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Catch per unit effort analyses and fisheries characterisation for BCO 3 from 1990 to 2024

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PLAIN LANGUAGE SUMMARY

This report provides an update of the characterisation and catch per unit effort (CPUE) analysis for the blue cod fishery in the BCO 3 area (east coast South Island from Clarence River to Slope Point) up to the end of the 2023–24 (2024) fishing year. Blue cod were caught mainly by cod pot (63% of catch) and bottom trawl (24%), over the last 35 years. The bulk of the landings from cod potting were taken from Statistical Areas 024 (north Otago) and 026 (south Otago), which have contributed 66%, and 20% of the catch respectively, over the 35-year time series. For the last five years, area 026 has become the main contributor, accounting for 56% of the catch compared to 32% from 024. The cod pot vessel fleet has declined by about one half from about 30 to 15 vessels since 2007. CPUE indices (assumed to be proportional to abundance) were estimated using Generalised Linear Models (GLM) run for Statistical Areas 024 and 026, and these fluctuated but generally trended upward, peaking in 2014, before declining steeply. The trends in CPUE were mirrored by the abundance estimates from both the north and south Otago potting surveys over the overlapping period from 2010 to 2022, suggesting that blue cod abundance in the Otago fishery dropped sharply from 2013 to 2018.

EXECUTIVE SUMMARY

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This report provides an update of the characterisation and catch per unit effort (CPUE) analysis for the blue cod (*Parapercis colias*) fishery in BCO 3 up to the end of the 2023–24 fishing year (2023–24 fishing year = 2024).

Catch effort data were extracted from the Fisheries New Zealand Enterprise Data Warehouse. The extracts consisted of all fishing and landing events for trips that reported a positive landing of blue cod in BCO 3, or where blue cod was listed as the target species, between 1 October 1989 and 30 September 2024. Blue cod catch effort data from 1990 up to 2019 by all fishing methods were recorded using predominantly Catch Effort Landing Return (CELR) paper forms with a transition to the Electronic Reporting System (ERS) beginning in 2019, after which data were virtually all reported by ERS. There were no clear changes in fishing or reporting behaviour due to changing to electronic reporting. Standard data grooming was carried out prior to the characterisation and CPUE analyses.

Blue cod in BCO 3 were caught mainly by cod pot (CP, 63%) and bottom trawl (24%), over the 35 years. The target species for method CP has been almost exclusively blue cod. The main blue cod landed states for CP have been headed and gutted (HGU), followed by gutted (GUT), with relatively little blue cod landed in the green state (GRE). The BCO 3 potting fishery operates throughout the year with no clear seasonal trends in the landings for any of the statistical areas over the time series except in Statistical Area 024 where catches were higher from February to May until the last few years. The bulk of the CP landings were taken from Statistical Areas 024 and 026, which have contributed 65.7%, and 19.8% of the catch respectively, over the 35-year time series. In the last five years, Area 026 has become the main contributor, accounting for 56% of the catch compared to 32% from Area 024. The cod pot vessel fleet has declined by about one half since 2007. ERS spatial effort data from 2020 to 2024 indicated a move to fishing in deeper water off Otago in the last two years.

For the CPUE analyses the linked data set was aggregated at the trip-stratum level for method CP, and target species blue cod, which aggregated catch-effort data by full-day fishing events for CELRs, and multiple within-day fishing events for ERS-Potting. Only core vessels that had participated most often each year, and consistently over multiple years, were included in the CPUE analyses. Generalised Linear Models (GLM) were run for Statistical Areas 024 and 026 combined. The response variable was the log-transformed positive blue cod catch, with a lognormal error structure. Three models with different effort types were run: 1) total pot lifts (no-swap); 2) the greater of total pot lifts or pots in the water at midnight (swap); and 3) the swap model excluding trips with fewer than 4 pot lifts (swap-2). CPUE in the swap-2 model was accepted by the Inshore Working Group. It fluctuated between years with a generally increasing trend until 2014, followed by a steep decline, most marked between 2016 and 2020. There was generally good overlap between the north and south Otago potting survey areas and the spatial distribution of commercial blue cod potting catch, notwithstanding the component of commercial fishing that occurred in deeper water in the last two years. The trends in CPUE were mirrored by the abundance estimates from both the north and south Otago potting surveys over the overlapping period from 2010 to 2022, suggesting that abundance has dropped sharply from 2013 to 2018.

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1. INTRODUCTION

This report provides an update of the characterisation and catch per unit effort (CPUE) analysis for the blue cod (*Parapercis colias*) fishery in BCO 3 up to 2023–24, updating the previous Fisheries New Zealand funded analyses up to 2017–18 by Holmes et al. (2022). It also compares the spatial overlap of BCO 3 commercial catch with the locations of the spatial strata used for the two Otago blue cod potting surveys.

BCO 3 is a Group 2 stock that is assessed relative to B_{MSY} and F_{MSY} proxies using a partial quantitative stock assessment, based on relative abundance and age structure from fisheries independent potting surveys and augmented by standardised commercial CPUE (Fisheries New Zealand 2025).

1.1 Biology

Blue cod is a demersal species endemic to New Zealand, found from about 5 m to as deep as 200 m and is 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. Mark-recapture and stable isotope studies have consistently shown that blue cod have a restricted home range and strong site fidelity (Rapson 1956, Mace & Johnston 1983, Mutch 1983, Cole et al. 2000, Carbines & McKenzie 2001, Govier 2001, Carbines & McKenzie 2004, Rodgers & Wing 2008). This suggests that blue cod are susceptible to localised and serial depletion. Despite this limited movement, blue cod populations along the New Zealand coastline are not genetically distinct (Gebbie 2014) suggesting that egg or larval dispersion coupled with the occasional larger scale movements of individuals are sufficient to prevent genetic isolation occurring. The oldest blue cod on record is a 32 year old, 58 cm male (Beentjes & Carbines 2003), but most exploited populations have few fish older than about fifteen years of age and recruitment is highly variable between years (Beentjes 2021). Males grow faster than females and the bulk of the largest fish in the populations are generally males (Beentjes 2021, Beentjes & Bian 2024). Blue cod are sequential protogynous hermaphrodites capable of changing sex (= sex reversal) from female to male (Mutch 1983, Carbines 2004, Beentjes 2021) with exploited populations dominated by males.

1.2 Recreational fishery

Blue cod was the third most common recreational finfish species caught in New Zealand determined during the 2017–18 national panel survey (Wynne-Jones et al. 2019). In BCO 3, recreational annual take was estimated at 98 t (33% of total national recreational blue cod catch), the highest of any QMA. Nearly all of this was taken by rod and line, and most of this catch in BCO 3 was from a few areas including Kaikoura, offshore Banks Peninsula, Moeraki and Taieri Mouth (Figure 1). All South Island areas have a minimum legal size (MLS) of 33 cm. Under Fisheries New Zealand's blue cod 'traffic light' management regime there is a range of daily bag limits (DBL) in different parts of BCO 3, that reflect stock status (Fisheries New Zealand 2018). For example, the DBL for blue cod in the red area is 2 (Hurunui to Rakai Rivers), in the orange areas is 10 (Clarence to Hurunui Rivers, and Rakaia River to Taiaroa Head), and in the green area it is 15 per day (Taiaroa Head to slope Point).

1.3 Commercial Fishery

Blue cod is an important inshore commercial finfish fishery on the east coast of the South Island, with documented catches since the 1930s, but it is likely that there was a target fishery before this time (Fisheries New Zealand 2025). BCO 3 is the third largest blue cod fishery with landings about 20% of those in Southland (BCO 5) and the Chathams (BCO 4) (Figure 2). For the first sixty years, catches in BCO 3 averaged around 50 t, increasing about three-fold to 148 t in 1988, a year after blue cod was introduced into the Quota Management System. Landings continued to increase until 2005 before levelling off between about 160 to 180 t annually. The TACC increased for the first few years, due to quota appeals, before settling at 163 t in 2002 where it remained until a 20 % cut in 2022 to 130 t

(Figure 2). Landings have exceeded the TACC in all but two years since 2003 including after the cut in 2022. The likely cause of the TACC overruns is bycatch by trawling for mixed species such as tarakihi, sea perch, red cod, and flatfish, where the excess blue cod catch is landed using the 'deemed value' system in which fishers are levied for the catch in excess of their caught annual catch entitlement (ACE).

Historically blue cod were taken predominantly by line fishing, but in the mid-1980s a pot fishery rapidly developed in New Zealand and became the prevalent commercial fishing method for targeting blue cod. Blue cod is often caught as bycatch using other methods such as bottom trawl, bottom long line, set net and rock lobster pot, but since 1990 about two-thirds of the blue cod catch in BCO 3 was taken by cod pot, and of this, 80% of the catch was from the most southern Statistical Areas 024 and 026 (Figure 1) (Holmes et al. 2022). The same vessels often target blue cod and rock lobster, and landings of blue cod were historically related to the Otago rock lobster Concession Area fishery (minimum 127 mm tail length) season from June to November, however in 2013 this seasonal restriction was removed.

The blue cod fishing fleet in BCO 3 was historically comprised of about 20 to 30 small inshore vessels around 12 m length, generally setting between 10 to 20 pots per trip, with trips on average about one to two days in duration and usually fishing in a single statistical area. Blue cod are caught using specialised cod pots with a mesh size originally selected to retain larger commercially sized fish. During a single fishing event, around 10 pots are usually set and left to soak for about an hour. In a day, several sets might be carried out, and the last set left to fish overnight on multi-day trips. 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 that is related to environmental cues. There were no regulated mesh size restrictions in BCO 3 until June 2009, after which a 48 mm minimum was introduced, and on 1 July 2020, this was increased to 54 mm. Increasing the mesh size to 54 mm was implemented to allow fish under the minimum legal size to escape (33 cm TL), reducing unwanted mortality on undersized fish. Captured blue cod are alive when they land on deck and any undersized fish are returned to the sea.

1.4 Reporting

The cod potting fishery was reported using statutory catch effort landing returns (CELRs) from 1986 when the QMS was implemented, until 2019 when electronic reporting was introduced. For CELRs a fishing event was in the form of daily aggregated estimated catch and effort (total pots lifted) for a target species, within a statistical area. Further there were no position data (latitude and longitude) or depth recorded on CELRs. The fishery began transitioning from CELRs to the Electronic Reporting System (ERS) in 2018–19, and in 2019–20 virtually all reporting was from the ERS. In the ERS a fishing event for method potting is comprised of the aggregated estimated catch and effort (total pot lifts) occurring within 2 nautical miles, and catch location is recorded by fine scale latitude and longitude before lifting the first pot, and again after the last pot is lifted. Hence there is usually more than one fishing event per day. Soak time of pots was also a new variable included in the ERS, but depth is still not recorded. Further, ERS does not have a field for port of landing as did CELRs (e.g., Bluff, Riverton, Stewart Island), but does have 'end trip position' recorded in the Trip End Report which should correspond to the latitude and longitude of where the vessel ties up and lands the catch. The current CPUE analyses presented in this report are the first to incorporate data from CELRs as well as the ERS for blue cod in BCO 3.

1.5 Aims of this report

The first BCO 3 CPUE analyses used data from 1989–90 to 2013–14 (Starr & Kendrick 2015) and was industry funded, followed by an update to 2017–18 funded by Fisheries New Zealand (Holmes et al. 2022). Both analyses used CELR data 'rolled-up by trip', and standardised indices were output for BCO 3, and Statistical Areas 024 and 026 combined, respectively. The standardised CPUE series showed no clear trend over the time series. The current analyses repeated the BCO 3 CPUE analyses, including six more years up to 2023–24, of which five years were ERS catch effort data.

An additional objective of this project was to compare the spatial distribution of commercial potting effort with the area covered by north and south Otago potting surveys, to determine the degree of spatial overlap. Both CPUE and the potting surveys provide indices of abundance for blue cod in specific parts of BCO 3 and, in theory, should provide the same trends in abundance if the two methods have adequate overlap and are indexing the same populations of blue cod. This comparison of the areas covered was possible because since 2019–20 the position of the commercial pot sets (latitude and longitude) has been recorded in the ERS.

1.6 Objectives

This report is an output of Fisheries New Zealand research project BCO2024-04.

Overall Research Objective:

To monitor abundance of blue cod in BCO 3 using CPUE indices.

Specific Objectives:

1. To characterise the BCO 3 fishery.
2. To analyse CPUE trends in commercial BCO 3 commercial fishery up to the end of 2023–24.
3. To determine the degree of spatial overlap between commercial fishing grounds and blue cod potting survey areas.
4. Broader outcomes.

2. METHODS

2.1 Data extract

The catch effort data were extracted from the Fisheries New Zealand Enterprise Data Warehouse (EDW). The extracts consist of all fishing and landing events associated with a set of fishing trips that reported a positive landing of blue cod in BCO 3, or where blue cod was listed as the target species, between 1 October 1989 and 30 September 2024. This data included catch from the 1989–90 to the 2023–24 fishing years (35 fishing years).

Blue cod catch effort data from 1989–90 up to 2018–19 by all fishing methods were recorded using predominantly paper forms with a transition to the Electronic Reporting System (ERS-potting), beginning in 2018–19, after which it was virtually all reported by ERS. Hence, the extract included data recorded in both CELRs and the ERS.

Henceforth in this report, fishing years will be referred to by the second year, i.e., 1989–90 = 1990.

2.2 Data grooming

Data grooming was carried out using the R language software written specifically to groom Fisheries New Zealand commercial fishing catch and effort data. The code is stored and maintained on NIWAs internal GitLab platform. Data were groomed prior to the characterisation, and the catch per unit effort analyses. The code allows the user to select various options for the way in which the data are groomed, linked to landings, and rolled-up to landings. The specific grooming details are provided in Appendix A, and a summary of groomed results in Appendix B.

Following the general methods used during the last BCO 3 CPUE analyses (Holmes et al. 2022) the estimated catch and effort data were firstly groomed separately for outliers, missing catch, illogical landing dates etc. The landed catch was then linked to fishing events in the effort data by trip ID. The allocation of landed greenweight to the fishing events was in proportion to blue cod estimated catches, or in proportion to the number of pot lifts if there was no estimated catch. The characterisation was undertaken on this linked data set.

Fishing events (day based) for CELR forms (1990 to 2019), sometimes show that the number of pots in the water at midnight (*effort_num*) was recorded as greater than the total number of pots lifts (*effort_total_num*), indicating that the skipper had likely transposed the variables, or entered incorrect data. In two of the CPUE model runs (swap and swap-2), these variables were swapped where pots in the water at midnight (*effort_num*) was greater than the total number of pots (*effort_total_num*). This grooming method does not appear to have been carried out in the previous BCO CPUE analyses, even though the FAR states that it was (Holmes et al. 2022).

As found in the previous analyses, there was misreporting of RCO 3 landings as BCO 3, probably due to data entry errors (Starr & Kendrick 2015). This problem was again resolved before undertaking the characterisation and CPUE analysis by dropping trips with landed blue cod catch greater than 100 kg and zero estimated catch. Most of this misreporting occurred in the mid-1990s.

Exploratory analyses of catch versus pots lifts per trip showed that there were often high catches associated with trips reporting effort of only a few pot lifts. To deal with this, in one of the CPUE model runs (swap-2), trips with fewer than 4 pots per trip were dropped. The cut-off of 4 pots was used because some fishers historically were known to have used as few as 4 pots (Tony Brett, pers com).

2.3 Fishery characterisation

The BCO 3 fishery was characterised by comparing the cod potting vessel fleet size, and catch and effort, over the 35-year time series. Catch was explored by fishing method, season, statistical area, reporting form, port of landing, and landed state. For the last 5 fishing years when ERS was used to report catch-effort data, spatial maps showing position and size of the catch from individual fishing events (latitude and longitude) at a resolution of 0.04 degrees square were output and presented to the Inshore Working Group (24 April 2025). In this report, however, these are not presented because Data Confidentiality rules restricted resolution of the presentation of catch data to 1-degree squares, with data from no fewer than three vessels in each square. This means that the plots are unable to show any trends or patterns in catch because of the fine scale nature of the fishery relative to the required resolution of 1 degree.

Depth by fishing event was not provided in CELRs or in the current ERS-potting and depth was estimated for fishing event positions for the ERS data only (2020 to 2024), from NOAA GEBCO 460 m resolution bathymetry using the R package marmap.

To explore if there has been a change in fishing or reporting behaviour during the transition from paper based (CELR) to electronic based (ERS) reporting of catch, the number of days fished, number of fishing events, number of statistical areas fished, and total catch were summarised by trip for the cod potting fleet from 2015 to 2024, where the first five years were recorded by CELR and the last five by ERS.

2.4 Overlap with potting surveys and commercial fishing

An objective of this project was to look at the spatial overlap of fisheries New Zealand blue cod potting surveys in north Otago and south Otago (Figure 3), with commercial cod potting effort in the associated Statistical Areas (024 and 026, respectively) (Beentjes & Fenwick 2023a, 2023b). This was done by overlaying the survey areal strata and catch rates for each survey time series (2013, 2018 and 2022 for both north and south Otago surveys), together with the spatial distribution of commercial catch for the combined fishing years 2020 to 2024 for trips using method cod potting.

The spatial distribution of commercial catch for the last five years (ERS data) indicated a trend of fishing deeper and closer to the shelf edge over time. This was quantified by calculating the proportion of the cod pot catch that was caught inside and outside 60 m depth, by fishing year, for north Otago (Statistical Area 024), and similarly inside and outside 80 m depth for south Otago (Statistical Area 026). The depth cut-offs (60 m and 80 m) were based on observed separation of commercial catches from spatial plots.

2.5 Standardised CPUE analyses

The approach used to carry out the standardised CPUE analyses on BCO 3 was similar to that used in the last update to 2018 (Holmes et al. 2022), but included six additional years of catch effort data (2018–19 to 2023–24), one of which was recorded on CELRs and the last five by ERS-potting. The CPUE data set was rolled-up to trip-stratum level for method of cod potting only, which aggregated catch-effort data by full day fishing events for CELRs, and multiple within day fishing events for ERS-Potting to a trip. The effort data were rolled-up to unique trip, target species, and statistical area. For trips where more than one statistical area was fished, the greenweight was prorated to each unique statistical area.

Estimates of year effects and associated standard errors were obtained using a forward stepwise Generalised Linear Model (GLM) (McCullagh & Nelder 1989). The identity link function was used and the response variable was the log-transformed positive blue cod catch, where target species was blue cod. The lognormal error structure was assumed and implies a multiplicative model, i.e., the combined effect of two predictors is the product of their individual effects.

The categorical predictor variables offered to the combined statistical area (024 and 026) models were fishing year (forced), vessel identifier, fishing month, statistical area; and the continuous variables were log(pot lifts), and log(days fished), fitted as 3rd-degree polynomials in log space. The interaction term fishing year:statistical area was also offered to the model.

A stepwise regression procedure was used to fit the GLM of log(catch) on these predictor variables. The relative year effect from the model was then interpreted as the CPUE index and presented using the canonical form, scaled to have a mean of 1.0. Model fits were investigated using standard residual diagnostics. Plots of model residuals and fitted values were investigated for evidence of departure from model assumptions, and the amount of deviance explained by each variable accepted into the model. Cook's distance and leverage were used to detect highly influential data points, i.e. data points that can have a large effect on the outcome and accuracy of the regression where Cook's distance values above 1.0 indicate highly influential points. Influence step plots and coefficient-distribution-influence plots (CDI) were used to interpret the standardisation effects of explanatory variables (Bentley et al. 2012).

The stepwise fitting method began with a basic model in which year was the only predictor and iteratively included predictors until there was insufficient improvement in the model. At each step, the predictor giving the greatest improvement in R^2 was included, providing that its inclusion resulted in an improvement in R^2 of at least 0.01.

Plots are provided for the time series of year effects (standardised indices) for each model along with unstandardised geometric and arithmetic indices based on nominal CPUE (kg/pot). The previous standardised indices up to 2018 are plotted for comparison.

Standardised CPUE Models

Three trip-based CPUE models were investigated (Table 1). The first model (no swap) used the *effort_total_num* as the effort variable, the second model (swap) used the larger of *effort_total_num* or *effort_num*, the third used the swap model but excluding trips with fewer than 4 pots. An additional model (ERS-event) was run using ERS data only (2020 to 2024), with effort rolled up to the fishing event level, and where only *effort_total_num* is reported for pot lift effort (Table 1). The ERS-event model also included additional categorical predictor variables 024-inshore and 024-offshore for fishing events with start position inside and outside 60 m depth; and 026-inshore, and 026-offshore for fishing events with start position inside and outside 80 m; and continuous variable depth of start fishing event position.

Core vessel selection

To ensure representativeness of the model data, a selection criterion was applied to each model data set, restricting analysis to core vessels. Core vessels were those that had participated most often each year, and consistently over multiple years, while those that had fished below a threshold were not included. Selection was based on two criteria: the number of years that the vessel had fished, and the number of trips per year. Selection involved a trade-off between these two criteria, i.e., the higher the minimum number of years, the lower is the minimum trips per year, and vice versa. The aim was to reduce the overall vessel number but retain at least 60% of the catch. As a starting point, the vessel selection criteria used in the previous analysis was adopted (Table 2).

3. RESULTS

3.1 BCO 3 fishery characterisation

3.1.1 Analyses dataset

The destination codes, greenweight amounts in the BCO 3 data extract, and codes used in the analyses are shown in Table 3. The extracted data from Quota Management Returns-Monthly Harvest Returns (QMR-MHR), greenweight landings, groomed estimated catch from CELRs and ERS, and the linked analysis data set (i.e., the greenweight from landings linked to effort data prorated by estimated catch) for 1989–90 to 2023–24 are plotted in Figure 4 and tabulated in Table 4. The groomed estimated catch was consistently less than the landed catch and QMR-MHR, and for all years combined was 79% of the landed catch. The linked analysis data set was close to the landings data except around 2003 to 2018 where it was sometimes noticeably less than the landings and for all years combined was 93% of the landed catch (Table 4). This is primarily because there were a large number of landed trips (N = 785) where there were no matching effort data resulting in lower values for the analyses dataset (Appendix B). Regardless, the landed catch and the analysis data set follow the same trends over time.

3.1.2 Method and target

There are a range of methods that have caught blue cod throughout BCO 3 with cod pot accounting for 63%, bottom trawl 24%, other 10%, and rock lobster pot 3% of the total BCO 3 catch over the 35 years (Figure 5). The two Statistical Areas where blue cod catch has been the highest (024 and 026) have provided 69% of the BCO 3 catch, with cod pot (CP) the main method, followed by bottom trawl (BT) and rock lobster pot (RLP) (Figure 5). In these two areas cod pot catch has accounted for 79% of the blue cod catch.

Blue cod has been caught from bottom trawl and set netting with a wide range of target species (Figure 6). The target species for method CP is almost exclusively blue cod, with some bycatch of blue cod when targeting ling. For method RLP some blue cod catch is taken with either blue cod or rock lobster as the target species, but these amounts are relatively small (Figure 6). Targeting blue cod with other potting methods (POT and FP) has resulted in relatively small blue cod catches and these methods appear to be primarily targeting ling.

3.1.3 Reporting form type

Blue cod catch effort data were historically recorded using CELR paper forms which captured cod and rock lobster potting, and most other methods except deepwater trawling (TCP) until 2005, after which method specific forms were introduced for lining, netting and bottom trawling for small inshore vessels (Figure 7). Reporting of commercial fishing transitioned to the Electronic Reporting System in 2018–19, with most of the target blue cod catch thereafter reported using ERS-potting.

3.1.4 Cod pot fishery

The bulk of the blue cod landings from method cod pot from 1990 to 2019 recorded on CELR forms were landed into ports in Kaikoura (Statistical Area 018), Karitane, Oamaru (Statistical Area 024), Catlins and Taieri Mouth (Statistical Area 026) (Figures 1 and 8). The port of landing is not recorded in the ERS and is shown in the 'other' (unknown) category from 2020 onward (Figure 8). The assumption is that there has been no change to the proportions of the catch landed to the main ports over the five years since the introduction of electronic reporting, although with increasing catches in 026 and lower catches in 024 it seems likely that proportionally more catch will have been landed in the ports in Statistical Area 026.

The main landed states for blue cod from method cod potting has consistently been headed and gutted (HGU), followed by gutted (GUT), and less commonly green and a number of other states (Figure 9). Relatively little blue cod has been landed in the green state (GRE), anecdotally because it does not keep well on ice during multi-day trips.

The blue cod potting fishery operates throughout the year with no clear seasonal trends in the landings for any of the BCO 3 statistical areas over the time series except in Statistical Area 024 where catches were higher from February to May until the last few years. There were no apparent changes after transitioning to the ERS-potting reporting in 2018–19 (Figure 10).

The bulk of the BCO 3 cod pot landings have historically been taken from Statistical Areas 018, 024, and 026, which have contributed 7.1%, 65.7%, and 19.8% of the catch respectively, over the 35-year time series (Figures 11 and 12, Table 5). Statistical Area 024 has consistently contributed most of the BCO 3 potting catch (63–90%) until 2020, after which catches from 024 declined and those from 026 increased dramatically, and over the last five years 026 has become the main contributor, accounting for 56% of the catch compared to 32% from 024 (Figures 11 and 12, Table 5). The relative contribution of the BCO 3 catch from the combined 024 and 026 areas, however, has remained largely the same at about 85%.

Over the 35-year time series, landings from Statistical Area 024 have fluctuated with no clear trend until the sharp decline in 2020, dropping from 69 t to 29 t and remaining at this lower level for the next five years. In contrast landings from Statistical Area 026 showed greater swings in catch between years, also with no trend, until the large increase in 2020, then remaining at this higher level (Figures 11 and 12, Table 5). From about the mid-1990s, catches from 024 and 026 have exhibited broad reciprocal trends with increases in one area matched by a decrease in the other.

Effort (pot lifts = *total_effort_num*) in Statistical Area 024 fluctuated widely over the first 30 years before peaking in 2017 and 2018, and then steeply declining thereafter with the lowest effort recorded in the last two years of the time series. Effort in 026 has also fluctuated, at about 20% of that in 024, with a steep increase in effort beginning in 2019, and staying high thereafter (Figure 13). The effort variable *effort_total_num* may not be a true indicator of pot lifts before 2020 because, as described above in the data grooming methods, there are likely to be many CELR day events when the skipper had transposed the effort variables *effort_total_num* and *effort_num*), or entered incorrect data, with the result that effort would sometimes be underestimated.

The cod potting fleet size in BCO 3 has ranged from 15 to 36 vessels annually with a clear declining trend with vessel numbers in the last two years less than half that of the early 1990s (Figure 14). The mean catch-per pot lift (kg per pot^{-1}) for all vessels peaked in about 2004 before steadily declining to the lowest values of the time series in the last three years (Figure 15). This trend was similar for the top ten vessels each year (Figure 15). There was no apparent change in mean catch rate with the introduction of the 48 mm mesh size in 2009. There was a decline in catch rates after the increase from 48 mm to 54 mm in 2021, but the decline had begun as early as 2015.

There were no clear changes in cod potting fishing behaviour after changing to electronic reporting in 2020, i.e. number of statistical areas, number of fishing days, and landed catch per trip in BCO 3 did not change (Figure 16). The number of fishing events did, however, increase from 2020 onward, reflecting the difference in the way these are recorded in CELRs and the ERS, i.e. pot lifts per day versus pot lifts within 2 nmi (Figure 16). Most often trips were of a single day duration, fishing in just one statistical area, with landings mostly less than 1000 kg of blue cod.

As shown, there was a seasonal change in catches in 024 around the time that the ERS was introduced (see Figure 10), but this is more to do with changes to the rock lobster season than to reporting. The recent decline in catch and effort in 024, and the increases in 026 preceded the ERS by a year (see Figures 12 and 13) indicating that other factors were responsible.

3.2 Spatial catch distribution and depth fished

Data Confidentiality restrictions on publishing spatial plot resolution to 1×1 degree squares mean that the plots are unable to show any trends or patterns in catch since within each of the two statistical areas of interest (024 and 026), the bulk of fishing effort area occurs in less than 1×1 degree squares. However spatial plots of catch shown by 0.04 degree squares for 2020 to 2024 (ERS data), were presented to the Inshore Working Group (24 April 2025) for review.

A broad depiction of the bounds of spatial distribution of the commercial cod pot catch from 2020 to 2024 in Statistical Areas 024 and 026 is therefore presented instead of the high-resolution spatial maps (Figure 17). The blue cod potting catch in 024 was generally taken off Waikouaiti to north of Moeraki from about 10 to 50 m depth, off Otago Peninsula near the head of Saunders Canyon, and south of the peninsula almost as far south as Taieri Mouth in about 20 to 70 m (Figure 17). In the last two years (2023 and 2024) there was a shift to fishing in deeper water closer to Otago Peninsula near the shelf edge (Figure 17). This can also be observed in the depth density plots by fishing year for BCO 3 which show that 2023 and 2024 potting was overall deeper than for the combined years' plot (Figure 18), and also in the proportion of catch from area 024 that was taken inside and outside 60 m in each fishing year from 2020 to 2024 (Figure 19).

The bulk of the cod pot blue cod catch in 026 was taken from the 024–026 Statistical Area border, as far south as the Clutha River Mouth in depths of 30 m to 70 m in an area commonly known as 'The Fantastics' (Figure 17). Similar to 024, there was a shift to fishing in deeper water closer to the shelf edge, particularly in 2024 (Figures 17, 18 and 20).

3.3 Overlap between potting surveys and commercial catch

There was good overlap between the north Otago potting survey areal strata and the spatial distribution of commercial blue cod potting catch in the northern part of Statistical Area 024 where fishing occurred inshore inside about 50 m (see Figure 17). The move to fishing deeper in the last two years was outside the north Otago survey area but was partially captured by the south Otago potting survey. Similarly, there was good overlap between the south Otago potting survey areal strata and the inshore fishing locations (inside 70 m), but there was no overlap with offshore fishing deeper than 100 m.

3.4 Standardised CPUE

3.4.1 Treatment of pot lift errors

The extent of the problem of pots in the water at midnight (*effort_num*) being greater than the total pot number (*effort_total_num*) set for the day is shown in Figure 21. If fishers were reporting correctly, the latter should always be greater. To further investigate the extent of the problem, the mean number of pots by trip for each effort variable was plotted by fishing year (Figure 22, top panel). The mean for *effort_num* was greater than *effort_total_num* in 2003, 2005 to 2008, 2012, and 2014 to 2019 which suggests that reporting of effort was poorest in these years as *effort_total_num* should always be the greater for a trip. After swapping *effort_total_num* for *effort_num*, when *effort_num* was larger, the mean pot lifts per trip increased for total pot lifts and decreased for midnight pots (Figure 22, bottom panel). The data before and after correction is also presented as boxplots (Figure 23). Here the median increased for total pot lift effort and decreased for midnight pots after the swap, resulting in a smoother transition in total pot lifts from CELR to ERS reporting, and also indicating that the increasing effort in the most recent years began in about 2016, before the ERS was introduced in 2020.

A further exploration of the catch by number of pot lifts on a trip was undertaken because the catch from trips with low pot numbers seemed higher than expected, and also the economics of fishing trips with fewer than 4 pots was questioned. The median catch per trip by number of pot lifts set for trip, for all fishing years combined (1990 to 2024) showed that overall more pot lifts on a trip resulted in more catch (Figure 24). However, median trip catch rate for different number of pot lifts set for trip, indicated exceptionally high catch rates using 1 or 2 pots suggesting that there may have been a transcription error in recording when the number may have been 10 or 20 pots (Figure 25). The working Group (1 May 2025) recommended that trips with fewer than 4 pots lifts be excluded from one of the CPUE analyses runs (swap-2).

3.4.2 No-swap model (Statistical Areas 024 and 026 combined)

The no-swap model (pot lifts = *effort_total_num*) core vessel selection in Statistical Areas 024 and 026 was a minimum of 3 qualifying years and 5 trips per year, and included 61 vessels (see Table 2, Figure 26). The core vessel proportion of the catch retained overall was 92%, ranging annually from about 80% to 95% per year, except in the last two years when it dropped to about 60% (Figure 27). The change in core vessels over the 35-year period indicates that some core vessels have exited, and others entered the fishery with only one vessel present in the fishery over the entire time series (Figure 28).

Core vessel number of trips per year showed a long-term decline since 2009, with positive catch taken from virtually all trips (Figure 29). The raw CPUE ranged from about 6 to 33 kg per pot, increasing until 2015, then generally declining. The mean pot lifts per trip ranged from about 7 to 28, declining until 2010, then increasing thereafter (Figure 29). Mean days fished was stable at about 1 day per trip before increasing slightly after 2007 with about 1.3 days per trip on average fished in the last few years.

The diagnostic plots indicating the fit of the standardised model to the blue cod catches from cod potting are shown in Figure 30. The Q-Q plot indicates that most of the points in the distribution fall on the reference line except for at the extremes of the data. The residuals show no pattern around zero and adhere to a normal distribution. Leverage is very low with no points outside the Cooks Distance indicating that there are no influential points in the regression model (Figure 30).

The variables vessel, pot lifts, and month were included in the model, with month having little impact, and overall explained 45% of the variance in the standardised CPUE index (Table 6). The blue cod standardised CPUE indices for the no-swap 024-026 model, together with unstandardised geometric and arithmetic indices are shown in Figure 31. The trends for all three indices are similar, with the standardised index fluctuating among years with no trend until a steep decline from 2018 to 2020, and then generally stable thereafter. With the addition of predictor variables into the model, the indices changed by lifting in the first two-thirds of the series and lowering in the last five years (Figure 32). The effect of the standardisation is particularly significant in the last four years, when the index reverses from a steep increase to a steep decrease. The influence plots show that this was caused mostly by vessel, with more effort by vessels with high catch coefficients in the last few years, followed by the number of pot lifts which were lowest in the mid period between about 2003 to 2016 and highest in the last five years (Figure 33).

Residual implied coefficients for the combined model statistical areas show that the coefficients are similar to the standardised index for Statistical Area 024 with a Pearson correlation of 0.98, and less so for Statistical Area 026 (correlation = 0.67), primarily because 024 is the dominant area in terms of records and catch (Figure 34).

3.4.3 Swap model (Statistical Areas 024 and 026 combined)

The swap model (pot lifts = larger of *effort_total_num* and *effort_num*) core vessel selection in Statistical Areas 024 and 026 was a minimum of 3 qualifying years and 5 trips per year, and included 61 vessels (see Table 2, Figure 35). The core vessel proportion of the catch retained overall was 92%, ranging annually from about 80% to 95% per year, except in the last two years when it dropped to about 60% (Figure 36). The change in core vessels over the 35-year period indicates that some core vessels have exited, and others entered the fishery with only one vessel present in the fishery over the entire time series (Figure 37).

Core vessel number of trips per year showed a long-term decline since 2009, with positive catch taken from virtually all trips (Figure 38). The raw CPUE ranged from about 6 to 17 kg per pot, increasing until 2014, then generally declining. The mean pot lifts per trip ranged from about 8 to 28, declining until 2010, then increasing thereafter (Figure 38). Mean days fished was stable at about 1 day per trip before increasing slightly after 2007 with about 1.3 days per trip on average fished in the last few years.

The diagnostic plots indicating the fit of the standardised model to the blue cod catches from cod potting are shown in Figure 39. The Q-Q plot indicates that most of the points in the distribution fall on the reference line except for at the extremes of the data. The residuals show no pattern around zero and adhere to a normal distribution. Leverage is very low with no points outside the Cooks Distance indicating that there are no influential points in the regression model (Figure 39).

The variables vessel and pot lifts were included in the model, and overall explained 48% of the variance in the standardised CPUE index (Table 6) The blue cod standardised CPUE indices for the swap 024-026 model, together with unstandardised geometric and arithmetic indices are shown in Figure 40. The trends for all three indices are similar, with the standardised index fluctuating among years but with a generally increasing trend until 2014, followed by a steep decline, most marked between 2016 and 2020. With the addition of predictor variables into the model, the index drops over the first seven years and lifts over the next eighteen years, before the steep decline beginning after 2014 (Figure 41). The effect of the standardisation is particularly significant in the last four years, when the index reversed from a steep increase to a steep decrease (Figure 41). The influence plots show that this was caused mostly by vessel, with more effort by vessels with high catch coefficients in the last few years, followed by the number of pot lifts which were lowest in the mid period between about 2003 to 2016 and highest in the last five years (Figure 42).

Residual implied coefficients for the combined model statistical areas show that the coefficients are similar to the standardised index for Statistical Area 024 with a Pearson correlation of 0.98, and less so for Statistical Area 026 (correlation = 0.33), primarily because 024 is the dominant area in terms of records and catch (Figure 43).

3.4.4 Swap-2 model (Statistical Areas 024 and 026 combined)

The swap-2 model (pot lifts = larger of *effort_total_num* and *effort_num*, excluding trips with fewer than 4 pot lifts) core vessel selection in Statistical Areas 024 and 026 was a minimum of 3 qualifying years and 5 trips per year, and included 56 vessels (see Table 2, Figure 44). The core vessel proportion of the catch retained overall was 92%, ranging annually from about 80% to 95% per year, except in the last two years when it dropped to about 60% (Figure 45). The change in core vessels over the 35-year period indicates that some core vessels have exited, and others entered the fishery with only one vessel present in the fishery over the entire time series (Figure 46).

Core vessel number of trips per year showed a long term decline since 2009, with positive catch taken from virtually all trips (Figure 47). The raw CPUE ranged from about 6 to 19 kg per pot, increasing until 2014, then generally declining. The mean pot lifts per trip ranged from about 10 to 31, declining until 2013, then increasing thereafter (Figure 47). Mean days fished was stable at about 1 day per trip before increasing slightly after 2007 with about 1.3 days per trip on average fished in the last few years.

The diagnostic plots indicating the fit of the standardised model to the blue cod catches from cod potting are shown in Figure 48. The Q-Q plot indicates that most of the points in the distribution fall on the reference line except for at the extremes of the data. The residuals show no pattern around zero and adhere to a normal distribution. Leverage is very low with no points outside the Cooks Distance indicating that there are no influential points in the regression model (Figure 48).

The variables vessel and pot lifts were included in the model, and overall explained 45% of the variance in the standardised CPUE index (Table 6). The blue cod standardised CPUE indices for the swap-2 024-026 model, together with unstandardised geometric and arithmetic indices are shown in Figure 49. The trends for all three indices are similar, with the standardised index fluctuating among years but with a generally increasing trend until 2014, followed by a steep decline, most marked between 2016 and 2020. With the addition of predictor variables into the model, the index drops over the first six years and lifts over the next eighteen years, before the steep decline beginning after 2014 (Figure 50). The effect of the standardisation is particularly significant in the last four years, when the index reversed from a steep increase to a steep decrease (Figure 50). The influence plots show that this was caused mostly by vessel, with more effort by vessels with high catch coefficients in the last few years, followed by the number of pot lifts which were lowest in the mid period between about 2003 to 2016 and highest in the last five years (Figure 51).

Residual implied coefficients for the combined model statistical areas show that the coefficients are similar to the standardised index for Statistical Area 024 with a Pearson correlation of 0.98, and less so for Statistical Area 026 (correlation = 0.38), primarily because 024 is the dominant area in terms of records and catch (Figure 52).

3.4.5 ERS-event model (Statistical Areas 024 and 026 combined)

The ERS-event model (pot lifts = *effort_total_num,* 2020 to 2024) for core vessel selection in Statistical Areas 024 and 026 was a minimum of 2 qualifying years and 4 trips per year, included 13 vessels and retained 94% of the data overall (see Table 2, Figure 53). Of the 13 vessels, only five were represented in all five fishing years (Figure 54).

The diagnostic plots indicating the fit of the standardised model to the blue cod catches from cod potting are shown in Figure 55. The Q-Q plot indicates that most of the points in the distribution fall on the reference line except for at the extremes of the data. The residuals show no pattern around zero and adhere to a normal distribution. Leverage is very low with no points outside the Cooks Distance indicating that there are no influential points in the regression model (Figure 55).

The blue cod standardised CPUE indices for the ERS-event model, together with unstandardised geometric and arithmetic indices are shown in Figure 56. With only five years of data it is not sensible to comment on trends in the index. The variables pot lifts, vessel, depth and month were included in the model, and overall explained 60% of the variance in the standardised CPUE index (Table 6).

Residual implied coefficients for the combined model statistical areas show that the coefficients are similar to the standardised index for Statistical Area 024 with a Pearson correlation of 0.90, and much less so for Statistical Area 026 (correlation = 0.18), primarily because 024 is the dominant area in terms of records and catch (Figure 57). Residual Implied coefficients were reasonably matched to 024-inshore, but not to the other spatial areas 024-offshore, 026-inshore, and 026-offshore (Figure 58).

3.4.6 CPUE Model Comparisons

The updated no-swap index is compared with those from the previous analyses and is a close match to the 2015 and 2019 indices (Figure 59) (Starr & Kendrick 2015, Holmes et al. 2022). In this model CPUE fluctuates considerably and there are no consistent trends until the steep decline after 2018.

The swap, no-swap and swap-2 models are shown in Figure 60. The swap model, which uses the larger of the *effort_num* and *effort_total_num*, generally drops below the no-swap index before 2008, and above thereafter, with the exception of one year. The swap-2 model, excluding trips with fewer than 4 pot lifts, is virtually the same as the swap model. The Inshore Working Group accepted the swap-2 model as the default CPUE index and this has been updated in the Plenary document for BCO 3 (Fisheries New Zealand 2025).

The ERS event-based model versus the last five years of the swap-2 trip-based model display the same patterns in CPUE (Figure 61).

4. DISCUSSION

This report provides an update of the characterisation and CPUE analysis for BCO 3 up to 2023–24, updating the previous Fisheries New Zealand funded analyses by Holmes et al. (2022) up to 2017–18.

4.1 General

There were two ways in which the current CPUE analyses differed from those of Holmes et al. (2022). Firstly, whereas previous CPUE analyses included only CELR catch effort data, the current analyses incorporated data from CELRs, along with that from the ERS for the last five years. Secondly, the current analyses included model runs for three types of effort: 1) total pot lifts (no-swap); 2) the greater of total pots lifts or pots in the water at midnight (swap); and 3) the swap model excluding trips with fewer than 4 pot lifts (swap-2). Of these, the no-swap model is equivalent to that used in the two previous analyses (Starr & Kendrick 2015, Holmes et al. 2022), even though the references state the swap was implemented. In addition, a standardised CPUE analyses was carried out for the five years of ERS data at the level of the fishing event, rather than the trip level as was used for the full time series. The event level analysis also included inshore and offshore strata in each of the two relevant statistical areas (024 and 026).

4.2 Transition to ERS reporting and mesh size changes

Exploration of fishing behaviour during the transition from paper based (CELR) to electronic based (ERS) reporting in 2020 indicated that there was no change in behaviour in such attributes as the number of days fished, number of statistical areas fished, and total catch by trip (see Figure 16). The number of fishing events per trip was, however, larger for ERS reported trips because of the way in which an event is recorded, i.e., all pot lifts set within 2 nautical miles for ERS, and all pot lifts in day/statistical area for CELRs. It was assumed that this difference in reporting fishing events has not altered the way in which effort (pot lifts) was recorded for a trip when changing to the ERS. An alternative, but untested, scenario is that when using CELRs, some fishers were not recording all pot lifts in the day, only the total number of pots carried on board or that were used over the day. There was a progressive increase in pot lifts in recent years, but this began in about 2016 suggesting that this was not associated with the transition to ERS reporting (see Figure 23, bottom panel).

The introduction of a minimum mesh size of 48 mm in 2009, increasing to 54 mm in 2021 had no apparent effect on raw catch rates or standardised CPUE in the time series (see Figures 15 and 49).

These findings provide confidence that the BCO 3 CPUE time series can be continuous without requiring separate indices for CELR and ERS data. Regardless, the ERS event based CPUE index beginning in 2020 should be routinely updated in future analyses.

4.3 Trends in abundance

The no-swap indices for Statistical Areas 024 and 026 combined, were similar to those of the previous analyses for the overlapping years (Holmes et al. 2022) (see Figure 59). In this model, CPUE fluctuated without trend before a steep decline after 2018. Both the swap and swap-2 models were similar and showed that CPUE fluctuated but generally had an increasing trend, peaking in 2014, before declining steeply (see Figure 60). The Inshore Working Group (1 May 2025) recommended that the swap-2 model should be used as the default CPUE abundance index for BCO 3, until the event scale model has sufficient years in the series to replace it.

The trends in CPUE are mirrored by the abundance estimates from both the north and south Otago potting surveys over the overlapping period from 2010 to 2022 (Figure 62) suggesting that abundance has dropped sharply from 2013 to 2018. Both the potting surveys' areal strata and the spatial distribution of the commercial potting effort in 024 and 026 showed good overlap over this period indicating that they were indexing the same blue cod population. There are other anecdotal signs that the fishery may be experiencing serial depletion such as the spatial shift in effort from Statistical Area

024 to 026 beginning in 2019, and fishing in deeper water near the shelf edge in the last two of the five most recent years (see Figures 11, 19 and 20). In addition, there has been a progressive decline in the blue cod potting vessel fleet since 2007, dropping by about one-half, before the TACC was reduced in 2021–22 (see Figure 14).

These results in BCO 3 are consistent with a decline in CPUE and potting survey abundance estimates in BCO 5 up to 2022–23 (Beentjes et al. 2024, Beentjes & Miller 2024).

5. POTENTIAL RESEARCH

1. Investigate further the reason for the relatively high landed catches associated with trips with low numbers of pot lifts.
2. Investigate further if pots lifts were recorded in the same way for CELRs and the ERS.
3. Explore vessel specific pot lift reporting as a means of improving grooming and clarifying the pot lift / pots in water at midnight issues.
4. Explore other aspects of CPUE standardisation, including:

    - testing models excluding pot lifts (sensitivity);
    - the utility of year.area and vessel.area interactions;
    - the inclusion of other pot types or targets;
    - simplifying accounting for offshore movement in the fishery (other than estimated depth on the basis of location).

6. FULFILMENT OF BROADER OUTCOES

As required under Government Procurement rules[2], Fisheries New Zealand considered broader outcomes (secondary benefits such as environmental, social, economic, or cultural benefits) that would be generated by this project.

NIWA is committed to contributing positively to the social, economic, cultural, and environmental wellbeing of New Zealand. This project has contributed towards capacity building within NIWA, growing staff expertise around the history and nature of the blue cod fishery, catch per unit effort analyses, and stock assessment modelling. This knowledge is vital for providing informed research advice to Fisheries New Zealand to aid in the sustainable management of blue cod fish stocks.

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9. TABLES

Table 1: Generalised Linear Models fitted to the blue cod (BCO 3) catch effort data. For all models the response variable was log (positive blue cod catch) for target species blue cod, with a log normal error structure. *total_effort_num*, total pots lifts; *effort_num*, pots in the water at midnight.

Model name	Data	Roll-up level	Effort type	Period
No-swap	Statistical Areas 024 and 026	Trip	*effort_total_num*	1990 to 2024
Swap	Statistical Areas 024 and 026	Trip	Larger of *effort_num* or *effort_total_num*	1990 to 2024
Swap-2	Statistical Areas 024 and 026	Trip	Larger of *effort_num* or *effort_total_num*; exclude trips with < 4 pots	1990 to 2024
ERS-event	Statistical Areas 024 and 026	Event	*effort_total_num*	2020 to 2024

Table 2: Core vessel selection criteria thresholds for each model run with minimum number of trips per year and minimum number of years fished.

	Minimum number	
Model name	Trips per year	Qualifying years
no swap	5	3
swap	5	3
swap_2	5	3
ERS_event	4	2

Table 3: BCO 3 destination codes and landed greenweight catch in the data extract (1989–90 to 2023–24). The 'Y' indicates that these data were used, and the 'N' not used in the characterisation and CPUE analyses. LFR: Licensed Fish Receiver.

Destination code	Description	Weight (t)	Percent	Keep
L	Landed in New Zealand to LFR	6 243.60	88.82	Y
F	Landed under an approval under section 111 of the Act	118.47	1.69	Y
QL	Placed in a holding container on land at the time of landing	93.99	1.34	Y
U	Bait used on board	16.74	0.24	Y
E	Eaten on board	14.64	0.21	Y
W	Wharf sales	8.95	0.13	Y
A	Abandoned or accidentally lost at sea	6.40	0.09	Y
C	Unknown	3.04	0.04	Y
LR	Landed to LFR (previously recorded under landing code R)	1.92	0.03	Y
LFL	Landed to LFR (previously recorded under landing code LF)	1.21	0.02	Y
EOY	Landed at end of year	0.05	0.00	Y
H	Loss from holding pot	0.02	0.00	Y
N	Removed from holding receptacle	0.01	0.00	Y
I	Unknown	0.00	0.00	Y
O	Conveyed outside New Zealand	0.00	0.00	Y
Q	Holding container on land	327.60	4.66	N
R	Retained on board	158.59	2.26	N
Y	Landed at end of year	12.96	0.18	N
J	Observer advised discards	8.36	0.12	N
B	Unknown	6.34	0.09	N
T	Transferred to another vessel	3.52	0.05	N
NP	Not provided	1.50	0.02	N
LF	Holding container on land	0.83	0.01	N
D	Discarded or lost (non-ITQ)	0.44	0.01	N
P	Holding container in water	0.40	0.01	N

Table 4: Blue cod catch in BCO 3 from Quota Management Returns-Monthly Harvest Returns (QMR-MHR), greenweight landings, groomed estimated catch from CELRs and ERS, and the analysis data set (i.e., the greenweight from landings linked to effort data prorated by estimated catch) for 1989–90 to 2023–24. The proportions of greenweight landings that are represented in the analyses data set are also shown.

Fishing year	Landings (t) QMR/MHR	Landings greenweight (t)	Estimated catch (t)	Analyses data set (t)	Prop. landings in analysis dataset
1990	121.0	109.8	82.8	104.4	0.950
1991	143.3	139.0	104.2	128.6	0.925
1992	135.0	144.2	119.9	138.1	0.958
1993	170.7	163.6	135.1	155.2	0.949
1994	141.7	148.5	108.6	135.7	0.914
1995	154.6	173.1	120.8	163.6	0.945
1996	165.2	170.6	137.4	163.1	0.956
1997	160.1	168.2	138.4	163.4	0.971
1998	162.9	164.4	135.7	155.3	0.944
1999	153.8	172.3	134.9	163.4	0.948
2000	165.4	162.4	135.7	158.1	0.974
2001	153.8	157.4	118.4	143.7	0.913
2002	138.1	149.7	120.6	139.0	0.929
2003	169.0	167.8	150.0	164.6	0.981
2004	166.8	164.8	138.7	154.4	0.937
2005	183.2	176.1	152.7	166.2	0.943
2006	182.7	191.0	143.3	173.4	0.908
2007	176.9	187.9	145.8	172.3	0.917
2008	167.2	184.6	150.1	171.2	0.927
2009	157.7	174.7	142.7	162.3	0.929
2010	170.8	180.5	134.7	156.8	0.868
2011	182.7	188.1	153.6	163.7	0.870
2012	166.3	169.4	129.9	144.5	0.853
2013	170.1	165.2	120.1	147.1	0.890
2014	158.8	159.2	125.6	138.1	0.868
2015	175.0	171.2	136.5	160.5	0.938
2016	168.9	162.7	104.7	130.5	0.802
2017	169.8	160.0	123.9	152.1	0.951
2018	173.7	171.7	125.4	160.1	0.933
2019	176.9	176.7	135.7	166.3	0.941
2020	180.0	188.5	153.9	179.3	0.951
2021	183.5	188.3	163.1	179.0	0.951
2022	132.4	144.5	131.6	139.7	0.966
2023	134.8	143.4	121.1	140.1	0.977
2024	142.0	144.6	120.0	140.6	0.972

Table 5: Cod pot landings (t) by Statistical Area in BCO 3 from 1989–90 to 2023–24.

Fishing year	Statistical Area								
	018	019	020	021	022	023	024	026	027
1990	0.48	0.00	0.00	0.00	0.00	0.00	50.13	5.24	0.05
1991	0.00	0.00	0.00	0.00	0.00	0.00	83.23	9.12	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00	70.75	13.36	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00	69.51	16.68	0.00
1994	1.20	0.00	0.00	0.00	0.00	0.00	70.06	15.37	0.00
1995	0.00	0.00	0.00	0.00	0.00	0.00	92.00	22.47	0.00
1996	0.00	0.00	0.00	0.00	0.73	0.00	89.72	23.55	0.00
1997	0.00	0.00	0.00	3.28	0.28	0.00	80.99	17.18	0.00
1998	3.17	0.00	0.00	7.50	0.00	0.00	77.51	1.01	2.09
1999	3.31	0.00	0.00	7.99	1.97	0.00	83.34	8.26	0.00
2000	7.14	2.94	0.79	2.62	1.91	0.00	70.74	10.65	0.02
2001	3.90	0.00	0.00	0.82	0.00	0.05	79.12	12.59	0.00
2002	5.64	0.00	0.00	8.44	0.15	0.38	63.37	15.47	4.56
2003	9.05	0.58	1.21	8.76	0.00	0.00	73.30	22.64	0.00
2004	22.50	0.00	4.31	2.52	0.00	0.00	75.22	10.71	0.00
2005	21.92	0.00	1.88	0.06	0.71	0.00	72.02	12.92	0.41
2006	14.79	0.00	1.38	4.74	0.00	0.00	88.68	14.64	2.12
2007	14.70	0.03	0.00	3.72	1.38	0.00	85.69	13.75	0.14
2008	11.84	0.00	2.89	5.04	0.00	0.00	82.40	8.04	0.13
2009	12.91	0.00	0.00	4.51	0.00	0.00	87.49	14.85	0.00
2010	11.74	0.00	0.00	0.37	0.00	0.00	84.26	19.44	2.60
2011	10.26	0.00	0.06	1.07	0.00	0.00	78.92	21.79	3.38
2012	6.68	0.00	0.24	1.80	0.00	0.00	70.31	23.07	0.34
2013	5.48	0.00	0.07	5.13	0.00	0.00	71.80	23.44	0.00
2014	7.06	0.00	0.00	0.08	0.00	0.00	64.85	24.11	0.00
2015	7.49	0.00	0.10	5.38	0.00	0.00	83.90	23.50	0.00
2016	5.89	0.00	0.44	11.33	0.00	0.00	67.38	14.33	0.00
2017	9.22	0.00	0.00	2.66	0.00	0.00	85.46	16.95	0.00
2018	4.58	0.00	0.00	0.03	0.15	0.00	94.98	10.04	0.00
2019	5.30	0.00	0.31	5.11	0.05	0.00	69.41	22.71	0.00
2020	4.85	0.00	0.00	0.00	0.00	0.00	28.89	63.41	0.00
2021	14.93	0.00	0.00	0.00	0.01	0.00	44.27	54.28	0.00
2022	7.07	0.00	0.00	0.42	0.03	0.00	30.55	44.12	0.00
2023	7.51	0.00	0.03	7.06	1.73	0.00	21.52	48.60	0.00
2024	8.94	0.00	0.68	2.15	1.65	0.00	21.41	45.65	0.00
Totals	267.56	22.55	34.39	123.61	32.74	23.43	2487.17	749.92	42.84
% all years	7.1	0.6	0.9	3.3	0.9	0.6	65.7	19.8	1.1
% last 5 years	9.4	0.0	0.2	2.1	0.7	0.0	31.9	55.7	0.0

Table 6: Predictor variables accepted in the standardised CPUE models, the degrees of freedom (df) and the proportion of variance in the model explained by addition of each variable (R.squared).

Model	Predictors	df	R.squared
No-swap	fish_year	34	0.04
	vessel	60	0.29
	poly(log_potlift, 3)	3	0.44
	month	11	0.45
Swap	fish_year	34	0.04
	vessel	59	0.3
	poly(log_potlift, 3)	3	0.48
Swap-2 (exclude pot lifts < 4)	fish_year	34	0.05
	vessel	55	0.3
	poly(log_potlift, 3)	3	0.45
ERS-Event	fish_year	4	0.02
	poly(log_potlift, 3)	3	0.44
	vessel	12	0.54
	poly(Bathy_Depth, 3)	3	0.59
	month	11	0.6

10. FIGURES

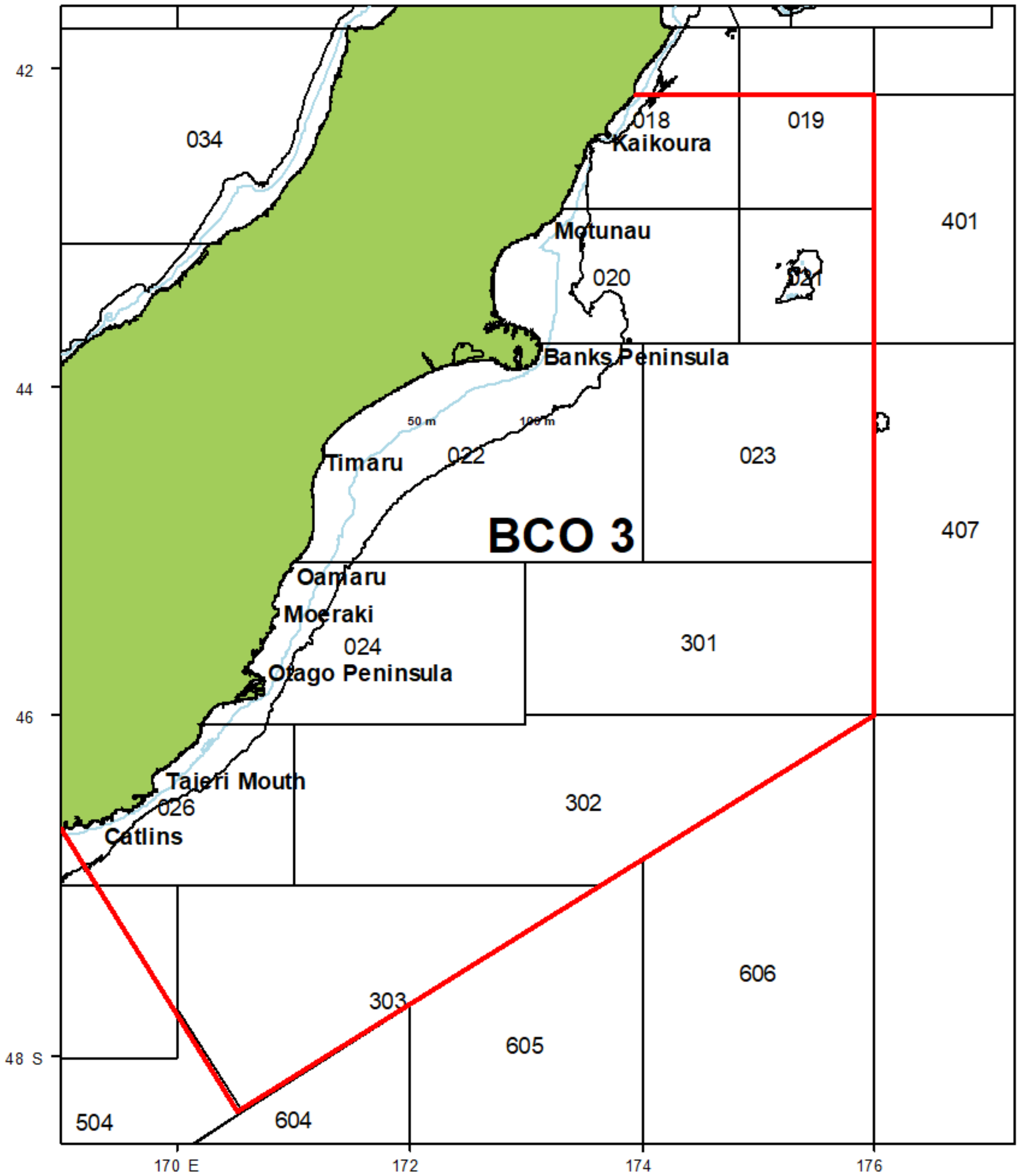


Figure 1: BCO 3 Quota Management Area and General Statistical Areas.

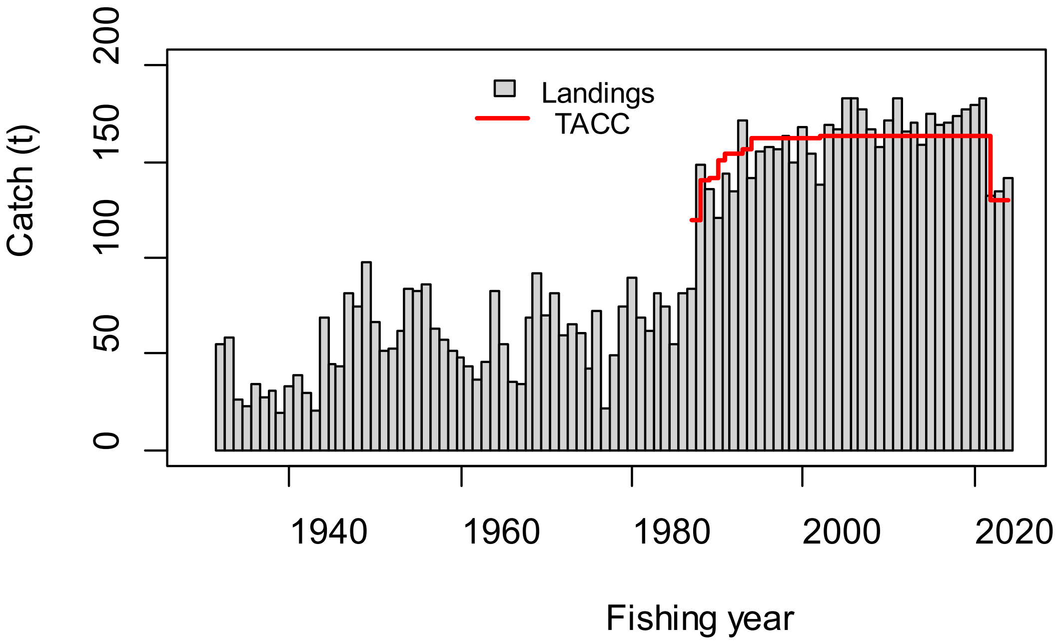


Figure 2: BCO 3 reported landings from 1932 to 2024. Data from 1932 to 1982 are from table 2 and 1983 to 2024 from table 3 of the blue cod plenary report chapter (Fisheries New Zealand, 2025). TACC, Total Allowable Commercial Catch.

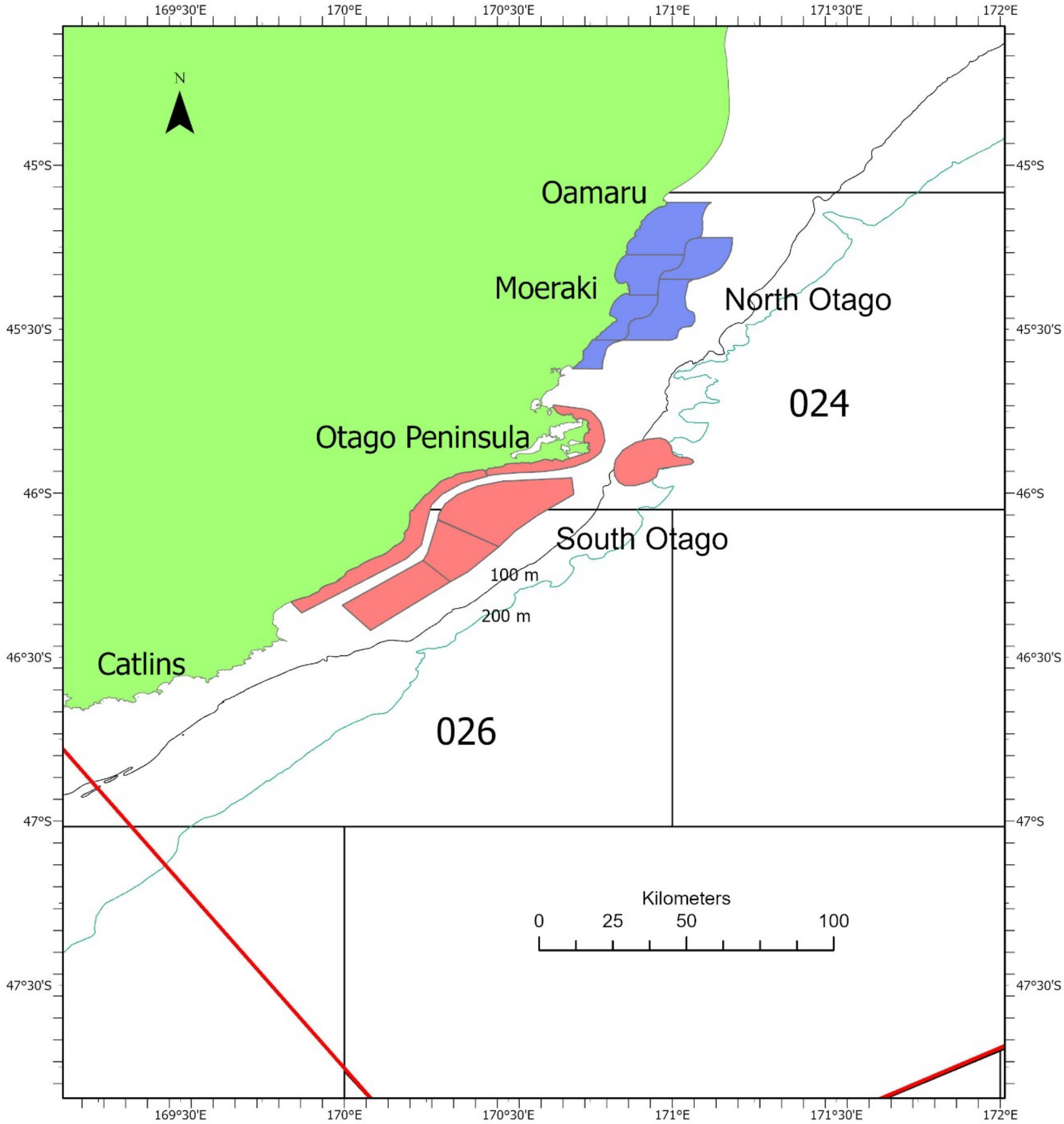


Figure 3: North Otago (blue) and south Otago (red) potting survey strata.

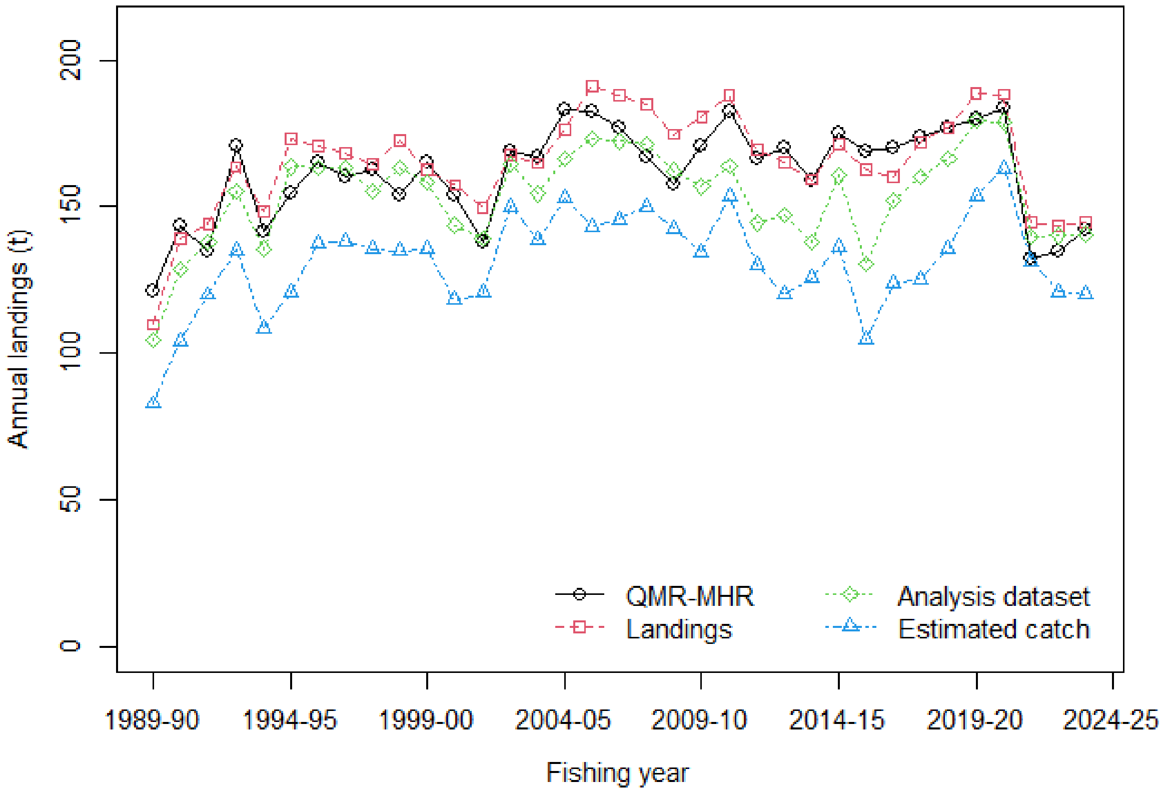


Figure 4: BCO 3 catch from Quota Management Returns-Monthly Harvest Returns (QMR-MHR), greenweight landings, groomed estimated catch from CELRs and ERS, and the analysis data set (i.e., the greenweight from landings linked to effort data prorated by estimated catch) for 1989–90 to 2023–24.

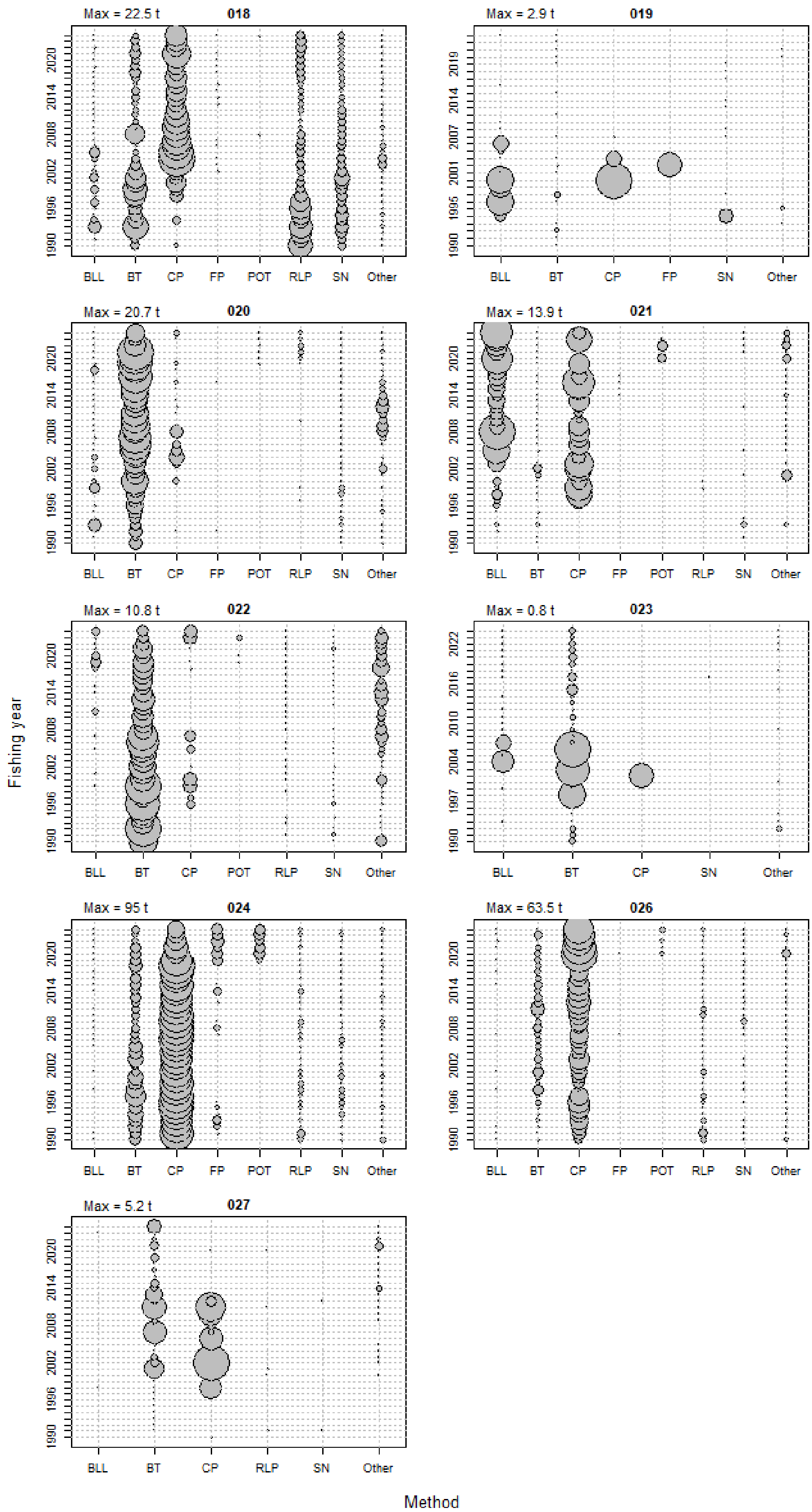


Figure 5: Landings (t) of blue cod by fishing method and statistical area in BCO 3 from 1989–90 to 2023–24. BLL, bottom long line, BT, bottom trawl; CP, cod pot; FP, Fish traps (including Box/Teiche nets); POT, potting (other); RLP, Rock lobster pot; SN, set net.

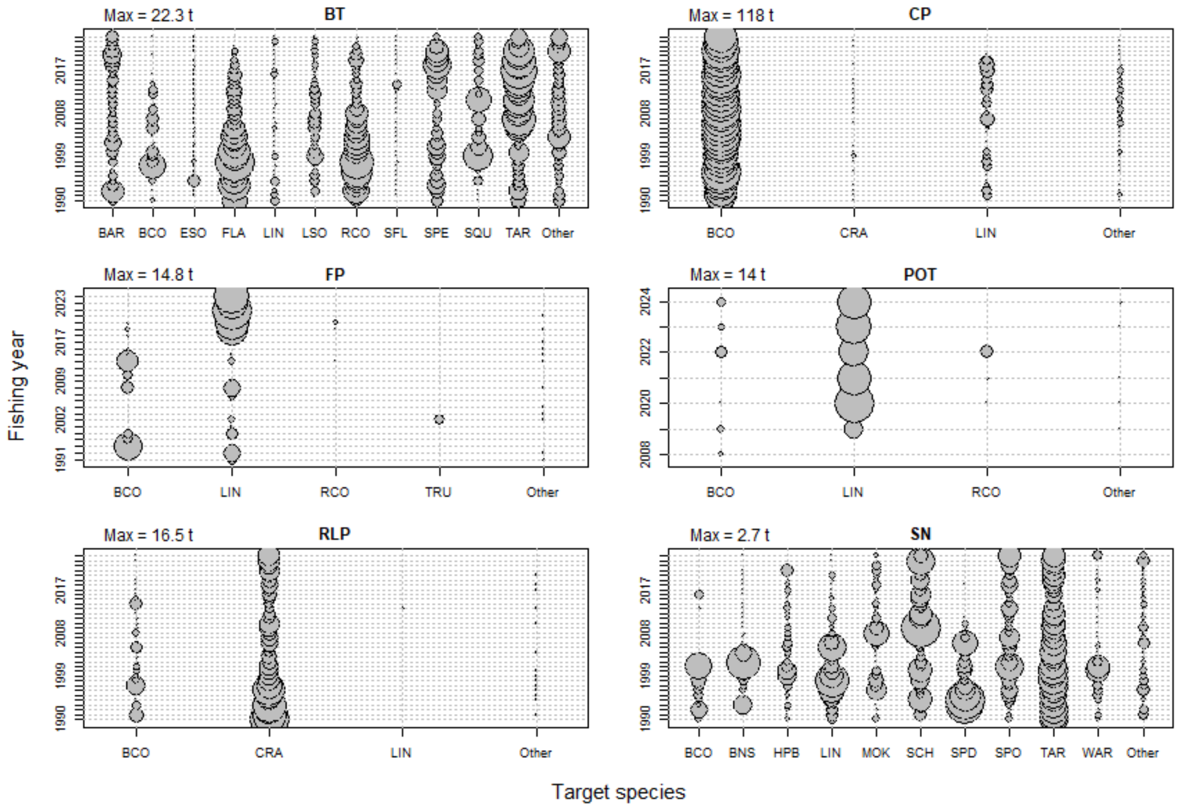


Figure 6: Landings (t) of blue cod in BCO 3 by target species and method from 1989–90 to 2023–24. Methods - BT, bottom trawl; CP, cod pot, FP, fish traps, POT, potting other, RLP, rock lobster pot, SN, set net; Species BAR, barracouta; BCO, blue cod; BNS, bluenose; CRA, rock lobster; ESO, New Zealand sole; FLA, flatfish species group; HPB, groper; LIN, ling; LSO, lemon sole; MOK, moki; RCO, red cod; SCH, school shark; SFL, sand flounder; SPD, spiny dogfish; SPE, sea perch; SPO, rig; SQU, arrow squid; TAR, tarakihi; TRU, trumpeter; WAR, blue warehou.

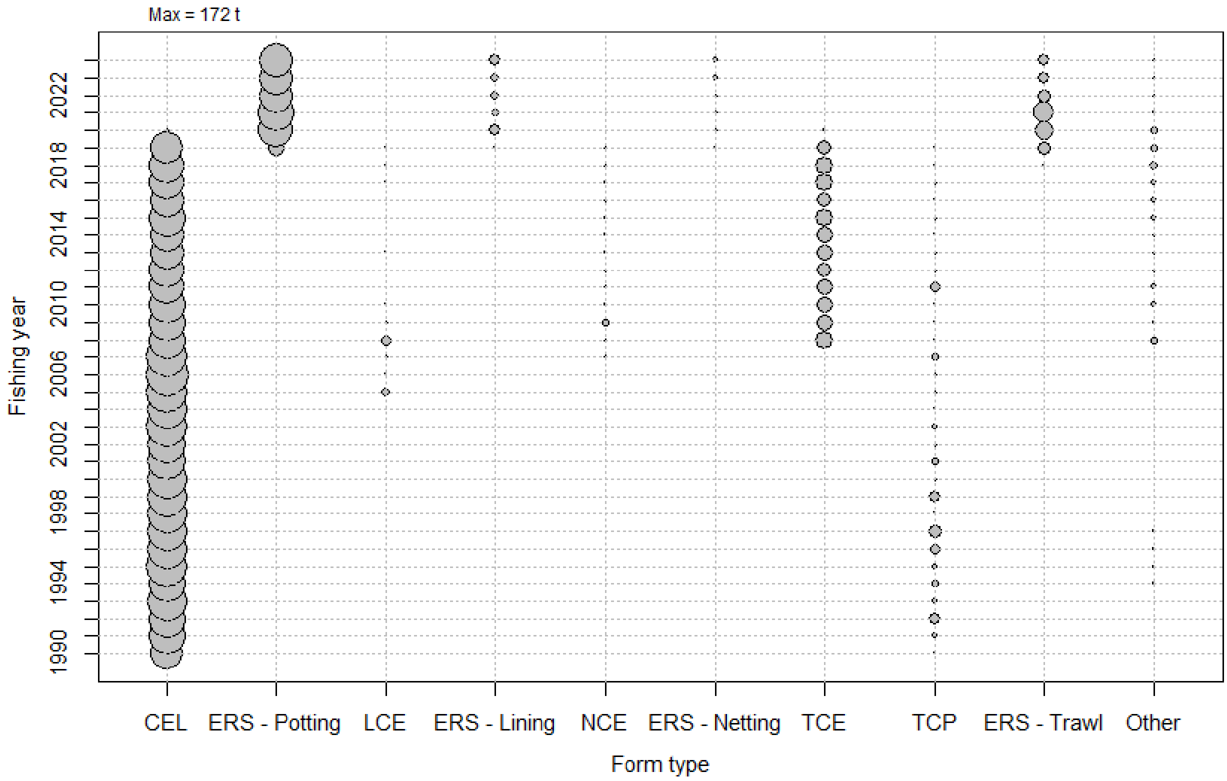


Figure 7: Landings (t) of blue cod in BCO 3 by form type used to report commercial catches from 1989–90 to 2023–24. CEL, catch effort landing return; ERS–Potting, electronic reporting system for method potting; LCE, longfin catch effort; ERS–Lining, electronic reporting system for method lining; NCE, net catch effort return; ERS–Netting, electronic reporting system for method netting; TCE, trawl catch effort return; TCP, trawl catch effort and processing return; ERS–Trawl, electronic reporting system for method trawl.

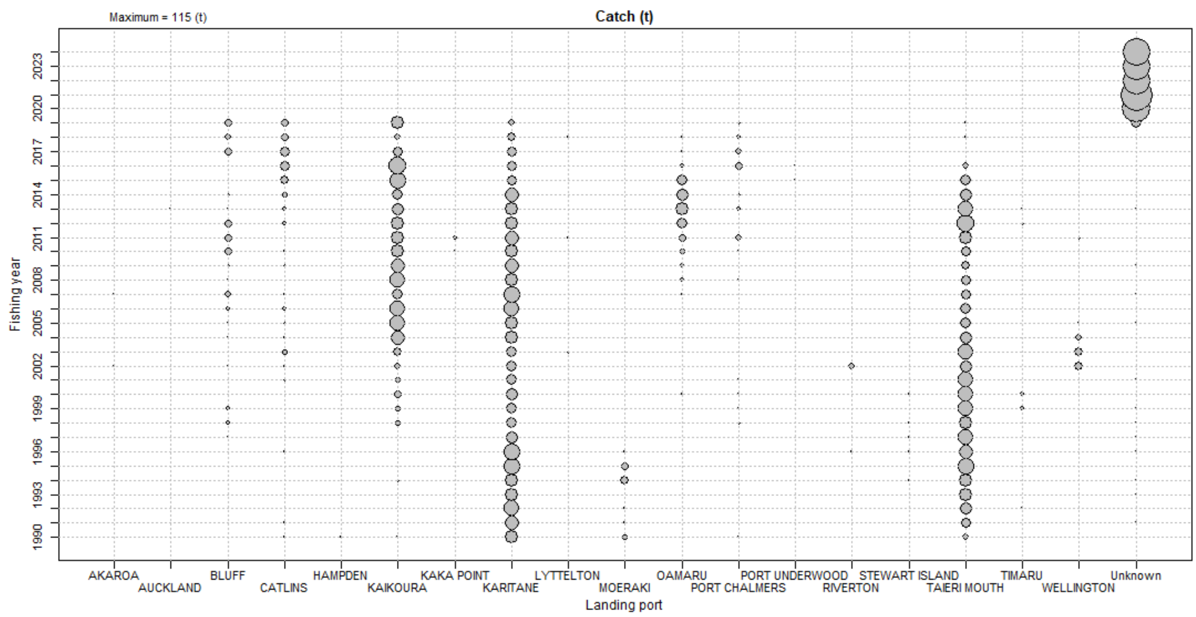


Figure 8: Cod pot landings (t) of blue cod in BCO 3 by port of landing, from 1989–90 to 2023–24. Note that the port of landing is not recorded in the ERS that replaced CELRs in 2019–20.

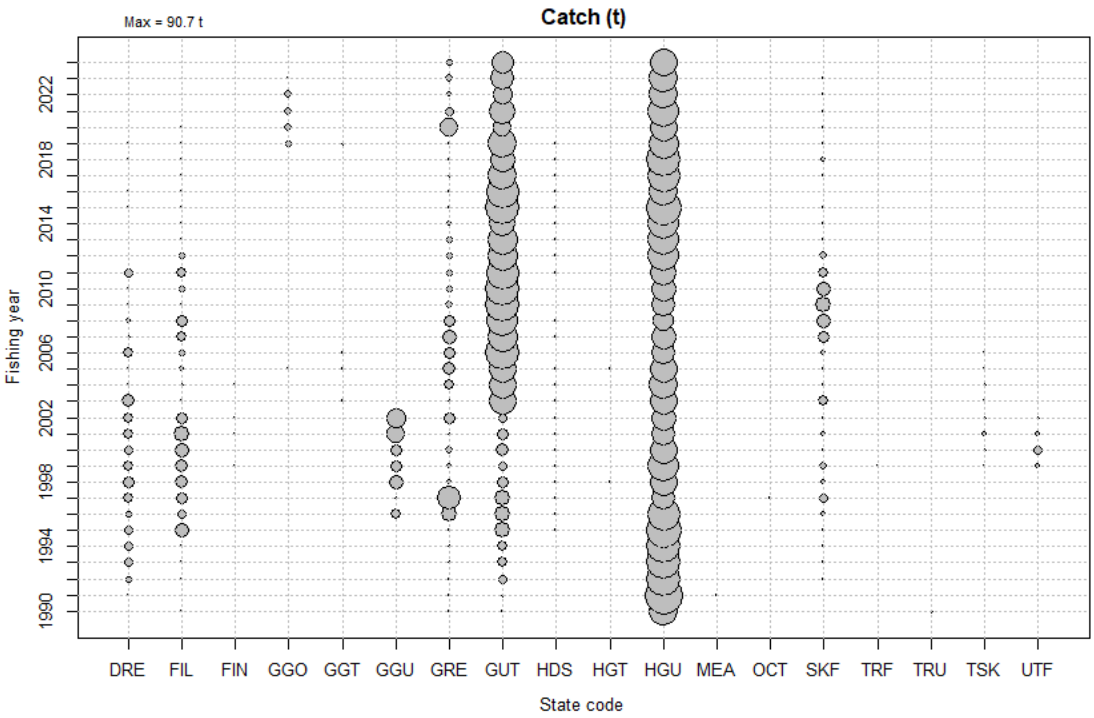


Figure 9: Cod pot landings (t) of blue cod from BCO 3 by processing state, from 1989–90 to 2023–24. DRE, dressed; FIL, fillets-skin on; FIN, unknown; GGO, gilled and gutted tail on; GGT, gilled and gutted tail off; GGU, gilled and gutted; GRE, green; GUT, gutted; HDS, heads; HGT, headed, gutted, and tailed; HGU, headed and gutted; MEA, fish meal; OCT, unknown; SKF, fillets, skin off; TRF, unknown; TRU, trunked; TSK, fillets, skin-off, trimmed; UTF, fillets, skin-off, untrimmed.

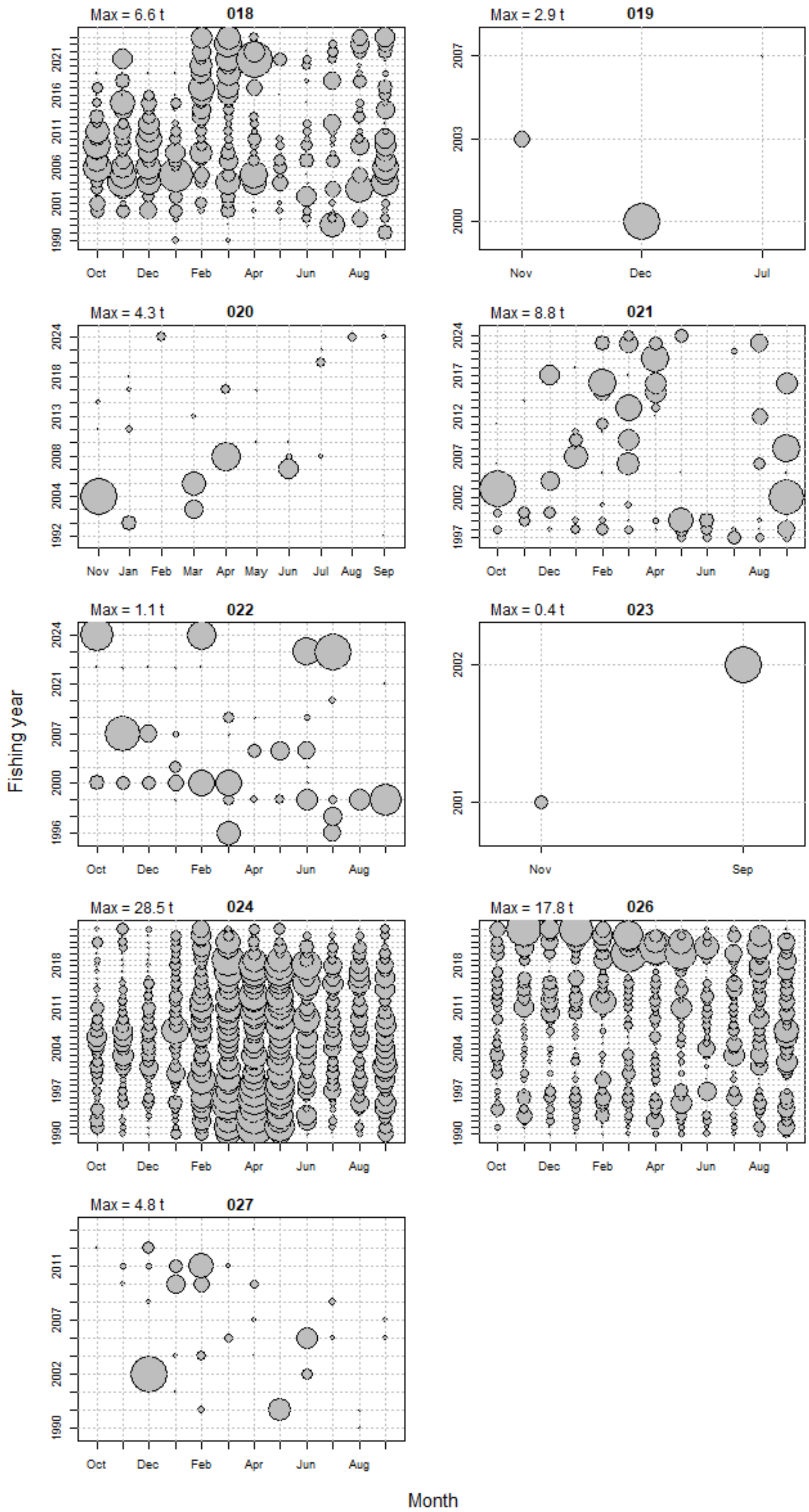


Figure 10: Cod pot landings (t) of blue cod in BCO 3 by statistical area and month, from 1989–90 to 2023–24.

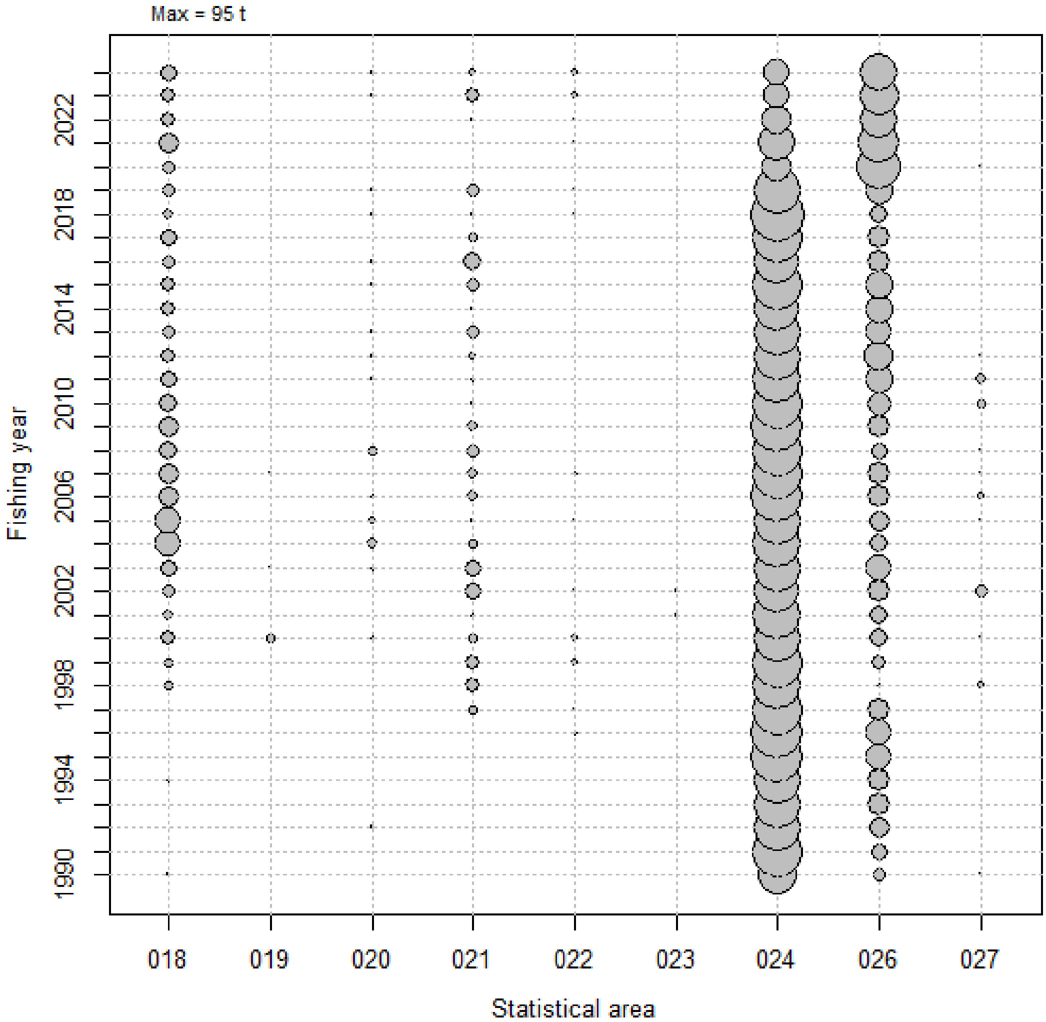


Figure 11: Cod pot landings (t) of blue cod from BCO 3 by statistical area, from 1989–90 to 2023–24 depicted by bubble plots.

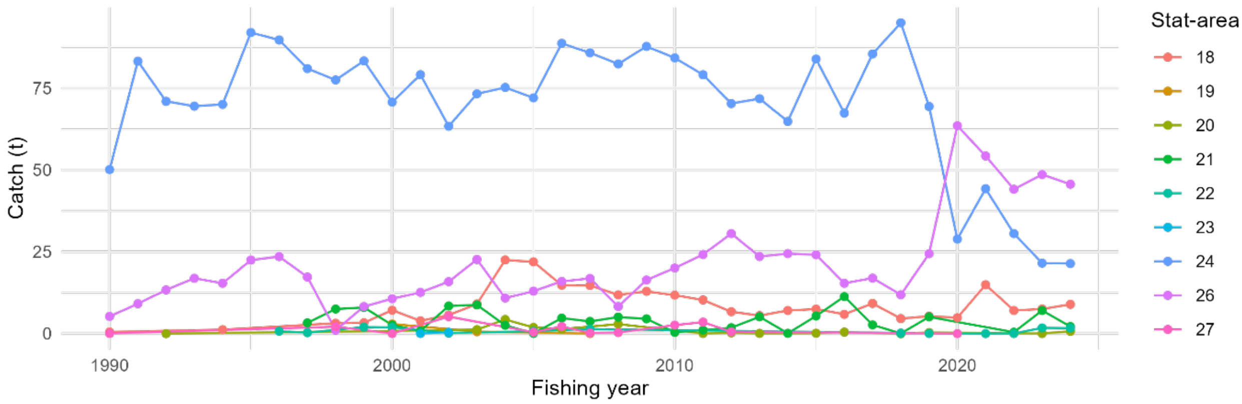


Figure 12: Cod pot landings (t) of blue cod from BCO 3 by Statistical Area, from 1989–90 to 2023–24 depicted by line plots.

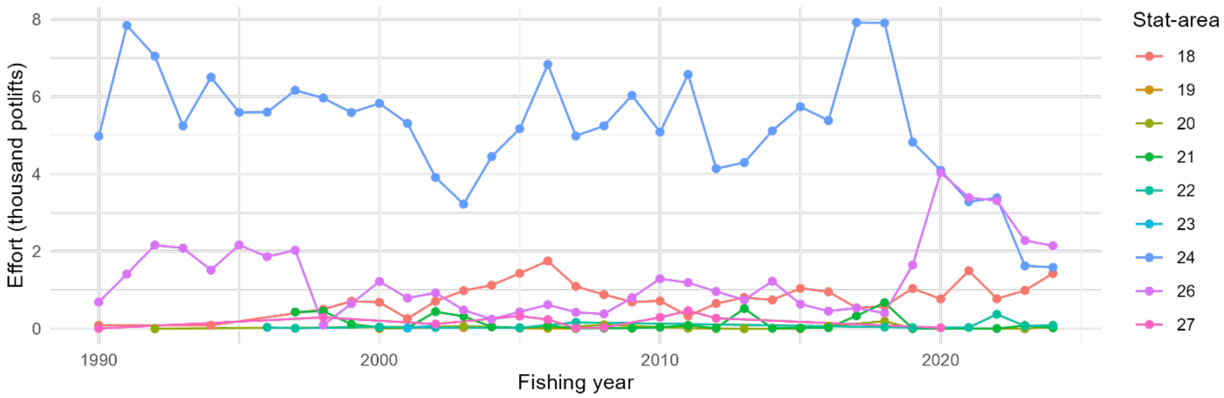


Figure 13: Cod pot effort (pot lifts) by Statistical Area in BCO 3 from 1989–90 to 2023–24.

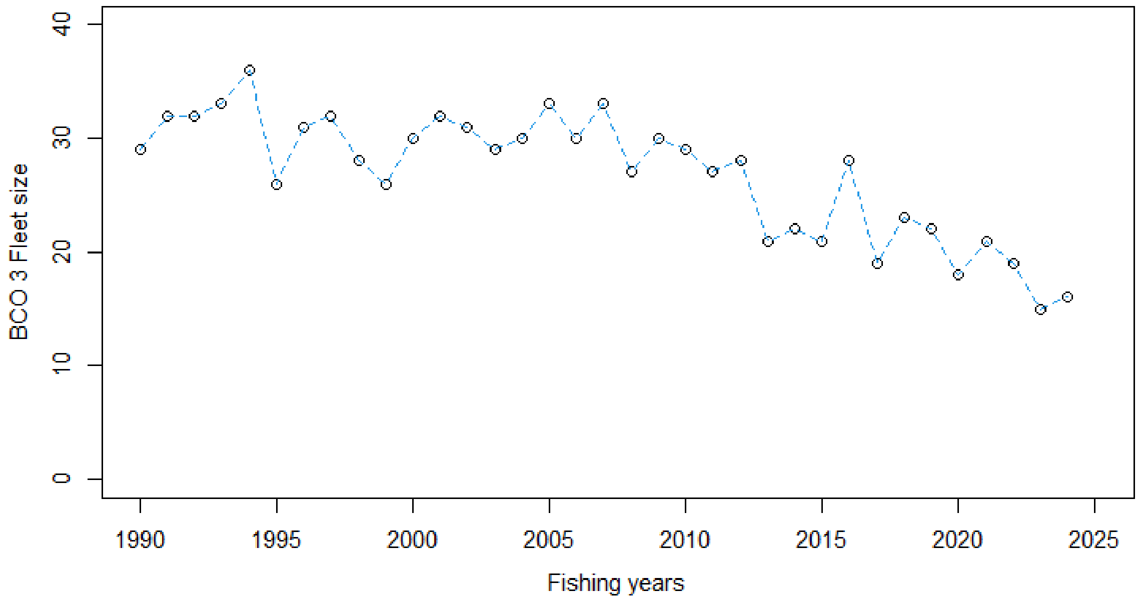


Figure 14: Number of vessels in the cod potting vessel fleet in BCO 3 from 1989–90 to 2023–24.

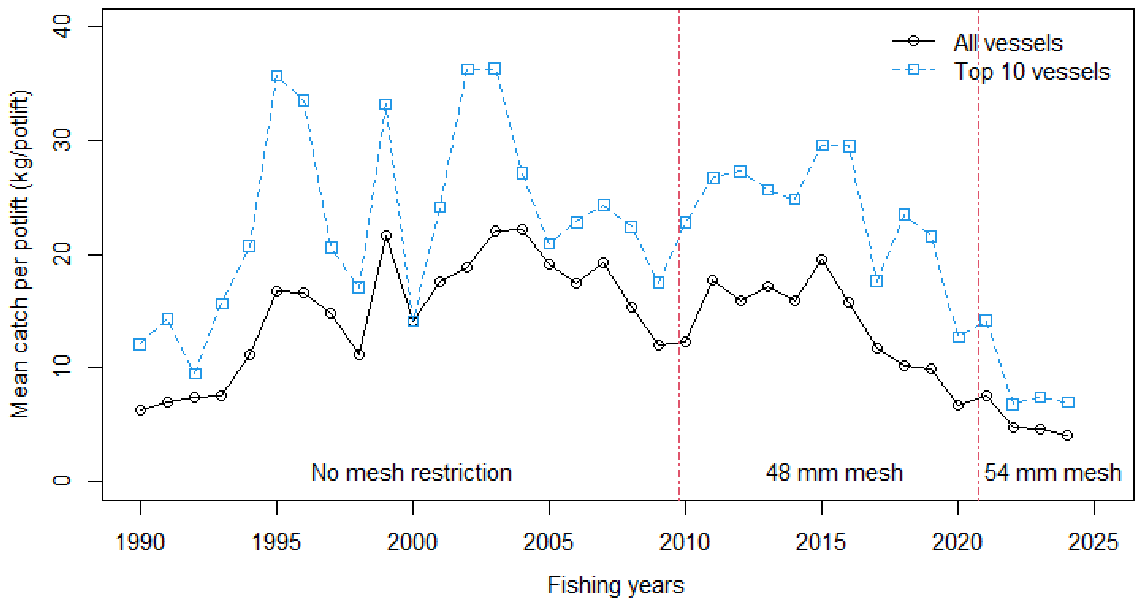


Figure 15: Mean catch per pot lift (*effort_total_num*) for the cod potting vessel fleet in BCO 3, for all vessels, and the 10 vessels that landed the most catch each year from 1989–90 to 2023–24. The red vertical dashed lines indicate when the pot mesh size was changed from no mesh restriction to 48 mm, and then from 48 mm to 54 mm.

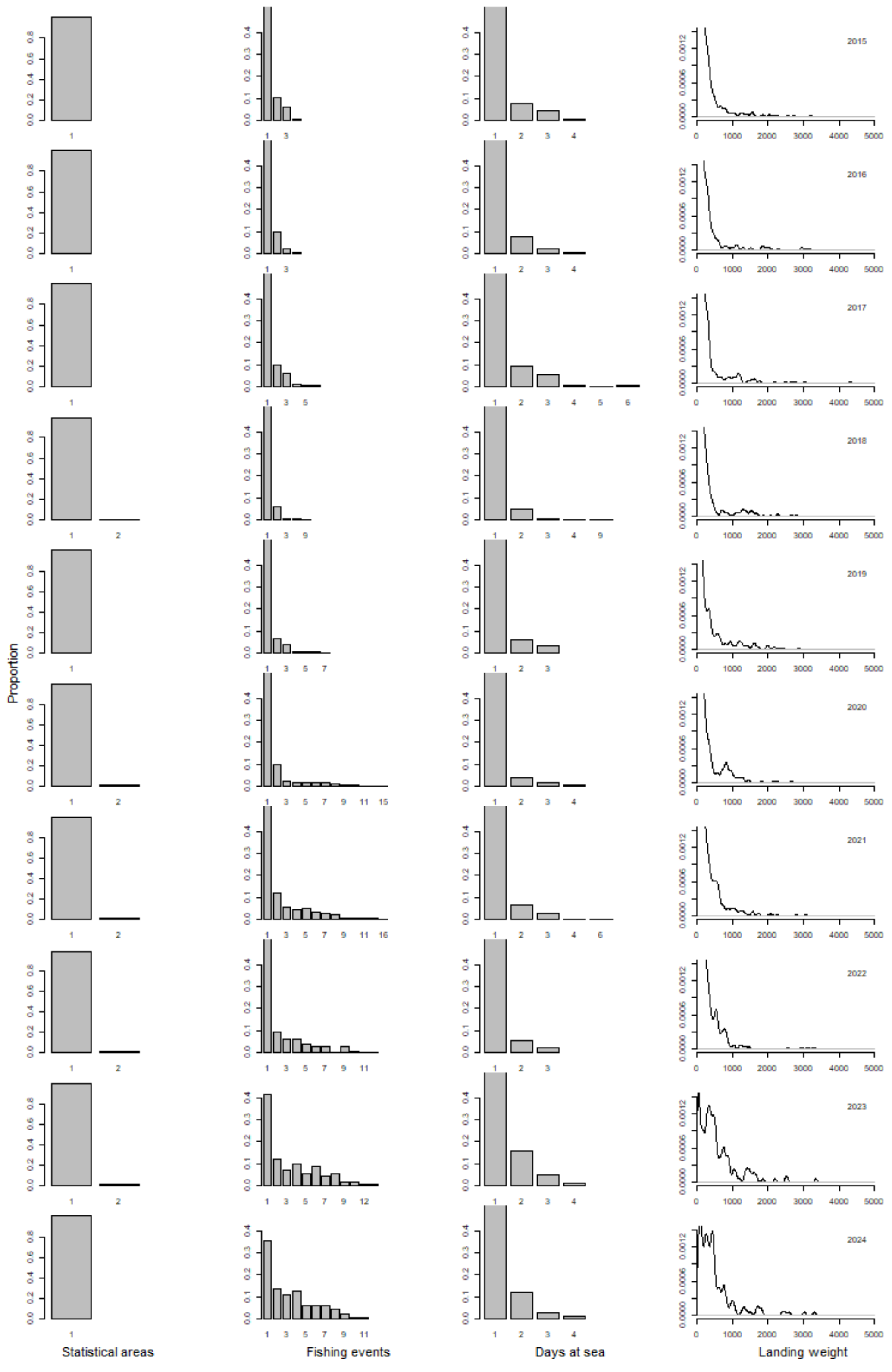


Figure 16: Trip summaries from BCO 3 cod potting vessels showing number of statistical areas fished, number of fishing events, number of days at sea, and landed catch from 2014–15 to 2023–24. The first 5 years are from CELR reporting, and the last 5 years are from ERS reporting.

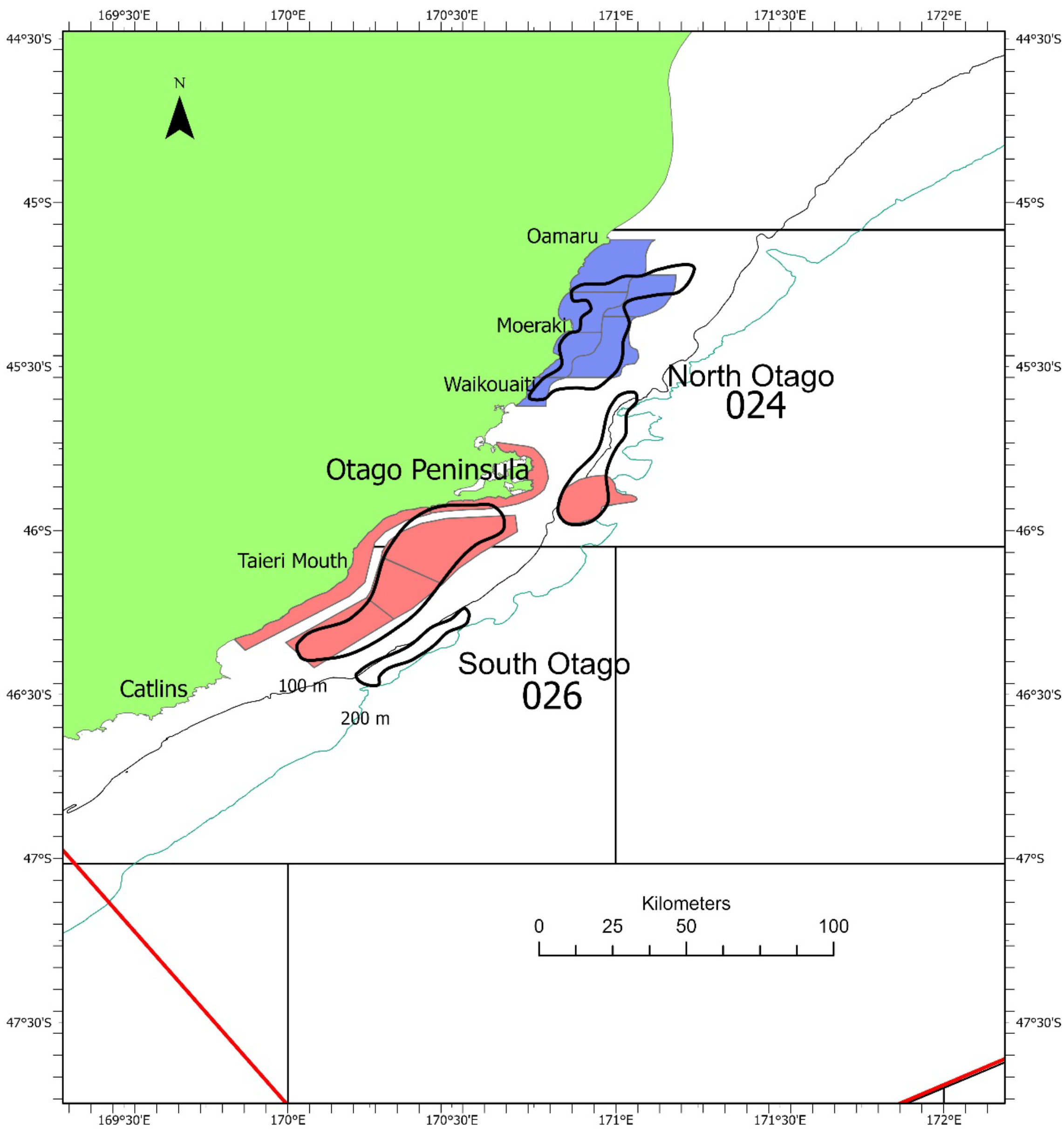


Figure 17: Areal strata for the north Otago (blue) and south Otago (red) potting survey time series, together with areas (inside black polygons) within which the bulk (88%) of the 2020 to 2024 commercial blue cod potting catch was taken in Statistical Areas 024 and 026. Black polygons depicting commercial catch were drawn by hand, based on position data from the Electronic Reporting System (ERS). The two offshore polygons included catch mostly from 2023 and 2024.

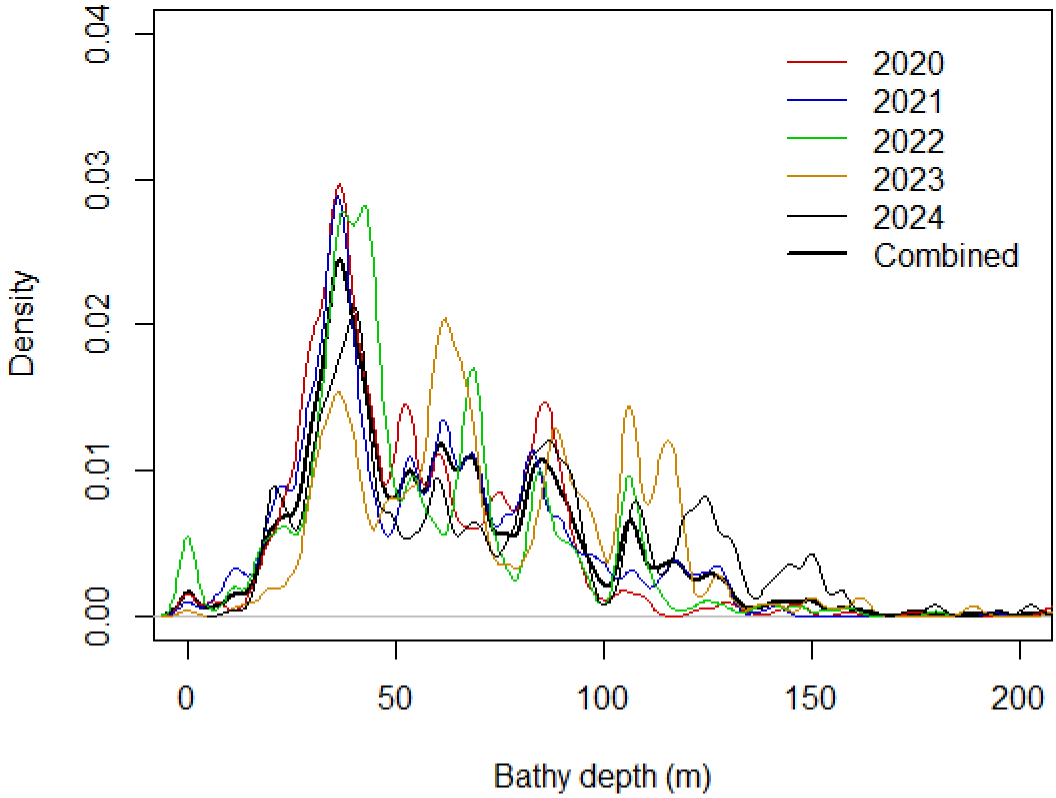


Figure 18: Density plots of depths fished by the cod potting fleet in BCO 3 for the fishing years 2019–20 to 2023–24, and for the five years combined. Depths were estimated from the position of the fishing event for ERS-potting data and known bathymetry. Depth was not recorded on CELR forms, or on the current ERS-potting returns. The peak at zero is an artefact and indicates that some positions were incorrectly reported on land.

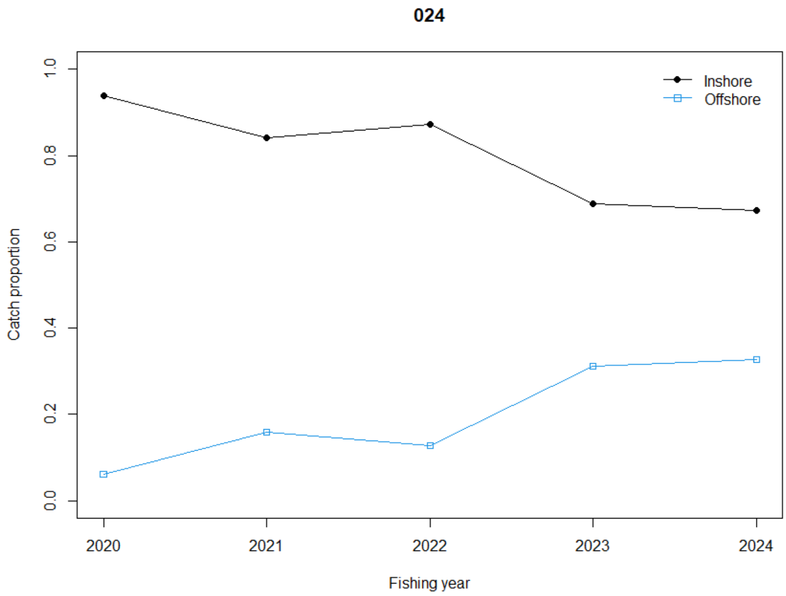


Figure 19: The proportion of commercial potting blue cod catch within Statistical Area 024 that was inside (inshore), and outside (offshore) 60 m depth from 2020 to 2024.

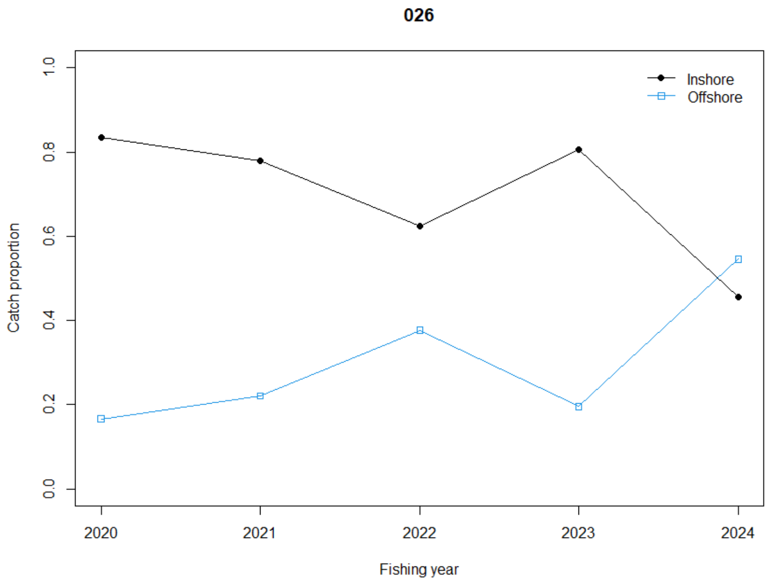


Figure 20: The proportion of commercial potting blue cod catch within Statistical Area 026 that was inside (inshore), and outside (offshore) 80 m depth from 2020 to 2024.

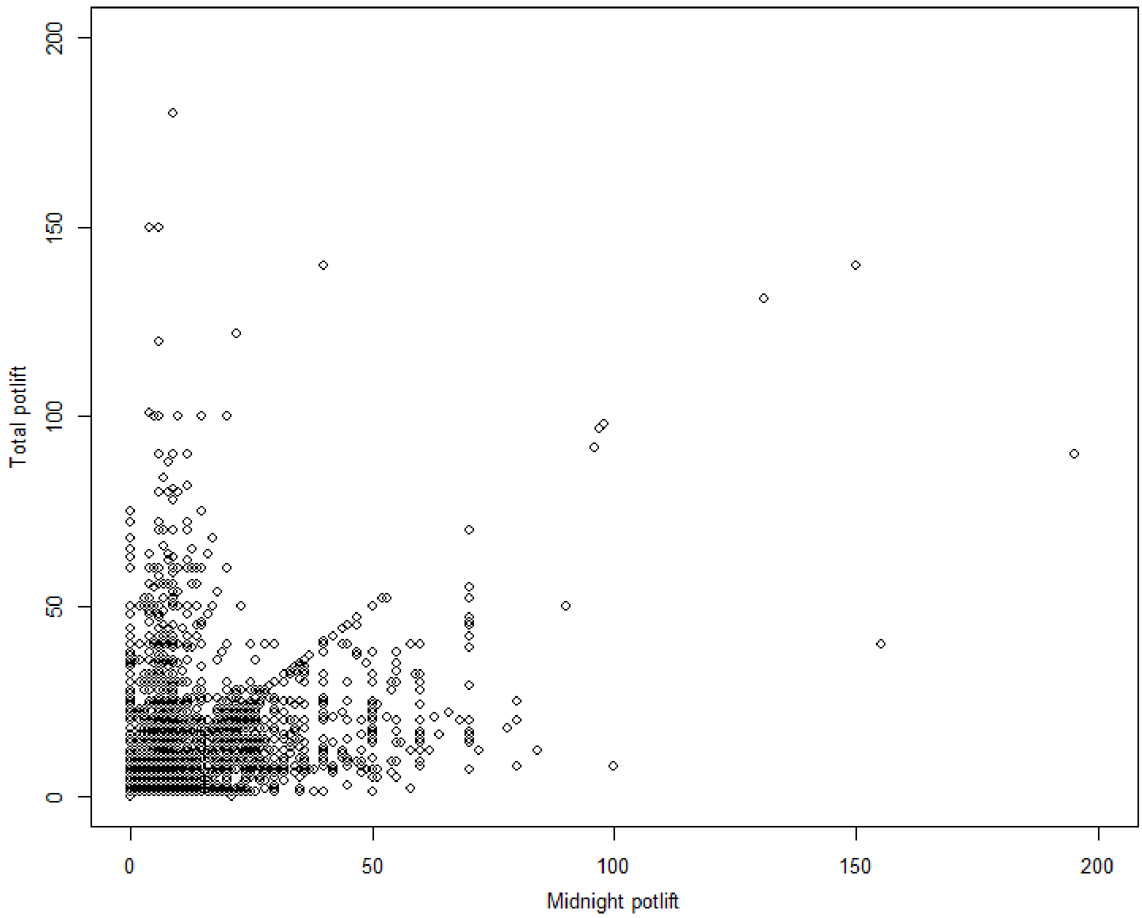


Figure 21: Scatterplot of pots in the water at midnight (*effort_num*) versus total pots set for the day fishing event (*effort_total_num*) per trip, recorded on CELR forms from 1989–90 to 2023–24 for BCO 3.

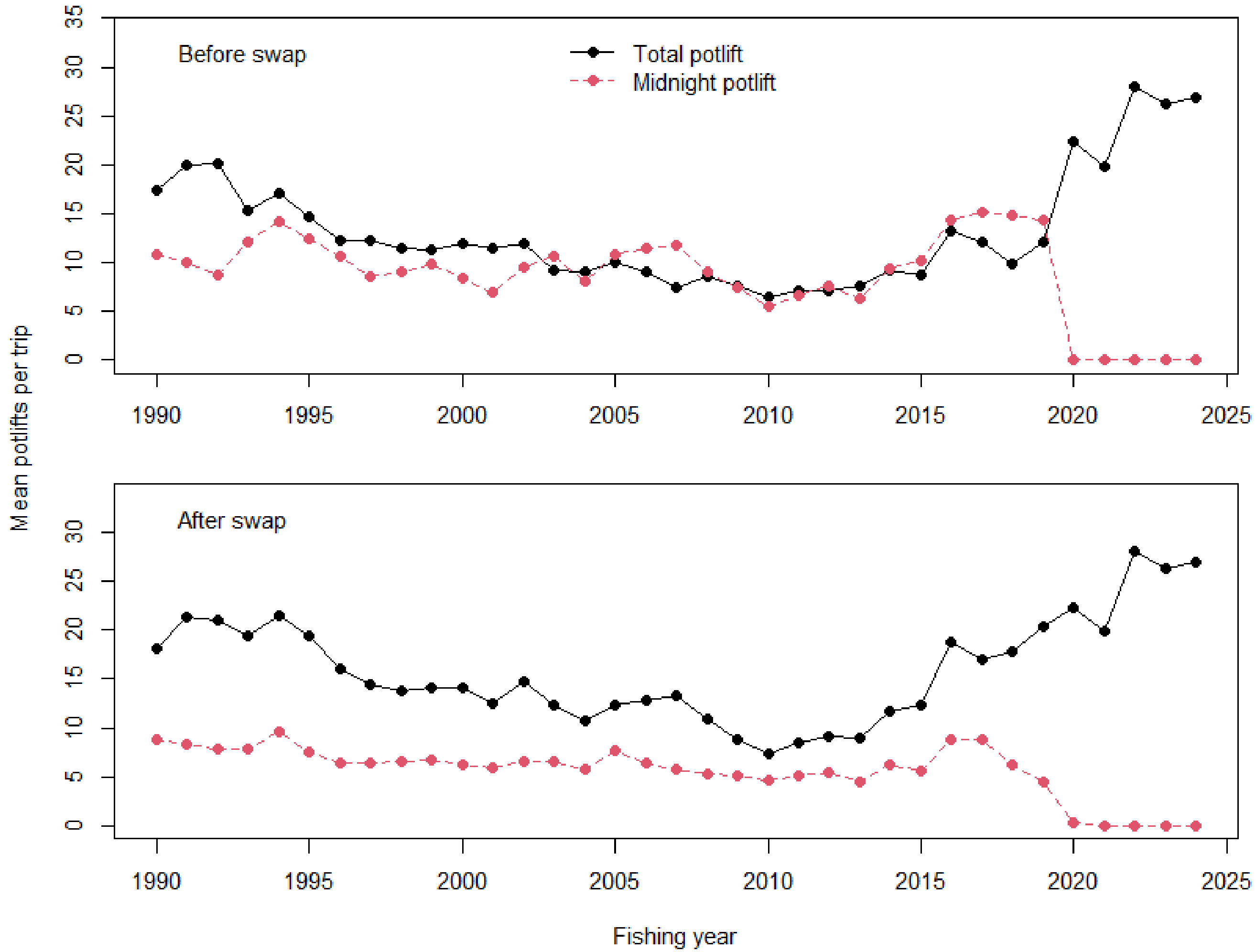


Figure 22: (top panel) Mean pot lifts per trip by fishing year for *effort_total_num* (total pot lifts) and *effort_num* (pots in the water at midnight); and (bottom panel) after swapping *effort_total_num* for *effort_num*, when *effort_num* was larger. The ERS only records *effort_total_num* which is why effort_num is zero from 2020 onward.

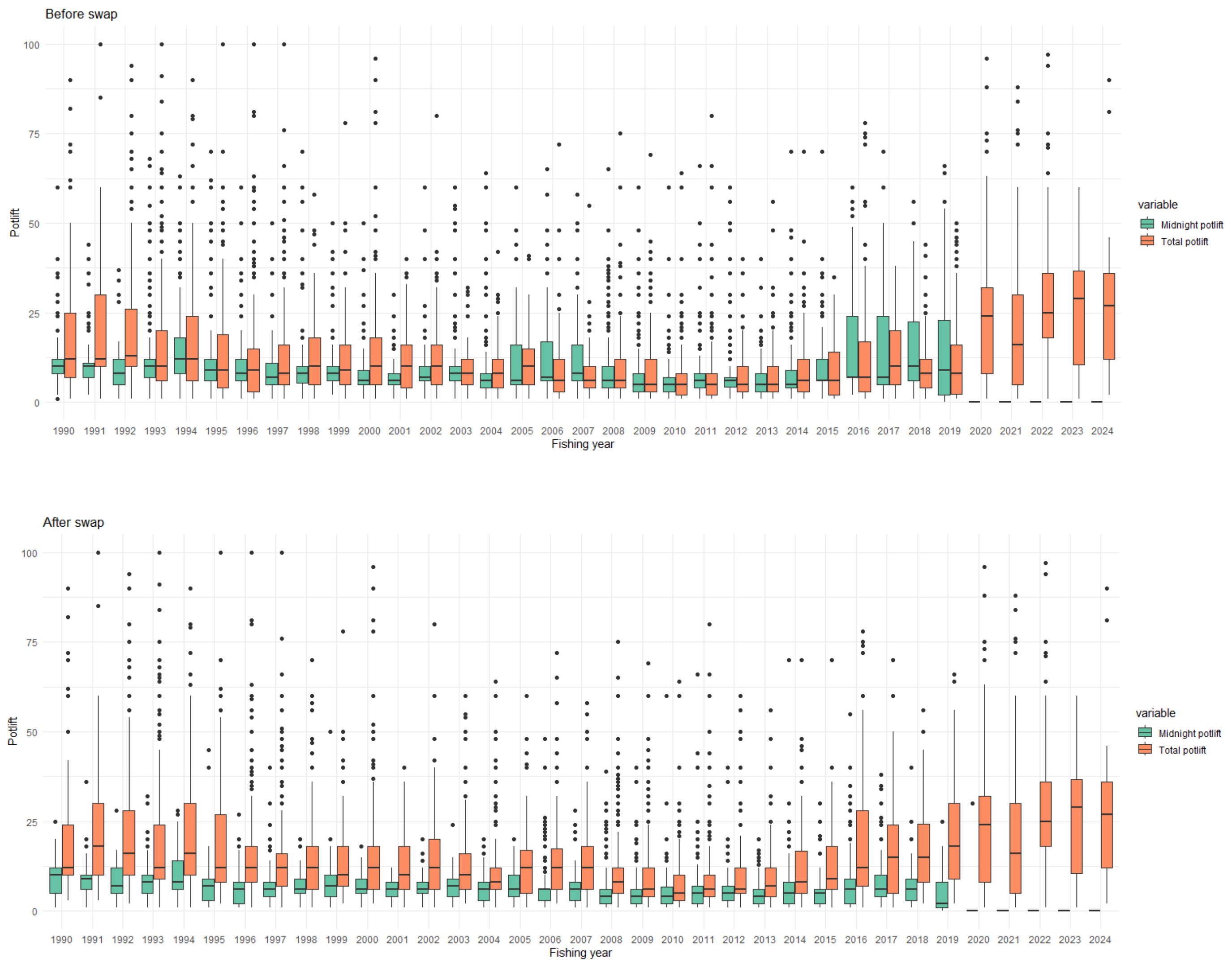


Figure 23: (top panel) Boxplot showing median pot lifts per trip by fishing year for *effort_total_num* (total pot lifts) and *effort_num* (pots in the water at midnight); and (bottom panel) after swapping *effort_total_num* for *effort_num*, when *effort_num* was larger. The ERS only records *effort_total_num* which is why there is no *effort_num* from 2020 onward.

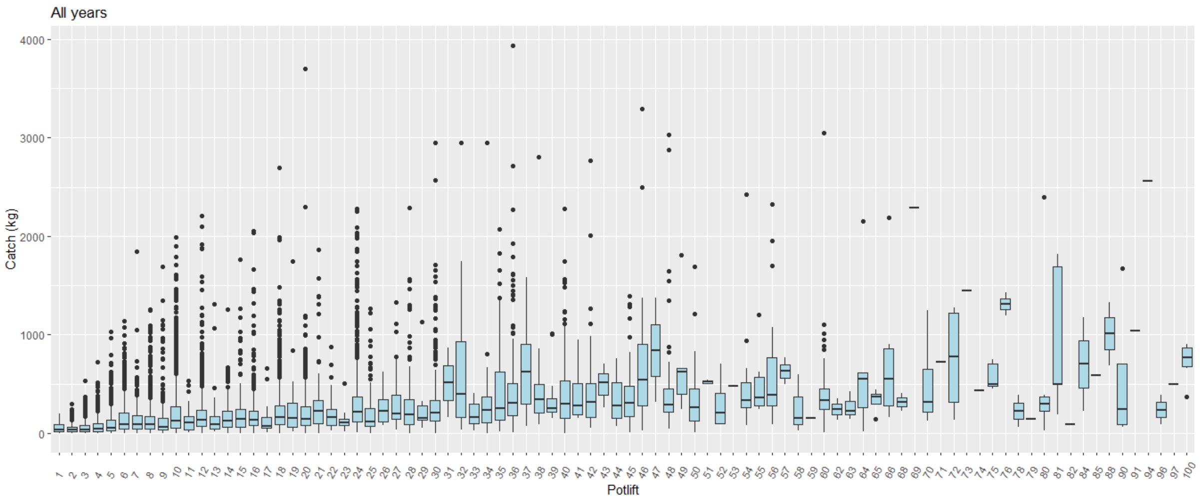


Figure 24: Boxplot showing median trip catch (kg) for different number of trip pot lifts, for all fishing years combined (1990 to 2024).

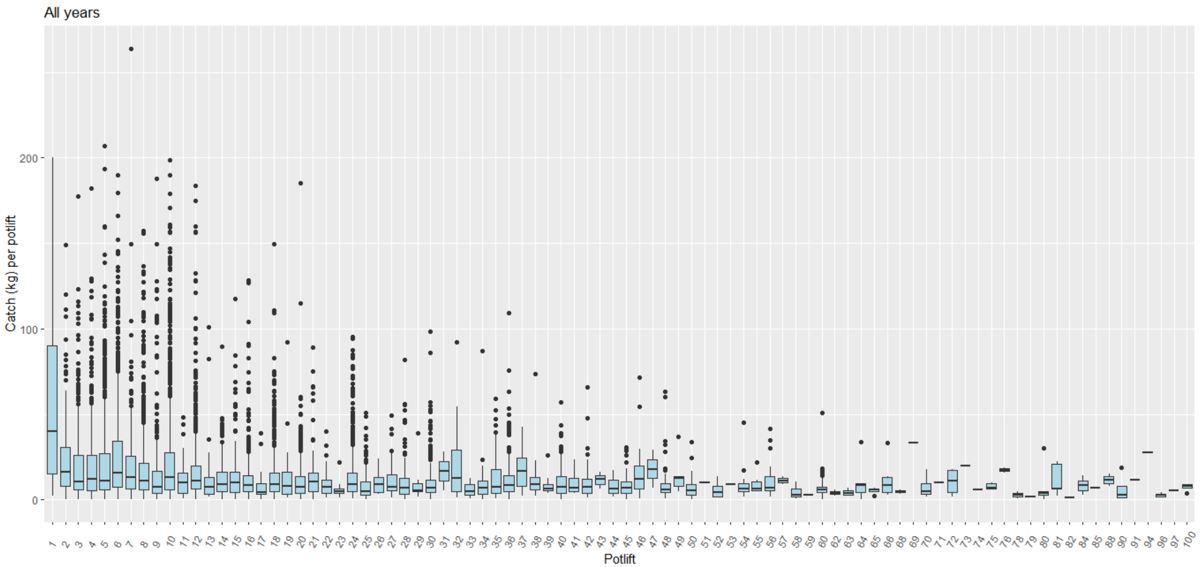


Figure 25: Boxplot showing median catch rate (kg per pot lift) for different number of trip pot lifts, for all fishing years combined (1990 to 2024).

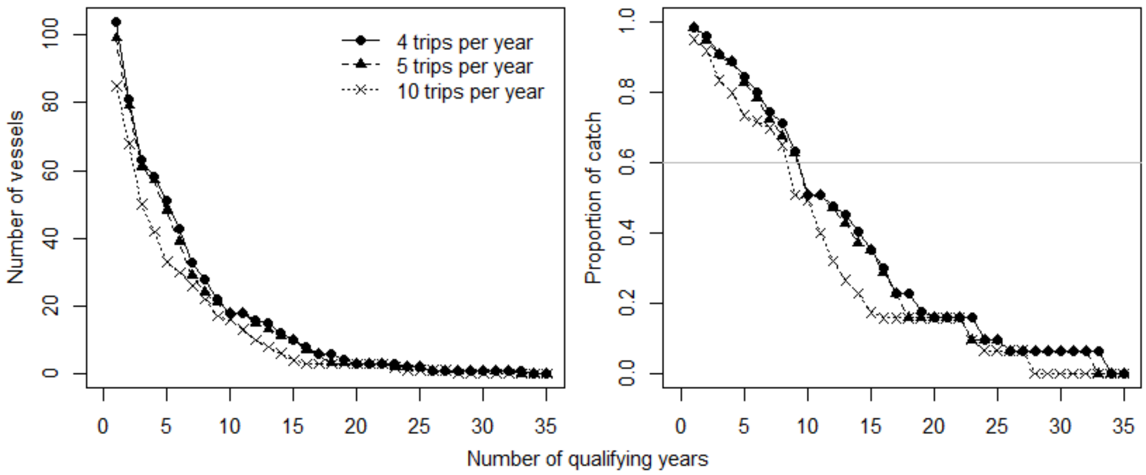


Figure 26: No-swap model (Statistical Areas 024 and 026 combined) number of qualifying years versus the number of vessels (left panel), and proportion of blue cod catch retained (right panel), for a minimum of 4, 5 or 10 trips per year. The grey line indicates a 60% retention of the catch in the core vessel dataset. The criteria for selection of core vessels were a minimum of 3 qualifying years and 5 trips per year (see Table 2).

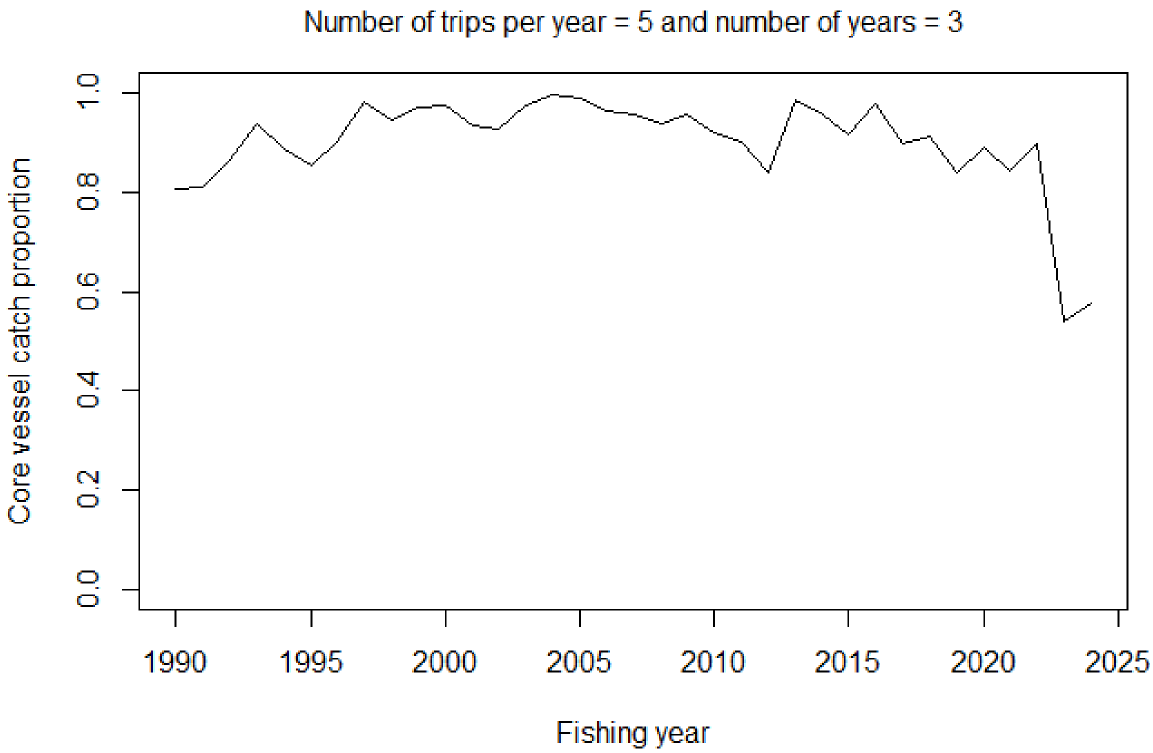


Figure 27: No-swap model (Statistical Areas 024 and 026 combined) proportion of blue cod catch retained in the core vessel analyses dataset each year from 1989–90 to 2023–24, where core vessels were restricted to a minimum of 3 qualifying years and 5 trips per year (see Table 2).

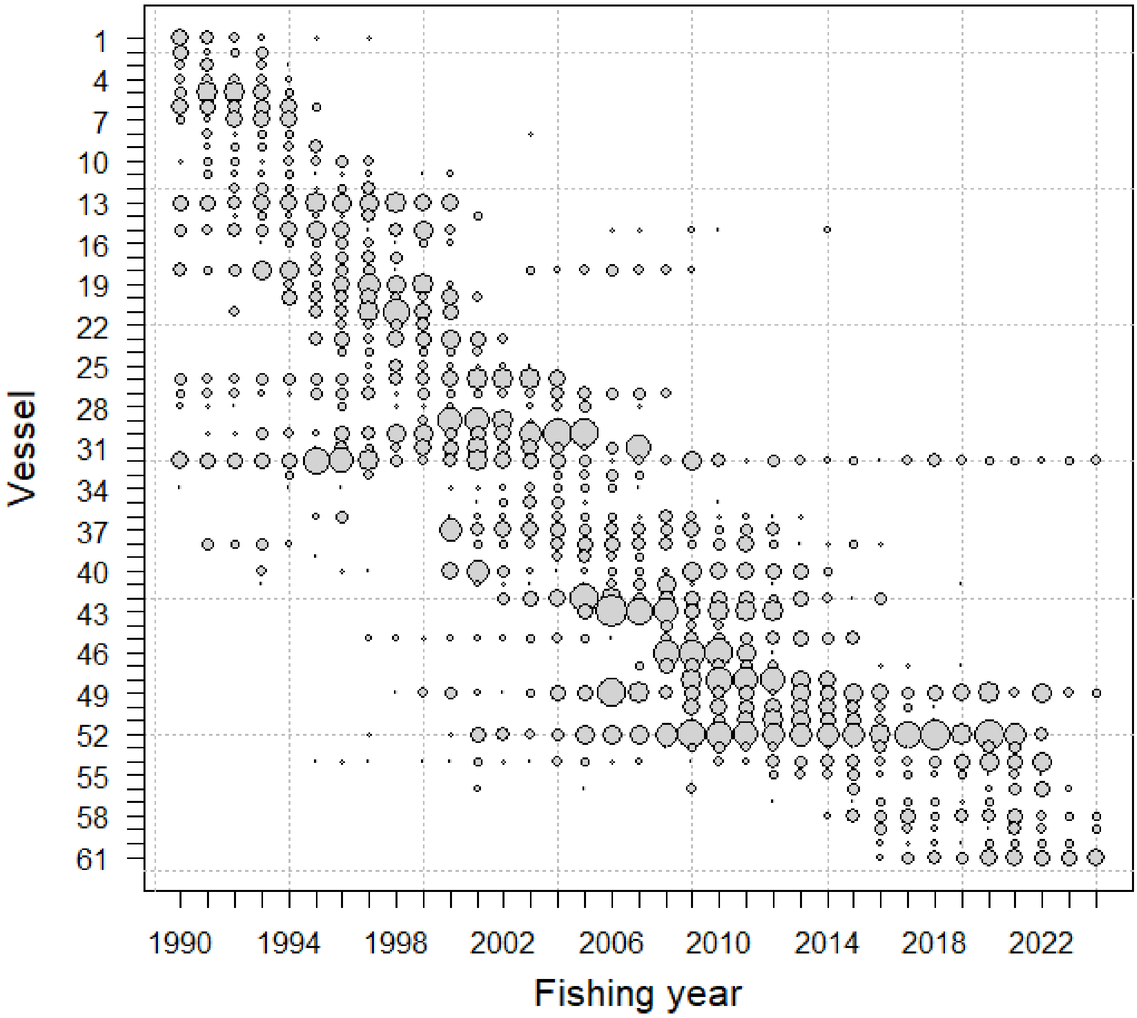


Figure 28: No-swap model (Statistical Areas 024 and 026 combined) core vessel relative number of fishing events from 1989–90 to 2023–24. N= 61 vessels.

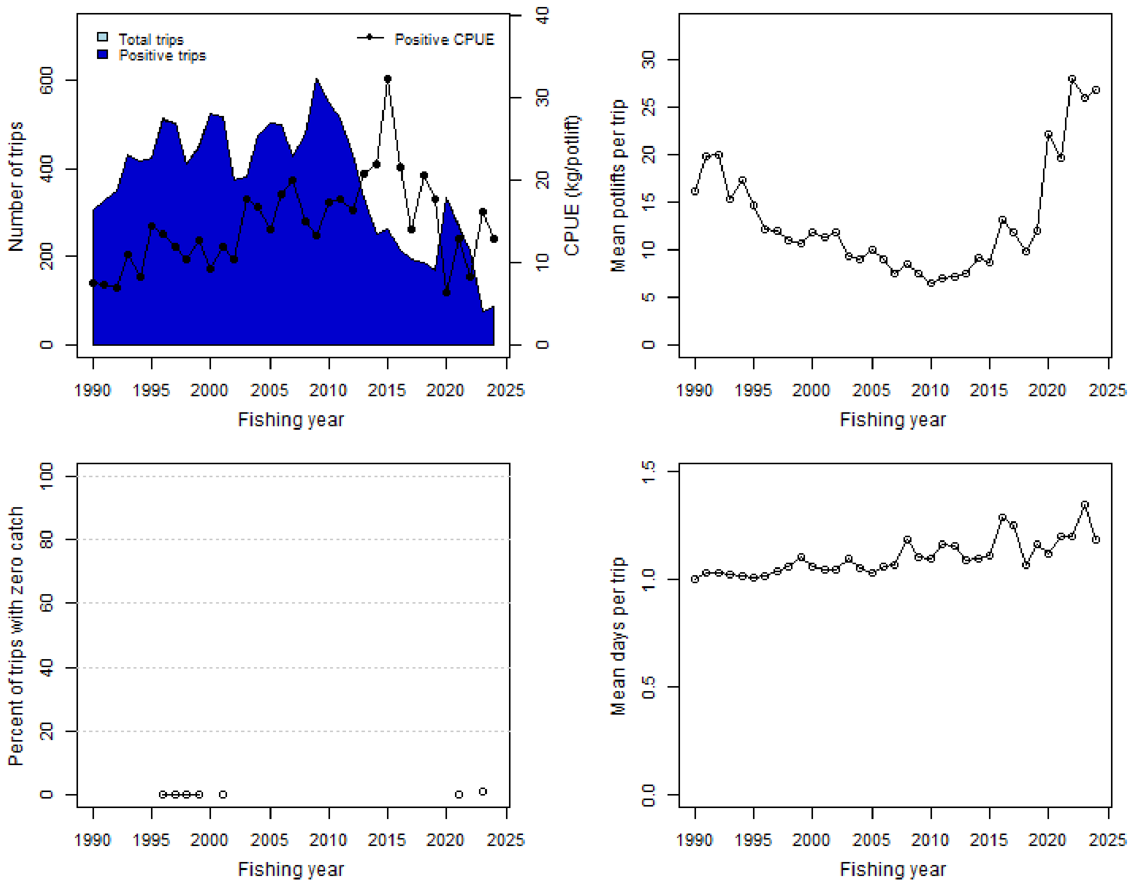


Figure 29: No-swap model (Statistical Areas 024 and 026 combined) blue cod core vessel trip metrics from 1989–90 to 2023–24. Total number of trips with positive catch, and raw CPUE (top left). Percentage of trips with zero catch (bottom left), mean pot lifts per trip (top right), and mean days fished per trip (bottom right).

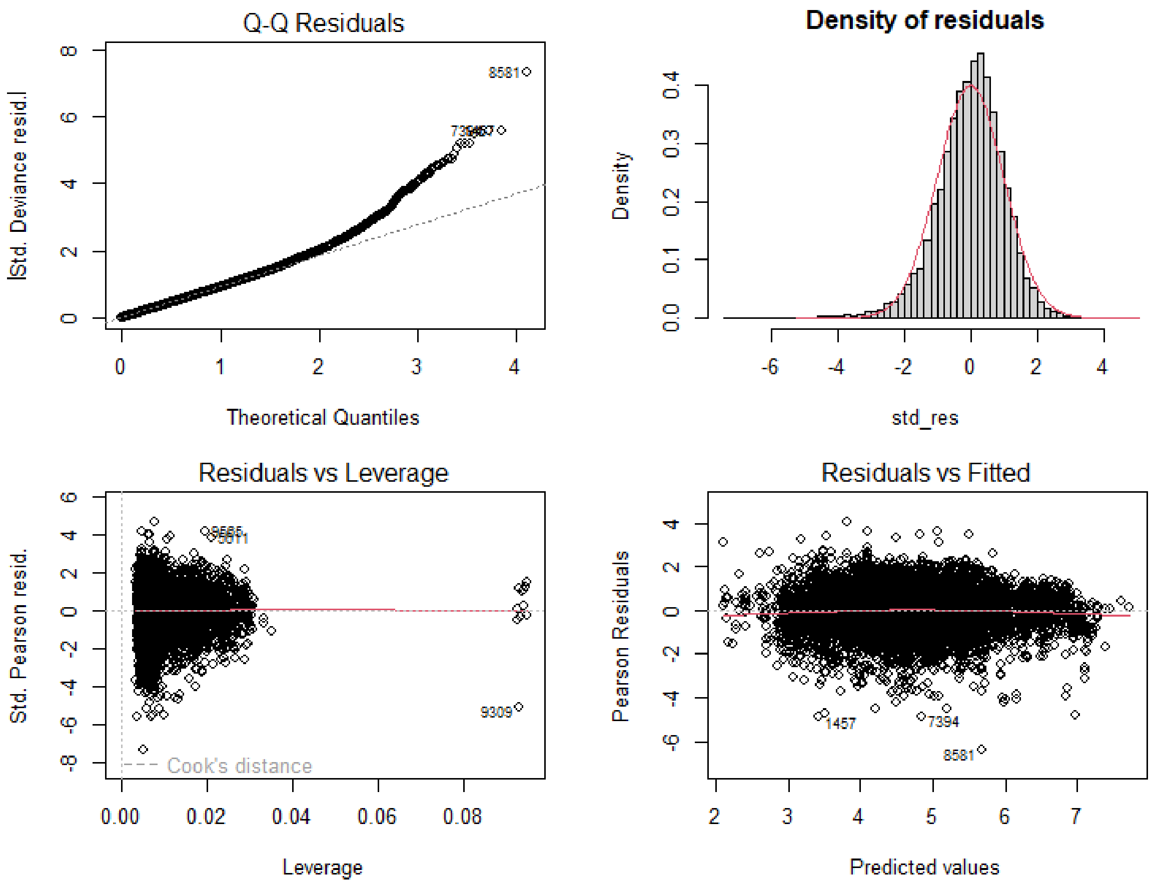


Figure 30: No-swap model (Statistical Areas 024 and 026 combined) diagnostic plots for the blue cod standardised CPUE analyses of blue cod catch from core vessels from 1989–90 to 2023–24. Q-Q plot of standardised residuals (top left), histogram of the standardised residuals compared to a normal distribution (top right), Pearson's residuals versus leverage plot (bottom left), and standardised residuals versus fitted values.

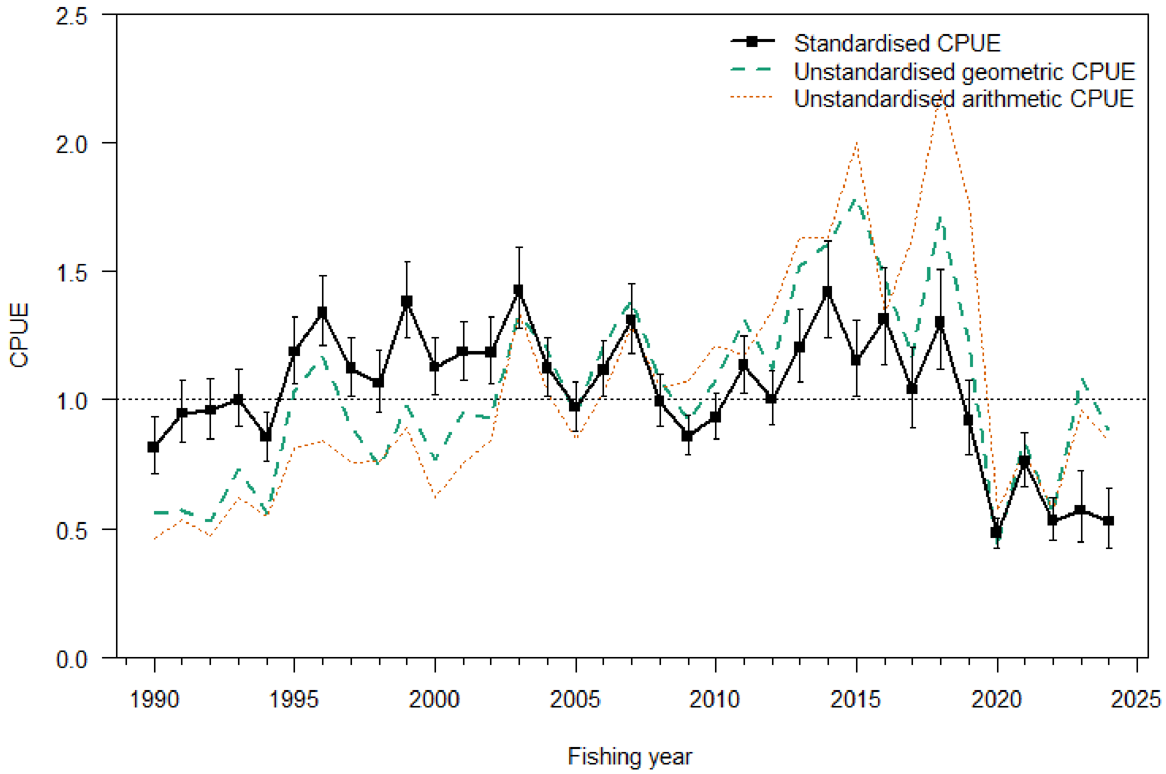


Figure 31: No-swap model (Statistical Areas 024 and 026 combined) blue cod standardised canonical CPUE indices for core vessels from 1989–90 to 2023–24. The geometric and arithmetic unstandardized indices for core vessels are also shown. Error bars are 95% confidence intervals. Indices are scaled to have a mean of 1.0.

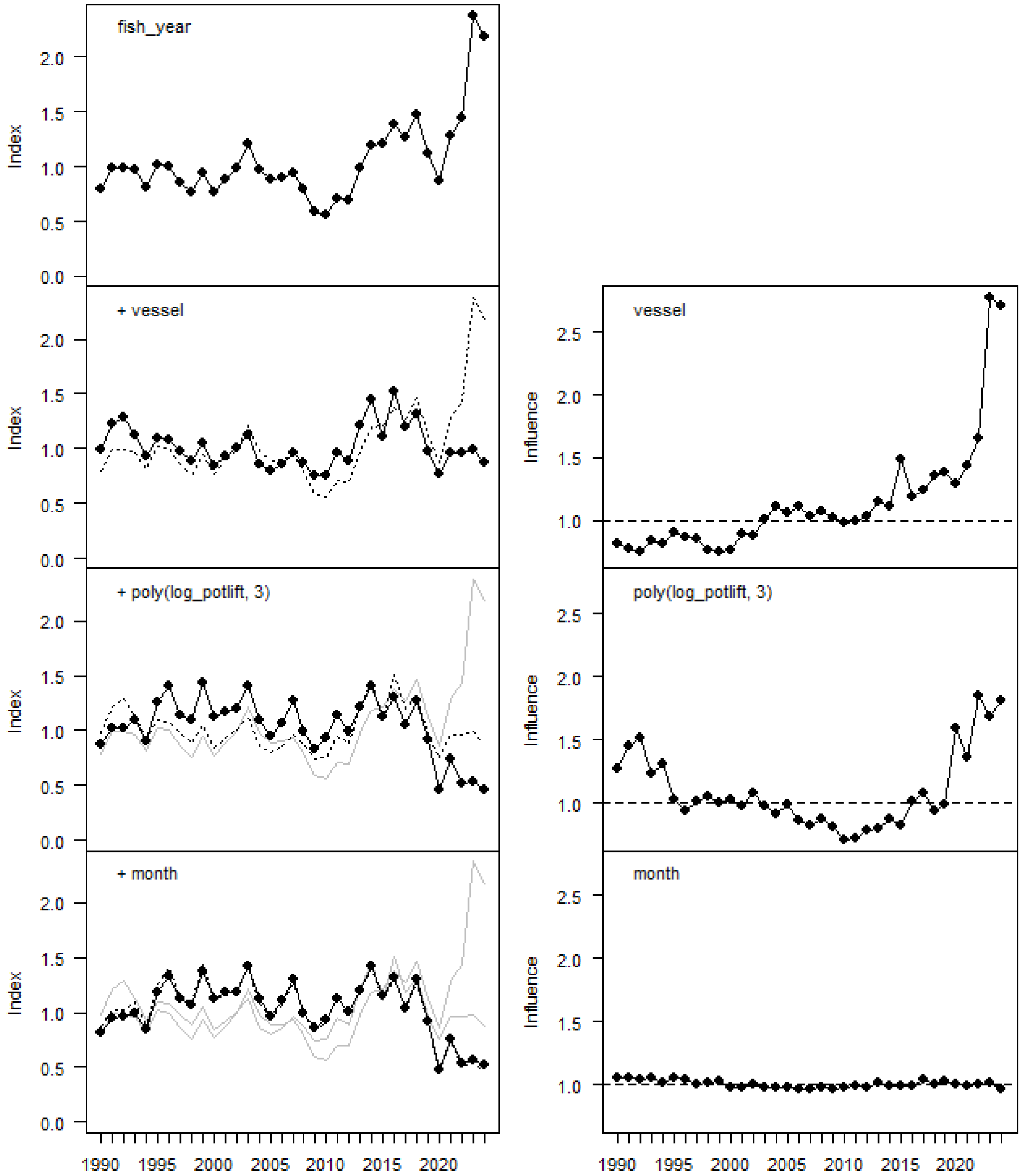
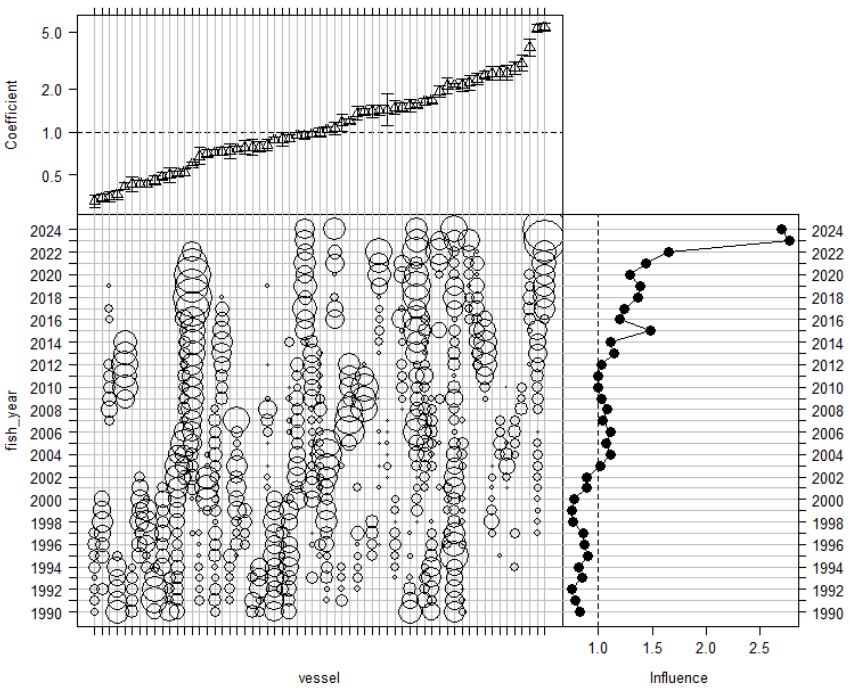


Figure 32: No-swap model (Statistical Areas 024 and 026 combined) blue cod standardised CPUE indices step plots (left) and influence plots for core vessels from 1989–90 to 2023–24. The step plots show how the indices change with the addition of predictor variables into the model. The influence plots show where the predictor variable influence the indices.



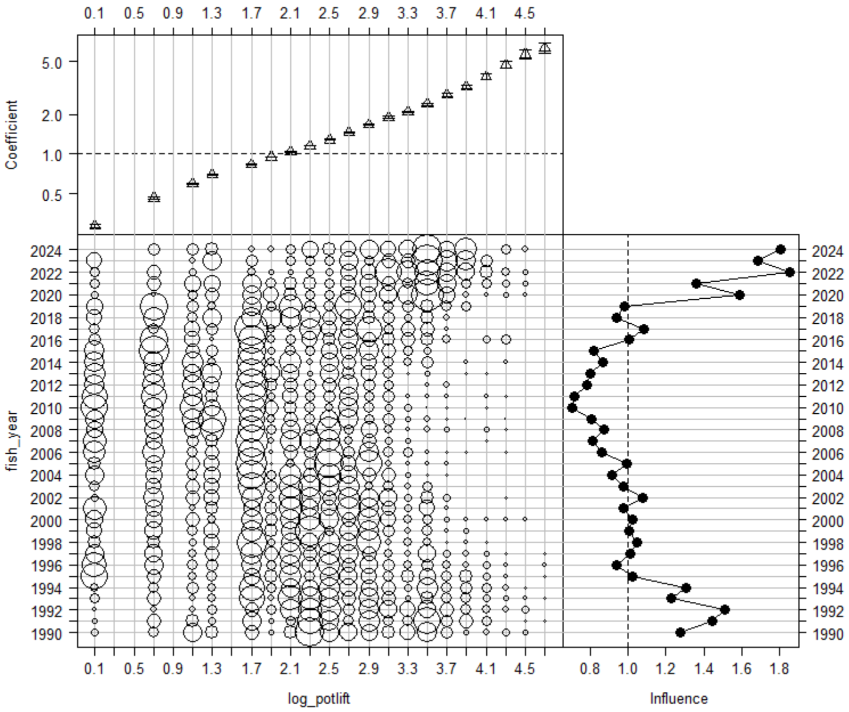


Figure 33: No-swap model (Statistical Areas 024 and 026 combined) blue cod standardised CPUE analyses coefficient-distribution-influence plots (CDI) for core vessels from 1989–90 to 2023–24. Plots are shown for each predictor variable included in the model. Effect by level of variable (top), distribution of variable by fishing year (bottom left), and cumulative effect of variable each year (right).

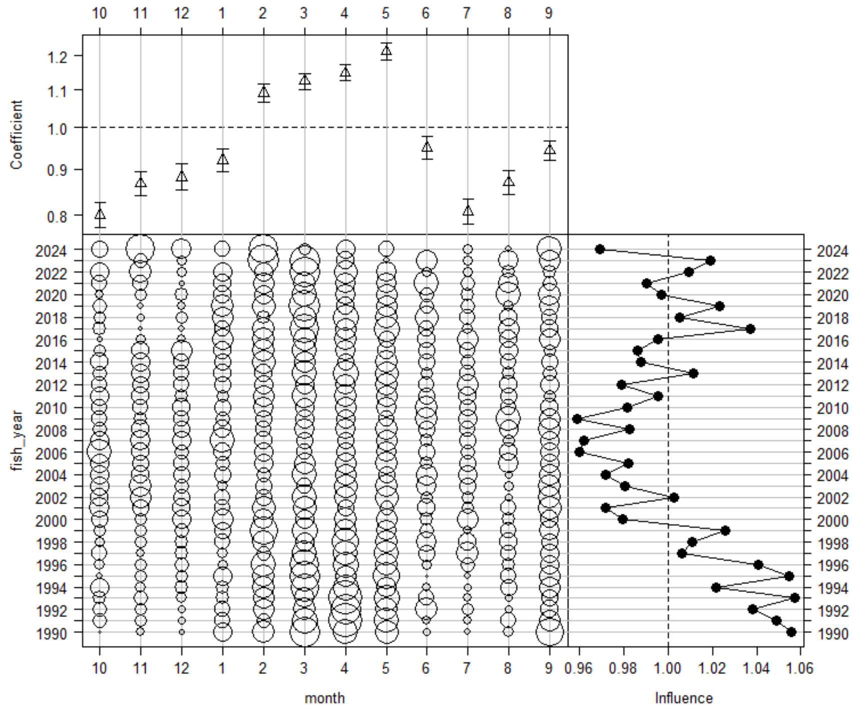


Figure 33– *continued*

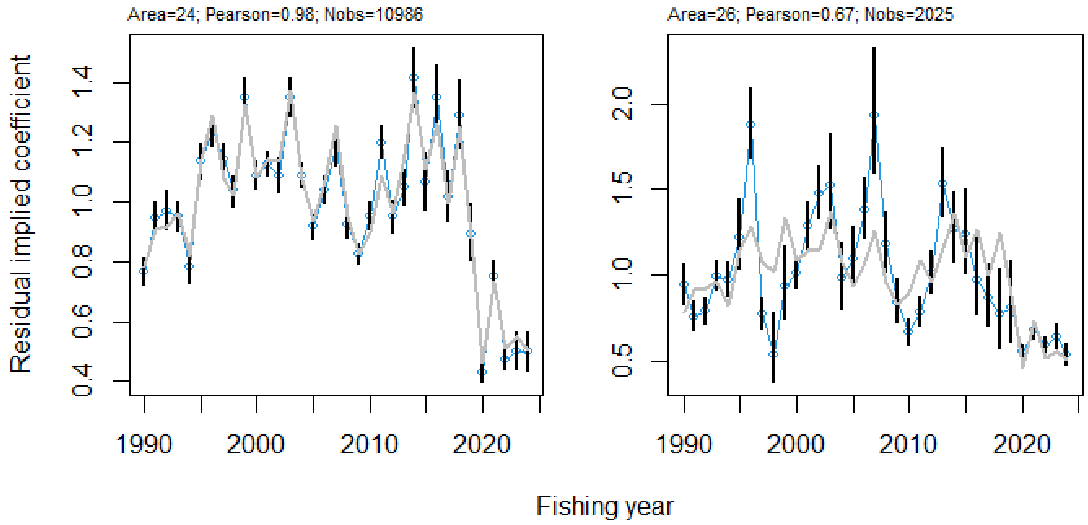


Figure 34: Residual implied coefficients for Statistical Areas 024 and 026 from the no-swap CPUE model (blue line). The grey lines represent the standardised index. Error bars represent ± one standard error.

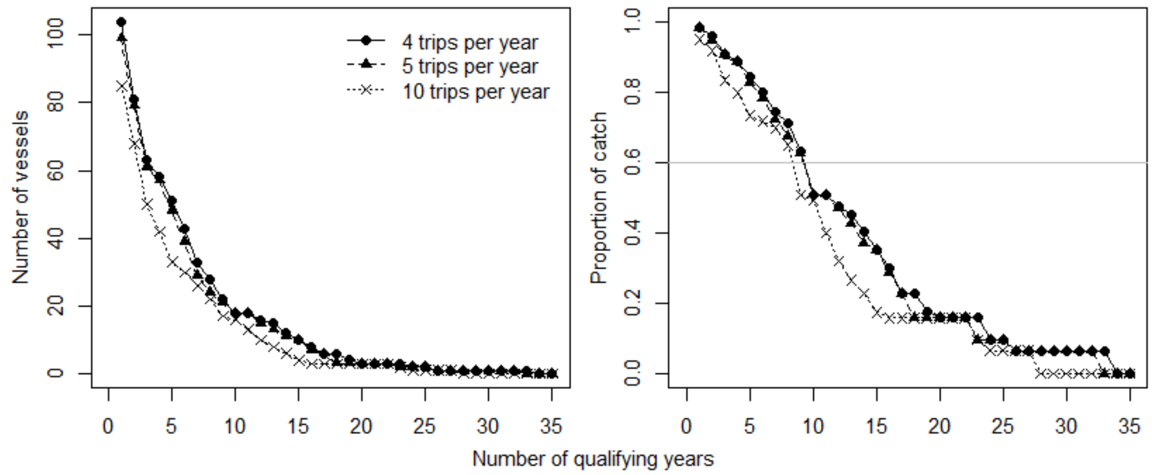


Figure 35: Swap model (Statistical Areas 024 and 026 combined) number of qualifying years versus the number of vessels (left panel), and proportion of blue cod catch retained (right panel), for a minimum of 4, 5 or 10 trips per year. The grey line indicates a 60% retention of the catch in the core vessel dataset. The criteria for selection of core vessels were a minimum of 3 qualifying years and 5 trips per year (see Table 2).

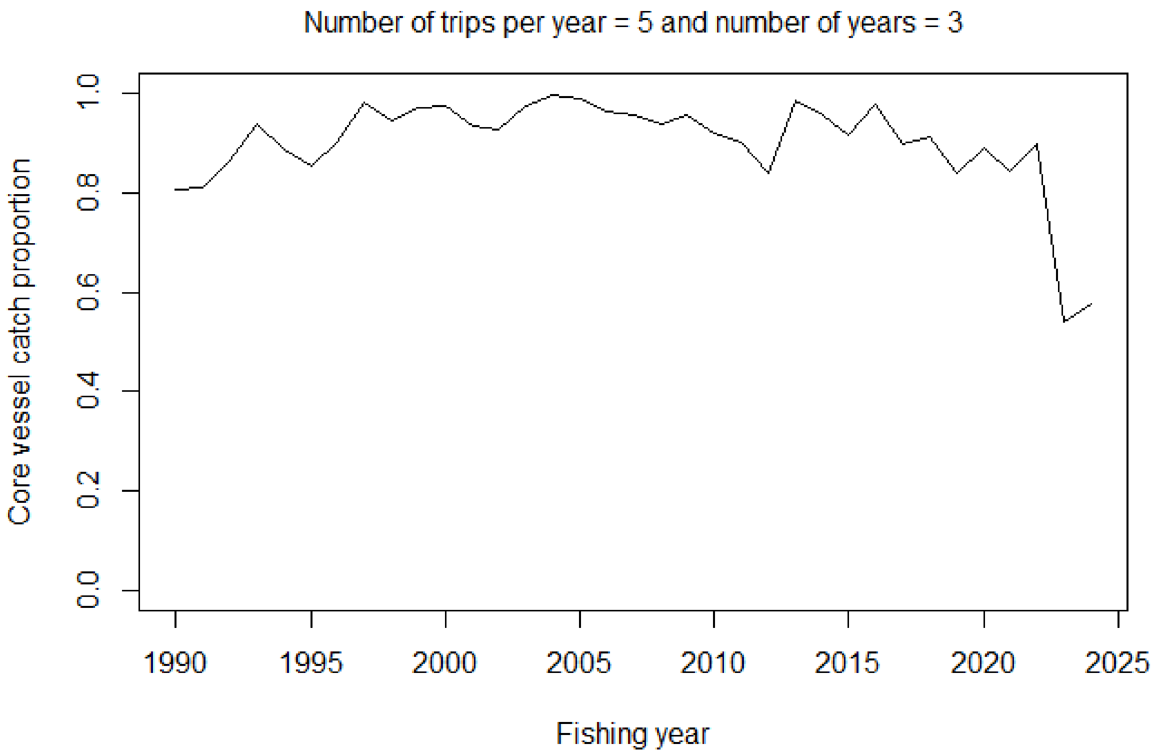


Figure 36: Swap model (Statistical Areas 024 and 026 combined) proportion of blue cod catch retained in the core vessel analyses dataset each year from 1989–90 to 2023–24, where core vessels were restricted to a minimum of 3 qualifying years and 5 trips per year (see Table 2).

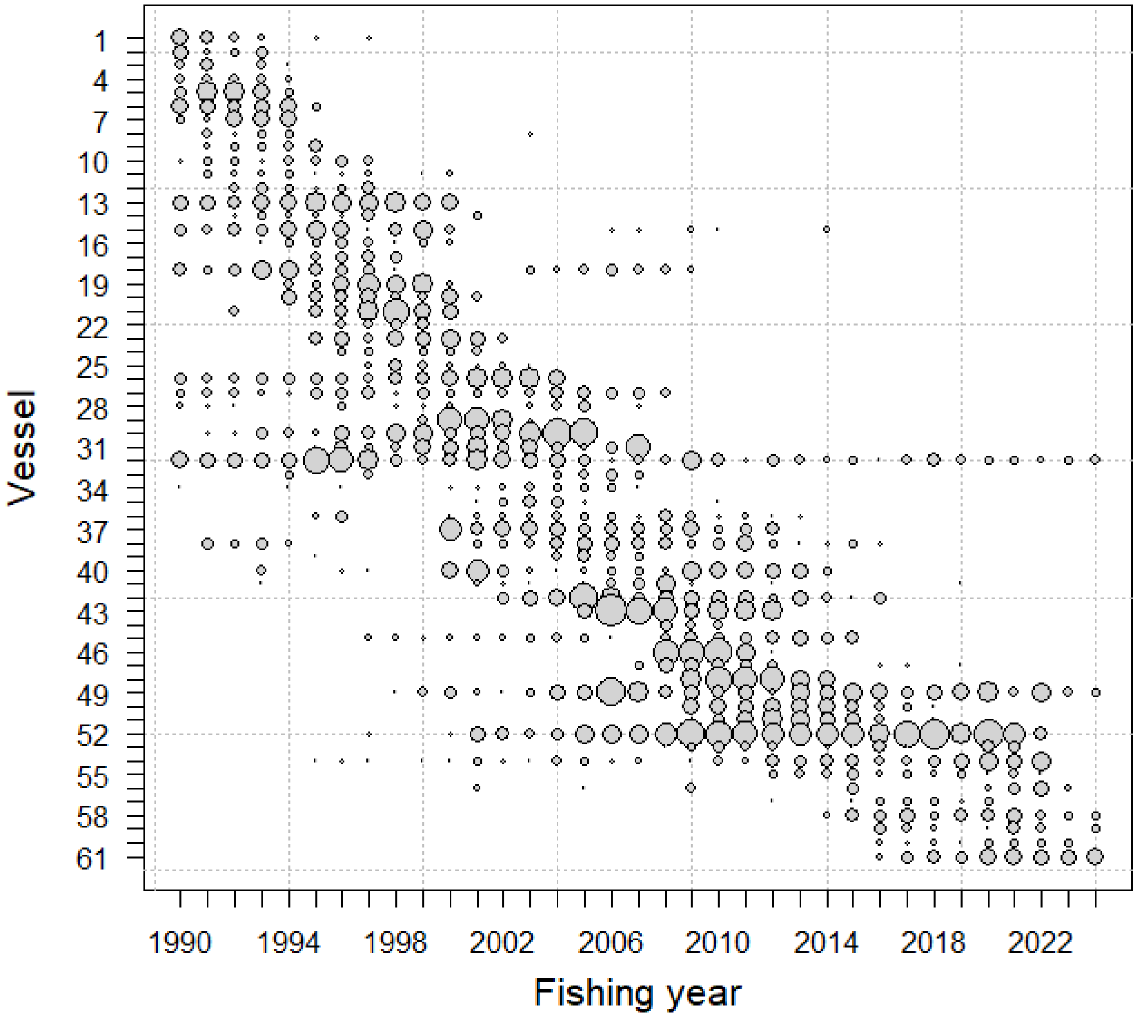


Figure 37: Swap model (Statistical Areas 024 and 026 combined) core vessel relative number of fishing events from 1989–90 to 2023–24. N= 61 vessels.

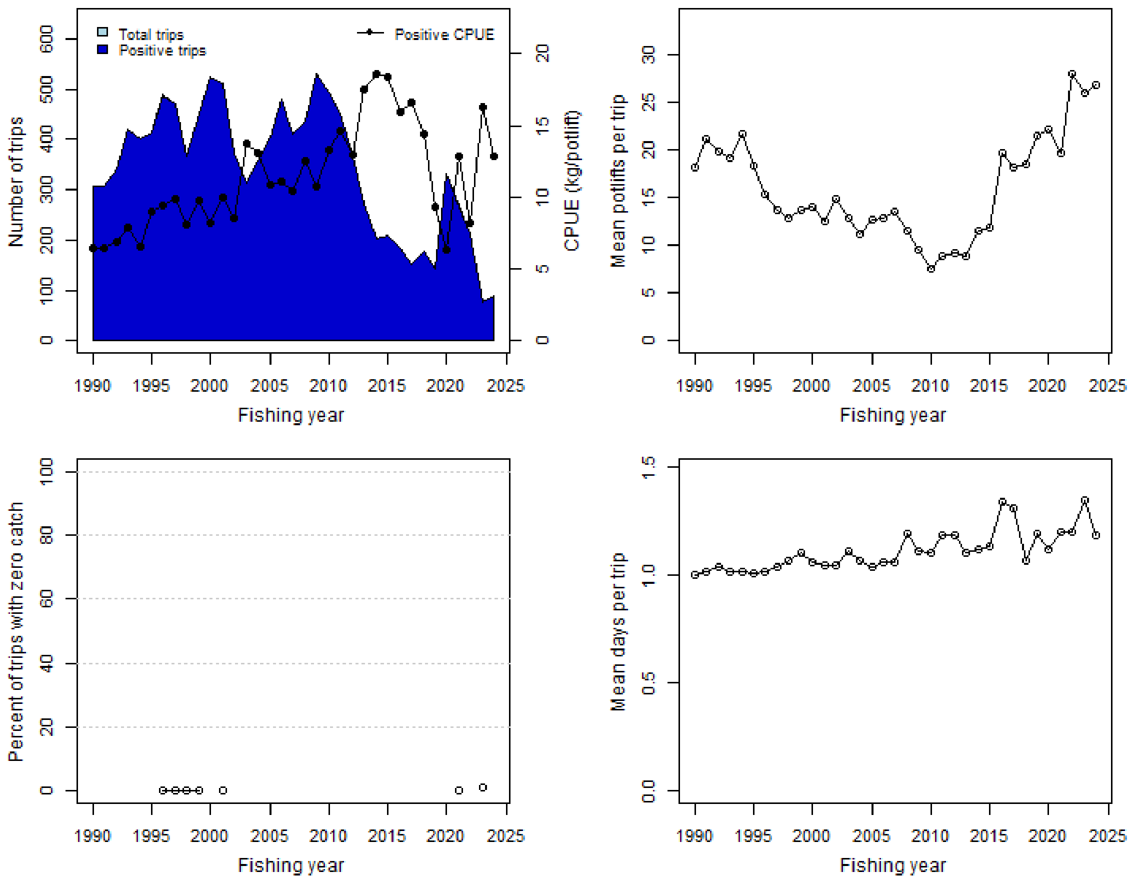


Figure 38: Swap model (Statistical Areas 024 and 026 combined) blue cod core vessel trip metrics from 1989–90 to 2023–24. Total number of trips with positive catch, and raw CPUE (top left). Percentage of trips with zero catch (bottom left), mean pot lifts per trip (top right), and mean days fished per trip (bottom right).

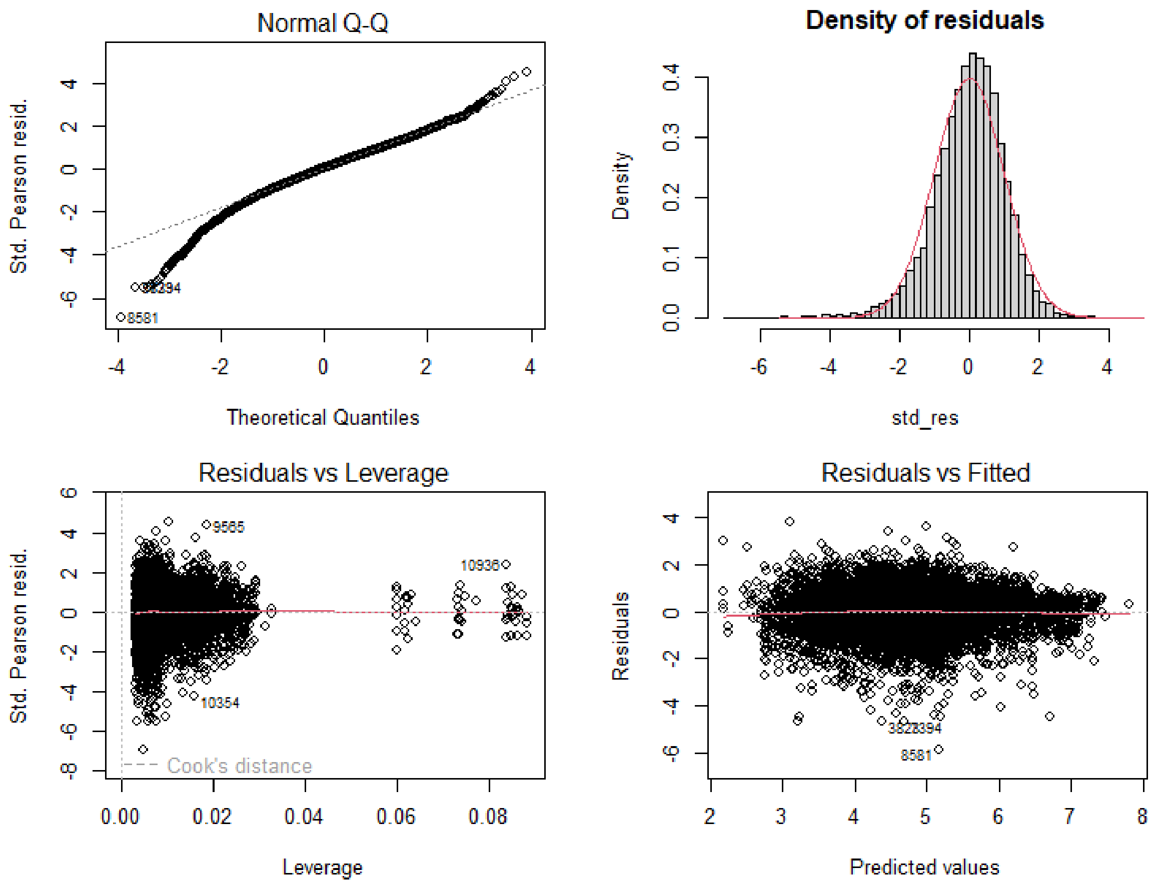


Figure 39: Swap model (Statistical Areas 024 and 026 combined) diagnostic plots for the blue cod standardised CPUE analyses of blue cod catch from core vessels from 1989–90 to 2023–24. Q-Q plot of standardised residuals (top left), histogram of the standardised residuals compared to a normal distribution (top right), Pearson's residuals versus leverage plot (bottom left), and standardised residuals versus fitted values.

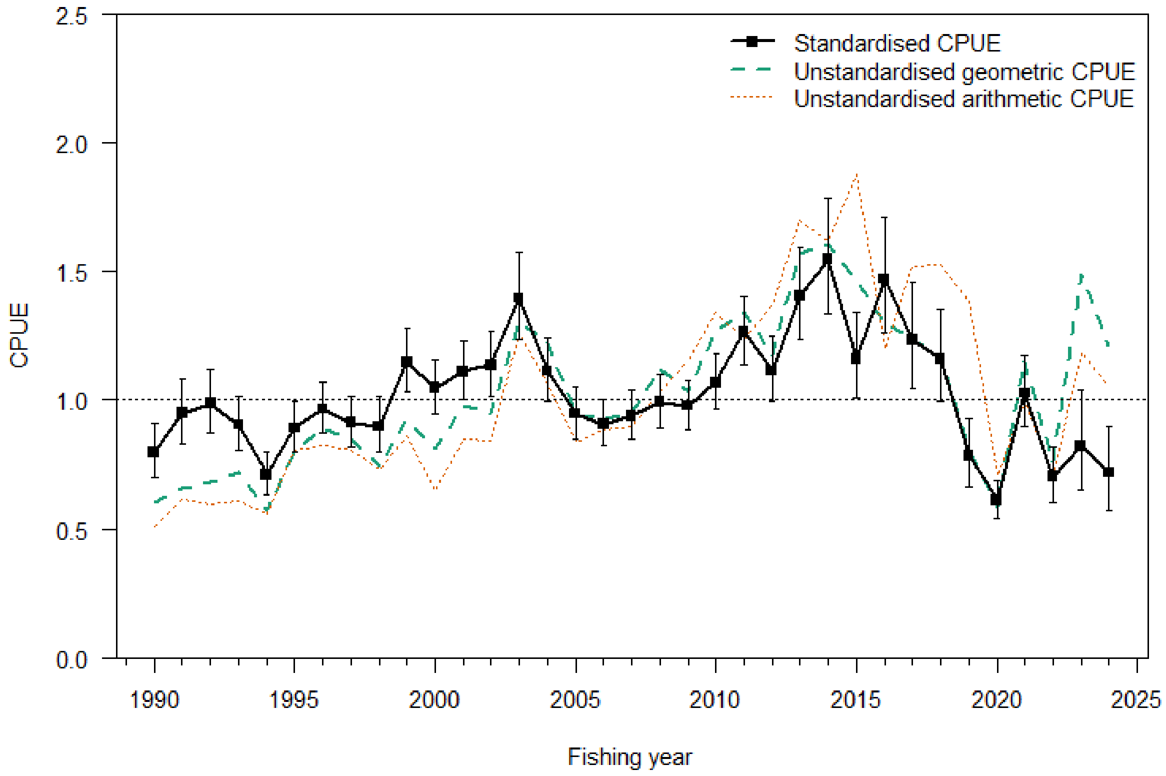


Figure 40: Swap model (Statistical Areas 024 and 026 combined) blue cod standardised canonical CPUE indices for core vessels from 1989–90 to 2023–24. The geometric and arithmetic unstandardized indices for core vessels are also shown. Error bars are 95% confidence intervals. Indices are scaled to have a mean of 1.0.

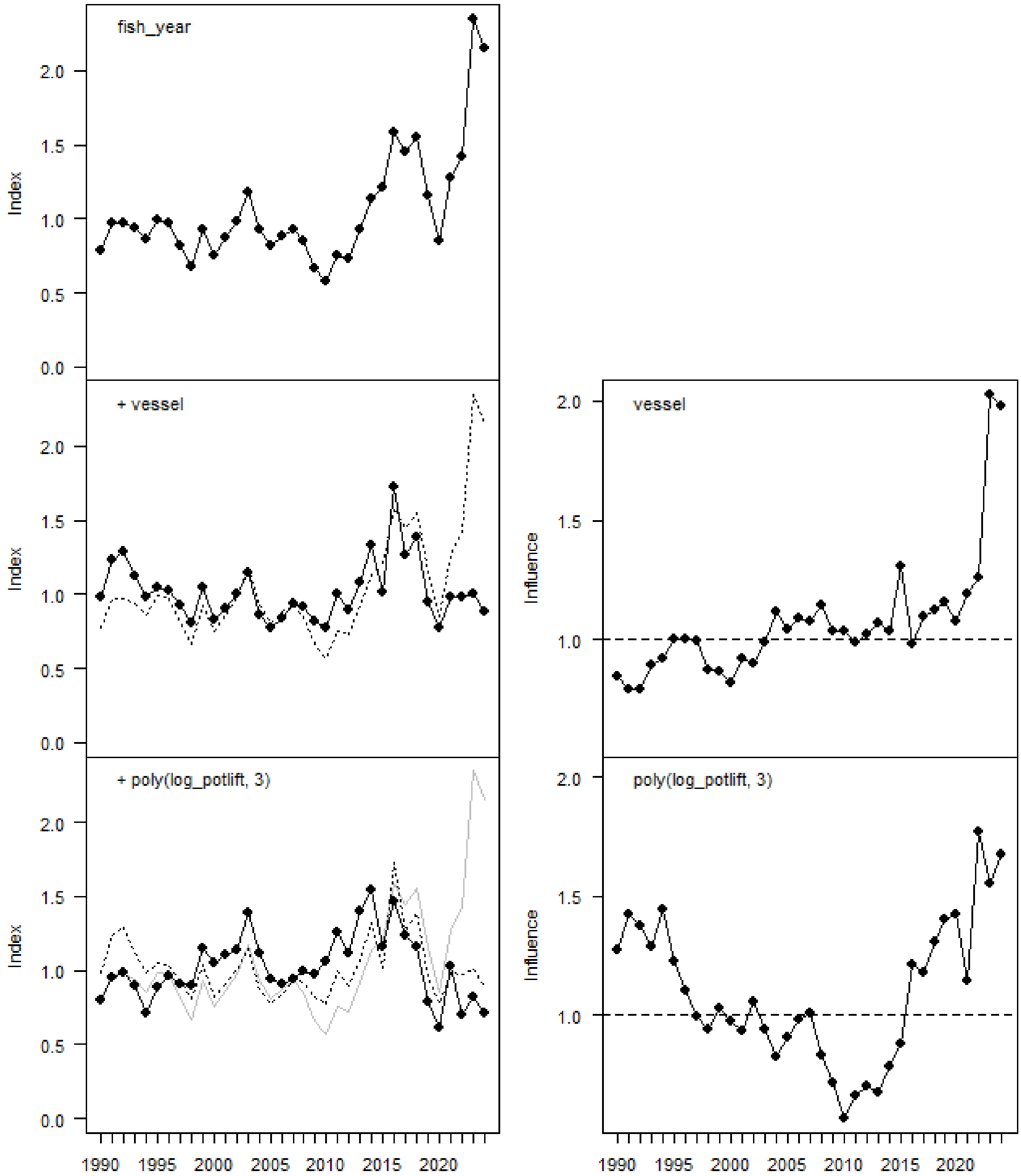


Figure 41: Swap model (Statistical Areas 024 and 026 combined) blue cod standardised CPUE indices step plots (left) and influence plots for core vessels from 1989–90 to 2023–24. The step plots show how the indices change with the addition of predictor variables into the model. The influence plots show where the predictor variable influence the indices.

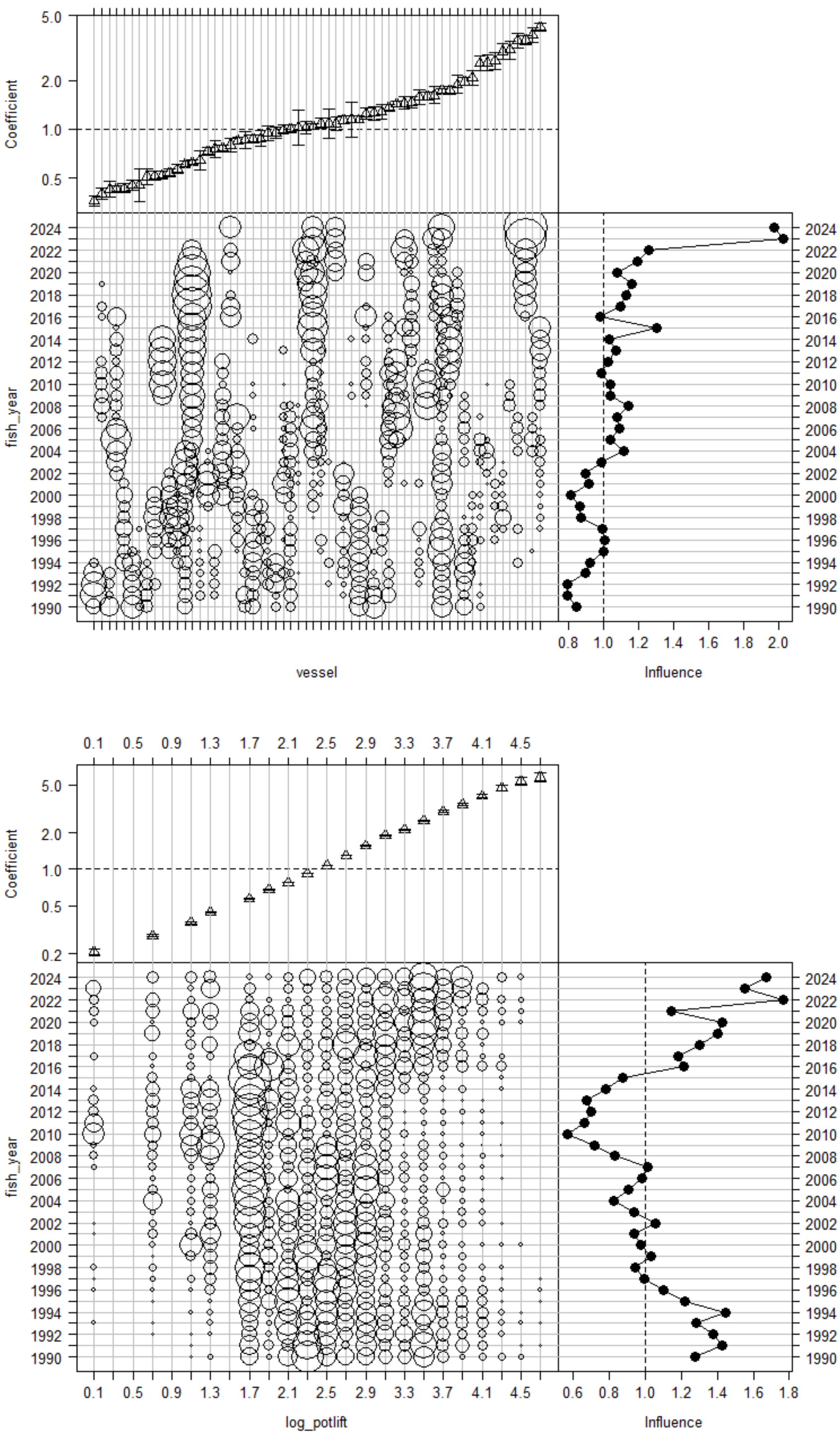


Figure 42: Swap model (Statistical Areas 024 and 026 combined) blue cod standardised CPUE analyses coefficient-distribution-influence plots (CDI) for core vessels from 1989–90 to 2023–24. Plots are shown for each predictor variable included in the model. Effect by level of variable (top), distribution of variable by fishing year (bottom left), and cumulative effect of variable each year (right).

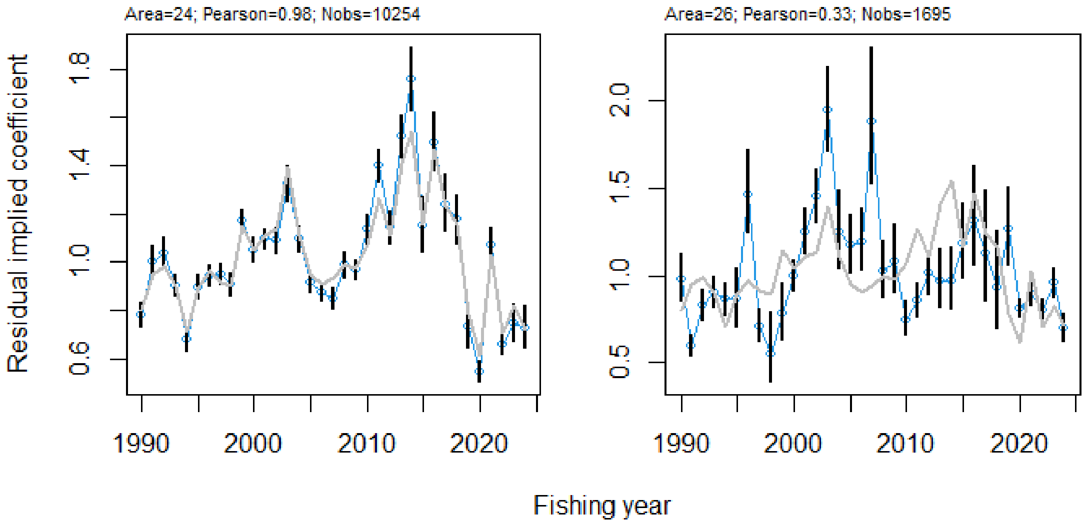


Figure 43: Residual implied coefficients for Statistical Areas 024 and 026 from the swap CPUE model (blue line). The grey lines represent the standardised index. Error bars represent ± one standard error.

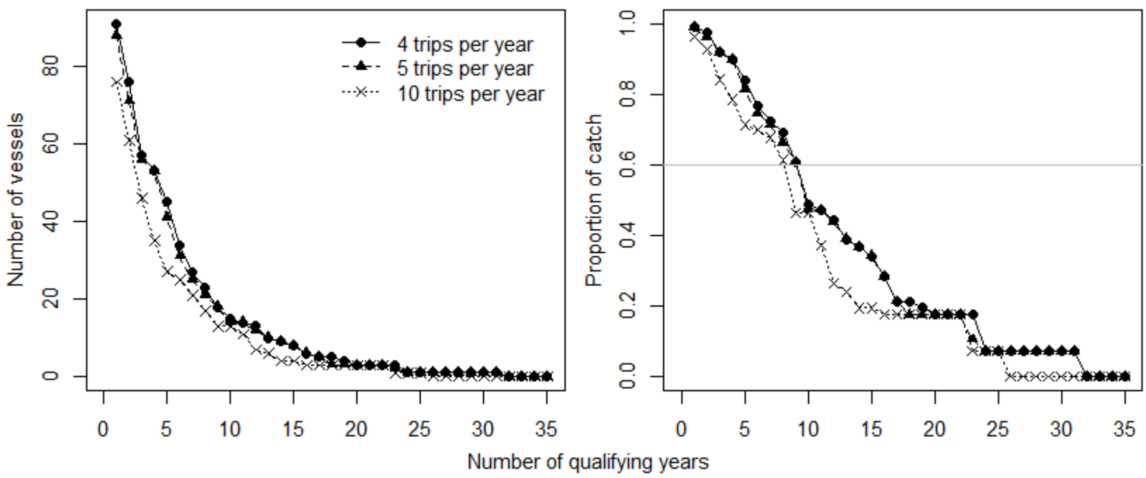


Figure 44: Swap-2 model (Statistical Areas 024 and 026 combined) number of qualifying years versus the number of vessels (left panel), and proportion of blue cod catch retained (right panel), for a minimum of 4, 5 or 10 trips per year. The grey line indicates a 60% retention of the catch in the core vessel dataset. The criteria for selection of core vessels were a minimum of 3 qualifying years and 5 trips per year (see Table 2).

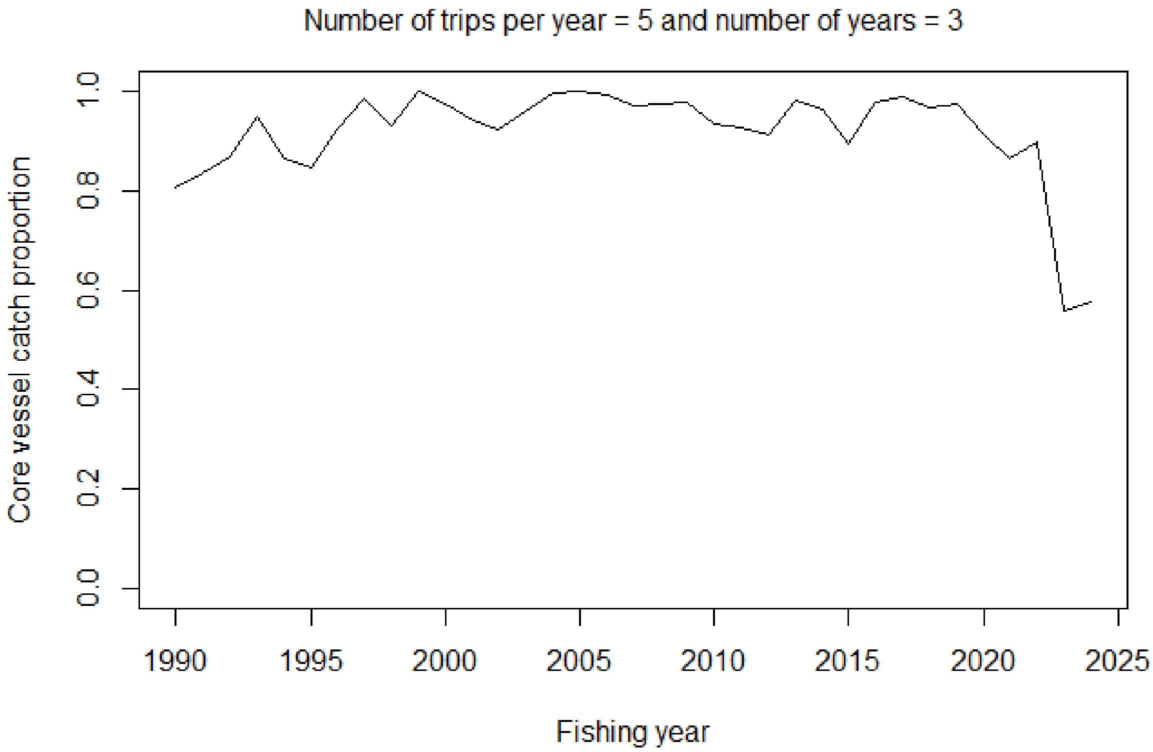


Figure 45: Swap-2 model (Statistical Areas 024 and 026 combined) proportion of blue cod catch retained in the core vessel analyses dataset each year from 1989–90 to 2023–24, where core vessels were restricted to a minimum of 3 qualifying years and 5 trips per year (see Table 2).

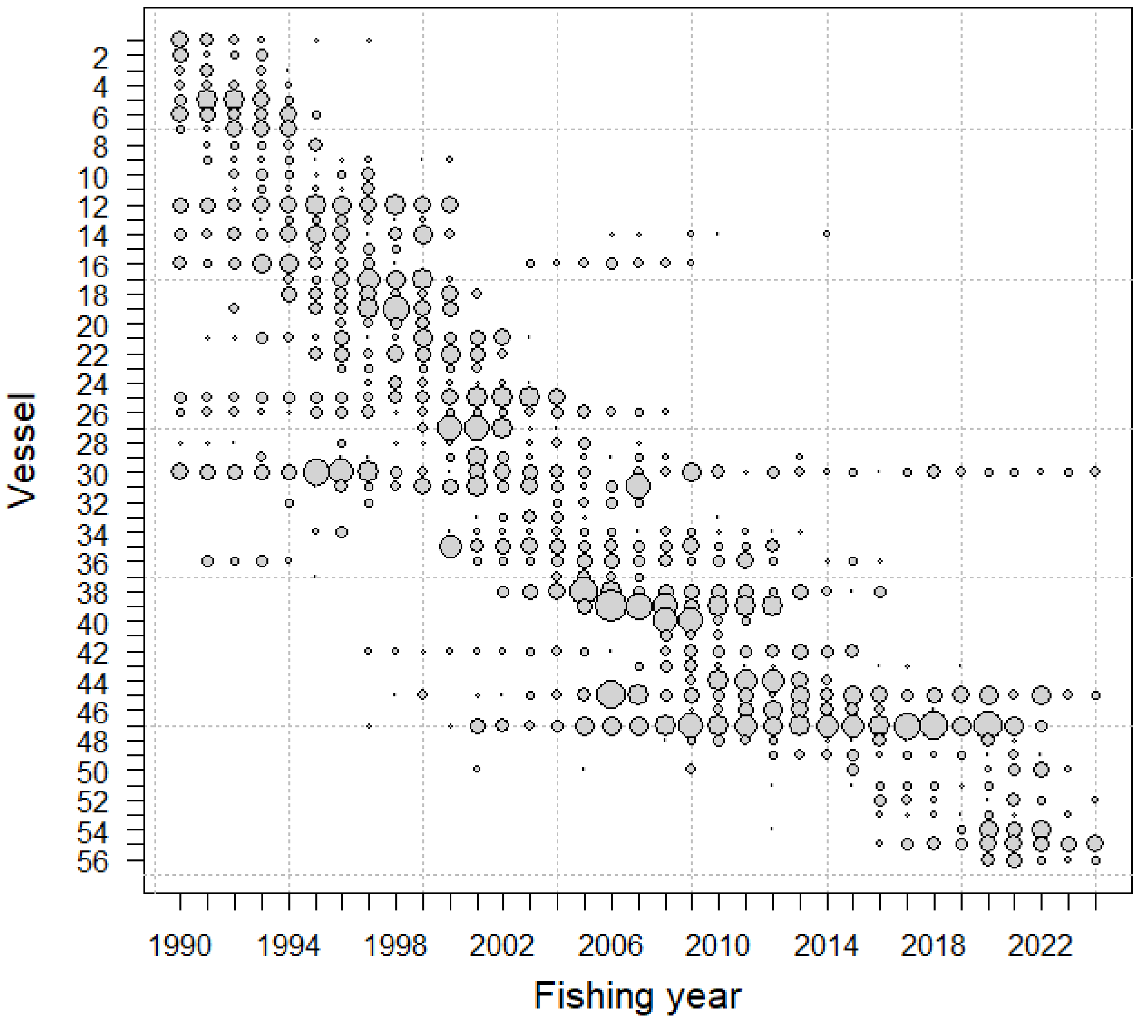


Figure 46: Swap-2 model (Statistical Areas 024 and 026 combined) core vessel relative number of fishing events from 1989–90 to 2023–24. N= 56 vessels.

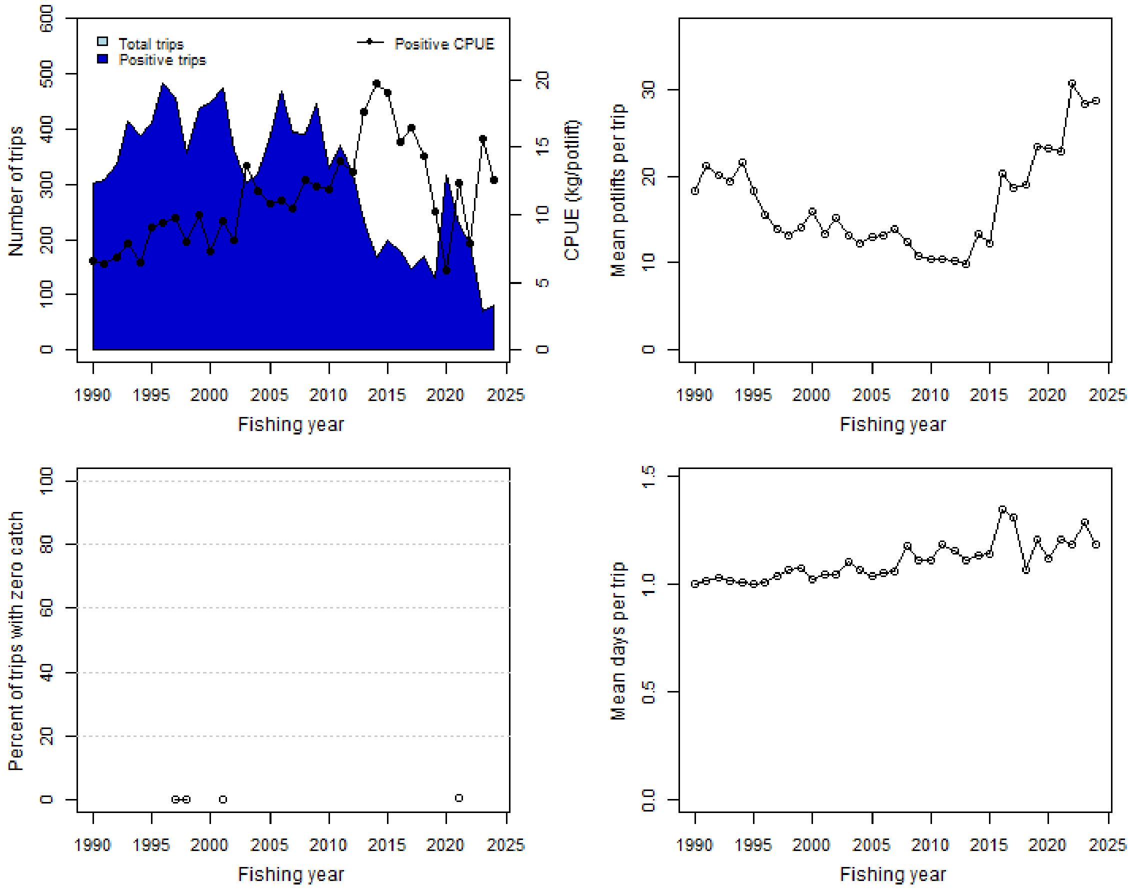


Figure 47: Swap-2 model (Statistical Areas 024 and 026 combined) blue cod core vessel trip metrics from 1989–90 to 2023–24. Total number of trips with positive catch, and raw CPUE (top left). Percentage of trips with zero catch (bottom left), mean pot lifts per trip (top right), and mean days fished per trip (bottom right).

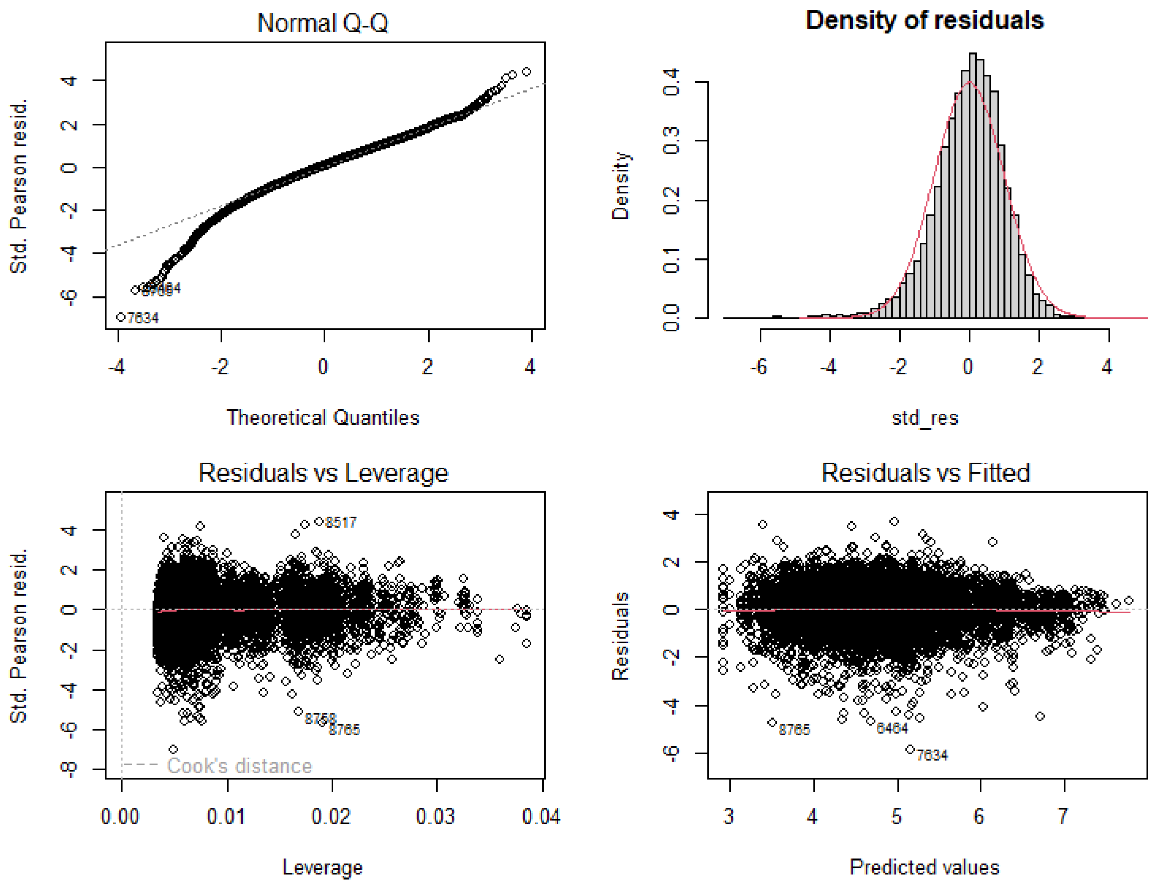


Figure 48: Swap-2 model (Statistical Areas 024 and 026 combined) diagnostic plots for the blue cod standardised CPUE analyses of blue cod catch from core vessels from 1989–90 to 2023–24. Q-Q plot of standardised residuals (top left), histogram of the standardised residuals compared to a normal distribution (top right), Pearson's residuals versus leverage plot (bottom left), and standardised residuals versus fitted values.

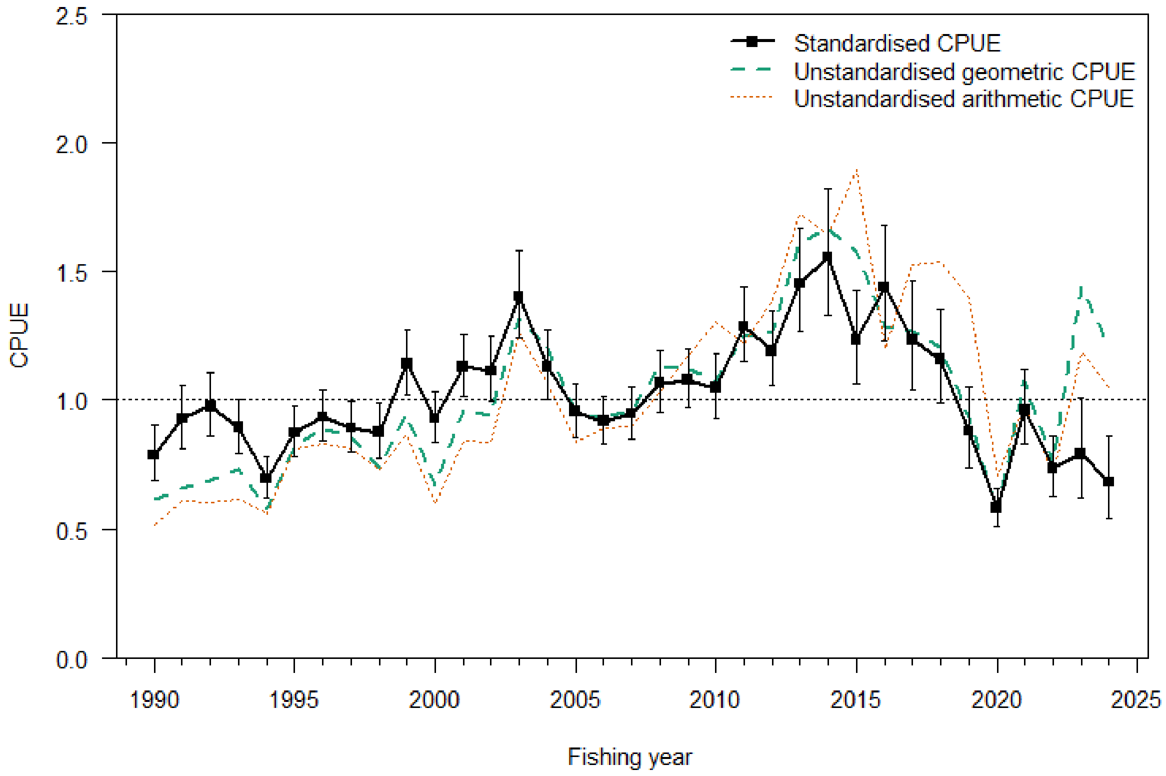


Figure 49: Swap-2 model (Statistical Areas 024 and 026 combined) blue cod standardised canonical CPUE indices for core vessels from 1989–90 to 2023–24. The geometric and arithmetic unstandardized indices for core vessels are also shown. Error bars are 95% confidence intervals. Indices are scaled to have a mean of 1.0.

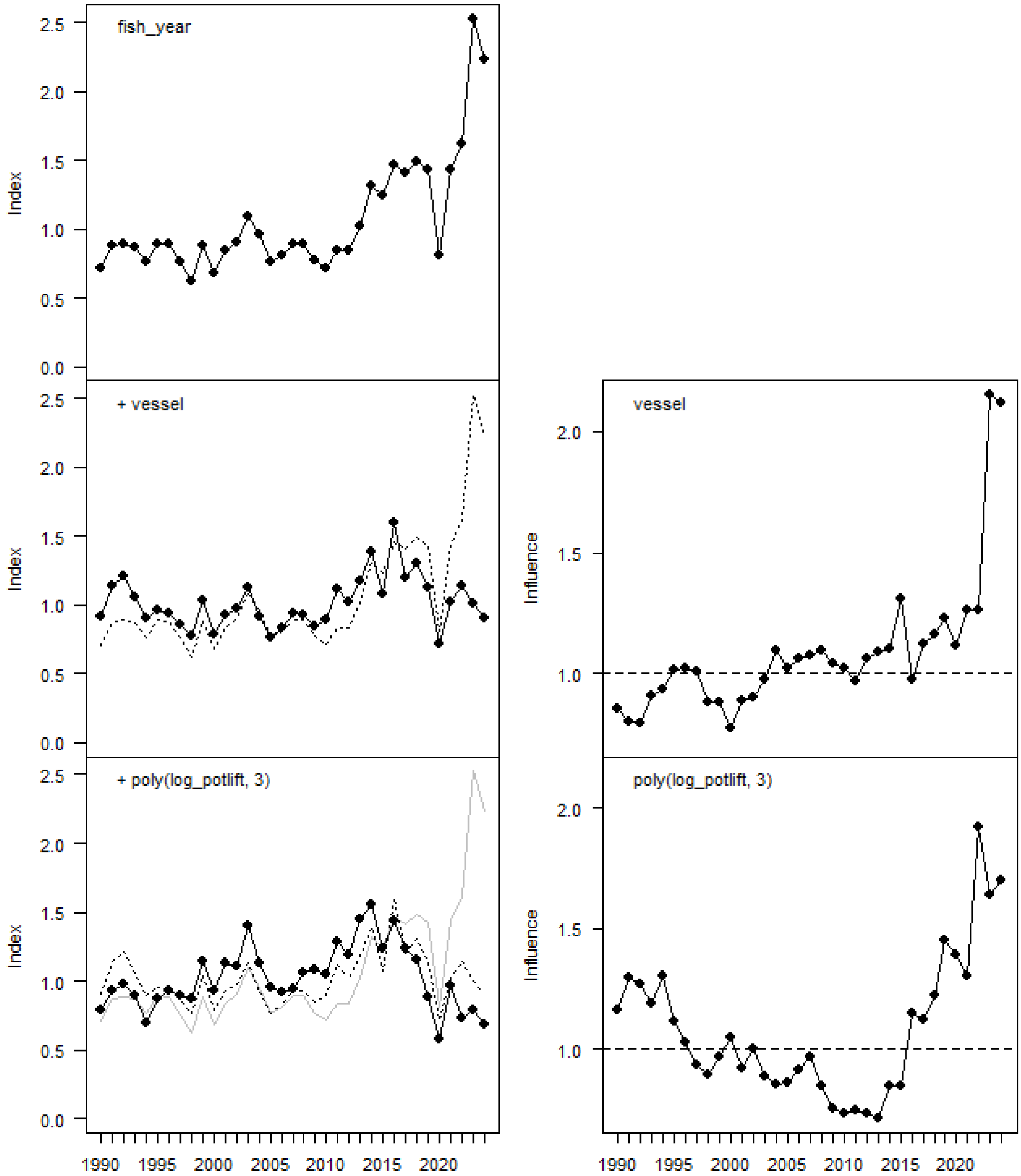
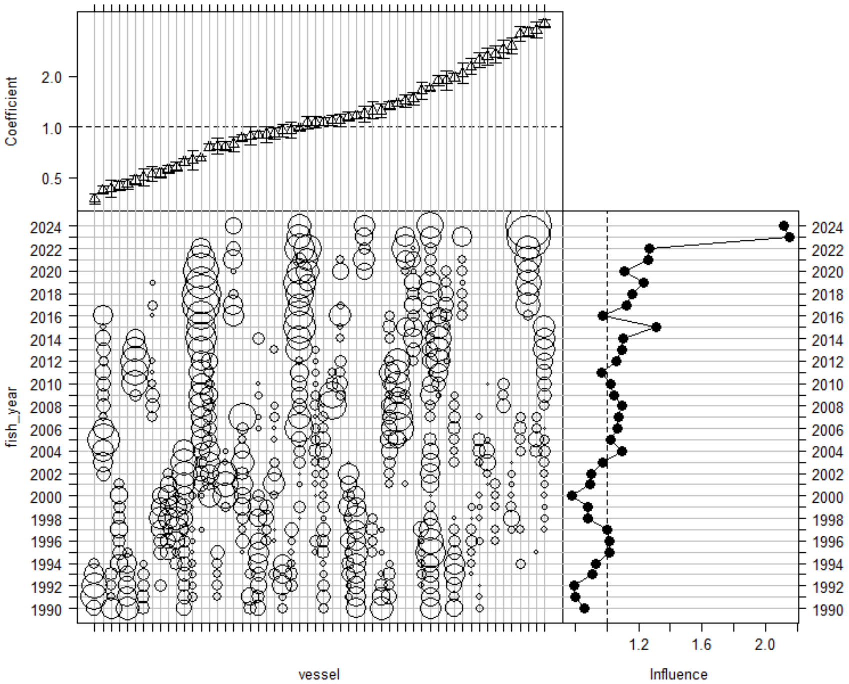


Figure 50: Swap-2 model (Statistical Areas 024 and 026 combined) blue cod standardised CPUE indices step plots (left) and influence plots for core vessels from 1989–90 to 2023–24. The step plots show how the indices change with the addition of predictor variables into the model. The influence plots show where the predictor variable influence the indices.



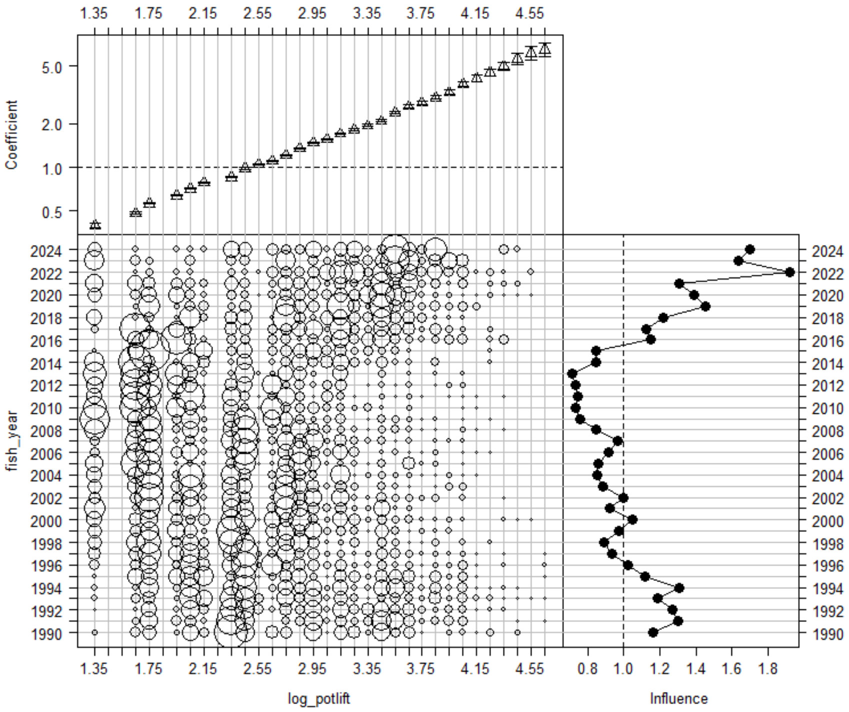


Figure 51: Swap-2 model (Statistical Areas 024 and 026 combined) blue cod standardised CPUE analyses coefficient-distribution-influence plots (CDI) for core vessels from 1989–90 to 2023–24. Plots are shown for each predictor variable included in the model. Effect by level of variable (top), distribution of variable by fishing year (bottom left), and cumulative effect of variable each year (right).

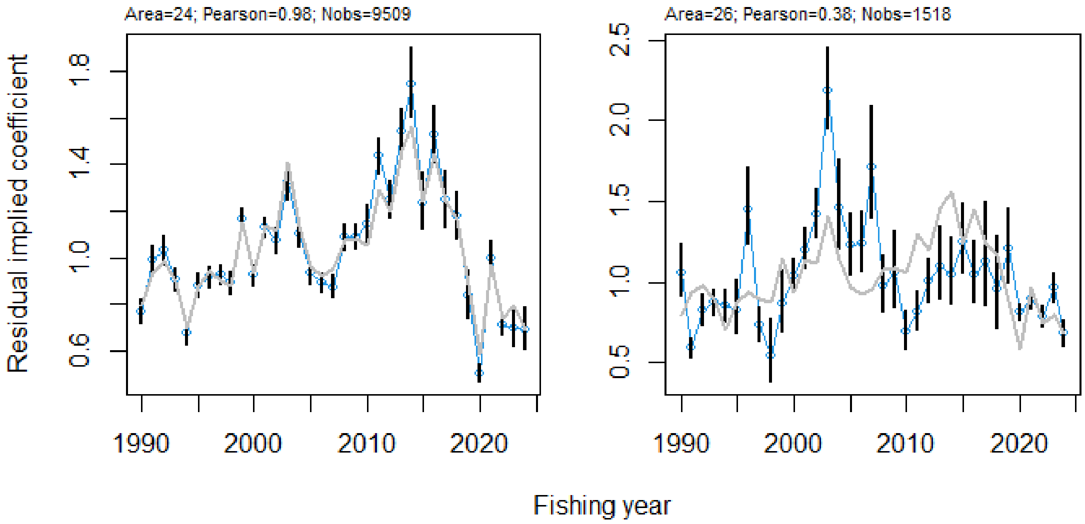


Figure 52: Residual implied coefficients for Statistical Areas 024 and 026 from the swap-2 CPUE model (blue line). The grey lines represent the standardised index. Error bars represent ± one standard error.

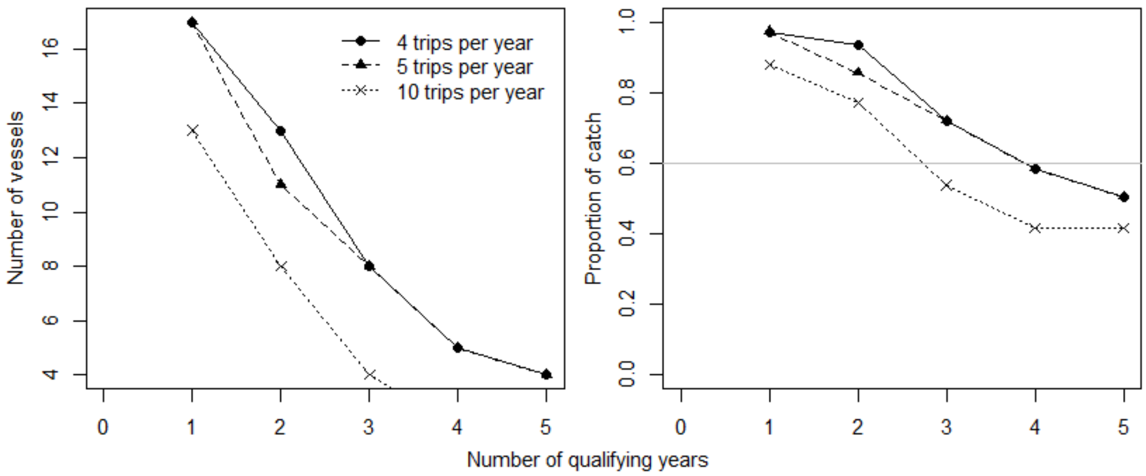


Figure 53: ERS-event model (Statistical Areas 024 and 026 combined) number of qualifying years versus the number of vessels (left panel), and proportion of blue cod catch retained (right panel), for a minimum of 4, 5 or 10 trips per year. The grey line indicates a 60% retention of the catch in the core vessel dataset. The criteria for selection of core vessels were a minimum of 2 qualifying years and 4 trips per year (see Table 2).

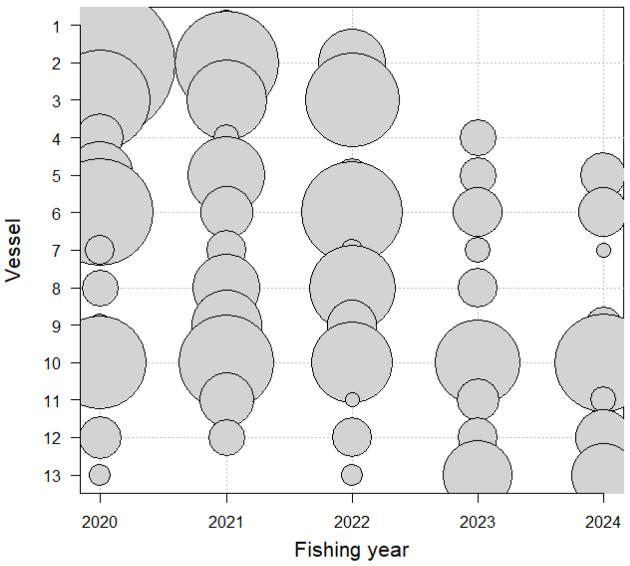


Figure 54: ERS-event model (Statistical Areas 024 and 026 combined) core vessel relative number of fishing events from 2019–20 to 2023–24. N= 13 vessels.

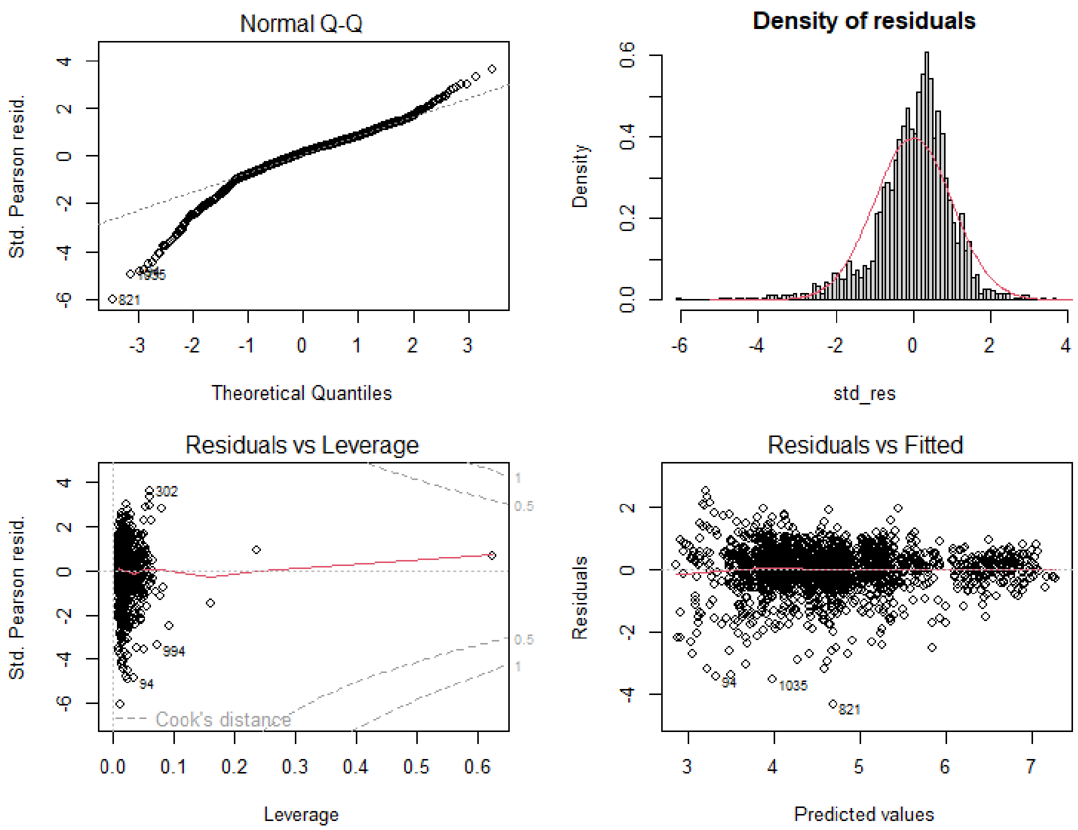


Figure 55: ERS-event (Statistical Areas 024 and 026 combined) diagnostic plots for the blue cod standardised CPUE analyses of blue cod catch from core vessels from 2019–20 to 2023–24. Q-Q plot of standardised residuals (top left), histogram of the standardised residuals compared to a normal distribution (top right), Pearson's residuals versus leverage plot (bottom left), and standardised residuals versus fitted values.

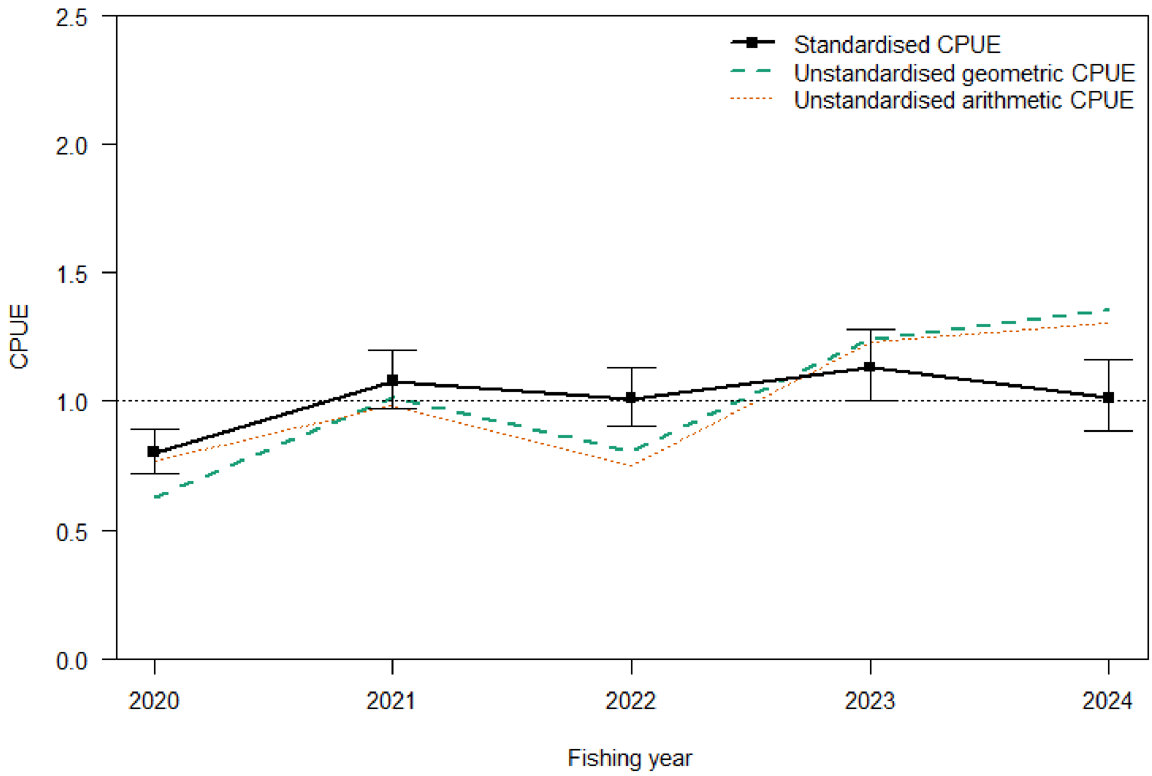


Figure 56: ERS-event model (Statistical Areas 024 and 026 combined) blue cod standardised canonical CPUE indices for core vessels from 2019–20 to 2023–24. The geometric and arithmetic unstandardized indices for core vessels are also shown. Error bars are 95% confidence intervals. Indices are scaled to have a mean of 1.0.

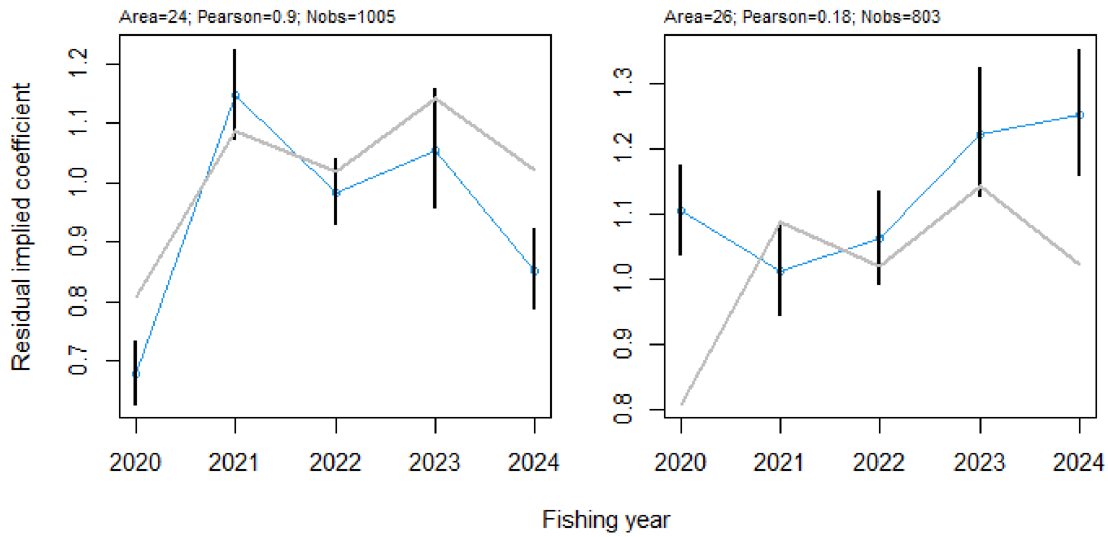


Figure 57: Residual implied coefficients for Statistical Areas 024 and 026 from the ERS-event model (blue line). The grey lines represent the standardised index. Error bars represent ± one standard error.

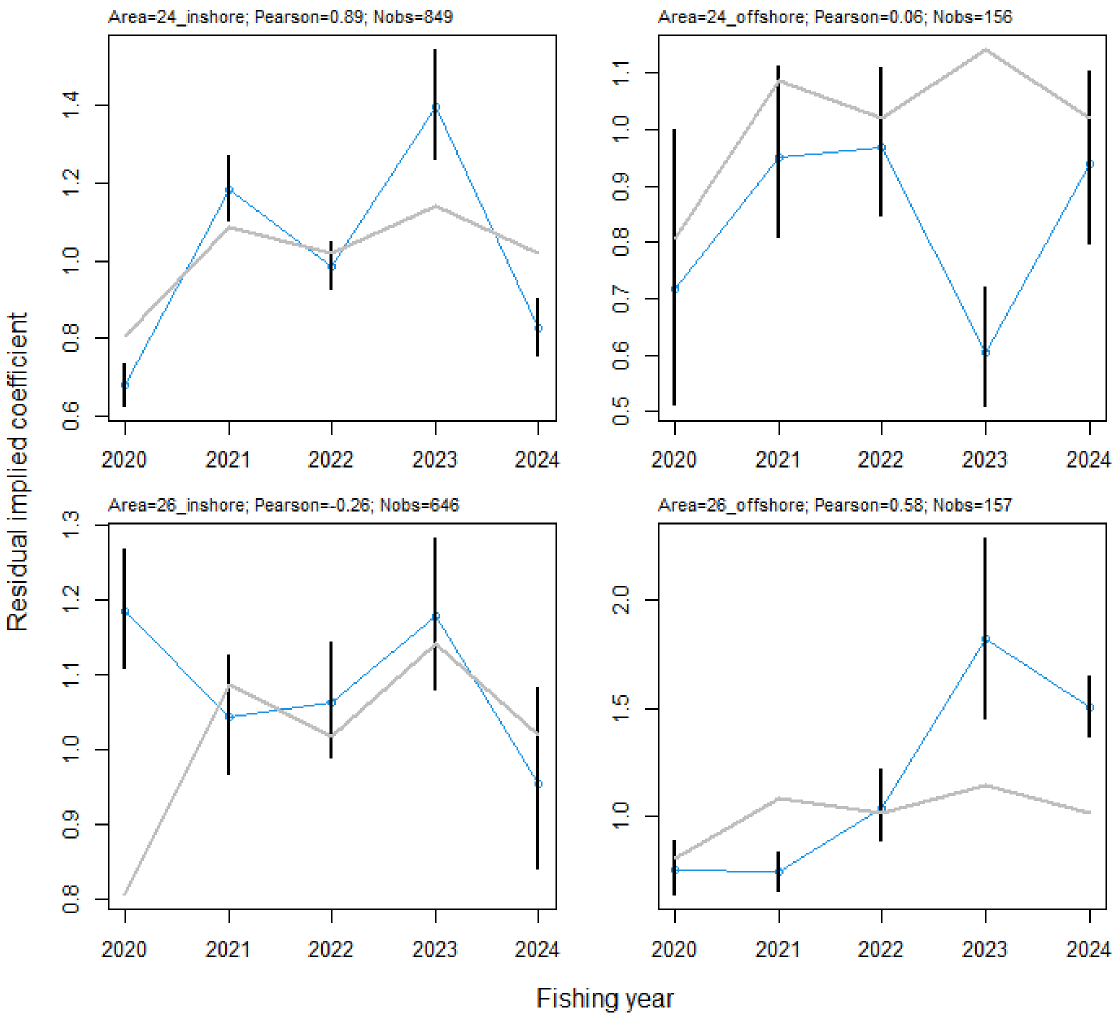


Figure 58: Residual implied coefficients for Statistical Areas 024-inshore, 024-offshore, 026-inshore and 026-offshore from the ERS-event CPUE model (blue line). The grey lines represent the standardised index. Error bars represent ± one standard error.

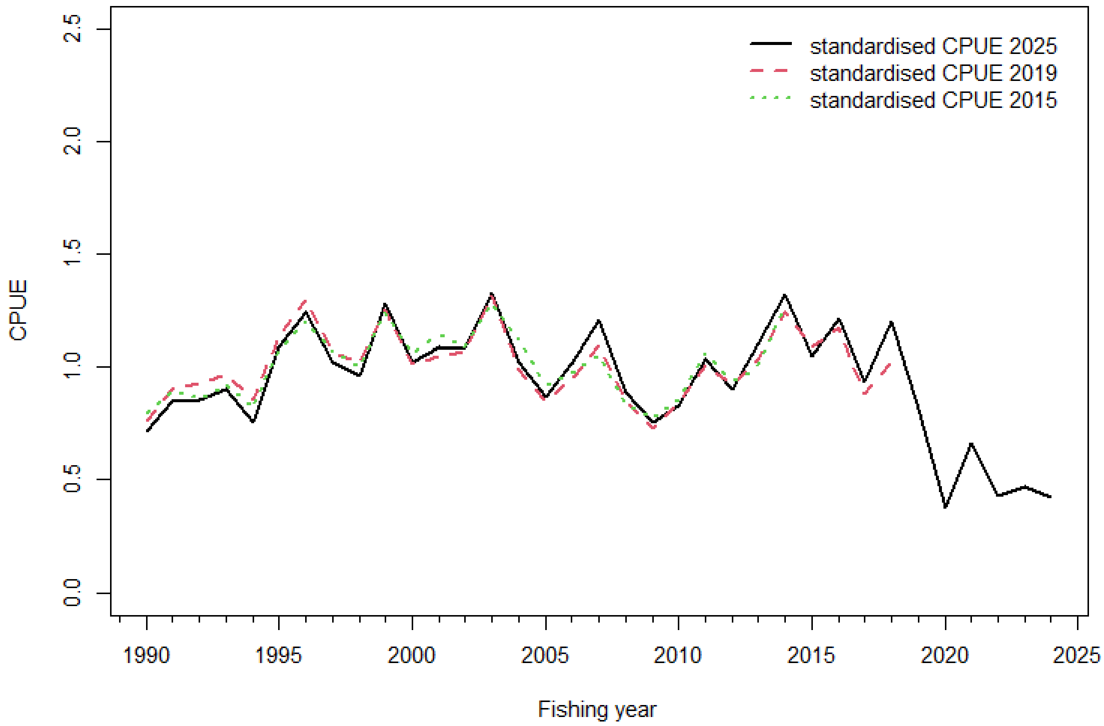


Figure 59: No-swap models (Statistical Areas 024 and 026 combined) of blue cod standardised canonical CPUE indices for core vessels. Indices are scaled to have a mean of 1.0. The current model is compared with those from 2015 (Starr & Kendrick 2015) and 2019 (Holmes et al. 2022).

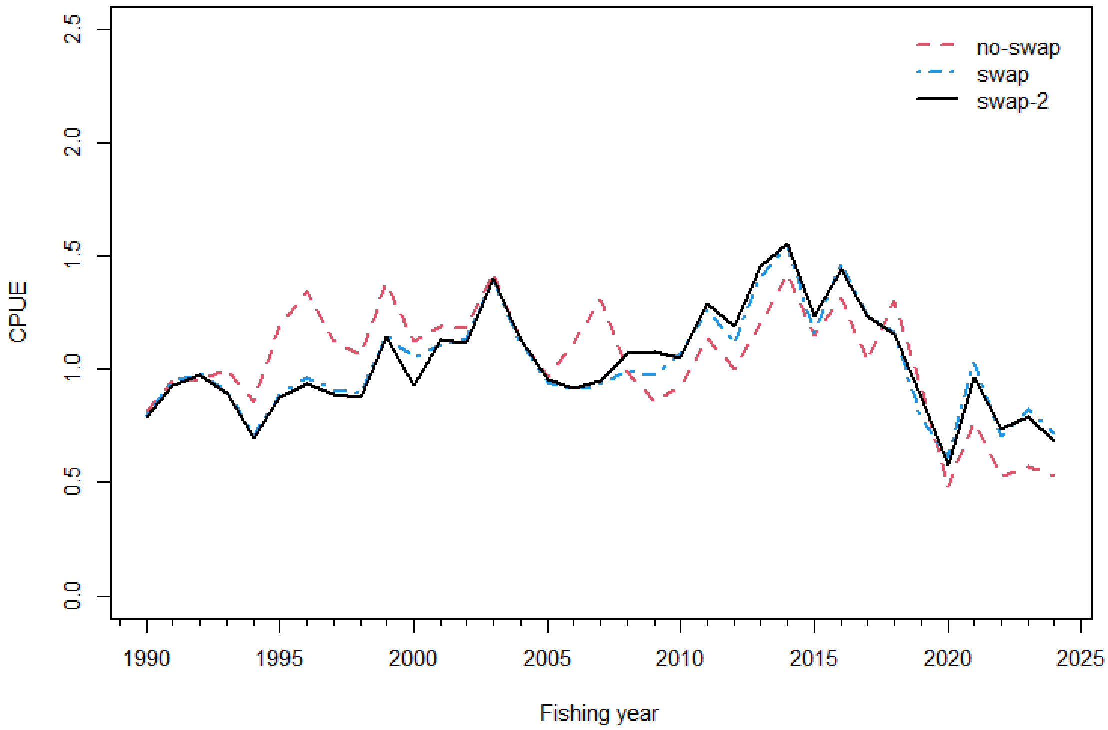


Figure 60: No-swap, swap, and swap-2 models (Statistical Areas 024 and 026 combined) of blue cod standardised canonical CPUE indices for core vessels from 1989–90 to 2023–24. Indices are scaled to have a mean of 1.0. See Table 1 for model descriptors.

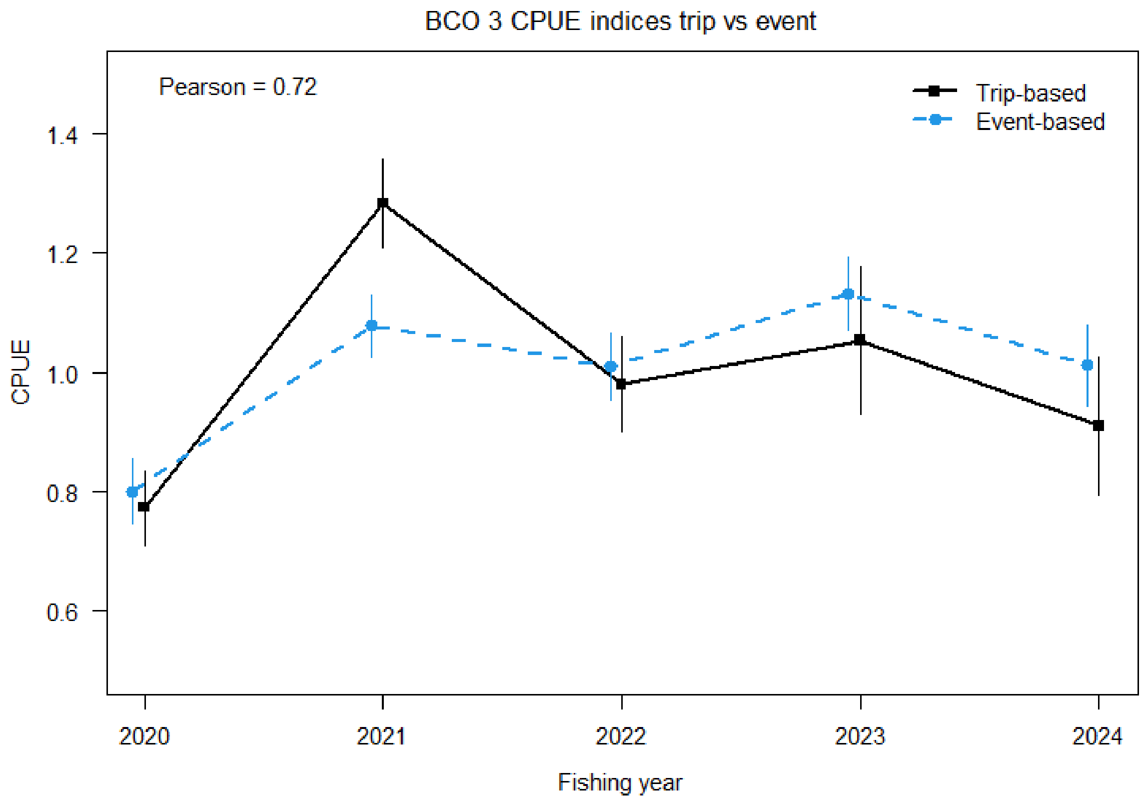


Figure 61: Trip based swap-2 model and ERS-event model (Statistical Areas 024 and 026 combined) of blue cod standardised canonical CPUE indices for core vessels from 2019–20 to 2023–24. Indices are scaled to have a mean of 1.0. See Table 1 for model descriptors.

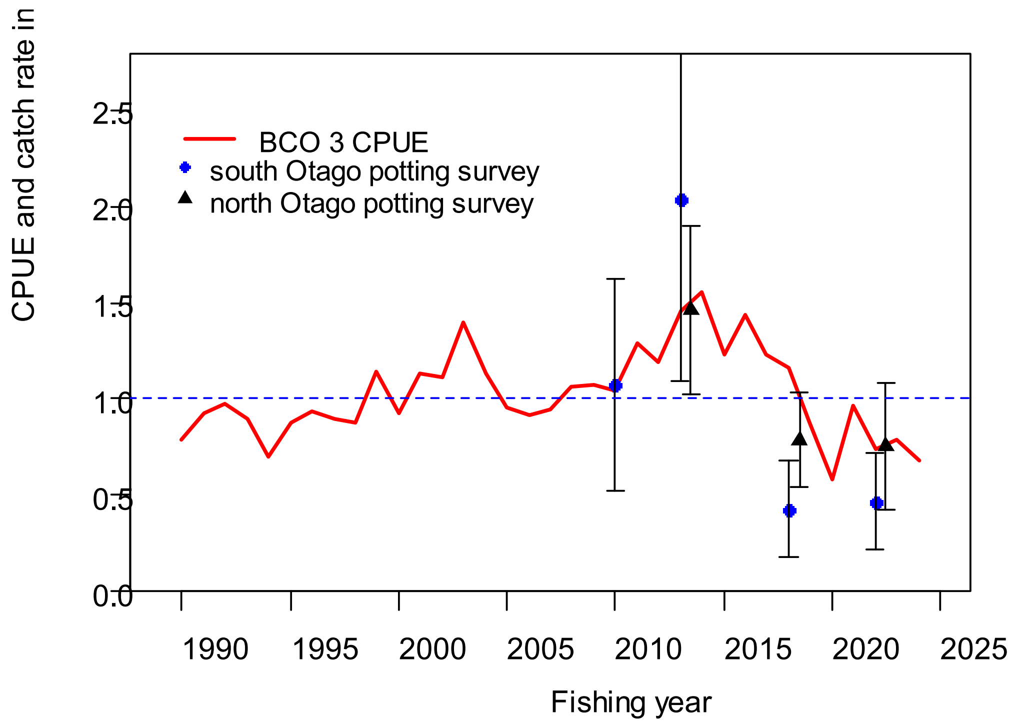


Figure 62: The swap-2 BCO 3 CPUE indices from 1989–1990 to 2023–24, and catch rates of blue cod from north and south Otago potting surveys with 95% confidence intervals. Both data sets are standardised to a mean of 1.0.

11. APPENDICES

Appendix A: Catch and effort data grooming summary

Landings data

- Best dates were determined for dubious landing dates by selecting the most appropriate date from the landing. (e.g., if landing date missing or logically flawed (e.g., before start date) use the end date.
- Landings data were imputed for missing records as follows:
    - If the green_weight was missing, then green_weight = conv_factor*unit_num*unit_weight.
    - If the conv_factor was missing it was imputed with the median of all other conv_factor reported within the same year and for the same state_code, (with a switch added so the user can choose to replace it with a value of 1)
    - Green_weights were adjusted for state_codes, e.g., DRE and HGU, i.e., green_weight = green_weight *1.95/conv_factor for DRE and green_weight = green_weight *1.85/conv_factor for HGU.
- Landings were excluded if their destination codes were:

B – Fish or fish product taken and stored during the period of a trip for subsequent use as bait for personal use.
D – Fish or fish product of a stock not managed under the QMS that are returned to the sea, abandoned in the sea, or accidentally lost at sea.
P – Fish or fish product placed in a holding receptacle in New Zealand fisheries waters.
Q – Holding receptacle on land.
R – Fish or fish product retained on board a vessel at the time of landing.
T – Transfer to another vessel.
J – Fish or fish products of a stock subject to the QMS that are returned to, or abandoned in, the sea in accordance with the requirements set out in section 72(5)(c)(i) to (iii) of the Act.
NP – Not provided.
Y – Fish below a minimum legal size, width or weight.
LF – Live fish that is placed in a holding container on land at the conclusion of a trip.
TT – Fish or fish product conveyed or sold to an LFR after being transferred from one vessel to another.
V – Fish or fish product taken by a scientific observer under Part 12 of the Act.
BS – Fish or fish product taken under section 81A of the Animal Products Act 1999, for the purposes of biotoxin sampling.

Multiple QMA areas – The threshold to determine whether a trip had fished in multiple or a single QMA was set to 0.95, so any trips with 95% or more of blue cod landed greenweight from one QMA was considered to be a single-trip_QMA. Trips that land catch from multiple QMAs were included and estimated catch was linked to landed catch by stock and by trip. The reason for using stock-trip instead of just trip is that a trip may cross boundaries of stocks and stock-trip is needed to allocate correctly the landed greenweights of those trips.

Effort data

- Effort data associated with zero landed catch was not kept for the characterisation, but retained for the CPUE analyses where it was taken from the prorated estimated catch.
- Effort records outside of the chosen stocks were determined from stat-areas and latitudes and longitude. These were insignificant and were retained.
- Some statistical areas can be split between two QMAs where the statistical area and QMA boundaries are not aligned, e.g., a very small part of Statistical Area 026 is in BCO 5 but most is within BCO 3. The manually edited stock link table was used to allocate stat-areas to QMAs.
- In the BCO 3 blue cod fishery, blue cod are often caught as bycatch in rock lobster pots which has its own fishery statistical areas. CRA statistical areas were converted to general statistical areas.

Prorating and linking landings to catch effort data

To get the landed catches for fishing events, the greenweights in the landing data were prorated proportionally to the fishing events in the effort data using the estimated catch collected at the day event level (CLRs) or multiple daily event level (ERS). For example, if the trip had a landing of 100 kg of blue cod from 5 fishing events with estimated blue cod catches of 20, 30, 10, 0 and 0 kg respectively. The 60 kg of estimated catch equates to proportions 0.33, 0.5, and 0.17 among the three events catching blue cod. These proportions are then applied to upscale the estimated catch to the landing, i.e. 100×0.33= 33 kg, 100×0.5=50 kg, and 100×0.17=17 kg.

Data roll-up – The level of aggregation (=roll-up) of prorated catch at the fishing event can be at the high resolution fishing event for recent ERS data, by day for CELR, or for both by trip. No roll-up was carried out for the characterisation data set, but the data were rolled up to unique trip-target species-statistical area for the standardised catch per unit effort input data set.

Data range checking and outlier treatment

Across all records and the major BCO 3 fishing methods (CP, BT, RLP and SN) the following range checking and outlier treatments were conducted:

- Check and exclude catch outliers for each fishing event record: calculate log(catch) and the median and standard deviation of log(catch) separately for all combinations of primary_method, form_type and vessel_id; and deem all records with catches greater than the median + 3.5 standard deviations as outliers, which were discarded (deleted).
- Check and impute cod potting (CP) effort (effort_total_num and effort_num) values separately for form_type CELR. This was done using plausible effort range(s) on the basis of expert knowledge and examination of the frequency distribution of effort. Max pots per trip was set at 100.
- Effort medians by vessel_ids were calculated and any effort values that were outside the specified ranges were replaced with their corresponding vessel medians. Where the imputed median was also out of range, the field was replaced with an NA, thereby excluded from CPUE analyses.

Appendix B. Data grooming summary outputs

Landing data file: ../1.Extract/16335_edit_15441A_4_landings_EDW.txt

Median conversion factors for the major landing state codes by fishing year in the landings data. 'NA': no landings. DRE=Dressed, EAT= eaten, FIL=Fillets skin on, GBP= Unknown, GGU=Gilled and gutted tail on, GRE=Green (or whole), GUT= Gutted, HDS=heads , HGT= Headed, gutted and tailed, HGU=headed and gutted, MEA=Fish meal, SKF=Fillets skin off, TRU=Trunked.

Fishing year	DRE	EAT	FIL	GBP	GGU	GRE	GUT	HDS	HGT	HGU	MEA	SKF	TRU
1990	NA	NA	1.9	NA	1.2	1	1.1	NA	1.8	1.5	NA	NA	1.8
1991	1.8	NA	1.9	NA	NA	1	1.1	NA	1.8	1.4	5.6	NA	NA
1992	1.7	NA	1.7	NA	NA	1	1.15	NA	NA	1.4	NA	2.6	NA
1993	1.7	NA	1.7	NA	NA	1	1.15	NA	NA	1.4	5.6	2.6	NA
1994	1.7	NA	1.7	NA	NA	1	1.15	NA	NA	1.4	NA	2.6	NA
1995	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
1996	1.7	1	1.7	NA	NA	1	1.15	0	NA	1.4	5.6	2.6	NA
1997	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
1998	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
1999	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
2000	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
2001	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	5.6	2.6	NA
2002	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
2003	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
2004	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
2005	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	5.6	2.6	NA
2006	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
2007	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	5.6	2.6	NA
2008	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
2009	1.7	NA	1.7	NA	NA	1	1.15	NA	NA	1.4	NA	2.6	NA
2010	1.7	NA	1.7	NA	NA	1	1.15	NA	NA	1.4	5.6	2.6	NA
2011	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	5.6	2.6	NA
2012	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	5.6	2.6	NA
2013	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	5.6	2.6	NA
2014	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	5.6	2.6	NA
2015	1.7	NA	1.7	0	NA	1	1.15	0	NA	1.4	5.6	2.6	NA
2016	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	5.6	2.6	NA
2017	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	5.6	2.6	NA
2018	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
2019	1.7	NA	1.7	NA	NA	1	1.15	0	NA	1.4	NA	2.6	NA
2020	1.7	NA	1.7	NA	NA	1	1.15	NA	NA	1.4	NA	2.6	NA
2021	1.7	NA	1.7	NA	NA	1	1.15	NA	NA	1.4	NA	2.6	NA
2022	1.7	NA	1.7	NA	NA	1	1.15	NA	NA	1.4	NA	2.6	NA
2023	1.7	NA	1.7	NA	NA	1	1.15	NA	NA	1.4	NA	2.6	NA
2024	1.7	NA	NA	NA	NA	1	1.15	NA	NA	1.4	NA	2.6	NA

- There are 2251 missing green_weights.
- Missing conv_factor is replaced with year.state.median
- There are still 1059 missing green_weights after calculation from conv_factor.
- Find those landings in file landings with missing green_weight.txt
- The landings with zero green_weight stay and those with NA excluded.

Effort data file: ../1.Extract/16335_edit_15441A_2_fishing_effort_EDW.txt

- There are 252 619 records in the effort data.
- 247 747 remain for trips existing in landings data.
- There are 785 trips in landings but not in effort data.
- Following stat areas are replaced with NA.

  Unknown G8 00A

- There are 164 152 records with start_stats_area_code to be located by lats and longs
- 308 records have no stats area code
- 245 218 records remain in effort data after allocating stock and fish_area

Estimated catches are loaded from ../1.Extract/16335_edit_15441A_3_est_catch_EDW.txt

- 201 blank catch in estimated catch table were replaced with 0
- There are 1334 events in effort but not in estimated catch data
- 1067 blank total_catch in effort data were replaced with 0
- 208 995 remain in effort data after linking to landing.
- There are 208 995 records in the prorated data.

Total landed catch, and that allocated to the effort data. There are 785 trips in landings but not in effort data.

Stock_year	Total	Allocated_catch	Prop allocted
BCO3_1990	128899.3	124782.3	0.96806
BCO3_1991	148676.8	140662.8	0.946098
BCO3_1992	159517.4	155060.4	0.972059
BCO3_1993	237847.6	229827.6	0.966281
BCO3_1994	161834.2	153979.2	0.951463
BCO3_1995	329372	322491	0.979109
BCO3_1996	232746.6	229053.1	0.984131
BCO3_1997	208558.7	206653.1	0.990863
BCO3_1998	199569.8	195217.5	0.978192
BCO3_1999	260959.7	250773.5	0.960966
BCO3_2000	174538.2	173141.5	0.991998
BCO3_2001	163266	155043.7	0.949639
BCO3_2002	158384.9	151050.8	0.953695
BCO3_2003	175967.3	174878.4	0.993812
BCO3_2004	175502.4	171955.6	0.979791
BCO3_2005	187348.4	180670	0.964353
BCO3_2006	201020.5	193170.7	0.96095
BCO3_2007	208449.8	202278.8	0.970396

BCO3_2008	212087.5	205025.9	0.966704
BCO3_2009	192584.8	187482.3	0.973505
BCO3_2010	186913.3	170898.8	0.914321
BCO3_2011	198498.2	184014.2	0.927032
BCO3_2012	174239	156201.9	0.896481
BCO3_2013	172491.8	159677.2	0.925709
BCO3_2014	164148.8	149532.6	0.910958
BCO3_2015	173532.9	165597.3	0.95427
BCO3_2016	176055.4	170029.2	0.965771
BCO3_2017	164940.5	162371.6	0.984425
BCO3_2018	178440.1	171247.9	0.959694
BCO3_2019	182265.3	177363.4	0.973106
BCO3_2020	193558.6	190684.6	0.985152
BCO3_2021	191522.7	184507.1	0.963369
BCO3_2022	145392.7	140633.8	0.967269
BCO3_2023	144229.5	142083.8	0.985123
BCO3_2024	145667.8	141679.7	0.972622

Appendix C: Standardised CPUE indices

Standardised lognormal indices and standard error (SE), arithmetic and geometric indices for the BCO 3 CPUE swap-2 model (Statistical Areas 024 and 026 combined) excluding trips with fewer than 4 pot lifts. The swap model takes the higher of *effort_total num* and *effort_num*.

Area/model	Fishing year	Lognormal index	SE	Arithmetic index	Geometric index
024-026	1990	0.787421	0.068025	0.515453	0.612642
024-026	1991	0.927222	0.066055	0.610553	0.659434
024-026	1992	0.974206	0.063233	0.600935	0.689963
024-026	1993	0.892341	0.057562	0.615085	0.733852
024-026	1994	0.694965	0.058103	0.561159	0.574366
024-026	1995	0.873571	0.055298	0.812449	0.814366
024-026	1996	0.933894	0.051873	0.826478	0.889544
024-026	1997	0.891592	0.054951	0.813313	0.855061
024-026	1998	0.87401	0.061099	0.730338	0.738866
024-026	1999	1.14119	0.054852	0.868834	0.948601
024-026	2000	0.928171	0.054183	0.594377	0.667694
024-026	2001	1.128356	0.052411	0.84405	0.95725
024-026	2002	1.112082	0.05658	0.838613	0.940487
024-026	2003	1.401207	0.060685	1.263424	1.314717
024-026	2004	1.129024	0.05883	1.06321	1.206384
024-026	2005	0.954755	0.054884	0.837086	0.943982
024-026	2006	0.917212	0.050062	0.889946	0.932851
024-026	2007	0.946332	0.053284	0.898493	0.961502
024-026	2008	1.065597	0.056672	1.03476	1.134149
024-026	2009	1.077862	0.052263	1.174946	1.121847
024-026	2010	1.047046	0.05916	1.305896	1.075927
024-026	2011	1.285144	0.05624	1.215516	1.247598
024-026	2012	1.191243	0.060871	1.391219	1.269251
024-026	2013	1.452126	0.068645	1.723548	1.603587
024-026	2014	1.555383	0.079291	1.644926	1.665038
024-026	2015	1.23286	0.073248	1.895465	1.574165
024-026	2016	1.438292	0.078108	1.19791	1.285702
024-026	2017	1.233047	0.085046	1.526496	1.265076
024-026	2018	1.158136	0.078318	1.537263	1.202509
024-026	2019	0.87844	0.088717	1.398098	0.935186
024-026	2020	0.579657	0.062717	0.705271	0.562931
024-026	2021	0.962665	0.074136	0.984889	1.078035
024-026	2022	0.734772	0.080077	0.711336	0.757798
024-026	2023	0.790109	0.12319	1.189044	1.438302
024-026	2024	0.682955	0.116396	1.052509	1.214222