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Length and age structure of commercial landings of blue cod in BCO 5 (2017 and 2018), and characterisation of the fishery

New Zealand Fisheries Assessment Report 2019/56

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ISSN 1179-5352 (online)
ISBN 978-1-99-000864-1 (online)

October 2019

New Zealand Government

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New Zealand Fisheries Assessment Report 2019/56. 58 p.

The results of catch sampling and catch-at-age analyses of the commercial blue cod fishery in BCO 5 in 2017–18 and the first quarter of 2018–19 fishing years are presented, together with a commercial fishery characterisation (1999–2000 to 2017–18).

The target pot fishery in BCO 5 accounts for most of the commercial catch, with the fishery focused in Foveaux Strait (Statistical Area 025) and the adjoining areas, including the coasts of Stewart Island and Fiordland (Statistical Areas 027, 029, 030, 031). The fishery operates year-round, with patterns in the spatial and temporal distribution of fishing varying little since the early 2000s.

Most of the commercial catch in BCO 5 is landed in a processed state (i.e. gutted, or headed and gutted), precluding the use of conventional landings-based catch-at-age sampling. A hybrid sampling programme was designed for BCO 5 which involved recruiting a small pool of fishers to retain the catch from the first pot hauled each day in a green (unprocessed) state. These catches were labelled and landed for sampling ashore.

In the months of November to September of the 2017–18 fishing year 2091 blue cod from Statistical Areas 025, 027, 029 and 030 were measured for length, and of these 359 males and 318 females were also sexed and had otoliths removed for ageing In the first quarter of 2018–19, 356 fish from Statistical Areas 025 and 027 were measured for length, and 88 males and 39 females were also sexed and had otoliths removed for ageing.

Scaled length frequency distributions in 2017–18 were unimodal, with no clear differences in the distributions by sex, except that the largest fish tended to be males. Overall, males were larger in areas 027 and 029 than in 025 and 030, and females were larger in area 027 and smaller in 025, but the differences in females were less marked. Mean lengths by area ranged from 37.8–41.9 cm for males and 36.7–38.1 cm for females. The percent of blue cod that was male by area ranged from 42.5–59.8%, and overall was 50.3% for BCO 5.

In 2017–18, the age range was 5–15 years for males and 5–21 for females, with 80% of fish less than 11-years-old. There was a wide range in length-at-age. Males generally grew faster and comprised most of the largest fish, but the oldest fish were the slower growing females. Length at age for females older than 10 years was consistently larger in Statistical Areas 027 and 029 than in 025 and 030 indicating that there may be geographic differences in growth or exploitation rates within BCO 5. Mean ages by area ranged from 7.4–8.2 cm for males and 8.6–11.8 cm for females, and for all fish were 7.8 cm and 9.8 cm respectively.

Statistical Area 025 had strong age classes for 6, 8, and 10-year-old males, and 8 and 12-year-old females. Similarly, there was a strong 8-year-old mode in area 029 and a strong-12-year old mode in area 030. The dominant age classes were not consistently present in all areas, indicating that there may be differences in year-class strengths and recruitment patterns across BCO 5. Low sample sizes and high CVs limit the interpretation of these data. There are too few data in 2018–19 to meaningfully summarise, but the three strong male ages classes in area 025 in 2017–18 progressed to be strong age classes in the following year.

1. INTRODUCTION

The results of catch sampling and catch-at-age analyses of the commercial blue cod fishery in BCO 5 in 2017–18 and the first quarter of 2018–19 fishing years are presented, together with a commercial fishery characterisation (1999–2000 to 2017–18).

1.1 The BCO 5 commercial fishery

The blue cod (*Parapercis colias*) commercial fishery in Southland has had documented catches since the 1930s (Middleton et al. 2013). Historically blue cod were predominantly taken by line fishing, but in the mid-1980s a pot fishery rapidly developed and is now the prevalent commercial fishing method (Middleton et al. 2013). The commercial catch from the BCO 5 fishery is almost exclusively taken by the target cod pot fishery operating within Foveaux Strait and around Stewart Island (Statistical Areas 025, 027, 029 and 030) (Fisheries New Zealand 2019) (Figure 1). Most blue cod fishing is from small inshore vessels (less than 15 m), setting around six pots in a set, which is allowed to soak for about an hour. In a day, four to five sets might be carried out, and the last set may be left to fish overnight on multi-day trips. Blue cod is a target fishery, caught using specialised pots that have a mesh size that allows fish under the minimum legal size (33 cm in BCO 5) to escape. The Fisheries (Commercial Fishing) Amendment Regulations 2017 amended the Fisheries (Commercial Fishing) Regulations 2001 with effect from 14 September 2017. As a result of the new Regulations 79A(1A) and 79A(1B), the minimum blue cod pot mesh size to be used by commercial fishers within the BCO 5 quota management area was increased from 48 mm to 54 mm, with the effect of further shifting the selectivity of the pots to larger fish.

BCO 5 supports the largest commercial blue cod fishery in New Zealand, with annual catches of 1000–1400 t in the ten years up to 2017–18. The recreational fishery in BCO 5 is considerably smaller, with harvest estimated at 44 t in 2011–12 and 67 t in 2017–18 (Fisheries New Zealand 2019). About half of the BCO 5 commercial catch is from Statistical Area 025 (Foveaux Strait), and 20% from each of Statistical Areas 030 (west of Stewart Island) and 027 (east of Stewart Island) (Figure 1) (Haist et al. 2013). Most of the catch is landed in a processed state such as headed and gutted (HGU), gutted (GUT), or fillets with skin on (FIL), with very little landed in the green or whole state (GRE).

Catch rates of blue cod are regarded by commercial fishers as ‘fickle’ in the sense that, within a short space of time, catches can increase or drop-off dramatically, presumably a consequence of feeding behaviour. Blue cod are caught from about 5 m to as deep as 200 m and tend to be distributed heterogeneously in association with preferred habitat, which can be rocky reef through to cobbles and shell substrata, and less commonly on mud and sand. Blue cod are found throughout Foveaux Strait (Statistical Area 025) which offers substantial and varied blue cod habitat, both inshore, within the strait, and around the many rugged islands to the east, although this area is dominated by patches of sand and gravel (Beentjes et al. 2019).

1.2 Previous BCO 5 commercial fishery sampling

Catch sampling of BCO 5 was last carried out in the period 2009 to 2011 as part of the ‘Ecosystem Spatial Management for blue cod’ (ESM) research programme (Middleton et al. 2013). There were two catch sampling components to the ESM programme: 1) a logbook project where commercial fishers recorded blue cod length (unsexed) and catch location at-sea, and 2) shed-sampling of blue cod landings recording length, sex and Statistical Area caught. The mean length of blue cod from shed sampling was smaller than that from the logbook project, which is thought to have arisen as a result of problems with the representativeness of the sampling (Haist et al. 2013). The smaller size from shed samples was attributed to more frequent landings sampled from locations closer to the home ports since samples were required to be landed green. These length data were subsequently used in a length-based stock assessment model for BCO 5 in 2013 (Haist et al. 2013). A new age-determination protocol for blue cod

was finalised in 2017 (Walsh 2017) and the results from the present study were used in a new age-based stock assessment (Fisheries New Zealand project BCO201801).

1.3 Fishery independent potting surveys in BCO 5

There have been three Fisheries New Zealand random-site blue cod potting surveys carried out in Foveaux Strait (in February of 2010, 2014 and 2018) covering most of Statistical Area 025 and a small northern part of Statistical Area 027 (Carbines & Beentjes 2012, Carbines & Haist 2017, Beentjes et al. 2019). These surveys provide data on relative abundance, growth, and length and age structure of the blue cod population in and around Foveaux Strait. Overall there were no trends in abundance, length and age distributions, or sex ratio across the three surveys. An additional industry funded random-site blue cod potting survey within Statistical Area 030 was carried out from March to June 2010 (Middleton et al. 2013).

1.4 Biology

Blue cod is a demersal fish species endemic to New Zealand and belongs to the family Pinguipedidae, often referred to as sandperches. Blue cod 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, contrary to an expected dominance of females resulting from selective removal of the larger male fish (Beentjes & Fenwick 2017, Beentjes & Sutton 2017, Beentjes et al. 2018). The shift towards a higher proportion of males in heavily fished blue cod populations may be caused by removal of the possible inhibitory effect of large males, resulting in a higher rate (and possibly earlier onset) of sex change by primary females. Foveaux Strait shows a balanced sex ratio of around 50% male from all three potting surveys (Beentjes et al. 2019). Despite having balanced sex ratios, there may be fishing induced sex change operating in Foveaux Strait, but the extent of sex change may be 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. Large dominant males hold defined territories within which they have a harem-based social structure of three to five females (Mutch 1983).

Blue cod tend to have a restricted home range (Rapson 1956, Mace & Johnston 1983, Mutch 1983) although tagging studies in Dusky Sound and Foveaux Strait have shown that while most blue cod move very little from the tagging location, some have been recaptured many kilometres away (Carbines & McKenzie 2001, Carbines & McKenzie 2004).

Growth in blue cod is highly variable among individuals, with a wide spread of length-at-age, and the maximum age is thought be about 32 years (Fisheries New Zealand 2019). After about 3 years of age, male growth exceeds that of females and the largest blue cod in a population generally tend to be males growing as large as 60 cm, although the oldest fish are frequently the slower growing females (Beentjes et al. 2019).

Blue cod are considered to be 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 that they will transition between the ripe and running-ripe conditions during this period.

1.5 Objectives

This in the final reporting requirement for Fisheries New Zealand research project BCO2015-01.

Overall Research Objective

To determine the length and age structure of commercial landings of blue cod in BCO 5.

Specific Research Objectives

1. To characterise the BCO 5 fishery by analysing existing commercial catch and effort data to the end of the 2017/18 fishing year.

2. To conduct representative sampling to determine the length, sex and age composition of the commercial catch of blue cod (*Parapercis colias*) in BCO 5 during the 2017/18 fishing year. The target coefficient of variation (CV) for the catch-at-age is 20 % (mean weighted CV across all age classes) combined across sexes.

2. METHODS

2.1 BCO 5 fishery characterisation

2.1.2 Data preparation

Statutory catch, effort and landings data for BCO 5 were sourced from Fisheries New Zealand. An initial characterisation using data to the end of September 2016 was carried out in order to design the sampling programme and this was updated to the end of December 2018 for this report.

Data were groomed within Trident's *kahawai* database which implements grooming methods described by Starr (2007) using code adapted from the groomer package (Bentley 2012). The grooming process implements error checks on both the effort and landings data.

Grooming of effort data used the logic described by Starr (2007) to correct likely erroneous or missing values in the reported target species, Statistical Area, primary method, date, time, position and units of effort. Likewise, the grooming of landings aims to correct likely erroneous or missing values in the reported date, destination type, state code, and conversion factor, and to remove duplicate landings.

Starr & Kendrick (2011) identified a transposition error that commonly occurs in the effort data from the BCO 5 fishery. On each fishing day cod pot fishers using CELR forms are required to enter the total number of pot lifts in the day, as well as the number of pots in the water at midnight at the start of the day. These are entered in adjacent columns on the CELR form, and Starr & Kendrick (2011) found them to be transposed in 25% of records such that the number of pots in the water at midnight is greater than the total pot lifts for the day. This issue is addressed in the *kahawai* grooming process and in this analysis 18% of records were corrected.

2.1.3 Fishery characterisation

The fishery characterisation was conducted using the individual effort records for all fishing methods. Landed catches were allocated to the fishing event records following the methodology of Starr (2007) and were predominantly allocated in proportion to the estimated catches associated with the fishing effort records.

2.2 Catch sampling design

Schofield et al. (2017) characterised the BCO 5 fishery and considered alternative sampling programme designs. Although a landings-based sampling programme was originally planned, the requirement for

assessing the sex of sampled fish necessitated a hybrid approach where fish specifically retained for the sampling programme were landed in a green (i.e. unprocessed) state.

Because the fishery normally lands processed catch, Fisheries New Zealand permitted catch for the sampling programme to be landed to stock code BCO 5E. Such landings were not required to be balanced with ACE.

2.2.1 Simulating sampling

The coverage likely to be achieved by different catch sampling designs for the BCO 5 cod pot fishery was assessed by simulation. Samples of eligible landings, trips, or days (depending on the design) were taken from by the relevant strata of the BCO 5 fishery until the sampling targets were attained. Replicate samples were taken to illustrate the levels of variation associated with a particular approach. The representativeness of the sampling achieved was assessed by comparing the proportions of sampled and total fishery catch by statistical area and month.

The simulations clearly demonstrated that sampling unprocessed fish (green) from regular fishery landings would not achieve sampling that was representative of the fishery (Figure 2). The hybrid sampling approach involved the recruitment of skippers that were willing to sample their catch using an approach defined under the programme. Simulations therefore considered the selection of a small pool of participating vessels with aggregate fishing patterns that were representative of the broader fleet when assessed at the statistical area and month level. Simulations indicated that sampling only from the vessels that were most active in the fishery tended to result in under-sampling of Statistical Area 025 (Figure 3). However, this could be addressed by selecting the vessels included in the sampling programme (Figure 4), albeit without achieving sampling of each statistical area in each month (Figure 5).

2.3 Catch sampling methods

2.3.1 At sea sampling procedures

Participating vessels were selected based on their historical fishing patterns and discussions with the vessel operator about their intended activity in 2018. Once a vessel was recruited to the programme, the operator was requested to sample one pot per day during all fishing trips undertaken in BCO 5. The sampled pot was the first pot hauled on each day fished.

Skippers were instructed to retain all the blue cod caught in the sampled pot, except those under the minimum legal size. The sampled fish were left in an unprocessed state, on ice in a labelled bin for sampling ashore. Bin tags were provided to participating vessels with fields for the following information:

- Unique bin number, with bins labelled sequentially through the trip
- Vessel name
- Skipper name
- Fish selector name – name of the person who selected the fish
- Fishing event start date
- Catch Effort form number (if available)
- Event start time (recorded as the time the sampling pot is lifted each day)
- Statistical Area
- Latitude and longitude – optional fields.

Skippers completed a Vessel Fish Selection form that duplicated the information from the bin tags. The information on this form provided a cross check that all sampled bins were received at the Licensed Fish Receiver (LFR) for sampling. All sampled fish were landed to Ngai Tahu Seafoods Ltd (Bluff), irrespective of the LFR that received the bulk of the landing. Skippers were asked to use the fishstock

code BCO 5E for the sampled fish in the landing data section of their Catch, Effort and Landing Return, and to exclude these fish from their Monthly Harvest Returns.

2.3.2 Processing of sampled fish

Trained factory staff sampled the fish ashore. Processing of the samples was dependent on factory workloads, and some samples were frozen for processing later rather than being processed immediately on receipt. Data were recorded in a manner designed for samples to be linked to the daily Catch, Effort and Landing return data.

For each fish in the sample, the total length was recorded. Lengths were recorded rounded down to the whole centimetre (e.g. 39.9 cm is recorded as 39 cm). Otoliths were taken from approximately every third fish, and sex was determined for these fish. The sampling forms indicated the fish from which otoliths should be taken and sex determined by highlighted rows that were preselected according to a randomised block design (i.e. one row in three was randomly highlighted). For fish from which otoliths were taken the number of otoliths recovered, and the number that were recovered broken, were recorded.

2.3.3 Sampling programme logistics

Participating skippers, and samplers at the participating LFR (Ngai Tahu Seafoods Ltd in Bluff), were trained by Trident Systems and the samplers were audited by NIWA.

2.4 Catch-at-length and -age analyses

2.4.1 Length and age composition

The estimated scaled numbers-at-length were calculated using Catch-at-length and -age frequency analysis program (CALA), developed by NIWA (Francis & Bian 2011). Length data were scaled by landed catch weights of blue cod from the sampled landings, and by commercial catch from the sampled strata, i.e., Statistical Areas 025, 027, 029 and 030. Scaled length-frequency distributions were estimated by sex, by Statistical Area, and overall for all areas combined. The mean-weighted coefficients of variation (MWCV) were estimated using a bootstrapping routine (1000 bootstraps).

The 'direct ageing' method was used to estimate the age composition of blue cod in BCO 5. This is also known as 'random age frequency sampling' where otoliths are collected from a random selection of all sampled fish, i.e., initially one-in-five fish measured for length but changed to one-in-three fish in January 2018. The original target number of otoliths to collect *a priori* was 1000 across the three Statistical Areas.

Age data were scaled in the same way as length data using CALA, and results presented by sex, by Statistical Area, and overall for all areas combined. The mean-weighted coefficients of variation (MWCV) were estimated by sex and overall using a bootstrapping routine (1000 bootstraps).

2.4.2 Otolith preparation and age determination

Preparation and reading of otoliths followed 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).

Otolith margin description (Line, Narrow, Wide) is determined according to the margin type anticipated *a priori* for the season/month in which the fish was sampled. The otolith is then interpreted and age determined based on the forced margin. The forced margin method is usually used in situations where fish are sampled throughout the year and otolith readers have difficulty correctly interpreting otolith margins. In this report, age conforms to the "fishing year age-class" of blue cod which is defined (following Ministry of Fisheries guidelines for New Zealand fish ageing protocols (Ministry of Fisheries 2011)) as the age of an age group at the beginning of the New Zealand fishing year (1 October). It does not change if the fish have a birthday during the fishing season. By chance, the nominal birthday of blue cod is taken as 1 October.

Between-reader ageing precision was assessed by the application of the methods and graphical techniques documented in Campana et al. (1995) and Campana (2001); including APE (average percent error) and coefficient of variation (CV).

2.4.3 Data storage

The 2017–18 and 2018–19 BCO 5 assigned catch sampling landing numbers were 20171001 to 20171004, and 20181001 to 20181062. At the completion of the sampling, data were entered into the *market* database and age data were entered into the *age* database in accordance with the database business rules. Otoliths are stored in the otolith library at NIWA, Wellington.

3. RESULTS

3.1 BCO 5 fishery characterisation

Landings

After excluding landings to non-terminal states (i.e. excluding records where the landing was to a temporary state, such as a holding pot, and therefore expected to be recorded again as a final landing), the majority of BCO 5 landings were to a Licensed Fish Receiver (Figure 6). Most landings were in a processed state, with gutted (GUT), and headed and gutted (HGU) states predominating (Figure 7). Landings in dressed (DRE) and fillet (FIL) states have reduced since 2006.

Catch and effort

Blue cod are taken by a range of fishing methods, but target cod potting (CP) has consistently accounted for most landings (Figure 8) since the 2000 fishing year. Potting effort has been reported using the Catch, Effort and Landing Return so spatial data on fishing patterns is limited to the resolution of the Statistical Areas illustrated in Figure 1. At this scale, the pot fishery shows a stable spatial pattern with the majority of catch being taken from Areas 025, 027, 029 and 030 (Figure 9). A small amount of catch is reported from rock lobster potting and using the rock lobster specific Statistical Areas. The fishery operates year-round with no strong seasonal pattern (Figure 10).

3.2 Catch sampling

Samples were obtained from 155 fishing days undertaken during 67 trips between 26 November 2017 and 13 December 2018. Over the course of the programme, seven vessels provided samples (Table 1). The decision to additionally sample the first quarter of the 2018–19 fishing year was made because there were only 24 otoliths collected from 4 landings in the first quarter of 2017–18.

Two aspects of catch-effort data reporting were highlighted as a result of the process of matching the samples to the statutory data. On one occasion, the only landings from a sampled trip related to catch that was transferred to another vessel. Green fish were recorded as landed to BCO 5E only on the subsequent trip.

Transhipments are rare in the BCO 5 fishery, being recorded on only two occasions in the 2018 fishing year. Effort from these trips was added back into the data set used for assessing the representativeness of sampling.

A small number of samples (n = 5) were matched to effort recorded as rock lobster potting (RLP) effort and using the rock lobster area codes. These were the only effort events recorded by the vessels on those days. Clarification was sought from one of the fishers, who confirmed that his main fishing on these occasions was targeting rock lobster, but he also set separate cod pots. The sampled cod was taken from the cod pots.

The recording only of the main fishing method for the day is a further example of the situation where the CELR reporting framework encourages fishers to generalise their reported fishing activity for the day (Langley 2014).

For these samples, the paperwork from the fishers (bin tag and CELR) confirmed the general Statistical Area from which the fish were sampled. For the purposes of the sampling programme (characterisation and representativeness), Statistical Area information was taken from the matched statutory data, except when a rock lobster statistical area was recorded.

There were five samples where the Statistical Area recorded by fishers at sampling (bin tag) did not match the statistical area in the catch-effort data, and this was not attributable to use of rock lobster areas. While these samples have been assigned to the area recorded in the catch-effort data, it is possible that fisher activity on these areas extended over multiple areas, but that the catch-effort recording only included the main area fished on the day.

Representativeness of sampling

During the period that the sampling programme was operating (1 October 2017 – 31 December 2018), 94 vessels landed (or transhipped) catches of BCO 5. For the purpose of assessing the representativeness of sampling, effort was restricted to the 58 vessels that reported any fishing by cod potting (CP) during the programme.

During the period of the programme these vessels undertook a range of fishing activity (Table 2). Notwithstanding the issue noted above with respect to mixed fishing activity, the bulk of the blue cod

catch is taken when vessels record cod potting activity. As a result, the sampling frame is considered to be the cod potting fishing activity only. Samples matched to rock lobster potting fishing events are considered to be samples of cod potting activity in the recorded General Statistical Area.

The sampling frame was further restricted to events where blue cod was reported as the target species. The small number of fishing events that met these conditions, but reported a Rock Lobster Statistical Area instead of a General Statistical Area, were dropped.

For the purposes of assessing representativeness of sampling, the catch from a vessel-day was considered to be sampled if a sample was taken by the vessel that day.

Overall, the sampling programme was representative of fishing in the four main Statistical Areas of the fishery (025, 027, 029, 030; Figure 11). Sampling representativeness by quarter (i.e. 3-month periods, beginning 1 October) was generally good, except that samples were not obtained from Statistical Areas 029 and 030 in quarter 4 of either 2017 or 2018 (Figure 12). At the monthly level, temporal representativeness was even worse (Figure 13).

Data quality assurance

Initial training of samplers, using fish from three landings, was carried out on 12 December 2017. The samplers were audited by NIWA on 23 January 2018, again using fish from three landings. The audit identified concerns about fish sexing during the first landing sampled, which were rectified for the subsequent landings. Samplers were also reported to be having difficulty with otolith extraction and some otoliths were broken.

Samplers were provided with further training on 20 February 2018, and a successful audit was conducted on 28 February 2018. Protocols around bin labelling were also addressed between the first and second audits.

A final audit was conducted on 25 January 2019, using samples collected in December 2018, with no concerns identified.

Data quality checks were conducted for each sample. In the case of the BCO 5 programme these focussed on assessing whether the sizes of fish sampled for sex and otolith data are representative of the larger sample of fish from which lengths were collected.

The sampling strategy was to extract otoliths and assess the sex of every *i*th fish, with the fish from which otoliths should be taken pre-selected according to a randomised block design. The sampling frequency was increased from every fifth fish to every third fish when it became apparent that some samples contained only small numbers of fish (Figure 14). Numbers of fish sampled by Statistical Area are shown in Table 3.

Aggregate distributions of length in the total fish sample and in the sub-sample from which otoliths had been taken (Figure 15 and Figure 16) suggest that in areas other than 025 there is a slight deficit of larger fish in the otolith sample. Samples from area 027 have the most extreme deviation between median fish length in the full sample and in the sub-sample from which otoliths had been taken (Figure 17).

There are no indications that samplers struggled to retrieve otoliths from fish of any particular size (Figure 18) or that otolith breakages were size dependent (Figure 19).

There is evidence that lengths with a unit digit of 5 are recorded more frequently than other digits (Figure 20). However, the fact that there is no evidence of rounding to numbers ending in 0, and that the observed size distributions have clear modes around 35 cm (Figure 15), suggests that this excess arises as a consequence of the underlying fish size distribution rather than a tendency to round to the nearest 5 cm.

3.3 Catch at length and age

Sampled fish

In 2017–18 2091 blue cod were measured for length, and 32% of these (359 males and 318 females) were also sexed and had otoliths removed for ageing (Table 4). Similarly, in 2018–19, of the 356 fish measured for length, 36% (88 males and 39 females) were also sexed and had otoliths removed for ageing.

Catch-at-length (2017–18)

Scaled length frequency distributions from the BCO 5 commercial potting fishery in 2017–18 were unimodal for both males and females and for all fish, although for individual statistical areas the sample numbers for sexed fish are low and distributions may not be fully representative as indicated by the high coefficients of variation (CV) (Figure 21). There were no clear differences in the distributions by sex, except that the largest fish tended to be males. The range of lengths were 32–52 cm for males, 31–52 cm for females, and 30–56 cm for all fish. For the all fish plots, the length distribution from Statistical Area 025 has proportionally fewer large blue cod, and that from area 027 proportionally more large blue cod than the other three areas (Figure 21). The cumulative length frequency plots show that males were, on average, larger in areas 027 and 029 than in 025 and 030, and females were larger in area 027 and smaller in 025, but the differences in females were less marked (Figure 22). Mean lengths by area ranged from 37.8–41.9 cm for males and 36.7–38.1 cm for females (Table 5). The percent of blue cod that was male by area ranged from 42.5–59.8%, and overall was 50.3% for BCO 5 (Table 4).

Catch-at-length (first quarter 2018–19)

Scaled length frequency distributions from the BCO 5 commercial potting fishery in the 2018–19 first quarter are only from two Statistical Areas (025 and 027), numbers of measured fish are low for sexed fish, and distributions are unlikely to be representative as indicated by the very high coefficients of variation (CV) (Figure 23). The all fish distributions however, are similar to those in 2017–18. There were no clear differences in the distributions by sex, except that the largest fish tended to be males. The length ranges were 33–50 cm for males, 32–48 cm for females, and 32–55 cm for all fish. For the all fish plots, the length distribution from Statistical Area 025 has proportionally fewer large blue cod than 027 (Figure 23). The cumulative length frequency plots show that males, females and all fish were larger in area 027 than in 025 (see Figure 22). Mean lengths by area ranged from 39.5–42.5 cm for males and 35.8–39.3 cm for females (Table 5). The percent of blue cod that was male by area ranged from 39.8–81.4, and overall was 67.1 for BCO 5 (Table 4).

Ageing precision

Age readings were very consistent between the two readers, with an APE of 1.25 and a CV of 1.25% (Figure 24). The percent agreement was 80% with very few readings disagreeing by more than 1 year. There was no age estimation bias across the age range (Figure 24).

Length and age composition (2017–18)

Otolith section ages from 355 males and 311 females were used to estimate the population age structure by individual Statistical Area and for BCO 5 from the 2017–18 BCO 5 catch sampling. The range of final agreed age estimates was 5–15 years for males and 5–21 for females although 80% of ages were less than 11 years (Figure 25). There was a large range in length-at-age. Males generally grew faster and comprised most of the largest fish, but the oldest fish were the slower growing females (Figure 25). Because there were no juvenile fish under 5 years of age, the growth curves lack the initial steep growth period and von Bertalanffy growth curves cannot be sensibly fitted to the data.

Length at age for females older than 10 years was consistently larger in Statistical Areas 027 and 029 than in areas 025 and 030 indicating that there may be geographic differences in growth within BCO 5 Figure 26.

The age compositions by Statistical Area and overall for 2017–18 are shown in Figure 27 and tabulated in Appendices 1 and 2. Statistical Area 025 had strong age classes for 6, 8, and 10 year-old males, but

these were not consistently present in the other Statistical Areas. Similarly, Statistical Area 025 had strong ages classes for 8 and 12 year-old females, and although there was a strong 8 year-old mode in area 029 and a strong 12-year old mode in area 030, the dominant age classes were not consistently present in all areas (Figure 27). This indicates that there may be differences in year-class strengths across the BCO 5 areas, however low samples sizes and high CVs limit interpretation of these data. Mean ages by area ranged from 7.4–8.2 years for males and 8.6–11.8 years for females, and for all fish were 7.8 cm and 9.8 years respectively (Table 5).

The cumulative age frequency plots show that females in area 030 had proportionally more older fish than other areas, with no clear differences in males (Figure 28).

Length and age composition (first quarter 2018–19)

Otolith section ages from 83 males and 37 females were used to estimate the population age structure by individual Statistical Area and for BCO 5 from the first quarter of 2018–19 BCO 5 catch sampling. The range of final agreed age estimates was 6–14 years for males and 8–23 for females although 64% of ages were less than 11 years (Figure 29). There was a large range in length-at-age. Males generally grew faster and comprised most of the largest fish, but the oldest fish were the slower growing females (Figure 29). Consistent with 2017–18, length at age for females older than 10 years was consistently larger in Statistical Areas 027 than in area 025 indicating that there may be geographic differences in growth within BCO 5 (Figure 30).

The age compositions by Statistical Area and overall for 2018–19 are shown in Figure 31 and tabulated in Appendices 3 and 4. The small sample sizes and very high CVs make interpretation of age class strength difficult, however the strong 9-year-old age class is present in both Statistical Areas 025 and 027. Further, the strong 6, 8, and 10 year old male ages classes in area 025 apparent in 2017–18 have progressed to be strong 7, 9, and 11-year-olds in 2018–19 (Figures 27 and 31).

4. DISCUSSION

The commercial fishery in BCO 5 is a target blue cod pot fishery, with the majority of the catch taken in Statistical Areas 025, 027, 029, and 030. The fishery operates throughout the year with little seasonality. Fishing patterns have changed little over the last two decades. The key obstacle to biological sampling of the BCO 5 fishery is that most of the catch is processed at sea. A hybrid catch sampling programme for BCO 5, which collected unprocessed fish at sea for processing ashore, was successfully developed and implemented. Other than timing issues around programme start-up, which are common in catch sampling programmes, the greatest challenge faced was fisher participation. Establishing the use of BCO 5E so that fish landed for the sampling programme did not need to be balanced by ACE, and paying for fish at normal rates, were both important in securing fisher participation. However, despite these measures, there was a reluctance on the part of some fishers to land fish for the sampling programme, over and above the quantities they were already asked to land as part of their existing commercial catch portfolios. This was exacerbated because catch rates were inevitably reduced by the increase in minimum pot mesh size in September 2017. Future programmes would therefore have to consider specifically incentivising participation, rather than simply ensuring that participation was cost neutral for fishers.

Despite a lower level of participation in the programme than anticipated in the design phase (Schofield et al. 2017), representative sampling of the core fishery was achieved at the Statistical Area level, and temporal representativeness was achieved in key areas by quarter. Fishing activity by several of the participating vessels was more sporadic than anticipated and representativeness at a monthly resolution was not achieved.

The opportunity to capture data at a finer spatial scale, than the large general Statistical Areas, was explored, but consultation processes around electronic reporting and vessel monitoring systems precluded pursuing this as part of the current programme. In future programmes, the anticipated

availability of finer scale spatial data from the electronic reporting regime will enable far greater insight into fine scale biological patterns in the fishery, and a more comprehensive assessment of spatial representativeness of sampling. The extent to which these new data demonstrate that individual fishers' fishing activity distributions overlap, or alternatively show evidence of spatial partitioning into 'patches', will influence the design of future sampling programmes.

A slight deficit in larger fish in the otolithed sample, relative to the full sample, is especially apparent in Statistical Area 030, but is also evident in Areas 027 and 029. The deficit is not evident in Area 025, which has the largest sample size. At the level of individual sampled pots, the difference between median length in all fish and the sample from which otoliths had been taken could be several centimetres. Scrutiny of particular samples with larger discrepancies between median fish size in the full and otolith samples provided no indications of a specific failure in the sampling process, and it is possible that the deficit arises due to natural variability and small sample sizes. When designing future sampling programmes, it is recommended that simulations are carried out to better understand how the apparent bias arises, and the magnitude of the expected bias given natural variability and sample sizes achieved.

4.1 Sample size adequacy

Although over 2000 fish were measured for length in 2017–18 (see Table 4), only 677 fish were sexed, and of these 671 were aged from the four BCO 5 Statistical Areas (025, 027, 029 and 030). The project specifications did not include sampling in Statistical Area 029, but it was easier to collect all data provided by participating fishers than to create another rule for fishers to observe at sea. It was only possible to sample commercial BCO 5 catches for length, sex and age by recruiting skippers and crew to actively participate by landing the catch from the first pot of each day in the green state, and further to label the sampled pot catch with an identification tag and land into a single processor in Bluff (Ngai Tahu Seafoods Ltd). The sampled pot catch was treated like other pot hauls and was first graded by removing any blue cod less than the MLS of 33 cm. The decision to additionally sample the first quarter of the 2018–19 fishing year was made because there were only 24 otoliths collected and aged from 4 landings in the first quarter of 2017–18. Further, these months comprise a period of fast growth in spring-early summer, and it was considered important to include data from this period in the BCO 5 stock assessment model (Fisheries New Zealand project BCO201801). The achieved MWCV for BCO 5 across all age classes for both sexes combined was 20%, meeting the target of 20% specified in the project objectives. However, comparisons of age compositions among the four statistical areas were hampered by low sample sizes that resulted in very high MWCVs from 33–59% (see Figure 29). Any work to determine whether stock structure is homogeneous by comparing age structure across statistical areas in BCO 5 will require more intensive sampling of landings and otoliths.

4.2 Growth and age-class strength

Accepting the limitations of the data, females older than 10 years tended to have larger length-at-age in the two southern Statistical Areas 027 and 029 than in areas 025 and 030 (see Figure 26). This suggests that there may be geographic differences in growth within BCO 5 with faster growth in the less fished areas. A possible explanation for this is that continued fishing in an area tends to remove more of the faster growing fish which reach MLS earlier, and over time this could even lead to a genetic shift to slower growing fish in the population (Fenberg & Roy 2008). The slower growth is from the two most heavily fished and accessible areas (025 and 030), which also have smaller mean lengths (see Table 5). High fishing pressure would remove faster growing individuals regardless of whether a genetic shift has occurred.

The age compositions are not homogeneous among the four Statistical Areas indicating that there may be differences in year-class strengths and recruitment patterns across BCO 5 stock areas; however, low sample sizes and high CVs limit comprehensive interpretation of these data. This finding is in contrast

to the east coast South Island blue cod populations from Kaikoura to south Otago which tend to have similar age structures and year class strength patterns (Beentjes et al. 2019).

4.3 Comparisons with 2010 and 2011 shed sampling

The shed sampling project in 2010 and 2011 included landings from Statistical Areas 025 and 027 (Haist et al. 2013, Middleton et al. 2013). Comparison with the 2017–18 shed sampling indicates that mean length has increased by about 1.5 cm for both sexes in 025 and for females in 027, but for males in 027 mean length has increased by 3–4 cm. Blue cod were larger overall in 027 than 025 in both shed sampling programmes. The increase in mean size may be partially a result of the increase in the minimum BCO 5 pot mesh size from 48 mm to 54 mm in September 2017, with the effect of increasing the length of the smallest blue cod caught to well above the MLS (33 cm). However, some of the differences in mean lengths are likely to be attributable to the geographic sampling bias identified in the first shed sampling programme where pot samples were often taken from the last set of the trip closest to the vessel home port where fishing intensity has been historically higher (Haist et al. 2013).

4.4 Depths and locations fished in BCO 5

Blue cod are caught from close inshore to as deep as 200 m around the South Island during regular potting surveys, and in the Foveaux Strait (Area 025) potting surveys they have been caught from 2–95 m (Carbines & Beentjes 2012, Beentjes et al. 2019). The commercial blue cod catch is currently reported using Catch Effort Landing Returns (CELR) on which location of the pots is only reported at the resolution of Statistical Area and depth is not recorded. Depths were recorded by vessels participating in the BCO 5 logbook programme in 2009 to 2011, however, and they ranged from a few metres to slightly over 100 m. There were two clear peaks, one at 35–40 m which corresponds mostly to fishing in area 025 and the other at 70–75 m corresponding mostly to fishing in areas 027, 029 and 030 (Figures 32 and 33). Most of the BCO 5 seafloor in Statistical Areas 027, 029 and 030 is deeper than 100 m, whereas virtually all of the seafloor within area 025 is less than 50 m depth (Figure 34). The potential extent of blue cod habitat corresponding to the area within the 100 m depth contour, is roughly 99%, 10%, 3%, and 25% for Statistical Areas 025, 027, 029 and 030 (Figure 34). This explains, to some extent, why annual landings are consistently the highest in 025 and lowest in 029.

5. ACKNOWLEDGEMENTS

This research was carried out by NIWA under contract to Fisheries New Zealand (project BCO201501). Trident Systems LP was subcontracted by NIWA to carry out the catch sampling of the BCO 5 and undertake the characterisation of the fishery. Thanks to the following people for contributing to this project: Ngai Tahu Seafoods Ltd for undertaking sampling in their Bluff factory (Rodney Tribe, Ram Keeripati, Lesley Tuhi, Verena Hartsuiker, and Natasha Leigh); Dave Banks (Trident) for training the sampling staff; skippers for collecting blue cod samples at sea (including Tim Crosbie, Stan Geary, Leon Herbert, Brad Johnson, Colin Johnson, Anthony Thomson); preparation and reading otoliths (Cameron Walsh – Stock Monitoring Services, Dane Buckthought and Keren Spong – NIWA); manuscript review (Peter Horn, Richard O'Driscoll – NIWA, Marc Griffiths – Fisheries New Zealand); editorial comments (Marianne Vignaux – Fisheries New Zealand).

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Table 1: Sampled fishing days by vessel and Statistical Area. 2017–18 and 2018–19 fishing years combined.

Vessel	Statistical Area			
	025	027	029	030
Vessel 1	0	0	0	3
Vessel 2	15	3	0	3
Vessel 3	1	0	0	2
Vessel 4	1	0	3	8
Vessel 5	7	0	0	0
Vessel 6	0	0	16	3
Vessel 7	40	35	5	10

Table 2: Fishing activity by the 58 vessels in the cod potting fleet during the sampling programme (1 October 2017 to 31 December 2018), together with estimated catches and allocated landings The POT method code, while present in the data and self-evident in interpretation, is not an accepted statutory method code.

			Blue cod catch (tonnes)	
Code	Method	Events	Allocated	Estimated
BLL	Bottom longlining	37	0.25	0.19
BT	Bottom trawl single	47	0.03	0.00
CP	Cod potting	3176	1154.73	1028.02
D	Dredging	1	0.00	0.00
DL	Drop/dahn lines	28	0.68	0.50
MH	Mechanical harvesting	63	4.01	3.50
PL	Pole and line	1	0.00	0.00
POT		7	0.75	0.72
RLP	Rock lobster potting	196	6.49	5.58
SN	Set netting	6	1.00	0.00
T	Trolling	2	0.00	0.00

Table 3: Fish sampled by Statistical Area. 2017–18 and 2018–19 fishing years combined.

	Number of fish sampled	
Statistical Area	Length only	Otolith, sex
025	605	302
027	382	179
029	285	144
030	365	179

Table 4: Blue cod sampled during the BCO 5 catch sampling programme in 2017–18, and first quarter of 2018–19. Total length was measured for all fish, and those where otoliths were taken were also sexed.

2017–18 fishing year

Statistical Area	Landings	Male otoliths	Female otoliths	Can't sex	Unsexed	Total measured
025	24	136	82	1	465	684
027	13	63	73	3	293	432
029	9	67	77	1	285	430
030	10	93	86	1	365	545
Total	56	359	318	6	1408	2091

2018–19 fishing year (first quarter)

Statistical Area	Landings	Male otoliths	Female otoliths	Can't sex	Unsexed	Total measured
025	7	68	16	0	140	224
027	3	20	23	0	89	132
029	0	0	0	0	0	0
030	0	0	0	0	0	0
Total	10	88	39	0	229	356

Table 5: Mean length, mean age and sex ratios for the BCO 5 catch sampling programme in 2017–18, and first quarter of 2018–19 from scaled data. 2018 is 2018–19 fishing year, and 2019 is 2018–19 fishing year. BCO 5 includes all data combined from the Statistical Areas sampled. Prop., proportion.

Fishing year	Statistical Area	Mean length (cm)		Mean age (years)		Prop. male
		Males	Females	Males	Females	
2018	025	37.8	36.7	7.6	9.9	59.8
	027	41.9	38.1	8.2	9.4	42.5
	029	39.6	37.5	7.4	8.6	48.8
	030	38.0	36.9	8.2	11.8	49.3
	BCO 5	39.2	37.4	7.8	9.8	50.3
2019	025	39.5	35.8	8.9	13.6	81.4
	027	42.5	39.3	9.3	14.6	39.8
	BCO 5	40.1	38.0	9.0	14.3	67.1

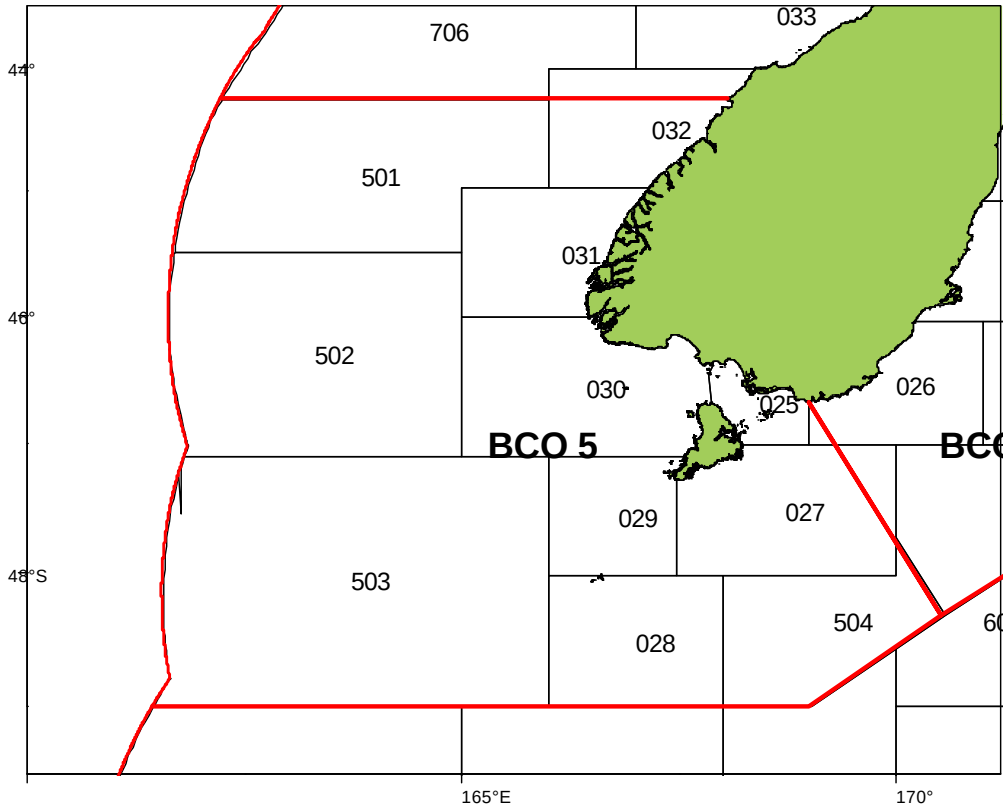

Figure 1: Blue cod Quota Management Area BCO 5 and statistical areas. Sampling of the blue cod commercial catch in 2017–18 and 2018–19 occurred in Statistical Areas 025, 027, 029 and 030.

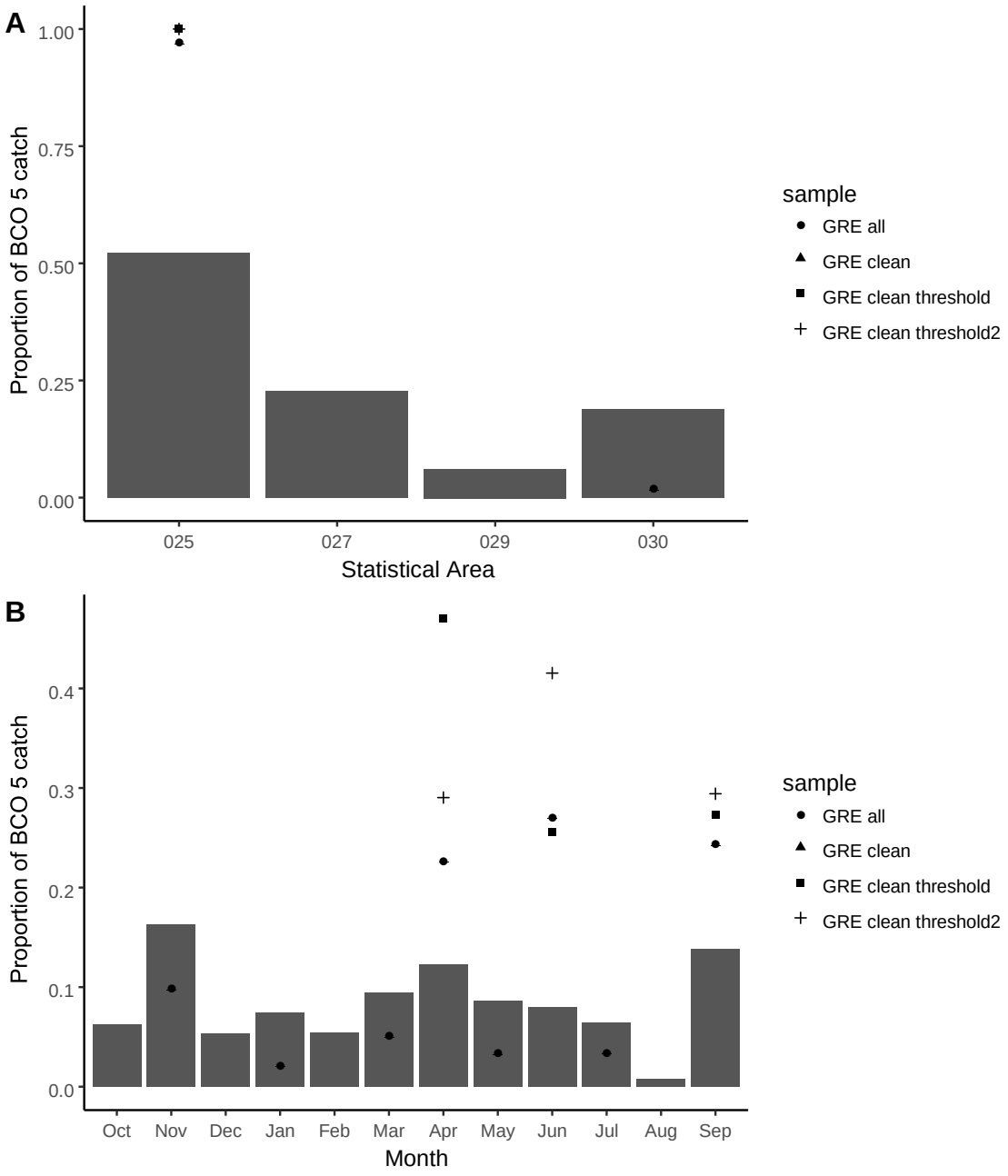

Figure 2: Simulation of the sampling coverage achieved by sampling only from the landings of unprocessed (green) blue cod from the four LFRs landing GRE BCO 5 in the 2016 fishing year. The bars show the proportion of the total landings of the fishery by (A) Statistical Area and (B) month, while the points show the proportions of sampled landings resulting from a variety of approaches to sampling from only the landings with some component of green (GRE; unprocessed) fish: 'GRE all' indicates that all landings of unprocessed fish were available for sampling; 'GRE clean' indicates landings were only sampled if the trip fished in a single Statistical Area. The two 'threshold' strategies indicate that the clean landings had to achieve a minimum (Statistical Area dependent) weight threshold in order to be eligible for sampling (Schofield et al. 2017).

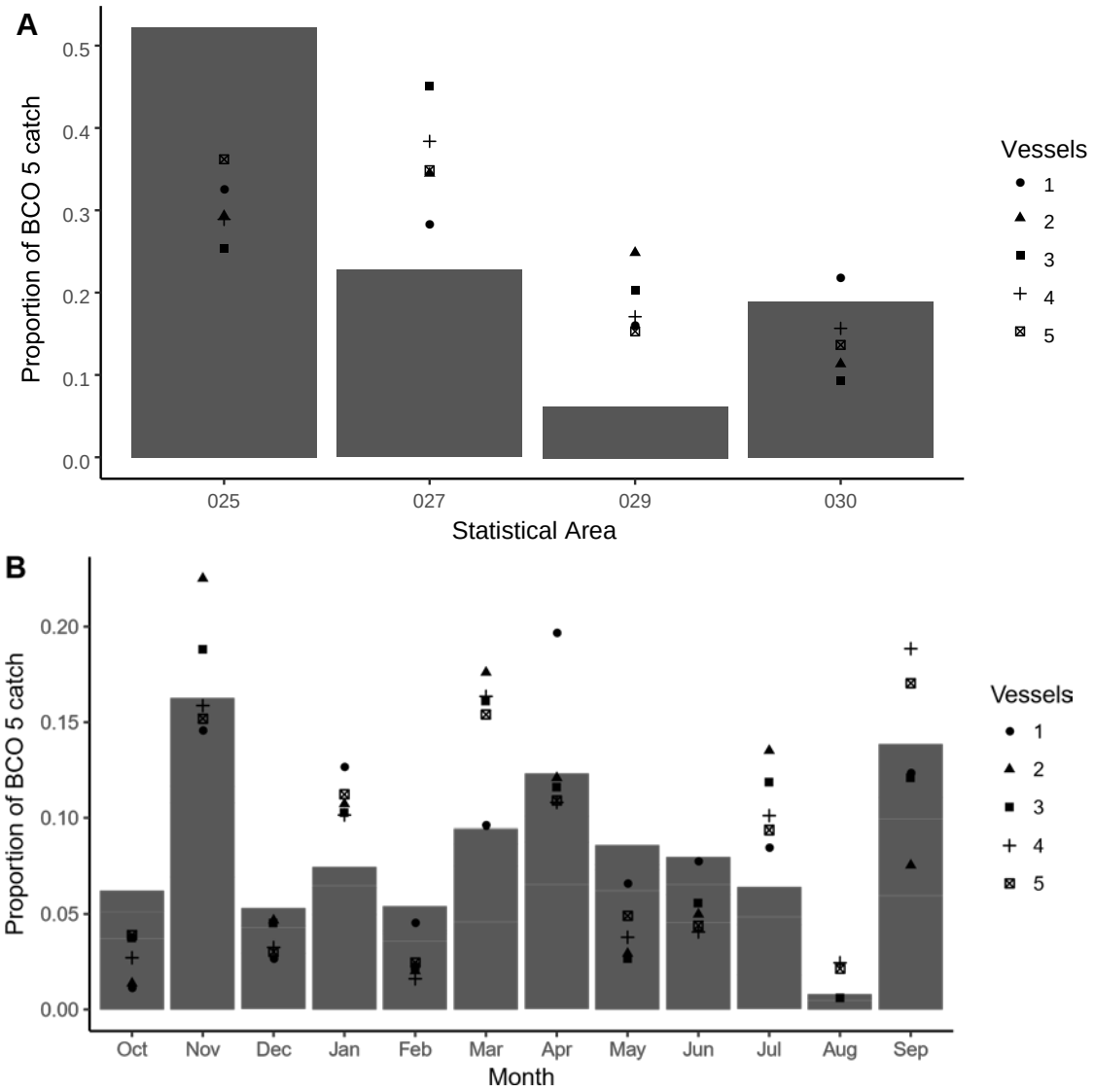

Figure 3: The expected sampling coverage achieved by routinely sampling from the top one, two, three, four and five BCO 5 vessels in the 2016 fishing year. The bars show the proportion of the total landings of the fishery by (A) Statistical Area and (B) month, while the points show the proportions of sampled landings from simulated sampling involving different numbers of participating vessels selected because they were the most active participants in the fishery.

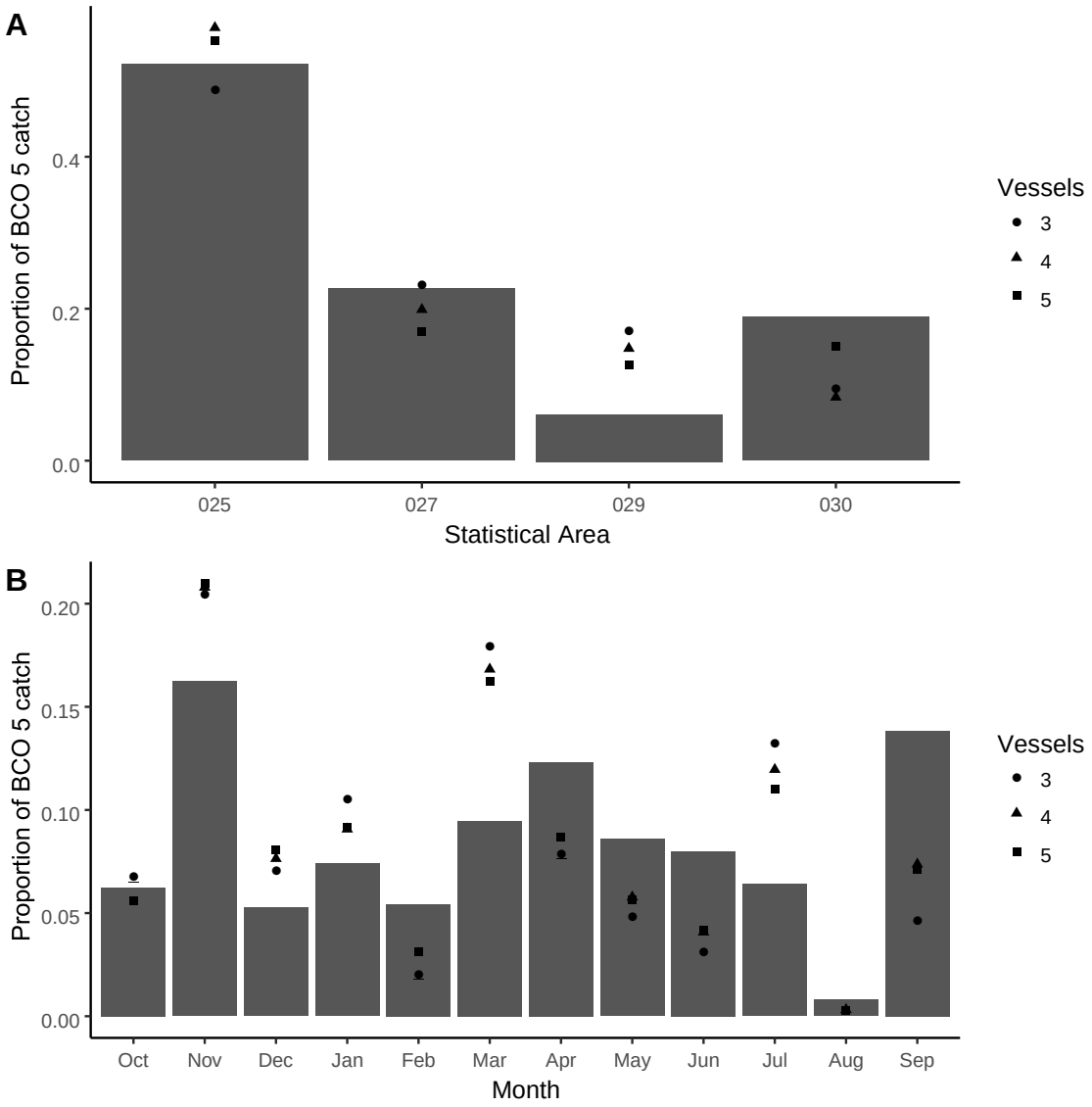

Figure 4: The expected sampling coverage achieved by routinely sampling from selected BCO 5 vessels in the 2016 fishing year. The bars show the proportion of the total landings of the fishery by (A) Statistical Area and (B) month, while the points show the proportions of sampled landings from simulated sampling involving different numbers of participating vessels selected to achieve more spatially balanced sampling than if only the most active vessels are selected.

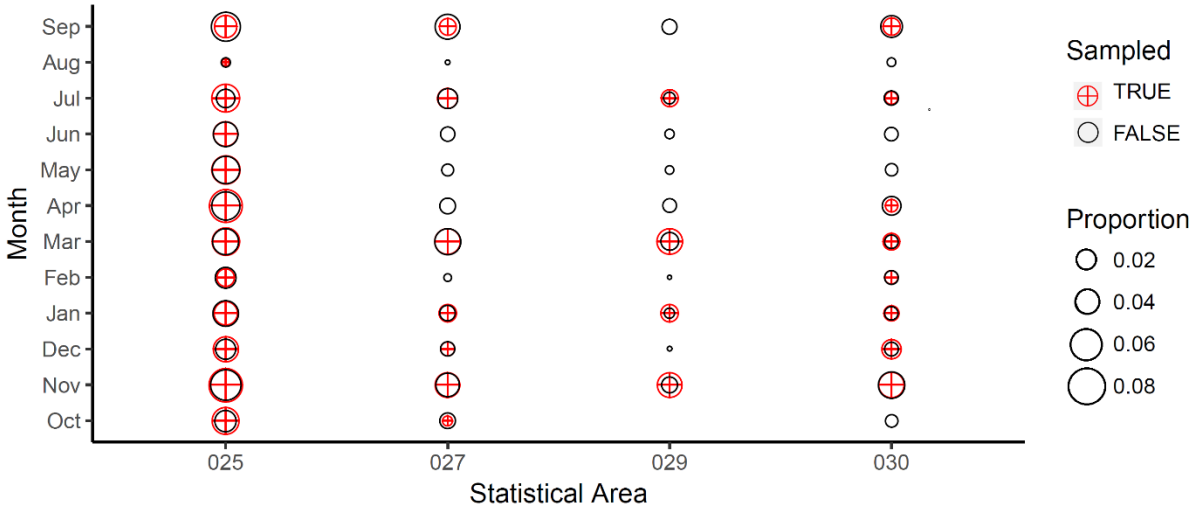

Figure 5: Sampling representativeness achieved by simulated sampling from five selected vessels in the 2016 fishing year. Proportions are of allocated landings (*sensu* Starr 2007).

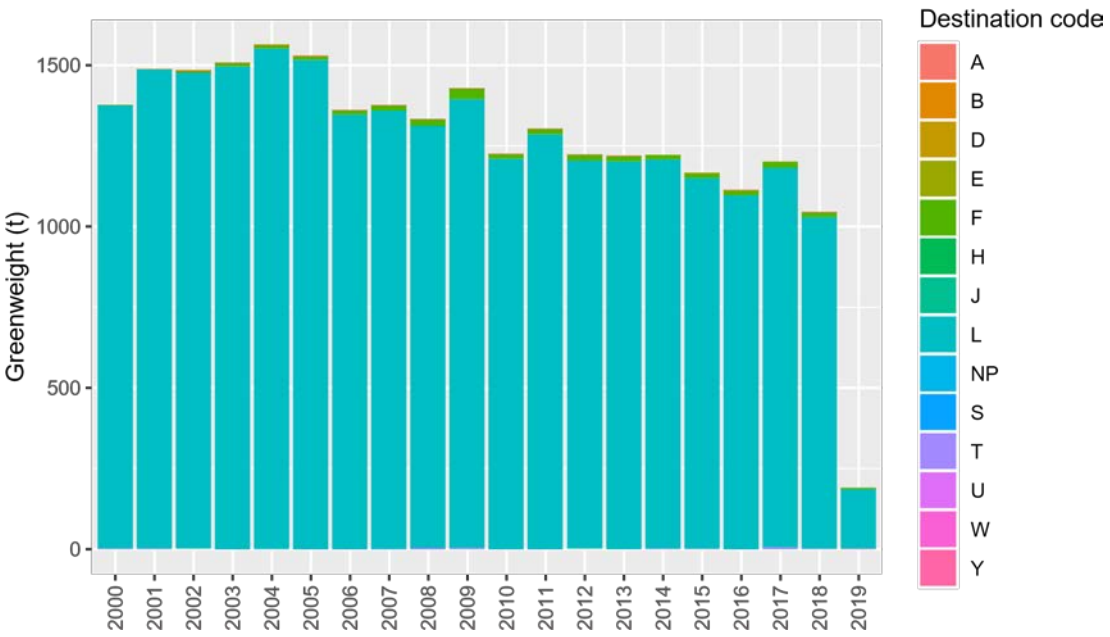

Figure 6: Destination codes reported for BCO 5 landings, after excluding landings to non-terminal states (i.e., records where the landing was to a temporary state, such as a holding pot, and therefore expected to be recorded again as a final landing). Destination codes are as follows: A = accidental loss; B = stored for bait; D = returned to the sea; E = eaten on board; F = section 111; H = lost from holding receptacle; J = required returns to the sea; L = landed to a LFR; NP = not provided; S = seized by the Crown; T = transferred to another vessel; U = used as bait; W = sold at wharf; Y = sub-MLS returns. Data are presented by fishing year where, for example, '2000' refers to the 1999–2000 fishing year. Note that the 2019 fishing year includes only the first quarter, to 31 December 2018.

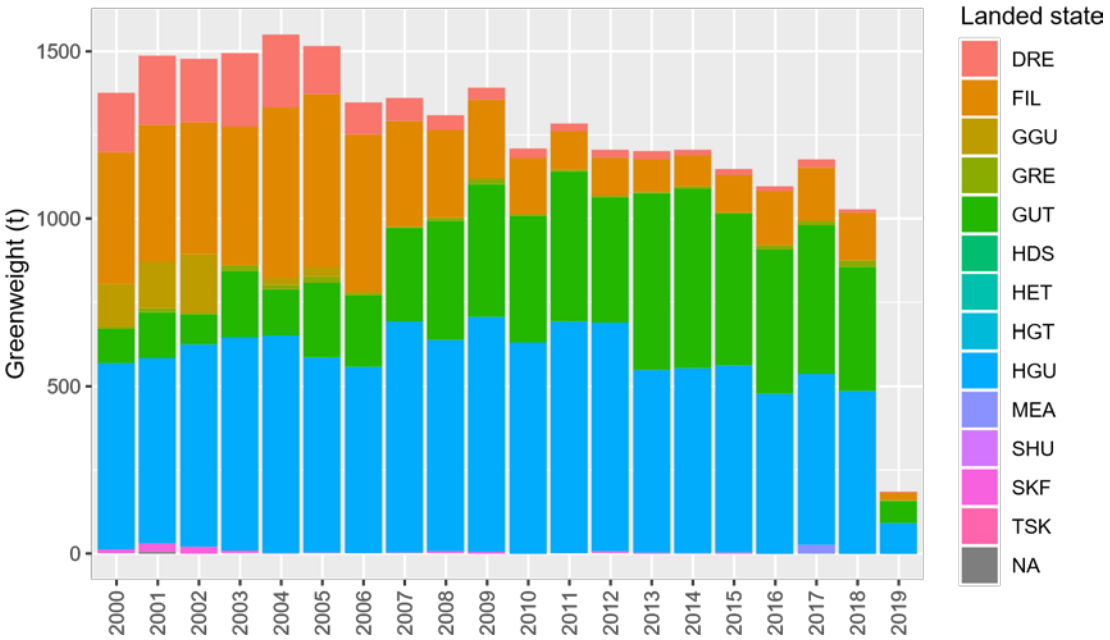

Figure 7: State codes reported for BCO 5 landings (destination code L (landed) only). State codes are as follows: DRE = dressed; FIL = fillets (skin on); GGU = gutted and gilled; GRE = green; GUT = gutted; HDS = heads; HET = heads and tentacles; HGT = headed, gutted, tailed; HGU = headed and gutted; MEA = fish meal; SHU = shucked; SKF = fillets (skin off); TSK = fillets (skin off, trimmed); NA = not reported. Data are presented by fishing year where, for example, '2000' refers to the 1999–2000 fishing year. Note that the 2019 fishing year includes only the first quarter, to 31 December 2018.

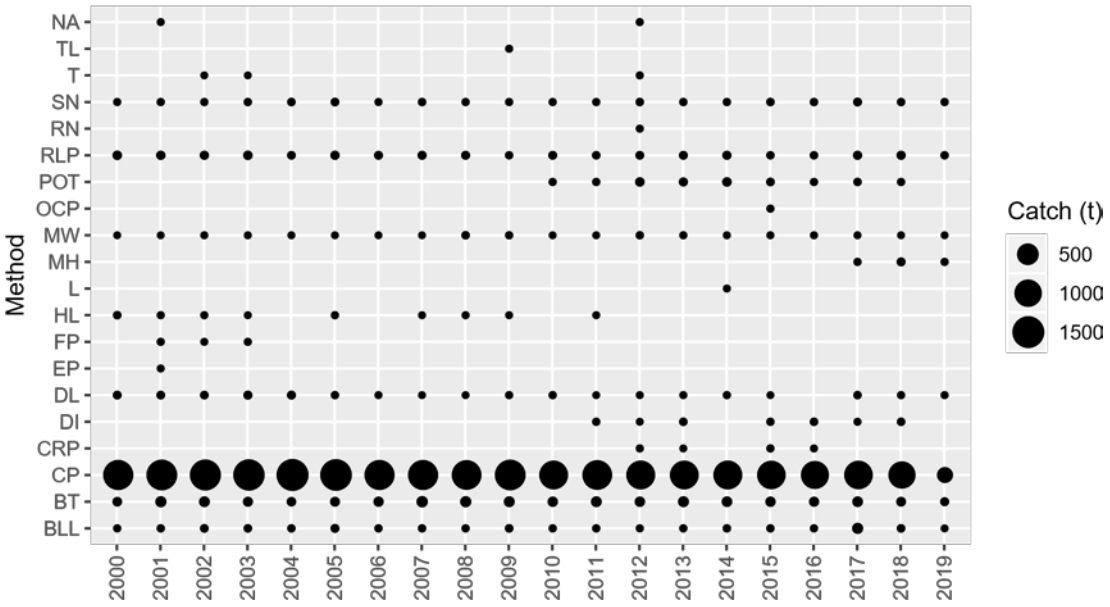

Figure 8: Allocated (*sensu* Starr 2007) blue cod landings by method for fishing events in Statistical Areas 025, 027, 028, 029, 030, 031, 032, 501–504, 601–625, and 923–927 from trips that landed BCO 5 from 2000 to 2019. The main method codes are defined in Table 2; other codes used here are: CRP, crab potting; DI, diving; EP, eel potting; FP, fish traps; HL, handlining; L, lampara; MW, midwater trawl single; OCP, octopus potting; RN, ring net; TL, trot lines; NA, not recorded. Data are presented by fishing year where, for example, '2000' refers to the 1999–2000 fishing year. Note that the 2019 fishing year includes only the first quarter, to 31 December 2018.

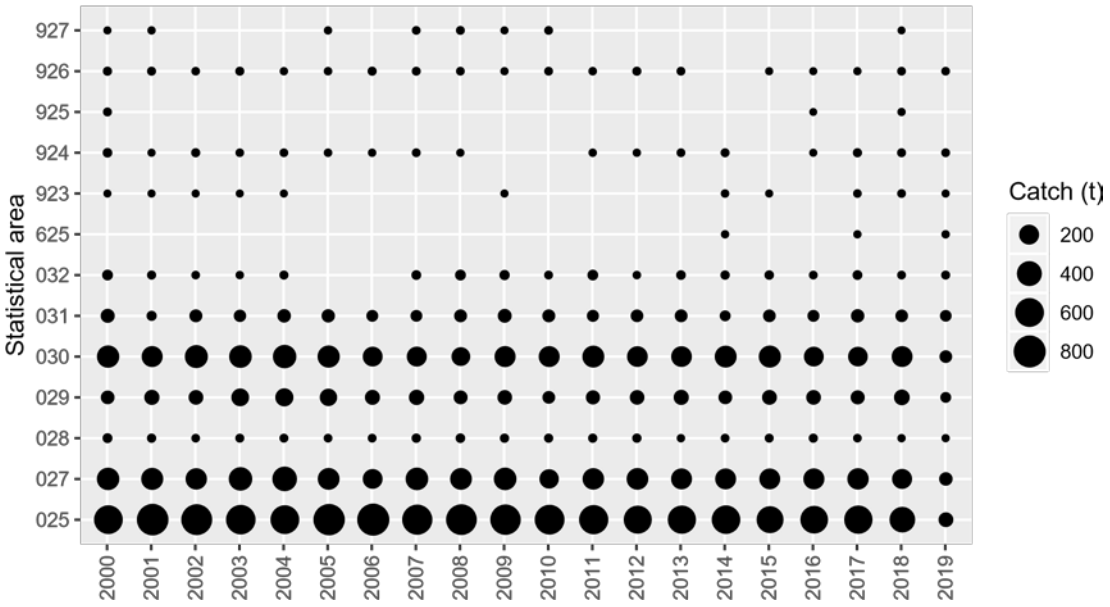

Figure 9: Allocated (*sensu* Starr 2007) blue cod landings by statistical area for fishing events in BCO 5 with potting methods (Cod pot and Rock lobster pot) from 2000 to 2019. Note that both general Statistical Areas and rock lobster Statistical Areas are included. Data are presented by fishing year where, for example, '2000' refers to the 1999–2000 fishing year. Note that the 2019 fishing year includes only the first quarter, to 31 December 2018.

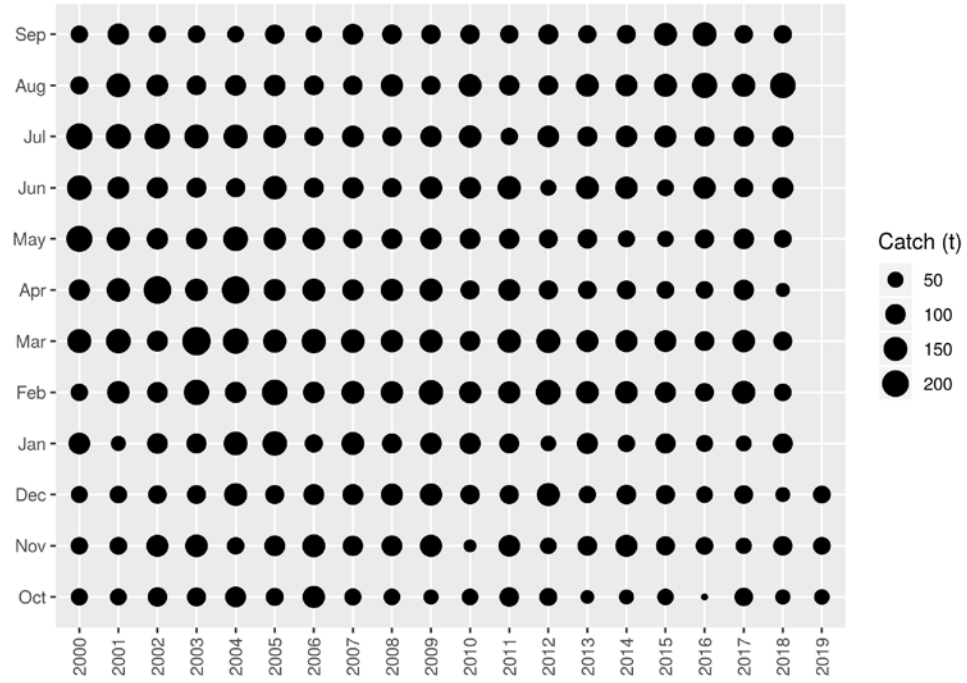

Figure 10: Allocated (*sensu* Starr 2007) blue cod landings by month for fishing events in BCO 5 with potting methods (CP, RLP) from 1 October 1999 to 31 December 2019. Data are presented by fishing year where, for example, '2000' refers to the 1999–2000 fishing year.

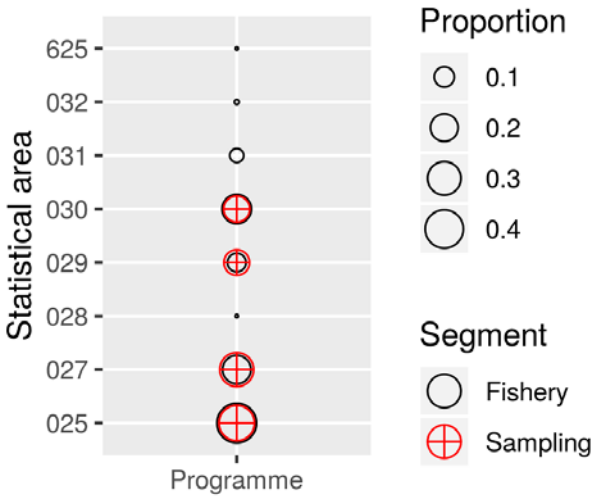

Figure 11: Sampling representativeness by Statistical Area for the period 1 October 2017 to 31 December 2018. Proportions are of allocated landings (*sensu* Starr 2007).

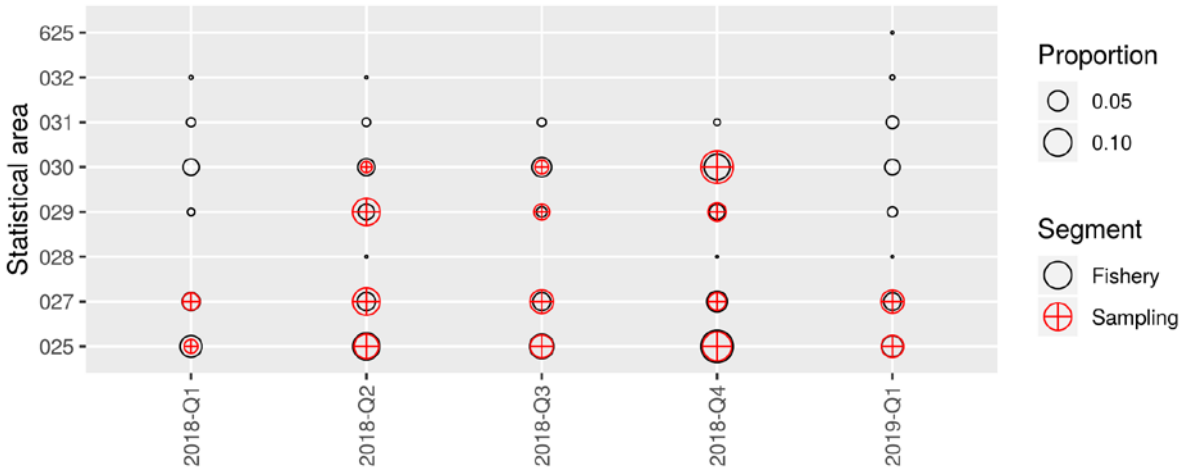

Figure 12: Sampling representativeness by Statistical Area and quarter for the period 28 November 2017 to 14 December 2018. Proportions are of allocated landings (*sensu* Starr 2007). Year labels refer to fishing year where, for example, '2000' refers to the 1999–2000 fishing year.

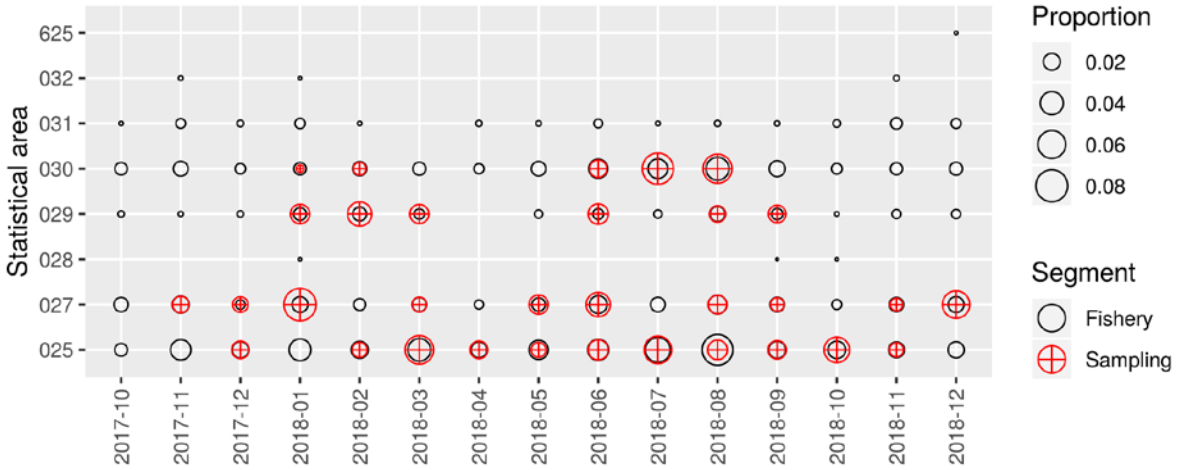

Figure 13: Sampling representativeness by Statistical Area and month for the period 28 November 2017 to 14 December 2018. Proportions are of allocated landings (*sensu* Starr 2007). Year labels refer to fishing year where, for example, '2000' refers to the 1999–2000 fishing year.

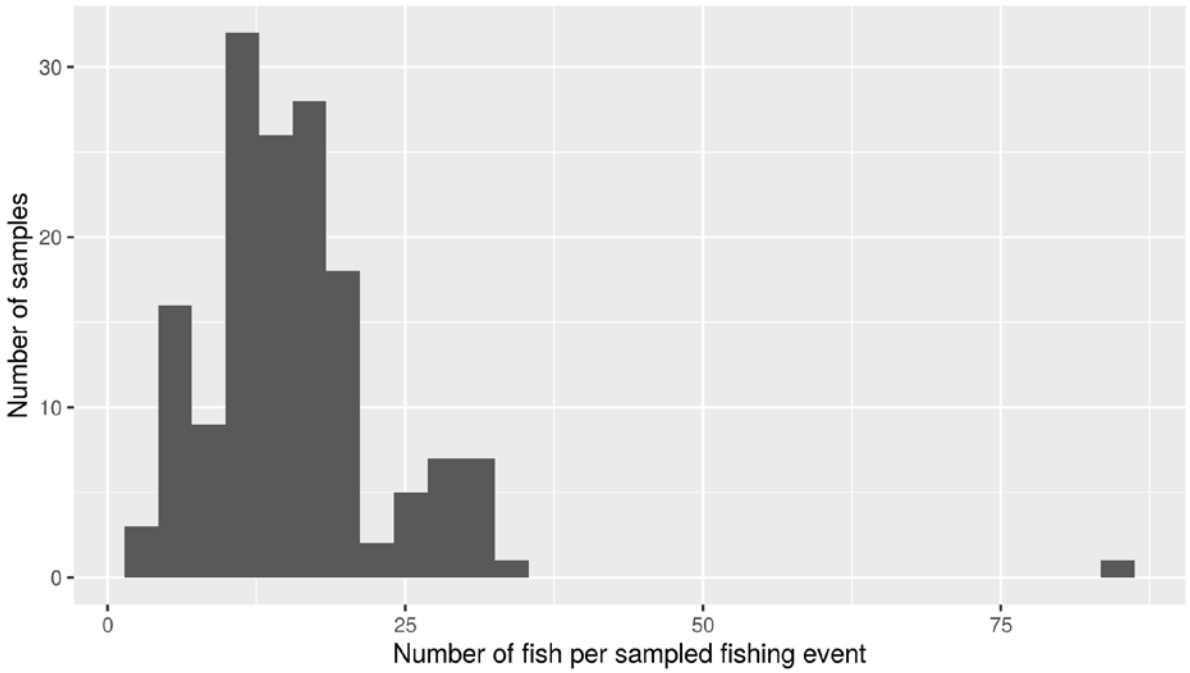

Figure 14: Numbers of fish per sample. N = 155 fishing events and 2447 fish.

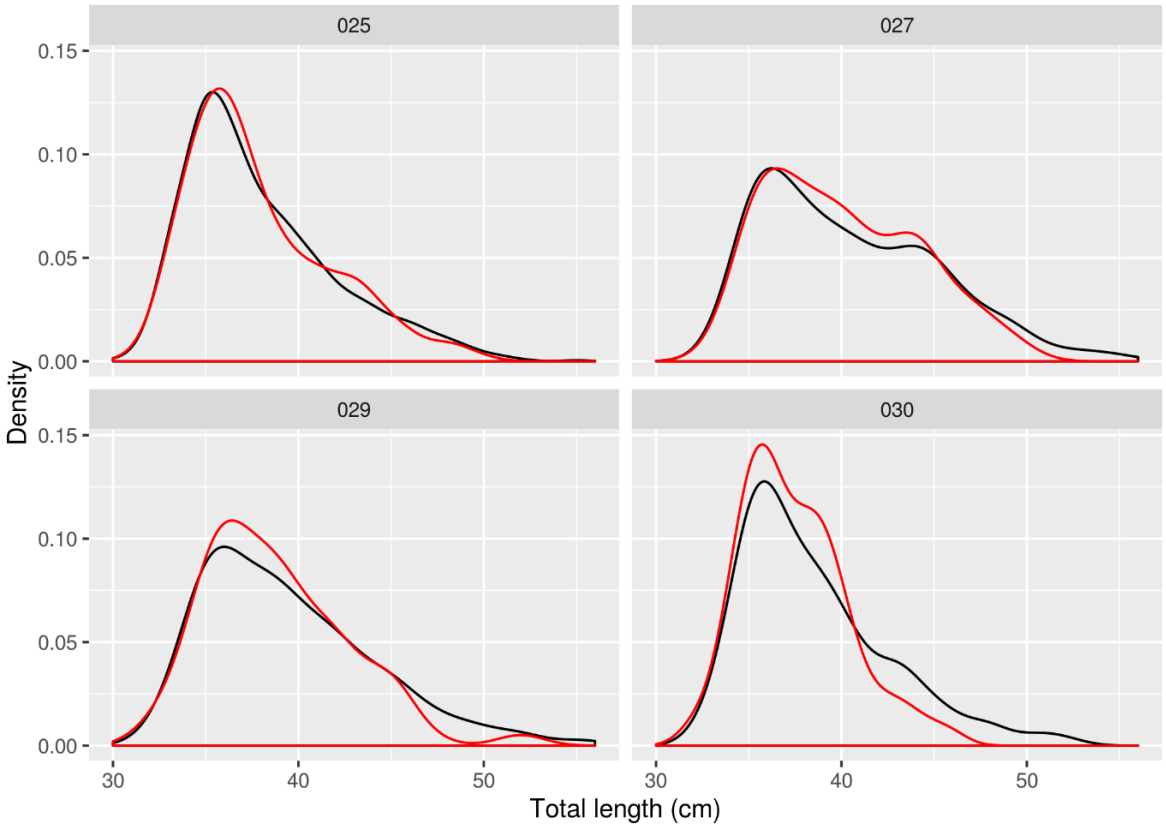

Figure 15: Distributions of blue cod total length for the full sample (black line) and the sub-sample from which otoliths were taken (red line), by Statistical Area.

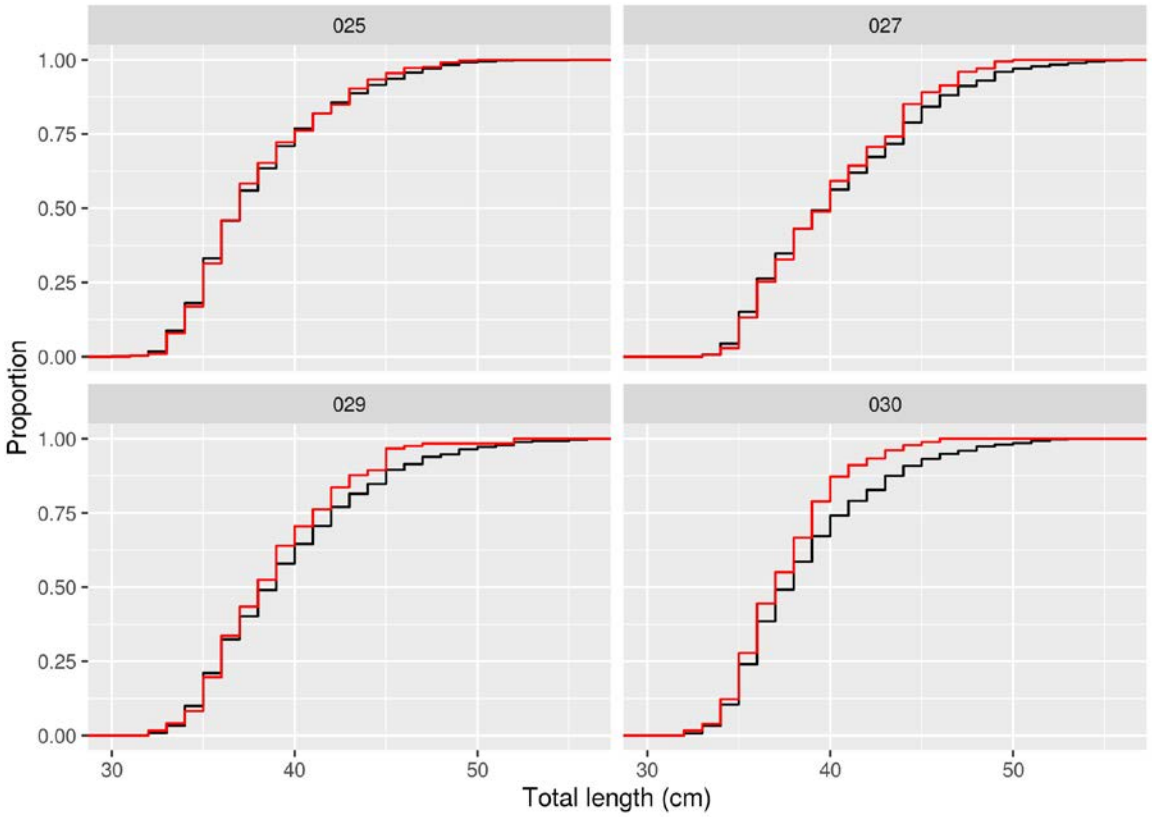

Figure 16: Cumulative distributions of blue cod total length for the full sample (black line) and the sub-sample from which otoliths were taken (red line), by Statistical Area.

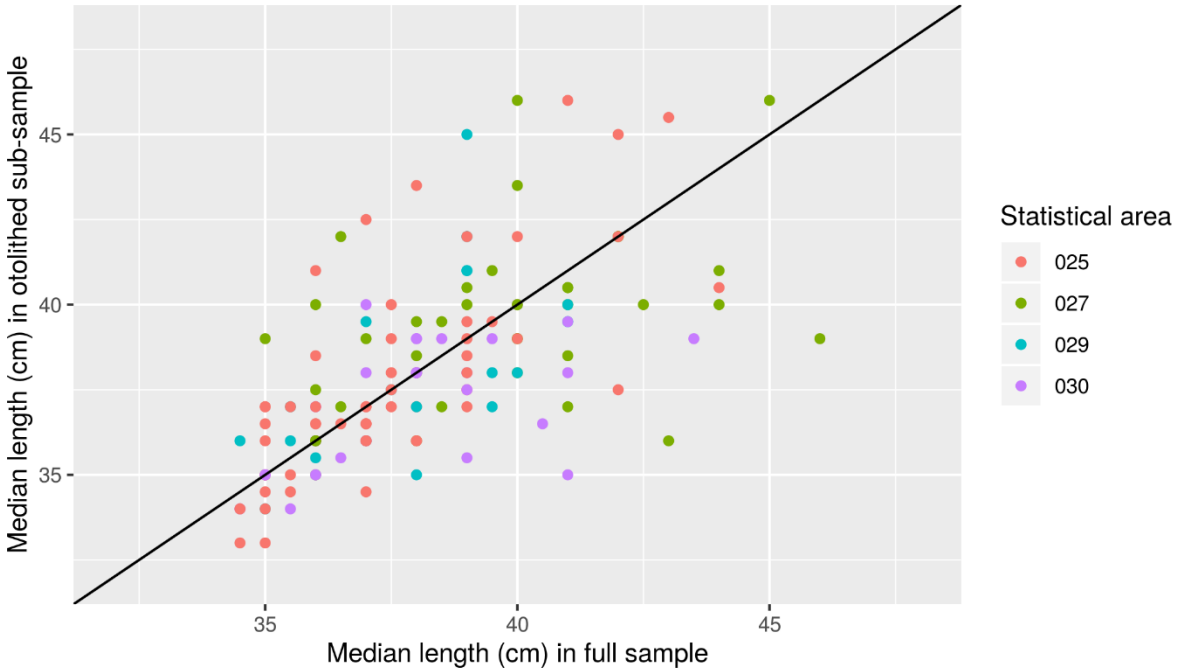

Figure 17: Median blue cod total length by sample for full samples and the sub-sample from which otoliths were taken, by Statistical Area.

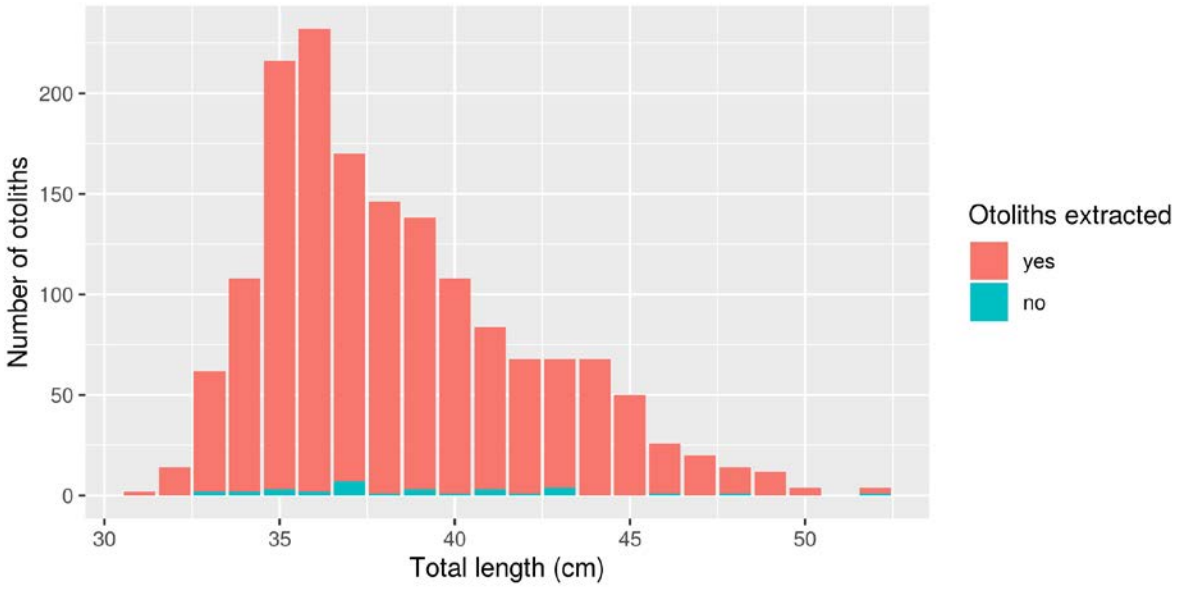

Figure 18: Otolith extraction success (i.e. retrieval of an otolith, broken or unbroken) by fish size. N= 807 fish (1614 potential otoliths).

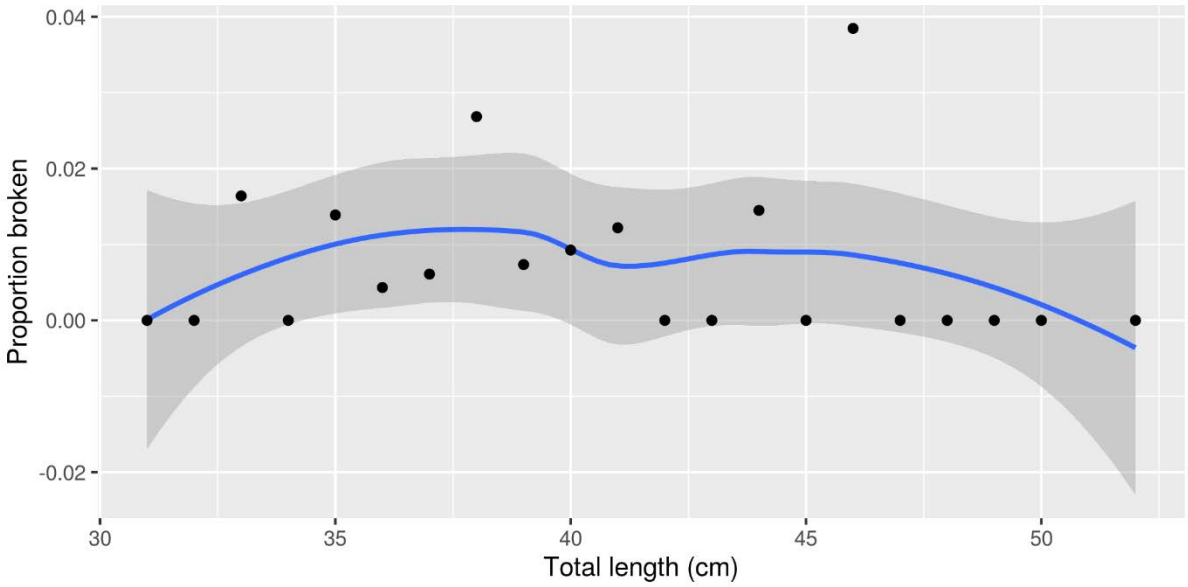

Figure 19: Otolith breakage by fish size. N = 15 broken otoliths. A loess smooth and 95% confidence interval is shown for reference. This is intended to assist in the visual assessment only and is not constrained to non-negative values.

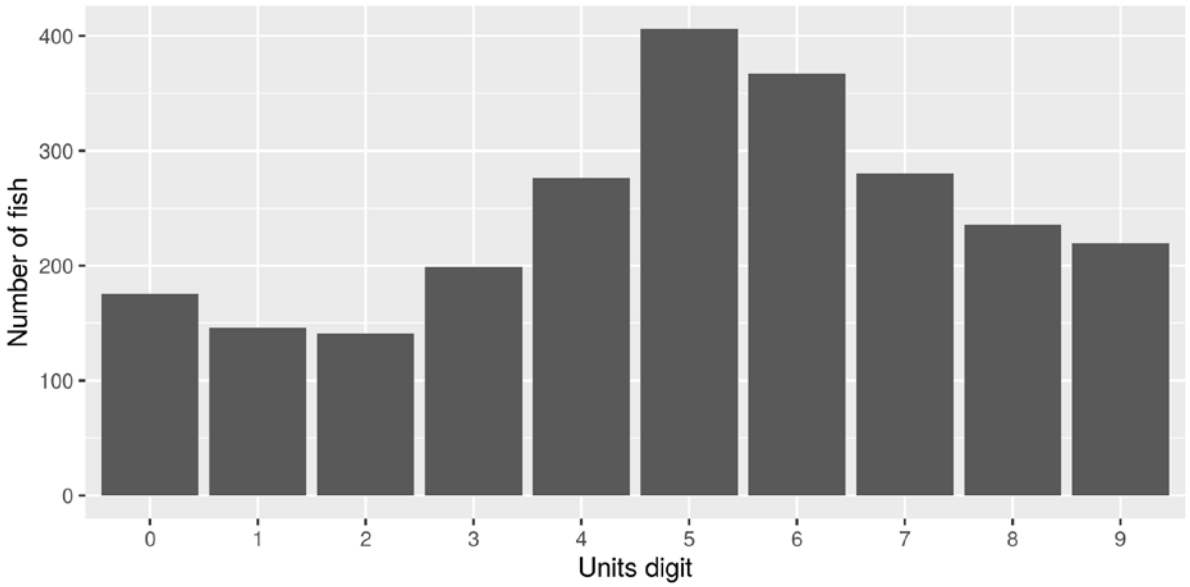

Figure 20: Distribution of units digit in fish lengths. The units digit is the digit in the ones column of an integer, e.g. the units digit for 38 is 8, and 108 is 8.

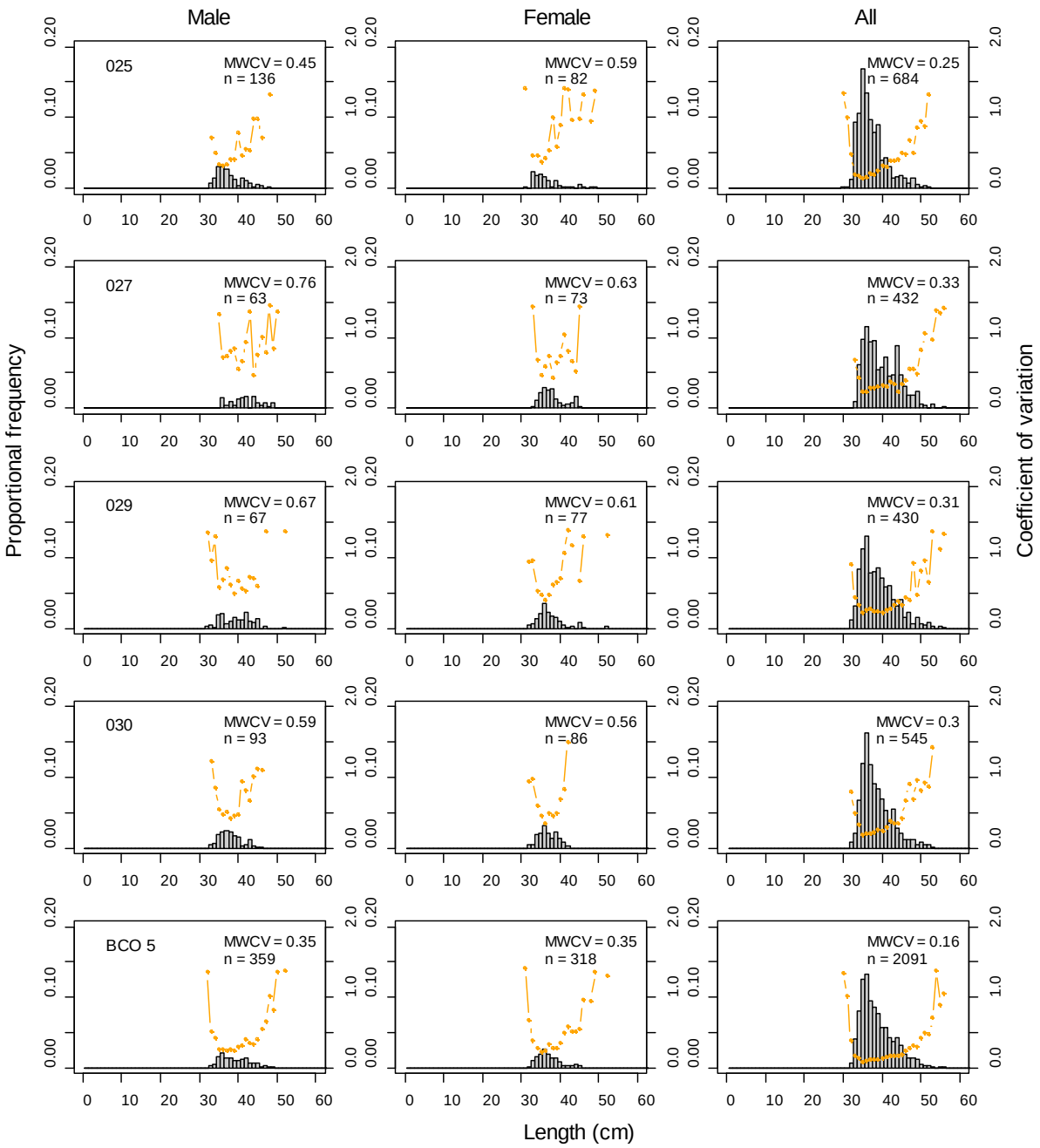

Figure 21: Blue cod scaled length frequency distributions from commercial potting landings in BCO 5 in the 2017–18 fishing year. Data are shown grouped by sex and all fish and stratified by statistical area, and for all sampled statistical areas combined. There are more fish in the 'All' plots because only fish where otoliths were taken were sexed. Line indicates the CV for each length class; n, number of fished measured; MWCV, mean weighted coefficient of variation.

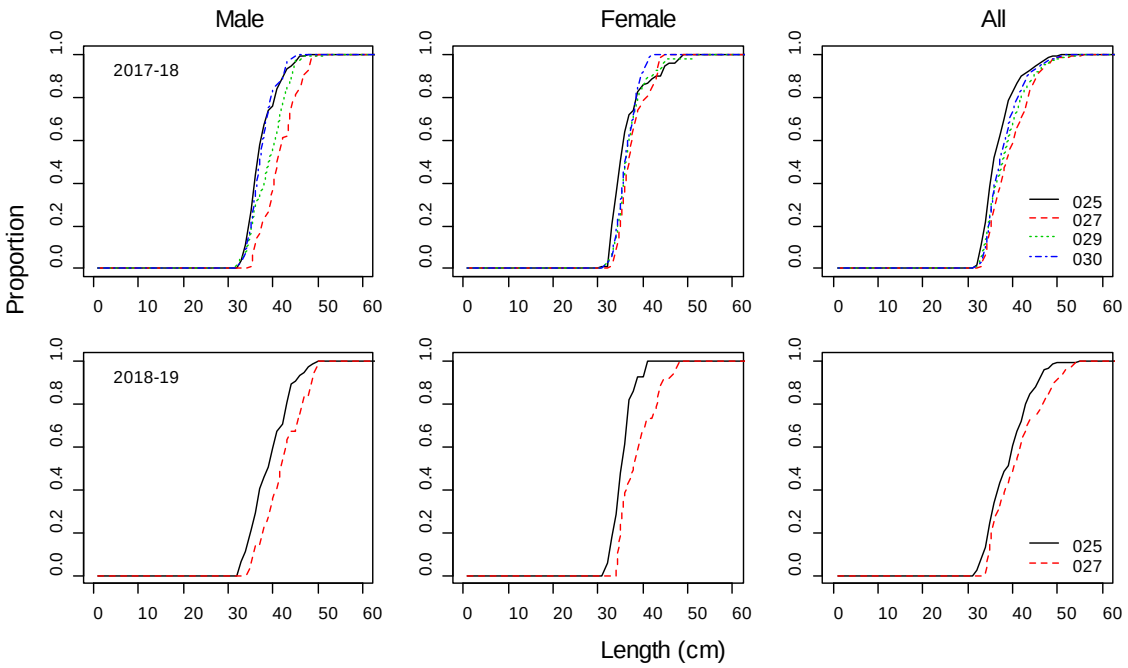

Figure 22: Cumulative proportion by length from the commercial potting landings in BCO 5 in the 2017–18 (top panel) and the first quarter of 2018–19 fishing years (bottom panel). Data are shown by statistical area.

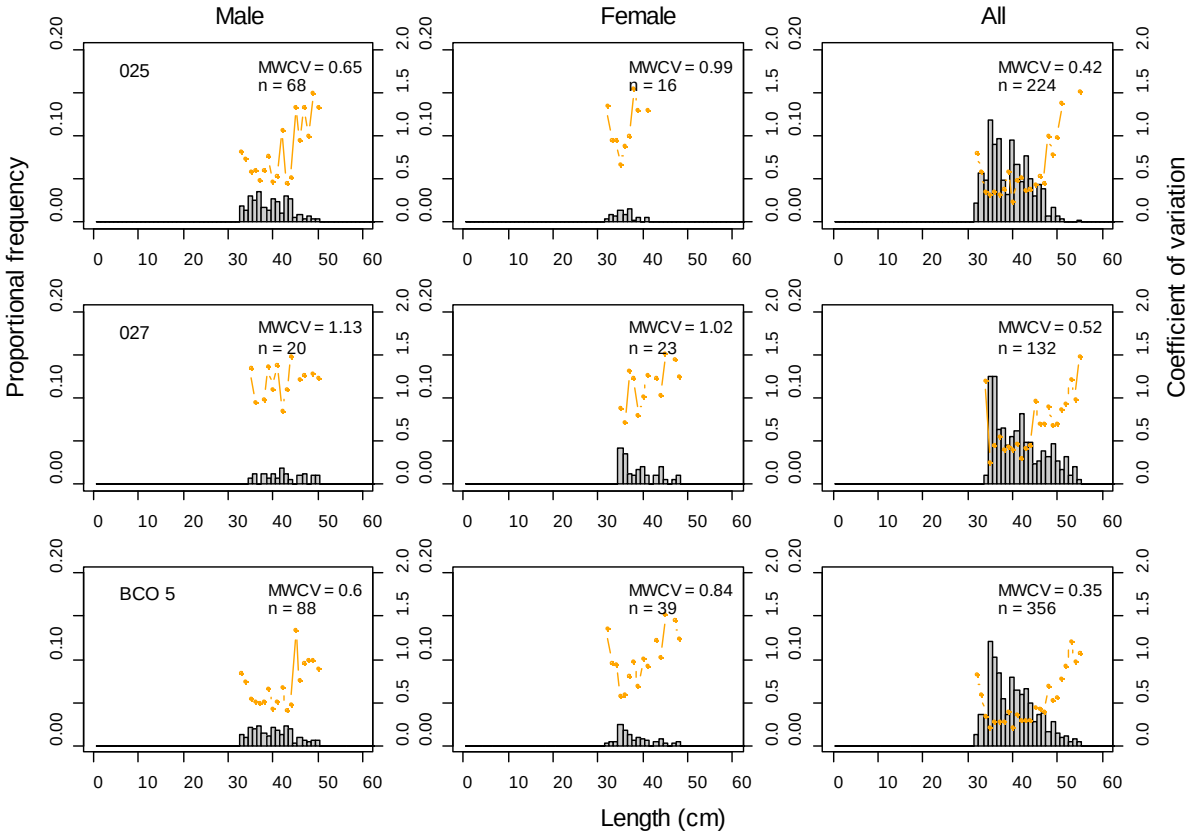

Figure 23: Blue cod scaled length frequency distributions from commercial potting landings in BCO 5 in the first quarter of 2018–19 fishing year. Data are shown grouped by sex and all fish and stratified by statistical area, and all sampled statistical areas combined. There are more fish in the 'All' plots because only fish where otoliths were taken were sexed. Line indicates the CV for each length class; n, number of fished measured; MWCV, mean weighted coefficient of variation.

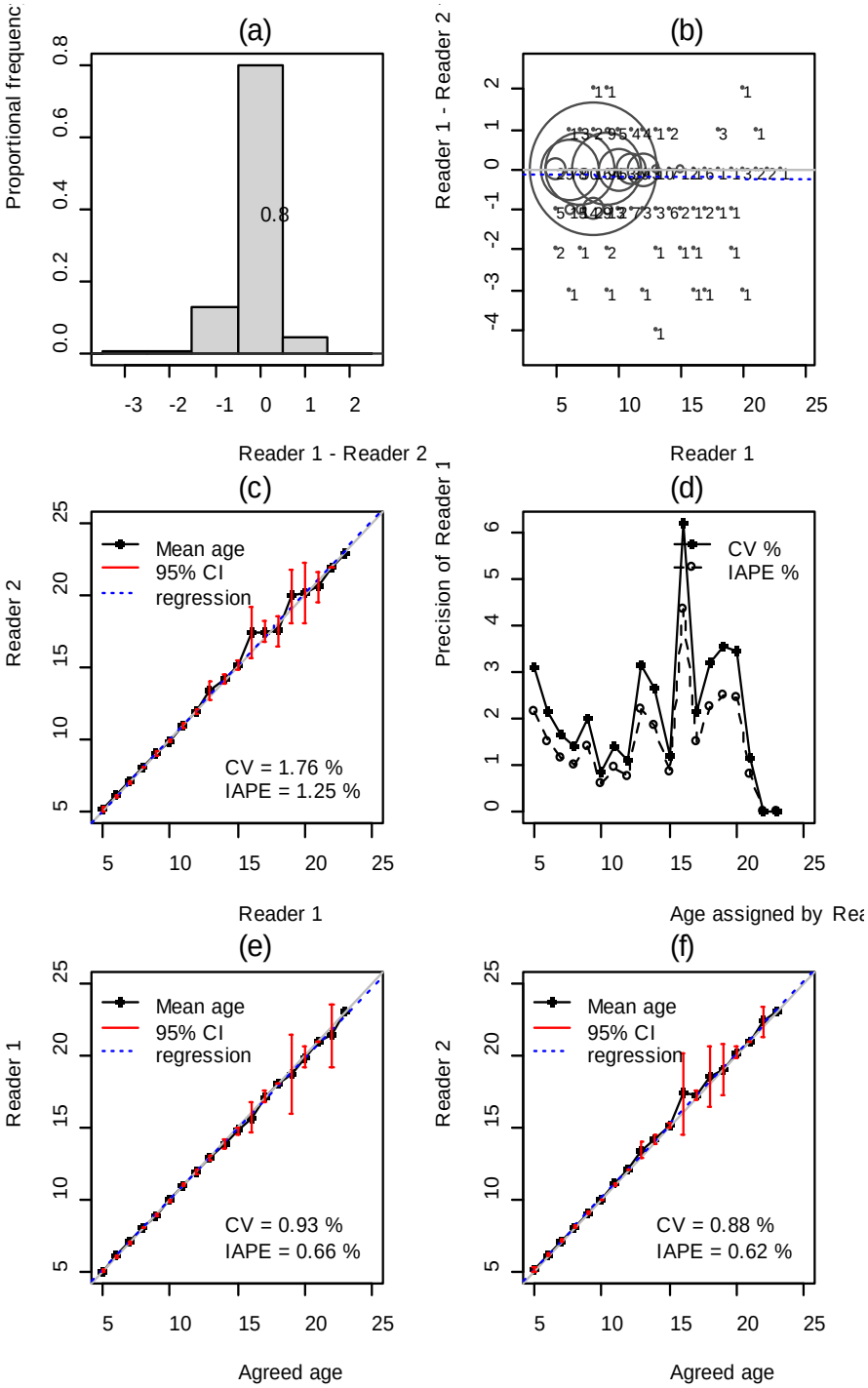

Figure 24: Blue cod age otolith reader comparison plots between reader 1 and reader 2 for the 2017–18 and 2018–19 BCO 5 catch sampling: (a) histogram of age differences between two readers; (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1, where the numbers of 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. N= 671 ages.

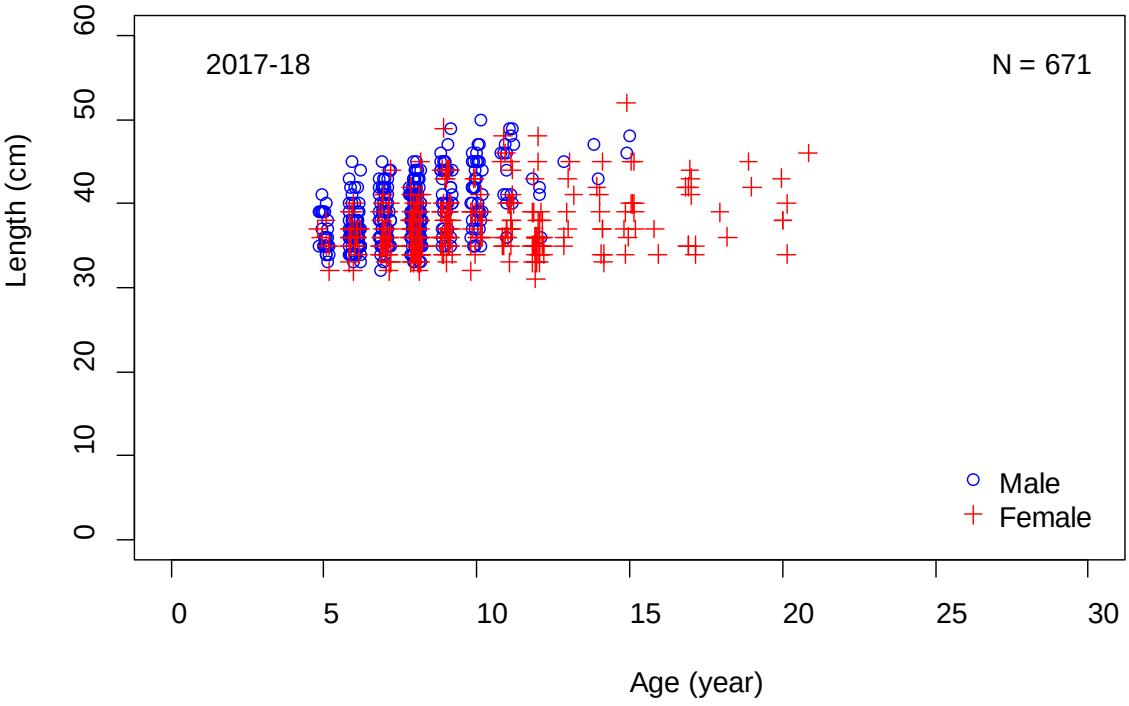

Figure 25: Observed blue cod age and length data by sex for the BCO 5 catch sampling programme in 2017–18 (N = 355 males and 311 females). Data are combined for all sampled statistical areas.

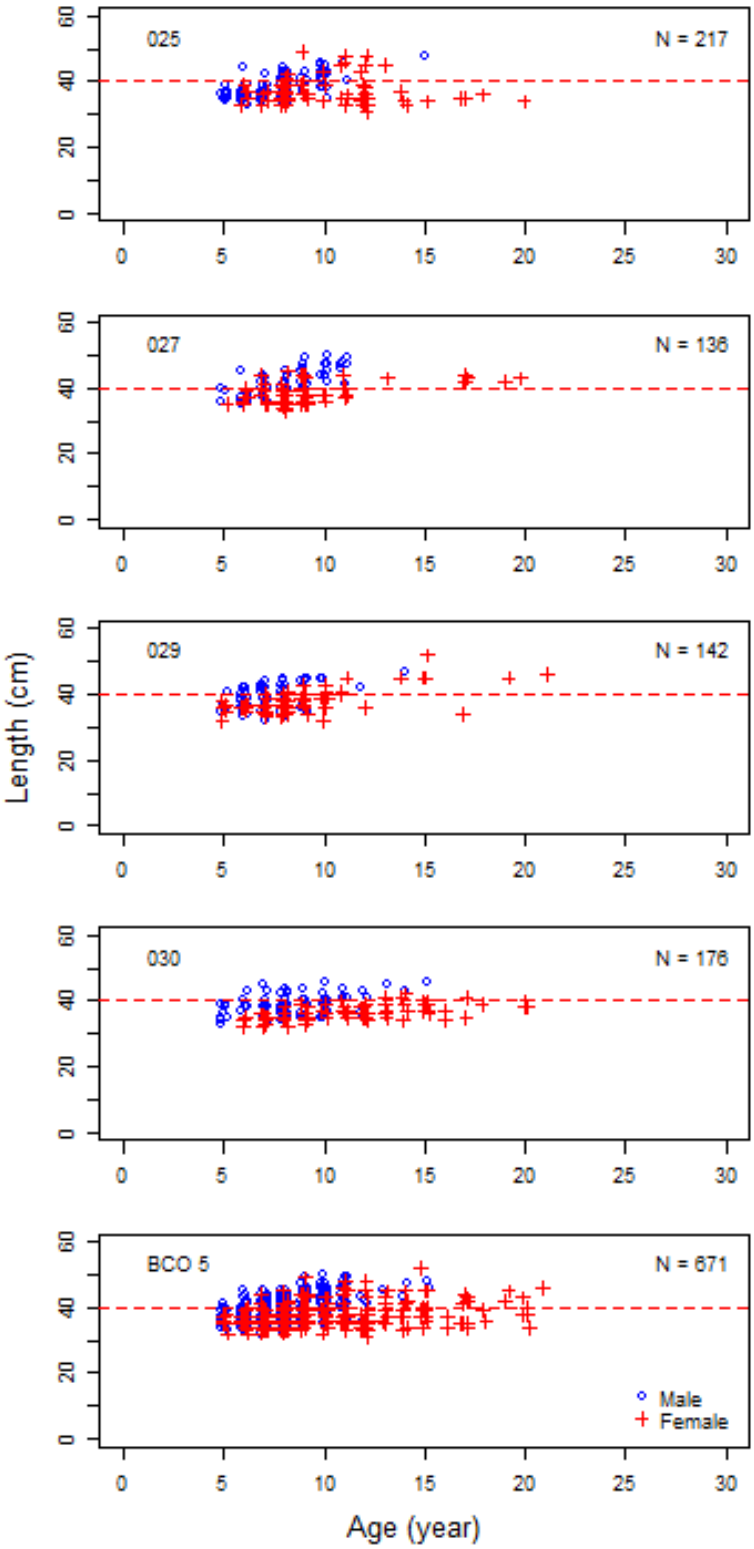

Figure 26: Observed blue cod age and length data by sex for the BCO 5 catch sampling programme in 2017–18 by statistical area and combined for all sampled statistical areas (BCO 5). The red dashed lines correspond to a length of 40 cm.

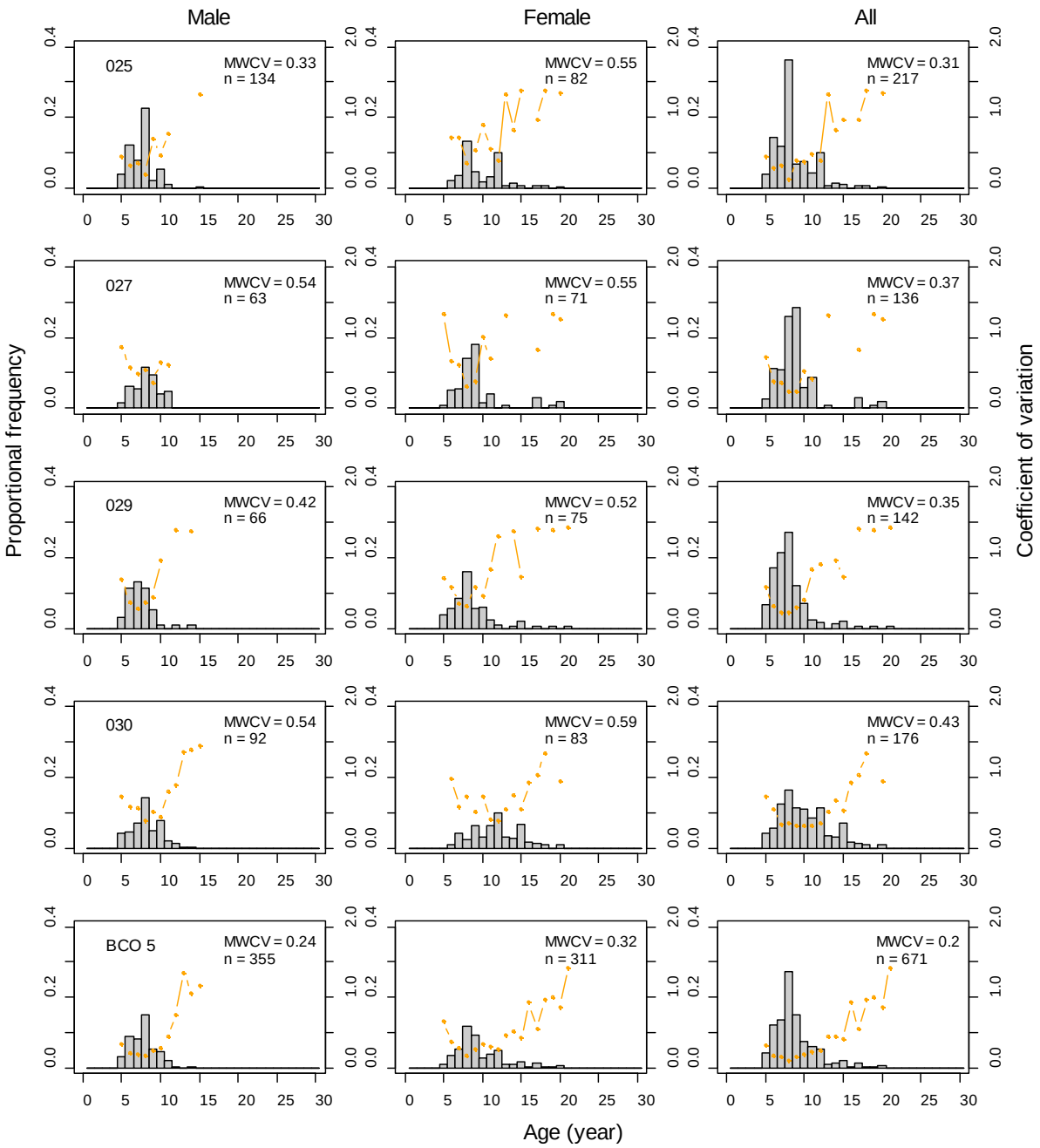

Figure 27: Blue cod scaled age frequency distributions from commercial potting landings in BCO 5 in 2017–18 fishing year. Data are shown grouped by sex, all fish, and stratified by statistical area, and all sampled statistical areas combined. There are more fish in the 'All' plots because only fish where otoliths were taken were sexed. Line indicates the CV for each length class; n, number of fished measured; MWCV, mean weighted coefficient of variation.

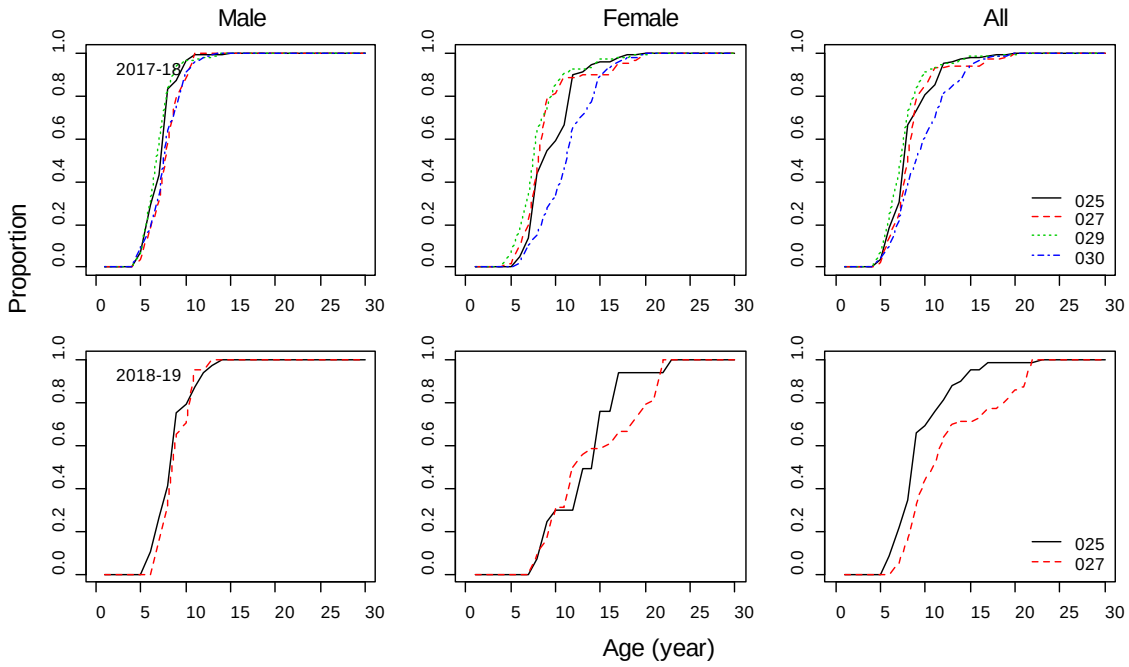

Figure 28: Cumulative proportion by age from the commercial potting landings in BCO 5 in the 2017–18 (top panel) and the first quarter of 2018–19 fishing year (bottom panel). Data are shown by statistical area.

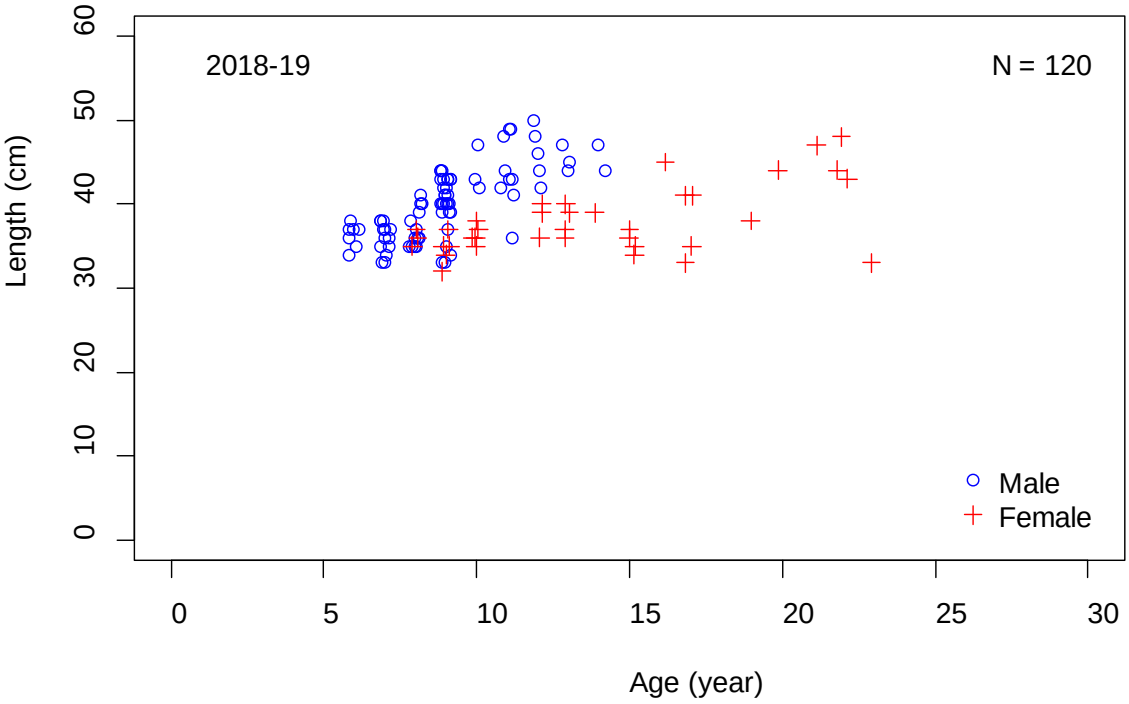

Figure 29: Observed blue cod age and length data by sex for the BCO 5 catch sampling programme in the first quarter of 2018–19 (N = 83 males and 37 females). Data are combined for sampled statistical areas (025 and 027).

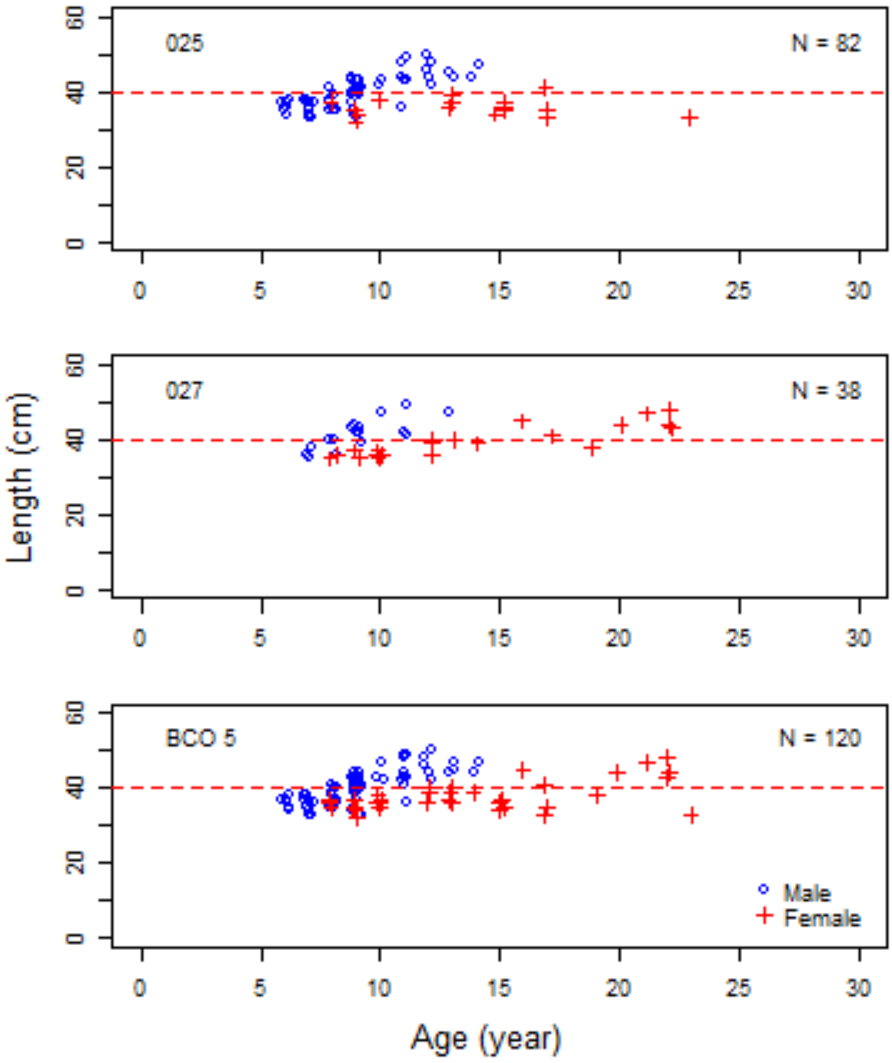

Figure 30: Observed blue cod age and length data by sex for the BCO 5 catch sampling programme in the first quarter of 2018–19 by statistical area and combined for sampled statistical areas (BCO 5).

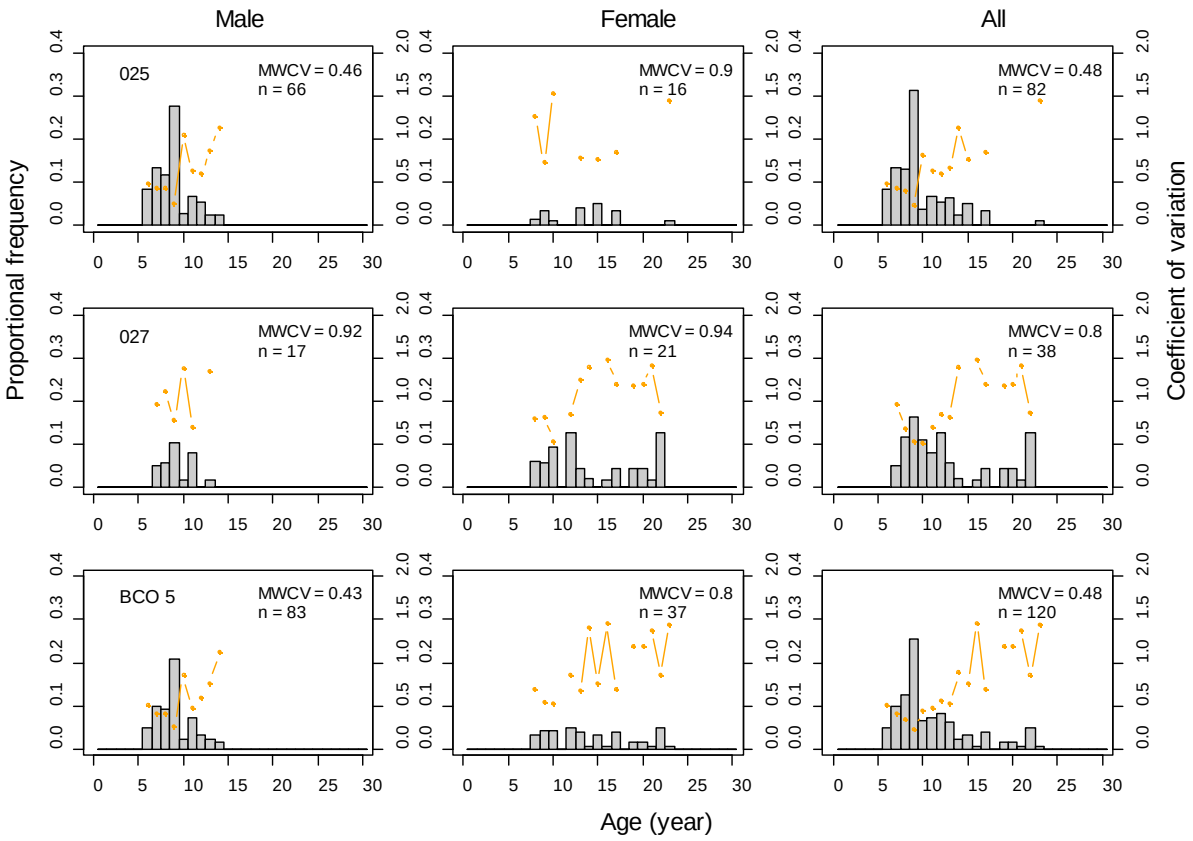

Figure 31: Blue cod scaled age frequency distributions from commercial potting landings in BCO 5 in the first quarter of 2018–19 fishing year. Data are shown grouped by sex, all fish, and stratified by statistical area, and all sampled statistical areas combined. There are more fish in the 'All' plots because only fish where otoliths were taken were sexed. Line indicates the CV for each length class; n, number of fished measured; MWCV, mean weighted coefficient of variation.

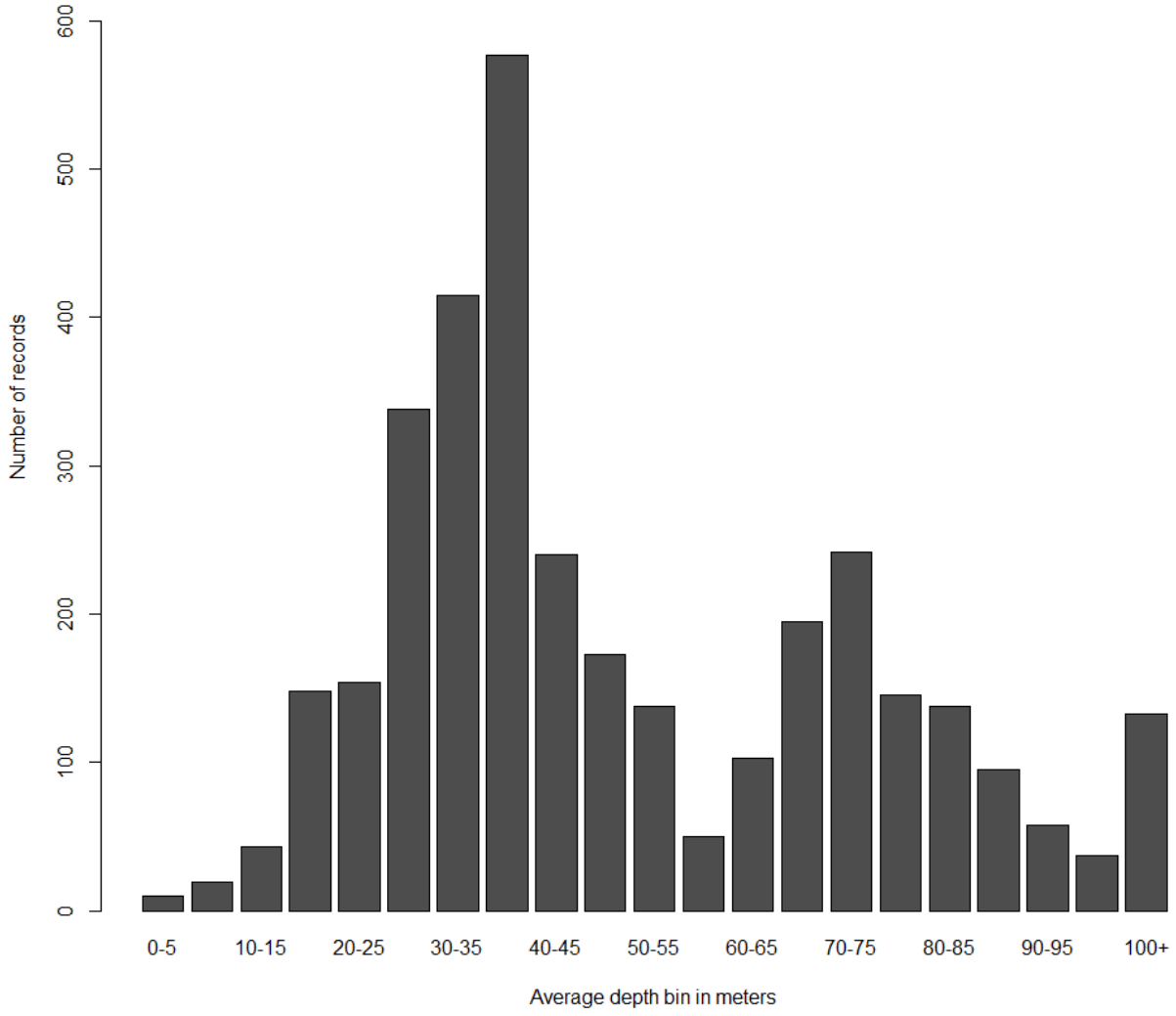

Figure 32: Distribution of records by average depth bins at 5 m intervals as recorded by participants in the 2009 to 2011 logbook programme (from Middleton et al. 2013).

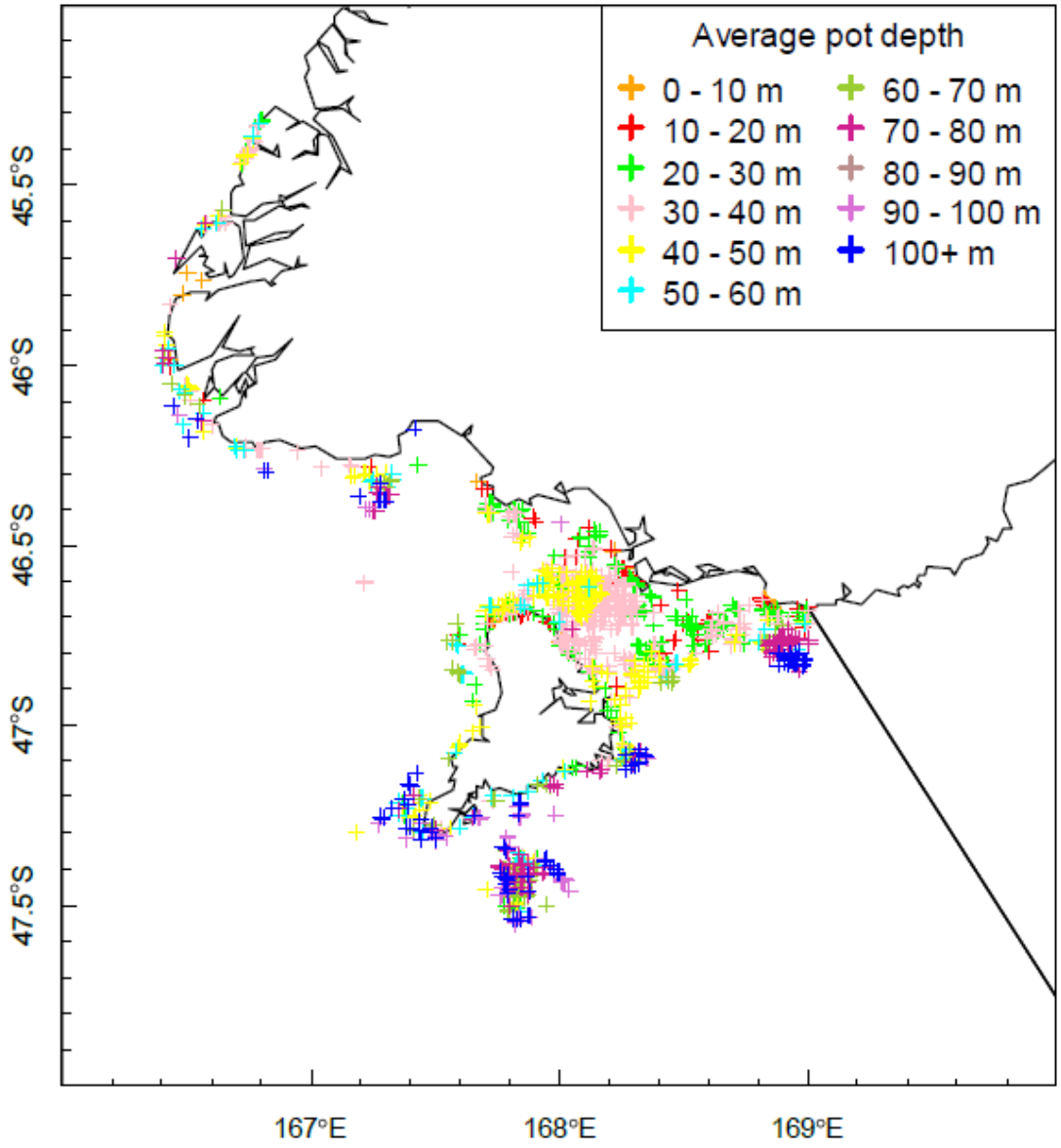

Figure 33: Average pot depth by depth bin as recorded by participants in the 2009 to 2011 logbook programme (from Middleton et al. 2013).

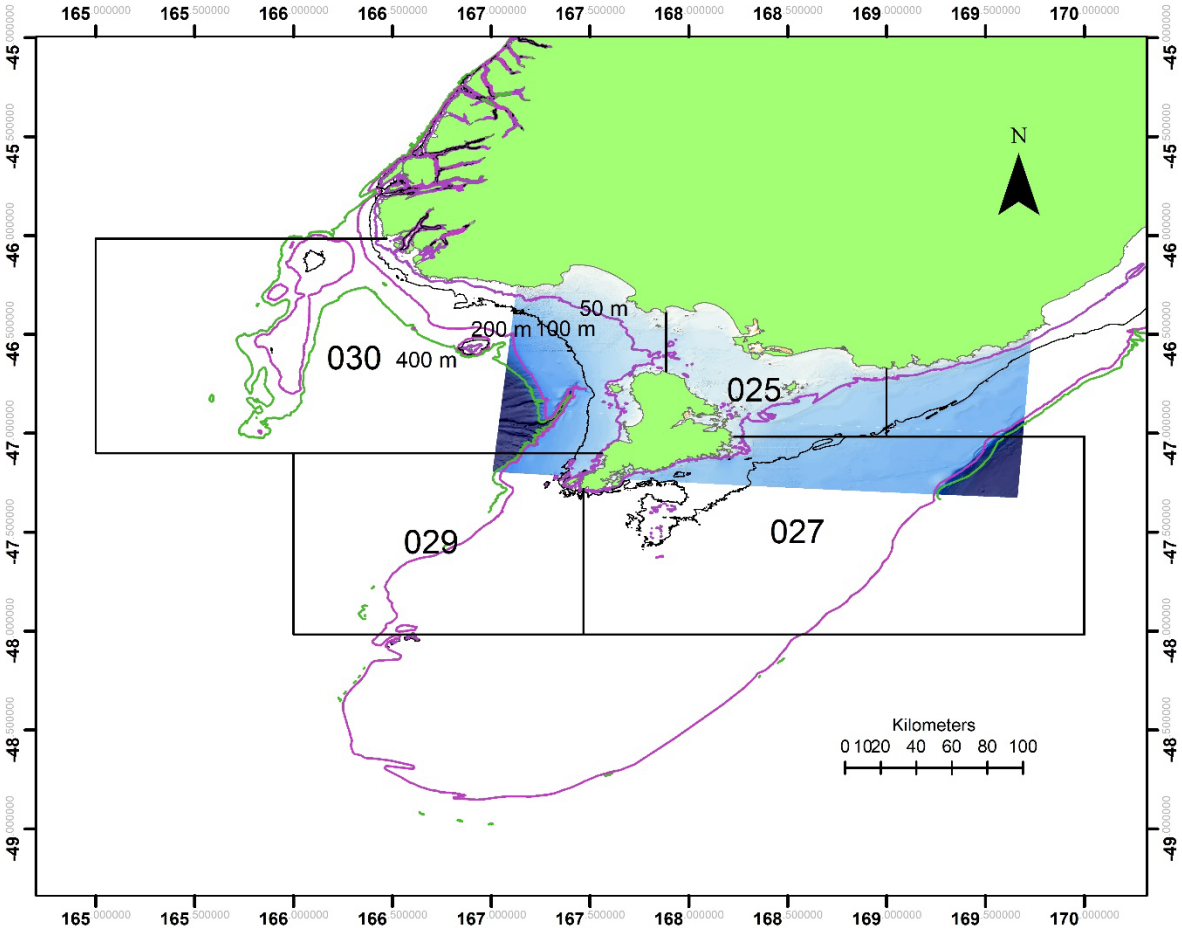

Figure 34. Depth contours at 50 m, 100 m, 200 m and 400 m, and BCO 5 Statistical Areas sampled in 2017–18 and 2018–19. A multibeam map (area with blue shading) is also shown.

Appendix 1: Scaled age frequencies (numbers) and coefficients of variation (CV) for the 2017–18 BCO 5 commercial potting catch sampling. Results are shown by age and sex and for all blue cod from all statistical areas combined (BCO 5).

Age class	Males	Females	unsexed	Total
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	2 904	1 002	0	3 906
6	8 196	3 308	0	11 504
7	7 620	5 032	179	12 831
8	14 182	11 079	180	25 442
9	5 112	8 571	461	14 143
10	4 259	2 730	0	6 989
11	2 011	3 646	0	5 657
12	387	4 756	0	5 144
13	62	919	0	981
14	221	982	0	1 202
15	162	1 807	0	1 970
16	0	296	0	296
17	0	1 404	0	1 404
18	0	370	0	370
19	0	331	0	331
20	0	777	0	777
21	0	98	0	98
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0
25	0	0	0	0
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	0	0	0	0

			Mean weighted CV
Males	Females	Unsexed	Total
0.24	0.33	1.07	0.20

Appendix 2: Scaled age frequencies (numbers) and coefficients of variation (CV) for 2017–18 BCO 5 commercial potting catch sampling. Results are shown by age, sex, and statistical area.

Stat. Area	Age class	Males	Females	Unsexed	Total
025	1	0	0	0	0
025	2	0	0	0	0
025	3	0	0	0	0
025	4	0	0	0	0
025	5	1 037	0	0	1 037
025	6	3 332	570	0	3 902
025	7	2 170	1 006	0	3 176
025	8	6 111	3 556	90	9 757
025	9	545	1 256	0	1 802
025	10	1 479	524	0	2 003
025	11	325	855	0	1 181
025	12	0	2 731	0	2 731
025	13	0	153	0	153
025	14	0	375	0	375
025	15	144	153	0	297
025	16	0	0	0	0
025	17	0	211	0	211
025	18	0	179	0	179
025	19	0	0	0	0
025	20	0	87	0	87
025	21	0	0	0	0
025	22	0	0	0	0
025	23	0	0	0	0
025	24	0	0	0	0
025	25	0	0	0	0
025	26	0	0	0	0
025	27	0	0	0	0
025	28	0	0	0	0
025	29	0	0	0	0
025	30	0	0	0	0
027	1	0	0	0	0
027	2	0	0	0	0
027	3	0	0	0	0
027	4	0	0	0	0
027	5	465	234	0	700
027	6	1 680	1 395	0	3 075
027	7	1 501	1 538	0	3 040
027	8	3 185	3 873	90	7 148
027	9	2 588	4 953	273	7 814
027	10	1 106	458	0	1 565
027	11	1 315	1 116	0	2 431
027	12	0	0	0	0
027	13	0	182	0	182
027	14	0	0	0	0
027	15	0	0	0	0

Stat. Area	Age class	Males	Females	Unsexed	Total
027	16	0	0	0	0
027	17	0	841	0	841
027	18	0	0	0	0
027	19	0	222	0	222
027	20	0	504	0	504
027	21	0	0	0	0
027	22	0	0	0	0
027	23	0	0	0	0
027	24	0	0	0	0
027	25	0	0	0	0
027	26	0	0	0	0
027	27	0	0	0	0
027	28	0	0	0	0
027	29	0	0	0	0
027	30	0	0	0	0
029	1	0	0	0	0
029	2	0	0	0	0
029	3	0	0	0	0
029	4	0	0	0	0
029	5	615	768	0	1 383
029	6	2 342	1 154	0	3 497
029	7	2 663	1 696	0	4 358
029	8	2 293	3 238	0	5 531
029	9	1 066	1 172	188	2 426
029	10	223	1 182	0	1 405
029	11	0	514	0	514
029	12	159	188	0	347
029	13	0	0	0	0
029	14	159	98	0	257
029	15	0	410	0	410
029	16	0	0	0	0
029	17	0	98	0	98
029	18	0	0	0	0
029	19	0	108	0	108
029	20	0	0	0	0
029	21	0	98	0	98
029	22	0	0	0	0
029	23	0	0	0	0
029	24	0	0	0	0
029	25	0	0	0	0
029	26	0	0	0	0
029	27	0	0	0	0
029	28	0	0	0	0
029	29	0	0	0	0
029	30	0	0	0	0
030	1	0	0	0	0
030	2	0	0	0	0

Stat. Area	Age class	Males	Females	Unsexed	Total
030	3	0	0	0	0
030	4	0	0	0	0
030	5	787	0	0	787
030	6	842	188	0	1 030
030	7	1 286	792	179	2 257
030	8	2 594	412	0	3 006
030	9	912	1 190	0	2 102
030	10	1 451	565	0	2 016
030	11	370	1 161	0	1 531
030	12	228	1 837	0	2 065
030	13	62	584	0	645
030	14	62	509	0	570
030	15	19	1 244	0	1 262
030	16	0	296	0	296
030	17	0	252	0	252
030	18	0	191	0	191
030	19	0	0	0	0
030	20	0	185	0	185
030	21	0	0	0	0
030	22	0	0	0	0
030	23	0	0	0	0
030	24	0	0	0	0
030	25	0	0	0	0
030	26	0	0	0	0
030	27	0	0	0	0
030	28	0	0	0	0
030	29	0	0	0	0
030	30	0	0	0	0

				Mean weighted CV
Stat. area	Males	Females	Unsexed	Total
025	0.33	0.56	1.35	0.32
027	0.53	0.56	1.32	0.38
029	0.43	0.52	1.40	0.36
030	0.54	0.60	1.37	0.44

Appendix 3: Scaled age frequencies (numbers) and coefficients of variation (CV) for the first quarter of 2018–19 BCO 5 commercial potting catch sampling. Results are shown by age and sex and for all blue cod from all statistical areas combined (BCO 5).

Age	Males	Females	unsexed	Total
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	761	0	0	761
7	1 512	0	0	1 512
8	1 392	482	0	1 874
9	3 174	655	0	3 829
10	345	642	0	987
11	1 081	0	0	1 081
12	491	744	0	1 235
13	324	607	0	931
14	211	107	0	319
15	0	472	0	472
16	0	91	0	91
17	0	576	0	576
18	0	0	0	0
19	0	248	0	248
20	0	248	0	248
21	0	91	0	91
22	0	744	0	744
23	0	106	0	106
24	0	0	0	0
25	0	0	0	0
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	0	0	0	0

			Mean weighted CV
Males	Females	Unsexed	Total
0.44	0.80	–	0.48

Appendix 4: Scaled age frequencies (numbers) and coefficients of variation (CV) for the first quarter of 2017–18 BCO 5 commercial potting catch sampling. Results are shown by age, sex, and statistical area.

Stat. Area	Age class	Males	Females	Unsexed	Total
025	1	0	0	0	0
025	2	0	0	0	0
025	3	0	0	0	0
025	4	0	0	0	0
025	5	0	0	0	0
025	6	761	0	0	761
025	7	1 222	0	0	1 222
025	8	1 070	127	0	1 196
025	9	2 561	315	0	2 877
025	10	254	88	0	342
025	11	618	0	0	618
025	12	491	0	0	491
025	13	232	359	0	592
025	14	211	0	0	211
025	15	0	472	0	472
025	16	0	0	0	0
025	17	0	328	0	328
025	18	0	0	0	0
025	19	0	0	0	0
025	20	0	0	0	0
025	21	0	0	0	0
025	22	0	0	0	0
025	23	0	106	0	106
025	24	0	0	0	0
025	25	0	0	0	0
025	26	0	0	0	0
025	27	0	0	0	0
025	28	0	0	0	0
025	29	0	0	0	0
025	30	0	0	0	0
027	1	0	0	0	0
027	2	0	0	0	0
027	3	0	0	0	0
027	4	0	0	0	0
027	5	0	0	0	0
027	6	0	0	0	0
027	7	290	0	0	290
027	8	322	356	0	678
027	9	613	339	0	952
027	10	91	554	0	646
027	11	463	0	0	463
027	12	0	744	0	744
027	13	91	248	0	339
027	14	0	107	0	107

Stat. Area	Age class	Males	Females	Unsexed	Total
027	15	0	0	0	0
027	16	0	91	0	91
027	17	0	248	0	248
027	18	0	0	0	0
027	19	0	248	0	248
027	20	0	248	0	248
027	21	0	91	0	91
027	22	0	744	0	744
027	23	0	0	0	0
027	24	0	0	0	0
027	25	0	0	0	0
027	26	0	0	0	0
027	27	0	0	0	0
027	28	0	0	0	0
027	29	0	0	0	0
027	30	0	0	0	0

	Mean weighted CV			
Stat. area	Males	Females	Unsexed	Total
025	0.47	0.90	–	0.49
027	0.92	0.94	–	0.80