structures show an abrupt decline on the right hand limb after eight years old and another after ten years old, with a low proportion of fish older than 11 years.

4.6 Total mortality (*Z*)

In the 2010 Paterson Inlet potting survey, fixed sites yielded proportionately more older fish than random sites (Figures 9 and 10) and the resulting mortality estimates (*Z*) from the fixed site survey (Table 14) were slightly lower than those derived from the random-stratified survey (Table 15). Because of the difference in population structure between survey designs, we suggest it is inappropriate to compare mortality estimates between random and fixed surveys. Comparing recent BCO 5 fixed site potting survey estimates of *Z* for an age of recruitment of 8, the 2010 Paterson Inlet fixed site survey estimate of 0.37 (Table 14) is higher than the 2008 Dusky Sound fixed site survey estimate of 0.30 (Carbines & Beentjes 2011). However, the 2010 Patterson Inlet survey estimate of 0.37 is substantially lower than the 2006 survey estimate of 0.63, although it is unclear whether this reflects a decrease in the fishing mortality rate between 2006 and 2010, because of the wide confidence intervals on both estimates. Comparing recent BCO 5 random-stratified potting survey estimates of *Z*, the 2010 Paterson Inlet survey estimate of 0.43 (Table 15) is slightly lower than the 2010 Foveaux Strait random-stratified survey estimate of 0.46 (Carbines & Beentjes 2012).

4.7 Stock status (spawning biomass per recruit ratio analyses)

The Ministry for Primary Industries *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 fishing mortality reference point for blue cod is F_{MSY}, which is the amount of fishing mortality that results in the maximum sustainable yield. A suggested proxy for F_{MSY} is in terms of spawning biomass per recruit, $F_{\%SPR}$. The Operational Guidelines for New Zealand's Harvest Strategy Standard' (Ministry of Fisheries 2011) includes the following table of recommended default values for $F_{\%SPR}$ and for B_{MSY} (expressed as $\%B_0$), based on stock productivity:

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

Based on the recommendation from the Southern Inshore Working Group, blue cod is categorised as a medium productivity species which results in a fishing mortality reference point for $F_{\%SPR}$ of 40%. In Paterson Inlet the SPR estimates for the default *M* value of 0.14 were 40.4% for the fixed site survey and 36.9% for the random-stratified survey (Tables 16 and 17), indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit has been reduced to 36.9 or 40.4% of the contribution in the absence of fishing. The recent level of exploitation (*F*) for the Paterson Inlet blue cod stock is close to the F_{MSY} reference point.

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 $F_{\%SPR}$ values (Tables 16 and 17, Figure 13). A higher natural mortality (0.17) increased the spawning biomass at current *F* relative to the unfished level by about 10%. Conversely, a lower natural mortality (0.11) decreased the spawning biomass at current *F* relative to the unfished level by a similar proportion.

4.8 Abundance and environmental data

Significant relationships were found between the survey relative abundance estimates ($kg.pot^{-1}$) and some of the covariates related to the set and environmental conditions for the 2010 Paterson Inlet potting survey. Variables included in GLM fits to the catch rate data included bottom type, depth, random or fixed-site, and current direction. Higher catch rates were observed at biogenic and rocky bottoms, greater depths, fixed-site stations, and with more westerly and northerly current directions.

Francis (2011) investigated whether environmental data affected abundance in blue cod potting surveys (not including ADCP current data), including data from four areas with multiple survey years in his analysis. He found no evidence for substantial and consistent effects of station, depth or environmental data on catch rates. The analyses conducted by Francis were more rigorous than those presented here in that; multiple years of observations were used for each analysis, leave-one-out cross validation was used to calculate statistics (percent variation explained), and the null hypothesis was based on the mean catch rate in each stratum rather than over the entire survey, as was done here. This suggests that the relationships indicated by the analysis of the 2010 Paterson Inlet survey data may be area specific or ephemeral and not hold over future surveys.

Of interest is the relatively high proportion of the total variation in catch rate explained by bottom type for the 2010 Paterson Inlet survey data. As a single factor in a GLM, set type (random or fixed-site) also explains a high proportion of the variability in catch rates, but when bottom type is also included in the GLM, the increased variability accounted for by set type is relatively small. This suggests an interaction between set type and bottom type. Because the fixed-site surveys use locations suggested by fishers, these will be locations of relatively high blue cod catch rates which may not fully sample the blue cod habitat, rather only their preferred habitat. As more blue cod potting surveys are conducted, consistent relationships between bottom type and blue cod abundance may become more apparent.

4.9 Comparison of pot catch 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).

In the 2010 Paterson Inlet potting survey we used concurrent observations of blue cod abundance and environmental descriptions from a flown drop underwater video (DUV) to investigate the relationship between actual counts of blue cod over a known area with catch rates and sizes of blue cod caught in survey pots (pot plan 2 in Beentjes & Francis 2011).

Does potting provide an index of relative abundance and size structure?

In Paterson Inlet, nineteen species were observed using DUV while only twelve were caught by pots concurrently surveyed (Tables 20, 21). Pots caught mainly carnivorous reef fish as well as predators of blue cod such as conger eels (*Conger verreauxi*) and octopus (*Octopus cordiformis*) that were not observed by the DUV. A similar group of carnivorous reef fish species were observed by the DUV to those caught by pots, however the DUV also observed southern pigfish (*Congiopodus leucopaecilus*), several species of planktivorous fishes, and some elasmobranchs that pots did not catch (Tables 20, 21).

Compared to the DUV, pots caught very few blue cod less than 20 cm and proportionately fewer below the legal size (33 cm). In contrast pots caught a higher proportion of blue cod over the legal size compared to the DUV (Figure 16). The current study provided a very similar relationship between observed densities and catch rates to those observed by Cole et al. (2001) using SCUBA counts and pot catches of blue cod in the Marlborough Sounds (Figures 18 and 19). While a higher correlation coefficient was observed between blue cod densities from DUV and pot catches in the adjacent Foveaux Strait (pot plan 2 - Carbines & Beentjes 2012), a lower correlation was observed between blue cod densities from DUV and pot catches in the Marlborough Sounds (pot plan 1 - Beentjes & Carbines 2012).

In Paterson Inlet there was one instance of high densities observed with concurrent low catch rates, and several sites where fish were caught when none (or few) were observed (see Figure 17). It appears that either pots are attracting blue cod in from a distance greater than the area surveyed by the DUV (i.e., transects are too short), or that the pot capture distance is quite small and blue cod populations are highly clumped within the survey area (i.e., not enough transects close to the pots). The relationship between catch and count (i.e., catchability) may also be highly variable over time and/or location. To help resolve this uncertainty we recommend that these catch-verses-count comparisons continue at several survey areas over several occasions, and that these comparisons use a wider DUV sample area or increase the number of DUV transects within the sample area closer to the pots.

Importance of recording habitat for blue cod potting surveys

Fixed sites (which are known good fishing spots) differed from random sites in both primary substrate and secondary habitat structures (as defined in Section 2.9). There were more categories of both primary substrate and secondary habitat structures observed at fixed sites than at random sites, with random sites generally characterized by more homogeneous and softer primary substrata with some shell, macro algae and sponge. In contrast, fixed sites were generally more heterogeneous with coarser/harder primary substrate supporting more macro algae (Figures 20 – 23).

The primary substrate most frequently observed with blue cod at both at fixed and random sites were sand with shell or gravel (Figures 20 and 21). The secondary benthic habitat most frequently observed with blue cod at fixed sites was macro algae, while at random sites it was both sponge and macro algae (Figures 22 and 23).

Using the ratio of fish-dependent and fish-independent habitat observations it was possible to determine which primary substrate and secondary habitat categories blue cod were found in association with at a higher rate than in the benthic environment as a whole. At fixed sites blue cod were most often found with macro algae (Figure 22), while at random sites they were found more often with sponge or macro algae on bedrock (Figure 23). However, in relation to the availability of each habitat category, at fixed sites blue cod were more associated with rocks and boulders covered in macro algae and sponge (Figure 22), while at random sites larger blue cod were more associated with rocks covered in macro algae and smaller blue cod with sponge (Figure 23).

Data on fish abundance and habitat from video provide information regarding environmental variables that appear to affect blue cod density and size structure. It identifies benthic habitats and structures of particular importance and allows for the construction of habitat maps, which will be particularly useful in terms of stratifying future potting surveys for more accurate scaling of relative abundance estimates (Stephenson et al. 2009). Video habitat data also provides a unique understanding of the ontogenetic needs of fish and can provide habitat information for other management purposes.

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Table 1: Paterson Inlet 2010 survey stratum area, number of phase 1 and 2 sites (number with zero catch), pot lifts (number with zero catch), and depth of fisher selected fixed sites. All DUV sites are paired to a subsequent set of six survey pots deployed immediately after filming.

	Size of strata	Number of Selected sites (0)		Number of pot lifts (0)	Depth (m)		DUV
Stratum	Area (km^2)	Phase 1	Phase 2	Total	Mean	Range	Sites
1	15.6	5 (0)		30 (7)	7.1	3–20	1
2	20.7	5 (0)		30 (2)	7.8	3–18	3
3 (Reserve)	10.7	5 (0)		30 (1)	9.6	4–19	4
4	20.7	5 (0)	3 (0)	48 (2)	11.0	3–25	3
5 (incl 6)	11.1	5 (0)		30 (11)	6.6	3–19	
Total	78.8	25 (0)	3 (0)	168 (23)	8.9	3–25	11

Table 2: Paterson Inlet 2010 survey stratum area, number of phase 1 and 2 sites (number with zero catch), pot lifts (number with zero catch), and depth of random sites. All DUV sites are paired to a subsequent set of six survey pots deployed immediately after filming.

	Size of strata	Number of Random sites		Number of pot lifts	Depth (m)		DUV
Stratum	Area (km^2)	Phase 1	Phase 2	Total	Mean	Range	Sites
1	15.6	6 (2)		36 (24)	15.1	4–21	
2	20.7	6 (1)		36 (19)	16.6	6–25	2
3 (Reserve)	10.7	5 (0)		30 (10)	20.5	5–26	2
4	20.7	6 (1)	3(2)	54 (38)	19.5	8–40	3
5	7.9	5 (2)		30 (27)	9.4	3–23	2
6 (Deep Mud)	3.2	5 (2)		30 (21)	25.2	24–26	2
Total	78.8	33 (8)	3 (2)	216 (139)	17.8	3–26	11

Table 3: Catch weights, numbers of blue cod, bycatch species, and percentage of total weight from the 2010 fixed sites.

Common name	Scientific name	Catch (kg)	Number	Percent of total catch
Blue cod	*Parapercis colias*	827.54	1506	77.94
Spotty	*Notolabrus celidotus*	140.18	1249	13.20
Banded wrasse	*Notolabrus fucicola*	38.64	38	3.64
Trumpeter	*Latris lineata*	22.94	40	2.16
Conger eel	*Conger verreauxi*	19.40	2	1.83
Leather jacket	*Parika scaber*	3.79	8	0.36
Girdled wrasse	*Notolabrus cinctus*	3.08	7	0.29
Red cod	*Pseudophycis bachus*	2.90	2	0.27
Scarlet wrasse	*Pseudolabrus miles*	1.95	7	0.18
Blue moki	*Latridopsis ciliaris*	1.08	3	0.10
Tarakihi	*Nemadactylus macropterus*	0.30	1	0.03
Total		1061.80	2863	100.00

Table 4: Catch weights, numbers of blue cod, bycatch species, and percentage of total weight from the 2010 random sites.

Common name	Scientific name	Catch (kg)	Number	Percent of total catch
Blue cod	*Parapercis colias*	224.85	639	51.26
Spotty	*Notolabrus celidotus*	210.21	2409	47.92
Octopus	*Octopus cordiformis*	1.71	2	0.39
Red cod	*Pseudophycis bachus*	1.05	1	0.24
Stargazer	*Kathetostoma giganteum*	0.34	1	0.08
Tarakihi	*Nemadactylus macropterus*	0.25	2	0.06
Leather jacket	*Parika scaber*	0.22	1	0.05
Total		438.63	3055	100.00

Table 5: Mean catch rates for all blue cod caught in the 2010 Paterson Inlet fisher-defined fixed sites survey. 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.

Stratum	Sites	Pot lifts (N)	Mean (kg.pot^{-1})	s.e.	CV (%)
1	5	30	2.72	0.83	30.42
2	5	30	4.35	0.79	18.25
3	5	30	8.36	1.36	16.30
4	8	48	6.64	1.13	17.09
5	5	30	1.54	0.39	25.47
Overall	28	168	4.78	0.44	9.28
Overall (excluding Stratum 3)	23	138	4.21	0.47	11.06

Table 6: Mean catch rates for blue cod 33 cm and over (MLS) caught in the 2010 Paterson Inlet fisher-defined fixed sites survey. 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.

Stratum	Sites	Pot lifts (N)	Mean (kg.pot^{-1})	s.e.	CV (%)
1	5	30	2.18	0.74	33.86
2	5	30	3.06	0.45	14.56
3	5	30	6.17	1.43	23.14
4	8	48	3.06	0.62	20.33
5	5	30	1.40	0.31	22.31
Overall	28	168	3.08	0.32	10.35
Overall (excluding Stratum 3)	23	138	2.59	0.29	11.28

Table 7: Mean catch rates for all blue cod caught in the 2010 Paterson Inlet random-stratified survey. 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.

Stratum	Sites	Pot lifts (N)	Mean (kg.pot^{-1})	s.e.	CV (%)
1	6	36	0.61	0.27	44.8
2	6	36	0.62	0.27	42.6
3	5	30	2.53	1.07	42.5
4	9	54	1.41	0.55	38.7
5	5	30	0.24	0.15	61.6
6	5	30	0.71	0.59	83.8
Overall	36	216	1.05	0.22	21.4
Overall (excluding stratum 3)	31	186	0.82	0.20	24.2

Table 8: Mean catch rates for blue cod 33 cm and over (MLS) caught in the 2010 Paterson Inlet random-stratified survey. 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.

Stratum	Sites	Pot lifts (N)	Mean (kg.pot^{-1})	s.e.	CV (%)
1	6	36	0.37	0.17	45.1
2	6	36	0.36	0.17	48.6
3	5	30	1.24	0.50	40.2
4	9	54	0.52	0.21	39.4
5	5	30	0.22	0.14	63.2
6	5	30	0.47	0.41	87.7
Overall	36	216	0.51	0.11	20.5
Overall (excluding stratum 3)	31	186	0.40	0.09	23.4

Table 9: Mean lengths of blue cod in the 2010 Paterson Inlet fixed site survey, by strata and sex: m, males; f, female; u, unsexed. Sex ratio is shown for all blue cod.

Strata	Sex	N	Mean	Length (cm) Minimum	Maximum	Sex ratio M:F (% male) All blue cod	≥ 33 cm
1	M	98	35.1	20	47	1:0.2 (82.4)	1:0.1 (89.5)
	F	21	30.3	20	39		
2	M	165	34.0	15	48	1:0.3 (74.7)	1:0.1 (93.7)
	F	56	27.9	19	40		
3 (Reserve)	*M*	*305*	*34.5*	*21*	*45*		
	F	*36*	*28.9*	*20*	*41*		
	U	*52*	*29.7*	*16*	*44*		
4	M	532	30.3	18	45	1:0.4 (73.9)	1:0.1 (94.4)
	F	188	26.3	15	36		
5	M	38	37.3	23	51	1:0.4 (71.7)	1:0.3 (73.8)
	F	15	35.7	27	45		
Overall (un-weighted)	M	833	31.9	15	51	1:0.3 (74.8)	1:0.1 (91.3)
(Excluding the reserve)	F	280	27.5	15	45		

Table 10: Mean lengths of blue cod in the 2010 Paterson Inlet random-stratified survey, by strata and sex: m, males; f, female; u, unsexed. Sex ratio is shown for all blue cod.

Strata	Sex	N	Length (cm) Mean	Minimum	Maximum	Sex ratio M:F (% male) All blue cod	≥ 33 cm
1	M	22	32.7	20	41	1:1.1 (46.8)	1:0.3 (75.0)
	F	25	28.6	20	38		
2	M	31	29.4	16	45	1:0.8 (55.4)	1:0.1 (85.7)
	F	25	26.5	11	38		
3 (Reserve)	*M*	*165*	*27.6*	*19*	*42*		
	F	*68*	*24.0*	*17*	*33*		
	U	*18*	*22.2*	*17*	*32*		
4	M	164	28.0	15	43	1:0.5 (68.9)	1:<0.1 (95.2)
	F	74	23.8	13	33		
5	M	2	42.0	40	44	1:2.5 (28.6)	1:3.0 (33.3)
	F	5	38.0	29	44		
6 (Deep)	M	17	35.1	26	43	1:1.4 (42.5)	1:0.3 (66.7)
	F	23	29.0	21	38		
Overall (un-weighted)	M	236	29.3	15	45	1:0.4 (60.1)	1:0.2 (81.0)
(Excluding the reserve)	F	152	26.3	11	44		

Table 11: Gonad stages of Paterson Inlet blue cod in 2010 fixed 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	2	132	848	155	1	1138
Females	0	92	215	9	0	316

Table 12: Gonad stages of Paterson Inlet blue cod in 2010 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	6	17	272	106	0	401
Females	3	27	146	44	0	220

Table 13: Otolith raw data used in the catch at age, *Z* estimates, and SPR analyses for both the fixed and random 2010 Paterson Inlet sites.

		Length of aged fish (cm)			Age (years)		
Survey	No. otoliths	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Total	282	30.1	11	51	8.1	1	25
Male	153	32.1	15	51	8.5	2	20
Female	129	27.7	11	45	7.5	1	25

Table 14: Blue cod total mortality estimates (*Z*) with 95% confidence intervals and corresponding $F_{\%SPR}$ values (assuming M=0.14) for ages of recruitment (AgeRec) from 5 to 11 for the 2010 Paterson Inlet fixed site survey. Analyses exclude the marine reserve stratum data.

		Confidence intervals		
AgeRec	*Z*	Lower	Upper	$F_{\%SPR}$
5	0.25	0.18	0.35	55.6
6	0.28	0.20	0.38	50.4
7	0.32	0.23	0.48	44.6
8	0.37	0.26	0.53	40.4
9	0.39	0.27	0.55	39.2
10	0.48	0.33	0.72	34.6
11	0.56	0.37	0.84	31.8

Table 15: Blue cod total mortality estimates (*Z*) with 95% confidence intervals and corresponding $F_{\%SPR}$ values (assuming M=0.14) for ages of recruitment (AgeRec) from 5 to 11 for the 2010 Paterson Inlet random stratified survey. Analyses exclude the marine reserve stratum data.

		Confidence intervals		
AgeRec	*Z*	Lower	Upper	$F_{\%SPR}$
5	0.31	0.21	0.45	46.5
6	0.32	0.22	0.47	45.0
7	0.37	0.25	0.53	40.5
8	0.43	0.29	0.62	36.9
9	0.43	0.28	0.65	36.8
10	0.50	0.32	0.79	33.5
11	0.59	0.33	0.99	31.0

Table 16: Mortality rates (Z, F, and M) and spawning biomass per recruit ($F_{\%SPR}$), assuming an age of recruitment of 8, at three values of M for the 2010 Paterson Inlet fisher-selected fixed sites survey. F, fishing mortality; M, natural mortality; Z, total mortality.

M	Z	F	$F_{\%SPR}$
0.11	0.37	0.26	29.8
0.14	0.37	0.23	40.4
0.17	0.37	0.20	50.8

Table 17: Mortality rates (Z, F, and M) and spawning biomass per recruit ($F_{\%SPR}$), assuming an age of recruitment of 8, at three values of M for the 2010 Paterson Inlet random stratified survey. F, fishing mortality; M, natural mortality; Z, total mortality.

M	Z	F	$F_{\%SPR}$
0.11	0.43	0.32	27.2
0.14	0.43	0.29	36.9
0.17	0.43	0.26	46.6

Table 18: Summary statistics for GLM fits to 2010 Patterson Inlet CPUE (in weight and in numbers) data. The model selected by the AIC criterion is noted with a box around the AICc value.

		Weight			Numbers		
Model terms	Residual df	Single variable r^2	Full model r^2	AICc	Single variable r^2	Full model r^2	AICc
bottom_type	58	0.417	0.417	308.6	0.388	0.388	319.5
+ depth	57	0.018	0.491	302.4	0.003	0.510	307.8
+ random/fixed	56	0.320	0.546	297.7	0.259	0.558	303.8
+ ACDP_direction	55	0.039	0.577	$\boxed{295.9}$	0.034	0.584	302.6
+ air_pressure	54	0.017	0.591	296.5	0.024	0.606	302.0
+ wind_dir	53	0.058	0.605	297.2	0.068	0.626	$\boxed{301.6}$

Table 19: Drop underwater video (DUV) and pot sample details. Note that stations are individual transects and pots. *=includes equivalent number of fish-dependent habitat quadrats.

	DUV	Random	Fixed	Pots	Random	Fixed
Sites	22	11	11	22	11	11
Stations	72	33	39	132	66	66
Habitat sections	252	76	176	-	-	-
Habitat quadrats	1109	340	769	-	-	-
Total transects length	46.8 km	16.3	30.5	-	-	-
Mean transect length	650 m (± 33.4)	492	783	-	-	-
Mean transect width	4.2 m (± 0.2)	4.2	4.2	-	-	-
Total area swept	194 175 m^2	68 309	125 866		Unknown	
Blue cod	590 *	168 *	422 *	918	122	796

Table 20: Pot catch, numbers of blue cod, bycatch species, and percentage of total numbers from the 11 fixed and 11 random potted video sites. Bracketed numbers are the proportion of catch per site selection method (fixed or random).

Common name	Scientific name	Fixed Sites	Random Sites	Total Number	Percent catch
Blue cod	*Parapercis colias*	796 (0.72)	104 (0.29)	900	61.4
Spotty	*Notolabrus celidotus*	267 (0.24)	251 (0.70)	518	35.4
Banded wrasse	*Notolabrus fucicola*	18 (0.02)	0	18	1.2
Trumpeter	*Latris lineata*	12 (0.01)	0	12	0.8
Leather jacket	*Parika scaber*	6 (<0.01)	0	6	0.4
Scarlet wrasse	*Pseudolabrus miles*	3 (<0.01)	0	3	0.2
Girdled wrasse	*Notolabrus cinctus*	2 (<0.01)	0	2	0.1
Tarakihi	*Nemadactylus macropterus*	1 (<0.01)	1(<0.01)	2	0.1
Blue moki	*Latridopsis ciliaris*	1 (<0.01)	0	1	0.1
Conger eel	*Conger verreauxi*	1 (<0.01)	0	1	0.1
Octopus	*Octopus cordiformis*	0	1(<0.01)	1	0.1
Red cod	*Pseudophycis bachus*	0	1(<0.01)	1	0.1
Total		1107	358	1465	100.0

Table 21: Drop underwater video observed numbers of blue cod, bycatch species, and percentage of total numbers from the 11 fixed and 11 random potted video sites. The numbers in parenthesis are the proportion of observations per site selection method (random or fixed). *=total does not include unidentified species.

Common name	Scientific name	Fixed Sites	Random Sites	Total Number	Percent of total catch
Spotty	*Notolabrus celidotus*	1742	113	1855	58.0
Blue cod	*Parapercis colias*	422	168	590	18.5
Southern pigfish	*Congiopodus leucopaecilus*	288	173	461	14.4
Tarakihi	*Nemadactylus macropterus*	105	1	106	3.3
Banded wrasse	*Notolabrus fucicola*	59	3	62	1.9
Butterfly perch	*Caesioperca lepidoptera*	23	0	23	0.7
Girdled wrasse	*Notolabrus cinctus*	17	3	20	0.6
Leather jacket	*Parika scaber*	10	3	13	0.4
Scarlet wrasse	*Pseudolabrus miles*	10	2	12	0.4
Blue moki	*Latridopsis ciliaris*	11	0	11	0.3
Opal fish	*Hemerocoetes* spp.	0	9	9	0.3
Gurnard	*Chelidonichthyskumu*	8	1	9	0.3
Trevally	*Pseudocaranx dentex*	5	1	6	0.2
Carpet shark	*Cephaloscyllium isabellum*	5	0	5	0.2
Skate	*Raja* spp.	2	3	5	0.2
Trumpeter	*Latris lineata*	3	1	4	0.1
Butterfish	*Odax pullus*	3	0	3	0.1
Sea perch	*Helicolenus* spp.	0	2	2	0.1
Flat fish	*Rhombosolea* spp.	0	1	1	0.0
Unidentified	Mainly *Triperygiidae/N. celidotus*	*4982*	*1*	*4983*	-
Total*		2713	484	3197	100.0

Table 22: Basic survey catch statistics from random-stratified design blue cod potting surveys completed to date. Concurrent fixed site design potting surveys were done in all areas except Foveaux Strait. Catch rates are pot-based, and s.e. and CV are set-based, the unbracketed number is for all blue cod and the bracketed number is for legal sized blue cod (BCO 3 and BCO 7 = 30 cm and over, BCO 5 = 33 cm and over). s.e., standard error; CV coefficient of variation. Data are from South Otago 2010 (Beentjes & Carbines 2011), Foveaux Strait (Carbines & Beentjes 2012), Pelorus Sounds (Beentjes & Carbines 2012) and Paterson Inlet (current report).

Survey area (FMA)	Waters	Survey design	Strata (N)	Pot lifts (N)	Mean ($kg.pot^{-1}$)	s.e.	CV (%)
South Otago 2009 (BCO 3)	Coastal	Fixed	3	108	9.7 (8.1)	1.7 (1.5)	17.1 (18.5)
South Otago 2009 (BCO 3)	Coastal	Random	3	108	4.4 (2.9)	0.8 (0.7)	17.8 (22.5)
Foveaux Strait 2010 (BCO 5)	Coastal	Random	8	336	4.8 (2.1)	0.5 (0.2)	11.3 (10.9)
Pelorus Sound 2010 (BCO 7)	Enclosed	Fixed	4	144	2.9 (2.5)	0.4 (0.3)	12.6 (12.6)
Pelorus Sound 2010 (BCO 7)	Enclosed	Random	3	108	2.2 (1.8)	0.4 (0.4)	19.1 (19.2)
Paterson Inlet 2010 (BCO 5)	Enclosed	Fixed	5	168	4.2 (2.7)	0.5 (0.3)	11.1 (11.3)
Paterson Inlet 2010 (BCO 5)	Enclosed	Random	6	216	1.1 (0.5)	0.2 (0.1)	24.2 (23.2)

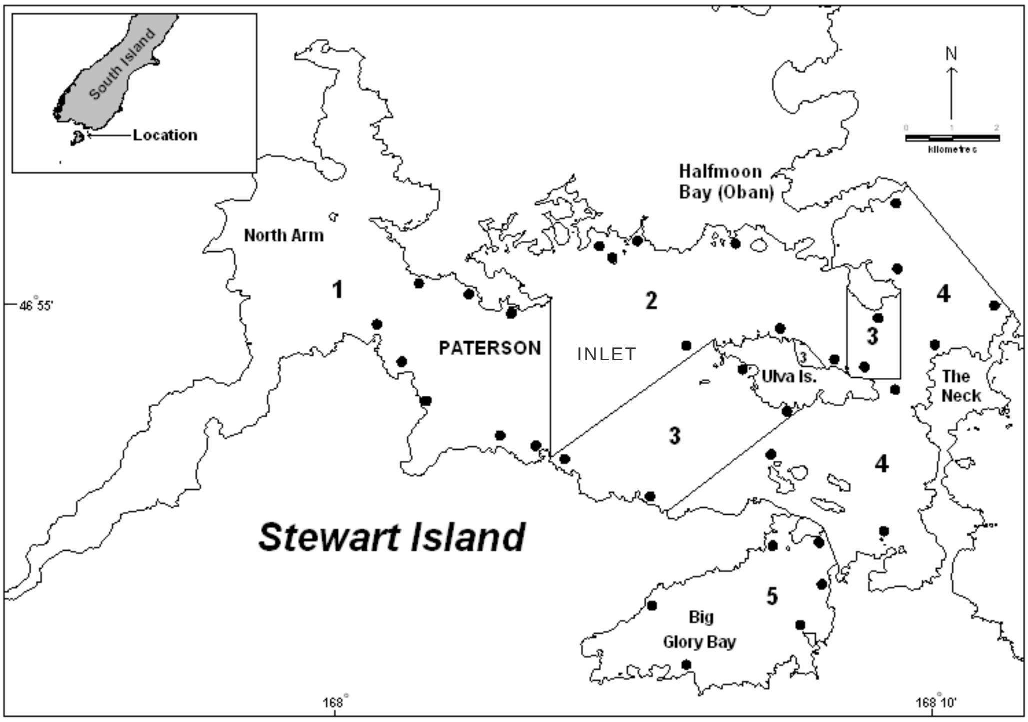


Figure 1: Selected fixed sites surveyed in the five strata of the 2006 Paterson Inlet survey (from Carbines 2007). Note that stratum 3 is the marine reserve.

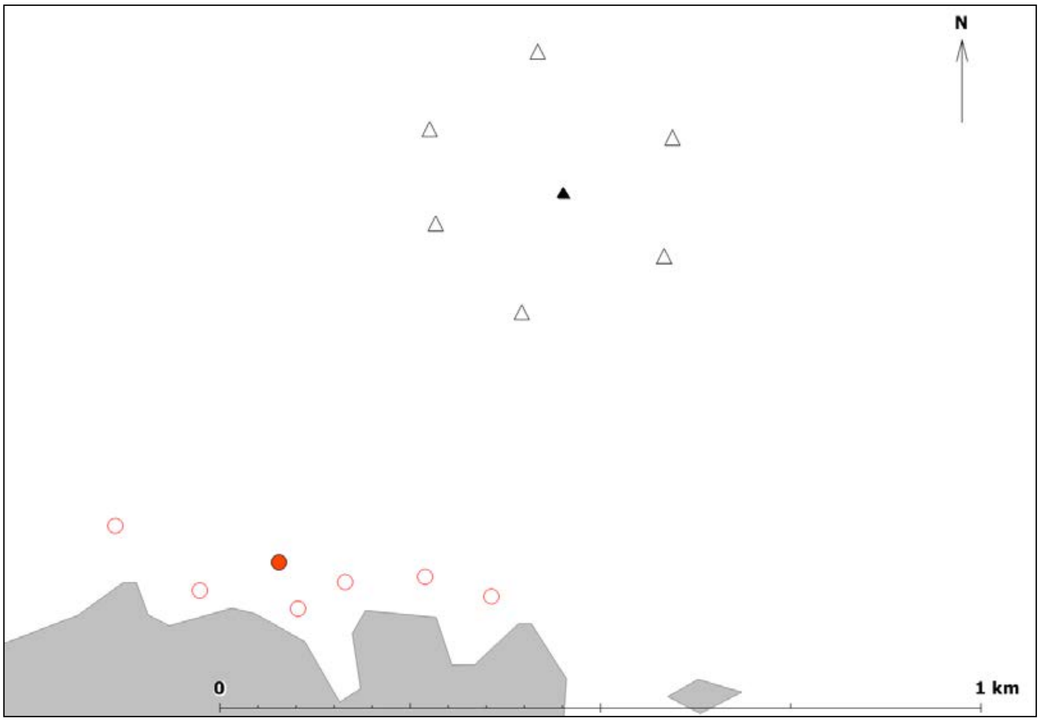


Figure 2: Placement of pots at a typical fixed (O) and random site (Δ) from the 2010 Paterson Inlet potting survey. Solid symbols are ADCP locations.

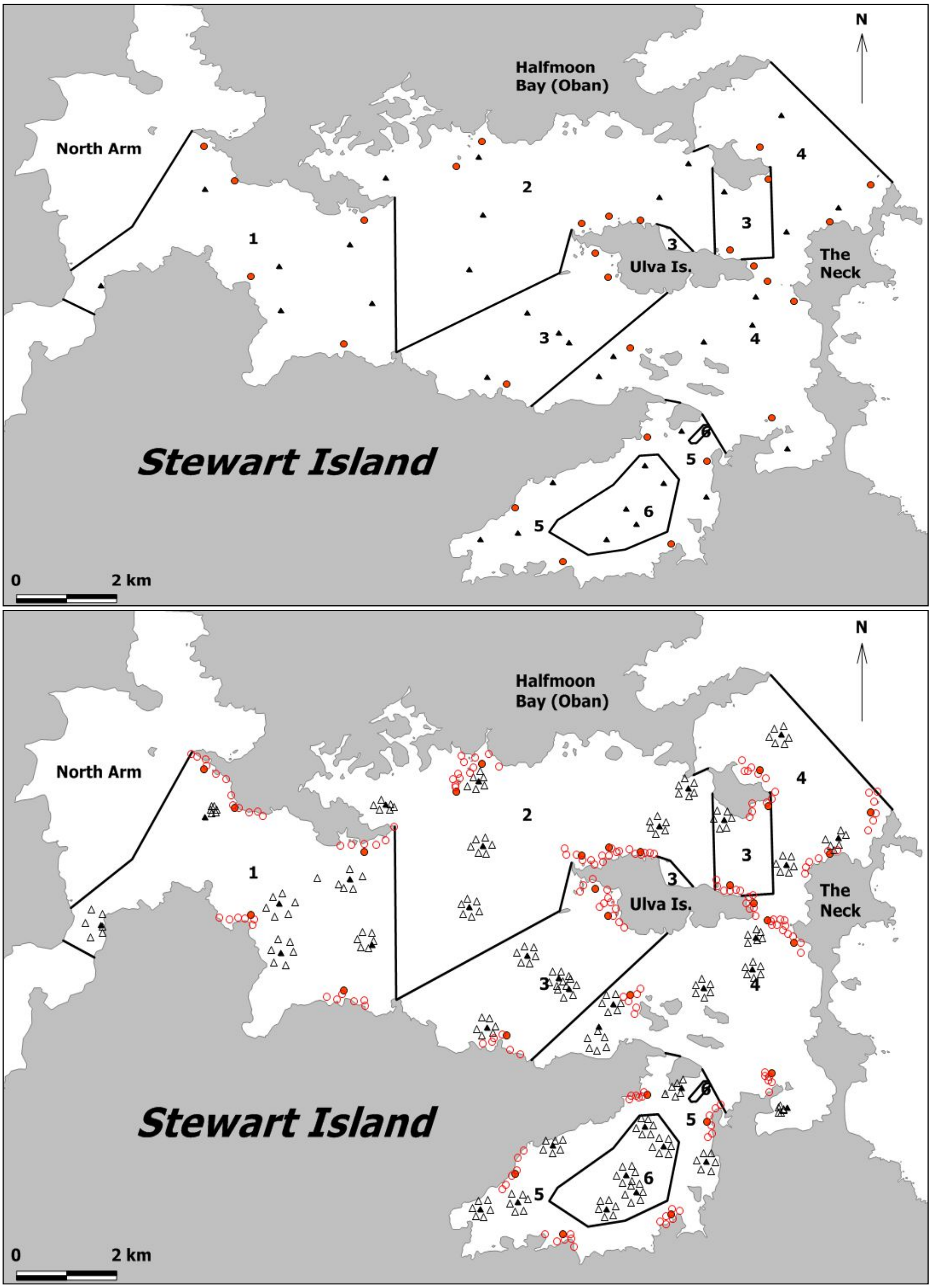


Figure 3: Fixed (●) and random (▲) sites (top) and stations (n=6 pots) locations surveyed in the 2010 Paterson Inlet survey. Note that the disjointed stratum 3 around Ulva Island is the marine reserve.

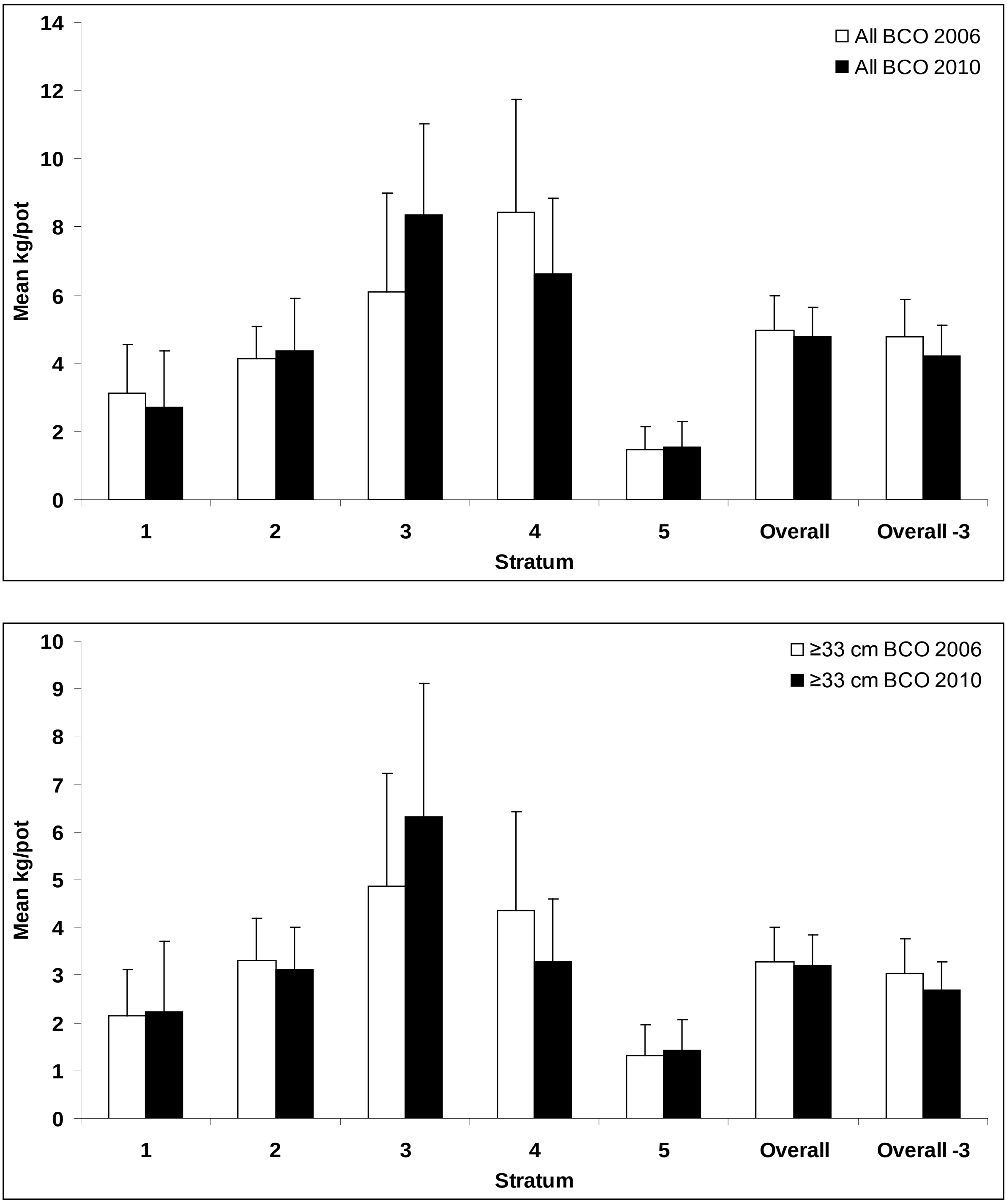


Figure 4: Catch rates (kg.pot^{-1}) and 95% confidence intervals for all blue cod and those 33 cm and over from the 2006 and 2010 Paterson Inlet fisher selected fixed site surveys.

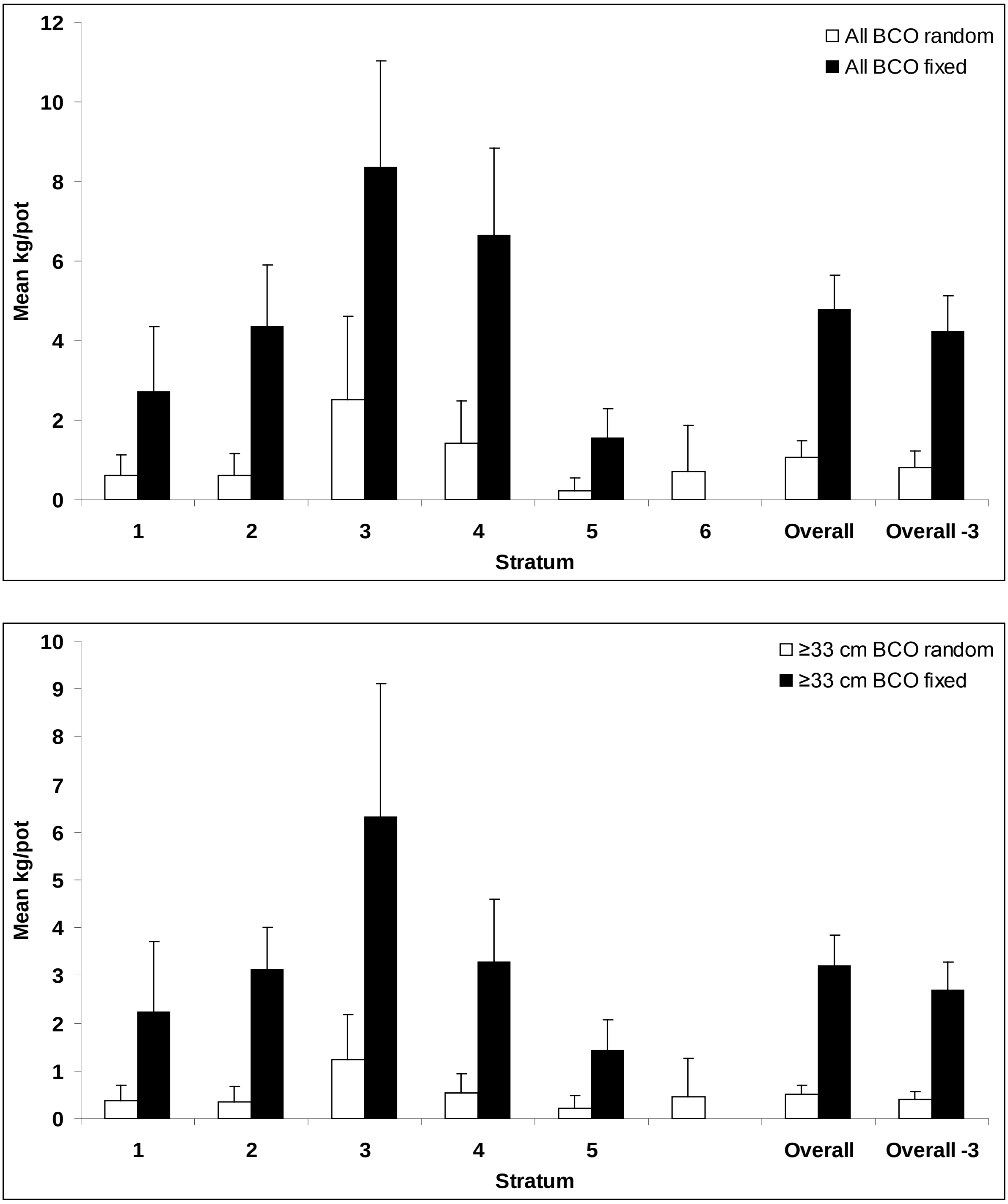


Figure 5: Catch rates ($kg.pot^{-1}$) and 95% confidence intervals for all blue cod and those 33 cm and over from the 2010 Paterson Inlet random and fisher selected fixed site surveys.

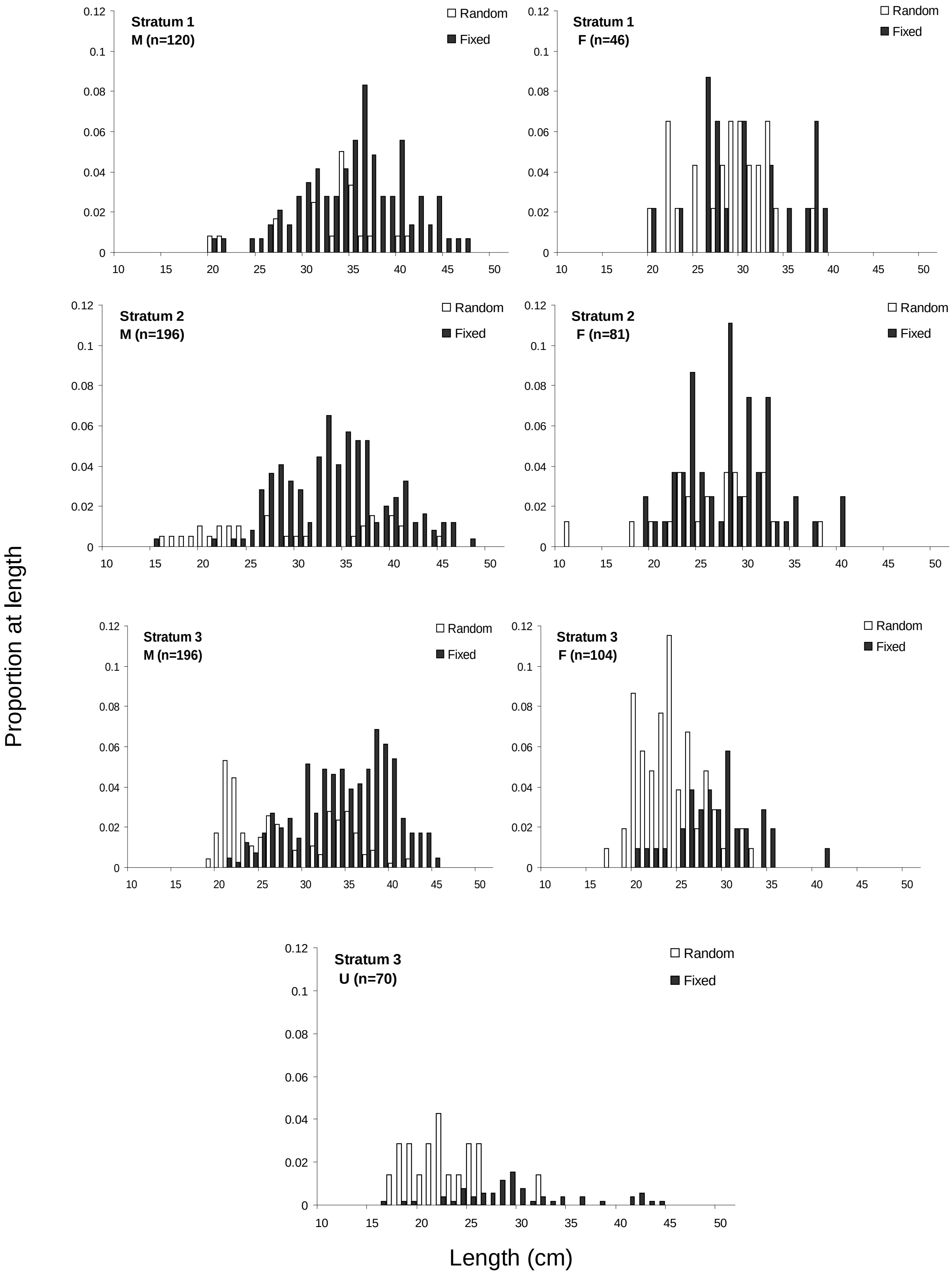


Figure 6: Unscaled proportion length frequency distributions by sex within stratum for fixed and random sites. Proportions for each sex within each stratum sum to 1.

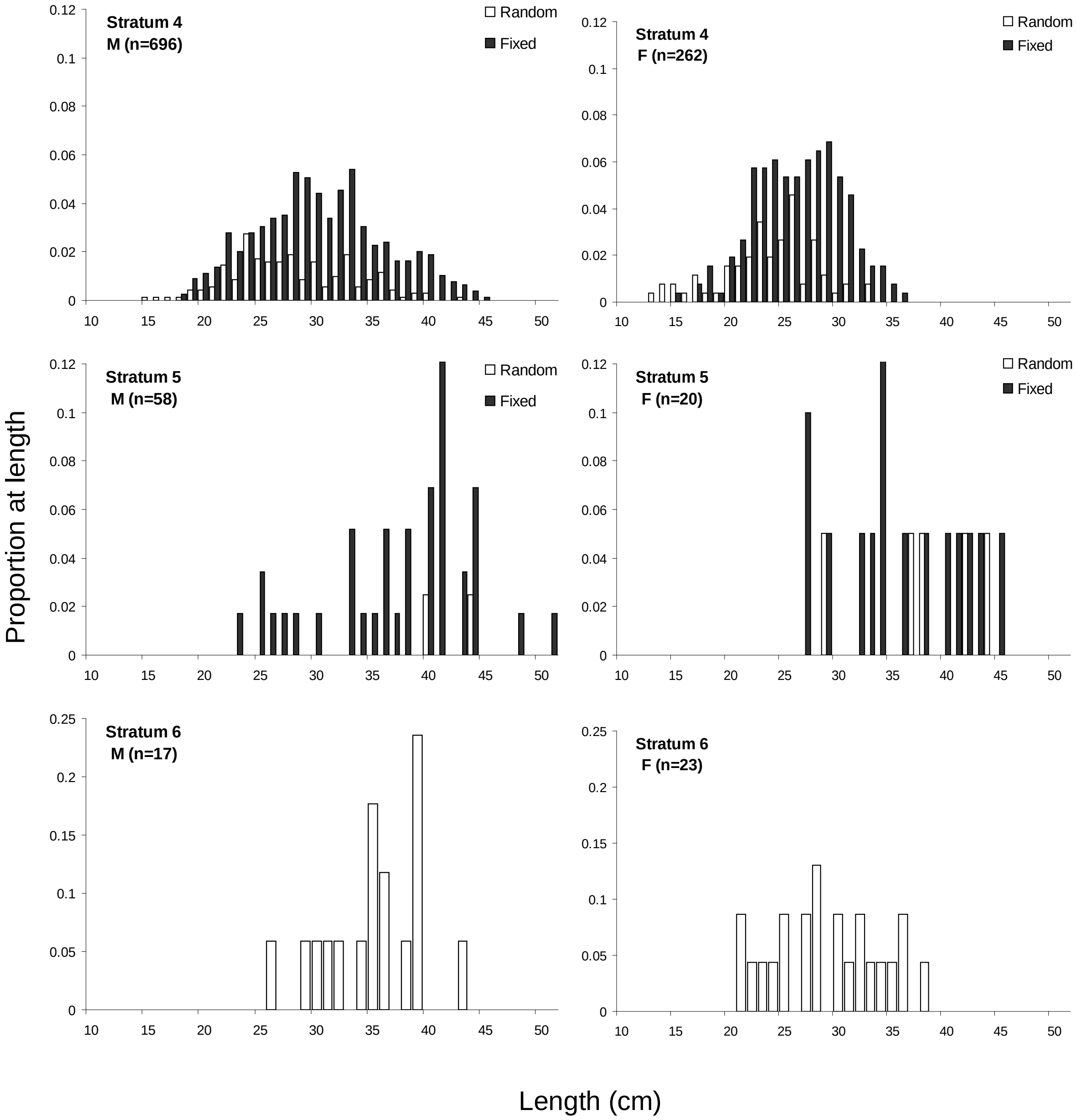


Figure 6 – *continued*

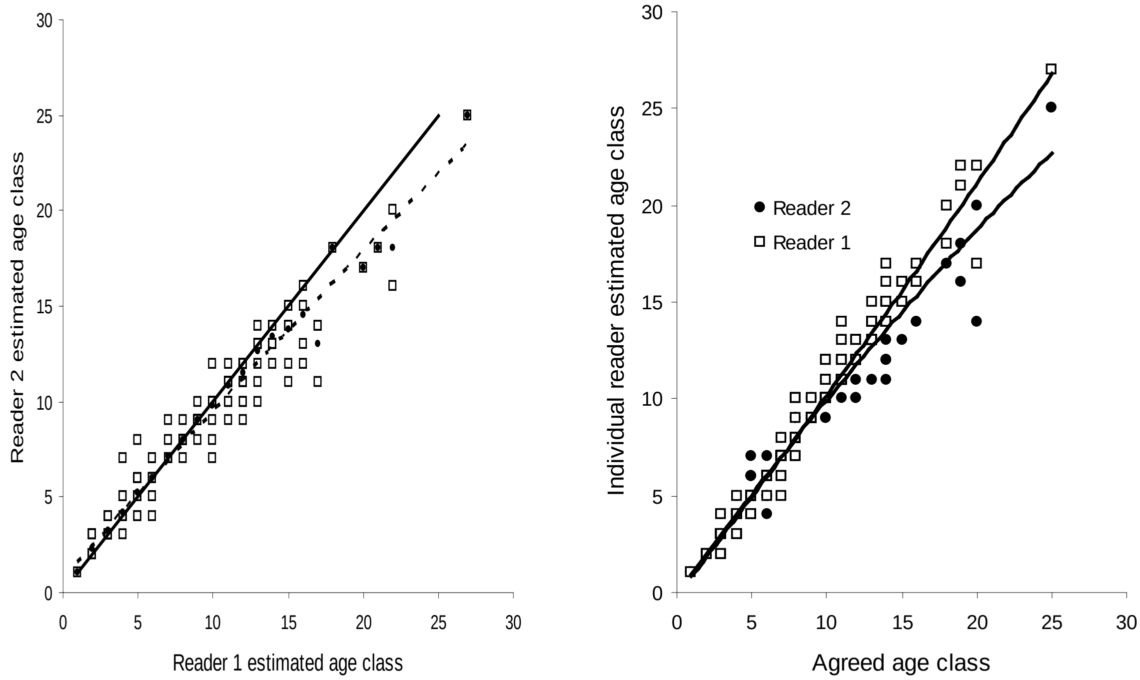


Figure 7: Paterson Inlet 2010 survey comparison of individual reader age class estimates from otoliths plotted against each other on the left with the 1:1 line plotted (solid) fitted, as well as the mean for each age recorded by reader 2 for each age recorded by reader 1 and a polynomial trend line fitted (dashed). In the right panel the agreed age class estimates on the right (n = 291), with polynomial trend line fitted.

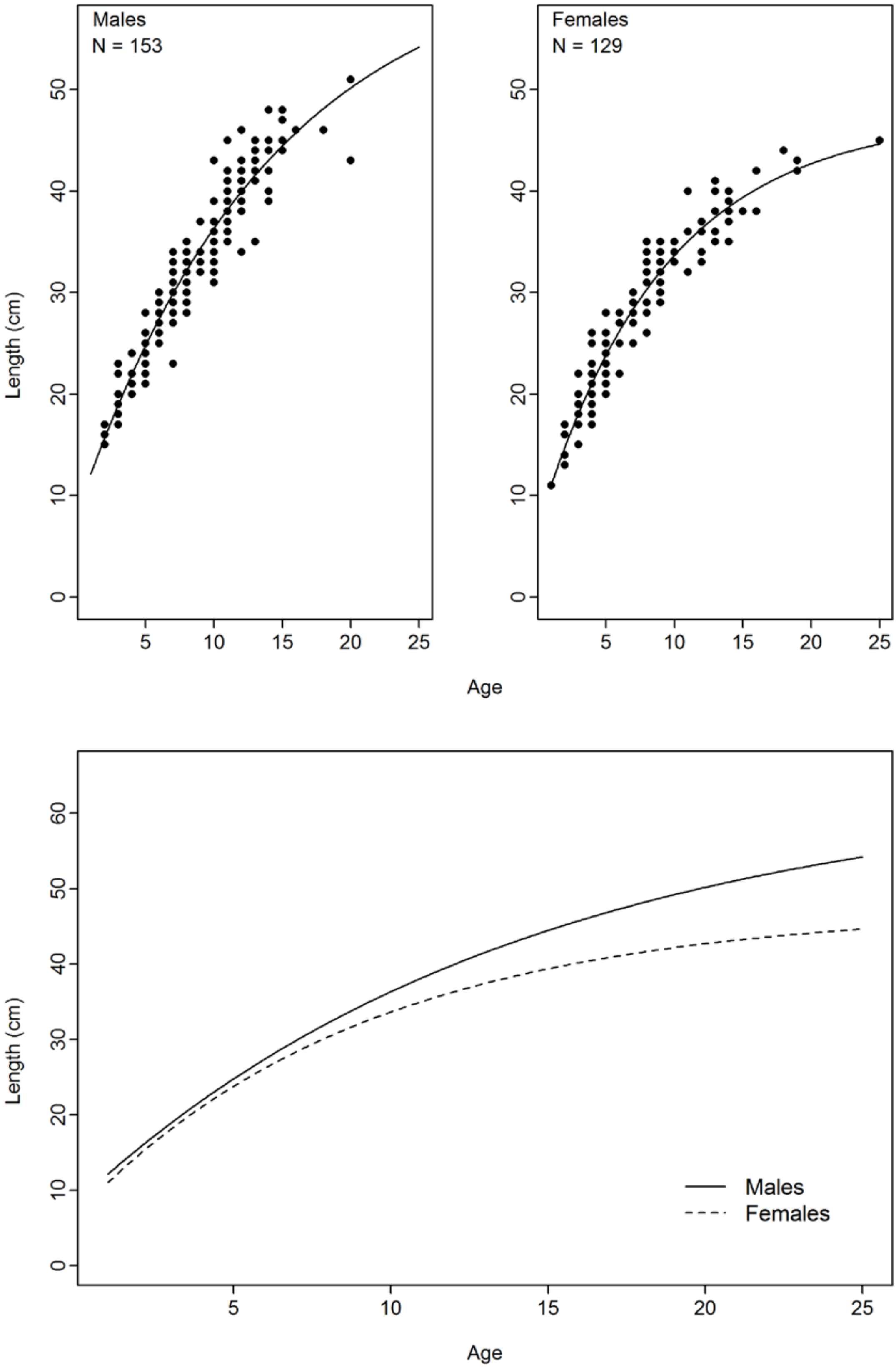


Figure 8: Observed age and length data by sex for the 2010 Paterson Inlet survey (upper panels) and comparison of male and female von Bertalanffy growth models fitted to the data (lower panel). See Table 13 for description of samples.

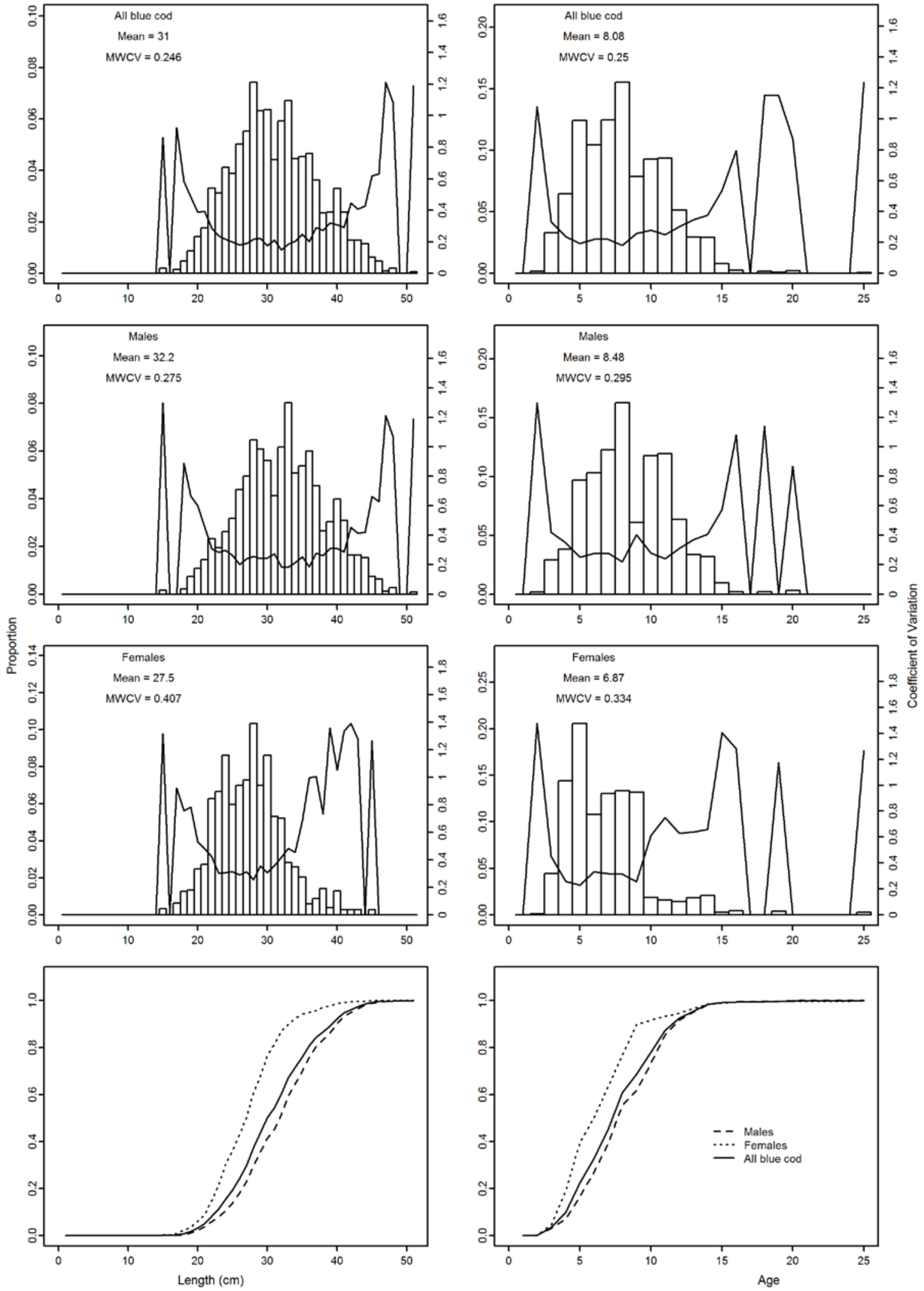


Figure 9: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata excluding stratum 3, for the 2010 Paterson Inlet fixed site survey. N, sample size; MWCV, mean weighted coefficient of variation.

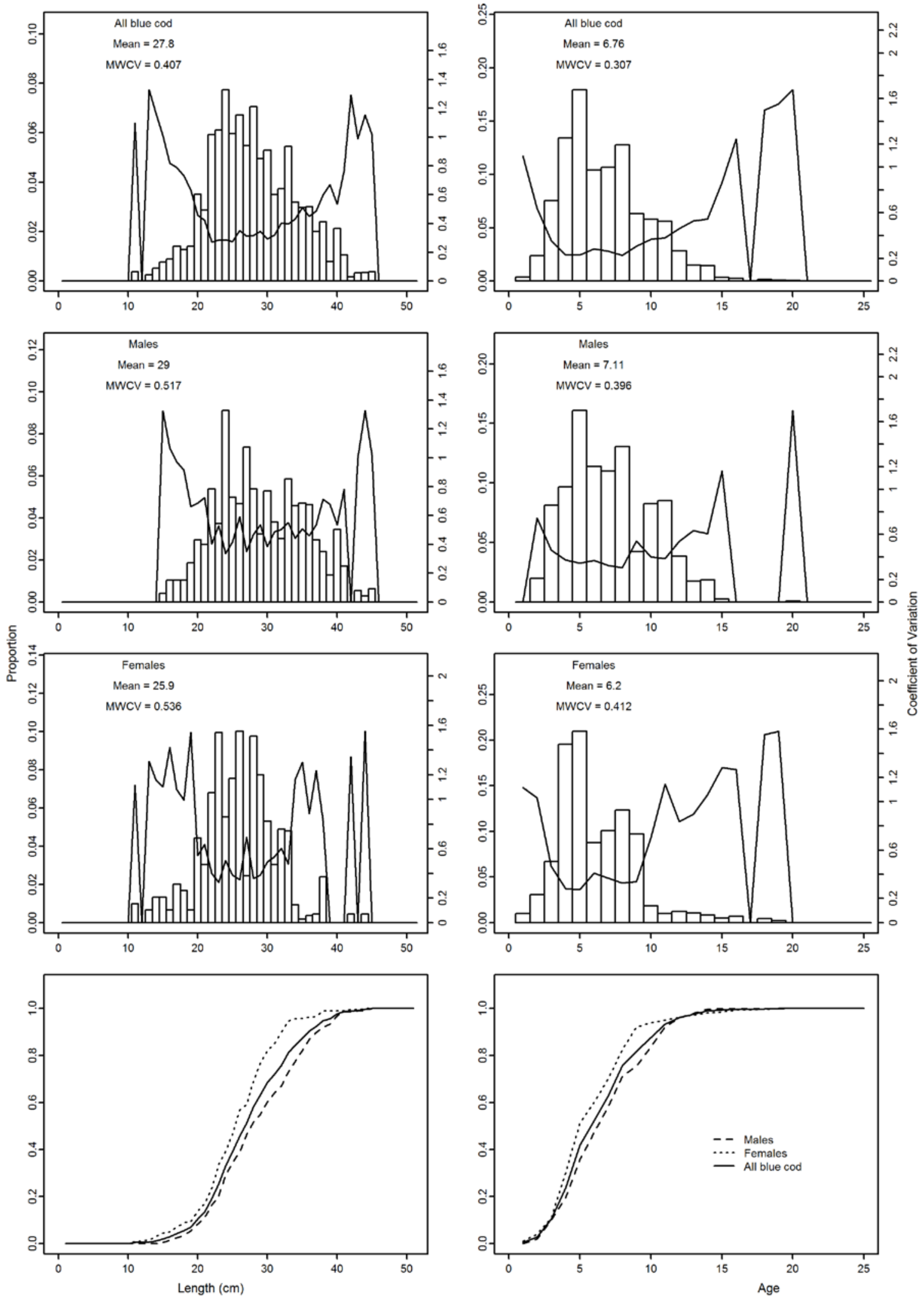


Figure 10: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata excluding stratum 3, for the 2010 Paterson Inlet random-stratified survey. N, sample size; MWCV, mean weighted coefficient of variation.

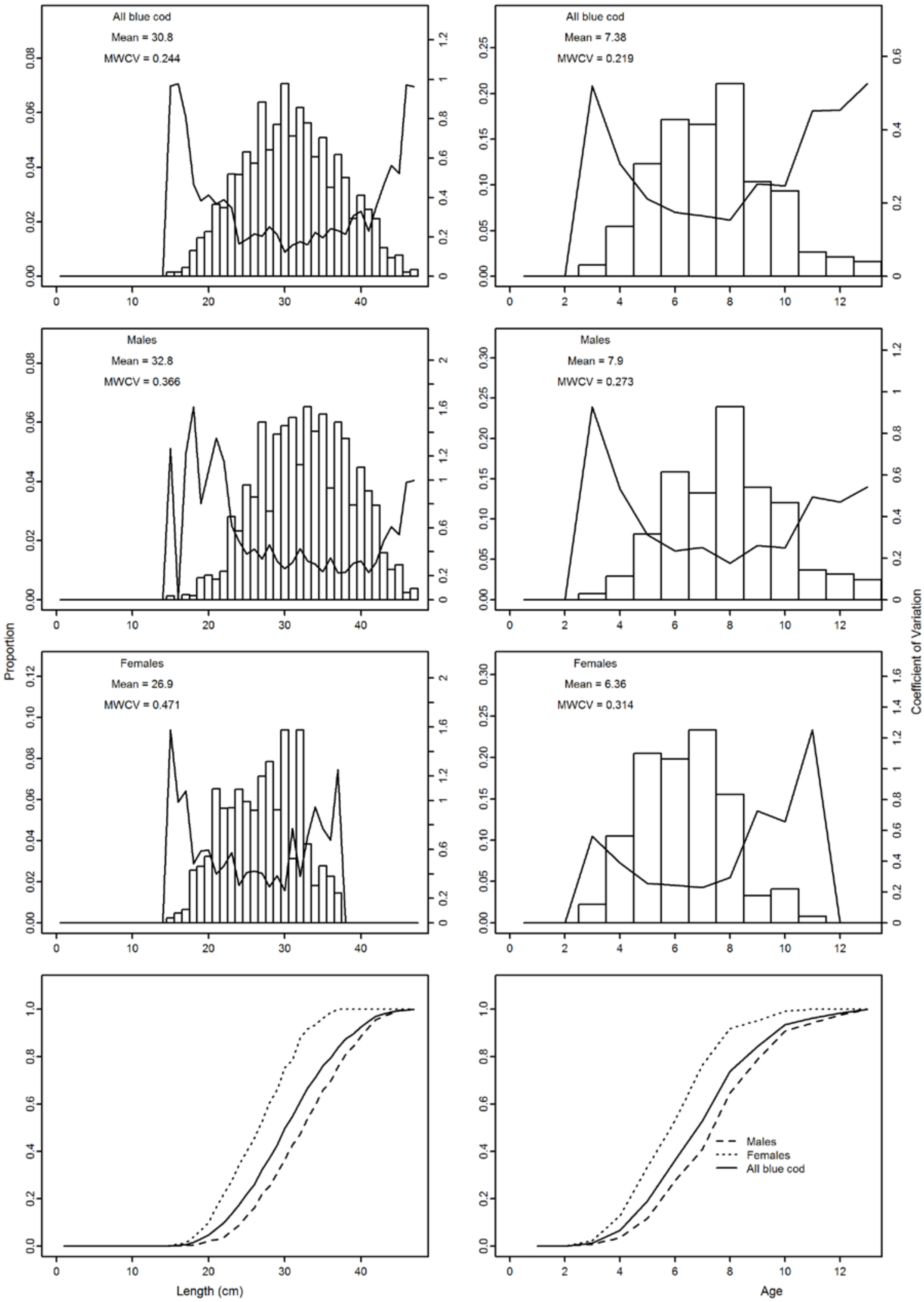


Figure 11: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata excluding stratum 3, for the 2006 Paterson Inlet fixed site survey. N, sample size; MWCV, mean weighted coefficient of variation.

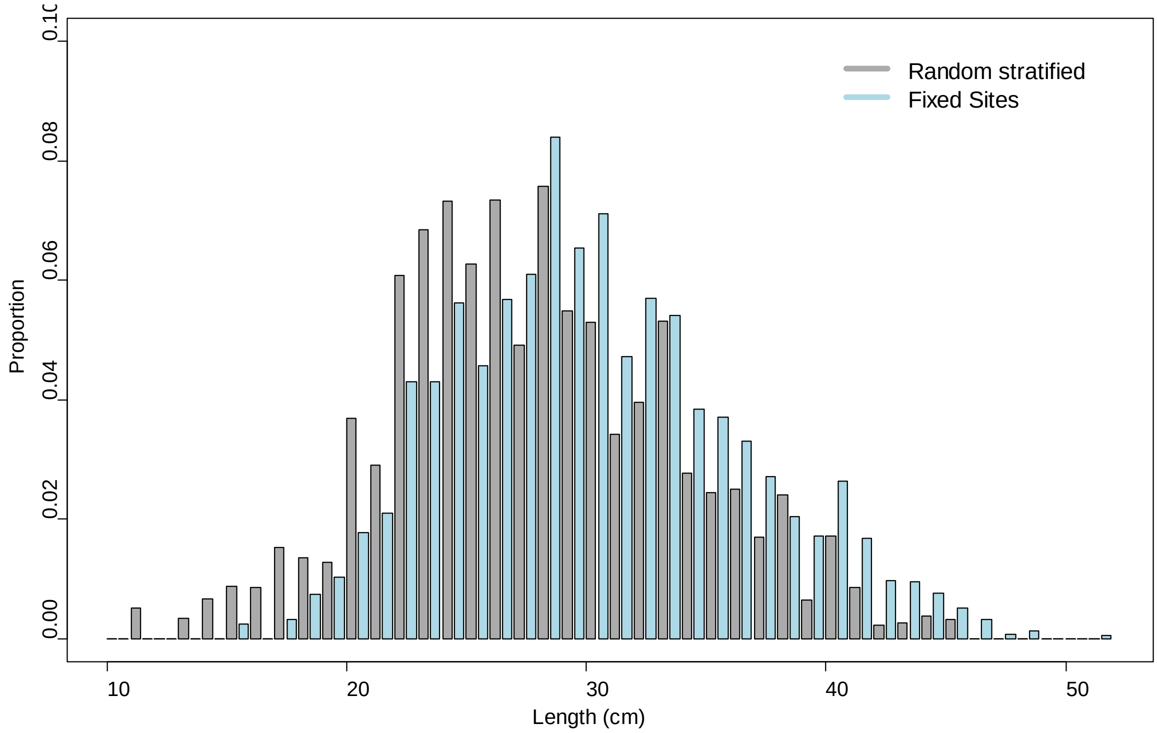


Figure 12: Paterson Inlet 2010 survey length frequencies scaled (by strata areas) from the random and fixed site surveys. Stratum 3 fish are not included in the scaled length frequencies.

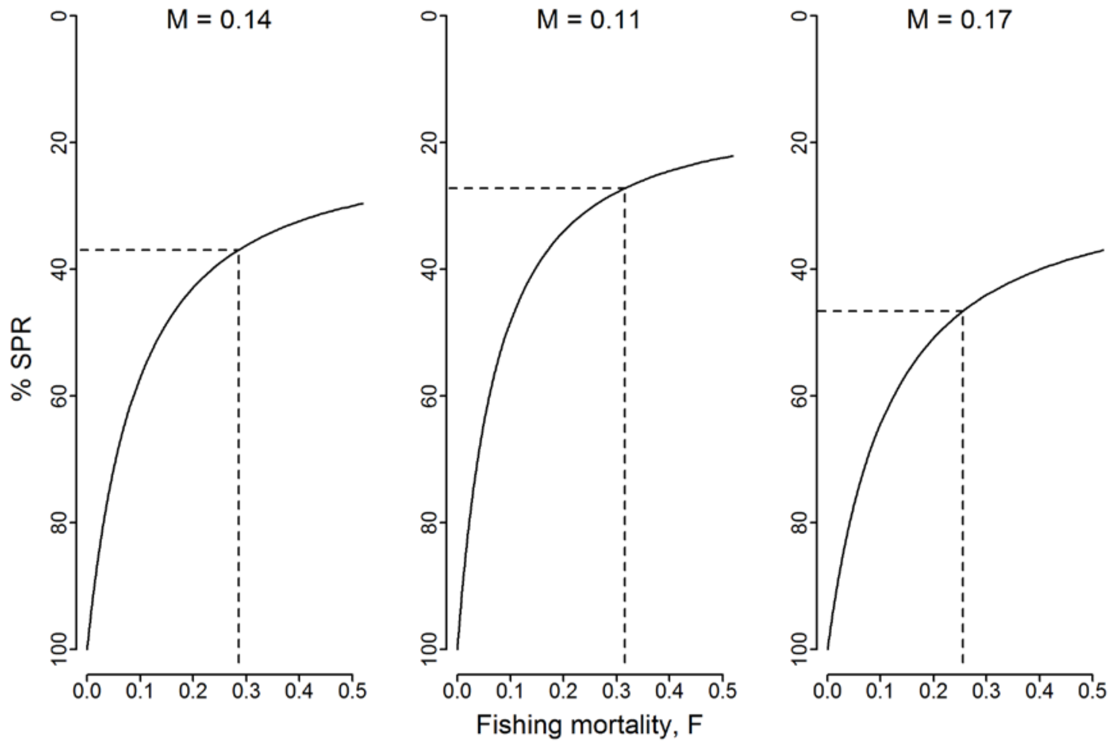


Figure 13: Plot of spawning biomass per recruit (SPR) as a function of fishing mortality for the 2010 Paterson Inlet random stratified survey at three values of M (0.11, 0.14, 0.17). See Table 17 for fishing mortalities and F%$_{SPR}$. The y-axis has been inverted because a low fishing mortality corresponds to a high %SPR.

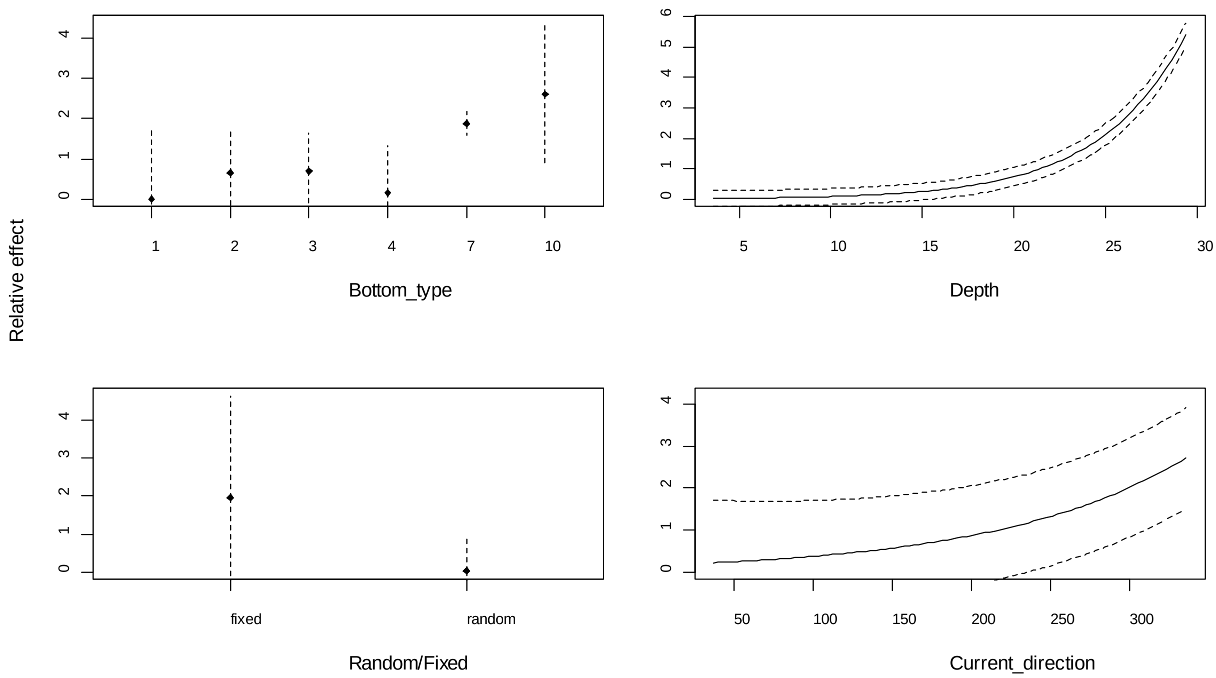
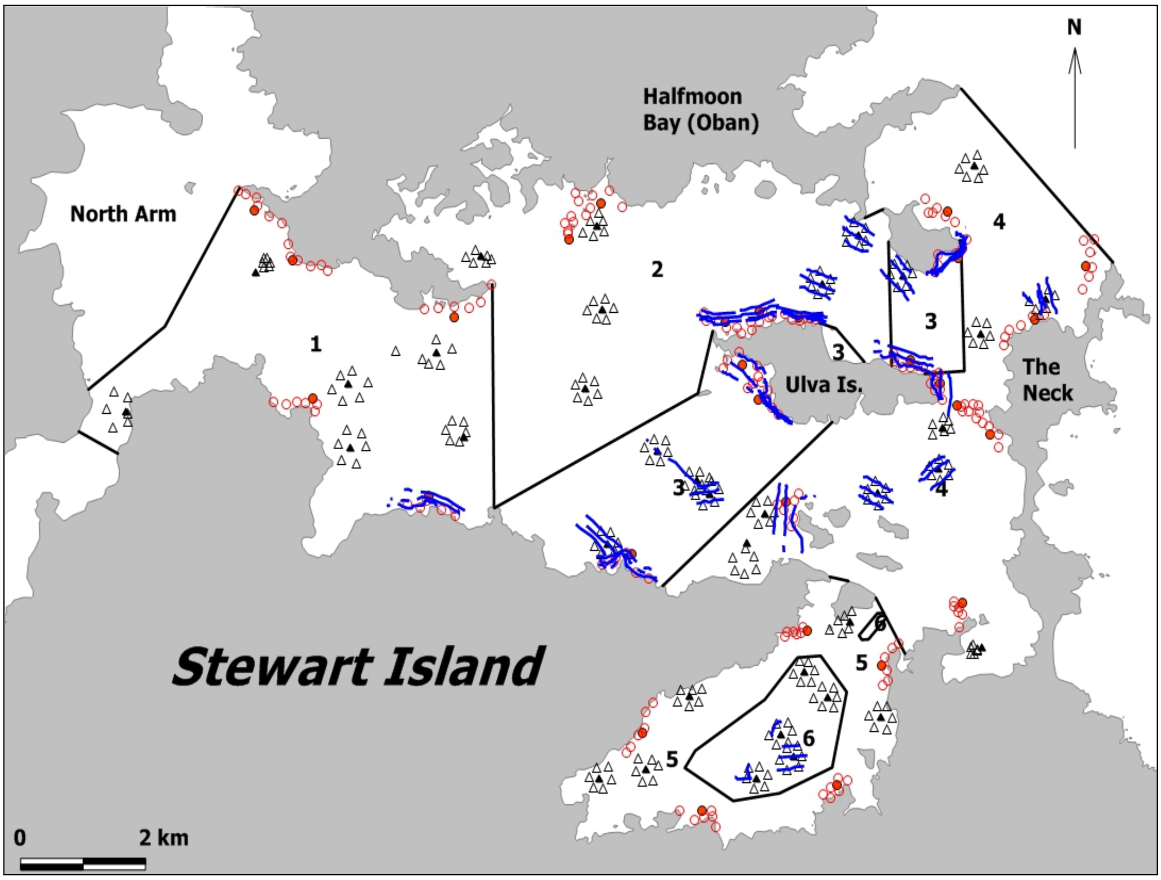
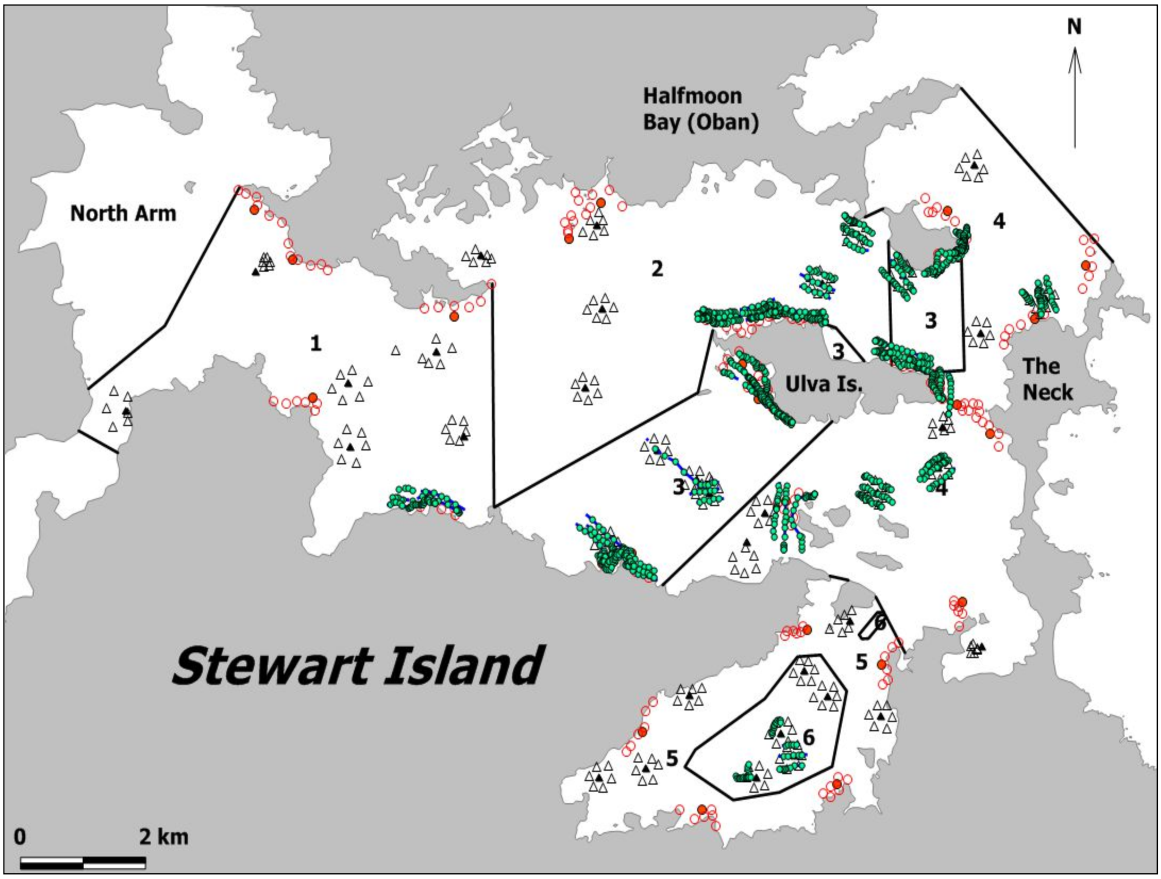


Figure 14: Relative effects of model co-variates (± 1 s.e.) for the GLM fit to 2010 Paterson Inlet CPUE [ln(Weight)] data. Bottom type categories are 1=mud, 2=mud/sand, 3=sand, 4=sand/gravel and shell, 7=rock, 10=biogenic (note this is an additional category referring to actual biogenic reef structure). Depth is in meters, random/fixed refers to the method of site selection, and current direction is in degrees magnetic.



N
Halfmoon Bay (Oban)
North Arm
1
2
3
4
5
6
Ulva Is.
The Neck
Stewart Island
0
2 km



N
Halfmoon Bay (Oban)
North Arm
1
2
3
4
5
6
Ulva Is.
The Neck
Stewart Island
0
2 km

Figure 15: Fixed (●) and random (▲) sites and stations (n=6 pots, open symbols) surveyed in the 2010 Paterson Inlet survey, with DUV transects (above) and systematic benthic habitat sub-transects (below) done at 11 fixed and 11 random sites.

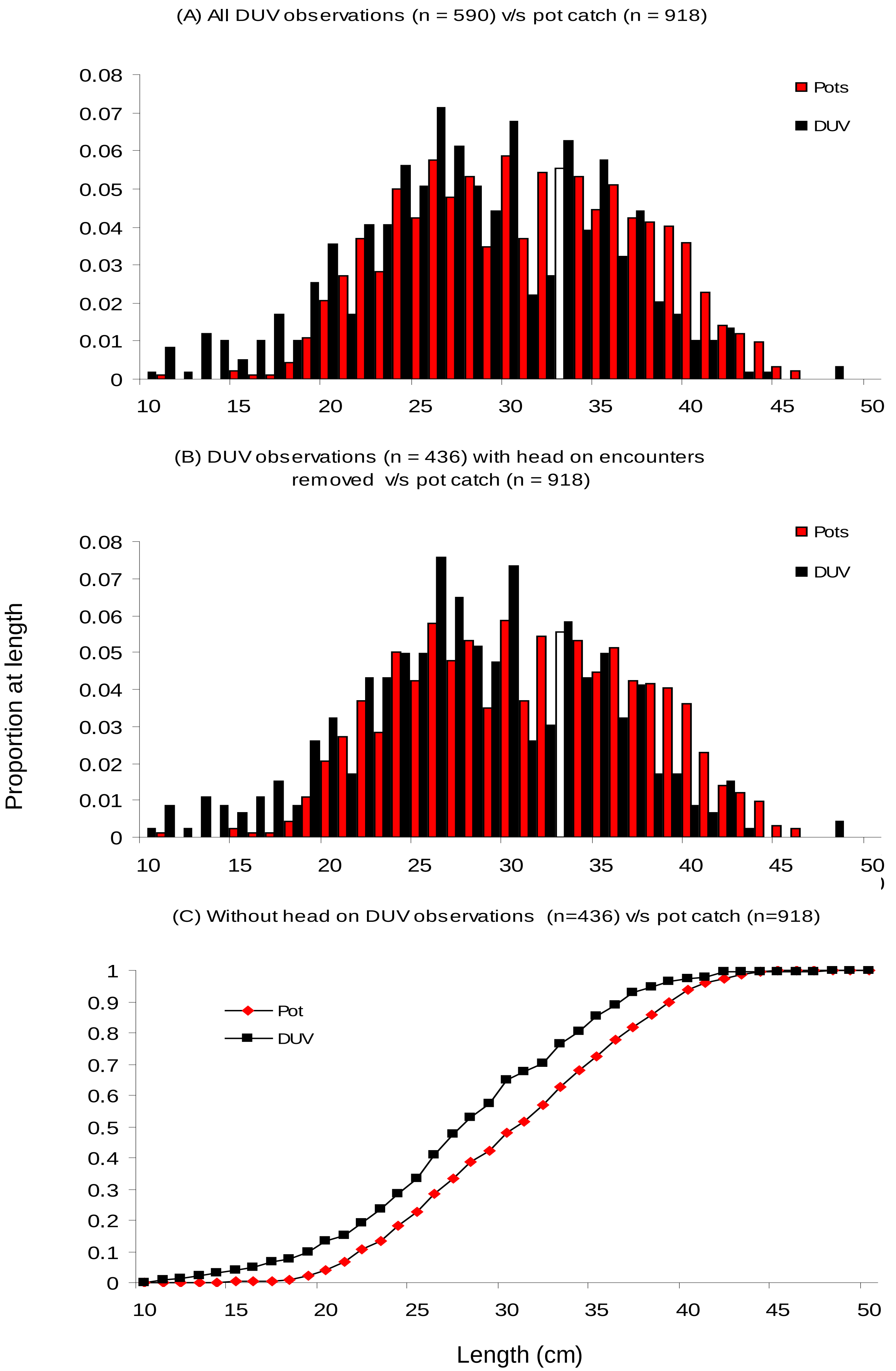


Figure 16: (A) –All measured video observations of blue cod sizes plotted against sizes from concurrent pot catch, the white bar is pots at the MLS (33 cm). (B) – Blue cod sizes from video observations without head-on body orientation to camera plotted against sizes from pot catch. (C)– Cumulative frequency distribution without video head-on body orientation.

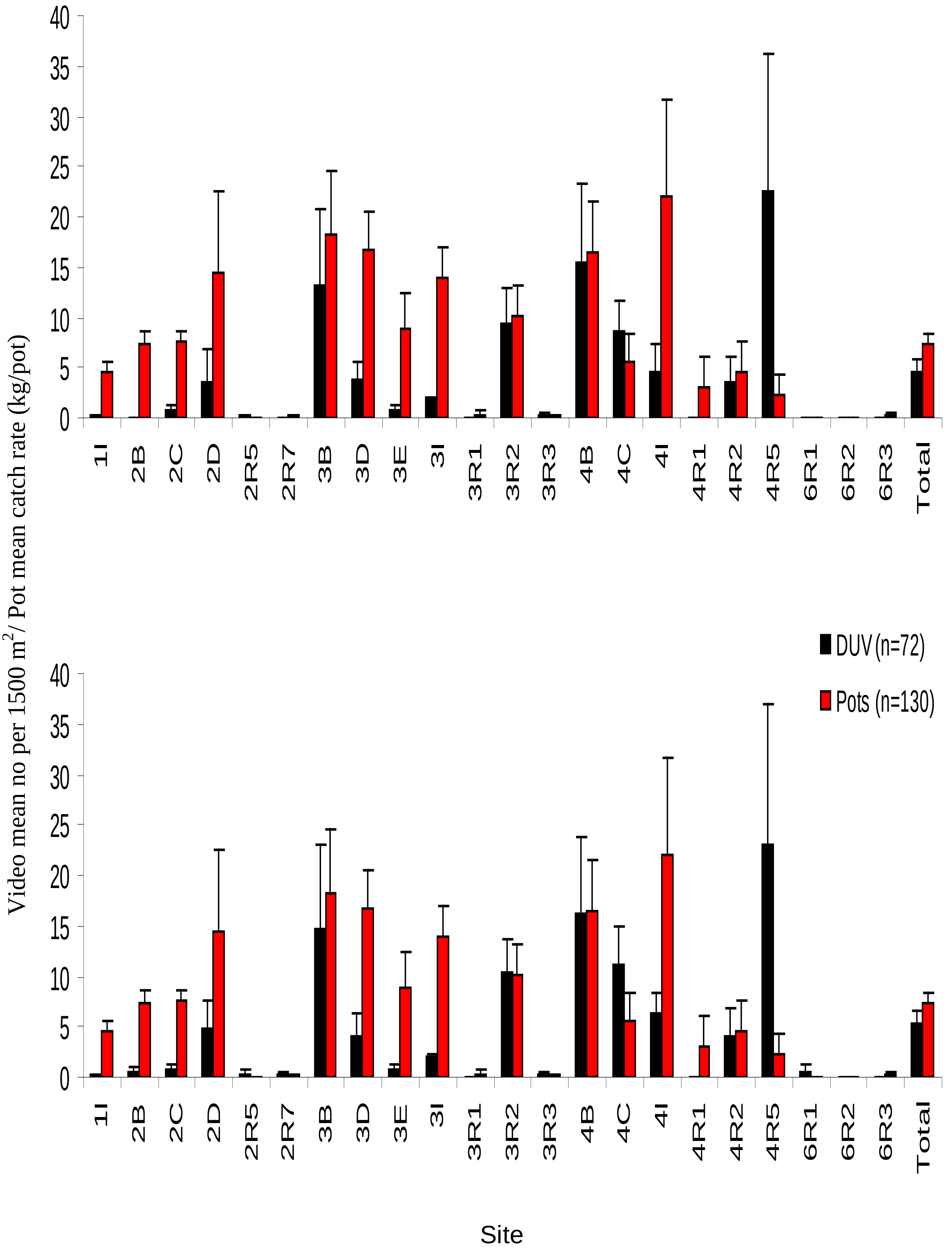


Figure 17: Mean site relative abundance (kg.pot^{-1}) from pots versus the equivalent mean site density estimates from the area swept video method for all blue cod (top) and blue cod 20 cm and over (bottom). Error bars are ± one standard error.

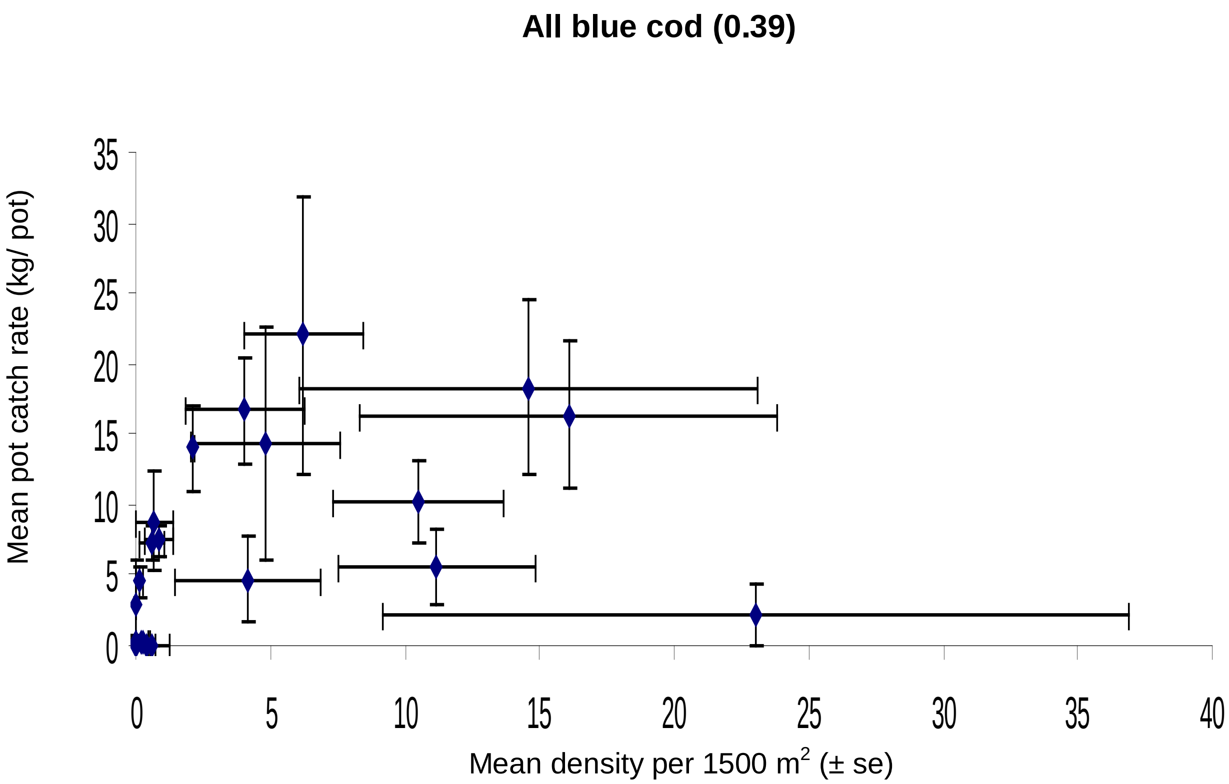


Figure 18: Mean density versus catch rate (kg.pot^{-1}) of all blue cod dual surveyed with DUV and pots. The number in brackets is the correlation coefficient, error bars are ± one standard error.

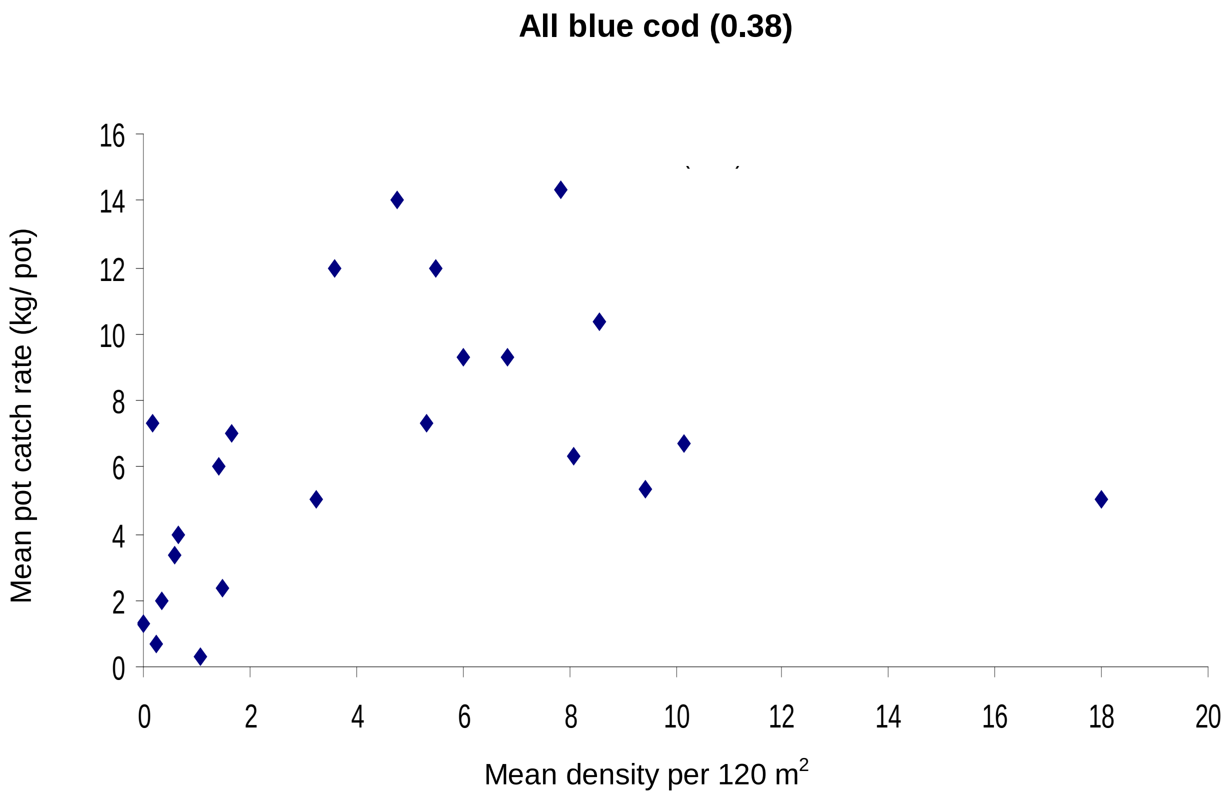


Figure 19: Mean density versus catch rate (kg.pot^{-1}) of all blue cod dual surveyed with SCUBA and pots in the Marlborough Sounds from Cole et al. (2001). The number in brackets is the correlation coefficient.

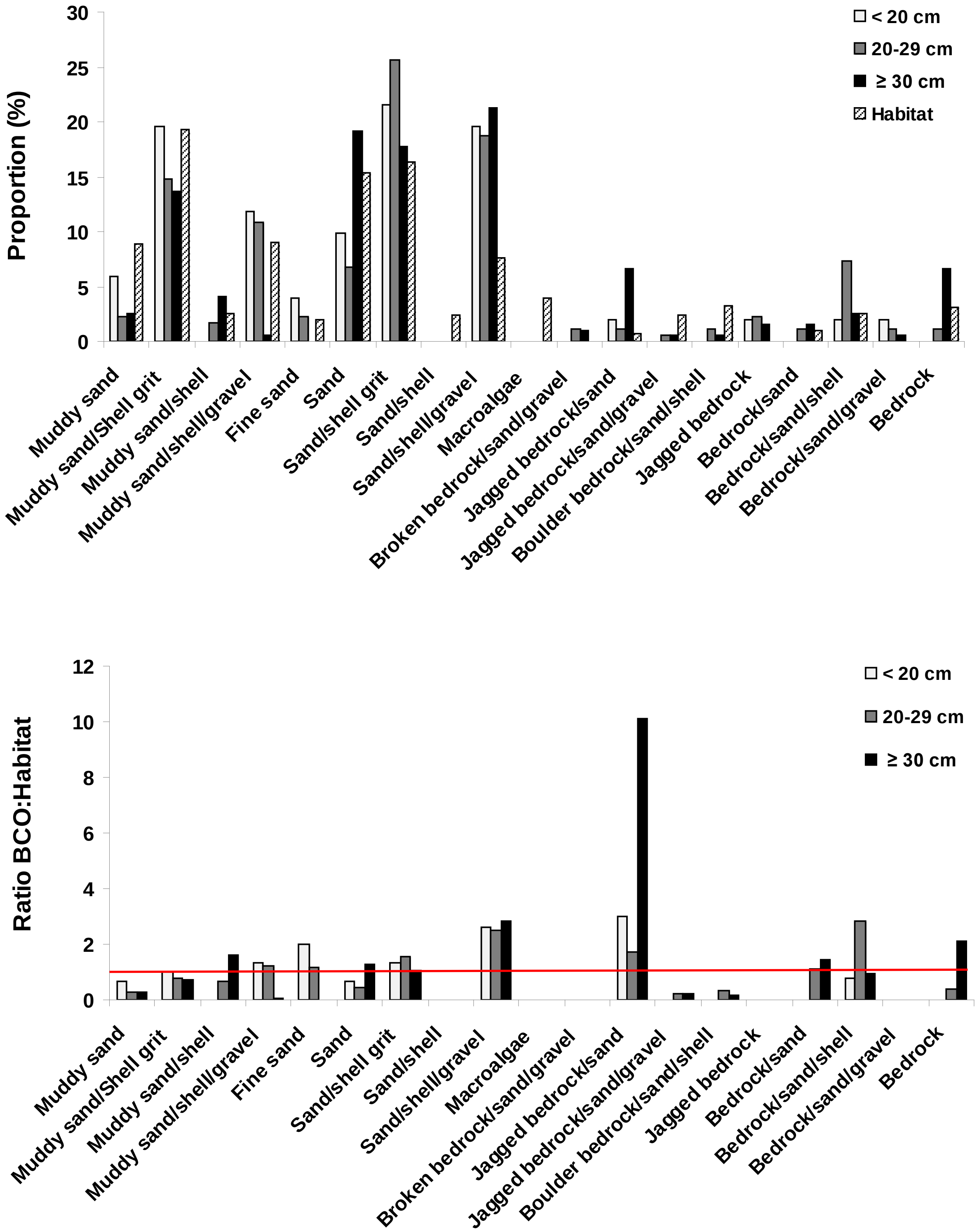


Figure 20: Proportion of blue cod (three size classes) and fish-independent DUV observations of primary substrate from fixed sites (top). The ratio of the proportion of blue cod-associated primary substrate and the fish-independent substrate recorded by the video at fixed sites is shown in the bottom figure with a line drawn at a 1:1 ratio.

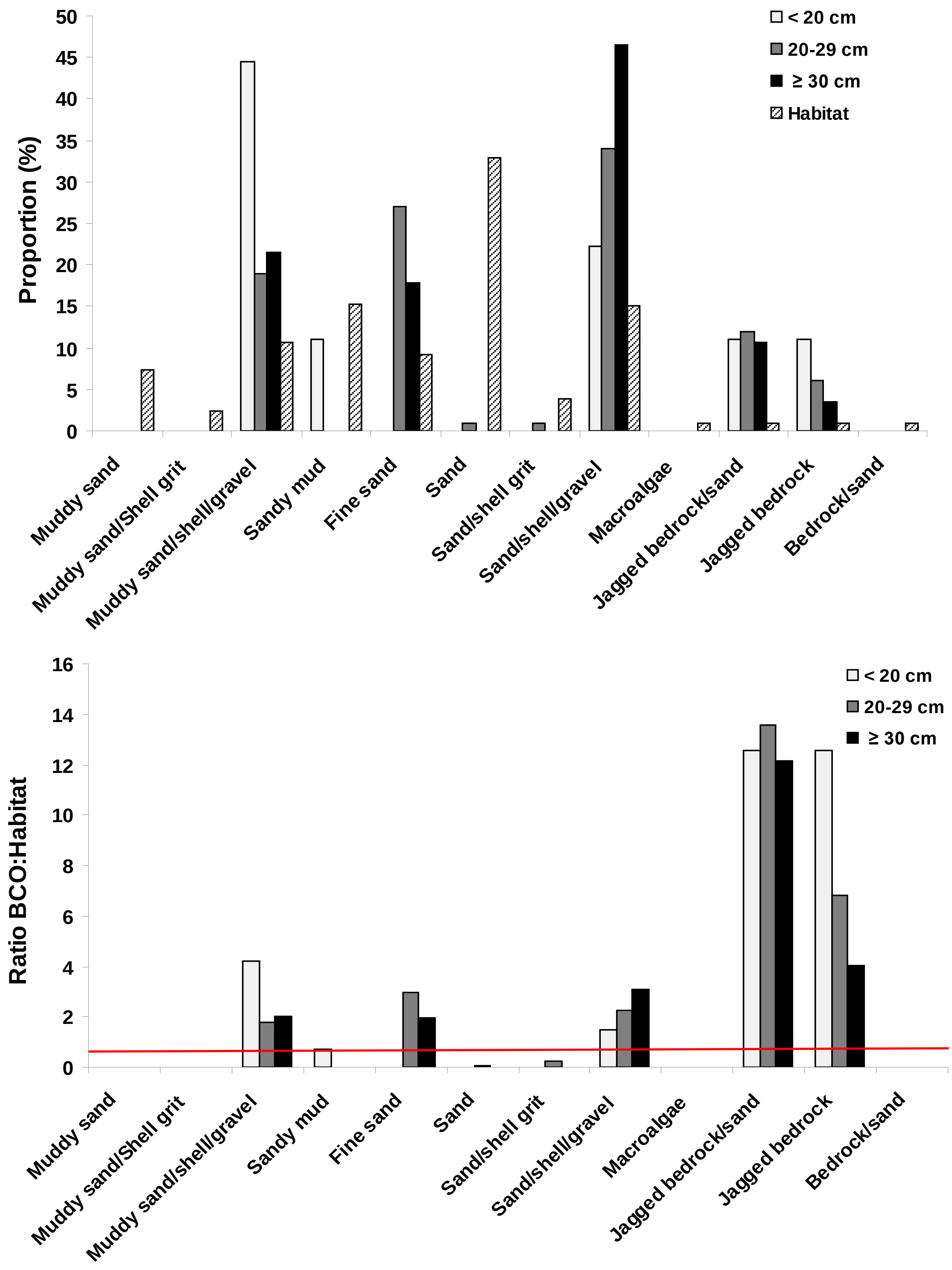
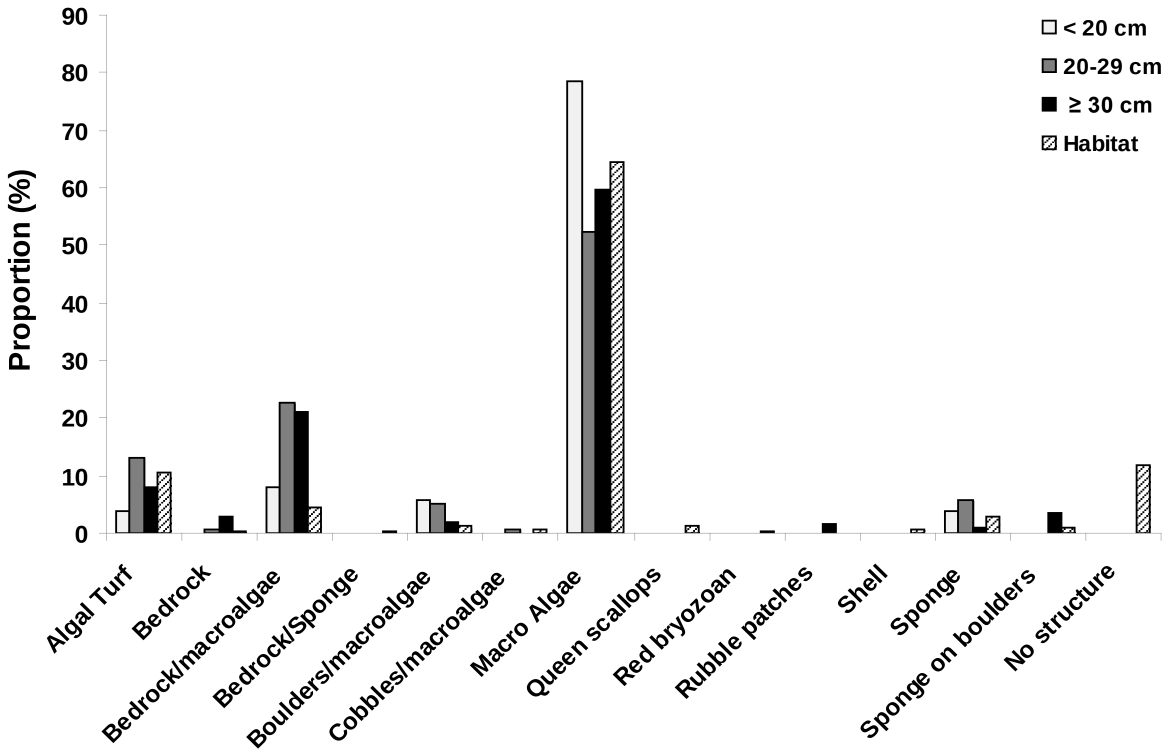


Figure 21: Proportion of blue cod (three size classes) and fish-independent DUV observations of primary substrate from random sites (top). The ratio of the proportion of blue cod-associated primary substrate and the fish-independent substrate recorded by the video at random sites is shown in the bottom figure with a line drawn at a 1:1 ratio.



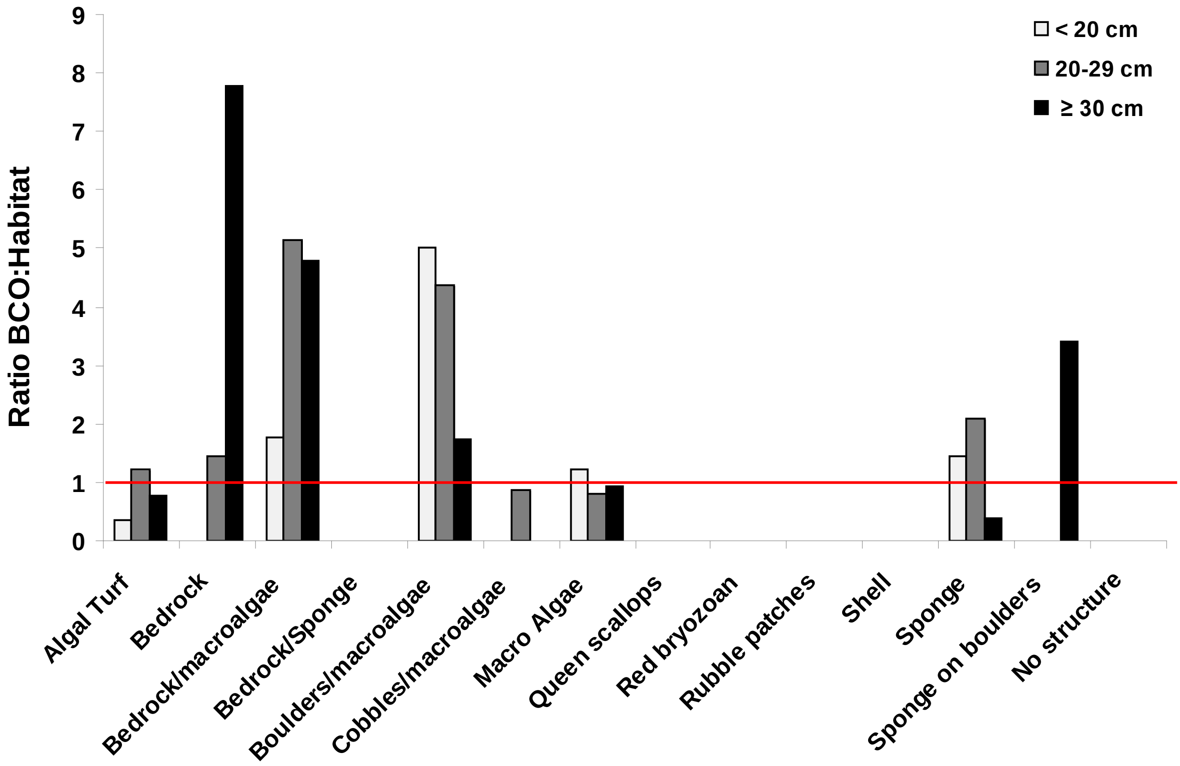


Figure 22: Proportion of blue cod (three size classes) and fish-independent DUV observations of secondary habitat structures from fixed sites (top). The ratio of the proportion of blue cod-associated secondary habitat structure and the fish-independent substrata recorded by the video at fixed sites is shown in the bottom figure with a line drawn at a 1:1 ratio.

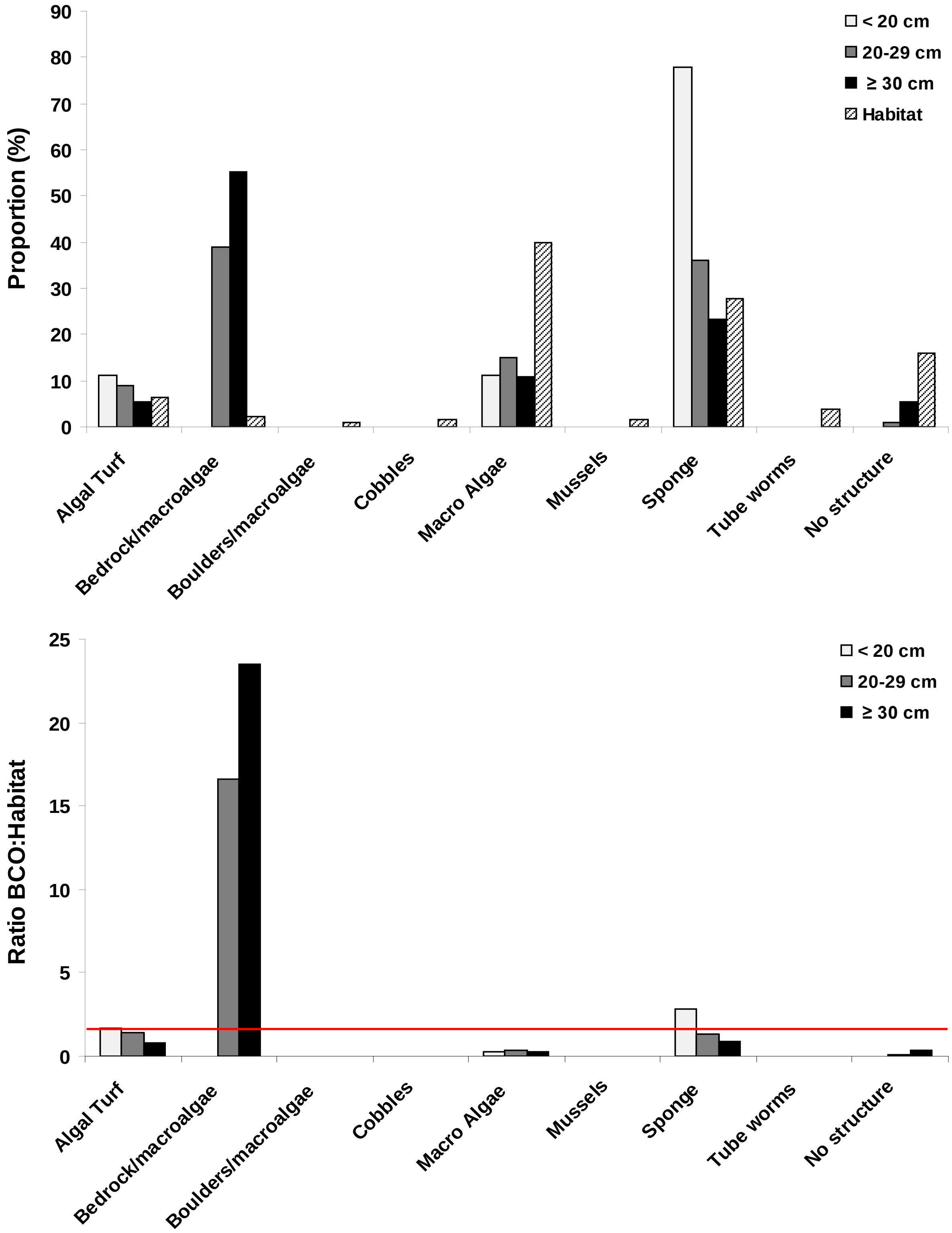


Figure 23: Proportion of blue cod (three size classes) and fish-independent DUV observations of secondary habitat structures from random sites (top). The ratio of the proportion of blue cod-associated secondary habitat structure and the fish-independent substrata recorded by the video at random sites is shown in the bottom figure with a line drawn at a 1:1 ratio.

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 label 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 the 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 which uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be station number 234. This convention is important in enabling users of the *trawl* database to determine whether two pots are from the same set.
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: Otolith reference library for Paterson Inlet blue cod potting surveys.

The Ministry for Primary Industries (MPI) blue cod potting survey network routinely estimates age of blue cod from potting surveys throughout the South Island of New Zealand to provide information to determine the status of fish stocks. This protocol documents the establishment and use of an otolith reference collection as part of routine age estimation using blue cod otoliths taken from regular potting surveys. The reference collection is designed to ensure consistency of age estimation through time by preventing long-term drift in interpretation by experienced readers, and as a training tool for inexperienced readers. Ultimately, two reference collections are prepared: an “original” and a “current” collection. Once included, otoliths are not removed from either reference collection. The following describes the initial development of an “original” otolith reference collection for the Paterson Inlet blue cod survey area.

Selecting the reference collection

The original reference collection needs to be representative of all factors that might reasonably be expected to influence the appearance or relative width of increments visible on otoliths. Ideally, a complete original reference collection contains a representative number of otoliths for each factor. From the 2010 Paterson Inlet potting survey otolith collection (n=303), 100 otoliths were selected from both sexes over the available age range, with examples from all readability grades (See Section 2.6)

For a species such as blue cod that has been subject to both several years of research in relation to aspects of its ageing and several years of routine age estimation, it was important to use a reader experienced in the biology of this species and previously exposed to the full range of variation in otolith appearance (i.e., 74). Two readers independently interpreted each otolith (74 and 128). The interpretations from each reader were then compared and where differences occurred, both readers consulted and cooperatively agreed on a single interpretation.

Two digital images were stored for each otolith in the reference collection; one image unmarked, the other annotated with the agreed interpretations of the two readers. Each annotated image contains relevant markings of the core (primordium) and the opaque zones (Figure 2.A). Digital images and details of the 2010 Paterson Inlet otolith reference collection are held by the MPI data manager.

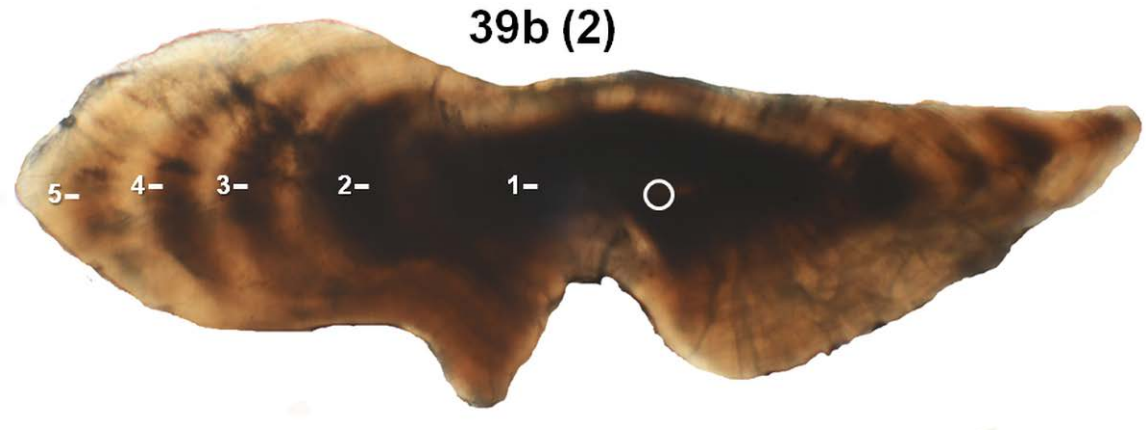


Figure 2.A. An example blue cod otolith section taken from the 2010 Paterson Inlet survey. Age estimates were made by counting the number of annuli (numbered opaque zones) from the core (○) to the distal edge.

Appendix 2– *continued*

Future collections
The original reference collection remains static once complete. A “current” (or ongoing) reference collection needs to be representative of all factors that presently influence the appearance or relative width of increments visible on otoliths. The composition of the current reference collection is influenced by the age structure of the sampled population each survey year. It is important that the current reference collection does not remain static. Continuous addition to the reference collection is important for two reasons: (1) it prevents the readers from unintentionally memorising structures and (2) keeps the reference collection current (representative of all factors that ‘at present’ influence the appearance or relative width of increments visible on otoliths). It is important to keep the reference collection current to reflect changes in the age structure of the sampled population or incremental macrostructure of otoliths (e.g. due to change in growth rates).

Routine reading of otoliths
Routine reading of otoliths comprises four main steps:

1) Reader qualification.
2) Reading the current sample.
3) Adding data to the database.
4) Adding sample to the current reference collection.

In steps 1 and 2, otoliths are read and incremental macrostructure interpreted, protocols outlined in Section 2.9. Interpretations are made without knowledge of fish length or sex (note that date of capture is a discrete fixed period for potting surveys, so the edge classification is not necessarily recorded as it would be in a catch sampling programme).
The following data are recorded when reading otoliths (See Section 2.9 for details):

- Reader’s name.
- Reading date.
- Increment count.
- Readability index.

Reader qualification
It is necessary for every reader to ‘qualify’ (i.e. reach the required standard) before carrying out routine reading of the current sample. Before qualifying, the reader first trains or familiarises themselves with the incremental macrostructure of the blue cod otoliths, by viewing otoliths in the original reference collection. Readers also need to be aware that the distance between opaque zones decreases as fish get older.

Training of inexperienced readers must involve discussions with an experienced reader about how to interpret the incremental macrostructure. Annotated images and physical otoliths from the reference collection are also used during these training sessions. Experienced readers also need to carry out re-training if any substantial period of time has lapsed since last reading blue cod otoliths, or if they have interpreted the otoliths of a different species in this period.

Following a period of training/re-training, the reader’s competency is tested using a random sub-sample from the original and current reference collections. The sub-sample is made up of 50% from the original reference collection and 50% from the current reference collection. In total, these sub-samples contain a minimum of 100 otoliths. However, as no current reference collection has yet been produced, at this stage we recommend reading the entire original collection in a random order.

The reader is tested by comparing their interpretations of the otoliths from the physical reference collection with the agreed interpretations that accompany the reference collections. Increment counts are tested for bias and precision (see Quality control measures). If there is an absence of significant bias and precision is acceptable, the reader is qualified to read the current survey sample. After demonstrating competency readers should read the current survey sample as soon as possible and avoid reading the otoliths of different species in the interim. If significant bias exists or precision is too low, then the reader should return to the physical reference collection and the annotated images for additional training and testing.

Appendix 2– *continued*

Reading future survey otoliths
The reader records data for each otolith for the new survey sample according to the protocols for reading blue cod otoliths (Section 2.9 and the blue cod potting survey SSM). After reading the new survey sample, a random sub-sample of otoliths is removed and re-read. A minimum of 50 otoliths is re-read.

Increment counts are tested for bias and precision, and if there is an absence of significant bias and precision is acceptable, data from the new survey otolith reading may be entered into the MPI "age" database following error checking protocols defined in the potting survey SSM. If significant bias exists or precision is too low, the reader must return to the initial Reader qualification step. In other words, the reader must re-train and undergo testing of their competency using the original reference collection. The reader must then re-read the new survey otolith collection and re-read another random sub-sample.

Adding the sub-sample to the current reference collection
Fifty randomly selected otoliths from the re-read new survey sub-sample should be added to the current reference collection. Two digital images should also be stored for each otolith. One image in an unmarked format, and the other annotated with the core and opaque zones.

Quality control measures
Increment counts are tested for bias and precision while readability is tested for precision only. These quality control measures are applied separately to sub-sample readings by comparing them to the agreed interpretations in the case of the reference collections, or the first reading in the case of a new survey sample.

Bias
Age bias plots should be used to detect unacceptable bias. They provide an increment by increment measure of deviation from an accepted value. Age bias plots present the mean increment count with 95% confidence intervals (Y axis), corresponding to each consensus-derived increment count in the reference collection (X axis). The objective of the 95% confidence intervals is not to assign statistical significance, but to assist interpretation of the magnitude of bias. The magnitude of bias is indicated by the deviation from the 1:1 equivalence line. A divergent trend across a series of ages shows that the reader is consistently under or over ageing (Figure 2B). Unacceptable bias is addressed by re-training using the reference collection. However, not all bias warrants corrective action; for example in Figure B, some bias exists but it is small (less than half a year), and that would be considered acceptable for this species.

Precision
Precision is measured by calculating an index of average percent error (APE).

$$APE_j = 100 \times \frac{1}{R} \sum_{i=1}^{R} \frac{|X_{ij} - X_j|}{X_j}$$

Where R is the number of times the otoliths are read, X_{ij} is the i^{th} increment count of the j^{th} fish; X_j is the mean increment count estimate for the j^{th} fish. When APE_j is averaged across many fish it becomes an index of average percent error (IAPE).

Readability
The precision of a readability index of 5, describes the readers ability to correctly identify an otolith as unreadable. Precision is measured as the percentage agreement between the sub-sample re-reads and the agreed interpretations from the reference collection, or the first reading in the case of the current sample.

Percentage agreement = (*n* agree/ *n*) x 100, where *n* is the number.

Appendix 2– ***continued***

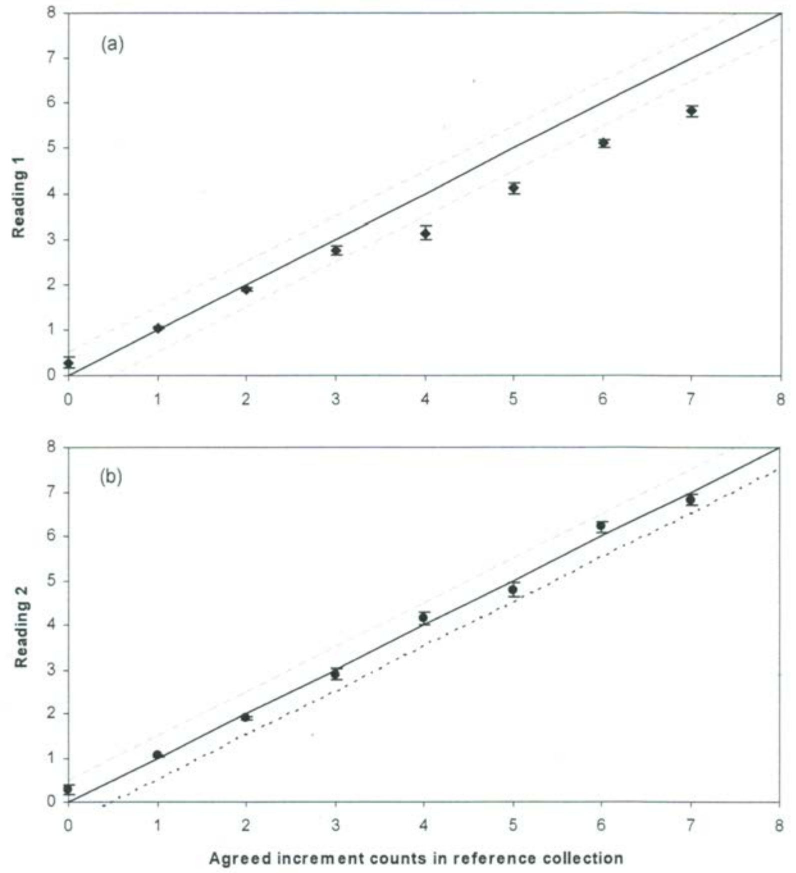


Figure 2.B. An example age bias plots presenting mean increment counts and 95% confidence intervals for each increment count in the reference collection. The 1:1 equivalence line is indicated by the solid line. In this example an acceptable bias of less than half a year has been set as a threshold, indicated by the dashed line. (a) An unacceptable level of bias is evident in reading 1 for otoliths with an increment count of 4 to 7. (b) Reading 2 shows acceptable bias.

Appendix 3: Number of fish sexed for the 2006 and 2010 Paterson Inlet surveys.

The numbers of sampled fish (i.e. length measured) in each sex category for the 2006 and 2010 Paterson Inlet blue cod potting surveys are shown in Table 3.A. For the 2010 survey, only fish in the marine reserve (stratum 3) were not sexed, while for the 2006 survey there were unsexed fish in all strata. The fish that were sexed are not a random sample from the population (Figure 3.A).

Table 3.A: Number of fish in each sex category, by survey stratum and survey year. Sex categories are: 1 for male; 2 for female; 4 for unsexed.

	2006 Survey Sex category			2010 Survey Sex category		
Stratum	1	2	4	1	2	4
1	61	18	177	331	145	
2	39	32	176	154	61	
3	2		310	354	53	70
4	160	76	523	639	232	
5	51	16	3	44	21	
6				17	24	
Total	313	142	1188	1539	536	70

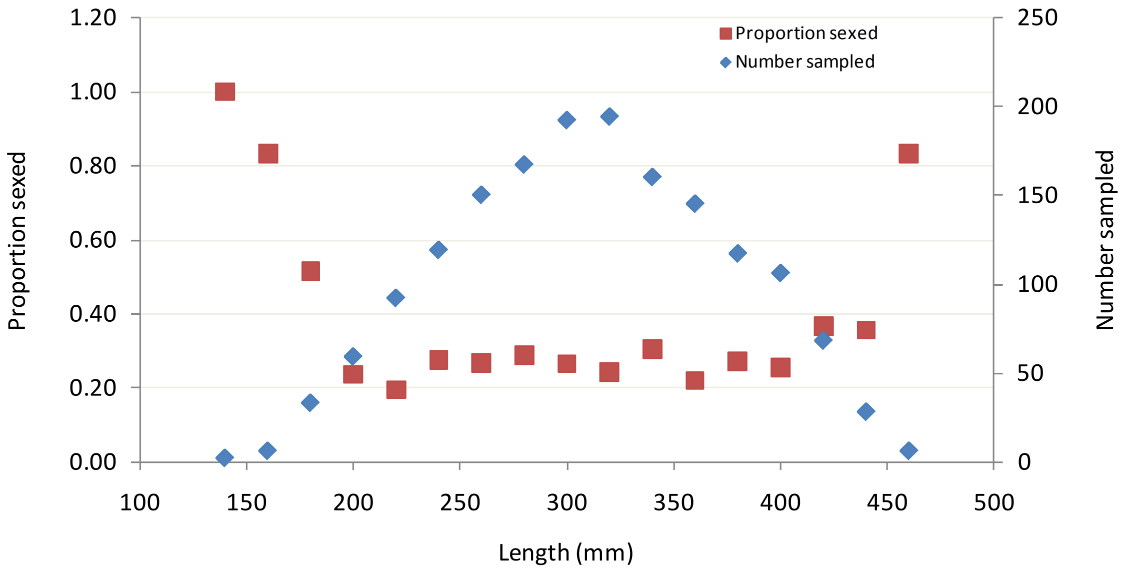


Figure 3.A: Number of blue cod sampled and the proportion that were sexed by length class, for the 2006 Paterson Inlet survey.

Appendix 4: Recalculated CPUE and Z estimates for the 2006 Paterson Inlet potting survey.

Table 4.A: Mean catch rates for all blue cod caught in the 2006 Paterson Inlet survey. 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.

Stratum	Sites	Pot lifts (N/)	Mean (kg.pot^{-1})	s.e.	CV (%)
1	8	48	3.12	0.74	23.75
2	7	42	4.13	0.49	11.80
3	6	36	6.11	1.47	24.08
4	7	42	8.42	1.70	20.16
5	6	36	1.47	0.34	23.36
Overall	34	204	4.95	0.53	10.67
Overall (Excluding stratum 3)	28	168	4.77	0.57	11.86

Table 4.B: Mean catch rates for blue cod 33 cm and over (MLS) caught in the 2006 Paterson Inlet survey. 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.

Stratum	Sites	Pot lifts (N)	Mean (kg.pot^{-1})	s.e.	CV (%)
1	8	48	2.15	0.52	24.02
2	7	42	3.15	0.41	12.94
3	6	36	4.65	1.18	25.44
4	7	42	4.09	1.02	24.84
5	6	36	1.32	0.32	23.95
Overall	34	204	3.15	0.35	11.06
Overall (Excluding stratum 3)	28	168	2.91	0.36	12.27

Table 4.C: Blue cod total mortality estimates (*Z*) with 95% confidence intervals and corresponding $F_{\%SPR}$ values (assuming M=0.14) for ages of recruitment (AgeRec) from 5 to 10 for the 2006 Paterson Inlet fixed site survey. Analyses exclude the marine reserve stratum data

		Confidence intervals		
AgeR	*Z*	Lower	Upper	$F_{\%SPR}$
5	0.32	0.24	0.47	37.4
6	0.40	0.29	0.59	30.6
7	0.49	0.34	0.71	26.1
8	0.63	0.42	0.95	22.1
9	0.67	0.43	1.00	21.4
10	0.85	0.53	1.36	19.0
11	0.79	0.45	1.45	19.7

Appendix 5: Summary of survey pot lift station data, Paterson Inlet 2010. For sites R=random.

								Catch of blue cod	
Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	(kg)	Number
1	23-Nov-10	1	1	R1	13.4	9:07	3	0.0	0
1	23-Nov-10	1	1	R1	7.7	9:16	5	0.0	0
1	23-Nov-10	1	1	R1	3.7	9:24	4	0.0	0
1	23-Nov-10	1	1	R1	3.7	9:30	6	0.0	0
1	23-Nov-10	1	1	R1	13.2	9:37	1	0.6	1
1	23-Nov-10	1	1	R1	10.2	9:44	2	0.0	0
2	23-Nov-10	1	1	R2	17.4	11:20	2	0.0	0
2	23-Nov-10	1	1	R2	18.5	11:26	1	0.0	0
2	23-Nov-10	1	1	R2	19.2	11:31	6	3.7	8
2	23-Nov-10	1	1	R2	16.1	11:38	4	1.2	2
2	23-Nov-10	1	1	R2	10.2	11:46	5	0.0	0
2	23-Nov-10	1	1	R2	12.6	11:52	3	0.0	0
3	23-Nov-10	1	1	R3	9.5	13:34	3	0.0	0
3	23-Nov-10	1	1	R3	10.2	13:39	5	0.0	0
3	23-Nov-10	1	1	R3	9.9	13:45	4	0.0	0
3	23-Nov-10	1	1	R3	9.0	13:52	6	0.0	0
3	23-Nov-10	1	1	R3	8.6	13:57	1	0.0	0
3	23-Nov-10	1	1	R3	7.3	14:03	2	0.0	0
4	23-Nov-10	1	1	R4	20.8	15:23	2	0.5	1
4	23-Nov-10	1	1	R4	20.7	15:28	1	0.0	0
4	23-Nov-10	1	1	R4	20.1	15:33	6	2.4	5
4	23-Nov-10	1	1	R4	20.8	15:37	4	3.2	10
4	23-Nov-10	1	1	R4	21.0	15:43	5	2.0	3
4	23-Nov-10	1	1	R4	21.0	15:48	3	0.9	3
5	24-Nov-10	1	2	R2	23.4	7:40	3	1.1	1
5	24-Nov-10	1	2	R2	23.4	7:45	5	0.9	2
5	24-Nov-10	1	2	R2	23.2	7:51	2	1.5	2
5	24-Nov-10	1	2	R2	22.9	7:56	6	0.8	4
5	24-Nov-10	1	2	R2	23.0	8:01	1	1.0	2
5	24-Nov-10	1	2	R2	22.9	8:06	4	2.2	4
6	24-Nov-10	1	1	D	11.2	9:30	2	0.0	0
6	24-Nov-10	1	1	D	7.9	9:36	1	0.0	0
6	24-Nov-10	1	1	D	15.9	9:42	6	0.0	0
6	24-Nov-10	1	1	D	20.5	9:48	4	0.0	0
6	24-Nov-10	1	1	D	13.4	9:55	5	0.3	1
6	24-Nov-10	1	1	D	17.0	10:04	3	0.0	0
7	24-Nov-10	1	2	R1	6.8	11:25	3	0.0	0
7	24-Nov-10	1	2	R1	6.9	11:30	5	0.0	0
7	24-Nov-10	1	2	R1	6.4	11:35	4	1.5	1
7	24-Nov-10	1	2	R1	6.8	11:40	6	0.0	0
7	24-Nov-10	1	2	R1	7.5	11:45	1	0.0	0
7	24-Nov-10	1	2	R1	7.5	11:50	2	0.0	0
8	24-Nov-10	1	2	H	9.1	13:28	2	2.6	3
8	24-Nov-10	1	2	H	10.8	13:34	1	0.0	0
8	24-Nov-10	1	2	H	4.9	13:40	6	2.4	3
8	24-Nov-10	1	2	H	5.1	13:47	4	2.0	2

								Catch of blue cod	
Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	(kg)	Number
8	24-Nov-10	1	2	*H*	*9.5*	13:54	*5*	*2.4*	*2*
8	24-Nov-10	1	2	*H*	*11.5*	13:59	*3*	*1.6*	*3*
9	24-Nov-10	1	2	*G*	*11.9*	15:30	*3*	*4.5*	*7*
9	24-Nov-10	1	2	*G*	*6.4*	15:35	*5*	*6.0*	*8*
9	24-Nov-10	1	2	*G*	*17.7*	15:41	*4*	*3.2*	*4*
9	24-Nov-10	1	2	*G*	*10.2*	15:47	*6*	*6.9*	*13*
9	24-Nov-10	1	2	*G*	*12.8*	15:55	*1*	*0.0*	*0*
9	24-Nov-10	1	2	*G*	*3.7*	16:00	*2*	*1.9*	*1*
10	25-Nov-10	1	5	*R2*	*6.0*	8:28	*2*	*0.0*	*0*
10	25-Nov-10	1	5	*R2*	*5.1*	8:38	*1*	*0.0*	*0*
10	25-Nov-10	1	5	*R2*	*3.7*	8:45	*6*	*0.0*	*0*
10	25-Nov-10	1	5	*R2*	*6.9*	8:53	*5*	*0.0*	*0*
10	25-Nov-10	1	5	*R2*	*6.0*	9:00	*4*	*0.0*	*0*
10	25-Nov-10	1	5	*R2*	*6.6*	9:07	*3*	*0.0*	*0*
11	25-Nov-10	1	5	*D*	*3.7*	10:25	*3*	*0.0*	*0*
11	25-Nov-10	1	5	*D*	*3.7*	10:37	*5*	*0.0*	*0*
11	25-Nov-10	1	5	*D*	*3.7*	10:45	*4*	*0.0*	*0*
11	25-Nov-10	1	5	*D*	*3.7*	10:52	*6*	*3.0*	*2*
11	25-Nov-10	1	5	*D*	*3.7*	10:59	*1*	*0.0*	*0*
11	25-Nov-10	1	5	*D*	*3.7*	11:06	*2*	*1.3*	*1*
12	25-Nov-10	1	D	*1R*	*25.6*	12:40	*2*	*0.0*	*0*
12	25-Nov-10	1	D	*1R*	*25.6*	12:47	*1*	*0.0*	*0*
12	25-Nov-10	1	D	*1R*	*25.6*	12:54	*6*	*0.0*	*0*
12	25-Nov-10	1	D	*1R*	*25.4*	13:02	*4*	*0.0*	*0*
12	25-Nov-10	1	D	*1R*	*25.6*	13:09	*5*	*0.0*	*0*
12	25-Nov-10	1	D	*1R*	*26.0*	13:16	*3*	*0.0*	*0*
13	25-Nov-10	1	D	*R2*	*25.4*	14:34	*3*	*0.0*	*0*
13	25-Nov-10	1	D	*R2*	*24.7*	14:41	*5*	*0.0*	*0*
13	25-Nov-10	1	D	*R2*	*24.3*	14:48	*4*	*0.0*	*0*
13	25-Nov-10	1	D	*R2*	*24.7*	14:55	*6*	*0.0*	*0*
13	25-Nov-10	1	D	*R2*	*25.1*	15:02	*1*	*0.0*	*0*
13	25-Nov-10	1	D	*R2*	*25.6*	15:08	*2*	*0.0*	*0*
14	26-Nov-10	1	3	*R5*	*25.4*	7:52	*2*	*5.3*	*12*
14	26-Nov-10	1	3	*R5*	*25.6*	7:57	*1*	*3.8*	*13*
14	26-Nov-10	1	3	*R5*	*25.6*	8:05	*6*	*5.5*	*17*
14	26-Nov-10	1	3	*R5*	*25.8*	8:12	*4*	*3.2*	*9*
14	26-Nov-10	1	3	*R5*	*25.8*	8:18	*5*	*3.1*	*18*
14	26-Nov-10	1	3	*R5*	*25.8*	8:26	*3*	*1.1*	*3*
15	26-Oct-10	1	3	*R4*	*25.6*	9:46	*3*	*5.9*	*16*
15	26-Oct-10	1	3	*R4*	*25.1*	9:55	*5*	*5.2*	*17*
15	26-Oct-10	1	3	*R4*	*24.9*	10:03	*4*	*6.2*	*25*
15	26-Oct-10	1	3	*R4*	*24.7*	10:12	*6*	*8.9*	*29*
15	26-Oct-10	1	3	*R4*	*25.1*	10:20	*1*	*6.2*	*25*
15	26-Oct-10	1	3	*R4*	*25.2*	10:29	*2*	*2.2*	*7*
16	26-Nov-10	1	4	*R3*	*39.3*	12:10	*2*	*4.6*	*18*
16	26-Nov-10	1	4	*R3*	*33.3*	12:20	*1*	*0.3*	*4*
16	26-Nov-10	1	4	*R3*	*40.4*	12:30	*6*	*2.0*	*3*
16	26-Nov-10	1	4	*R3*	*28.0*	12:40	*4*	*0.7*	*7*

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Catch of blue cod Number
16	26-Nov-10	1	4	R3	27.4	12:50	5	0.4	6
16	26-Nov-10	1	4	R3	39.1	13:00	3	22.7	72
17	26-Nov-10	1	2	R3	19.0	16:50	3	3.9	18
17	26-Nov-10	1	2	R3	19.0	16:57	5	0.0	0
17	26-Nov-10	1	2	R3	14.4	17:02	4	0.0	0
17	26-Nov-10	1	2	R3	17.4	17:07	6	0.1	1
17	26-Nov-10	1	2	R3	20.1	17:13	1	0.2	1
17	26-Nov-10	1	2	R3	20.8	17:19	2	0.0	0
18	27-Nov-10	1	2	R7	17.2	11:16	2	0.0	0
18	27-Nov-10	1	2	R7	15.5	11:22	1	0.0	1
18	27-Nov-10	1	2	R7	12.8	11:28	6	0.0	0
18	27-Nov-10	1	2	R7	18.3	11:35	4	0.0	0
18	27-Nov-10	1	2	R7	15.2	11:43	5	0.0	0
18	27-Nov-10	1	2	R7	18.3	11:49	3	0.0	0
19	27-Nov-10	1	2	B	3.3	15:05	3	3.7	4
19	27-Nov-10	1	2	B	5.1	15:13	5	4.7	7
19	27-Nov-10	1	2	B	5.5	15:19	4	7.3	12
19	27-Nov-10	1	2	B	3.7	15:26	6	4.3	7
19	27-Nov-10	1	2	B	5.5	15:33	1	4.2	5
19	27-Nov-10	1	2	B	5.1	15:40	2	5.6	9
20	28-Nov-10	1	2	C	5.5	9:32	2	7.2	10
20	28-Nov-10	1	2	C	10.1	9:43	6	4.5	9
20	28-Nov-10	1	2	C	10.4	9:52	1	6.1	10
20	28-Nov-10	1	2	C	5.9	10:02	4	3.5	6
20	28-Nov-10	1	2	C	7.7	10:12	5	4.0	7
20	28-Nov-10	1	2	C	5.5	10:22	3	1.8	3
21	28-Nov-10	1	2	D	5.5	13:18	3	1.6	1
21	28-Nov-10	1	2	D	4.6	13:28	4	2.5	4
21	28-Nov-10	1	2	D	5.5	13:38	5	4.0	6
21	28-Nov-10	1	2	D	9.1	13:48	1	12.0	21
21	28-Nov-10	1	2	D	9.7	13:56	6	20.0	53
21	28-Nov-10	1	2	D	11.5	14:06	2	0.0	1
22	28-Nov-10	1	4	C	12.4	16:22	2	7.0	13
22	28-Nov-10	1	4	C	13.5	16:31	1	5.7	15
22	28-Nov-10	1	4	C	9.9	16:40	6	1.9	2
22	28-Nov-10	1	4	C	10.4	16:50	5	0.7	1
22	28-Nov-10	1	4	C	4.6	17:00	4	0.5	2
22	28-Nov-10	1	4	C	15.0	17:10	3	1.1	1
23	29-Nov-10	1	3	B	19.2	10:30	3	17.4	39
23	29-Nov-10	1	3	B	8.2	10:40	5	3.9	4
23	29-Nov-10	1	3	B	8.2	10:50	4	6.0	8
23	29-Nov-10	1	3	B	11.3	11:00	1	1.7	3
23	29-Nov-10	1	3	B	12.6	11:10	6	14.2	29
23	29-Nov-10	1	3	B	11.9	11:20	2	11.5	27
24	29-Nov-10	1	3	R1	14.8	14:27	2	0.0	0
24	29-Nov-10	1	3	R1	5.5	14:33	1	0.8	2
24	29-Nov-10	1	3	R1	16.6	14:38	6	0.0	0
24	29-Nov-10	1	3	R1	16.5	14:55	4	0.0	0

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Number
24	29-Nov-10	1	3	R1	12.3	14:50	5	0.0	0
24	29-Nov-10	1	3	R1	15.9	14:55	3	0.0	0
25	30-Nov-10	1	3	R3	16.5	12:40	3	0.0	0
25	30-Nov-10	1	3	R3	16.5	12:45	4	0.0	0
25	30-Nov-10	1	3	R3	15.0	12:50	5	1.1	1
25	30-Nov-10	1	3	R3	12.8	12:55	6	0.0	0
25	30-Nov-10	1	3	R3	9.1	13:00	1	0.0	0
25	30-Nov-10	1	3	R3	13.2	13:05	2	0.0	0
26	30-Nov-10	1	3	I	4.9	14:16	2	22.5	28
26	30-Nov-10	1	3	I	4.9	14:24	1	10.2	15
26	30-Nov-10	1	3	I	10.2	14:31	6	6.4	9
26	30-Nov-10	1	3	I	10.6	14:40	5	6.2	8
26	30-Nov-10	1	3	I	5.1	14:50	4	10.9	11
26	30-Nov-10	1	3	I	6.4	14:53	3	12.3	13
27	01-Dec-10	1	4	R5	14.3	9:39	2	0.0	0
27	01-Dec-10	1	4	R5	13.4	9:46	6	0.0	0
27	01-Dec-10	1	4	R5	12.3	9:52	1	0.0	0
27	01-Dec-10	1	4	R5	17.0	9:58	5	0.0	0
27	01-Dec-10	1	4	R5	15.5	10:06	4	0.0	0
27	01-Dec-10	1	4	R5	14.6	10:16	3	4.6	13
28	01-Dec-10	1	4	E	6.8	11:35	3	0.3	1
28	01-Dec-10	1	4	E	6.8	11:45	4	1.1	3
28	01-Dec-10	1	4	E	10.6	11:55	5	0.7	1
28	01-Dec-10	1	4	E	6.4	12:05	1	6.2	7
28	01-Dec-10	1	4	E	14.1	12:16	6	23.1	66
28	01-Dec-10	1	4	E	15.5	12:25	2	27.7	91
29	01-Dec-10	1	4	R2	19.2	16:08	2	0.0	0
29	01-Dec-10	1	4	R2	19.0	16:14	6	0.0	0
29	01-Dec-10	1	4	R2	19.2	16:18	1	0.0	0
29	01-Dec-10	1	4	R2	18.3	16:24	5	0.0	0
29	01-Dec-10	1	4	R2	16.3	16:30	4	6.0	17
29	01-Dec-10	1	4	R2	15.4	16:35	3	1.5	11
30	02-Dec-10	1	3	E	6.0	10:26	3	0.0	0
30	02-Dec-10	1	3	E	5.5	10:36	5	12.1	13
30	02-Dec-10	1	3	E	9.1	10:46	4	4.9	7
30	02-Dec-10	1	3	E	4.6	10:56	1	1.8	2
30	02-Dec-10	1	3	E	6.9	11:07	6	16.3	24
30	02-Dec-10	1	3	E	11.3	11:17	2	5.6	7
31	02-Dec-10	1	3	D	13.2	12:36	2	21.3	31
31	02-Dec-10	1	3	D	5.1	12:46	6	7.9	11
31	02-Dec-10	1	3	D	8.2	12:56	1	8.9	11
31	02-Dec-10	1	3	D	11.0	13:06	4	4.7	7
31	02-Dec-10	1	3	D	14.1	13:16	5	13.8	25
31	02-Dec-10	1	3	D	14.6	13:26	3	6.9	15
32	02-Dec-10	1	3	R2	24.1	16:45	3	1.5	6
32	02-Dec-10	1	3	R2	24.7	16:54	4	6.5	21
32	02-Dec-10	1	3	R2	24.7	17:06	5	2.2	8
32	02-Dec-10	1	3	R2	23.8	17:16	1	3.2	11

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Catch of blue cod Number
32	02-Dec-10	1	3	R2	23.6	17:25	6	3.0	8
32	02-Dec-10	1	3	R2	23.8	17:35	2	1.0	3
33	03-Dec-10	1	4	B	20.1	9:22	2	3.1	11
33	03-Dec-10	1	4	B	7.7	9:33	1	0.0	0
33	03-Dec-10	1	4	B	5.5	9:43	6	3.6	9
33	03-Dec-10	1	4	B	11.5	9:53	5	10.3	27
33	03-Dec-10	1	4	B	23.8	10:03	4	4.0	16
33	03-Dec-10	1	4	B	25.2	10:13	3	6.7	35
34	03-Dec-10	1	3	C	15.4	16:02	3	1.9	5
34	03-Dec-10	1	3	C	12.4	16:15	5	4.4	10
34	03-Dec-10	1	3	C	11.7	16:25	4	16.1	28
34	03-Dec-10	1	3	C	4.2	16:34	6	0.4	1
34	03-Dec-10	1	3	C	6.8	16:45	1	0.4	1
34	03-Dec-10	1	3	C	14.1	16:54	2	0.3	1
35	04-Dec-10	1	D	R3	25.1	10:33	2	0.2	1
35	04-Dec-10	1	D	R3	25.6	10:37	6	0.7	1
35	04-Dec-10	1	D	R3	25.8	10:45	1	0.0	0
35	04-Dec-10	1	D	R3	25.6	10:50	4	0.0	0
35	04-Dec-10	1	D	R3	25.1	10:56	5	0.0	0
35	04-Dec-10	1	D	R3	25.1	11:03	3	0.0	0
36	04-Dec-10	1	5	B	18.3	12:21	3	0.0	0
36	04-Dec-10	1	5	B	4.6	12:28	5	3.4	3
36	04-Dec-10	1	5	B	4.6	12:36	4	2.1	1
36	04-Dec-10	1	5	B	19.2	12:43	1	0.0	0
36	04-Dec-10	1	5	B	8.2	12:50	6	2.1	2
36	04-Dec-10	1	5	B	19.2	13:00	2	0.0	0
37	04-Dec-10	1	D	R4	24.0	14:26	2	2.0	4
37	04-Dec-10	1	D	R4	26.0	14:31	6	0.6	1
37	04-Dec-10	1	D	R4	24.3	14:36	1	6.5	11
37	04-Dec-10	1	D	R4	24.3	14:42	4	7.0	10
37	04-Dec-10	1	D	R4	24.3	14:47	5	2.3	6
37	04-Dec-10	1	D	R4	24.7	14:53	3	0.0	0
38	05-Dec-10	1	5	R1	5.5	8:17	3	0.0	0
38	05-Dec-10	1	5	R1	7.7	8:25	5	0.0	0
38	05-Dec-10	1	5	R1	8.6	8:30	4	0.0	0
38	05-Dec-10	1	5	R1	9.3	8:35	1	0.0	0
38	05-Dec-10	1	5	R1	9.7	8:40	6	0.0	0
38	05-Dec-10	1	5	R1	9.3	8:46	2	0.0	0
39	05-Dec-10	1	5	C	4.2	10:10	6	0.0	0
39	05-Dec-10	1	5	C	6.0	10:18	2	0.0	0
39	05-Dec-10	1	5	C	3.3	10:26	1	0.0	0
39	05-Dec-10	1	5	C	5.9	10:35	4	0.7	1
39	05-Dec-10	1	5	C	3.3	10:43	5	3.5	3
39	05-Dec-10	1	5	C	2.9	10:50	3	0.8	1
40	05-Dec-10	1	5	R3	22.9	12:32	3	0.0	0
40	05-Dec-10	1	5	R3	12.8	12:39	5	0.0	0
40	05-Dec-10	1	5	R3	11.5	12:49	4	0.0	0
40	05-Dec-10	1	5	R3	4.4	12:56	1	0.0	0

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Number
40	05-Dec-10	1	5	R3	3.7	13:07	6	3.2	4
40	05-Dec-10	1	5	R3	11.9	13:14	2	0.0	0
41	05-Dec-10	1	D	R5	25.6	14:34	2	0.0	0
41	05-Dec-10	1	D	R5	25.6	14:42	6	0.0	0
41	05-Dec-10	1	D	R5	26.2	14:50	1	0.2	1
41	05-Dec-10	1	D	R5	25.8	14:58	4	0.0	0
41	05-Dec-10	1	D	R5	24.7	15:06	5	1.8	5
41	05-Dec-10	1	D	R5	25.4	15:15	3	0.0	0
42	06-Dec-10	1	4	R1	20.7	9:27	3	0.0	0
42	06-Dec-10	1	4	R1	21.6	9:34	4	0.0	0
42	06-Dec-10	1	4	R1	22.3	9:41	5	0.0	0
42	06-Dec-10	1	4	R1	18.3	9:48	1	0.0	0
42	06-Dec-10	1	4	R1	16.6	9:58	6	0.0	0
42	06-Dec-10	1	4	R1	15.2	10:07	2	7.3	18
43	06-Dec-10	1	4	I	16.5	13:39	2	0.0	0
43	06-Dec-10	1	4	I	11.0	13:49	6	14.1	22
43	06-Dec-10	1	4	I	6.0	14:00	1	1.9	5
43	06-Dec-10	1	4	I	10.6	14:10	5	17.9	53
43	06-Dec-10	1	4	I	8.4	14:22	4	21.6	32
43	06-Dec-10	1	4	I	13.5	14:32	3	0.4	3
44	06-Dec-10	1	4	R4	13.7	16:05	3	0.0	0
44	06-Dec-10	1	4	R4	12.3	16:10	4	0.0	0
44	06-Dec-10	1	4	R4	11.2	16:17	5	0.0	0
44	06-Dec-10	1	4	R4	11.7	16:23	1	0.0	0
44	06-Dec-10	1	4	R4	11.5	16:30	6	0.0	0
44	06-Dec-10	1	4	R4	8.4	16:35	2	0.0	0
45	07-Dec-10	1	1	A	5.5	8:07	2	1.1	4
45	07-Dec-10	1	1	A	3.1	8:15	6	0.0	0
45	07-Dec-10	1	1	A	2.9	8:24	1	6.5	8
45	07-Dec-10	1	1	A	3.7	8:32	5	3.2	6
45	07-Dec-10	1	1	A	3.1	8:40	4	2.7	3
45	07-Dec-10	1	1	A	3.3	8:50	3	2.4	2
46	07-Dec-10	1	1	R6	15.7	10:10	3	0.0	0
46	07-Dec-10	1	1	R6	16.3	10:16	4	0.0	0
46	07-Dec-10	1	1	R6	15.0	10:24	5	0.0	0
46	07-Dec-10	1	1	R6	15.7	10:31	6	0.0	0
46	07-Dec-10	1	1	R6	17.4	10:37	1	0.0	0
46	07-Dec-10	1	1	R6	15.5	10:45	2	0.0	0
47	07-Dec-10	1	1	G	3.7	12:10	2	1.6	1
47	07-Dec-10	1	1	G	3.7	12:18	1	2.9	2
47	07-Dec-10	1	1	G	3.8	12:26	6	8.1	10
47	07-Dec-10	1	1	G	3.1	12:34	5	2.9	3
47	07-Dec-10	1	1	G	8.2	12:43	4	5.3	7
47	07-Dec-10	1	1	G	6.6	12:51	3	10.9	18
48	07-Dec-10	1	2	R4	24.9	14:26	3	2.1	4
48	07-Dec-10	1	2	R4	24.9	14:33	5	1.2	3
48	07-Dec-10	1	2	R4	25.1	14:40	4	2.7	5
48	07-Dec-10	1	2	R4	24.9	14:48	6	0.2	1

Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	Catch of blue cod (kg)	Number
48	07-Dec-10	1	2	R4	24.7	14:56	1	1.1	2
48	07-Dec-10	1	2	R4	24.9	15:05	2	1.8	4
49	08-Dec-10	1	2	R5	13.0	8:38	2	0.0	0
49	08-Dec-10	1	2	R5	13.2	8:43	1	0.0	0
49	08-Dec-10	1	2	R5	12.4	8:50	6	0.0	0
49	08-Dec-10	1	2	R5	9.5	8:55	4	0.0	0
49	08-Dec-10	1	2	R5	5.7	9:00	5	0.0	0
49	08-Dec-10	1	2	R5	7.5	9:08	3	0.0	0
50	08-Dec-10	1	4	R6	19.6	10:48	3	2.4	5
50	08-Dec-10	1	4	R6	21.0	10:55	5	13.0	28
50	08-Dec-10	1	4	R6	16.3	11:00	4	0.0	0
50	08-Dec-10	1	4	R6	11.2	11:06	6	0.0	0
50	08-Dec-10	1	4	R6	11.9	11:14	1	0.0	0
50	08-Dec-10	1	4	R6	13.7	11:20	2	0.0	0
51	08-Dec-10	1	1	I	8.4	14:31	2	5.0	7
51	08-Dec-10	1	1	I	6.9	14:39	6	3.6	7
51	08-Dec-10	1	1	I	6.2	14:47	1	2.6	5
51	08-Dec-10	1	1	I	7.3	14:54	4	2.8	5
51	08-Dec-10	1	1	I	4.4	15:03	5	0.0	0
51	08-Dec-10	1	1	I	5.9	15:10	3	2.0	3
52	08-Dec-10	1	1	B	3.8	16:40	3	1.4	2
52	08-Dec-10	1	1	B	7.9	16:47	5	6.5	13
52	08-Dec-10	1	1	B	5.7	16:53	4	1.7	3
52	08-Dec-10	1	1	B	6.6	17:00	1	2.2	3
52	08-Dec-10	1	1	B	4.9	17:08	6	2.0	2
52	08-Dec-10	1	1	B	9.7	17:20	2	3.8	4
53	09-Dec-10	1	5	R4	21.8	8:00	2	0.0	0
53	09-Dec-10	1	5	R4	22.1	8:07	6	0.0	0
53	09-Dec-10	1	5	R4	21.4	8:15	1	0.0	0
53	09-Dec-10	1	5	R4	5.5	8:24	4	0.0	0
53	09-Dec-10	1	5	R4	4.6	8:31	5	0.0	0
53	09-Dec-10	1	5	R4	3.5	8:38	4	0.0	0
54	09-Dec-10	1	4	J	17.9	10:11	3	12.0	29
54	09-Dec-10	1	4	J	9.5	10:20	5	1.9	3
54	09-Dec-10	1	4	J	6.4	10:28	4	13.1	19
54	09-Dec-10	1	4	J	15.4	10:34	1	7.3	23
54	09-Dec-10	1	4	J	15.7	10:38	6	11.1	16
54	09-Dec-10	1	4	J	7.7	10:47	2	15.9	30
55	09-Dec-10	1	5	G	3.7	12:39	2	2.9	4
55	09-Dec-10	1	5	G	9.0	12:47	6	1.6	1
55	09-Dec-10	1	5	G	7.5	12:55	1	5.4	6
55	09-Dec-10	1	5	G	6.4	13:03	4	1.7	2
55	09-Dec-10	1	5	G	6.0	13:10	5	0.0	0
55	09-Dec-10	1	5	G	7.1	13:15	3	4.9	6
56	09-Dec-10	1	5	J	4.6	14:53	3	4.0	5
56	09-Dec-10	1	5	J	6.9	15:00	4	1.1	1
56	09-Dec-10	1	5	J	7.3	15:07	5	0.9	2
56	09-Dec-10	1	5	J	9.7	15:15	1	3.3	7

								Catch of blue cod	
Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	(kg)	Number
56	09-Dec-10	1	5	J	2.7	15:23	6	0.3	1
56	09-Dec-10	1	5	J	5.3	15:31	2	3.3	4
57	10-Dec-10	2	4	F	9.9	7:53	2	10.8	18
57	10-Dec-10	2	4	F	19.4	8:00	1	7.9	29
57	10-Dec-10	2	4	F	11.0	8:08	6	7.1	14
57	10-Dec-10	2	4	F	17.9	8:17	5	11.1	26
57	10-Dec-10	2	4	F	12.4	8:24	4	9.1	16
57	10-Dec-10	2	4	F	11.9	8:30	3	6.5	12
58	10-Dec-10	2	4	H	8.8	10:05	3	0.6	4
58	10-Dec-10	2	4	H	4.9	10:12	4	6.3	8
58	10-Dec-10	2	4	H	12.3	10:20	5	9.2	12
58	10-Dec-10	2	4	H	11.0	10:27	6	6.1	10
58	10-Dec-10	2	4	H	8.2	10:35	1	2.5	7
58	10-Dec-10	2	4	H	7.7	10:44	2	4.1	6
59	10-Dec-10	2	4	G	5.5	12:10	2	2.2	5
59	10-Dec-10	2	4	G	3.1	12:17	1	0.7	3
59	10-Dec-10	2	4	G	5.7	12:19	6	2.5	3
59	10-Dec-10	2	4	G	3.8	12:30	5	8.1	8
59	10-Dec-10	2	4	G	8.4	12:36	4	1.4	1
59	10-Dec-10	2	4	G	8.2	12:43	3	1.7	2
60	10-Dec-10	2	4	R7	17.7	14:27	3	0.0	0
60	10-Dec-10	2	4	R7	22.3	14:35	4	3.1	13
60	10-Dec-10	2	4	R7	23.2	14:42	5	3.4	10
60	10-Dec-10	2	4	R7	21.6	14:49	6	0.7	1
60	10-Dec-10	2	4	R7	18.1	14:57	1	0.0	0
60	10-Dec-10	2	4	R7	17.2	15:04	2	3.7	12
61	11-Dec-10	1	5	R5	9.9	8:53	2	0.0	0
61	11-Dec-10	1	5	R5	11.0	9:00	6	0.0	0
61	11-Dec-10	1	5	R5	10.2	9:07	1	0.0	0
61	11-Dec-10	1	5	R5	8.6	9:14	5	0.0	0
61	11-Dec-10	1	5	R5	6.6	9:23	4	1.2	1
61	11-Dec-10	1	5	R5	6.6	9:29	3	2.6	2
62	11-Dec-10	2	4	R8	24.7	11:22	3	0.0	0
62	11-Dec-10	2	4	R8	25.2	11:29	4	0.0	0
62	11-Dec-10	2	4	R8	29.4	11:37	5	0.0	0
62	11-Dec-10	2	4	R8	25.8	11:44	1	0.0	0
62	11-Dec-10	2	4	R8	28.0	11:53	6	0.0	0
62	11-Dec-10	2	4	R8	31.8	12:00	2	0.0	0
63	11-Dec-10	2	4	R9	28.0	13:24	2	0.0	0
63	11-Dec-10	2	4	R9	11.2	13:29	6	0.0	0
63	11-Dec-10	2	4	R9	14.6	13:34	1	0.0	0
63	11-Dec-10	2	4	R9	15.0	13:39	5	0.0	0
63	11-Dec-10	2	4	R9	9.9	13:46	4	0.0	0
63	11-Dec-10	2	4	R9	12.6	13:54	3	0.0	0
64	30-Nov-10	1	1	R5	19.8	16:27	3	0.0	0
64	30-Nov-10	1	1	R5	20.1	16:34	4	0.0	0
64	30-Nov-10	1	1	R5	21.0	16:42	5	0.5	1
64	30-Nov-10	1	1	R5	20.7	16:50	6	2.6	6

								Catch of blue cod	
Set	Date	Phase	Stratum	Site	Depth (m)	Time set	Pot	(kg)	Number
64	30-Nov-10	1	1	*R5*	*20.5*	17:00	*1*	*3.0*	*5*
64	30-Nov-10	1	1	*R5*	*20.5*	17:08	*2*	*1.4*	*2*

Appendix 6: Summary of the Paterson Inlet 2010 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 the Douglas classification 1 (low) to 3 (heavy), 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	Average 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	9	240	4	13.0	1035	3	1	5	0.0	999	3	1	13.0	12.5	22.0	3.4
2	16	240	5	13.3	1035	3	1	5	0.0	999	3	1	13.0	12.8	32.0	2.6
3	9	200	4	14.5	1036	6	1	5	0.0	999	3	1	13.5	13.1	24.0	4.8
4	21	240	4	14.4	1035	3	1	5	0.0	999	4	1	13.1	13.1	28.0	4.9
5	23	260	4	16.5	1028	4	1	5	0.0	999	3	1	12.6	13.1	23.0	4.6
6	14	240	4	16.4	1029	6	2	5	0.3	240	7	3	13.0	13.2	31.0	4.1
7	7	240	6	16.6	1028	7	2	5	0.1	240	3	2	13.3	13.3	48.0	3.5
8	9	240	5	17.5	1028	8	2	5	0.0	999	7	3	13.3	13.3	39.0	3.7
9	10	240	5	18.9	1027	8	2	5	0.0	999	7	3	13.5	13.5	32.0	4.1
10	6	260	3	15.5	1026	8	1	5	0.0	999	2	1	13.1	13.1	14.5	5.7
11	4	260	0	15.3	1026	8	1	5	0.0	999	7	2	13.1	13.1	0.0	8.3
12	26	260	1	16.4	1024	8	1	5	0.0	999	1	1	13.1	13.1	7.2	10.2
13	25	260	3	16.7	1023	8	1	5	0.0	999	1	1	13.1	13.1	14.0	10.5
14	26	270	4	14.5	1025	8	2	5	0.0	999	10	1	13.1	13.2	20.7	6.1
15	25	270	4	16.2	1025	5	2	7	0.0	999	10	1	13.1	13.2	27.5	6.2
16	35	270	4	17.0	1025	6	2	4	0.0	999	4	2	13.4	13.4	22.0	7.6
17	18	230	3	18.7	1024	6	2	4	0.0	999	2	1	13.8	13.8	18.3	3.4
18	16	100	1	14.2	1029	8	1	6	0.0	999	3	1	13.5	13.5	6.1	5.5
19	5	100	1	14.6	1029	8	1	6	0.0	999	3	1	13.5	13.5	5.5	5.3
20	7	050	2	16.8	1027	8	0	6	0.0	999	7	3	13.5	13.5	7.6	7.3
21	8	240	3	20.1	1026	3	3	6	0.5	240	7	4	13.5	13.5	17.6	6.4
22	11	240	4	19.9	1025	5	2	8	0.5	225	7	3	13.4	13.4	24.4	7.0
23	12	320	4	18.7	1021	2	2	6	0.0	999	7	4	13.5	13.5	23.1	8.0
24	14	270	4	23.4	1021	4	1	5	0.0	999	3	1	14.8	14.5	21.4	7.5
25	14	270	2	15.8	1030	3	1	6	0.0	999	4	1	14.0	14.0	12.3	8.0
26	7	270	4	16.1	1030	2	1	7	0.0	999	7	4	14.0	14.0	30.6	7.2
27	15	245	1	14.4	1035	8	1	4	0.0	999	3	3	13.4	13.5	4.2	8.0
28	10	245	1	16.8	1035	8	1	7	0.0	999	7	4	13.5	13.5	4.5	8.2
29	18	90	3	14.3	1034	7	1	4	0.0	999	3	1	14.0	13.9	14.2	6.3

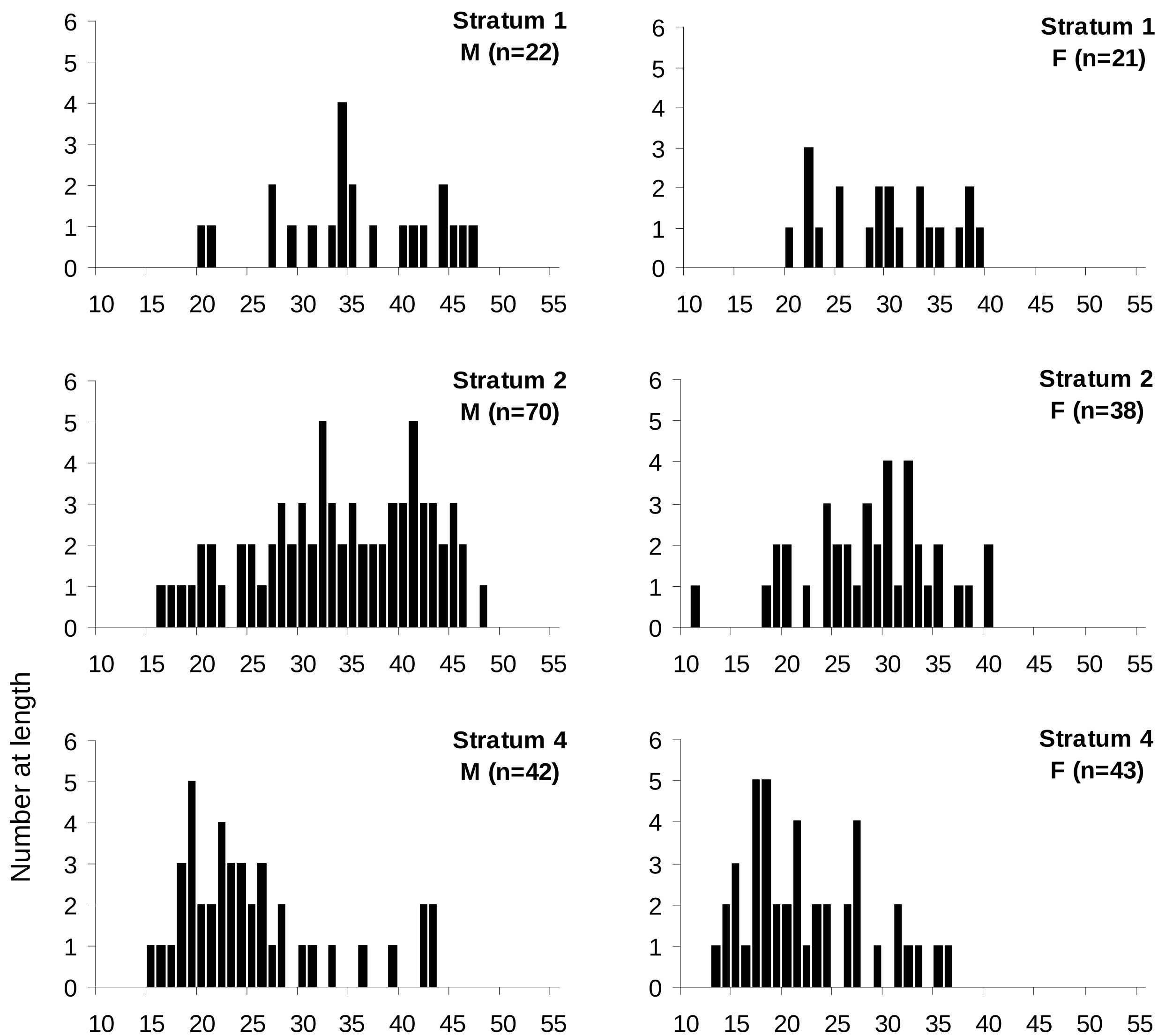
Appendix 6– *continued*

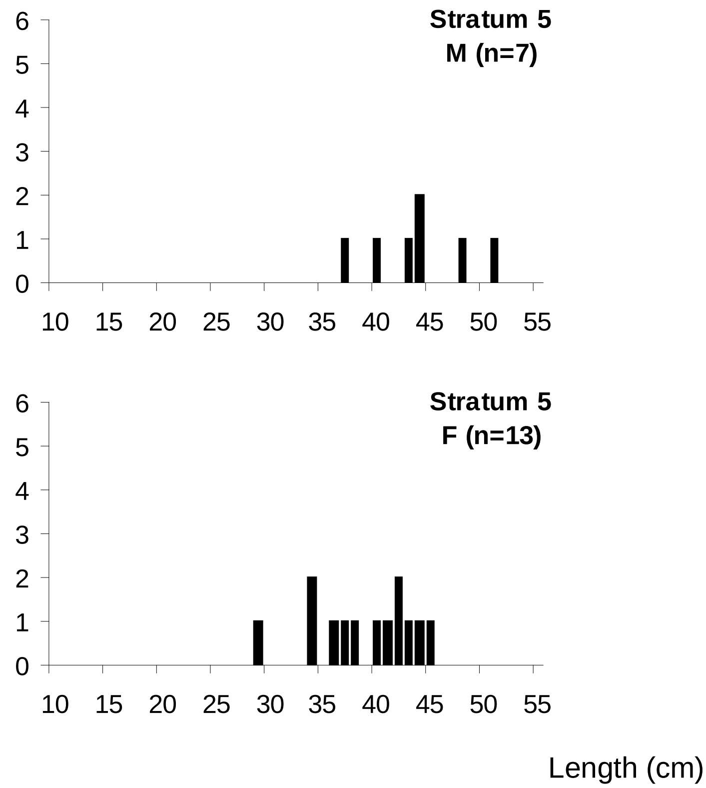
Set	Average Depth	Wind Direction	Wind Force	Air Temp	Air Pressure	Cloud Cover	Sea Condition	Sea Colour	Swell Height	Swell Direction	Bottom Type	Bottom Contour	Surface Temp	Bottom Temp	Wind Speed	Secchi Depth
30	7	250	2	13.7	1034	8	1	7	0.0	999	7	2	13.4	12.8	10.4	6.0
31	11	250	3	14.5	1034	8	1	7	0.0	999	7	2	13.4	12.8	15.5	6.0
32	24	245	0	16.7	1033	8	2	6	0.0	999	4	2	14.0	13.6	0.0	6.7
33	16	240	1	13.5	1030	6	2	6	0.3	315	7	5	13.5	13.5	5.9	7.4
34	11	240	4	15.5	1029	6	2	6	0.0	999	7	5	14.0	14.0	29.5	5.8
35	25	250	4	18.6	1025	2	1	5	0.0	999	2	1	14.0	14.5	27.3	8.9
36	12	250	4	18.5	1024	3	1	7	0.0	999	7	3	14.8	14.6	21.8	8.0
37	25	250	4	17.1	1022	6	1	5	0.0	999	2	2	14.4	14.0	22.0	8.6
38	8	315	1	16.6	1015	8	0	6	0.0	999	2	2	14.0	14.0	4.8	6.7
39	4	315	3	17.0	1014	7	1	6	0.0	999	7	3	14.0	14.0	17.5	7.7
40	11	270	3	19.1	1014	8	1	5	0.0	999	2	1	14.8	14.5	16.3	5.4
41	26	180	1	20.3	1013	8	1	6	0.0	999	3	1	14.4	14.2	2.8	7.1
42	19	220	4	10.9	1021	8	1	6	0.0	999	3	1	13.9	13.8	22.2	8.8
43	11	280	2	13.4	1021	7	1	7	0.0	999	7	4	14.0	13.8	7.7	8.2
44	11	30	1	14.2	1021	8	1	7	0.0	999	2	1	14.0	14.0	2.4	7.0
45	4	240	4	11.3	1027	5	2	6	0.0	999	7	3	13.5	13.6	24.0	7.4
46	16	240	4	12.7	1028	6	2	8	0.0	999	4	1	13.5	13.6	22.0	4.7
47	5	270	3	12.9	1028	6	1	7	0.0	999	7	3	13.8	13.8	14.8	7.0
48	25	210	4	12.1	1029	5	2	7	0.0	999	2	1	13.6	13.5	22.2	8.1
49	10	240	3	10.7	1034	7	1	6	0.0	999	3	2	13.5	13.5	14.4	9.1
50	16	240	3	11.6	1035	7	1	6	0.0	999	2	1	13.4	13.3	15.0	9.3
51	7	180	2	13.9	1034	3	1	6	0.0	999	7	3	14.0	13.6	11.7	8.5
52	6	180	2	13.7	1033	3	1	8	0.0	999	7	3	14.2	14.0	11.0	5.5
53	13	999	0	16.9	1029	0	0	6	0.0	999	2	2	14.0	14.0	0.0	9.0
54	12	60	3	13.0	1029	4	0	7	0.0	999	7	3	13.3	13.3	14.8	10.1
55	7	60	3	13.6	1028	5	1	7	0.0	999	7	3	14.2	14.0	14.4	8.6
56	6	75	3	13.5	1026	4	1	7	0.0	999	7	3	14.1	14.0	14.5	8.8
57	14	15	4	12.1	1012	8	2	5	0.5	999	7	4	13.1	13.2	20.2	7.8
58	9	0	3	13.4	1008	8	1	5	0.3	300	7	4	13.1	13.2	19.2	8.3
59	6	345	4	14.3	1006	8	2	6	0.0	999	7	4	13.7	13.5	21.5	8.5
60	20	330	0	15.6	1003	8	0	6	0.0	999	3	1	14.0	14.0	0.7	9.0

Appendix 6– *continued*

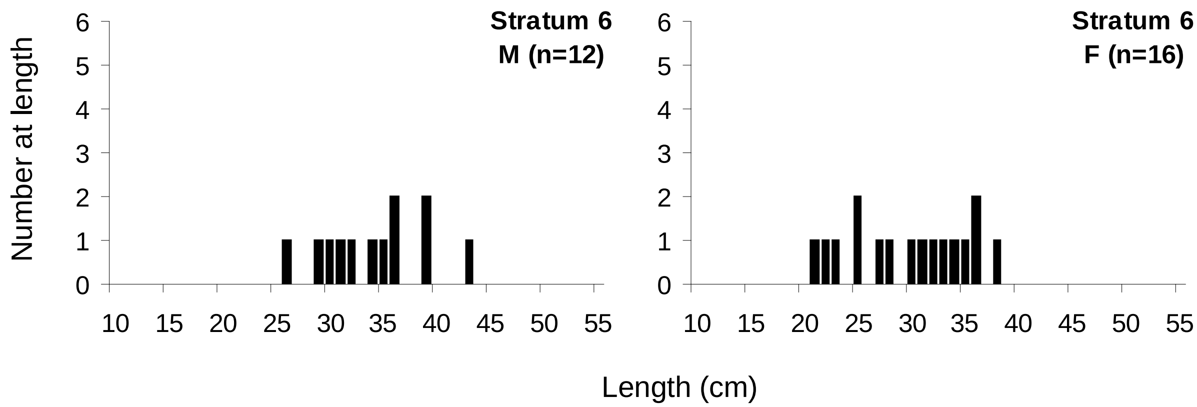
Set	Average Depth	Wind Direction	Wind Force	Air Temp	Air Pressure	Cloud Cover	Sea Condition	Sea Colour	Swell Height	Swell Direction	Bottom Type	Bottom Contour	Surface Temp	Bottom Temp	Wind Speed	Secchi Depth
61	9	210	2	12.8	1003	8	1	8	0.0	999	2	1	14.1	13.8	12.1	5.2
62	27	270	5	13.4	1005	8	3	6	0.0	999	4	2	13.6	13.5	32.0	7.2
63	15	270	5	15.3	1005	8	2	5	0.5	50	3	1	13.1	13.0	36.0	7.3
64	20	270	4	15.6	1031	2	1	8	0.0	999	3	1	14.0	13.7	24.0	7.8

Appendix 7: Unscaled length frequency distributions of blue cod for each stratum from which otoliths were used in the Paterson Inlet 2010 age length key.




Stratum 5
M (n=7)
6
5
4
3
2
1
0
10
15
20
25
30
35
40
45
50
55
Stratum 5
F (n=13)
6
5
4
3
2
1
0
10
15
20
25
30
35
40
45
50
55
Length (cm)

Appendix 7– *continued*



Appendix 8: Between-reader comparisons (using first independent readings only) for otolith data collected in Paterson Inlet 2010.

Reader two																Age class (reader one)					
difference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
-6																	1			1	2
-5																					0
-4															1	1					2
-3										1		1	1		1	1	2			2	9
-2						1				1	1	2	1	1						2	9
-1				1	2	2		1	1	1	2	4	1	6	3	2					26
0	1	9	27	19	20	13	17	23	17	12	12	13	9	6	3	2		1			204
1		4	6	3	5	3	1	1	1		1		1								26
2							1			1											2
3				1	1																2
																				5	5
Total	1	13	33	24	28	19	19	25	19	16	16	20	13	13	8	6	3	1	19	5	282
% agreement	100	69	82	79	71	68	89	92	89	75	75	65	69	46	38	33	0	100		0	72

Appendix 9: Independent reader comparisons with agreed age from otolith data collected in Paterson Inlet 2010.

Reader two																Agreed age class					
difference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
-6																				1	1
-5																					0
-4																					0
-3														1					1		2
-2						1						2	1	3	1	1					9
-1					1	2		1		2	1	1		1				1	1		11
0	1	9	32	25	22	14	20	26	18	14	16	14	13	9	5	2		1		2	243
1			1	1	4	1	1	2	1		1		1								13
2					1					1	1										3
Total	1	9	33	26	28	18	21	29	19	17	19	17	15	14	6	3	0	2	2	3	282
% agreement	100	100	97	96	79	78	95	90	95	82	84	82	87	64	83	67		50	0	67	86

Reader one																Agreed age class					
difference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
-3																					1
-2							1													1	0
-1			4	5	3	1	2	2													17
0	1	9	28	20	25	17	17	24	18	13	14	15	10	8	3	2		1			225
1			1	1			1	1	1	2	3	2	4	4	3	1					24
2								2		2	1		1	1				1	1		9
3											1			1					1	2	5
Total	1	9	33	26	28	18	20	29	19	17	19	17	15	14	6	3	0	2	2	2	281
% agreement	100	100	85	77	89	94	85	83	95	76	74	88	67	57	50	67		50	0	0	80

Appendix 10: The proportion of fish at age and length and the total number at length and at age for male blue cod sampled from the 2010 Paterson Inlet survey (age -length-key, ALK).

	Age (years)																									
Len (cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
15	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
16	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
17	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
18	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
19	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
20	0	0	0.8	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
21	0	0	0	0.8	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
22	0	0	0.2	0.6	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
23	0	0	0.33	0	0.33	0	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
24	0	0	0	0.4	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
25	0	0	0	0	0.75	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
26	0	0	0	0	0.4	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
27	0	0	0	0	0	0.6	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
28	0	0	0	0	0.4	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
29	0	0	0	0	0	0.25	0.5	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
30	0	0	0	0	0	0.2	0.2	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
31	0	0	0	0	0	0	0.2	0.6	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
32	0	0	0	0	0	0	0.17	0.33	0.17	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
33	0	0	0	0	0	0	0.2	0.2	0.4	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
34	0	0	0	0	0	0	0.14	0.43	0.14	0.14	0	0.14	0	0	0	0	0	0	0	0	0	0	0	0	0	7
35	0	0	0	0	0	0	0	0.33	0	0.33	0.17	0	0.17	0	0	0	0	0	0	0	0	0	0	0	0	6
36	0	0	0	0	0	0	0	0	0	0.4	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
37	0	0	0	0	0	0	0	0	0.25	0.25	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
38	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	2
39	0	0	0	0	0	0	0	0	0	0.33	0.33	0.17	0	0.17	0	0	0	0	0	0	0	0	0	0	0	6
40	0	0	0	0	0	0	0	0	0	0	0.4	0.2	0	0.4	0	0	0	0	0	0	0	0	0	0	0	5
41	0	0	0	0	0	0	0	0	0	0	0.17	0.5	0.33	0	0	0	0	0	0	0	0	0	0	0	0	6
42	0	0	0	0	0	0	0	0	0	0	0.33	0.33	0.17	0.17	0	0	0	0	0	0	0	0	0	0	0	6
43	0	0	0	0	0	0	0	0	0	0.14	0	0.43	0.29	0	0	0	0	0	0	0.14	0	0	0	0	0	7
44	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0.33	0.33	0	0	0	0	0	0	0	0	0	0	6
45	0	0	0	0	0	0	0	0	0	0	0.25	0	0.25	0.25	0.25	0	0	0	0	0	0	0	0	0	0	4
46	0	0	0	0	0	0	0	0	0	0	0	0.33	0	0	0	0.33	0	0.33	0	0	0	0	0	0	0	3
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	2
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Total	0	4	17	10	13	10	11	16	5	13	15	13	9	8	5	1	0	1	0	2	0	0	0	0	0	15

Appendix 11: The proportion of fish at age and length and the total number at length and at age for female blue cod sampled from the 2010 Paterson Inlet survey (age -length-key, ALK).

	Age (years)																									
Len (cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
13	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
14	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
15	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
16	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
17	0	0.2	0.6	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
18	0	0	0.83	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
19	0	0	0.75	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
20	0	0	0.25	0.5	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
21	0	0	0	0.6	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
22	0	0	0.17	0.5	0.17	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
23	0	0	0	0.75	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
24	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
25	0	0	0	0.17	0.33	0.33	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
26	0	0	0	0.25	0.5	0	0	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
27	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
28	0	0	0	0	0.2	0.4	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
29	0	0	0	0	0	0	0.5	0.33	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
30	0	0	0	0	0	0	0.33	0	0.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
31	0	0	0	0	0	0	0	0.6	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
32	0	0	0	0	0	0	0	0.5	0.33	0	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
33	0	0	0	0	0	0	0	0.17	0.33	0.33	0	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	6
34	0	0	0	0	0	0	0	0.2	0.4	0.2	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	5
35	0	0	0	0	0	0	0	0.2	0.2	0.2	0	0	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	5
36	0	0	0	0	0	0	0	0	0	0	0.5	0.25	0.25	0	0	0	0	0	0	0	0	0	0	0	0	4
37	0	0	0	0	0	0	0	0	0	0	0	0.33	0	0.67	0	0	0	0	0	0	0	0	0	0	0	3
38	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	5
39	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
40	0	0	0	0	0	0	0	0	0	0	0.33	0	0.33	0.33	0	0	0	0	0	0	0	0	0	0	0	3
41	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0.5	0	0	0	0	0	0	2
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Total	1	5	16	16	15	8	10	13	14	4	4	4	6	6	1	2	0	1	2	0	0	0	0	0	1	129

Appendix 12: Mean age-at-length for the 2010 Paterson Inlet survey.

	Males		Females		All fish	
Length (cm)	N	Mean age	N	Mean age	N	Mean age
11	0	0.0	1	1.0	1	1.0
13	0	0.0	1	2.0	1	2.0
14	0	0.0	2	2.0	2	2.0
15	1	2.0	3	3.0	4	2.8
16	2	2.0	1	2.0	3	2.0
17	2	2.5	5	3.0	7	2.9
18	4	3.0	6	3.2	10	3.1
19	6	3.0	4	3.3	10	3.1
20	5	3.2	4	4.0	9	3.6
21	5	4.2	5	4.4	10	4.3
22	5	4.0	6	4.3	11	4.2
23	3	5.0	4	4.3	7	4.6
24	5	4.6	5	5.0	10	4.8
25	4	5.3	6	5.5	10	5.4
26	5	5.6	4	5.5	9	5.6
27	5	6.4	6	6.5	11	6.5
28	5	6.2	5	6.4	10	6.3
29	4	7.0	6	7.7	10	7.4
30	5	7.4	6	8.3	11	7.9
31	5	8.2	5	8.4	10	8.3
32	6	8.7	6	8.8	12	8.8
33	5	8.6	6	9.7	11	9.2
34	7	8.9	5	9.6	12	9.2
35	6	10.0	5	10.8	11	10.4
36	5	10.6	4	11.8	9	11.1
37	4	10.3	3	13.3	7	11.6
38	2	11.5	5	14.2	7	13.4
39	6	11.3	1	14.0	7	11.7
40	5	12.4	3	12.7	8	12.5
41	6	12.2	1	13.0	7	12.3
42	6	12.2	2	17.5	8	13.5
43	7	13.1	1	19.0	8	13.9
44	6	14.0	1	18.0	7	14.6
45	4	13.3	1	25.0	5	15.6
46	3	15.3	0	0.0	3	15.3
47	1	15.0	0	0.0	1	15.0
48	2	14.5	0	0.0	2	14.5
51	1	20.0	0	0.0	1	20.0
Total	153	8.5	129	7.5	282	8.1

Appendix 13: Parameter values used in the 2010 Patterson Inlet SPR analyses.

	Males				Females			
Age	Length (cm)	Weight (kg)	Selectivity	Maturity	Length (cm)	Weight (kg)	Selectivity	Maturity
1	12.1	0.022	0	0	11.0	0.016	0	0
2	15.6	0.049	0	0	14.7	0.041	0	0
3	18.9	0.091	0	0	18.1	0.080	0	0
4	22.0	0.146	0	0.1	21.1	0.132	0	0.1
5	24.8	0.215	0	0.4	23.8	0.196	0	0.4
6	27.4	0.298	0	0.7	26.2	0.268	0	0.7
7	29.9	0.392	0	1	28.4	0.347	0	1
8	32.2	0.496	0	1	30.3	0.430	0	1
9	34.3	0.610	1	1	32.1	0.516	0	1
10	36.3	0.730	1	1	33.6	0.602	1	1
11	38.2	0.857	1	1	35.1	0.687	1	1
12	39.9	0.987	1	1	36.3	0.771	1	1
13	41.5	1.121	1	1	37.4	0.852	1	1
14	43.1	1.256	1	1	38.5	0.929	1	1
15	44.5	1.391	1	1	39.4	1.002	1	1
16	45.8	1.527	1	1	40.2	1.071	1	1
17	47.0	1.661	1	1	40.9	1.136	1	1
18	48.1	1.793	1	1	41.6	1.196	1	1
19	49.2	1.922	1	1	42.2	1.252	1	1
20	50.2	2.048	1	1	42.7	1.304	1	1
21–50	from growth curve	from growth curve	1	1	from growth curve	from growth curve	1	1