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Relative abundance, size and age structure, and stock status of blue cod in Paterson Inlet in 2018

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EXECUTIVE SUMMARY

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This report describes the results of the random-site blue cod (*Parapercis colias*) potting survey carried out in Paterson Inlet in November 2018. Estimates are provided for population abundance, size and age structure, sex ratio, total mortality, and spawner biomass-per-recruit ratio. This is the third random-site survey in the time series, following those in 2010 and 2014. The random-site survey design has now replaced fixed-site surveys previously carried out in 2006, 2010, and 2014.

Forty-one random sites (6 pots per site, producing 246 pot lifts) at depths of 3.5–28.0 m from five strata in Paterson Inlet were surveyed in November 2018. Seven of these sites were inside the Ulva Island Marine Reserve. Mean catch rates of blue cod (all sizes) by stratum were 0.59–2.73 kg pot^{-1} with the lowest catch in stratum 5 (Big Glory Bay) and highest in strata 2 and 3 (north of Ulva Island and the Ulva Island Marine Reserve). The all-blue-cod overall survey catch rate, excluding the marine reserve, was 1.51 kg pot^{-1} with a CV of 17.7%. Catch rates for recruited blue cod (33 cm and over) followed a similar pattern among strata as for all blue cod, and the overall survey catch rate, excluding the marine reserve, was 0.72 kg pot^{-1} (CV 21.0%). Of the 204 random-site pots set outside the marine reserve 48.5% had zero catch of blue cod and within the marine reserve 21.4% had zero catch of blue cod.

Outside the marine reserve the sex ratios were 33–71% male across the four strata and the overall weighted sex ratio was 67% male. The overall weighted mean length for males was 29.6 cm (range 14–45 cm) and 27.2 cm for females (range 15–47 cm). The all-strata survey scaled length frequency distributions were generally unimodal with indications of a small juvenile mode for both sexes. Inside the marine reserve only three fish were sexed, and all were released alive. Length was 12–43 cm and the mean length was 26.2 cm for unsexed fish. The scaled length frequency distribution was unimodal with indications of a small adult mode.

Age in 2018 ranged from 2 to 16 years for males and 2 to 25 years for females, but most blue cod were 3–7 years old. The estimated population age distributions indicated that blue cod were partially selected to the potting method at 2 years and fully selected at 4 to 5 years of age. There were indications of a strong 7-year-old age class for both males and females. Mean age was 5.3 years for males and 6.1 years for females. Nearly half the males were in a running ripe spawning condition whereas females were mostly resting and maturing.

Total mortality (Z) for age-at-full recruitment of eight years was estimated at 0.25 (95% confidence interval 0.17–0.36). Based on the default M of 0.17, estimated fishing mortality (F) was 0.08 and the associated spawner biomass-per-recruit ratio (SPR) was 68% (95% confidence interval 49–100%). The traditional catch curve did not follow the ideal straight-line descending limb, suggesting that the assumption of constant recruitment had been violated. The point estimates of Z, F, and SPR in 2018 should therefore be treated with caution.

Neither the fixed or random-site survey time series show any clear indications of a change in relative abundance, size or sex ratio, although there was a large increase between 2010 and 2014 for the random site series. More random-site surveys are required before trends can be correctly identified.

Of the three random-site surveys, abundance was highest in the marine reserve stratum only once for all blue cod and not at all for recruited blue cod. Inside the marine reserve there were fewer pots with zero catch, however, blue cod were smaller overall.

1. INTRODUCTION

This report describes the random-site potting survey of blue cod (*Parapercis colias*) relative abundance, population length/age structure, and stock status in Paterson Inlet in November 2018. This is the fourth survey in Paterson Inlet with previous surveys in 2006, 2010, and 2014 (Carbines 2007, Carbines & Haist 2014, 2018a). The 2006 survey was a fixed-site survey design, 2010 and 2014 were dual fixed- and random-site surveys, and 2018 was a solely random-site survey.

1.1 Blue cod recreational fishery

Blue cod is the third most common recreational species caught in New Zealand with a total catch of 292 t (nearly 600 000 fish) estimated during the 2017–18 panel survey involving face to face interviews with fishers (Wynne–Jones et al. 2019). Blue cod were virtually all taken by rod and line, mainly from trailer motor boat and to a lesser extent by larger boat/launch. Of the total 292 t, 80% were caught from the South Island where blue cod is the most frequently targeted and landed finfish, by recreational fishers. Blue cod can be caught from a few metres depth to 150 m in a range of habitats including reef edges, shingle/gravel, biogenic reefs, or sandy bottoms close to rocky outcrops.

Quota Management Area BCO 5 extends from Slope Point in Southland to Awarua Point in Fiordland (Figure 1). The 2017–18 panel survey estimated BCO 5 recreational annual take at 67 t, accounting for 23% of the total national recreational blue cod catch (Wynne–Jones et al. 2019). The most common bag size in BCO 5 was 2–3 blue cod with half of all bag-sizes less than 6 blue cod. The recreational catch was spread across BCO 5 with 38% from Slope Point to Te Waewae Bay, 33% from Stewart Island and Foveaux Strait, 19% from Fiordland, and 10% from Paterson Inlet (unpublished data from 2017–18 panel survey, pers. comm. Bruce Hartill). Within Fiordland, a 2006–08 recreational fishing survey indicated that effort was centred on Dusky and Doubtful Sounds, and off Preservation Inlet (Davey & Hartill 2008). A recreational survey of Paterson Inlet from 1993–94 to 1997–98 indicated that blue cod was the most targeted and caught species, with most effort focused in the outer inlet around Ulva Island and the Neck (Carbines 1998a).

1.2 Paterson Inlet location

Paterson Inlet/Whaka a Te Wera is a sheltered natural harbour extending inland for more than 25 km on the east coast of Stewart Island/Rakiura, just south of the Oban township (Figure 2). It is shallow with depths mostly between 10 and 30 m and about 45 m at its deepest, with substrates that include rocky reef, sand, and soft mud bottom. Features of the inlet include the many small islands, most notably Ulva Island and Native Island, the long narrow neck that guards the entrance, the South West and North Arms, and Big Glory Bay (an important aquaculture site for salmon farms, and recently for farmed Bluff oysters before the *Bonamia ostreae* outbreak). The entire inlet is encircled in steep hillsides covered in virgin native forest and is fed by many freshwater streams and rivers, the largest of which are the Freshwater River and Rakeahua River.

Paterson Inlet is a key area for blue cod recreational fishing around Stewart Island (Carbines 1998a, James et al. 2004). Commercial fishing was banned in Paterson Inlet in 1992 and two years later the recreational daily blue cod bag limit was reduced from 30 to 15 per person and in 1993 the minimum legal size (MLS) was increased from 30 to 33 cm. In 2004 the entire Paterson Inlet, excluding Big Glory Bay, became a mātaitai known as Te Whaka a Te Wera Mātaitai Reserve, and the Ulva Island Marine Reserve was established (Te Wharawhara Marine Reserve). The daily bag limit was further reduced to 10 blue cod per person in 2006.

1.3 South Island blue cod potting surveys

South Island recreational blue cod fisheries are monitored using potting surveys. These surveys take place predominantly in areas where blue cod recreational fishing is common, but in some areas there is substantial overlap between the commercial and recreational fishing grounds. Surveys are generally carried out every four years and provide data that can be used to monitor local relative abundance, size, age, and sex structure of geographically separate blue cod populations. The surveys provide a measure of the response of populations to changes in fishing pressure and management initiatives such as changes to the daily bag limit, minimum legal size, and area closures. Fishing mortality and the associated spawner-per-recruit ratio (SPR) (Maximum Sustainable Yield related proxy) are used to investigate the status of blue cod stocks. The recommended Harvest Strategy Standard SPR target reference point for blue cod (a low productivity stock) is $F_{45\%SPR}$ (Ministry of Fisheries 2011); i.e., target fishing mortality should be at or below a level that reduces the spawner biomass to 45% of that if there was no fishing.

In addition to Paterson Inlet, there are currently eight other South Island areas supporting key recreational fisheries that are surveyed by Fisheries New Zealand: Kaikōura (Carbines & Beentjes 2006a, 2009, Beentjes & Page 2017, 2018, Carbines & Haist 2018d); Motunau (Carbines & Beentjes 2006a, 2009, Beentjes & Sutton 2017, Carbines & Haist 2018d); Banks Peninsula (Beentjes & Carbines 2003, 2006, 2009, Beentjes & Fenwick 2017, Carbines & Haist 2017b); north Otago (Carbines & Beentjes 2006b, 2011, Carbines & Haist 2018b, Beentjes & Fenwick 2019a); south Otago (Beentjes & Carbines 2011, Carbines & Haist 2018c, Beentjes & Fenwick 2019b); Foveaux Strait (Carbines & Beentjes 2012, Carbines & Haist 2017a, Beentjes et al. 2019); Dusky Sound (Carbines & Beentjes 2006a, 2009, Beentjes & Page 2016); and the Marlborough Sounds (Blackwell 1997, 1998, 2002, 2006, 2008, Beentjes & Carbines 2012, Beentjes et al. 2017, Beentjes et al. 2018).

1.4 Potting survey design

All South Island potting surveys, except Foveaux Strait, originally used a fixed site design, with predetermined (fixed) locations randomly selected from a limited pool of such sites (Beentjes & Francis 2011). The South Island potting surveys were reviewed by an international expert panel in 2009, which recommended that blue cod would be more reliably surveyed using random-site potting surveys (Stephenson et al. 2009). Following this recommendation, all survey series began the transition to fully random survey designs with interim sampling of both fixed and random sites allowing comparison of catch rates, length and age composition, and sex ratios between the survey designs. Random sites were the only site type used in all the Foveaux Strait surveys, and all other surveys, except Dusky Sound, have now transitioned to solely random-site surveys.

1.5 Objectives

This is the final reporting requirement for Fisheries New Zealand research project BCO2018-02.

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, age structure by sex, and sex ratio.
2. To analyse biological samples collected from this potting survey.
3. To determine stock status of blue cod populations in this area and compare this with other survey areas.
4. To determine F_{msy} proxies for Paterson Inlet blue cod.

2. METHODS

In this report, all terms are defined in the blue cod potting survey standards and specifications (Beentjes 2019) (Appendix 1).

2.1 2018 survey timing and area

A random-site potting survey of Paterson Inlet Strait was carried out by NIWA from 12–23 November 2018. The survey was consistent with dates of the three previous surveys.

The survey area for the 2018 Paterson Inlet random-site survey (Figure 3) was identical to the 2014 survey. There are five strata; strata 1, 2, and 4 fall within the mātaitai area, stratum 3 is identical to the Ulva Island Marine Reserve, and stratum 5 encompasses all of Big Glory Bay. In 2010 stratum 5 was subdivided into two strata, but these were combined again in 2014. Each stratum was assumed to contain roughly random distributions of blue cod habitat and the total area (km^2) within each stratum was taken as a proxy for available habitat for blue cod.

2.2 2018 survey design

2.2.1 Allocation of sites

Simulations to determine the optimal allocation of random sites among the five strata were carried out using catch rate data from the 2010 and 2014 random-site surveys and the National Institute of Water and Atmospheric Research (NIWA) Optimal Station Allocation Program (*allocate*). The 2010 survey sites in the two Big Glory Bay strata were all assigned to stratum 5. Simulations were constrained to have a minimum of three sites per stratum and a CV (coefficient of variation) of no greater than 15%. The simulations indicated that 41 random sites were required to achieve the target CV of 15%.

The 2018 survey used a two-phase stratified random station design (Francis 1984) with 37 sites allocated to phase 1 and the remaining four available for phase 2, consistent with the proportion of phase 2 sites used in previous surveys (Table 1). Allocation of phase 2 stations was based on the mean pot catch rate (kg pot^{-1}) of all blue cod per stratum and optimised using the "area mean squared" method of Francis (1984). In this way, stations were assigned iteratively to the stratum in which the expected gain is greatest, where expected gain is given by:

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

where for the ith stratum $mean_i$ is the mean catch rate of blue cod per pot, $area_i$ is the fishable stratum 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.

A random site has a location (single latitude and longitude) generated randomly within a stratum (Beentjes 2019). Sufficient sites to cover both first and second phase stations were generated for each stratum using the NIWA Random Station Generator Program (*Rand_stn* v1.00-2014-07-21) with the constraint that sites were at least 800 m apart. From this list, the allocated number of random sites per stratum to be surveyed was selected in the order they were generated.

Pot configuration and placement for random sites is defined in the blue cod potting manual (Beentjes 2019). Random-site surveys used systematic pot placement where the position of each pot was arranged systematically with the first pot set 200 m to the north of the site location and remaining pots set in a hexagon pattern around the site, at about 200 m from the site position. Where the site was located too near the coast to allow a hexagon configuration to be achieved, pots were set systematically along the coast around the site position.

2.2.2 Vessels and gear

The Stewart Island-based vessel F.V. *Provider* (Vessel registration 900807) was used on the 2018 Paterson Inlet survey. The *Provider* is a 17-m fibreglass over plywood monohull boat, equipped with Cummins diesel engines rated at 1375 kw. The *Provider* was skippered by Brett Hamilton, who has considerable experience in commercial blue cod potting and was the skipper on the 2014 Paterson Inlet blue cod survey using the F.V. *Francis*.

Six custom designed and built cod pots were used to conduct the survey (Pot Plan 2 in Beentjes 2019). Pots were baited with 700 g pāua (*Haliotis iris*) viscera in "snifter pottles". Bait was topped up after every lift. The same pot design and bait type were used in all previous surveys.

A high-performance, 3-axis (3D) acoustic Doppler current profiler (ADCP, RDI Instruments, 600 kHz) was initially deployed at each site. The ADCP records current flow and direction in 1-m depth bins above the seafloor as well as bottom water temperature.

2.2.3 Sampling methods

All sampling methods adhered strictly to the blue cod potting survey standards and specifications (Beentjes 2019).

At each site, six pots were set and left to fish (soak) for a target period of one hour during daylight hours. As each pot was placed, a record was made of sequential pot number (1 to 6), latitude and longitude from GPS, depth, and time of day. After each site was completed, the next closest site in the stratum was sampled. The ADCP was deployed at the centre of each site prior to the setting of pots and recovered after the last pot of each set was lifted. The order that strata were surveyed depended on the prevailing weather conditions, with the most distant strata and/or exposed sites sampled in calm weather. Because of biosecurity concerns regarding *Bonamia ostreae*, the last phase 1 sites sampled were those in stratum 5 (Big Glory Bay). All pots and fishing gear were decontaminated with bleach before and after being used in Big Glory Bay.

Pots were lifted aboard using the vessel's hydraulic pot lifter in the order they were set, and the time of each lift was recorded. Pots were then emptied and the contents sorted by species. Total catch weight per pot was recorded for each species to the nearest 10 g using 0–6/6–15 kg Marel motion compensating scales. The number of individuals of each species per pot was also recorded. Total length to the nearest centimetre below actual length, individual fish weight to the nearest 10 g, sex, and gonad maturity were recorded for all blue cod except those in the Ulva Island Marine Reserve (stratum 3) which were all returned alive (see below). Sagittal otoliths were removed from a representative length range of blue cod males and females over the available length range across all strata. To ensure that otolith collection was spread across the survey area, the following collection schedule was used – collect three otoliths per 1 cm size class for each sex in strata 1 and 2 combined, and strata 4 and 5 combined (Appendix 2). Sex and maturity were determined by dissection and macroscopic examination of the gonads (Carbines 1998b, 2004).

Blue cod gonad staging was undertaken using the five stage Stock Monitoring (SM) method used on previous surveys. Gonads were recorded as follows: 1, immature 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.

2.2.4 Ulva Island Marine Reserve survey

Pot placement and sampling of blue cod in the Ulva Island Marine Reserve was carried out using the standard random site methodology described above. Pots were cleaned with freshwater, dried, and cleaned of any fouling organisms prior to being deployed in the marine reserve. After hauling, blue cod were transferred directly from pots into bins with circulating water. Numbers and catch weights were recorded for bycatch species, and length for blue cod. Sex was only determined if milt or eggs were observed when the fish was gently squeezed. To reduce potential blue cod mortality, catch weight per pot and individual fish weight were not always recorded in each set, but instead were estimated from the length-weight relationship obtained from blue cod that were weighed from the survey. All blue cod and bycatch species were then returned alive by gently lowering the fish inside a plastic crate to the water.

Jennifer Ross (Department of Conservation) joined the vessel to assist on the Ulva Island survey for a day. All sampling within the reserve was permitted under a Department of Conservation Special Permit issued to NIWA (Authorisation to undertake specified scientific study within a marine reserve, Authorisation number 69334).

2.2.5 Data storage

The 2018 Paterson Inlet survey trip code was PRO1802. At the completion of the survey, trip, station, catch, and biological data were entered into the *trawl* database in accordance with the business rules and the blue cod potting survey standards and specifications (Beentjes 2019). All catch rate, length, and sex-based analyses were from data extracted from the *trawl* database. Catch-at-age analyses were based on the ageing results provided by the otolith readers, and at the completion of the catch-at-age analyses, after any possible errors in the age and length data were identified and corrected, age data were entered into the *age* database. Random sites were entered into attribute *stn_code*, prefixed with R (e.g., R1A, R2B). Random-site locations were also entered into *trawl* table *t_site*. Pot locations were entered in table *t_station* in attribute *station_no* (concatenating set number and pot number, e.g., 11 to 16, or 31 to 36 etc.). In the *age* database the *sample_no* is equivalent to *station_no* in the *trawl* database.

ADCP data were sent to the Research Database Manager (Fisheries New Zealand) in spreadsheet format.

2.2.6 Otolith preparation and reading

Preparation and reading of otoliths followed the methods of the blue cod age determination protocol (ADP) (Walsh 2017).

1. Blue cod otolith thin-section preparations were made as follows: otoliths were individually marked on their distal faces with a dot in the centrum using a cold light source on low power to light the otolith from behind. Five otoliths (from five different fish) were then embedded in an epoxy resin mould and cured at 50 ºC. Thin sections were taken along the otolith dorso-ventral axis through the centrum of all five otoliths, using a Struers Accutom-50 digital sectioning machine, with a section thickness of approximately 350 µm. Resulting thin section wafers were cleaned and embedded on microscope slides using epoxy resin and covered with a coverslip. Finally, these slides were oven cured at 50ºC.
2. Otolith sections were read against a black background using reflected light under a compound microscope at a magnification of 40–100 times. Under reflected light opaque zones appear light and translucent zones dark. Translucent zones were counted (ageing of blue cod otolith thin sections prior to 2015 counted opaque zones to estimate age).
3. Two readers read all otoliths without reference to fish length.
4. When interpreting blue cod zone counts, both ventral and dorsal sides of the otolith were read, mainly from the core toward the proximal surface close to the sulcus.
5. The forced margin method was used: ‘Wide’ (a moderate to wide translucent zone present on the margin), October–February; ‘Line’ (an opaque zone in the process of being laid down or fully formed on the margin), March–April; ‘Narrow’ (a narrow to moderate translucent zone present on the margin), May–September.
6. Where between-reader counts differed, the readers rechecked the count and conferred until agreement was reached, unless the section was a grade 5 (unreadable) or damaged (removed from the collection).
7. Between-reader ageing precision was assessed by the application of the methods and graphical techniques documented in Campana et al. (1995) and Campana (2001); including APE (average percent error) and CV.

2.2.7 Data analyses

Analyses of catch rates, sex ratios, scaled length distribution, catch-at-age, total mortality (*Z*) estimates, and spawner-per-recruit were carried out and are presented for the 2018 Paterson Inlet random-site survey. Analyses of catch rates and coefficients of variation (CV), length-weight parameters, scaled length and age frequencies and CVs, sex ratios, mean length, and mean age, were carried out using the equations documented in the blue cod potting survey standards and specifications (Beentjes 2019). Fish length was recorded to the nearest millimetre on the survey, but following standard protocol, all lengths were rounded down to the nearest centimetre for analyses of the scaled length distribution and mean length (i.e., using data extracted from t_lgth in the *trawl* database). For the Ulva Island Marine Reserve, analyses were limited to catch rate and scaled length frequencies and catch-at-age, and Z estimates were not carried out because the age and growth data collected from outside the marine reserve may not be representative of that inside the marine reserve.

2.2.7.1 Catch rates

The catch rate (kg pot^{-1}) estimates were pot-based and the CV estimates were set-based (Beentjes & Francis 2011). Catch rates and 95% confidence intervals (± 1.96 standard error) were estimated for all blue cod and for recruited blue cod (33 cm and over). Catch rates of recruited blue cod were based on the sum of the weights of individual recruited fish. The stratum areas (km^2) given in Table 1 were used as the area of the stratum (A_t) when scaling catch rates (equations 3 and 5 in Beentjes 2019). Catch rates are presented by stratum and overall. Catch rates were estimated for individual strata and for all strata combined and excluding the marine reserve.

2.2.7.2 Length-weight parameters

The length-weight parameters a_k, b_k from the 2018 Paterson Inlet survey were used in the following equation:

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

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

2.2.7.3 Growth parameters

Separate von Bertalanffy growth models (von Bertalanffy 1938) were fitted to the 2018 Paterson Inlet survey length-age data by sex as follows:

$$L_t = L_\infty(1 - \exp^{-K[t - t_0]})$$

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

2.2.7.4 Scaled length and age frequencies

Length and age compositions were estimated using the NIWA program Catch-at-Age (Bull & Dunn 2002). The program scales the length frequency data by the area of the stratum, number of sets in each stratum, and estimated catch weight determined from the length-weight relationship of individual fish. The latter scaling should be negligible or very close to one if all fish caught during the survey were measured (which they were) and if the actual weight of the catch is close to the estimated weight of the catch. The stratum area given in Table 1 was taken as the area of the stratum (A_t), and the length-weight parameter estimates are from the 2018 Paterson Inlet survey data for males and females separately.

Length and age frequencies were calculated as numbers of fish from equations 7, 8, and 9 of Beentjes (2019). The length and age frequencies in this report are expressed as proportions by dividing by total numbers.

Bootstrap resampling (300 bootstraps) was used to calculate CV for proportions and numbers-at-length and age using equation 12 of Beentjes (2019). That is, simulated data sets were created by resampling (with replacement) sets from each stratum, and fish from each set (for length and sex information); fish from the age-length-sex data were used to construct the age-length key.

Catch-at-age was estimated using an age-length-key (ALK) for each sex applied to the length data from the entire survey area. Scaled length frequency and age frequency proportions are presented, together with CVs for each length and age class, and the mean-weighted coefficients of variation (MWCV).

2.2.7.5 Unsexed fish

All blue cod outside the marine reserve were sexed, whereas all but three blue cod inside the marine reserve were unsexed during the 2018 Paterson Inlet survey. The unsexed fish in the marine reserve were not used in estimating age composition or total mortality (Z), but were used to show the total scaled length frequency.

2.2.7.6 Sex ratios, and mean length and age

Sex ratios (expressed as percentage male) and mean lengths, for the stratum and survey, were calculated using equations 10 and 11 of Beentjes (2019) from the stratum or survey scaled length frequency distribution (LFs). Mean ages were calculated analogously from the scaled age frequencies. Sex ratios were also estimated for recruited blue cod (33 cm and over), and overall survey 95% confidence intervals around sex ratios were generated from the 300 LF bootstraps.

2.2.7.7 Total mortality estimates

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

Estimates of CR total mortality, Z, were calculated for age-at-recruitment values of 5 to 10 y using the maximum-likelihood estimator (equation 13 of Beentjes (2019)). Variance (95% confidence intervals) associated with Z was estimated under three different parameters of recruitment, ageing error, and Z estimate error (equations 14 to 18 of Beentjes (2019)). Catch-at-age distributions were estimated separately for males and females and then combined before the CR analysis, hence providing a single Z estimate for the population.

A traditional catch curve was also plotted from the natural log of catch (numbers) against age and a regression line fitted to the descending curve from age-at-full recruitment. Although the Z estimate from the traditional catch curve was not used in further analyses, it provides a diagnostic for the CR estimate of Z. This is useful in situations where there are not many age classes, and so there is potential for strong or weak year classes to introduce bias.

2.2.7.8 Spawner-per-recruit estimates

A spawner-per-recruit analysis for the 2018 Paterson Inlet survey was conducted using CASAL (Bull et al. 2005). The calculations involved simulating fishing with constant fishing mortality (F), and estimating the equilibrium spawning biomass per recruit (SPR) associated with that value of F (Beentjes

& Francis 2011). The %SPR for that F is then simply that SPR, expressed as a percentage of the equilibrium SPR when there is no fishing (i.e., when $F = 0$ and %SPR =100%).

Input parameters used in SPR analyses

Growth parameters — von Bertalanffy growth parameters and length-weight coefficients were from the 2018 Paterson Inlet survey:

Parameter	Males	Females
$K\ (yr^{-1})$	0.210	0.200
$t_0\ (yr)$	0.215	-0.431
$L_\infty\ (cm)$	46.84	39.96
a	0.006975	0.005265
b	3.1951	3.2907

Natural mortality — default assumed to be 0.17 (revised from 0.14 in 2019, see Beentjes 2019). Sensitivity analyses were carried out for M values 20% above and below the default (0.14 and 0.20).

Maturity — the following maturity ogive was used: 0, 0, 0, 0.1, 0.4, 0.7, and 1; where 10% of blue cod are mature at 4 years old and all are mature at 7 years.

Selectivity — selectivity to the fishery (recreational/commercial) is described as knife-edge equal to age-at-MLS calculated from the 2018 Paterson Inlet survey von Bertalanffy model. The Paterson Inlet recreational MLS is 33 cm and selectivity was 6.0 years for males and 8.3 years for females.

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

Maximum age — assumed to be 31 years.

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

The SPR estimates are based on age at recruitment equal to the MLS for females, 8 years in this case.

2.3 Analyses of 2006, 2010, and 2014 Paterson Inlet surveys

The 2006 and 2010 Paterson Inlet surveys (trip_codes GOL0601, WEX1001) were re-analysed for this report to ensure consistency and compliance with the analytical methods in the revised potting manual (Beentjes 2019). All analyses used survey data extracted from the Fisheries New Zealand *trawl* database. Catch rates of recruited blue cod were based on sum of the weights of individual fish 33 cm and over, estimated from the respective 2006 and 2010 survey's published length-weight coefficients (Carbines 2007, Carbines & Haist 2014). The catch rates for the 2014 survey (FRA1402) were taken from the published report (Carbines & Haist 2018a). For all three surveys the length data were extracted from the *trawl* database and scaled length compositions were estimated using the NIWA program Catch-at-Age (Bull & Dunn 2002) as described above for the 2018 survey.

3. RESULTS

3.1 2018 random-site survey

Forty-one random sites (6 pots per site, producing 246 pot lifts) from five strata in Paterson Inlet were surveyed from 12–23 November 2018 (Table 1, Figure 3). Depths sampled were 3.5–28.0 m (mean = 16.2 m). Thirty-seven sites were sampled in phase 1 and four in phase 2. An example of the systematic pot placement configuration for random sites is shown in Figure 4.

3.1.1 Catch and catch rates

A total of 422.1 kg of blue cod (1168 fish) was taken, comprising 59.1% by weight of the catch of all species on the survey (Table 2). Bycatch species included seven teleost fishes and octopus. The most abundant bycatch species was spotted wrasse, AKA spotty (*Notolabrus celidotas*), comprising 37.4% of the catch weight.

Mean catch rates (kg pot^{-1}) of blue cod (all blue cod, and 33 cm and over) are presented by stratum and overall (Table 3, Figure 5). Mean catch rates of blue cod (all sizes) by stratum were 0.59–2.73 kg pot^{-1} with the lowest catch in stratum 5 (Big Glory Bay) and highest in strata 2 and 3 (north of Ulva Island and the Ulva Island Marine Reserve) (Table 3, Figure 5). The all-blue-cod overall survey catch rate, excluding the marine reserve, was 1.51 kg pot^{-1} with a CV of 17.7%. Catch rates for recruited blue cod (33 cm and over) followed a similar pattern among strata as for all blue cod and the overall survey catch rate, excluding the marine reserve, was 0.72 kg pot^{-1} (CV 21.0%) (Table 3, Figure 5). Of the 204 random-site pots set outside the marine reserve, 99 (48.5%) had zero catch of blue cod. Within the marine reserve, of the 42 pots set, nine (21.4%) had zero catch of blue cod.

3.1.2 Biological and length frequency data

Of the 815 blue cod caught outside the marine reserve, all were measured for length, weighed, and sexed (Table 4). The sex ratios were 33–71% male across the four strata and the overall weighted sex ratio was 67% male (Table 4). The length range was 14–45 cm for males and 15–47 cm for females, and the overall weighted mean length was 29.6 cm for males and 27.2 cm for females. The all strata survey scaled length frequency distributions were generally unimodal with indications of a small juvenile mode for both sexes. Individual strata distributions were broadly similar where there were sufficient numbers of fish caught (Figure 6).

Of the 353 blue cod caught in the marine reserve, all were measured for length, but only three fish were sexed (Table 4). The length range was 12–43 cm and the mean length was 26.2 cm for unsexed fish. The scaled length frequency distribution was unimodal with indications of a small adult mode (Figure 6).

3.1.3 Age and growth

Otolith section ages from 155 males and 117 females were used to estimate the population age structure from Paterson Inlet in 2018 (Table 5). The length-age data and the von Bertalanffy model fits and growth parameters (K, t_0, and L_∞) are shown for males and females separately (Figure 7). There is a large range in length-at-age, particularly for males; and males generally grow faster and comprise most of the largest fish whereas the oldest fish are females.

Between-reader age comparisons for 2018 are presented in Figure 8. The first counts of the two readers showed 89% agreement, and overall there was no bias between readers with a CV of 1.7% and average percent error (APE) of 1.2%.

3.1.4 Spawning activity

Gonad stages of blue cod sampled on the Paterson Inlet survey in November 2018 are presented for all fish combined (Table 6). Nearly half the males were in a running ripe spawning condition whereas females were mostly resting and maturing.

3.1.5 Population length and age composition

The scaled length frequency and age distributions for the 2018 Paterson Inlet random-site survey are shown for all strata combined (excluding the marine reserve), as histograms, and as cumulative frequency line plots for males, females, and both sexes combined (Figure 9).

The scaled length frequency distribution for males had a broad flat peak centred at about 28 cm, indications of a smaller juvenile mode, and an overall mean length of 29.2 cm. The female distribution had a broad peak at about 25 cm but was strongly skewed to the right, with a smaller juvenile mode, and an overall mean length of 27 cm (Figure 9). The cumulative distribution plots of length frequency are generally similar between sexes, but males are larger overall. The mean weighted coefficients of variation around the length distributions were 32% and 42% for males and females respectively.

The 2018 survey age estimates were 2–16 years for males and 2–25 years for females, but most males and females were 3–7 years old (Figure 9). The estimated population age distributions indicate that blue cod are partially selected to the potting method at two years and fully selected at 4 to 5 years of age. There were indications of a strong 7-year-old age class for both males and females. The cumulative distribution plots of age frequency show clearly that females had a higher proportion of older fish than males and the oldest fish were also females (Figure 9). The mean age of females was greater than that of males (5.3 for males and 6.1 years for females). The MWCVs around the age distributions were 25% for males and 34% for females; the latter was higher than desired to provide a good representation of the overall population age structure.

3.1.6 Total mortality estimates (*Z*) and spawner-per-recruit (SPR)

Chapman-Robson total mortality estimates and 95% confidence intervals are given for a range of recruitment ages (5–10 y) in Table 7. Age-at-full recruitment (AgeR) is assumed to be eight years, equal to the age at which females reach the MLS of 33 cm. In 2018 the CR *Z* for AgeR of eight years was 0.25 (95% confidence interval of 0.17–0.36).

The traditional catch curve, based on log catch (numbers) plotted against age with a regression line fitted to the descending limb from age-at-full recruitment at eight years, is shown for the 2018 survey for diagnostic purposes (Figure 10). There were few blue cod ages over 10 years, with many age classes not represented, and this has influenced the slope of the regression line and hence Z. The natural log of numbers-at-age does not follow the ideal straight-line descending limb, particularly for females, suggesting that the assumption of constant recruitment had been sufficiently violated to detract from the results. Although the CR estimation is less sensitive to age classes with few fish, this will have introduced error (and probably bias) into the *Z* estimate, which is reflected in the wide 95% confidence intervals around *Z* (see Table 7).

Mortality parameters (CR *Z* and *F*, and *M*) and spawner-per-recruit (SPR) estimates at three values of *M* and age at full recruitment of eight years are shown for the 2018 survey in Table 8. Based on the default *M* of 0.17, estimated fishing mortality was 0.08 and associated spawner-per-recruit was 68.0% (Figure 11). At the 2018 levels of fishing mortality, the expected contribution to the spawning biomass over the lifetime of an average recruit is reduced to 68% of the contribution in the absence of fishing, but this is likely biased high as a result of a probable underestimate of *F*. The 95% confidence intervals around the 2018 SPR ratios were 49–100% (Table 8).

3.2 Paterson Inlet time series

3.2.1 Fixed-site surveys (2006, 2010, and 2014)

Mean catch rates (kg pot^{-1}) for all blue cod and recruited blue cod for the three fixed-site surveys are presented in Figure 12. The pattern of catch rates among the five strata are similar for all three surveys, with the highest catch rates in strata 3 and 4, and the lowest in stratum 5 (see Figure 3). The large confidence intervals indicate that catch rates within strata were not significantly different between surveys. For Paterson Inlet overall, there was no trend in abundance across the three surveys and no difference including or excluding the Ulva Island Marine Reserve (Figure 12).

Excluding the marine reserve

In the three fixed-site surveys there were restrictions on the numbers of blue cod that could be killed inside the mātaitai and in 2006 most fish were unsexed. In 2010 and 2014, however, about half of the fish in the mātaitai were sexed by 'milking' or squeezing the fish for the presence of milt or eggs. Hence the scaled length frequency distributions are only comparable in 2010 and 2014 when the distributions and mean length of all blue cod were remarkably similar, shown clearly by the cumulative distributions (Figure 13). Similarly, there was no change in the mean length of recruited blue cod over time (Figure14).

The sex ratio for the 2010 and 2014 surveys (when fish were sexed), excluding the marine reserve, was 75% male for all blue cod in both 2010 and 2014, and 92% and 95% male for recruited blue cod, with no trend (Figure 15).

The proportions of pots with zero catch for the three fixed-site surveys, excluding the marine reserve, were 30%, 16%, and 18%, halving between 2006 and 2010 (Figure 16).

Otoliths were collected and read for all three Paterson Inlet fixed-site surveys (Carbines 2007, Carbines & Haist 2014, 2018a), but the ageing was carried out before the blue cod age determination protocol (Walsh 2017) was available, and published ages, mortality, and spawner-per-recruit estimates are considered unreliable.

Marine Reserve

Mean catch rates (kg pot^{-1}) for all blue cod and recruited blue cod inside the Ulva Island Marine Reserve (stratum 3) for the three fixed-site surveys showed no trend in abundance (see Figure 12).

In the three Ulva Island Marine Reserve fixed-site surveys no fish were killed and in 2006 nearly all fish were unsexed. In 2010 and 2014, as in the mātaitai, fish in the marine reserve were sexed by 'milking' or squeezing. The scaled length frequency distributions in 2010 and 2014, and mean lengths of all blue cod were remarkably similar, shown clearly by the cumulative distributions (Figure 17). Similarly, there was no change in the mean length of recruited blue cod (see Figure 14).

The sex ratio inside the marine reserve in 2010 and 2014 (when fish were sexed) was 89% and 81% male for all blue cod, and 97% and 95% male for recruited blue cod, with no trend (Figure 18).

Inside the marine reserve the proportions of pots with zero catch were 25%, 3%, and 7%, showing a large decrease between 2006 and 2010 (see Figure 16).

3.2.2 Random-site surveys (2010, 2014 and 2018)

Mean catch rates (kg pot^{-1}) for all blue cod and recruited blue cod for the three random-site surveys are presented in Figure 19. The pattern of catch rates among the five strata are not consistent for all three surveys but in general the highest catch rates were in the marine reserve (stratum 3) and the lowest in Big Glory Bay (Stratum 5). The large confidence intervals indicate that catch rates within strata may not be significantly different between surveys. There was, however, a large and likely statistically significant increase in catch rates in all strata, except Big Glory Bay, between 2010 and 2014. For Paterson Inlet overall, the increase in abundance from 2010 to 2014 was likely to be statistically significant and there was no difference including or excluding the Ulva Island Marine Reserve (Figure 19).

Excluding the marine reserve

In the 2010 and 2014 random-site surveys there were restrictions on the numbers of blue cod that could be killed inside the mātaitai and about half of the fish in the mātaitai were sexed by 'milking' or squeezing the fish for the presence of milt or eggs. This restriction did not apply in 2018, when all fish in the mātaitai were killed and sex was determined by examination of the gonad. The scaled length frequency distributions and mean length of all blue cod for the three surveys were remarkably similar, shown clearly by the cumulative distributions (Figure 20). Similarly, there were no major differences in the mean length of recruited blue cod over time (see Figure 14).

The sex ratio for the three random-site surveys, excluding the marine reserve, ranged from 61–67% male for all blue cod, and 76–85% male for recruited blue cod, with no trend (see Figure 15).

The proportions of pots with zero catch for the three random-site surveys, excluding the marine reserve, were 69%, 49% and 48%, dropping by 20% between 2010 and 2014 (see Figure 16).

Only the 2018 random site survey has had ageing carried out using the blue cod age determination protocol (Walsh 2017).

Marine reserve

Mean catch rates (kg pot^{-1}) for all blue cod and recruited blue cod inside the Ulva Island Marine Reserve (stratum 3) for the three random-site surveys showed no trend in abundance with overlapping confidence intervals (see Figure 19).

In the three Ulva Island Marine Reserve random-site surveys no fish were killed and where sex was determined this was by 'milking' or squeezing. The scaled length frequency distributions by sex are only comparable in 2010 and 2014, with few fish sexed in 2018, and were remarkably similar as shown by the cumulative distributions (Figure 21). Similarly, there was no major change in the mean length of recruited blue cod (see Figure 14).

The sex ratio inside the marine reserve in 2010 and 2014 (when fish were sexed) was 71% and 64% male for all blue cod, and 98% and 95% male for recruited blue cod, with no trend (see Figure 18).

The proportions of pots with zero catch inside the marine reserve were 33%, 23%, and 21%, with a large decrease between 2010 and 2014 (see Figure 16).

3.3 Comparison of fixed-site and random-site surveys

Comparison of the concurrent fixed- and random-site surveys in 2010 and 2014, excluding the marine reserve, show that the catch rates from fixed sites were substantially higher with non-overlapping confidence intervals (Figure 22). The difference was five-fold in 2010 and nearly three-fold in 2014. The CVs and associated confidence intervals were also considerably lower for the fixed-site surveys in 2010 and 2014 (11% and 13% for fixed-site surveys, and 24% and 20% for random-site surveys). The patterns of catch rates across strata also differed in 2010 and 2014 (see Figures 12 and 19).

Blue cod were larger overall in the fixed-site surveys than the random-site surveys in 2010 and 2014, both outside and inside the marine reserve (Figure 23).

Both fixed-site surveys had higher proportions of all blue cod males than random-site surveys outside the marine reserve (75% compared with 61% in 2010, and 75% compared with 67% in 2014 for fixed- and random-site surveys, respectively (see Figure 15). Differences in sex ratios between recruited blue cod were similar. Inside the marine reserve, fixed-site surveys also have higher proportions of males than random-site surveys for all blue cod, but there was no difference for recruited blue cod, which were close to 100% male in all cases (see Figure 18).

The proportions of pots with zero catch were markedly higher for random-site surveys outside the marine reserve (16% compared with 69% in 2010, and 18% compared with 49% in 2014 for fixed- and random-site surveys, respectively (see Figure 16)). The differences were even greater inside the marine reserve.

Comparison of blue cod size inside and outside the marine reserve by survey type indicate that for the three fixed-site surveys (2006, 2010, and 2014) blue cod were larger overall inside the marine reserve (Figure 24),in contrast to the three random-site surveys (2010, 2014, and 2018), where blue cod were smaller overall inside the marine reserve (Figure 24).

There was no clear or consistent difference in spawning condition (mature and running ripe) of blue cod from fixed-site or random-site surveys which have all coincided with active spawning activity (Figure 25).

4. DISCUSSION

4.1 General

The 2018 Paterson Inlet random-site potting survey was the third Fisheries New Zealand random-site survey in the time series of relative abundance and population structure of blue cod from this area, after surveys in 2010 and 2014. Following a transition period with two concurrent surveys, the random-site survey design has now replaced the fixed-site surveys previously carried out in 2006, 2010, and 2014.

Differences in catch rates for equivalent strata, the overall length distribution, and sex ratios between the 2010 and 2014 Paterson Inlet fixed-site and random-site surveys, suggest there is no suitable way of quantitatively linking the fixed-site with the random-site series. Accordingly, the random-site surveys provide a separate time-series that will become more informative with each successive survey.

The most striking differences in these survey designs are the much higher catch rates, the larger size of blue cod, and the lower proportion of empty pots in the fixed-site surveys. Although size distributions can sometimes vary, catch rates tend to be higher in fixed-site than random-site surveys throughout the South Island; for example, Marlborough Sounds, Kaikōura, Motunau, Banks Peninsula, south Otago, and north Otago (Beentjes & Fenwick 2017, Beentjes & Sutton 2017, Beentjes & Page 2018, Beentjes et al. 2018, Beentjes & Fenwick 2019b, 2019a). The likely reason for this is that fixed sites were selected as locations where blue cod were known to be abundant, whereas random sites can fall anywhere within a stratum, including on marginal habitat. In Paterson Inlet the random sites can fall anywhere within the stratum boundaries, including on mud, whereas fixed sites are all hard-up against the coastline, much of which is rocky biogenic reef substrates.

Neither of the fixed-site or random-site survey time series show any clear indications of a change in relative abundance, size, or sex ratio, although there was a large increase between 2010 and 2014 for the random-site series (see Figure 22). This may simply be a result of between survey variability associated with the random allocation of sites to poor habitat, and more surveys are required before trends can be correctly identified.

4.2 Survey precision

The survey CV around relative abundance (catch rates) was not specified in the project objectives for the 2018 Paterson Inlet survey, but a CV of around 15% is generally targeted. The achieved CV of 18% in 2018 (from 34 sites excluding the marine reserve) was slightly higher than desired but was an improvement on 2010 and 2014 when CVs were 24% and 20%. The CVs were improved with the addition of the marine reserve, but abundance estimates and CVs for Paterson Inlet should ideally exclude the marine reserve which is a separate survey. The achieved 2018 CV of 18% indicates that the number of sites used is adequate, but more may be required in future surveys if lower CVs are desired.

4.3 Blue cod habitat and abundance

Paterson Inlet seafloor substrate is predominantly sand with patches of mud and gravel (Stuart et al. 2009). It has a wide range of benthic fauna, including Mollusca, Annelida, Arthropoda, and Bryozoa, several species of branchiopods, and the most diverse algal flora in New Zealand (Adams et al. 1974, Willan 1981, Stuart et al. 2009). The inlet has clear water, with low sediment load from the surrounding catchment, and a wide range of hard and soft shore types providing diverse species habitats.

The relative abundance of blue cod across the four main survey strata for the random-site surveys does not show any clear consistent pattern except that abundance is lowest in Big Glory Bay (stratum 5) where mud substrate predominates (Stuart et al. 2009). Although blue cod are found throughout the entire inlet, they are more abundant closer to the shore where habitat is generally more suitable.

The Paterson Inlet survey abundance estimates, length and age distributions, and sex ratio were weighted (scaled) by the area of each stratum. Scaling by stratum area assumes that average blue cod density in sampled sites is similar to density in unsampled areas within that stratum. A detailed sediment/substrate map of Paterson Inlet would be required to attempt to relate abundance with habitat type.

4.4 Age composition and genetic mixing

Growth estimates indicate that males are on average 6 years old, and females 8 years old when they reach the current MLS of 33 cm in Paterson Inlet (see Figure 7). Blue cod are not fully selected to the potting method until at least 4 to 5 years old, a finding also supported by the age composition in other areas surveyed, most recently Kaikōura and north Otago (Beentjes & Page 2018, Beentjes & Fenwick 2019a) and in the contiguous Foveaux Strait, where growth rates are similar up to the MLS (Beentjes et al. 2019).

Although there is no valid age composition before the 2018 random-site survey, the stable length distributions suggest that the composition may have been similar in 2014 and 2010 (see Figure 9). The age composition shows high mortality between 5 and 10 years, but there are still some males surviving to 16 years of age and females to 25 years of age. In comparison, the adjoining Foveaux Strait has few fish older than 10 years, but relatively more fish between 5 and 10 years.

Both the Paterson Inlet and Foveaux Strait age structures differ from the east coast South Island areas surveyed from 2015 to 2018 (Banks Peninsula, Kaikōura, Motunau, south Otago, and north Otago) which have all displayed a strong 2012 year class and weak 2011 year class (Beentjes & Fenwick 2017, Beentjes & Sutton 2017, Beentjes & Page 2018, Beentjes & Fenwick 2019a, 2019b). These findings indicate that blue cod on the east coast South Island have had variable recruitment in recent years with intermittent pulses of strong and weak year classes, but this was not evident in the southern Paterson Inlet and Foveaux Strait. There is no evidence that blue cod are genetically distinct around the New Zealand mainland (Gebbie 2014) suggesting that limited mixing is occurring on a wider geographical scale than within the mainly restricted home range indicated by some tagging studies (Carbines & McKenzie 2001, Carbines & McKenzie 2004). The age compositions from Paterson Inlet and Foveaux Strait compared with those of the east coast South Island surveys suggest that there may be different environmental conditions affecting recruitment in these areas.

4.5 Sex change and sex ratio

The 2018 Paterson Inlet sex ratio (excluding the marine reserve) has been consistently dominated by males (see Figure 15) at about 60–70% male which is not uncommon for fished blue cod populations. Blue cod belong to the family Pinguipedidae or sandperches and are protogynous hermaphrodites with some (but not all) females changing into males as they grow (Carbines 2004). In areas where fishing pressure is known to be high, such as Motunau, inshore Banks Peninsula, and the Marlborough Sounds, the sex ratios are strongly skewed towards males (more than 80% male), contrary to an expected dominance of females resulting from selective removal of the larger final phase male fish (Beentjes & Carbines 2003, 2006, Carbines & Beentjes 2006a, Beentjes & Carbines 2012, Beentjes & Sutton 2017). Beentjes & Carbines (2005) suggest that the shift towards a higher proportion of males in heavily fished blue cod populations may be caused by removal of the inhibitory effect of large males, resulting in a higher rate (and possibly earlier onset) of sex change by primary females. Recent experimental studies have indicated that in the protogynous hermaphroditic tuskfish (*Choerodon schoenleinii,* Family Labridae), this process may be density dependent, with the degree of male to female tactile stimulation regulating the extent of sex change from females to males (Sato et al. 2018). Sex change is more likely to occur at low levels of behavioural interaction between a dominant male and a female.

In the southern region, blue cod populations in Foveaux Strait and Dusky Sound have sex ratios that are more balanced, suggesting that fishing pressure is less intense (Beentjes & Carbines 2009, Carbines & Beentjes 2012, Beentjes & Page 2016, Beentjes et al. 2019). Despite having balanced sex ratios, there may be fishing-induced sex change operating in these areas, but the extent of sex change is in equilibrium with the removal of large males. The processes that drive sex change in blue cod are poorly understood and these may differ regionally.

4.6 Reproductive condition

All Paterson Inlet surveys (fixed-site and random-site) have taken place in November with the 2010 and 2014 surveys extending into early December. All surveys show indications of active spawning for both sexes, with variable proportions in the mature and running-ripe condition. There were higher proportions of males in the running-ripe state than females in all surveys, and in 2018 there were no running-ripe females (see Figure 25).

Blue cod are serial or batch-spawners with a protracted spawning period that can extend from June to January, with peak spawning occurring later in southern latitudes (Beer et al. 2013). During the spawning period, individuals can spawn multiple times (Pankhurst & Conroy 1987), and it seems likely they will transition back and forth between the ripe and running-ripe conditions during this period. The lack of running-ripe female fish in 2018 suggests that peak spawning did not occur during the time of the survey in November, or that the survey took place between spawning events. Blue cod in Foveaux Strait have been shown to be actively spawning in February (Beentjes et al. 2019) suggesting that the spawning period in this region may last for several months.

4.7 Stock status and management implications

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

The 2018 Paterson Inlet random-site survey Z was 0.25, F was 0.08, and the SPR estimate (M value of 0.17 and age at full recruitment of 8 years) was $F_{68.0\%SPR}$ ($F_{49\%–100\%}$, 95% CIs), indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit was reduced to 68% of the contribution in the absence of fishing (see Figure 11). These results suggest that the level of exploitation (F) of Paterson Inlet blue cod stocks in 2018 was below the F_{MSY} target reference point of $F_{45\%SPR}$ (under-exploited). However, examination of the traditional catch curves suggests that the Z estimates that underpin the SPR ratio may be biased (see Figure 10). Total mortality (Z) is a product of the slope of the right-hand descending curve of age versus population numbers. The wide scatter of numbers at age, especially females, and the absence of a clear dome on the catch curve may be a result of variable recruitment, and hence a violation of the catch curve assumption that recruitment is constant.

The point estimates of *Z*, *F*, and SPR in 2018 should therefore be treated with caution and *Z* and SPR estimates that fall within the 95% confidence intervals may be plausible.

4.8 Management implications

The catch rates in Paterson Inlet are relatively low compared with other regions, yet in Foveaux Strait they are the highest of the nine South Island areas surveyed, indicating a large difference in productivity between contiguous areas. Foveaux Strait (in General Statistical Area 025) also contributes about half of the annual commercial catch from BCO 5 and supports the largest commercial blue cod fishery in New Zealand.

Displacement of recreational fishing effort from Canterbury to north Otago is likely to have occurred in recent years because of low catch rates around inshore Banks Peninsula combined with lower daily bag limits and larger MLS at Motunau and Kaikōura. It is not known if this displacement of fishing effort extends to Foveaux Strait and Paterson Inlet, but the panel survey in 2017–18 estimates that 25% of the New Zealand blue cod recreational catch is from BCO 5, and of that 10% is taken from Paterson Inlet (Wynne-Jones et al. 2019). Further, because females do not grow as large as males and there are more males in the population, more of the recreational fishery catch is likely to be comprised of males (see Figure 20).

4.9 Status of blue cod stocks inside the Ulva Island Marine Reserve

The abundance estimates of blue cod inside the Ulva Island Marine Reserve on all three fixed-site surveys, were substantially higher than for strata 1, 2, and 5, but were no different to those in the adjacent stratum 4, which lies at the entrance to the inlet (see Figures 3 and 12). Blue cod were larger overall inside the marine reserve (see Figure 24), and there were fewer pots with zero catch (see Figure 16); however, the proportion of males was surprisingly high (see Figures 15 and 18). Because sex was determined by observation of expressible eggs or sperm in 2010 and 2014, there may be bias in these sex ratios. However, 303 blue cod caught outside the marine reserve in 2010 were sexed by milking and then killed to definitively determine sex, which was correctly assigned for all fish and Carbines & Haist (2014) considered the method of milking fish to determine sex to be validated. In the 2018 survey, however, few fish could be reliably sexed using the milking method.

Of the three random-site surveys, abundance was highest in the marine reserve only once for all blue cod and not at all for recruited blue cod. There were fewer pots with zero catch (see Figure 16) and the proportion of males was similar (notwithstanding the reliability of the method used to sex fish), but in contrast to fixed-site surveys, blue cod lengths were overall smaller inside than outside the marine reserve.

The expectation of establishing a no-take marine reserve is that fish within this zone will become more abundant and attain greater overall length and age. Ulva Island Marine Reserve was established in 2004 affording fourteen years of no fishing. Notwithstanding the differences between the fixed- and random-site survey designs, there is little difference in abundance inside and outside the marine reserve, and no difference in the sex ratio (assuming the method of assigning sex by milking is acceptable). Indeed, blue cod from the preferred random-site survey design were overall smaller inside the marine reserve. For a marine reserve to be effective for blue cod, at minimum the reserve needs to be larger than their home range. Tagging studies of blue cod captured and released around the shores of Native Island and Ulva Island in the late 1990s, before these areas were included in the Ulva Island Marine Reserve, showed that movement from the tagging site was either negligible or small, with distances mostly less than 400 m and as far as 800 m (Govier 2001). This very restricted movement within enclosed waters is consistent with other tagging studies on blue cod (Rapson 1956, Mace & Johnston 1983, Mutch 1983, Carbines & McKenzie 2001, Carbines & McKenzie 2004). Despite this limited home range, the expected increases in size and abundance within the marine reserve are not apparent. The reasons may be related to the fragmented nature of the marine reserve which is split into three geographically separated parts (see

Figure 3) and within each part there may be sufficient mixing at the borders and away from the coast to render the population homogenous. In contrast, a potting survey of blue cod inside the Long Island Marine Reserve in the Marlborough Sounds, which at about 15 km^2 is less than half the area of Ulva Island Marine Reserve, showed that these fish were considerably more abundant and larger than those in the adjacent stratum (Beentjes et al. 2018). This suggests that island marine reserves may be the most effective for blue cod.

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7. TABLES AND FIGURES

Table 1: Effort and catch data for the 2018 Paterson Inlet random-site blue cod potting survey. MR, marine reserve.

Stratum	Area (km^2)	Site type	Number of sets (sites) Phase 1	Phase 2	*N* pots (stations)	Catch (blue cod) Number	kg	Depth (m) Mean	Range
1	15.6	Random	8		48	193	75.2	15.3	4.6–22.3
2	20.7	Random	9	1	60	439	162.9	18.1	5.8–26.0
3 (MR)	10.7	Random	7		42	353	114.7	20.6	6.2–26.3
4	20.7	Random	10	3	78	168	58.7	12.9	3.5–28.0
5	11.1	Random	3		18	15	10.6	14.2	3.7–25.2
Total	78.8	Random	37	4	246	1168	422.1	16.2	3.5–28.0

Table 2: Total catch and numbers of blue cod and bycatch species caught on the 2018 Paterson Inlet random-site blue cod potting survey. Percent of the catch by weight is also shown.

Common name	Species	Code	Number	Catch (kg)	% catch
Blue cod	*Parapercis colias*	BCO	1 168	422.1	59.13
Spotty	*Notolabrus celidotas*	STY	2 598	267.0	37.40
Common octopus	*Octopus maorum*	OCT	9	13.1	1.83
Banded Wrasse	*Notolabrus fucicola*	BPF	7	7.6	1.06
Tarakihi	*Nemadactylus macropterus*	NMP	10	1.9	0.27
Red cod	*Pseudophycis bachus*	RCO	1	1.6	0.22
Leatherjacket	*Meuschenia scaber*	LEA	2	0.2	0.03
Pigfish	*Congiopodus leucopaecilus*	PIG	1	0.2	0.03
Scarlet wrasse	*Pseudolabrus miles*	SPF	1	0.2	0.03
Totals			3 797	713.9	

Table 3: Mean catch rates for all blue cod and recruited blue cod (33 cm and over) from the 2018 Paterson Inlet random-site blue cod potting survey. Catch rates are pot-based, and s.e. and CV are set-based. s.e., standard error; CV, coefficient of variation; MR, marine reserve.

Stratum	Pot lifts (Number)	All blue cod Catch rate (kg pot^{-1})	s.e.	CV (%)	Recruited blue cod ≥ 33 cm Catch rate (kg pot^{-1})	s.e.	CV (%)
1	48	1.57	0.69	43.8	0.75	0.32	42.6
2	60	2.72	0.64	23.5	1.25	0.36	29.0
3 (MR)	42	2.73	0.75	27.5	1.02	0.32	31.7
4	78	0.75	0.19	25.1	0.27	0.07	26.1
5	18	0.59	0.46	78.5	0.52	0.42	82.3
Overall	246	1.67	0.25	15.1	0.76	0.14	18.1
Overall (excl. MR)	204	1.51	0.27	17.7	0.72	0.15	21.0

Table 4: Descriptive statistics for blue cod caught on the 2018 Paterson Inlet random-site blue cod potting survey. Outputs are raw for each stratum and weighted overall. Sex ratio is also given for recruited blue cod (33 cm and over). m, male; f, female; u, unsexed; MR, marine reserve; –, no data.

		Random-site survey					
			Length (cm)			Percent male	
Stratum	Sex	Number	Mean	Minimum	Maximum	All blue cod	Recruited blue cod ≥ 33 cm
1	m	122	30.0	16.5	43.4	63.2	71.8
	f	71	26.9	18.2	40.8		
	u	0	–	–	–		
2	m	303	29.8	17.0	45.0	69.1	81.5
	f	136	27.1	20.5	39.6		
	u	0	–	–	–		
3 (MR)	m	3	35.5	30.5	38.1	NA	NA
	f	0	–	–	–		
	u	350	26.2	12.6	43.5		
4	m	119	28.5	14.6	40.4	71.3	90.4
	f	49	26.0	15.0	35.0		
	u	0	–	–	–		
5	m	5	37.2	32.8	41.8	33.5	36.6
	f	10	36.1	26.7	47.2		
	u	0	–	–	–		
Overall (excl. MR)	m	549	29.6	14.6	45.0	67.0	76.3
	f	266	27.2	15	47.2		
	u	0	–	–	–		
Overall (incl. MR)	m	552	29.2	14.6	45.0	NA	NA
	f	266	27.0	15	47.2		
	u	350	26.6	12.6	43.5		

Table 5: Otolith ageing data used in the catch-at-age, *Z* estimates, and SPR analyses for the 2018 Paterson Inlet random-site blue cod potting survey.

		Length of aged fish (cm)		Age (years)	
Sex	No. otoliths	Minimum	Maximum	Minimum	Maximum
Total	272	14	47	2	25
Male	155	14	45	2	16
Female	117	15	47	2	25

Table 6: Gonad stages (%) of blue cod from the 2018 Paterson Inlet random-site blue cod potting survey in November 2018 for all blue cod by sex. 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent.

	Gonad stage (%)					
Sex	1	2	3	4	5	Number
Males	6.3	36.8	10.9	46.0	0	552
Females	30.1	64.3	4.5	0.0	1.1	266

Table 7: Chapman-Robson total mortality estimates (*Z*) and 95% confidence intervals of blue cod for the 2018 Paterson Inlet Strait random-site blue cod potting survey (excluding the marine reserve). AgeR, age at full recruitment.

		95% CIs	
AgeR	*Z*	Lower	Upper
5	0.49	0.34	0.70
6	0.44	0.30	0.61
7	0.47	0.32	0.67
8	0.25	0.17	0.36
9	0.24	0.15	0.34
10	0.22	0.14	0.31

Table 8: Mortality parameters (Chapman Robson *Z*, *F* and *M*) and spawner-per-recruit ($F_{SPR\%}$) point-estimates at three values of *M* for blue cod from the 2018 Paterson Inlet Strait random-site blue cod potting survey (excluding the Marine Reserve). Fishing mortality and spawner-per-recruit estimates are also given for the 95% confidence interval values of *Z* for the default *M* (0.17). AgeR, age at recruitment (age at which females reach MLS of 33 cm); *M*, natural mortality; *Z*, total mortality; *F*, fishing mortality; LowerCI, lower 95% confidence interval; UpperCI, Upper 95% confidence interval.

AgeR	*M*	*Z*	*F*	$F_{\%SPR}$	Estimate
8	0.17	0.17	0	$F_{100\%}$	LowerCI
8	0.17	0.25	0.08	$F_{68.0\%}$	Point
8	0.17	0.36	0.19	$F_{49.0\%}$	UpperCI
8	0.14	0.25	0.11	$F_{55.5\%}$	Point
8	0.20	0.25	0.05	$F_{80.3\%}$	Point

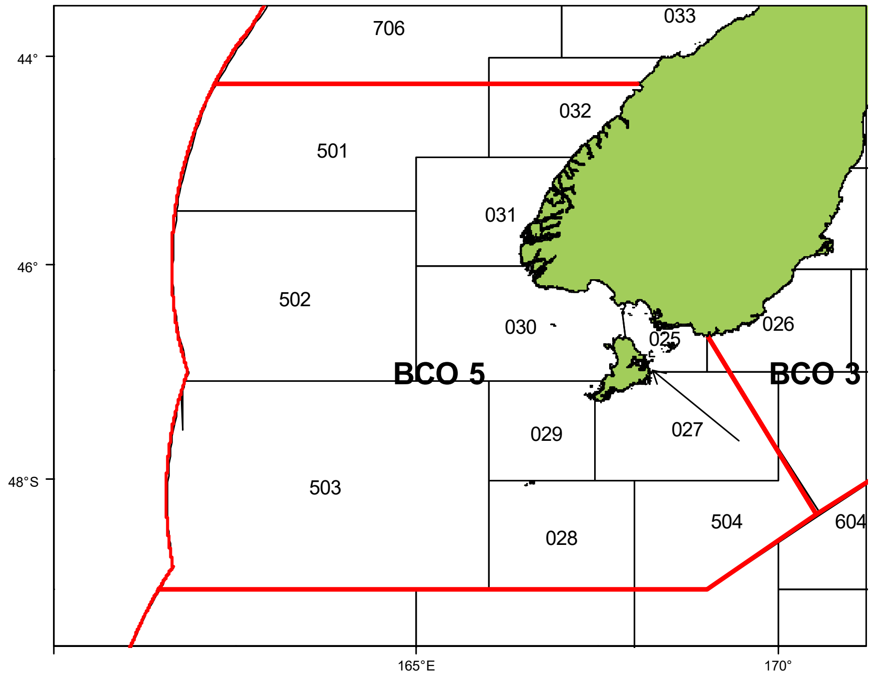

Figure 1: Blue cod Quota Management Area BCO 5 and General Statistical Areas. Paterson Inlet location is indicated by the arrow.

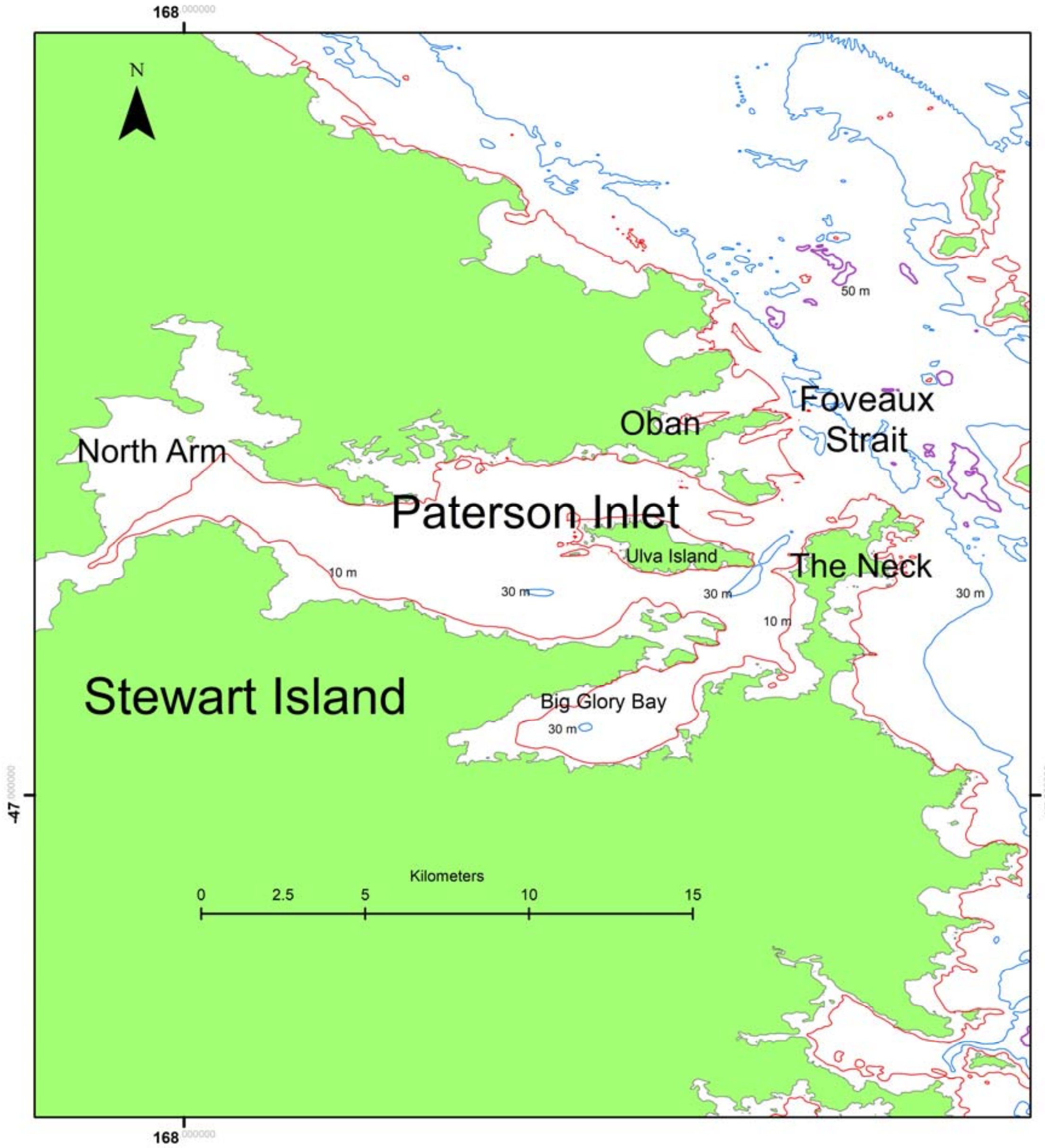

Figure 2: Paterson Inlet at Stewart Island. The 10 m, 30 m, and 50 m depth contours are shown.

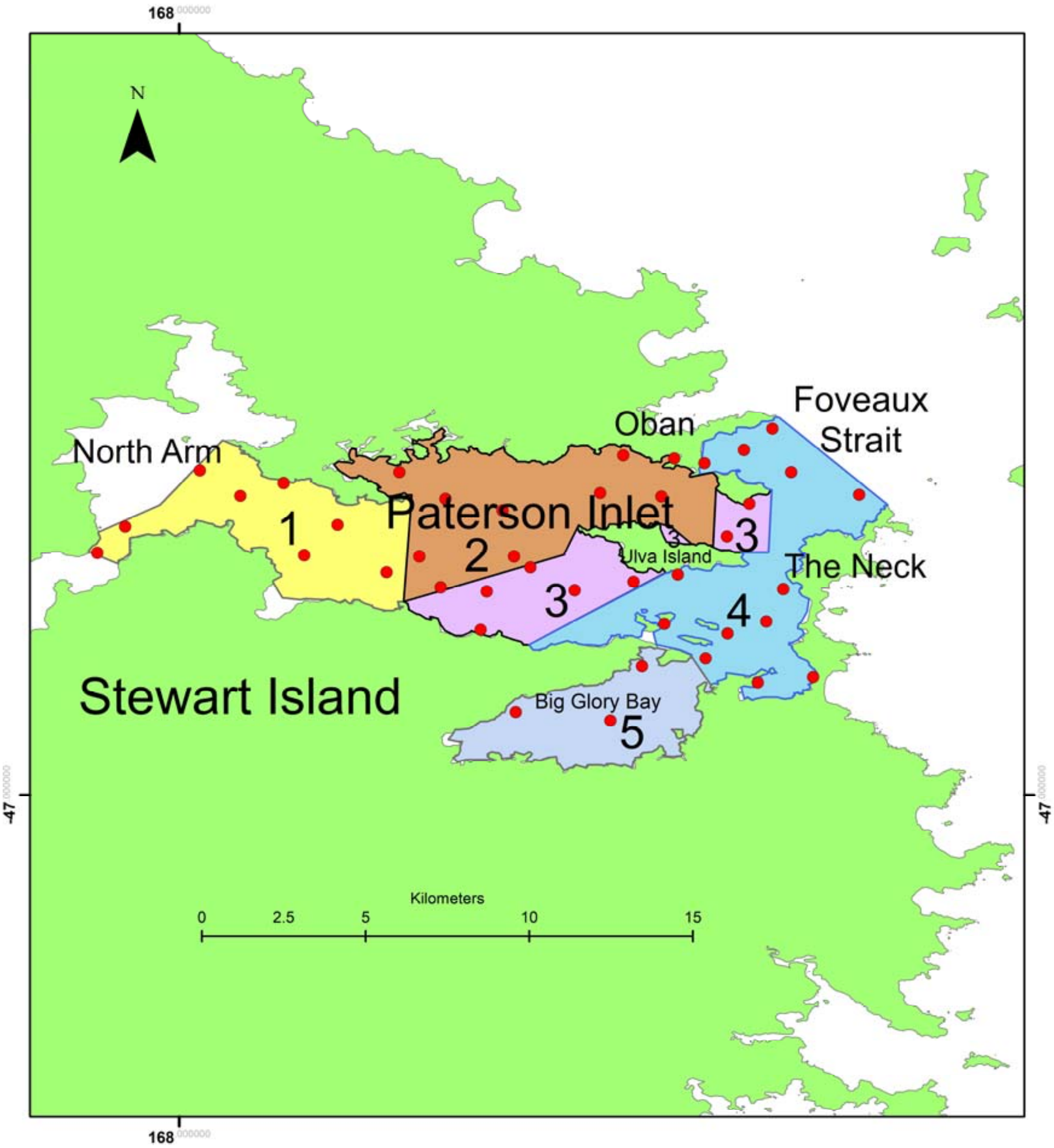

Figure 3: Paterson Inlet 2018 survey strata and site positions (•) for the 2018 Paterson Inlet random-site blue cod potting survey. The mātaitai area includes strata 1, 2, and 4, and Ulva Island Marine Reserve is equivalent to stratum 3.

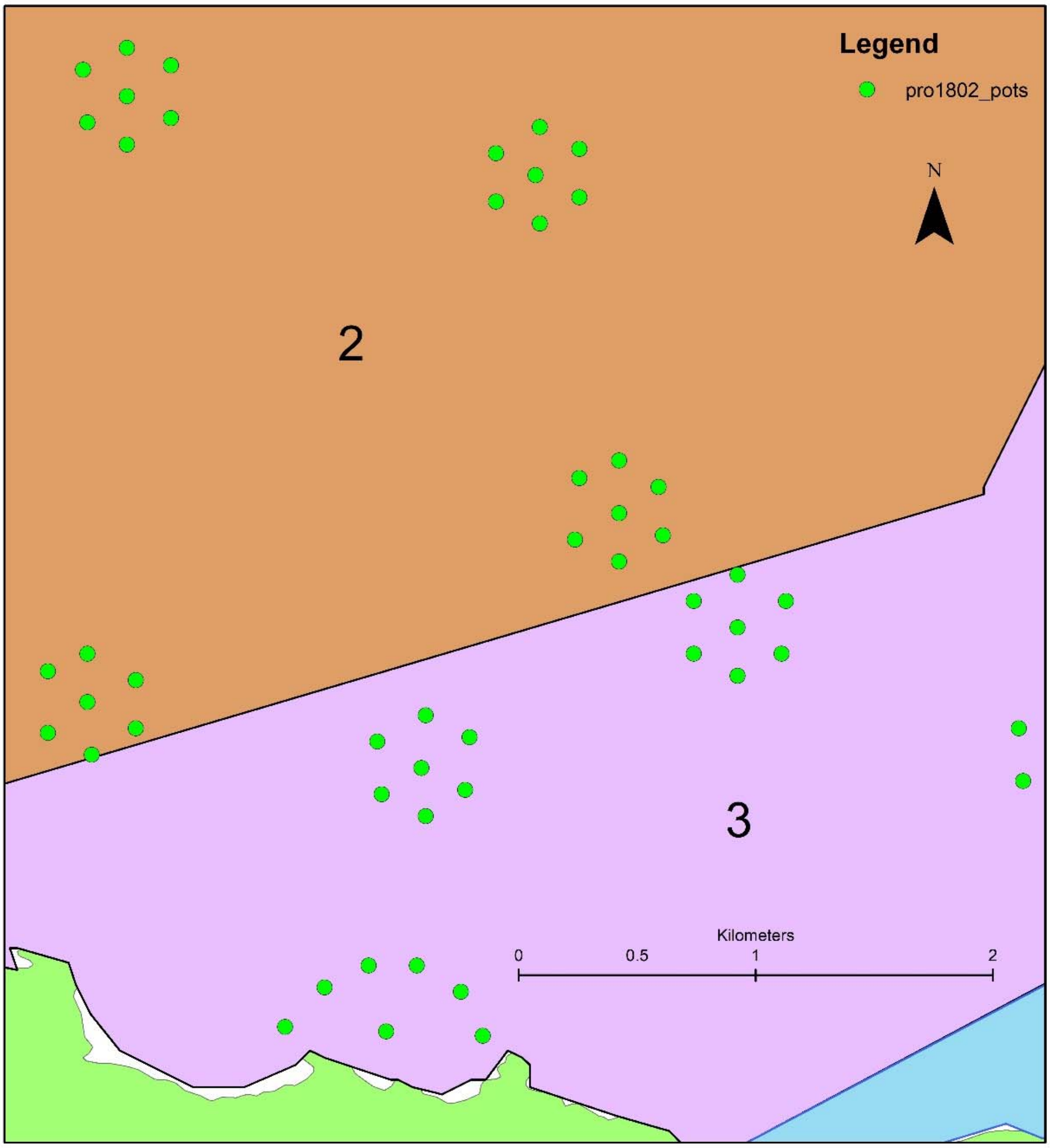

Figure 4: Paterson Inlet 2018 random-site blue cod potting survey pot placement example in strata 2 and 3. Six pots were placed in a hexagon pattern around the central random-site location where the ADCP was deployed. One site near the coast is shown where a hexagon configuration could not be achieved, and pots were set systematically along the coast around the site position.

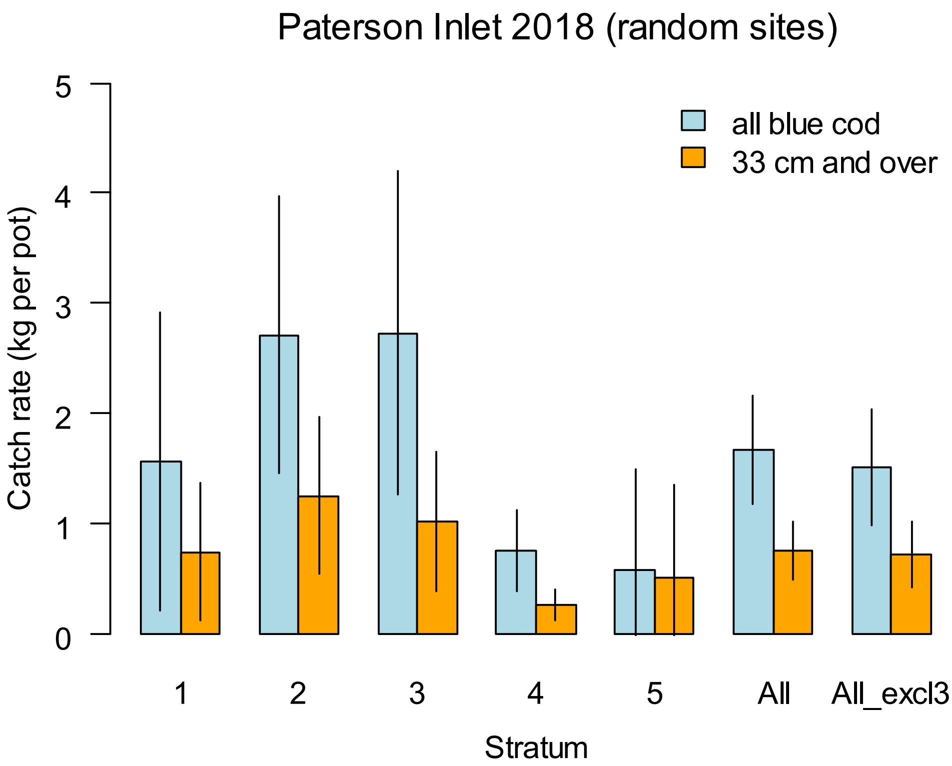

Figure 5: Mean catch rates (kg pot^{-1}) of all blue cod and recruited blue cod (33 cm and over) by strata, and overall for the 2018 Paterson Inlet random-site survey. Error bars are 95% confidence intervals.

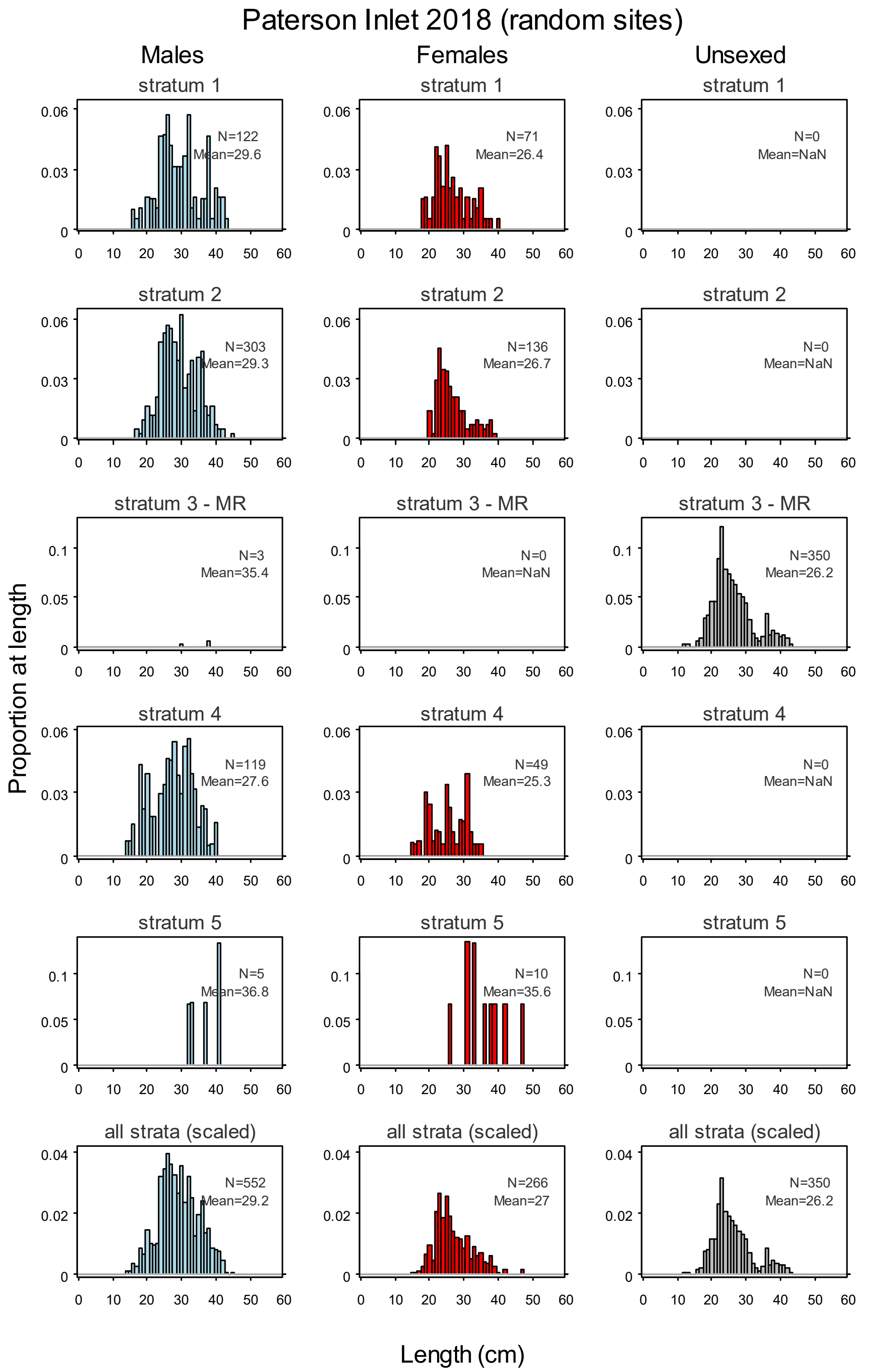

Figure 6: Scaled length frequency distributions by strata and overall for the 2018 Paterson Inlet random-site potting survey. N, sample numbers; Mean, mean length (cm). Scales differ for individual strata and for the 'all strata' panels.

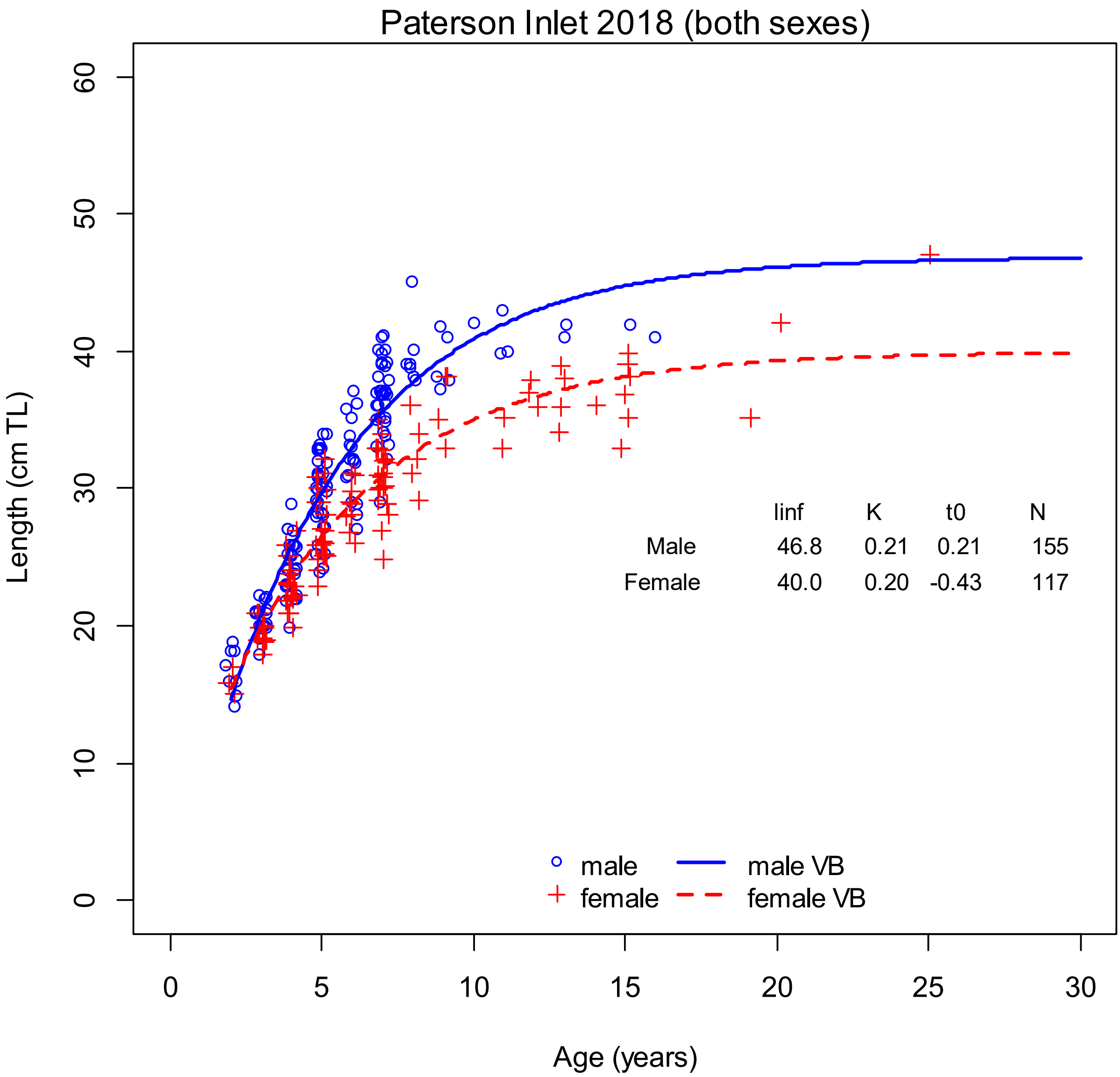

Figure 7: Observed blue cod age and length data by sex for the 2018 Paterson Inlet survey with von Bertalanffy (VB) growth models fitted to the data. Linf, average size at the maximum age (cm); K, Brody growth coefficient (yr^{-1}); t0, theoretical age when the average size is zero.

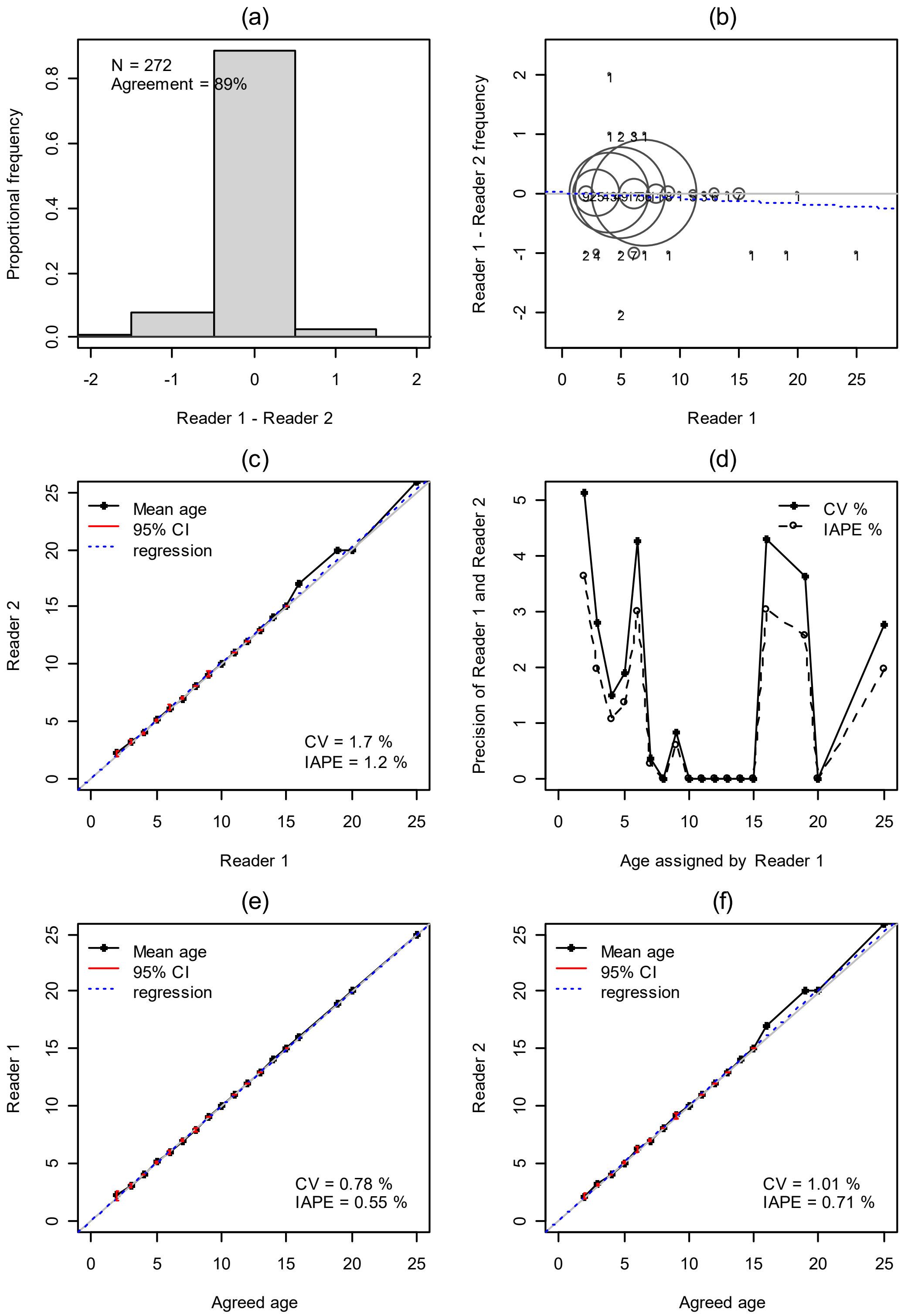

Figure 8: Blue cod age otolith reader comparison plots between reader 1 and reader 2 for the 2018 Paterson Inlet survey: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of fish in each age bin are annotated and proportional to circle size; (c) age bias plot, showing the correspondence of ages between reader 1 and reader 2 for all ages; (d) precision of readers; (e and f) reader age compared with agreed age. In panels b, c, e, and f, solid grey lines show perfect agreement, dashed blue lines show the trend of a linear regression of the actual data.

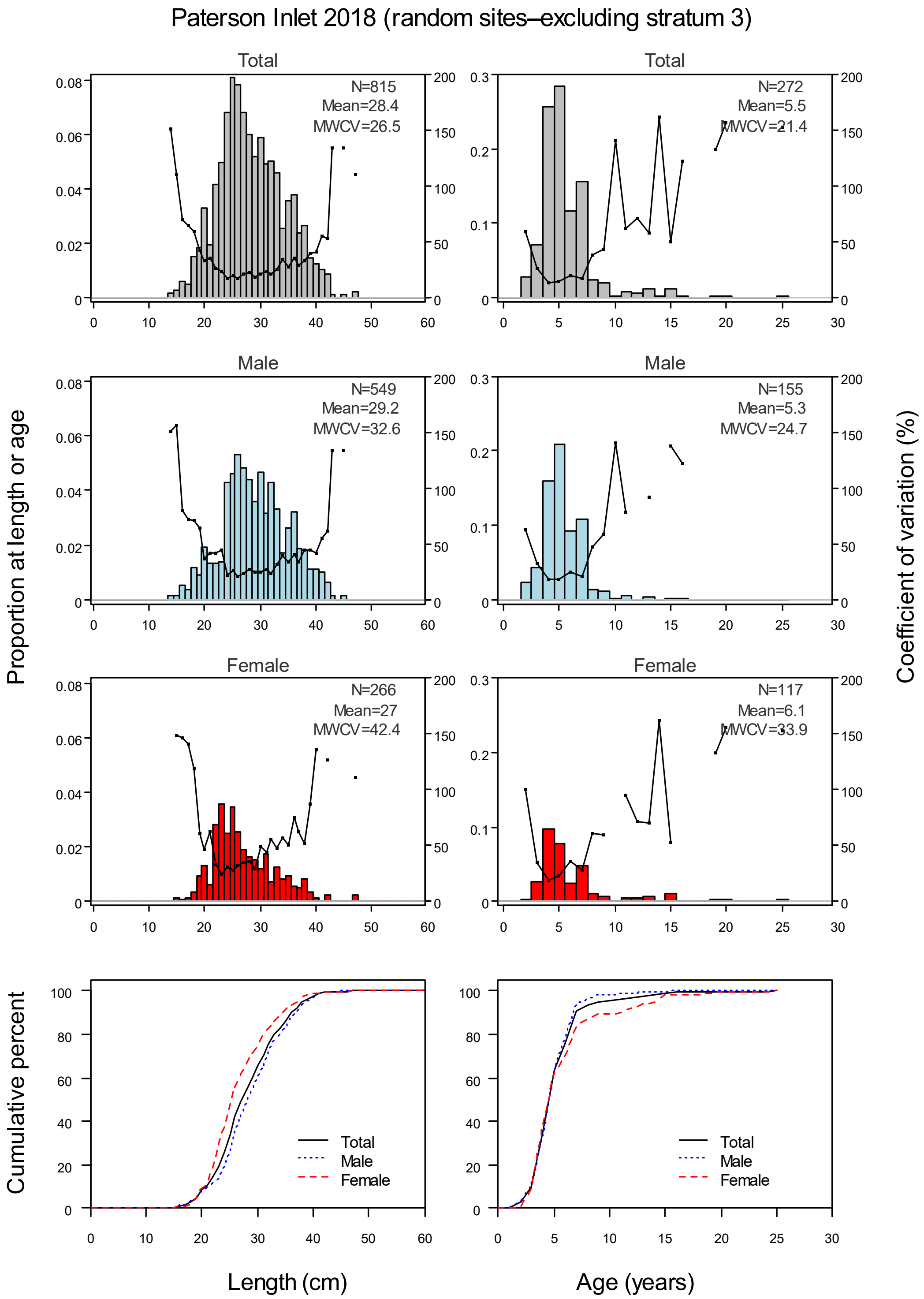

Figure 9: Scaled length frequency, age frequency, and cumulative distributions for total, male, and female blue cod for all strata (excluding the marine reserve – stratum 3) in the 2018 Paterson Inlet random-site blue cod potting survey (N, sample size; MWCV, mean weighted coefficient of variation, %).

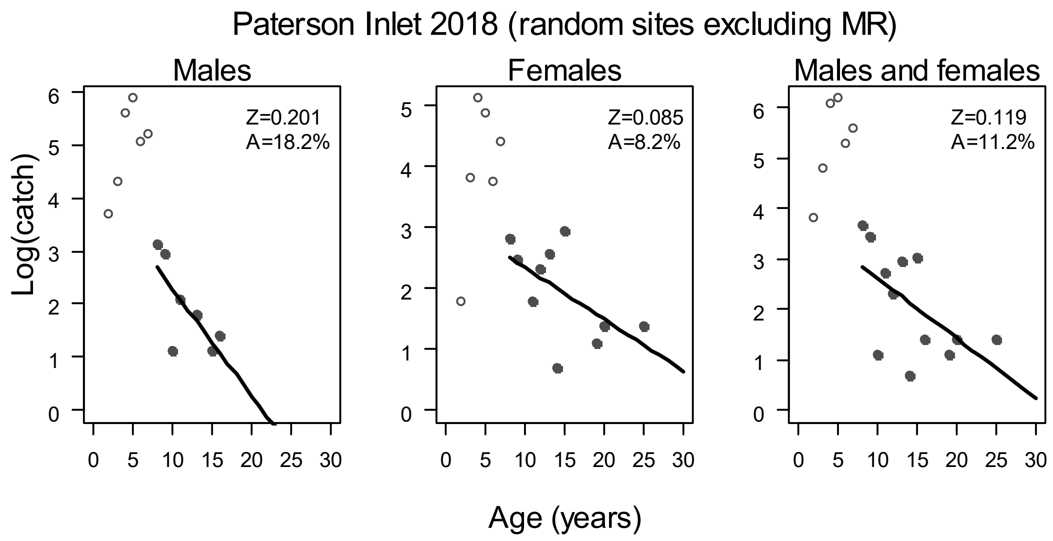

Figure 10: Catch curves (natural log of catch numbers versus age) for Paterson Inlet 2018 random-site survey. The regression line is plotted from age at full recruitment of 8 years (i.e., dark points on the graph). Z, instantaneous total mortality; A, the annual mortality rate or the proportion of the population that suffers mortality in a given year.

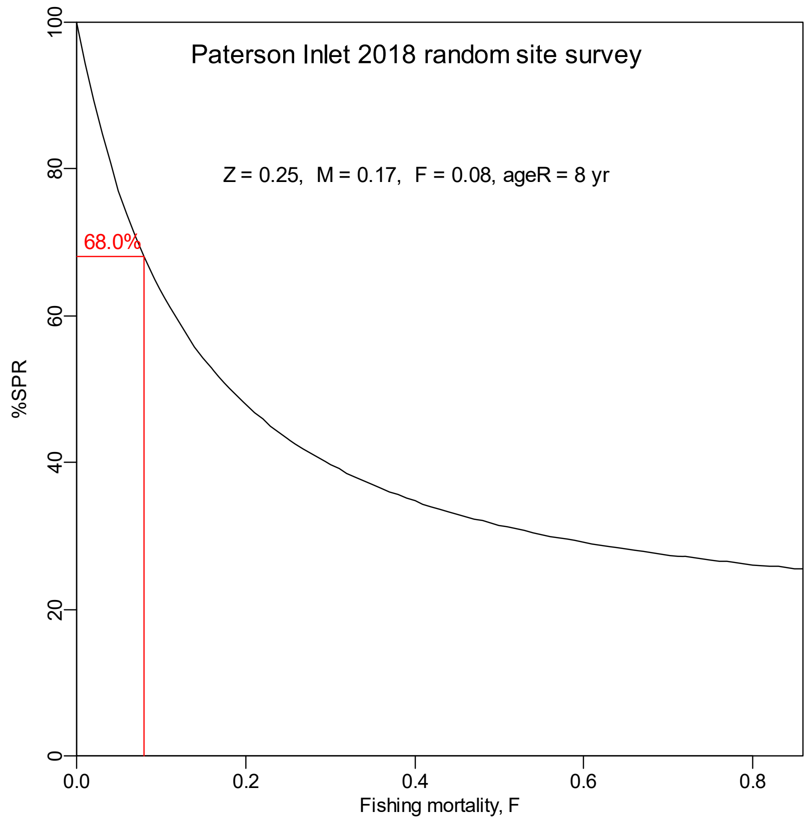

Figure 11: Spawner-per-recruit (SPR) as a function of fishing mortality (*F*) for the 2018 Paterson Inlet random-site survey. In this plot M = 0.17, and the F value is for age-of-full recruitment equal to 8 years for females.

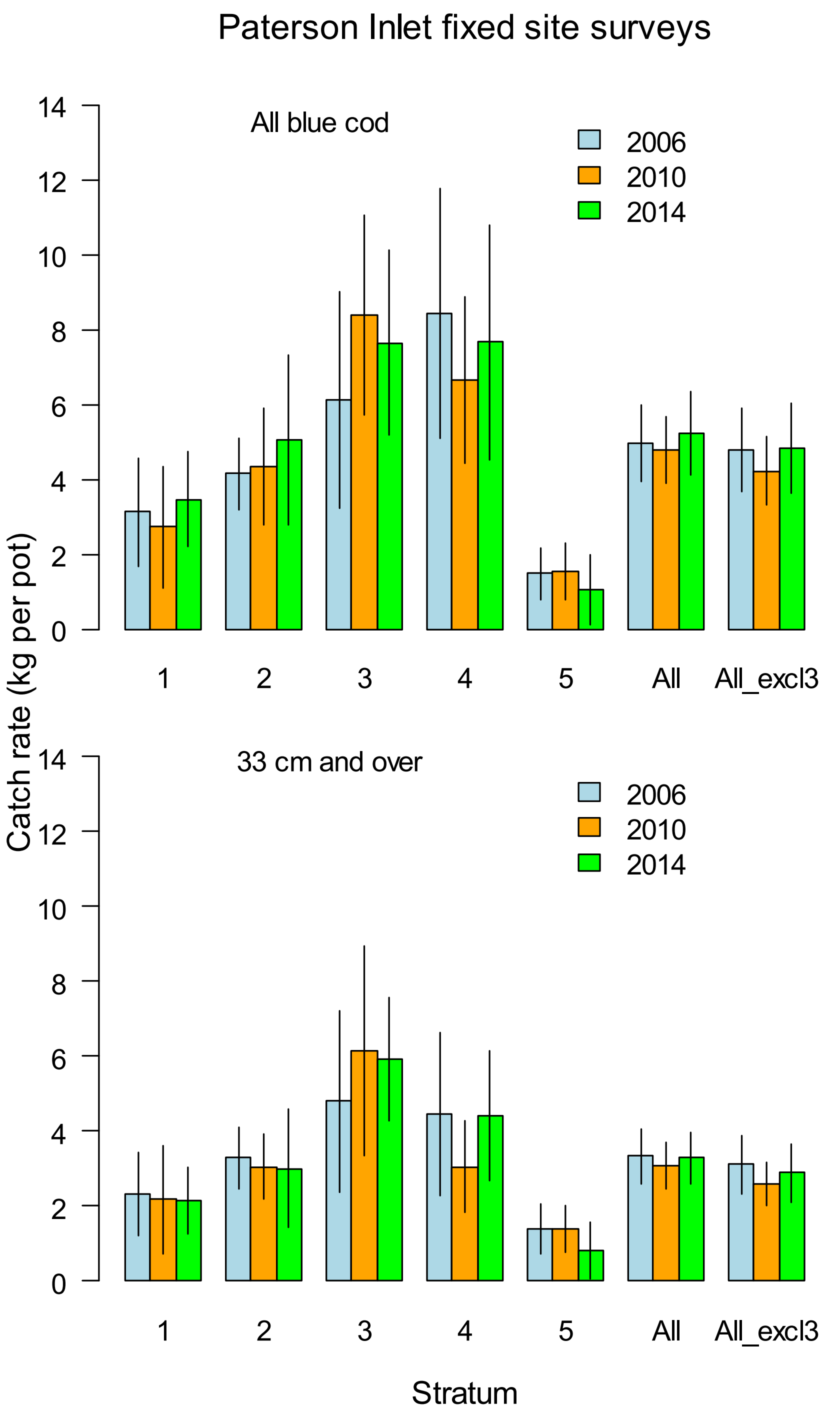

Figure 12: Mean catch rates (kg pot^{-1}) of all blue cod and for recruited blue cod (33 cm and over) for the Paterson Inlet fixed-site potting surveys in 2006, 2010, and 2014. Error bars are 95% confidence intervals. Sites in 2010 stratum 6 were reassigned to stratum 5 (see Figure 5).

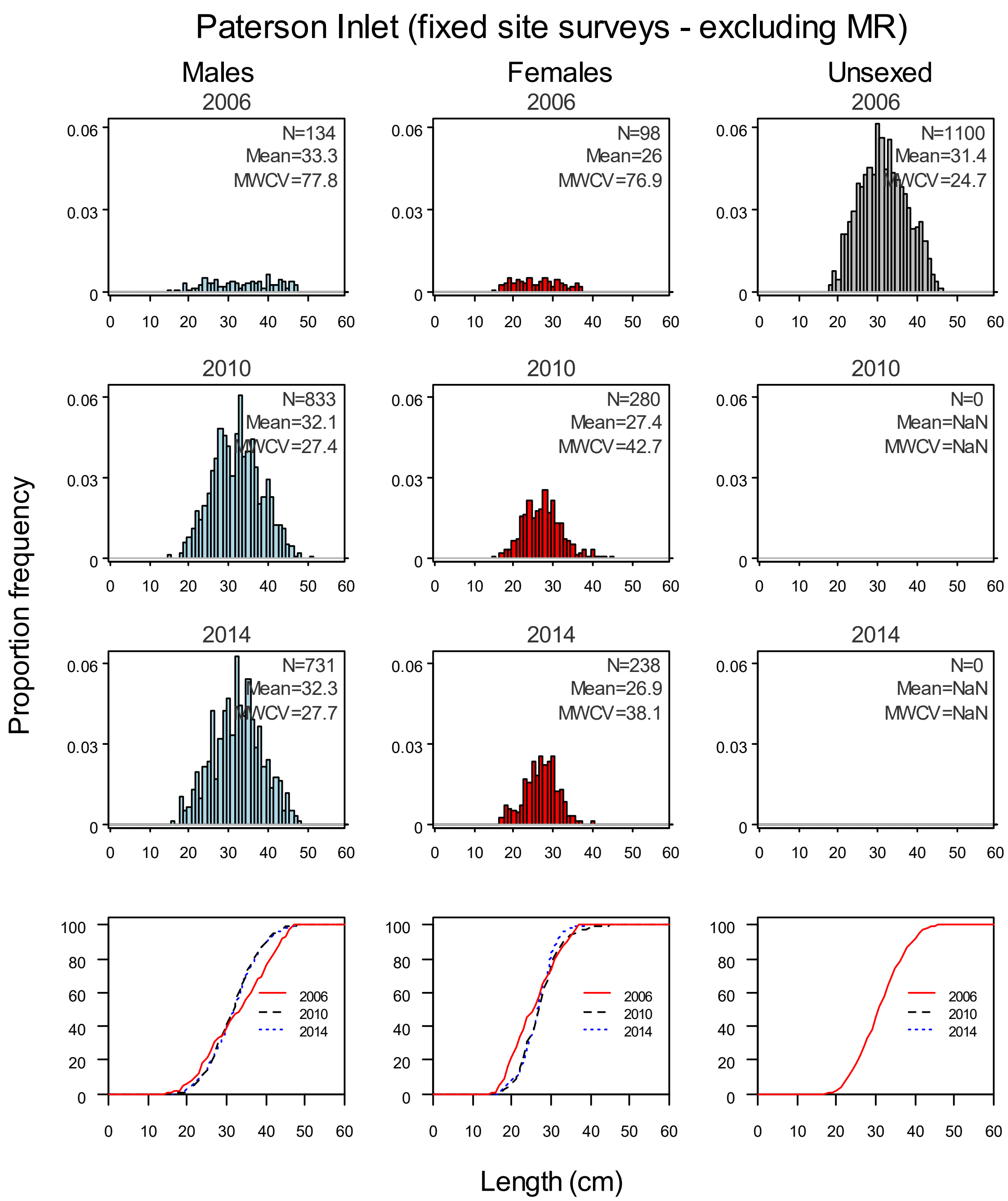

Figure 13: Scaled length frequency and cumulative distributions for male, female, and unsexed blue cod from Paterson Inlet fixed-site blue cod potting surveys in 2006, 2010, and 2014 (excluding the marine reserve). N, sample numbers; Mean, mean length (cm); MWCV, mean weighted coefficient of variation (%). In these surveys there were restrictions on the numbers of blue cod that could be killed inside the mātaitai and in 2010 and 2014 about half of the fish were sexed by 'milking' or squeezing the fish for signs of milt or eggs.

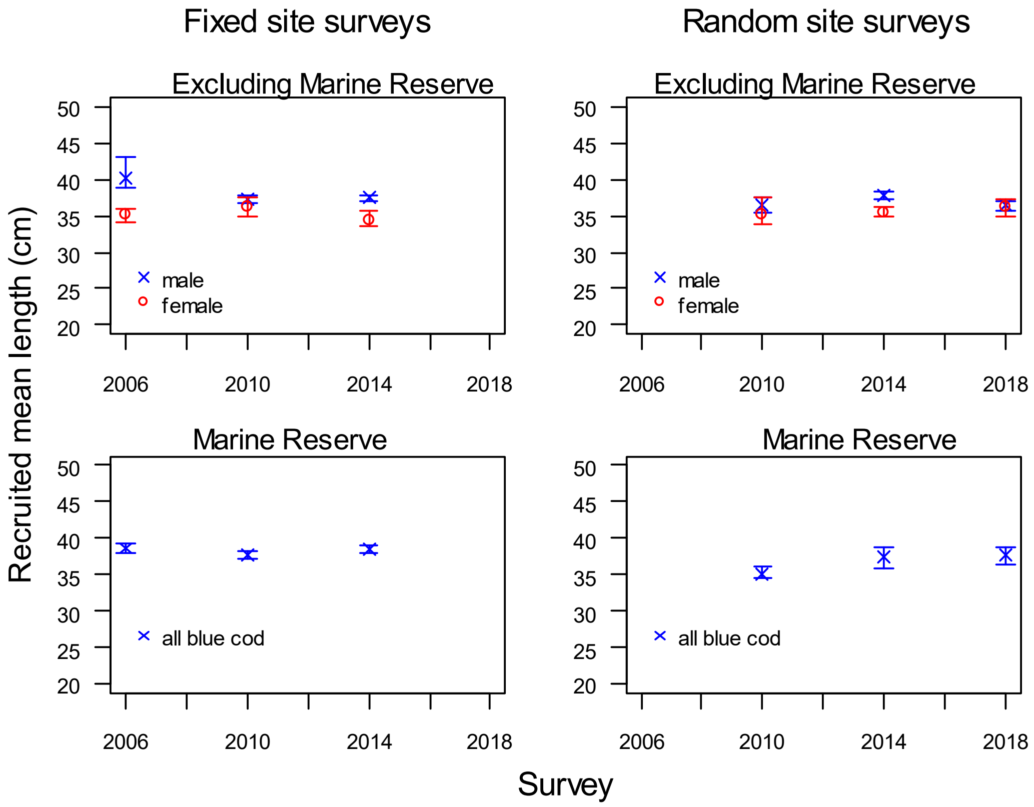

Figure 14: Mean length of recruited blue cod (33 cm and over) for males and females from Paterson Inlet fixed-site (2006, 2010, and 2014) and random-site blue cod potting surveys (2010, 2014, and 2018). Mean lengths are shown excluding the marine reserve (top panels) and only for the marine reserve (bottom panels). Error bars are 95% confidence intervals around the mean.

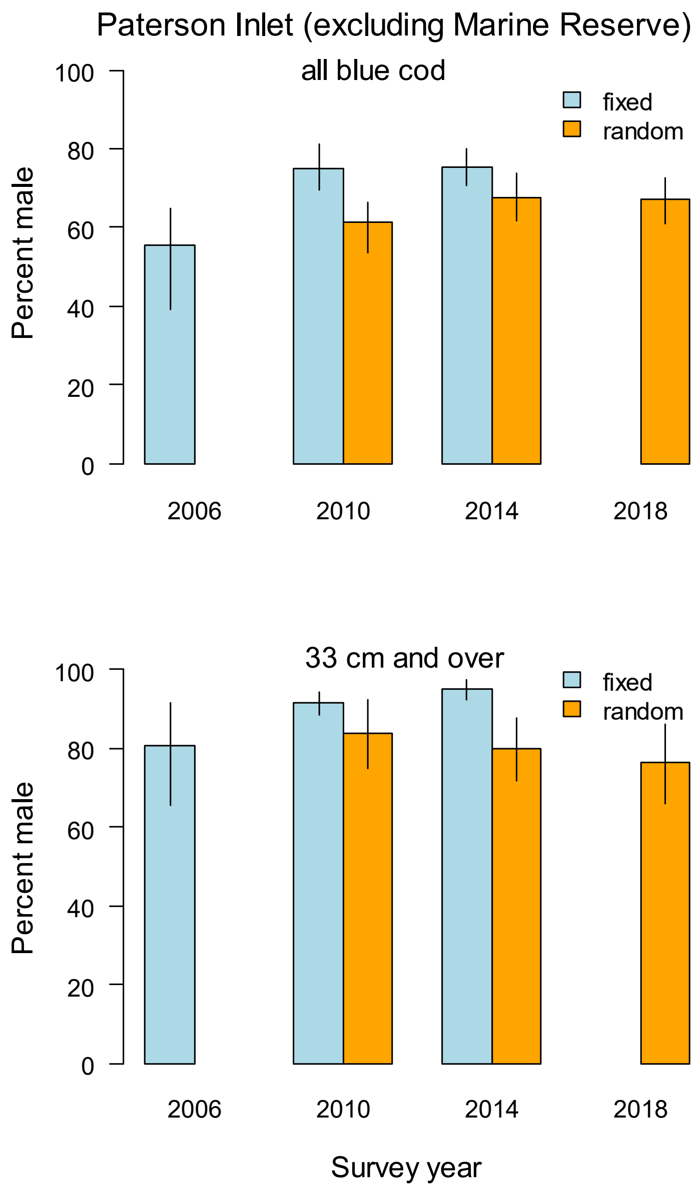

Figure 15: Proportion of males for all blue cod and recruited blue cod from Paterson Inlet fixed-site (2006, 2010, and 2018) and random-site (2010, 2014, and 2018) blue cod potting surveys excluding the marine reserve. 95% confidence intervals are shown. Most fish were unsexed in 2006.

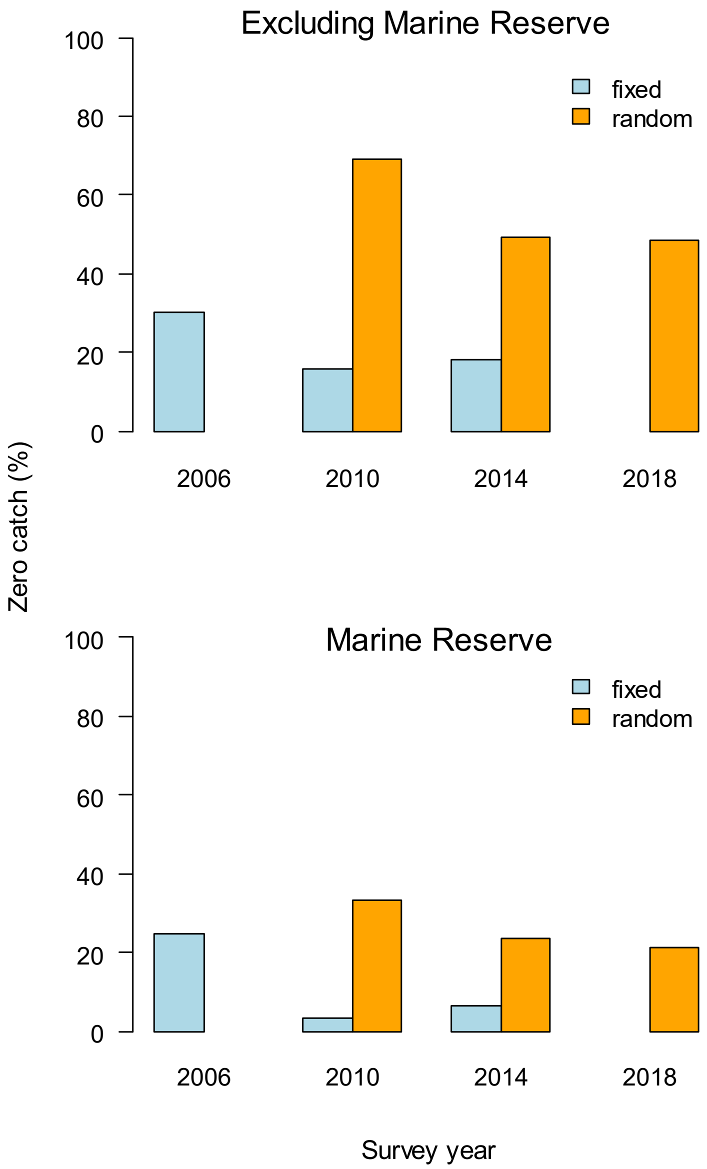

Figure 16: Proportion of pots with zero blue cod catch for the Paterson Inlet fixed-site (2006, 2010, and 2014) and the random-site potting surveys (2010, 2014, and 2018) excluding the Ulva Island Marine Reserve and within the marine reserve.

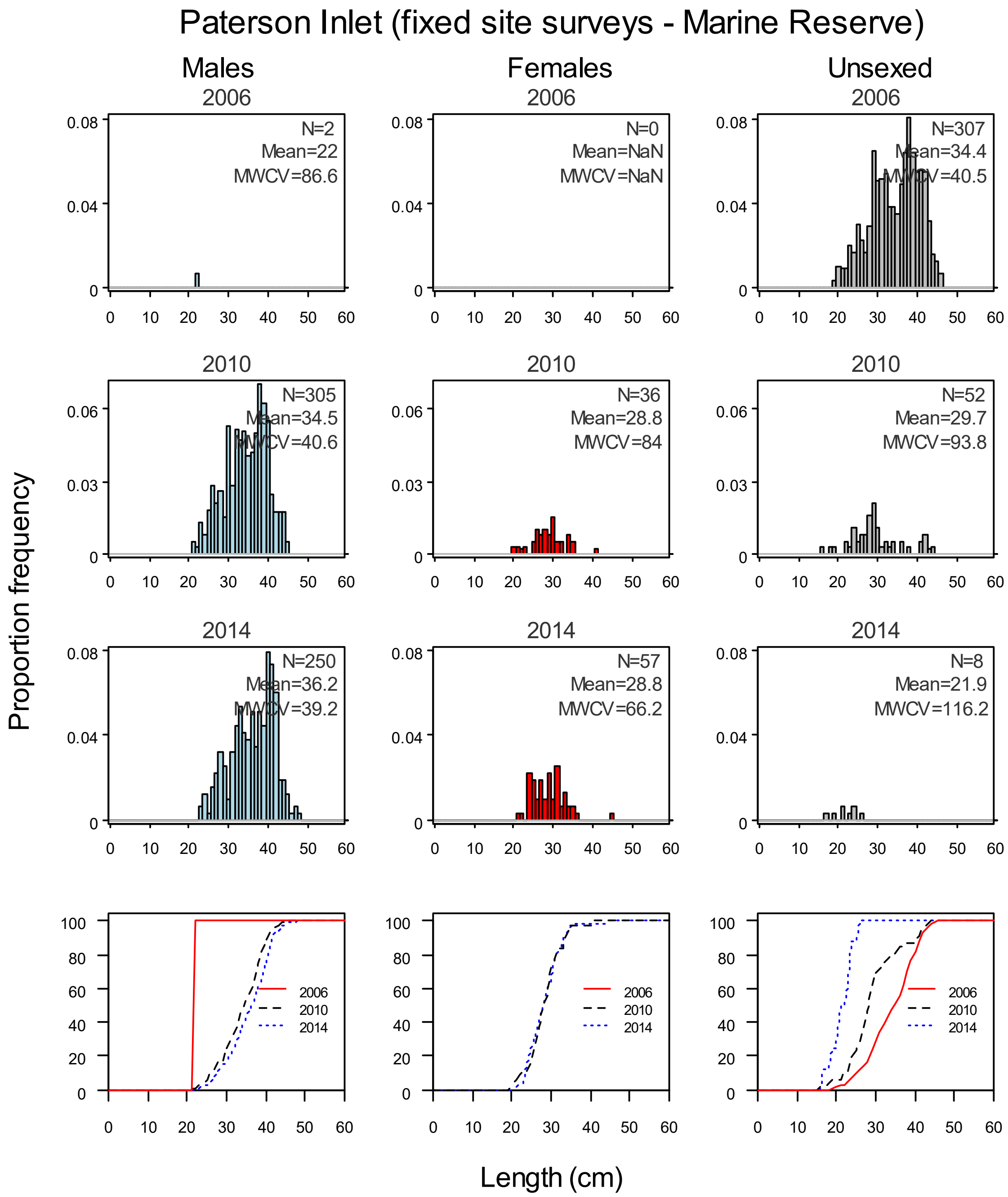

Figure 17: Scaled length frequency and cumulative distributions for male, female, and unsexed blue cod from Paterson Inlet fixed-site blue cod potting surveys in 2006, 2010, and 2014 in the marine reserve. N, sample numbers; Mean, mean length (cm); MWCV, mean weighted coefficient of variation (%). No blue cod were killed inside the Ulva Island Marine Reserve and fish were sexed by 'milking' or squeezing the fish for signs of milt or eggs.

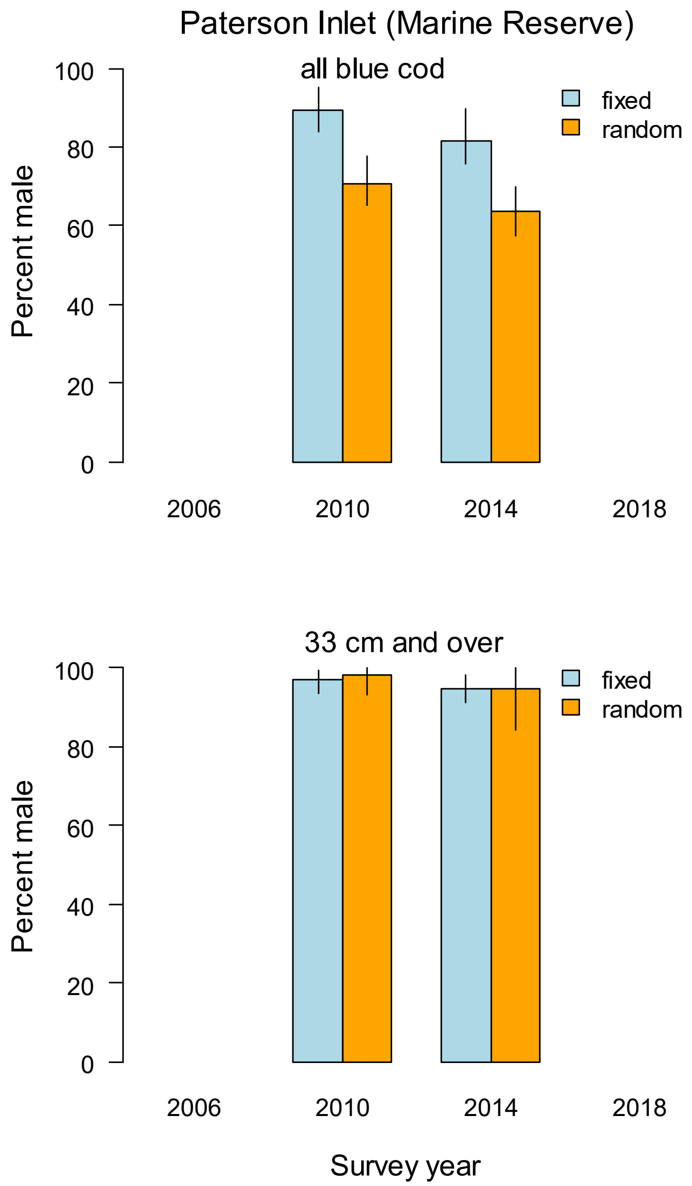

Figure 18: Proportion of males for all blue cod and recruited blue cod from Paterson Inlet fixed-site and random-site blue cod potting surveys inside the Ulva Island Marine Reserve in 2010 and 2014. 95% confidence intervals are shown. Most fish were unsexed in 2006 and 2018.

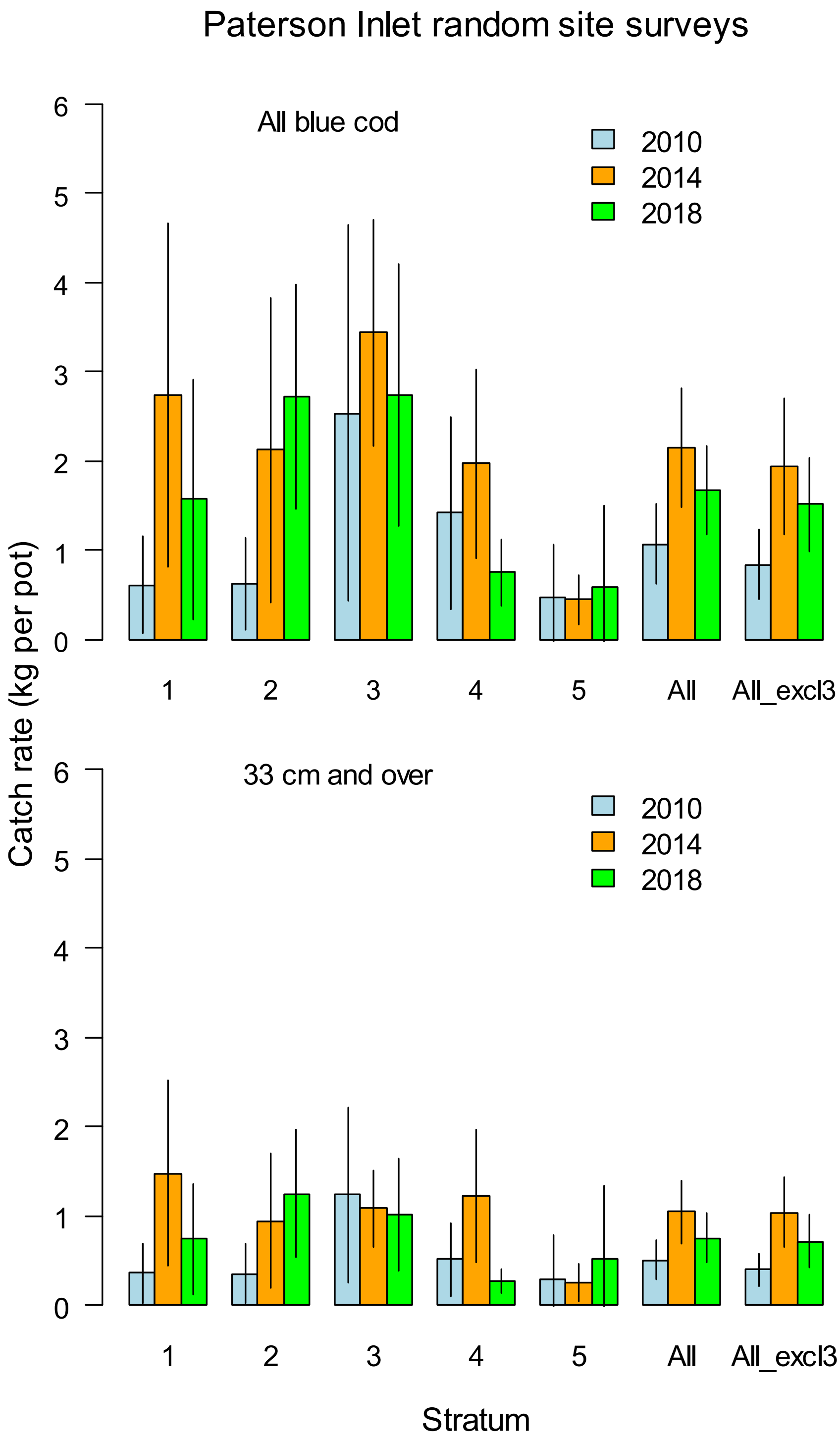

Figure 19: Mean catch rates (kg pot^{-1}) of all blue cod and for recruited blue cod (33 cm and over) for the Paterson Inlet random-site potting surveys in 2010, 2014, and 2018. Error bars are 95% confidence intervals.

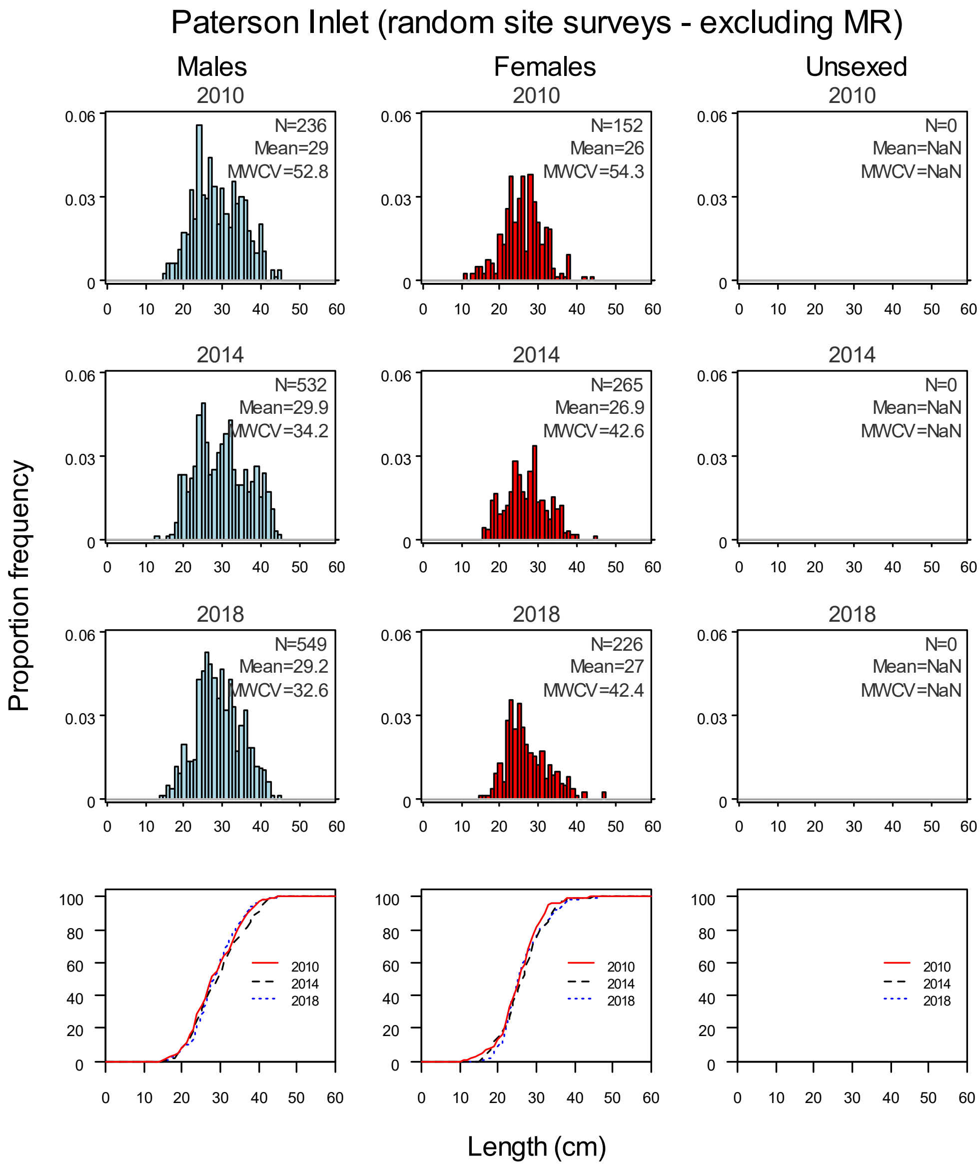

Figure 20: Scaled length frequency and cumulative distributions for male, female, and unsexed blue cod from Paterson Inlet random-site blue cod potting surveys in 2010, 2014, and 2018 (excluding the marine reserve). N, sample numbers; Mean, mean length (cm); MWCV, mean weighted coefficient of variation (%). In 2010 and 2014 there were restrictions on the numbers of blue cod that could be killed inside the mätaitai and about half of the fish were sexed by 'milking' or squeezing the fish for signs of milt or eggs. No restrictions were in effect for the 2018 survey.

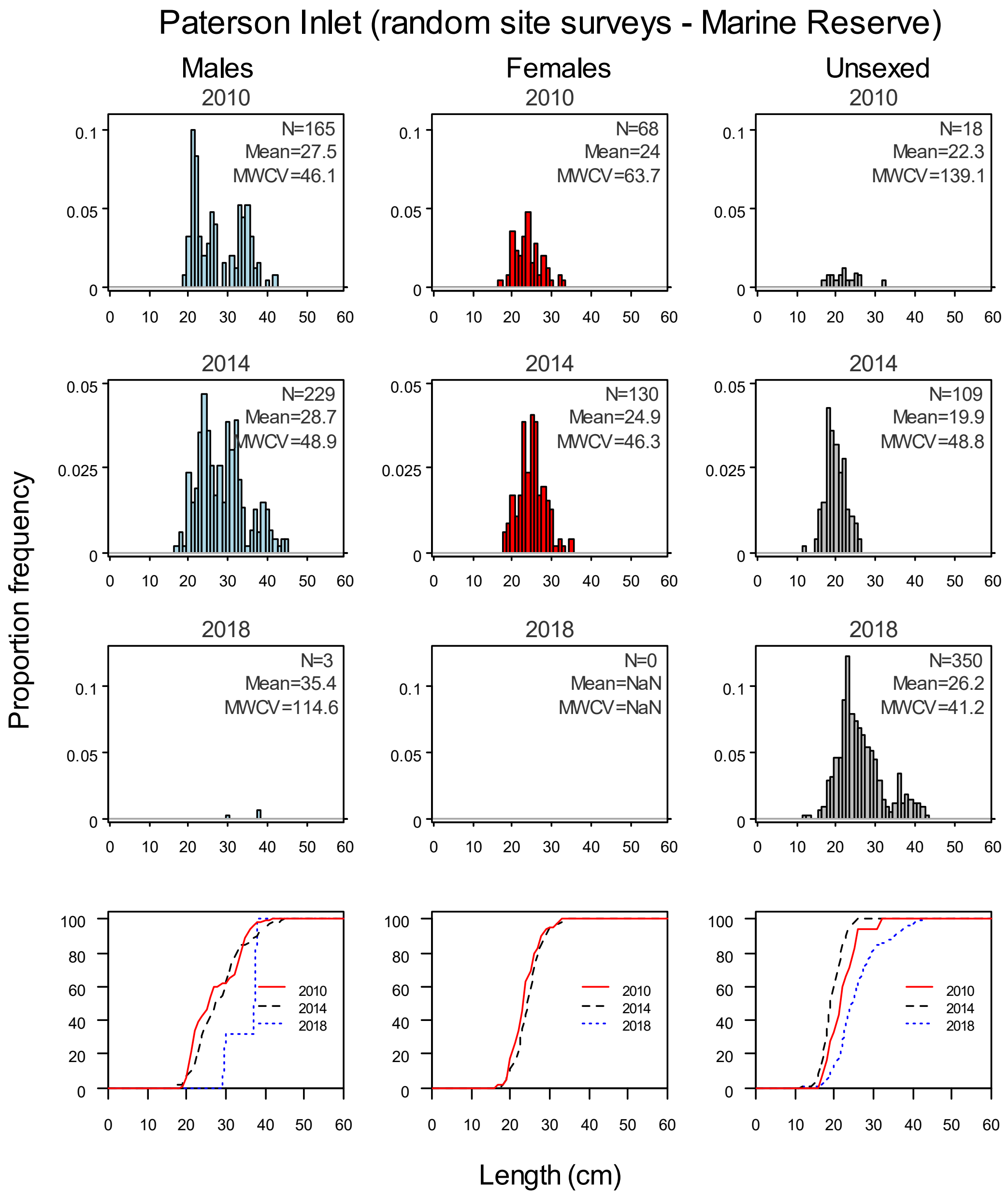

Figure 21: Scaled length frequency and cumulative distributions for male, female, and unsexed blue cod from Paterson Inlet random-site blue cod potting surveys in 2010, 2014, and 2018 in the marine reserve. N, sample numbers; Mean, mean length (cm); MWCV, mean weighted coefficient of variation (%). No blue cod were killed inside the Ulva Island Marine Reserve and fish were sexed by 'milking' or squeezing the fish for signs of milt or eggs.

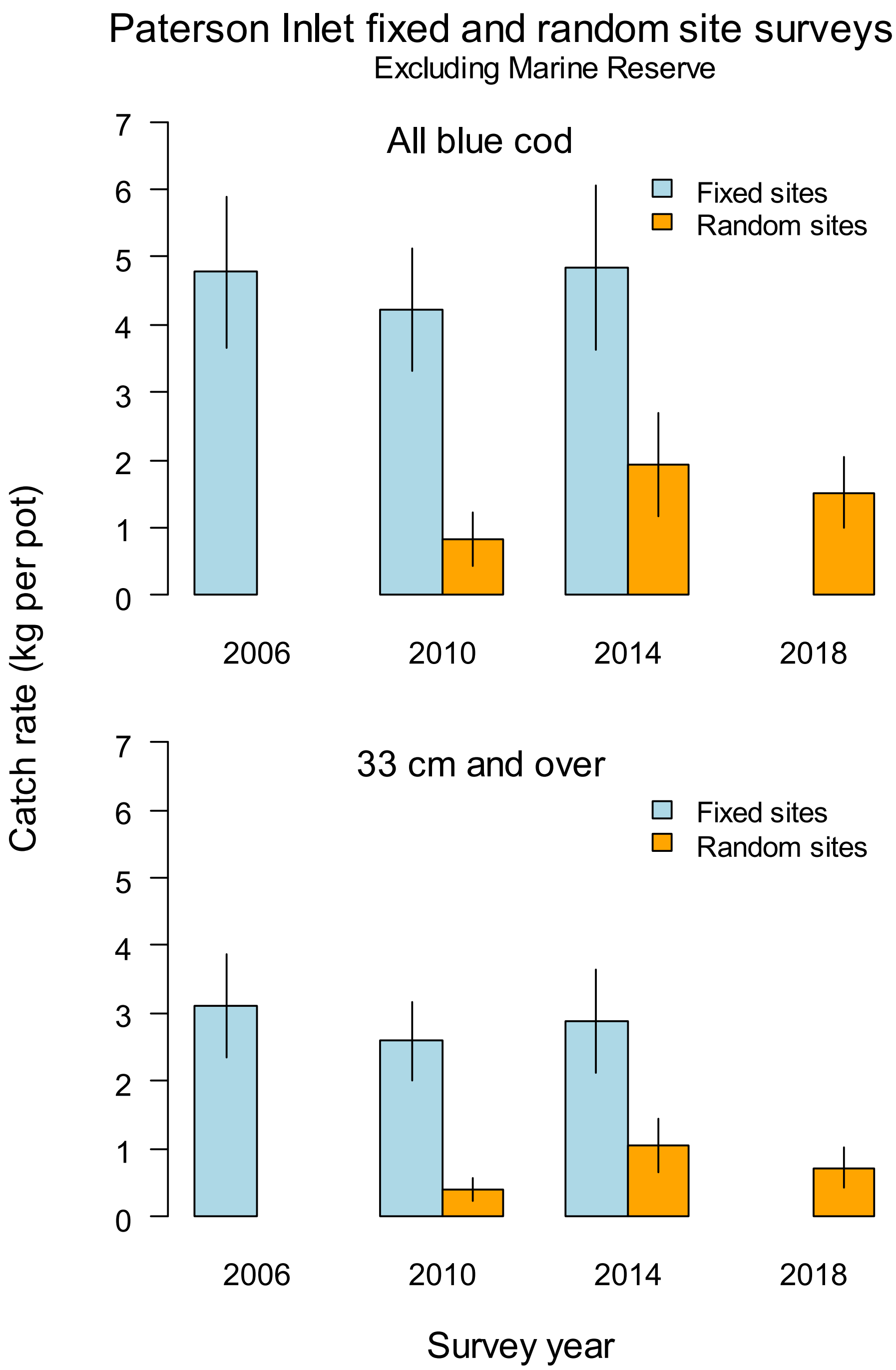

Figure 22: Catch rates (kg pot^{-1}) of all blue cod and recruited blue cod for the Paterson Inlet fixed- and random-site potting surveys, excluding the marine reserve. The 2010 and 2104 surveys were concurrent. Error bars are 95% confidence intervals.

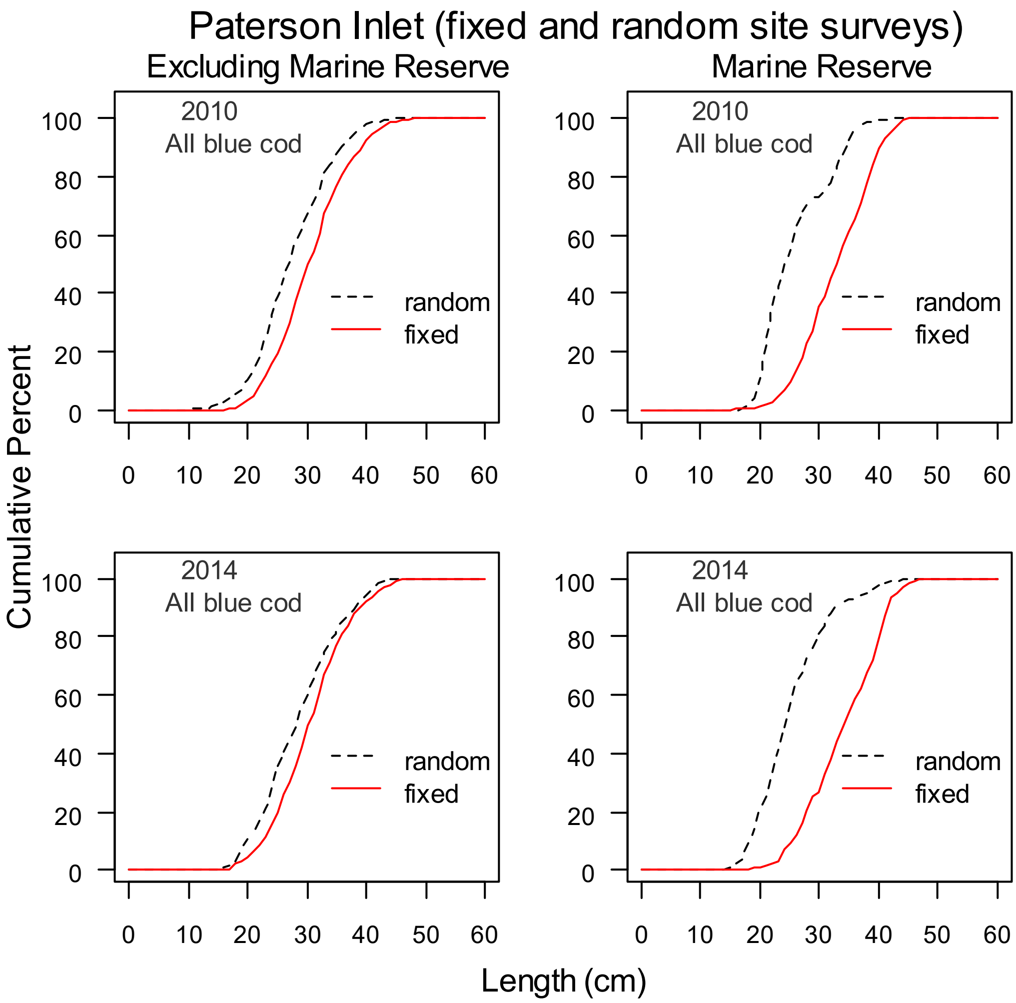

Figure 23: All blue cod scaled cumulative length frequency distributions for the 2010 and 2014 concurrent Paterson Inlet fixed- and random-site blue cod potting surveys excluding, and inside, the marine reserve.

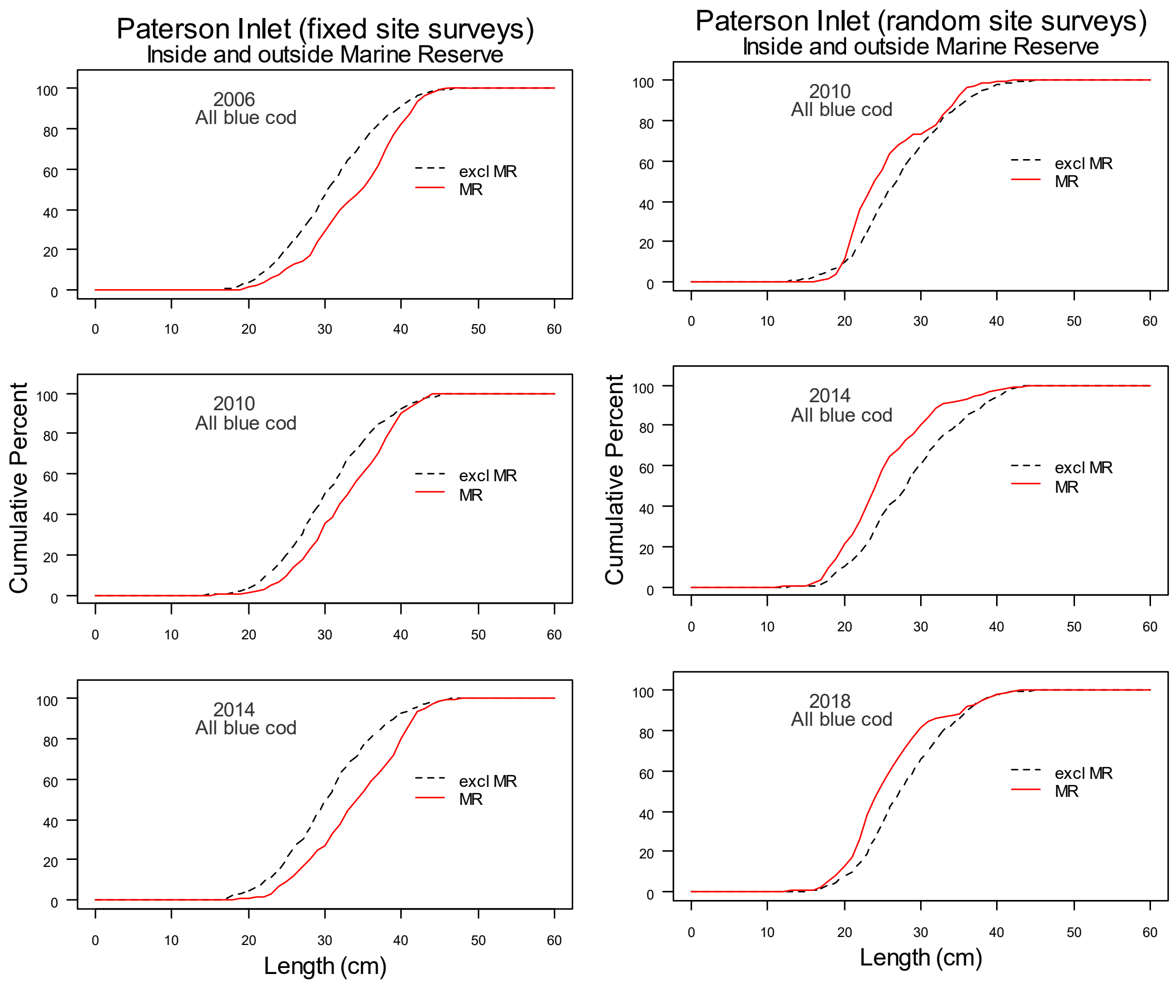

Figure 24: All blue cod scaled cumulative length frequency distributions for the Paterson Inlet fixed-site surveys (2006, 2010, and 2014) and the random-site surveys (2010, 2014, and 2018) inside, and outside, the marine reserve.

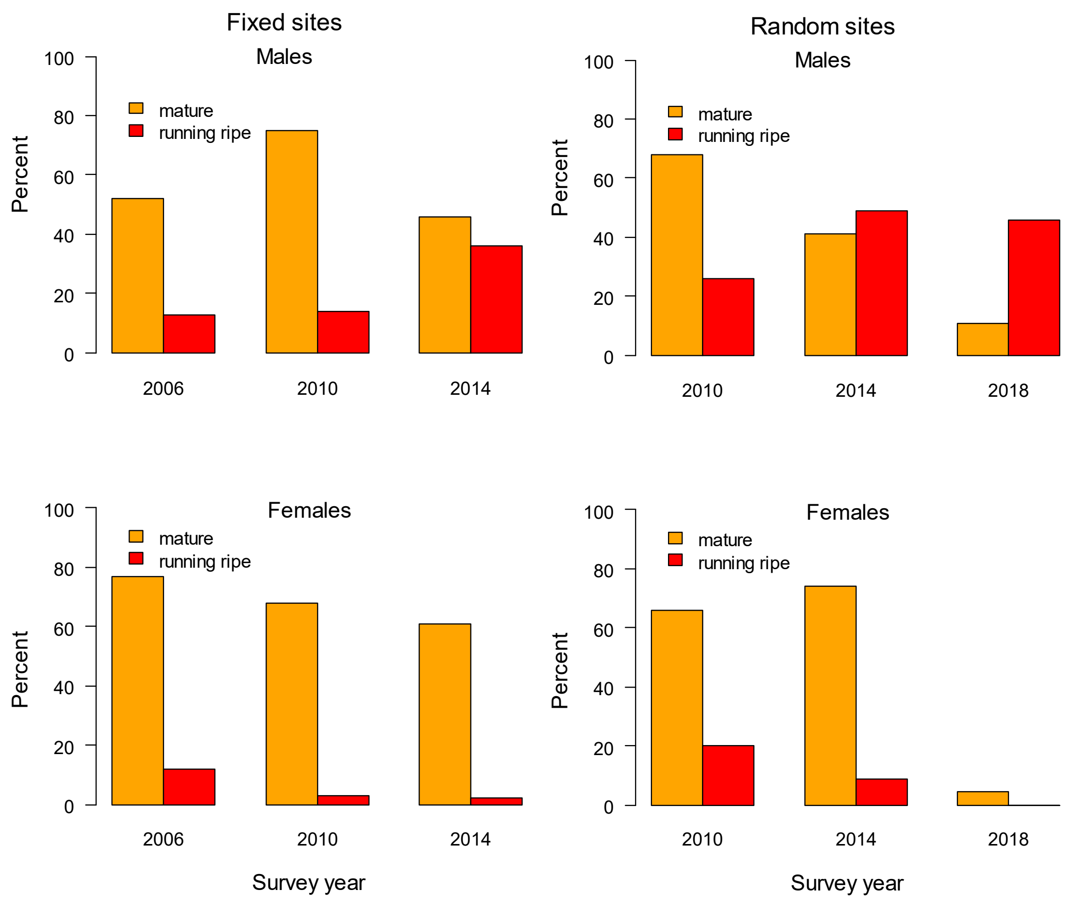

Figure 25: Blue cod percentage mature and running-ripe states for the Paterson Inlet fixed-site surveys (2006, 2010, and 2014) and the random-site surveys (2010, 2014, and 2018).

8. APPENDICES

Appendix 1: Glossary of terms used in this report (modified from Beentjes 2019). See the potting survey standard and specifications for more details.

Fixed site	A site that has a fixed location (single latitude and longitude or the centre point location of a section of coastline) in a stratum and is available to be used repeatedly on subsequent surveys in that area. The fixed sites used in a survey are randomly selected from the list of all available fixed sites in each stratum. Fixed sites are sometimes referred to as index sites or fisher-defined sites and were defined at the start of the survey time series (using information from recreational and commercial fishers)
Pot number	Pots are numbered sequentially (1–6 or 1–9) in the order they are placed during a set. In the Foveaux Strait survey six pots were used.
Pot placement	There are two types of pot placement: **Directed**–the position of each pot is directed by the skipper using local knowledge and the vessel echosounder to locate a suitable area of reef/cobble or biogenic habitat. **Systematic**–the position of each pot is arranged systematically around the site, or along the site for a section of coastline. For the former site, the first pot is set 200 m to the north of the site location and remaining pots are set in a hexagon pattern around the site, at about 200 m from the site position.
Random site	A site that has the location (single latitude and longitude) generated randomly within a stratum, given the constraints of proximity to other selected sites for a specific survey.
Site	A geographical location near to which sampling may take place during a survey. A site may be either fixed or random. A site may be specified as a latitude and longitude or a section of coastline (for the latter, the latitude and longitude at the centre of the section is used).
Site label	An alphanumeric label of no more than four characters, unique within a survey time series. A site label identifies each fixed site and also specifies which stratum it lies in. Site labels are constructed by concatenating the stratum code with an alpha label (A–Z) that is unique within that stratum. Thus, sites within stratum 2 could be labelled 2A, 2B, and sites in stratum 3 could be labelled 3A, 3B etc. Site labels for random sites are constructed in the same way but prefixed with R (e.g., R4A, R4B etc.).
Station	The position (latitude and longitude) at which a single pot (or other fishing gear such as ADCP) is deployed at a site during a survey, i.e., it is unique for the trip.
Station number	A number which uniquely identifies each station within a survey. The station number is formed by concatenating the set number with the pot number. Thus, pot 4 in set 23 would be *station_no* 234. This convention is important in enabling users of the *trawl* database to determine whether two pots are from the same set. Note that the set numbers for potting surveys are not recorded anywhere else in the *trawl* database.

Appendix 2: Numbers of otoliths collected during the 2018 Paterson Inlet survey for males and females, by stratum and length class. Lgth, length.

						Males
	Stratum					
Lgth (cm)	1	2	3	4	5	Totals
14				1		1
15				1		1
16	1			1		2
17		1				1
18	1			2		3
19		1		1		2
20	1	2		3		6
21	2	1		3		6
22	3	1		3		7
23	1	2				3
24	1	2		4		7
25	2	1		2		5
26	1	2		2		5
27	1	2		3		6
28	2	1		3		6
29	2			3		5
30	1	2		3		6
31	1	2		3		6
32	1	3		3		7
33	1	4		3	1	9
34	2	1		3		6
35	1	3		2		6
36		2		3		5
37	2	5		3	1	11
38	1	4		1		6
39	1	6		1		8
40	1	2		3		6
41	1	2			2	5
42	3	1				4
43	1					1
44						
45		1				1
46						
47						
48						
49						
50						
Totals	35	54		60	4	153

	Females					
	Stratum					
Lgth (cm)	1	2	3	4	5	Totals
15				1		1
16				1		1
17				1		1
18	1					1
19	3			3		6
20	1	2		3		6
21	2	1		1		4
22	1	2		2		5
23	1	2		2		5
24	2	1		1		4
25	1	2		4		7
26	3	2		3		8
27		3		2		5
28	1	2		1		4
29	2	3		3		8
30	1	3		3		7
31	2	1		4	1	8
32	1	2		2		5
33	2	2		1	2	7
34		2		1		3
35	3	1		1		5
36	1	2			1	4
37	1	2				3
38		4			1	5
39		1			1	2
40	1					1
41						
42					1	1
43						
44						
45						
46						
47					1	1
48						
49						
50						
Totals	30	40	0	40	8	118