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Tini a Tangaroa

Descriptive analysis of ling off the west coast South Island (LIN 7WC) up to 2021–22 and inputs for the 2023 stock assessment

New Zealand Fisheries Assessment Report 2023/51

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EXECUTIVE SUMMARY

Mormede, S.¹; Dunn, A.²; Webber, D.N.³ (2023). Descriptive analysis of ling off the west coast South Island (LIN 7WC) up to 2021–22 and inputs for the 2023 stock assessment.

New Zealand Fisheries Assessment Report 2023/51. 91 p.

Ling (*Genypterus blacodes*) are an important commercial species caught mainly by bottom trawls and bottom longlines and more recently by potting; they are found throughout the middle depths of New Zealand waters. High catches of ling were recorded in the late 1970s before dropping in the early 1980s and increasing again to a series high in the mid-1990s followed by lower and variable levels of catch since. Ling are managed as eight administrative Quota Management Areas (QMAs) with five of those reporting about 95% of the landings. There are at least five major biological stocks: the Chatham Rise, the Sub-Antarctic (including the Stewart-Snares shelf and Puysegur Bank), the Bounty Plateau, the west coast of the South Island, and Cook Strait.

This report summarises a characterisation of the ling stock off the west coast of the South Island (LIN 7WC) and fishery up to the 2021–22 fishing year. It provides an updated characterisation of the spatial structure of the stock, revised catch per unit effort (CPUE) indices for the longline fishery, and a summary of the input parameters for the 2023 stock assessment of LIN 7WC.

Both the ling Total Allowable Commercial Catch (TACC) and catches have been stable in most QMAs recently. The majority of ling has been caught in LIN 5, which was also the QMA where the catch is closest to the TACC, by a combination of bottom trawl and longline fleets. Recent catches of ling in LIN 7 (the west coast of the South Island and the western part of the Cook Strait) are close to the TACC. In 2023, Statistical Area 032 was reassigned from the Sub-Antarctic stock (LIN 5&6) to the west coast of the South Island stock (LIN 7WC) based on the continuity of catch locations.

The spatial-temporal structure of the stock was investigated using length, age, and sex ratio data. Multiple spatial and temporal splits were investigated and yielded similar patterns in the length frequencies to the previous split between longline and trawl fisheries. Therefore, the fishery stratification and scaled age frequency distributions developed in previous analyses were used in this update.

The length-weight relationship for ling in LIN 7WC was updated with the latest available data. The growth function was also updated, including using Bayesian inference, and the Bayesian von Bertalanffy growth estimates were used for the stock assessment.

The rolled-up longline standardised CPUE and commercial trawl standardised CPUE for ling in LIN 7WC and the trawl survey biomass index all showed similar patterns from 2000, with a decline from 2012. The trawl CPUE was higher than the longline CPUE prior to 2000. Both the longline and trawl CPUE indices, and the trawl survey biomass indices, were considered in the stock assessment.

The annual catches used in the 2023 stock assessment model were re-calculated to account for all fishing methods, the inclusion of Statistical Area 032, and the change of the definition to the model year to be the calendar year.

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1. INTRODUCTION

Ling (*Genypterus blacodes*) are an important commercial species targeted by both bottom trawls and demersal longlines, with a small but increasing use of pots. Adult ling are found throughout the middle depths of the New Zealand Exclusive Economic Zone (EEZ) typically in depths of 100 m to 800 m (Hurst et al. 2000). Ling are caught mainly by deepwater trawlers, often as bycatch in hoki (*Macruronus novaezelandiae*) target fisheries, and by demersal longliners (Mormede et al. 2021, 2022). Small quantities of ling are also caught by inshore trawls and set nets, and more recently by potting.

Ling are managed as eight administrative Quota Management Areas (QMAs), with five (LIN 3, 4, 5, 6, and 7) reporting about 95% of landings. There are at least five major biological stocks of ling in New Zealand waters (Horn 2005)—the Chatham Rise, the Sub-Antarctic (including the Stewart-Snares shelf and Puysegur Bank), the Bounty Plateau, the west coast of the South Island, and the Cook Strait.

Stock assessments have been carried out for ling for the biological stocks of the Chatham Rise (LIN 3&4), the Sub-Antarctic (including the Campbell Plateau and Stewart-Snares shelf comprising LIN 5 and the part of LIN 6 west of 176° E, labelled LIN 5&6), the Bounty Plateau (the part of LIN 6 east of 176° E, labelled LIN 6B), the west coast South Island (LIN 7 west of Cape Farewell, labelled LIN 7WC), and the Cook Strait (the part of LIN 2 and LIN 7 between latitudes 41° and 42° S and longitudes 174° and 175.4° E, labelled LIN 7CK). An administrative Fishstock (with no recorded landings) is also defined for the Kermadec Fisheries Management Area (FMA) (LIN 10) (Fisheries New Zealand 2020).

The ling biological stocks were defined using statistical areas as described in Table 1, Figure 1, and Figure 2. Starting in 2023, the LIN 7WC ling stock included Statistical Area 032, which was previously considered part of the Sub-Antarctic stock (LIN 5&6). Based on the continuity of catches of ling from LIN 7WC to Statistical Area 032, this area was included within LIN 7WC, rather than in LIN 5&6.

The catch and Total Allowable Commercial Catch (TACC) for ling in LIN 7 are shown in Figure 3. Note that the catch for the ling stock off the west coast of the South Island (LIN 7WC) includes part of the catch in LIN 5 (as Statistical Area 032) and excludes the part of LIN 7 which is part of the Cook Strait stock (LIN 7CK).

This report fulfils Specific Objective 1 of Project LIN2022-01. The overall Objective was “To carry out a stock assessment of ling (*Genypterus blacodes*) from the west coast of the South Island including estimating biomass and sustainable yields”. The Specific Objective 1 was “To complete a descriptive analysis of the commercial catch and effort data, trawl survey data, and observer data for ling off the west coast of the South Island (LIN 7)”. This report provides a descriptive summary of catch and effort data since 1989–90, a spatial-temporal analysis, updated biological parameters, and an analysis of the catch per unit of effort (CPUE) data for ling off the west coast of the South Island for the fishing years 1990–91 (denoted 1991) to 2021–22 (2022).

Table 1: Definition of the biological stocks for ling adapted from Ballara (2019). The change of Statistical Area 032 from the Southland stock to the ling stock off the west coast of the South Island in this analysis are noted in bold.

Area	Statistical Areas	Administrative stock	Assessment stock
Northern North Island	041–048, 001–010, 101–110, 801	LIN 1	—
East North Island	011–015, 201–206	LIN 2	—
East South Island	018–024, 301	LIN 3	LIN 3&4
Chatham Rise	049–052, 401–412	LIN 4	LIN 3&4
Southland	025– 031 , 302, 303, 501–504	Part of LIN 5	LIN 5&6
Sub-Antarctic	601–606, 610–612, 616–620, 623–625	Part of LIN 6	LIN 5&6
Bounty	607–609, 613–615, 621, 622	Part of LIN 6	LIN 6B
West South Island	032 –036, 701–706	Parts of LIN 7 & 5	LIN 7WC
Cook Strait	016, 017, 037–040	Parts of LIN 2 & 7	LIN 7CK

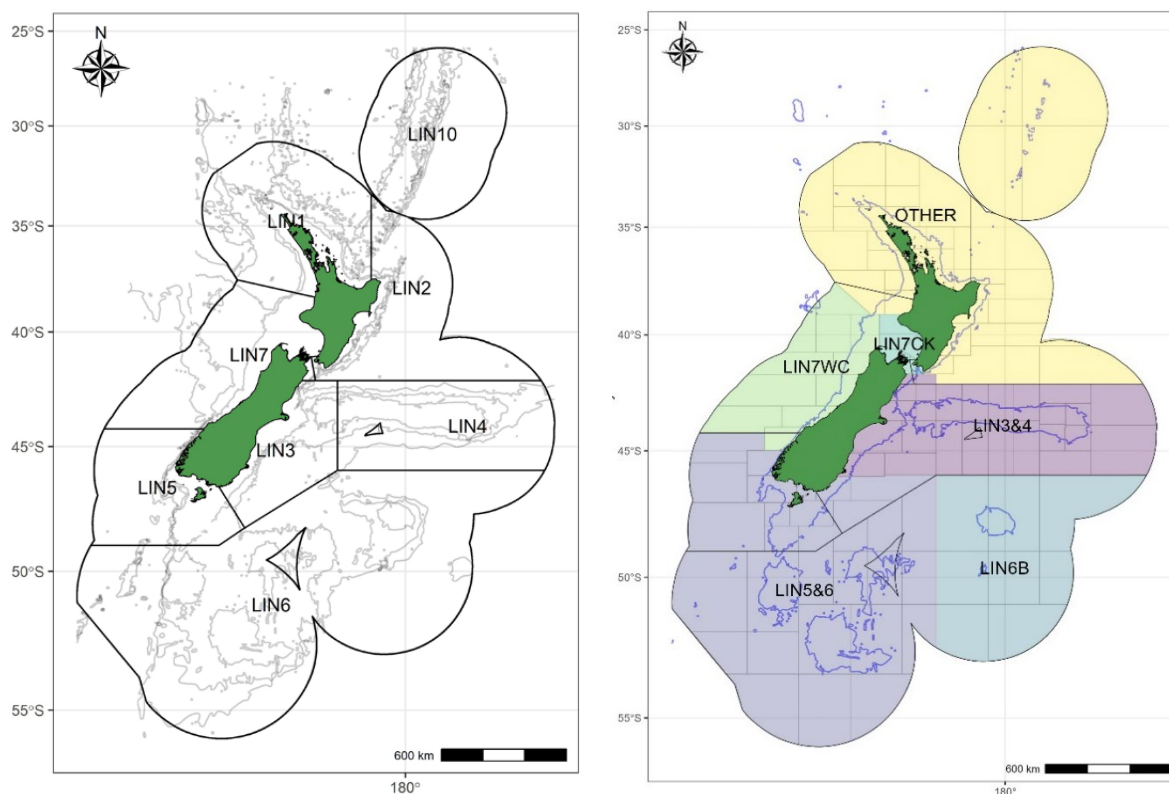


Figure 1: Quota Management Areas (QMAs, left) and biological stock boundaries (right) for ling, as used in this analysis. In 2023, Statistical Area 032 was reassigned from the LIN 5&6 stock to the LIN 7WC stock.

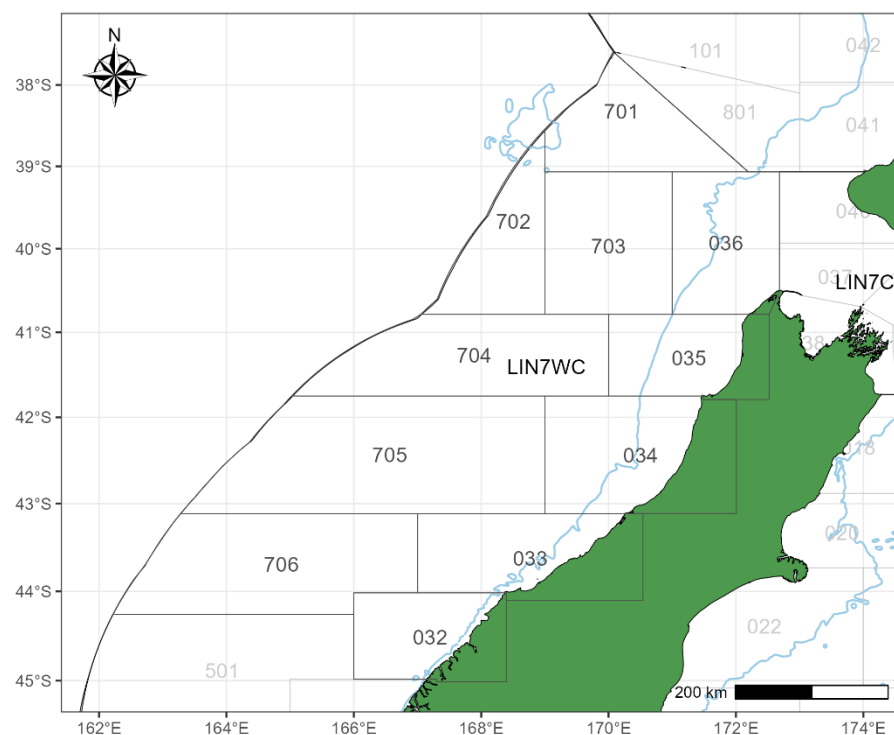


Figure 2: Statistical areas in the LIN 7WC region (labelled in black), and the surrounding statistical areas (labelled in grey).

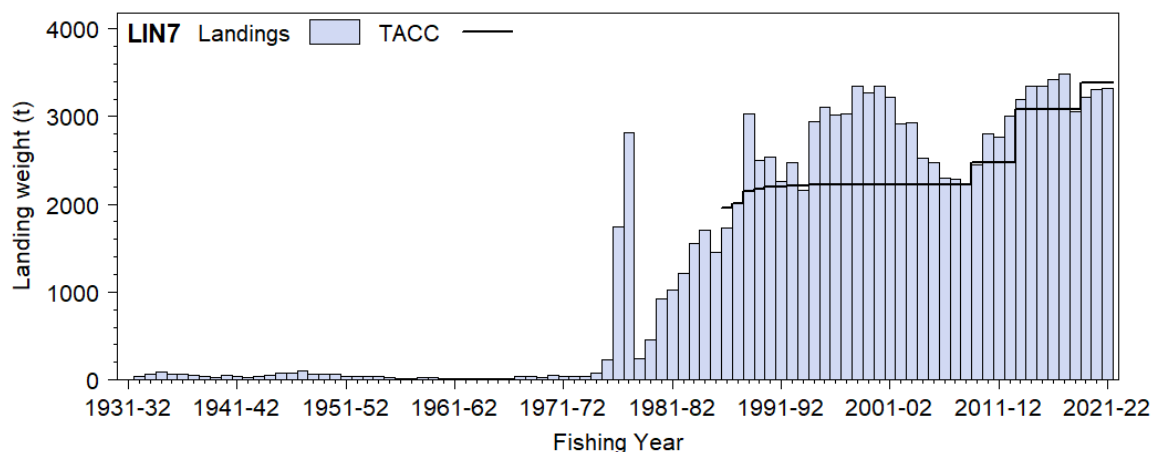


Figure 3: Annual reported catch of ling in LIN 7 (bars) and the TACC for ling (black line) for fishing years to 2021–22 (Fisheries New Zealand 2023).

2. SUMMARY OF THE LING FISHERY IN LIN 7WC

2.1 Available data

Data available for ling off the west coast of the South Island include catch and effort data, observer data from observed trips, and resource surveys.

Commercial catch and effort data were analysed to summarise and characterise the ling fishery and revise the CPUE indices for the stock. Catch and effort data and landings of ling have been misreported in the past; however, the amount of catch misreported off the west coast was low (Dunn 2003) and was therefore only included in the stock assessment as a sensitivity run (Mormede et al. in prep.).

Catch and effort data were extracted by Fisheries New Zealand for the period from 1st October 1989 to 30th September 2022 that included all available data at the date of the extract (15th November 2022) (REPLOG 14762). The data extract included all data from trips where hoki, hake (*Merluccius australis*), or ling were reported as either caught, processed, or landed and all fishing recorded on trawl catch, effort and processing returns (TCEPRs); trawl catch and effort returns (TCERs); catch, effort and landing returns (CELRs); lining catch and effort returns (LCERs); lining trip catch and effort returns (LTCERs); netting catch, effort and landing returns (NCELRs); electronic reporting system returns for all methods (ERS); and any high seas reports.

Observer data for ling from the Fisheries New Zealand observer sampling programme were also extracted and included all observer trips that reported hoki, hake, or ling as of 15th November 2022 and updated on 18th January 2023 (REPLOG 14067 and 14805). In addition, biological and length frequency information from these trips were also extracted, along with any otolith age readings associated with these trips.

Resource survey data (including data from the RV *Tangaroa* west coast South Island standardised trawl survey and any other research voyages that reported ling) were extracted, along with any biological, length frequency information, and associated otolith age readings from these trips (REPLOG 14672).

2.2 Data checks

Catch and effort data were corrected for errors using checking and imputation algorithms similar to those reported by Mormede et al. (2021) and implemented in the software package ‘R’ (R Core Team 2019). Individual tows were investigated, and errors were corrected using median imputation for start/finish latitude or longitude, fishing method, target species, tow speed, net depth, bottom depth,

wingspread, duration, number of events, and headline height for each fishing day for a vessel. Range checks were defined for the remaining attributes to identify potential outliers in the data. The outliers were checked and corrected with median or mean imputation on larger ranges of data such as vessel, target species, and fishing method for a year or month.

Fish biological stocks and statistical areas were assigned based on the corrected positions or the reported statistical area where no specific location was available. Longlining events were assigned to either manual baiting or autoline based on vessel name and, where available, year ranges provided by Fisheries New Zealand on 18th February 2021 (Dave Foster, MPI, pers. comm.). Vessels were assigned as having a meal plant or not, based on the vessel identifier number provided by Fisheries New Zealand on 2nd February 2021 (Dave Foster, MPI, pers. comm.), noting that no date range was available for this information. Tows were classified as bottom trawl (BT), midwater trawl (MW), and midwater trawl fished within 5 m of the seafloor (MB) for the purposes of this analysis.

Non-landed destination codes and end of year codes were removed from the landings data. Because ling trips often covered multiple QMAs, the estimated catch for each record in the catch and effort data was first scaled to the landings by trip and QMA, and then scaled to the Monthly Harvest Returns (MHR) by QMA prior to being used to determine the catch per year and fishery for stock assessment purposes.

2.3 Results

The TACC for ling has been stable in most QMAs since 2005; it was increased in LIN 5 in 2019 and 2023, and in LIN 7&8 in 2020 (Table A.1 of Appendix A). Most of the ling was caught in LIN 5, followed by LIN 6 and LIN 7, then LIN 3 and LIN 4, with little caught elsewhere. This trend has been stable over time (Table A.2 to Table A.4). Over the last few years, ling catches have been well below the TACC, apart from LIN 5 and LIN 7 where catches were at about the TACC in recent years. The forms ling was reported on have changed over time: from predominantly CELR and LCER to predominantly LTCER and TCEPR in the 2000s, and then to ERS forms starting in 2018 (Table A.5).

Catches of ling off the west coast of the South Island (LIN 7WC) when excluding Statistical Area 032 were similar to those reported by Kienzle (2021) up to and including the 2013 fishing year but different thereafter, as shown in Figure A.1 in Appendix A. The difference was due to the exclusion of some of the fishing methods from 2014 and highlighted the need to recalculate the entire catch series each year to identify and correct potential inconsistencies. The catches for the 2023 stock assessment, which included Statistical Area 032, were also plotted.

Ling were caught predominantly by bottom longliners targeting ling, followed by bottom trawlers and midwater trawlers targeting either hoki or ling; potting has become a more important method off the west coast of the South Island starting in 2021 (Table A.6 and Figure A.2 to Figure A.4). Catches of ling caught by longliners have increased over time, particularly since 2011. Ling have been caught throughout the year for longliners and predominantly between June and September for bottom and midwater trawls (Figure A.5). Trawl vessels are a mixture of smaller and larger vessels, whereas the most common vessel length for longliners is under 28 m (Figure A.6). Ling was predominantly the top species caught by longline vessels and was usually within the top three species caught by bottom trawl vessels (Figure A.7 and Figure A.8). Ling have typically been caught at bottom depths of between 250 and 750 m; the depths fished has spread slightly over time for bottom longlines but not for bottom trawls (Figure A.9).

The location of the catches differs slightly between the bottom trawl and longline fleets (Figure A.10 by statistical area, Figure A.11 and Figure A.12 at about 0.5° resolution but only showing locations with a minimum of three vessels as per the Fisheries New Zealand data confidentiality requirements), with Statistical Areas 032 and 033 being predominantly fished by bottom longlines and Statistical Area 035 predominantly fished by bottom trawls. To represent the expansion or retraction of the area fished over time, the area covered by the fishing fleet targeting 90% of the ling catches was investigated at the 0.1° cell, by summarising the number of those 0.1° cells where fishing occurred based on location of fishing

in any one year as well as the cumulative number of cells fished for the first time each year (Figure A.13). Both bottom trawl and longline fleets showed a continued increase in the number of new areas explored to date, consistent with the spatial plots (Figure A.11 and Figure A.12). The longline fleet showed a continued increase in the area fished in any year, consistent with the increase in annual total catches of ling (Table A.6), noting that only a third of longline records prior to 2008 had location information. The location of the research survey encompasses most ling catches by bottom trawl but only a small portion of the longline catches, highlighting that the survey does not adequately cover the longline fishing grounds (Figure A.14).

The effort characteristics of the bottom trawl and longline fleets have been relatively stable over time except for the depth and vessel length of longline fishing of the fishery which have increased over time (Figure A.15 and Figure A.16). The number of hooks reported per fishing event in LIN 7WC since 2020 has dropped dramatically (Figure A.16 and Figure A.17), with an associated increase in the number of fishing events recorded per vessel and per day (Figure A.18), but no change in the number of hooks set per day (not shown). This pattern was not seen in the other stocks. Further investigation attributed this change to the move from LTCER reporting forms, and the reporting of multiple sets within two nautical miles of each other as a single record, to ERS forms and the reporting of each set individually regardless of how close they were to other sets. This characteristic of the data precludes the standardisation of longline CPUE by event for this stock.

3. SPATIAL-TEMPORAL ANALYSES

Stratifying the catch into fisheries or areas for population modelling allows differences in age frequency distributions or sex ratios between the different parts of the population to be described; in particular, if there are changes in selectivity and relative catch between strata over time. By having different fisheries in a stock assessment model, different selectivities enable the assessment model to remove the appropriate components of the population, i.e., the appropriate number of fish at each age and sex observed as caught in the fishery, and estimate year class strength when possible.

The strata used in previous analyses of the LIN 7WC biological stock were derived from a 2005 analysis (Horn 2005) to define fisheries and, within each fishery, the strata for scaling length frequency distributions. These have been used since 2005 for LIN 7WC (Horn & Sutton 2019). LIN 7WC was split in two fisheries and the trawl survey as follows:

- bottom longline:
 - single stratum
 - catch, length, and otolith data from 1st May to 31st August
- bottom trawl:
 - three strata:
 - deep (≥ 498 m)
 - north shallow (< 498 m and latitude $< 42.42^\circ$ S)
 - south shallow (< 498 m and latitude $\geq 42.42^\circ$ S)
 - catch, length, and otolith data from 1st June to 31st September
- trawl survey
 - core strata cover the 300 to 650 m depth range

The time window used for the bottom trawl strata represents when most of the fishing occurs, but it is spread over the entire year for the longline fishery (Figure A.5). Furthermore, the observer coverage of this fishery has been limited over time, with few length data collected (Figure B.1 of Appendix B). The ling birth date was assumed to be 1st October (Richard Saunders, pers. comm., and Deepwater Working Group on 10th February 2022).

Modelling the spatial distribution of mean length or age and correcting for variables such as month and year (as in a CPUE standardisation), can help better understand the spatial and temporal patterns in fish

size/age. Looking at the data alone can result in biased conclusions, because spatial-temporal patterns of fish size/age could be different depending on when and where fishing occurred.

3.1 Methods

Tree regression

A series of tree regression analyses were done following a similar procedure to that used elsewhere; for example, to establish the fisheries in the toothfish Ross Sea Region stock assessment (e.g., Mormede & Parker 2018). This analysis was carried out for LIN 7WC and implemented in 'R' (R Core Team 2019) using the R package *rpart*. A tree regression of the mean length of ling per fishing event was carried out for bottom trawl and longline fleets separately, with potential parameters offered to the regression detailed in Table B.1 of Appendix B.

Spatial-temporal analysis

Integrated Nested Laplace Approximation (INLA) (Rue et al. 2009) was used to develop spatial-temporal models of fish length. A spatial mesh was developed using constrained Delaunay triangulation (Figure B.2). The mesh was limited to 1500 nodes (i.e., fewer nodes than data points where $N_{LF} = 63\,404$). Each node becomes an estimated model parameter, constrained by the stochastic partial differential equation (SPDE) underpinning the INLA spatial smoothers. Records with unknown sex were dropped, length was rounded down to the nearest integer, and three-year blocks were defined.

The length observations were fitted using normal distribution (the minimum length was well away from zero and models specified using the normal distribution run much faster in INLA). The variables year, month, sex, fishing method, depth, fishing event (as a random effect variable), and spatial structure were offered to models for both data sets. Spatial structure was either constant, sex-specific, or year-block specific. A limited set of plausible model structures was constructed. Both the deviance information criterion (DIC) and Watanabe-Akaike information criterion (WAIC) were used for model selection.

There is likely to be high correlation within fishing events (e.g., either tows or sets) in the length frequency data which was accounted for by including fishing event as a random-effect term within the model. It is common in tree-based regression to fit to the mean length per fishing event (as was done in this analysis); however, this approach ignores the variability of length within a fishing event.

Finally, the R package *ClustGeo* was used to derive spatial fishery strata using hierarchical clustering with geographic constraints (Chavent et al. 2018). This package implements a clustering algorithm that includes soft contiguity constraints. The algorithm requires two dissimilarity matrices (D0 and D1) and a mixing parameter alpha. D0 is a matrix containing the Euclidean distance between all data points, and D1 is a matrix containing the distance in space (in metres) between all data points. The alpha parameter (a real value between 0 and 1) stipulates the relative importance of the data (D0) compared to space (D1).

The value of alpha can be somewhat subjective and can radically change the clusters. However, a semi-objective method for finding a good starting value for alpha involves:

1. Defining the number of clusters (e.g., $K = 4$ clusters).
2. Running the clustering algorithm for evenly spaced values of alpha between 0 and 1 (e.g., $\alpha = \{0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0\}$).
3. Examining a plot of the proportion of explained inertia of the partitions in K clusters for each alpha value and deciding on an alpha value.

Evaluation of the candidate strata

The performance of the candidate strata was evaluated by calculating the scaled age frequency distributions of ling for these strata and plotting the change in catches and in sex ratio of these candidate

strata over time. The ideal stratum structure is one where the length frequency distributions and sex ratios remain constant over time and data are available for all strata.

3.2 Results

An initial investigation of the biological stocks was carried out. The timing of spawning in the different ling stocks around New Zealand was investigated using observer data. Using all years combined and gonad stages 3 (mature) or 4 (running ripe) as evidence of spawning, the ling stock off the west coast of the South Island is expected to spawn mostly from August to October (Figure B.3). This is consistent with previous analyses (e.g., Ballara 2019). Only ling in LIN 6B were found to spawn over a longer period and across calendar years (September to February) and therefore a model year equal to the calendar year was deemed adequate for all ling stocks and adopted by the working group in 2022 (Fisheries New Zealand 2022).

Tree regression analysis

Using mean length per fishing event and the tree regression method for bottom trawl and bottom longline separately, the data split was as follows:

- Longline fleet:
 - Depth shallower than 445 m
 - Longitude west of 169.7° E: mean length of 104 cm
 - Longitude east of 169.7° E: mean length of 108 cm
 - Depth deeper than 445 m
 - Latitude south of 41.66° S
 - October to January: mean length of 106 cm
 - February to September: mean length of 112 cm
 - Latitude north of 41.66° S: mean length of 121 cm
- Trawl fleet:
 - Latitude north of 42.45° S
 - August, September
 - Latitude south of 41.16° S: mean length of 89 cm
 - Latitude north of 41.16° S: mean length of 99 cm
 - October to July: mean length of 97 cm
 - Latitude south of 42.45° S
 - Longitude west of 170.5° E
 - Latitude south of 42.59° S: mean length of 92 cm
 - Latitude north of 42.59° S: mean length of 100 cm
 - Longitude east of 170.5° E: mean length of 114 cm

The spatial distribution of the strata based on the sex ratio in the measured catch is depicted in Figure B.4, noting that the strata are only spatially defined (only statistical area was selected in the model, fleet was not selected as an explanatory variable). The mean proportion of females in these strata were either 47 or 59%, with the highest proportion of females found in the north part of the stock and deeper.

The strata obtained through the tree regression analysis were generally similar to those used previously, although time of the year was an important component not investigated in previous analyses. Smaller fish were expected in August and September, and generally smaller fish and more females north of 42.5° S.

Spatial-temporal analysis

Both the DIC and WAIC suggested the most complex models with sex or time-block specific spatial effects were the most parsimonious models for explaining length (Table B.2). However, a simpler model was used to define spatially explicit fisheries strata because the more complex models would imply that the strata were also sex specific and / or varied over time. The use of these strata would require sex-specific and / or time varying selectivities be estimated within the stock assessment,

requiring additional complexity to be added to the assessment model that would be unlikely to affect model estimates or outcomes in any significant manner.

The length model suggests larger fish are in the shallow areas off the northern part of the west coast of the South Island and off the southern part of the same area (Figure B.5). It appeared that females and males had a similar spatial distribution (Figure B.6) and that the spatial distribution of fish varies throughout the year (Figure B.7), which is consistent with month being a factor in the tree regression analysis.

Clustering is driven by the parameter alpha, which represents the trade-off between the Euclidian distance D0 and the distance in space D1. Increasing values of alpha led to further consolidated clusters in space and increasing loss in the precision of the Euclidian distance (here differences in lengths between points). When clustering the length data, an alpha value of about 0.25 retained the highest level of explained inertia in D0 while maximising the explained inertia in D1 (Figure B.8). The clusters (for $K = 3$ spatial clusters since fishing method was selected) exhibited good spatial contiguity, but there were small components of non-contiguous spatial areas flecked inside the spatial clusters (Figure B.9). The alpha value of 0.3 was retained for this analysis as it presented slightly fewer non-contiguous areas. The clusters favoured similar splits to the tree regression analysis and to the previous analysis.

Evaluation of the candidate strata

Three potential fishery structures were investigated:

- Option 1. Status quo: one stratum for bottom longline and three strata for bottom trawl (deep, north shallow, and south shallow)
- Option 2. Based on the INLA analysis of length: bottom trawl or longline gear, and three clusters each (generally south, north shallow and deep combined, and north intermediate depths).
- Option 3. Based on the tree regression analysis: four strata for bottom longline (deep with an east / west split and shallow with a north / south split) and bottom trawl (north with a time split and south with an east / west split).

All fishery structure options presented a changing catch over time for each of the strata. The scaled length frequency distributions for the four options were calculated and are presented for the 2010 to 2020 fishing years in Figure B.10 to Figure B.12. The length frequency distributions were variable for all options regardless of the split, and no option could successfully split the mode of smaller fish caught in the bottom trawl fishery, even at stratum level.

3.3 Discussion

Because the resulting scaled length frequency distributions were mostly insensitive to the choice of these four options of stratification, the existing stratification was kept (bottom longline and bottom trawl with three strata, see above) and the age frequencies provided by Saunders et al. (2021) were used, providing continuity and comparison with previous analyses. This analysis highlighted that the makeup of this stock is highly complex, both spatially and temporally. The scaled age frequencies showed weak indication of year class strength progression (Figure B.13 to Figure B.15). This is partly attributed to the variability in the makeup of the stock and the limited sampling of the longline fishery.

4. UPDATE OF BIOLOGICAL PARAMETERS

4.1 Methods

Length-weight parameters

Length-weight parameters for ling used in the stock assessment were calculated in 2005 (Horn 2005). These were recalculated in 2017 and 2022 (Edwards 2017, Horn 2022) but were not used in the 2020 stock assessment model.

This analysis updates the length-weight relationship by applying a log-linear regression to the available length and weight parameters, where $Weight = a \cdot (length)^b$, to estimate the a and b parameters for each sex separately—assuming a bias correction resulting from the transformation from log-space for a . Plots of residuals were checked for any evidence of fitting issues or trends over time.

Growth models

Age-length parameters for ling used in the stock assessment were calculated in 2005 (Horn 2005) and parameterised as a von Bertalanffy curve. These were updated in 2017 and 2022 (Edwards 2017, Horn 2022) but were not used in the 2020 stock assessment model.

This analysis updates the age-length relationship by applying the von Bertalanffy models to all available age data for the west coast of the South Island using maximum likelihood estimation (MLE) and Bayesian inference. In the MLE estimation, the coefficient of variation (CV) was assumed constant as a function of mean length and set equal for males and females.

Bayesian growth models were developed using the R package *brms* which uses Stan (Stan Development Team 2020) to run Bayesian GLMs and non-linear models. Two different models were developed to describe the length L at age t : a von Bertalanffy model (von Bertalanffy 1938) and a Bayesian non-linear monotonically increasing mean length-at-age model. The von Bertalanffy model was defined as:

$$\bar{L}_i = L_i^\infty \left(1 - \exp \left(-k_i(t - t_i^0) \right) \right) + \varepsilon \text{ where } \varepsilon \sim N(0, c\bar{L}_i)$$

with:

$$\begin{aligned} L_\infty &\sim N(100, 100^2) \\ k &\sim N(0, 100^2) \\ t_0 &\sim N(0, 100^2) \\ \tau &\sim N(0, 100^2) \\ L_t &\sim N(\mu_t, \sigma^2) \\ \mu_t &= L_\infty(1 - e^{-k(t-t_0)}) \\ \sigma &= \tau\mu_t \end{aligned}$$

where L_∞ is asymptotic length (cm), k is the Brody growth coefficient, t_0 is the age at which the length is zero, μ_t is the expected length at age, and L_t is the predicted length at age. The mean length-at-age model was defined as:

$$\begin{aligned} \tau &\sim N(0, 100^2) \\ L_t &\sim N(\eta_t, \sigma^2) \\ \eta_t &= f(t) + f(m) \\ \sigma &= \tau\eta_t \end{aligned}$$

where $f(t)$ is a monotonic increasing term for each age, and $f(m)$ is a monotonic increasing term for each month. These two models were run independently for each sex (i.e., no shared parameters).

4.2 Results

Length-weight parameters

Length-weight data were collected only during trawl surveys and as such have a limited temporal coverage within each survey year as well as a limited number of samples (Figure C.1 of Appendix C). The length-weight parameters derived in this analysis were very similar to those reported previously and used in the previous stock assessments (Table C.1 and Figure C.2). There were very limited differences in the pattern of residuals over time (Figure C.3), indicating no clear inter-annual pattern of weight at length for ling in LIN 7WC.

Growth models

All data available in the 't.age' database provided by Fisheries New Zealand were used whether they were collected during the west coast South Island trawl surveys or by observers. Most of the data available were from July and August, the months when the survey took place and when a large proportion of the trawl fishery operates (Figure C.4).

The MLE von Bertalanffy models had poor residuals for ages 3 (Figure C.5). The patterns of residuals per cohort did not show any indication of annual variability in growth; the lower growth rates for very early and late years were likely confounded with the lack of a full range of fish for those cohorts (Figure C.6). The resulting MLE growth curve was almost identical to those derived by Edwards (2017, not shown), but departed from the growth curve calculated by Horn (2005) for old males in particular (Table C.2 and Figure C.7).

In the Bayesian growth model, the leave-one-out information criterion (LOO IC, Vehtari et al. 2017) suggested that the mean length-at-age model provided a more parsimonious fit to the data when compared with the Bayesian von Bertalanffy model. The improvement in model fit was observed when comparing the empirical distribution of the data with the posterior predictive distributions of simulated data for each model run, in particular for old males (Figure C.8 and Figure C.9). Further, the standardised residuals suggested that the mean length-at-age model fitted the data better across the full range of observed ages (Figure C.10 and Figure C.11).

The mean length-at-age model estimate of length captured the continued increase in length at age of older animals and did not drift implausibly high for the older fish when compared with either the MLE or Bayesian von Bertalanffy models (Figure C.12). This suggests that outputs from this mean length-at-age model (Table C.3) could be used for stock assessment purposes once Casal2 (Casal2 Development Team 2022) is able to accommodate such parameterisation, as it will capture the growth of larger males better than the von Bertalanffy parameterisation.

4.3 Discussion

The length-weight relationship derived using all data up to and including 2022 had very similar values for the parameters to those used previously. The new parameters were used for the 2023 stock assessment and updated in the ling plenary document (Fisheries New Zealand 2023).

The growth curve obtained by the mean length-at-age models fitted better to the data than the two von Bertalanffy models, in particular capturing the continued growth of older males. The Bayesian von Bertalanffy parameterisation was used for the 2023 update of the stock assessment of ling in biological stock LIN 7WC as Casal2 (Casal2 Development Team 2022) does not currently support monotonic growth.

5. CPUE ANALYSES

5.1 Methods

Trawl CPUE

The standardised catch per unit effort used in the 2020 model used observer trawl catch and effort data because commercial logbook data prior to 1997 was likely to be unreliable to use to derive CPUE indices (Dutilloy 2021, Kienzle 2021). The observer coverage by day of year, latitude, and depth was likely an adequate representative sample (not shown). However, the observer data coverage under-sampled the small vessels (Figure D.1 of Appendix D) even though they represent about a quarter of the trawl catches for this stock (Figure A.6). Therefore, an alternative CPUE standardisation was carried out on commercial bottom trawl catch and effort data starting in 1997 using trips that targeted hoki, hake, or ling, rather than on observer bottom trawl catch and effort as was done previously.

The CPUE standardisation followed similar methods that have been used for other ling stocks (e.g., Mormede et al. 2021). The unit of effort used for the standardisation was the catch per fishing event (in kilograms). All explanatory variables offered to the models are detailed in Table D.1. Year was defined as calendar year to match the year definition to be used in the assessment model (Mormede et al. in prep.).

Details of the data selection for the bottom trawl CPUE indices are summarised in Table D.2 and were largely consistent with data used previously (Dutilloy 2021), in particular with regards to restricting the data to the June to September months when most of the trawl fishery operates. Because of the change over time in the reporting requirements, and in particular the number of species that require reporting (Figure A.7 and Figure A.8), fishing events where ling was not recorded in the top five species, or top five Quota Management System (QMS) species for ERS reporting, were assumed to have caught no ling; they were retained in the analysis but assigned a catch of 0 kg. This allows for comparability of the data reported over the entire time series. CPUE analyses were carried out on the ‘core’ fleet for each of the indices, aiming to keep at least 80% of the ling catch in each instance and cover the duration of the fishery with overlaps between fishing vessels over the entire time series (Figure D.2).

All the CPUE standardisations assumed a lognormal distribution for the positive catches and a binomial distribution for the probability of catch. The final model was obtained through the stepwise addition of parameters with highest deviance explained (r^2) until the deviance explained by any additional term was less than 1%. Model fits were investigated using standard residual diagnostics.

Bottom longline CPUE

The longline CPUE for ling off the west coast of the South Island (LIN 7WC) used to not be considered an adequate index of stock abundance (Dunn et al. 2013, Dutilloy 2021); the indices were thought to be biased to some extent as the fishery was likely to be targeting ling on clearly defined geological features using relatively short lines that could be accurately placed.

The assumption that longlines are set on specific features was tested using the R package *dbscan* (Hahsler et al. 2019, Hahsler & Piekenbrock 2022). Latitude and longitude were projected to equal area and then clustered using a minimum of five sets per feature and the radius of the nearest neighbour of 6 km, optimised using *kNNdistplot*. Sensitivities using a minimum of 10 sets per feature and / or the radius of the nearest neighbour of 3 km representing median longline length in that area were carried out and led to similar results. Results showed that 94% of effort and 95% of catch was concentrated in cluster 1 (Figure D.3), leading to the conclusion that longline fishing was unlikely to target discrete geological features, and therefore might be an adequate index of abundance of the stock. Furthermore, the longline fishery covers a much larger area than is covered by the trawl survey (Figure A.14) and therefore was deemed to index a larger portion of this stock than the trawl survey does.

Prior to the early 2000s, longline catch and effort data were mostly recorded daily on CELR forms, rather than individually for each set on other form types (Figure A.2). To obtain as much of a time series of longline CPUE as possible, all longline data that were available on a set-by-set basis were ‘rolled-up’ into daily equivalents by vessel, day, and statistical area (e.g., using the approach of Starr 2008, Starr & Kendrick 2016). Furthermore, the recent change in reporting processes has affected the reporting of sets in this fishery and makes the use of set-by-set data fraught (see discussion above and Figure A.17 and Figure A.18). The catch was assumed as the sum of all catches reported by each vessel in each day and statistical area and the number of hooks was assumed to be the total of the number of hooks set on each day in each statistical area.

All explanatory variables offered to the models are detailed in Table D.3. Because the longline fishery operates year-round (Figure A.5), data from all months were used. Details of the data selection for the bottom longline CPUE indices are summarised in Table D.4. Because of the change over time in the reporting requirements, and in particular the number of species that require reporting (Figure A.7 and Figure A.8), fishing events where ling was not recorded in the top five species, or top five Quota

Management System (QMS) species for ERS reporting, were assumed to have caught no ling; they were kept for the analysis but assigned a catch of 0 kg. This allows for comparability of the data reported over the entire time series. CPUE analyses were carried out on the ‘core’ fleet for each of the indices, aiming to keep at least 80% of the ling catch in each instance and cover the duration of the fishery with overlaps between fishing vessels over the entire time series (Figure D.4).

The longline CPUE standardisation assumed a lognormal distribution for the positive catches. There was a negligible number of longline sets with no ling catch, therefore a binomial model was not done for the standardised longline CPUE index. The final model was obtained by the stepwise addition of parameters with highest deviance explained (r^2) until the deviance explained by any additional term was less than 1%. Model fits were investigated using standard residual diagnostics.

5.2 Results

Trawl CPUE

An update of the observer trawl CPUE analysis carried out in 2020 (Dutilloy 2021) provided similar standardised CPUE indices to those previously calculated (not shown). As per the previous analysis, the CPUE indices showed a different trend to the survey biomass series, with the CPUE indices increasing during the 2013–2019 period when the survey biomass showed a decline. Because of this disagreement with the trawl survey indices and because the observer data did not adequately capture the trawl fishery of small vessels (Figure D.1), the CPUE indices of the observer trawl data were not likely to be representative of the fishery or the stock.

The combined CPUE trend for the commercial trawl fishery for ling off the west coast of the South Island (LIN 7WC) was markedly different to that obtained in 2020 for the observer trawl fishery (Dutilloy 2021) and had less variability. The indices obtained in this analysis were also consistent with the trend in the survey biomass series (Figure D.5).

The lognormal model explained 23% of the variance (Table D.5 and Figure D.6 to Figure D.13). Highest catch rates were obtained at depths of about 400 m, further south and east, and around midday. The effect of *effort height* was expected to be an alias for midwater vs. bottom trawls. The *vessel* and *effort height* parameters had the largest influence on the CPUE indices (Figure D.6). The implied trends by statistical area did not show obvious departures from the overall CPUE trend (Figure D.14).

The binomial model explained 27% of the variance (Table D.6 and Figure D.15). The parameter *method* was the most important predictor of the probability of capture, with bottom trawl having the highest probability of capture. The next most important parameter was the vessel identifier.

Bottom longline CPUE

The standardised lognormal CPUE indices for rolled-up bottom longline fishing for ling off the west coast of the South Island (LIN 7WC) were very similar to those calculated previously (Dutilloy 2021, not shown), and consistent with the survey biomass series (Figure D.16). It was also consistent with the commercial trawl CPUE indices obtained in this study but only since 2000; between 1997 and 2000 the trawl CPUE indices showed a large increase then decline, when the longline CPUE indices remained mostly flat.

The lognormal model explained 43% of the variance and three parameters were included additional to model year (Table D.7 and Figure D.17 to Figure D.21). No binomial model was carried out as almost all longline sets caught ling in the fishery. The *number of hooks* parameter had the largest influence on the standardised index; highest catch rates were obtained in September. The implied trends by statistical area showed limited departure from the overall standardised CPUE trend in Statistical Area 033; this was likely to be an artefact of sampling size as it was located in the middle of this stock and such trends were not seen in the other statistical areas (Figure D.14).

5.3 Discussion

The change from observer-only trawl CPUE to all commercial trawl CPUE led to CPUE indices that were more consistent with the trawl survey series and with the bottom longline CPUE indices from about 2000 (Figure D.16). All three series show a decline starting in 2012. The trend between 1998 and 2000 did differ markedly between the bottom longline and bottom trawl CPUE indices.

6. INPUTS INTO THE 2023 STOCK ASSESSMENT

6.1 Catches

Two fisheries were defined for the 2023 stock assessment: the trawl and longline fisheries. The pot fishery is increasingly important. There were no length data for the pot fishery in this region as there had been no observer sampling of ling on these trips, and for the purpose of the stock assessment it was added to the longline fishery, similar to the approach used for ling on the Chatham Rise (Mormede et al. 2023). In calculating total catches, the definition of the year was the calendar year.

The annual scaled-up catches per fishery and model year are summarised in Table E.1 of Appendix E. These were different from those used in the 2020 stock assessment (Kienzle 2021), as depicted in Figure A.1 and discussed above. The reasons for those differences are a combination of the omission of some fishing methods in previous analyses, the change in the definition of year, and the addition of Statistical Area 032 to the stock of ling off the west coast of the South Island that was introduced in this analysis.

6.2 Age frequencies

The commercial fishery age frequencies for the ling assessments are usually calculated as part of the Fisheries New Zealand middle-depths ageing project (e.g., Saunders et al. 2021). Because the fishery stratification assumed in the assessment models was similar to that used previously, the age frequencies reported by Ballara et al. (2022) were used. Progressions in year classes are shown in Figure B.15.

6.3 Indices of abundance

The trawl survey biomass and associated scaled age frequencies were used in the model. Because the trawl and longline fisheries covered different fishing grounds and the trawl survey only captured a small portion of the area covered by the longline fishery, both sets of CPUE indices were used in the stock assessment models (Table D.8).

7. POTENTIAL RESEARCH

In this analysis, catches from Statistical Area 032 were added to the ling stock off the west coast of the South Island based on the continuity of catches along the depth contour along Statistical Areas 032, 033, and 034. A further analysis of data available might be able to conclusively assign Statistical Area 032 to either the west coast of the South Island ling stock (LIN 7WC) or the Sub-Antarctic ling stock (LIN 5&6).

The potting fishery has been increasing since 2021. Observer length data and age readings are required to develop an age frequency and associated selectivity for this fishery.

Scaled age frequencies for the longline fishery are currently calculated based on data collected between May and August. However, most of the fishery and observer data collection happens at other times of the year. The sampling of length and ages and estimation of age frequencies should be re-evaluated.

8. FULFILLMENT OF BROADER OUTCOMES

Whakapapa links all people back to the land, sea, and sky, and our obligations to respect the physical world. This research aims to ensure the long-term sustainability of ling stocks, for the good of the wider community (including stakeholders and the public) and the marine ecosystems that ling inhabit. This project supports Māori and regional businesses, diversity and inclusion, and our research is inextricably linked to the moana from the work it carries out and the tangata whenua it supports.

As part of this project, the team has continued to build capacity and capability in fisheries science and stock assessment, its commitment to zero waste and carbon neutrality, environmental stewardship, and social responsibility.

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11. APPENDIX A – DESCRIPTION OF THE FISHERY

Table A.1: Ling TACC (in tonnes) per QMA by fishing year (from Fisheries New Zealand 2023).

Fishing year	LIN 1&9	LIN 2	LIN 3	LIN 4	LIN 5	LIN 6	LIN 7&8	LIN 10	Total
1987	200	910	1 850	4 300	2 500	7 000	1 960	10	18 730
1988	237	918	1 909	4 400	2 506	7 000	2 008	10	18 988
1989	237	955	1 917	4 400	2 506	7 000	2 150	10	19 175
1990	265	977	2 137	4 401	2 706	7 000	2 176	10	19 672
1991	265	977	2 160	4 401	2 706	7 000	2 192	10	19 711
1992	265	977	2 160	4 401	2 706	7 000	2 192	10	19 711
1993	265	980	2 162	4 401	2 706	7 000	2 212	10	19 737
1994	265	980	2 167	4 401	2 706	7 000	2 213	10	19 741
1995	265	980	2 810	5 720	3 001	7 100	2 225	10	22 111
1996	265	980	2 810	5 720	3 001	7 100	2 225	10	22 111
1997	265	982	2 810	5 720	3 001	7 100	2 225	10	22 113
1998	265	982	2 810	5 720	3 001	7 100	2 225	10	22 113
1999	265	982	2 810	5 720	3 001	7 100	2 225	10	22 113
2000	265	982	2 810	5 720	3 001	7 100	2 225	10	22 113
2001	265	982	2 060	4 200	3 001	7 100	2 225	10	19 843
2002	265	982	2 060	4 200	3 001	7 100	2 225	10	19 843
2003	400	982	2 060	4 200	3 001	7 100	2 225	10	19 978
2004	400	982	2 060	4 200	3 001	7 100	2 225	10	19 978
2005	400	982	2 060	4 200	3 595	8 505	2 225	10	21 977
2006	400	982	2 060	4 200	3 595	8 505	2 225	10	21 977
2007	400	982	2 060	4 200	3 595	8 505	2 225	10	21 977
2008	400	982	2 060	4 200	3 595	8 505	2 225	10	21 977
2009	400	982	2 060	4 200	3 595	8 505	2 225	10	21 977
2010	400	982	2 060	4 200	3 595	8 505	2 474	10	22 226
2011	400	982	2 060	4 200	3 595	8 505	2 474	10	22 226
2012	400	982	2 060	4 200	3 595	8 505	2 474	10	22 226
2013	400	982	2 060	4 200	3 595	8 505	2 474	10	22 226
2014	400	982	2 060	4 200	3 955	8 505	3 080	10	23 192
2015	400	982	2 060	4 200	3 955	8 505	3 080	10	23 192
2016	400	982	2 060	4 200	3 955	8 505	3 080	10	23 192
2017	400	982	2 060	4 200	3 955	8 505	3 080	10	23 192
2018	400	982	2 060	4 200	3 955	8 505	3 080	10	23 192
2019	400	982	2 060	4 200	4 735	8 505	3 080	10	23 972
2020	400	982	2 060	4 200	4 735	8 505	3 387	10	24 279
2021	400	982	2 060	4 200	4 735	8 505	3 387	10	24 279
2022	400	982	2 060	4 200	4 735	8 505	3 387	10	24 279
2023	400	982	2 060	4 200	5 208	8 505	3 387	10	24 752

Table A.2: Ling catch (in tonnes) by QMA and fishing year as reported on catch and effort forms.

Fishing year	LIN 1	LIN 2	LIN 3	LIN 4	LIN 5	LIN 6	LIN 7	LIN 10	Total
1990	83	562	1 433	509	2 103	1 026	2 424	0	8 167
1991	138	829	2 062	2 153	2 382	2 360	2 010	–	11 950
1992	183	672	2 101	4 346	3 674	3 239	1 875	0	16 119
1993	302	738	1 894	3 530	3 055	5 558	1 969	0	17 065
1994	289	636	1 842	3 701	3 121	3 248	1 844	–	14 722
1995	405	717	2 062	4 376	3 658	3 860	2 646	–	18 155
1996	311	782	2 453	4 085	4 731	3 804	2 474	–	18 748
1997	690	741	2 189	3 469	4 721	4 921	2 397	0	19 272
1998	339	770	2 240	4 229	4 303	5 511	2 506	0	20 147
1999	301	770	2 054	3 906	3 992	4 492	2 738	0	18 332
2000	366	778	2 188	3 969	3 834	5 391	2 614	0	19 146
2001	312	922	1 830	3 415	3 915	5 206	2 975	–	18 584
2002	277	801	1 779	3 217	3 774	5 416	2 614	–	17 882
2003	216	746	2 076	2 719	3 747	5 257	2 313	0	17 075
2004	200	817	1 605	2 385	4 052	5 698	2 446	–	17 204
2005	223	741	1 313	2 570	4 911	4 029	2 077	–	15 863
2006	289	702	1 341	1 663	4 519	2 250	2 016	–	12 819
2007	228	740	1 814	1 942	5 380	2 770	1 794	–	14 670
2008	359	690	1 604	2 306	5 196	3 275	1 899	–	15 344
2009	298	560	1 525	1 815	3 867	1 706	1 866	–	11 640
2010	354	506	1 524	1 844	3 882	1 494	1 987	0	11 593
2011	389	598	1 445	1 398	4 086	968	2 220	–	11 105
2012	353	428	1 076	2 016	4 291	1 287	2 071	–	11 523
2013	346	514	1 188	1 918	5 860	1 218	2 386	–	13 431
2014	365	553	1 218	2 041	4 945	2 061	2 531	–	13 713
2015	369	561	1 016	1 877	5 147	1 757	2 602	0	13 330
2016	388	599	1 160	2 267	4 647	1 290	2 741	–	13 093
2017	382	904	1 572	2 213	5 114	2 110	2 743	–	15 041
2018	378	1 006	1 914	2 375	5 204	3 183	2 713	–	16 776
2019	354	857	1 747	1 849	5 816	2 308	2 552	–	15 487
2020	348	640	1 449	1 601	5 255	2 867	2 782	–	14 944
2021	283	551	1 321	1 914	5 954	2 695	2 830	–	15 585
2022	327	494	1 022	2 324	5 965	2 661	2 918	–	15 711
Total	10 444	22 923	55 058	85 941	145 101	104 917	78 574	1	504 238

Table A.3: Ling catch (in tonnes) by QMA and fishing year as reported in MHR forms.

Fishing year	LIN 1	LIN 3	LIN 4	LIN 5	LIN 6	LIN 7	Total
1990	121	1 876	587	2 277	935	2 496	8 291
1991	207	2 410	2 420	2 291	2 845	2 534	12 708
1992	241	2 423	4 710	3 867	3 461	2 262	16 964
1993	253	2 247	4 100	2 546	6 504	2 475	18 125
1994	234	2 167	3 917	2 459	4 248	2 155	15 179
1995	261	2 654	5 072	2 558	5 477	2 946	18 967
1996	245	2 962	4 632	3 137	6 341	3 103	20 420
1997	313	2 976	4 087	3 438	7 510	3 024	21 348
1998	326	2 943	5 215	3 321	7 331	2 955	22 091
1999	208	2 706	4 642	2 937	6 112	3 345	19 949
2000	313	2 779	4 402	3 136	6 707	3 274	20 611
2001	296	2 330	3 861	3 430	6 177	3 352	19 446
2002	303	2 164	3 602	3 295	5 945	3 219	18 529
2003	246	2 529	2 997	2 939	6 283	2 918	17 912
2004	249	1 990	2 618	2 899	7 032	2 926	17 713
2005	283	1 597	2 758	3 584	5 506	2 522	16 250
2006	364	1 711	1 769	3 522	3 553	2 479	13 398
2007	301	2 089	2 113	3 731	4 696	2 295	15 226
2008	381	1 778	2 383	4 401	4 246	2 282	15 471
2009	320	1 751	2 000	3 232	2 977	2 223	12 503
2010	386	1 718	2 026	3 034	2 414	2 446	12 024
2011	438	1 665	1 572	3 856	1 335	2 800	11 667
2012	384	1 292	2 305	3 649	2 047	2 771	12 449
2013	383	1 475	2 181	3 610	3 102	3 010	13 761
2014	380	1 442	2 373	3 935	3 221	3 200	14 551
2015	374	1 325	2 246	3 924	3 115	3 344	14 329
2016	422	1 440	2 659	3 868	2 222	3 351	13 963
2017	404	1 808	2 565	4 051	3 323	3 428	15 579
2018	415	2 171	2 636	4 034	4 846	3 487	17 589
2019	383	2 016	2 044	4 596	3 706	3 059	15 804
2020	371	1 685	1 778	4 678	3 972	3 216	15 701
2021	319	1 489	2 129	4 949	3 916	3 308	16 109
2022	353	1 167	2 607	5 044	3 885	3 325	16 382
Total	10 480	66 775	97 007	116 228	144 988	95 528	531 007

Table A.4: Ling catch (in tonnes) by stock and fishing year as reported in catch and effort forms and scaled to MHR returns. Note LIN 7WC includes Statistical Area 032.

Fishing year	LIN 3&4	LIN 5&6	LIN 6B	LIN 7CK	LIN 7WC	OTHER	Total
1990	2 215	3 430	14	570	2 307	518	9 054
1991	4 644	5 218	34	719	2 375	703	13 691
1992	6 838	6 654	870	409	2 246	807	17 824
1993	6 020	8 207	1 162	414	2 359	925	19 087
1994	5 765	5 890	1 082	280	2 078	903	15 999
1995	7 543	7 666	455	366	2 876	1 345	20 250
1996	7 476	8 790	608	509	3 143	1 053	21 579
1997	6 850	10 526	434	565	3 100	1 205	22 679
1998	7 920	10 208	401	356	3 140	1 307	23 331
1999	7 233	8 383	596	444	3 520	922	21 099
2000	7 090	8 827	1 017	416	3 342	908	21 601
2001	6 056	8 443	1 139	480	3 447	994	20 560
2002	5 502	8 741	643	382	3 264	1 034	19 567
2003	5 275	8 298	1 029	483	2 960	865	18 910
2004	4 442	9 093	994	465	2 871	893	18 759
2005	4 236	9 115	48	461	2 536	789	17 187
2006	3 299	7 112	72	334	2 525	875	14 216
2007	4 001	8 329	256	281	2 318	917	16 101
2008	4 056	8 265	446	205	2 320	986	16 277
2009	3 608	6 074	232	154	2 235	837	13 140
2010	3 589	5 573	2	100	2 425	921	12 610
2011	2 947	5 242	55	172	2 882	1 038	12 337
2012	3 293	5 764	4	142	2 930	823	12 956
2013	3 460	6 730	4	190	3 101	856	14 339
2014	3 615	6 840	290	197	3 360	923	15 225
2015	3 387	6 940	38	182	3 508	948	15 003
2016	4 026	5 665	214	222	3 559	983	14 668
2017	4 155	6 345	815	285	3 773	1 233	16 604
2018	4 542	8 475	252	378	3 851	1 198	18 696
2019	3 855	8 000	222	278	3 271	1 122	16 747
2020	3 252	8 473	254	150	3 270	1 060	16 458
2021	3 505	8 190	637	113	3 451	893	16 790
2022	3 716	8 789	221	109	3 345	733	16 914
Total	157 411	248 293	14 541	10 808	97 688	31 519	560 259

Table A.5: Ling catch (in tonnes) for the LIN 7WC biological stock (including Statistical Area 032) by form type and fishing year as reported in catch and effort forms.

Fishing year	CELR	LTCER	ERS - Lining	TCEPR	TCER	ERS - Trawl	Other	Total
1990	693	0	0	1 625	0	0	0	2 318
1991	946	0	0	1 000	0	0	0	1 946
1992	1 150	0	0	712	0	0	0	1 863
1993	1 048	0	0	829	0	0	0	1 877
1994	1 025	0	0	757	0	0	0	1 782
1995	1 106	0	0	1 501	0	0	0	2 607
1996	1 374	0	0	1 226	0	0	0	2 600
1997	1 225	0	0	1 252	0	0	0	2 477
1998	1 192	0	0	1 482	0	0	0	2 674
1999	1 229	0	0	1 649	0	0	0	2 878
2000	1 178	0	0	1 486	0	0	0	2 664
2001	1 196	0	0	1 873	0	0	0	3 069
2002	858	0	0	1 784	0	0	0	2 642
2003	918	0	0	1 421	0	0	0	2 338
2004	815	0	0	1 573	0	0	13	2 401
2005	958	0	0	1 098	0	0	0	2 056
2006	788	0	0	1 261	0	0	2	2 052
2007	883	0	0	826	0	0	88	1 797
2008	115	894	0	612	245	0	43	1 909
2009	125	763	0	635	285	0	43	1 850
2010	26	840	0	730	317	0	47	1 960
2011	9	895	0	994	364	0	26	2 288
2012	13	834	0	924	347	0	22	2 141
2013	51	937	0	1 128	341	0	0	2 457
2014	54	1 132	0	1 121	333	0	22	2 661
2015	19	1 138	0	1 326	262	0	0	2 745
2016	16	1 149	0	1 346	340	0	40	2 890
2017	19	1 104	0	1 501	392	0	5	3 021
2018	18	1 160	0	0	342	1 475	7	3 002
2019	13	543	576	0	95	1 323	176	2 726
2020	0	5	1 462	0	0	1 357	24	2 848
2021	0	0	1 651	0	0	1 181	125	2 957
2022	0	0	1 516	0	0	1 232	193	2 941
Total	19 063	11 395	5 204	33 671	3 661	6 567	875	80 437

Table A.6: Ling catch (in tonnes) for the LIN 7WC biological stock (including Statistical area 032) by gear type and target species by fishing year as reported in catch and effort forms for the main gear types. Potting is defined as catches from the following forms: CP (cod pot), CRP (cray pot), OCP (octopus pot), POT, FP (fish pot), and RLP (rock lobster pot). Bottom trawl also includes midwater trawl within 5 m of the bottom.

Fishing year	Bottom trawl				Bottom longline		Midwater trawl		Potting		Other	Total
	LIN	HOK	HAK	Other	LIN	Other	HOK	Other	LIN	Other		
1990	58	578	1	92	149	1	1 044	0	0	0	393	2 318
1991	58	381	0	61	351	2	649	0	0	0	444	1 946
1992	94	400	24	126	608	25	263	0	0	0	322	1 863
1993	135	565	30	143	633	33	164	13	0	0	161	1 877
1994	30	537	30	84	679	21	178	11	0	0	212	1 782
1995	21	681	6	155	812	57	734	18	0	0	123	2 607
1996	16	672	10	124	977	12	612	6	0	0	173	2 600
1997	41	772	15	166	895	24	441	4	0	0	119	2 477
1998	8	835	16	82	880	33	679	10	0	0	130	2 674
1999	4	1 182	39	159	860	60	500	5	0	0	69	2 878
2000	13	1 044	12	100	685	62	637	15	0	0	97	2 664
2001	0	1 468	9	56	868	47	567	5	1	0	50	3 069
2002	8	1 456	19	45	649	9	391	3	0	0	63	2 642
2003	21	1 100	39	45	655	24	396	2	0	0	57	2 338
2004	31	1 235	50	46	658	12	331	2	0	0	36	2 401
2005	79	847	69	91	702	25	211	1	0	0	31	2 056
2006	70	980	158	75	547	14	167	1	0	0	40	2 052
2007	76	459	152	187	711	34	85	2	0	0	91	1 797
2008	197	305	227	111	938	71	17	0	0	0	42	1 909
2009	164	322	203	205	848	37	25	0	0	0	44	1 850
2010	213	516	124	154	838	27	39	1	0	0	48	1 960
2011	251	653	209	155	847	56	89	0	0	0	28	2 288
2012	173	731	124	127	809	39	114	0	0	0	22	2 141
2013	111	972	154	132	919	35	101	0	0	0	34	2 457
2014	107	887	144	116	1 146	44	197	0	0	0	18	2 661
2015	86	988	205	72	1 133	25	237	0	0	0	0	2 745
2016	105	1 028	99	146	1 114	35	307	0	16	0	40	2 890
2017	159	1 191	61	101	1 108	18	360	0	1	0	20	3 021
2018	110	1 172	35	54	1 135	28	341	0	13	0	114	3 002
2019	119	782	35	132	1 288	15	304	1	6	0	43	2 726
2020	348	589	29	140	1 398	69	227	0	0	0	47	2 848
2021	345	474	23	170	1 555	96	161	0	87	35	10	2 957
2022	291	573	14	118	1 464	52	234	0	192	0	3	2 941
Total	3 545	26 375	2 363	3 772	28 860	1 142	10 801	101	316	36	3126	80 437

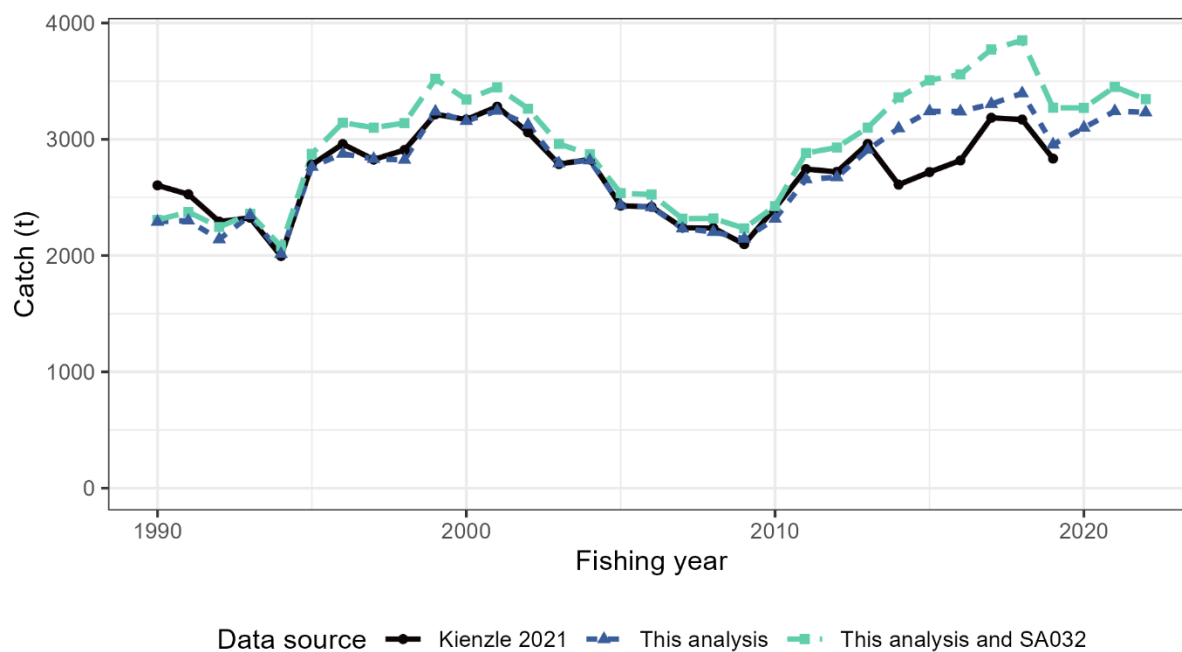


Figure A.1: LIN 7WC estimated ling catches as reported in the catch and effort forms and scaled to landings and MHR calculated in this analysis (with and without Statistical Area 032) and reported in the 2021 analysis (without Statistical Area 032, Kienzle 2021) by fishing year.

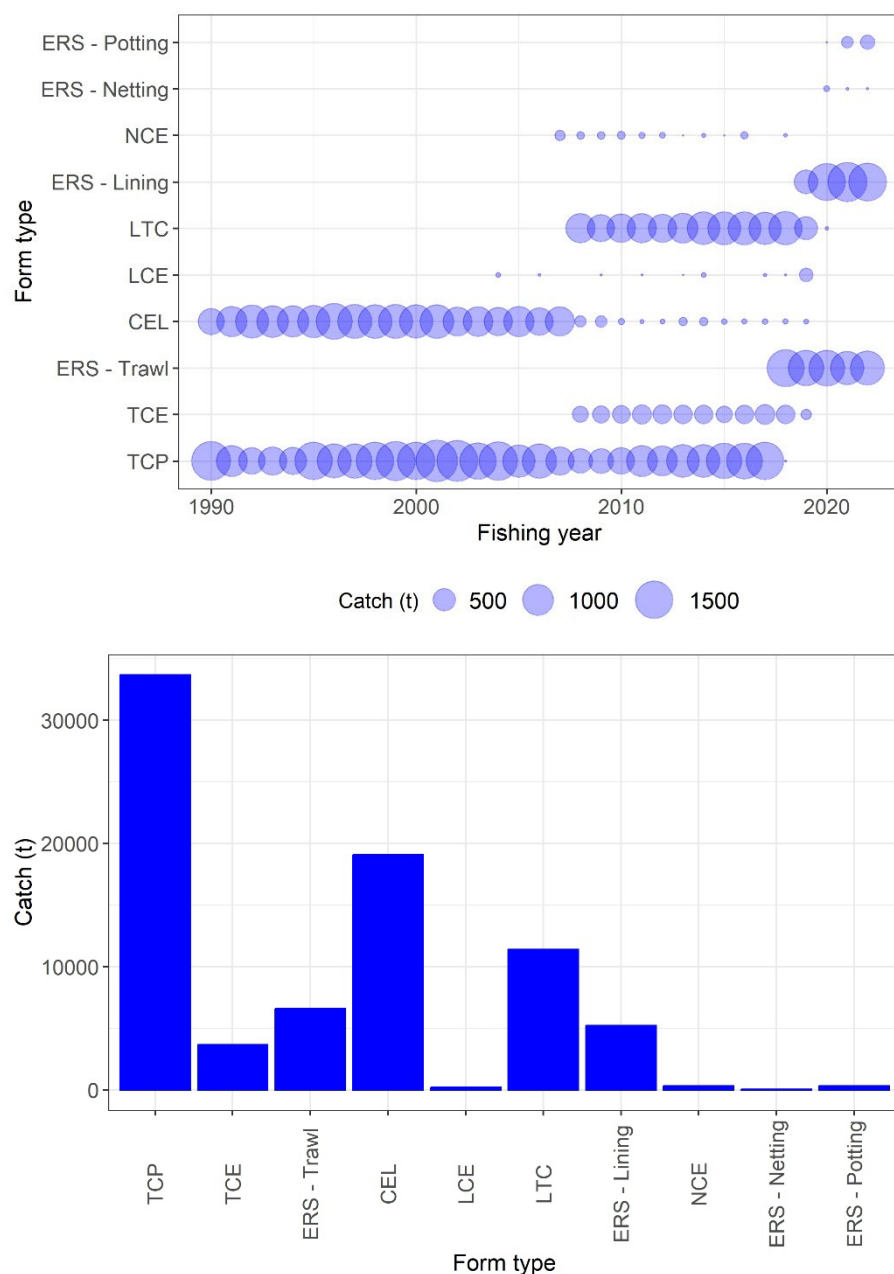


Figure A.2: LIN 7WC distribution of annual ling catch reported in catch and effort forms by form type: trawl catch effort and processing return (TCP), trawl catch effort return (TCE), electronic reporting system return (ERS), catch effort landing return (CEL), lining catch effort return (LCE), lining trip catch effort return (LTC), and netting catch effort return (NCE).

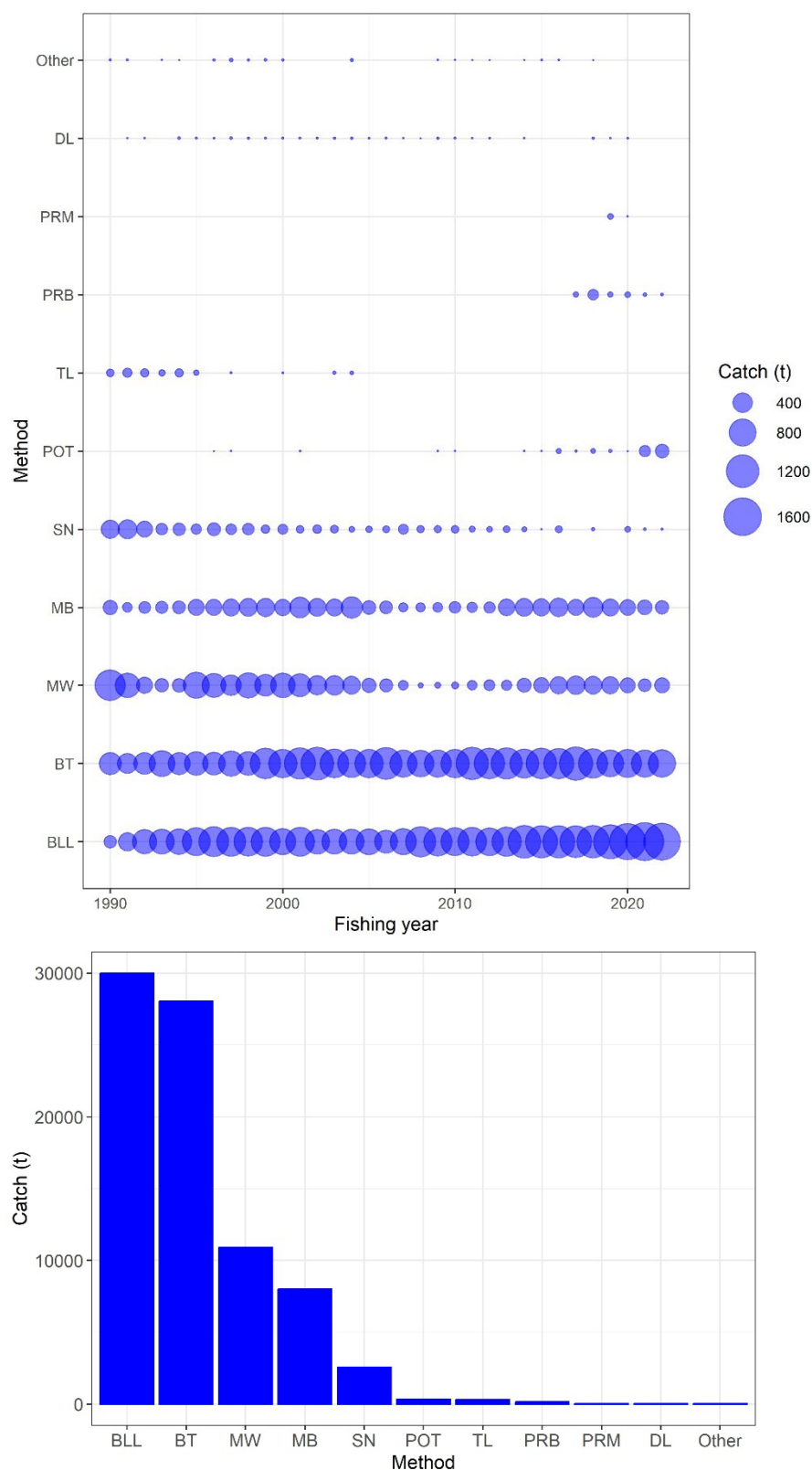


Figure A.3: LIN 7WC distribution of annual ling catch reported in catch and effort forms by method and fishing year. Method is bottom longlining (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis), set net (SN), all potting methods (POT – code defined within the analysis), trot line (TL), precision bottom trawl (PRB), precision midwater trawl (PRM), drop/Dahn line (DL), and all other codes (Other).

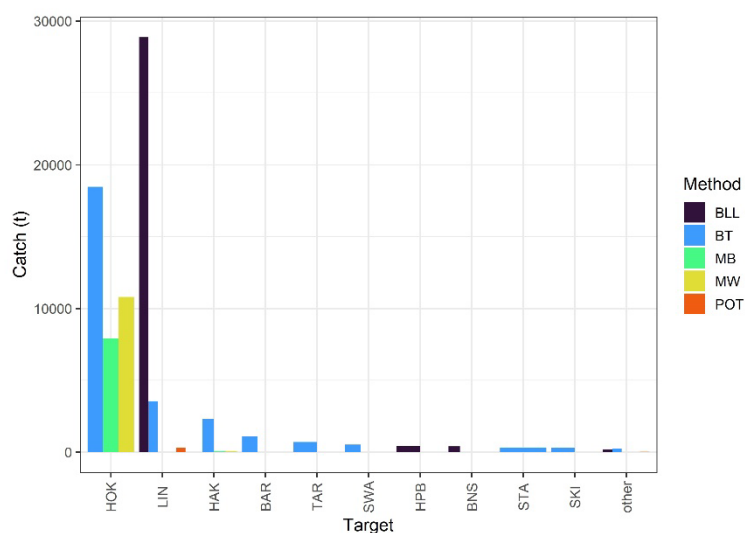
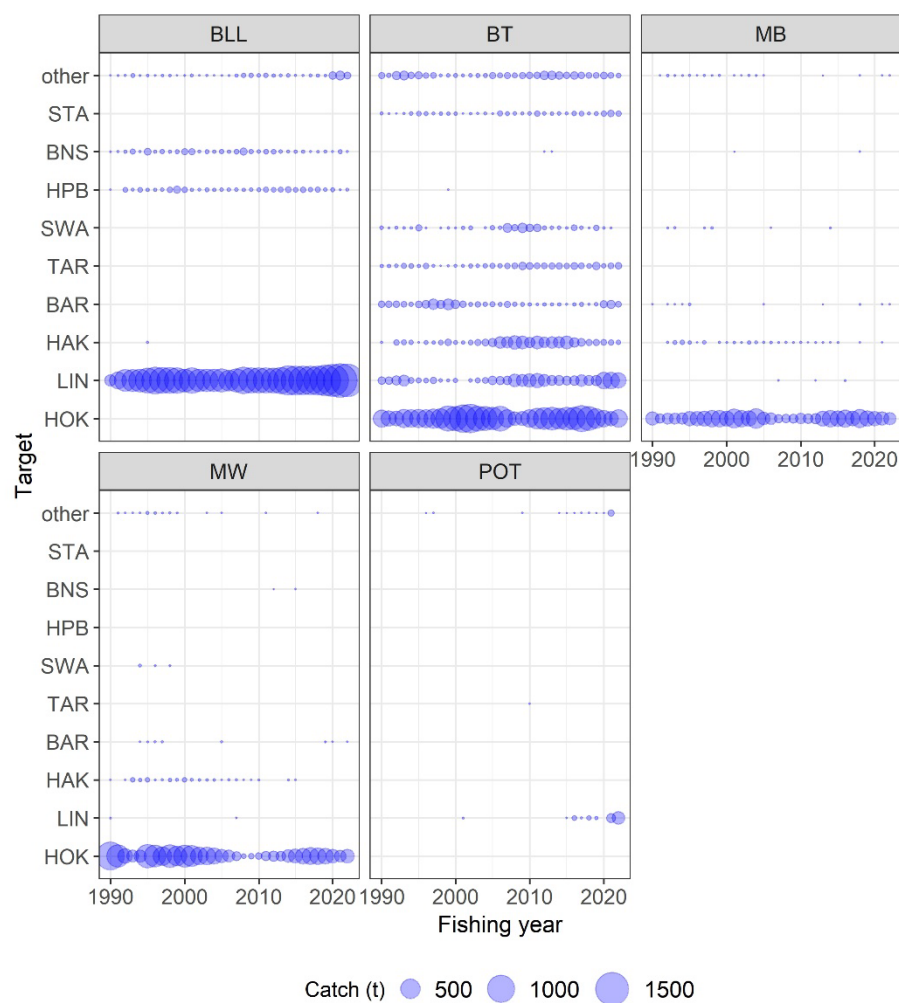


Figure A.4: LIN 7WC distribution of annual ling catch reported in catch and effort forms by target species for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawls within 5 m of the bottom (MB – code defined within the analysis above), and all potting methods (POT – code defined within the analysis) gears separately. Target is barracouta (BAR – *Thyrsites atun*), bluenose (BNS – *Hyperoglyphe antarctica*), hake (HAK), hoki (HOK), hāpuku and bass (HPB – *Polyprion oxygeneios*, *P. americanus*), ling (LIN), gemfish (SKI – *Rexea* spp.), giant stargazer (STA – *Kathetostoma* spp.), silver warehou (SWA – *Seriola punctata*), tarakihi (TAR – *Nemadactylus macropterus*, *Nemadactylus* sp.), and all other targets combined (other).

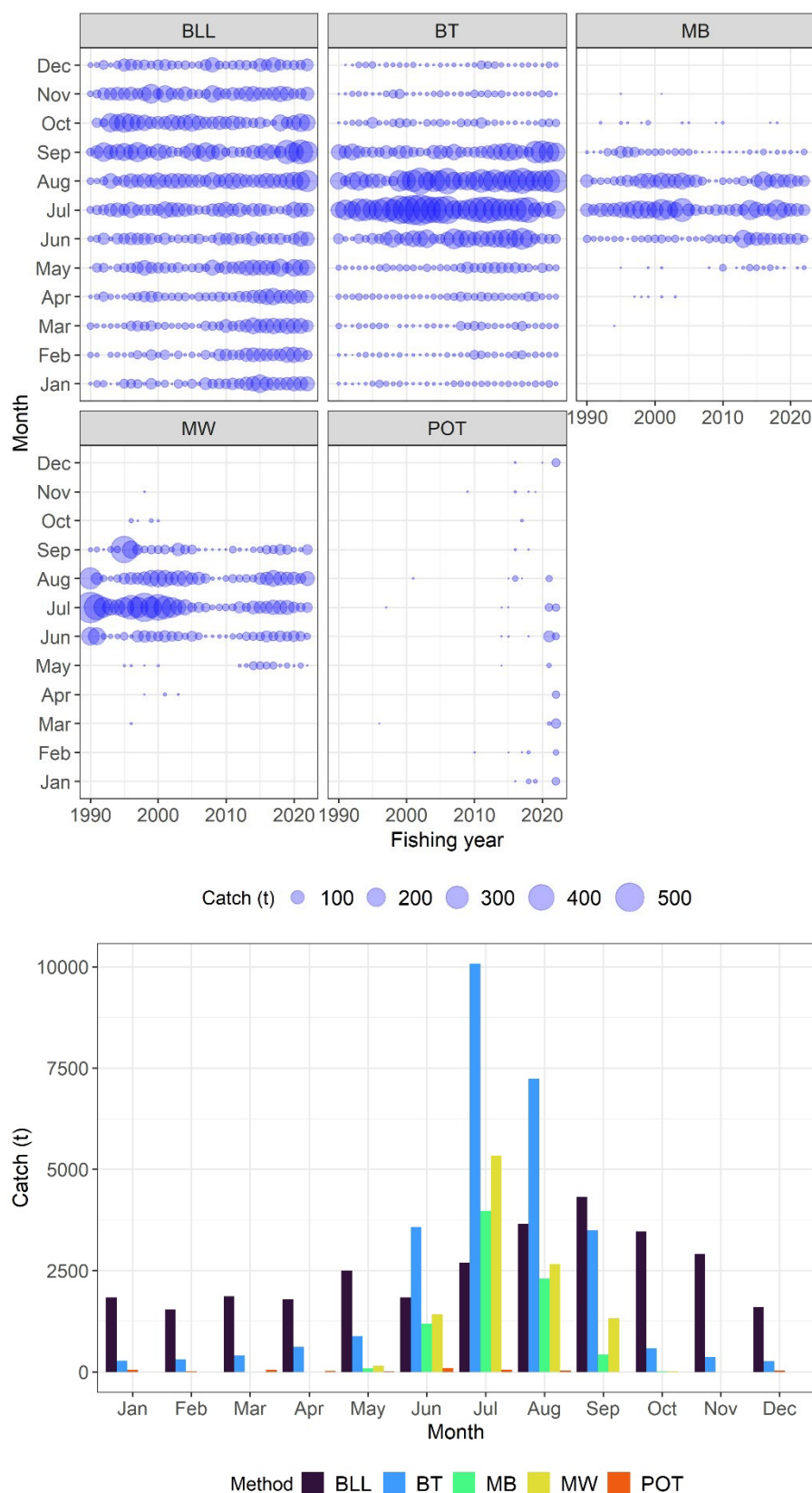


Figure A.5: LIN 7WC distribution of annual ling catch reported in catch and effort forms by month for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis), and all potting methods (POT – code defined within the analysis above) gears separately.

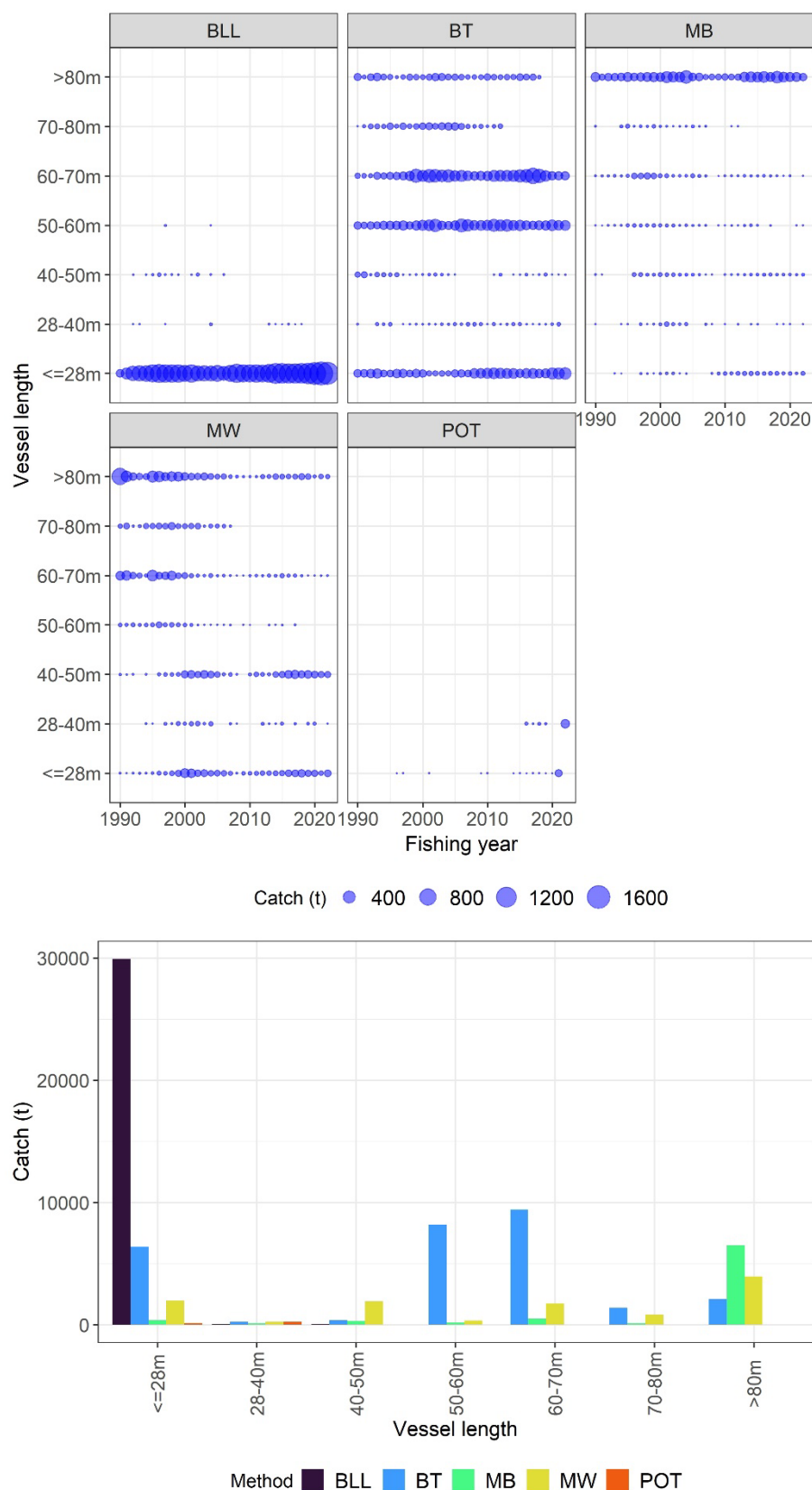


Figure A.6: LIN 7WC distribution of annual ling catch reported in catch and effort forms by vessel length for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis above), and all potting methods (POT – code defined within the analysis) gears separately.

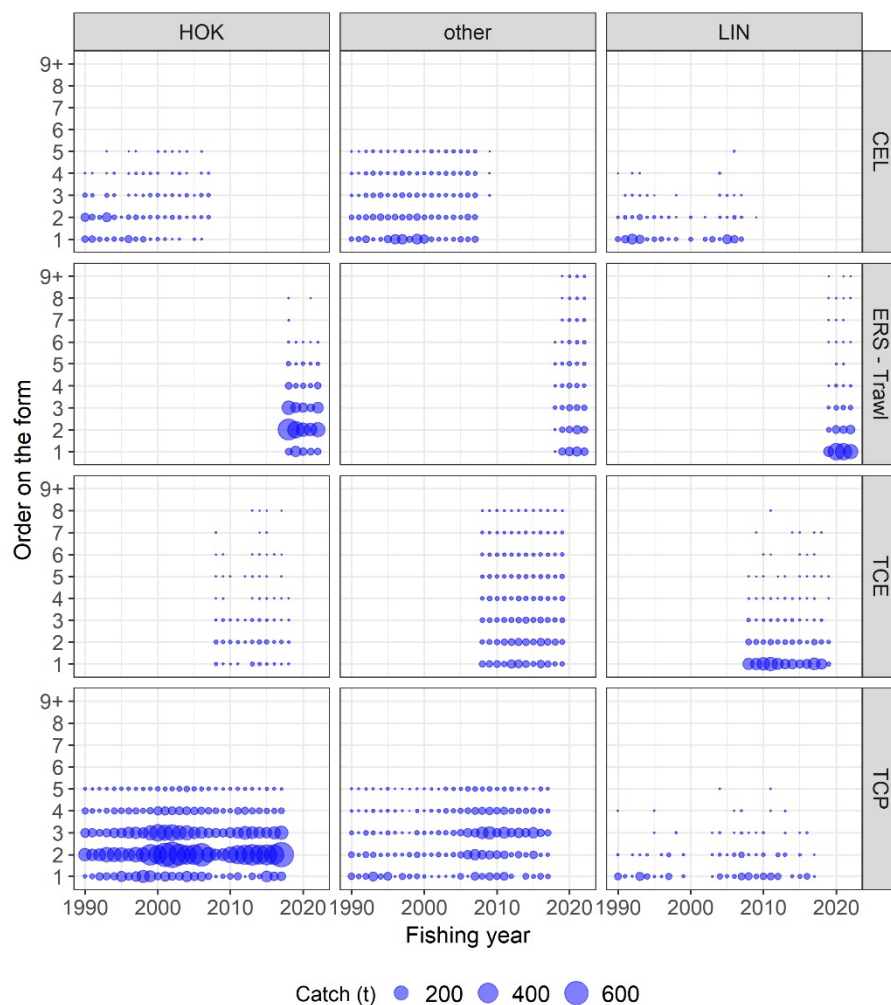


Figure A.7: LIN 7WC distribution of annual ling catch reported in catch and effort forms by order (where greatest catch is 1) reported in the forms for bottom trawl major target species (ling – LIN, hoki – HOK, or other). The order is for QMS species for ERS forms and all species otherwise, matching the reporting requirements. Form type is trawl catch effort and processing return (TCP), trawl catch effort return (TCE), electronic reporting system return (ERS), and catch effort landing return (CEL).

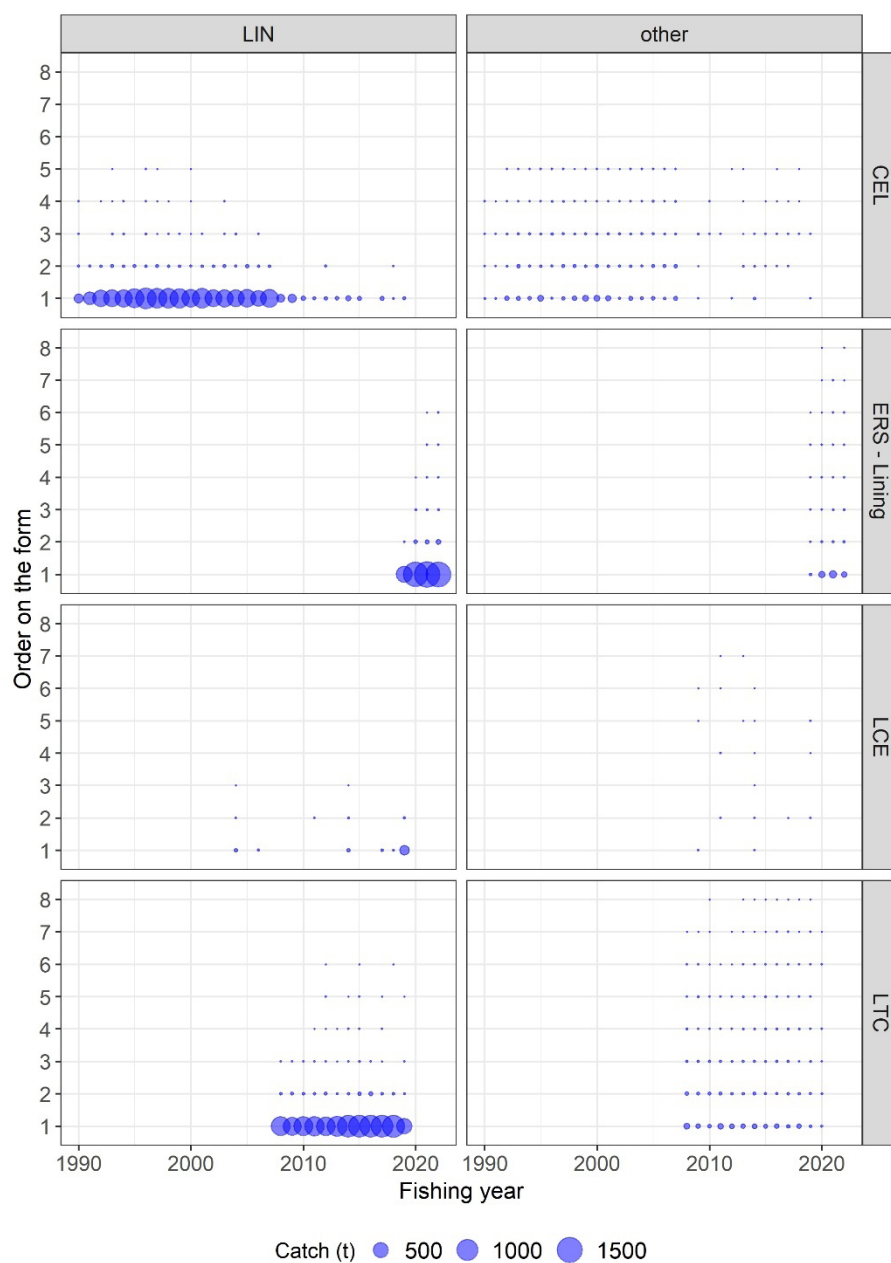


Figure A.8: LIN 7WC annual ling catch reported in catch and effort forms by order reported in the forms for longline gears (where greatest catch is 1) and target species (ling – LIN or other). The order is for QMS species for ERS forms and all species otherwise, matching the reporting requirements. Form type is electronic reporting system return (ERS), catch effort landing return (CEL), lining catch effort return (LCE), and lining trip catch effort return (LTC).

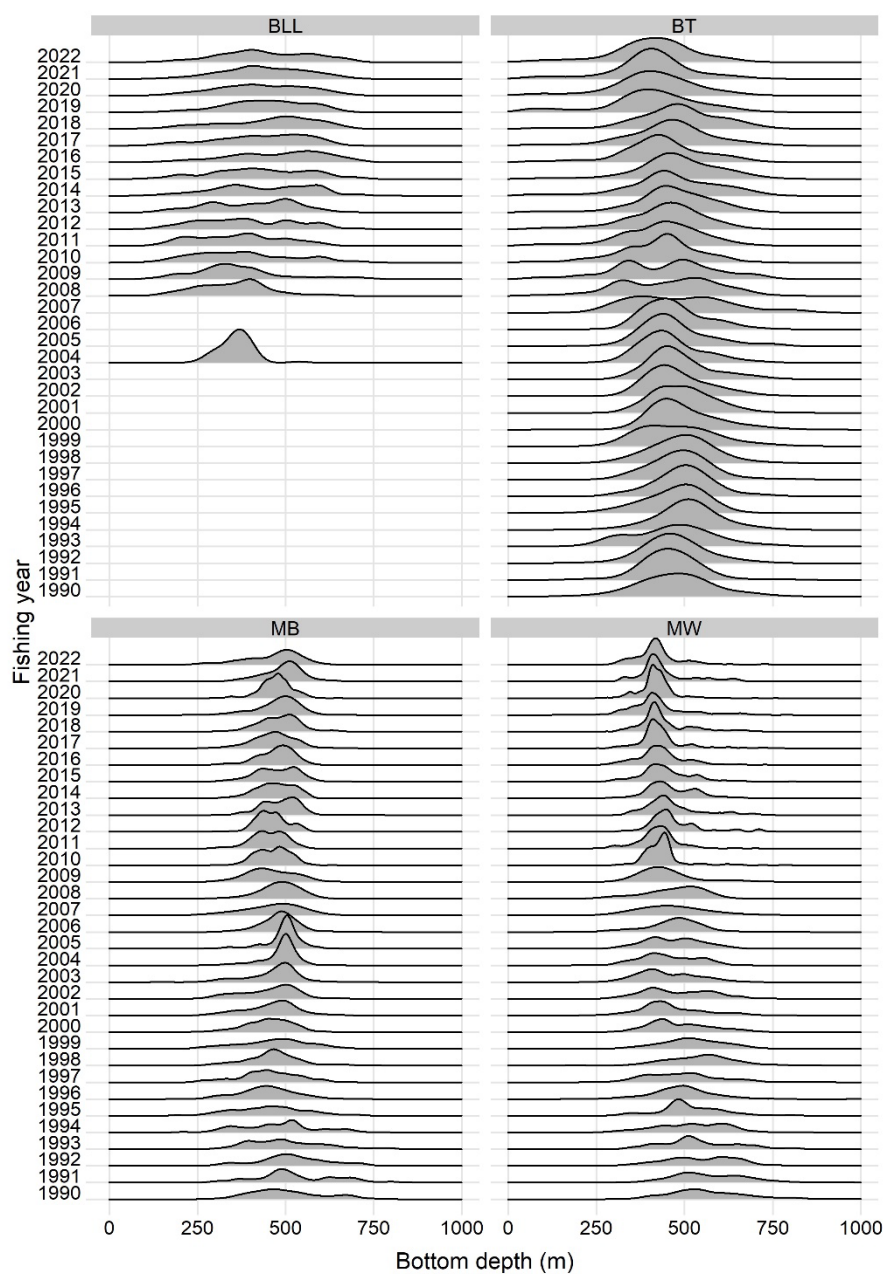


Figure A.9: Catch-weighted LIN 7WC distribution of bottom depth by fishing year for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), and midwater trawl within 5 m of the bottom (MB – code defined within the analysis above).

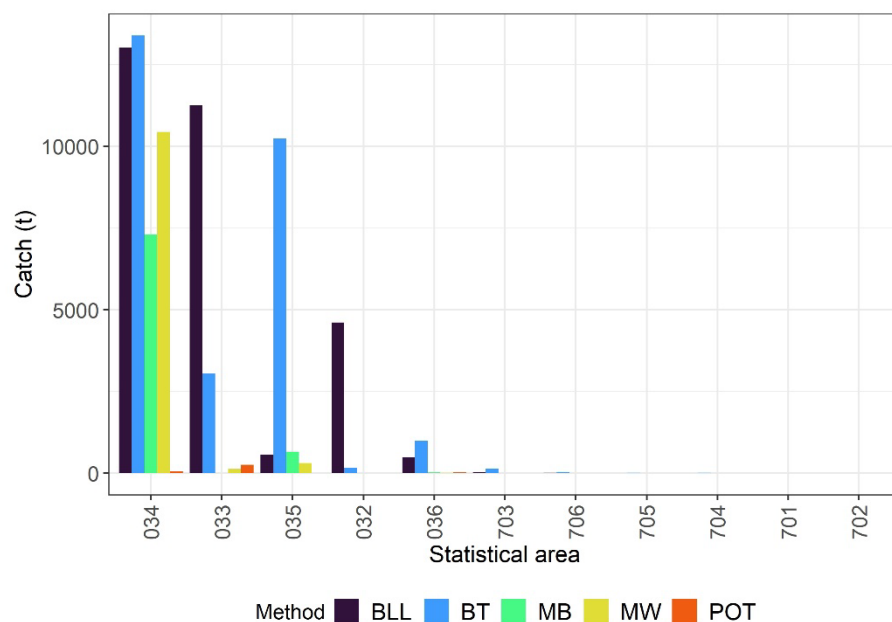
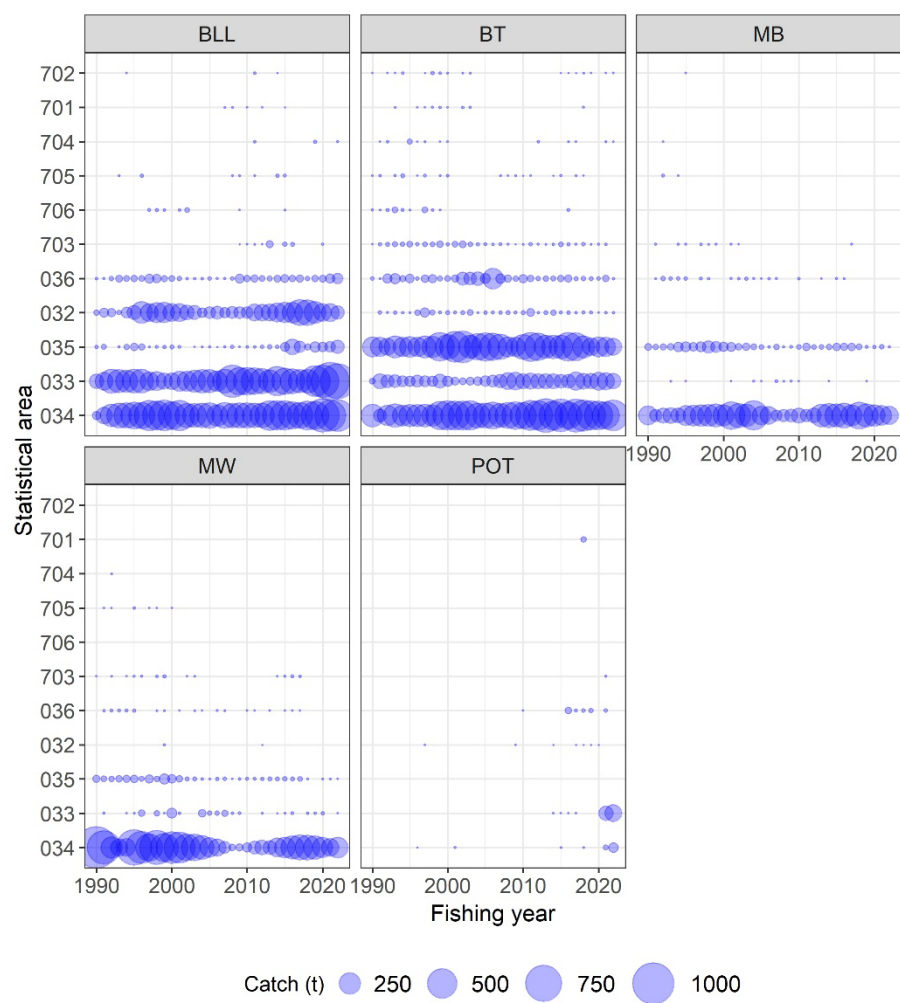


Figure A.10: LIN 7WC distribution of annual ling catch reported in catch and effort forms by Statistical Area for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis above), and all potting methods (POT – code defined within the analysis above).

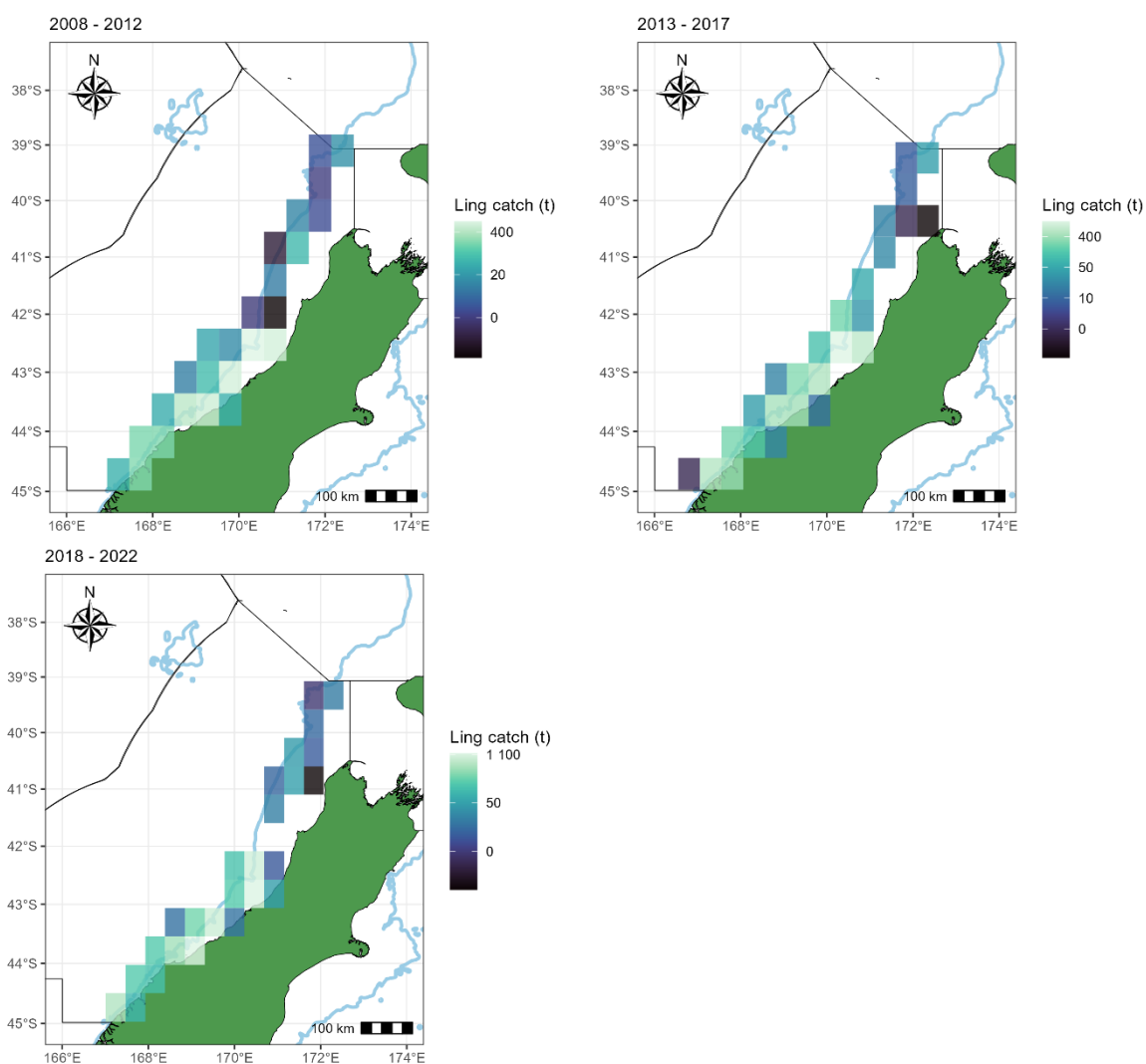


Figure A.11: Distribution of ling catches in the LIN 7WC biological stock area by bottom longlines between 2008 and 2022. Year ranges are fishing years. Areas are plotted at about 0.5° resolution and only where at least three vessels fished in any cell in the period. Data prior to 2008 are not shown as over two-thirds of records did not report locations.

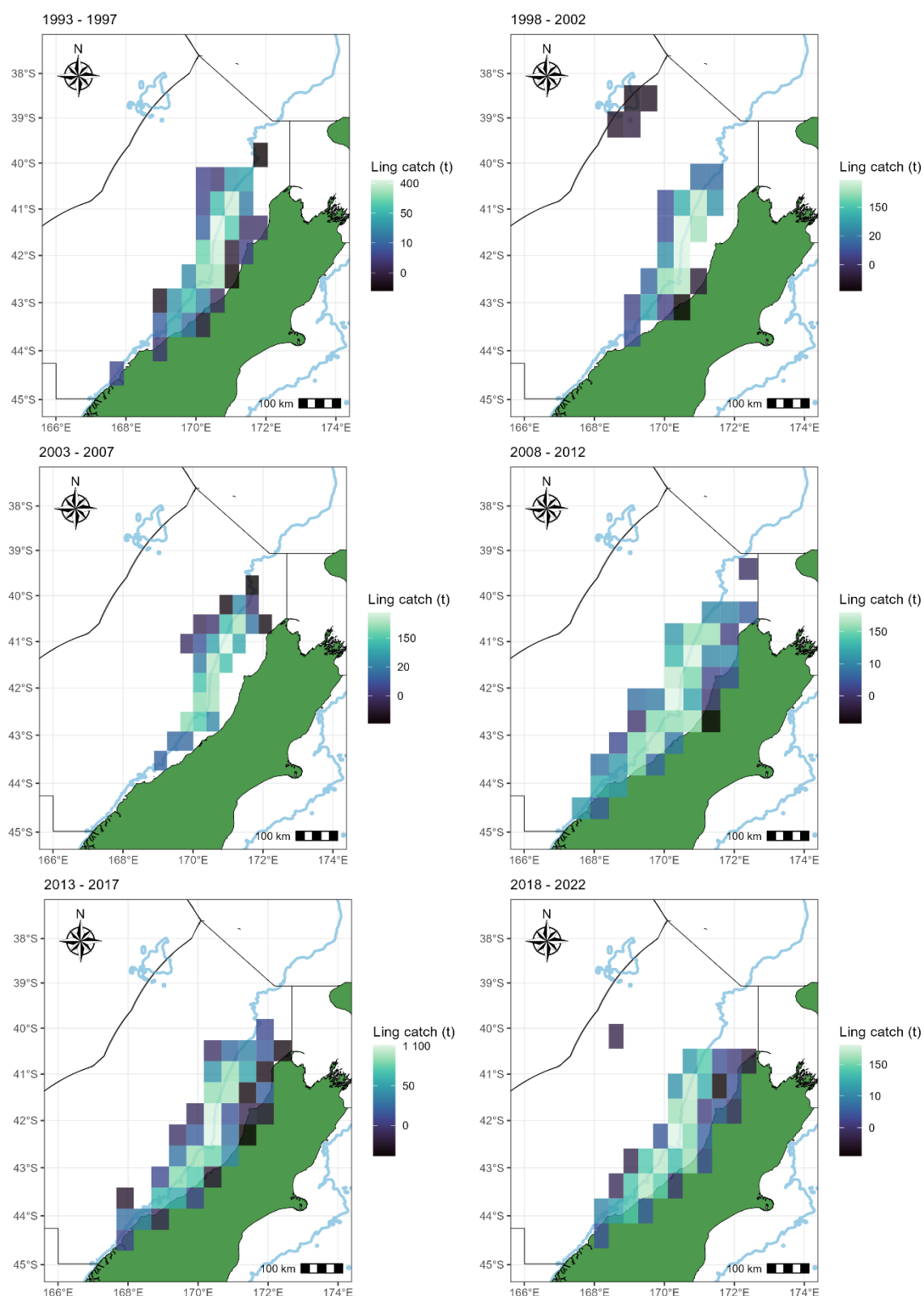
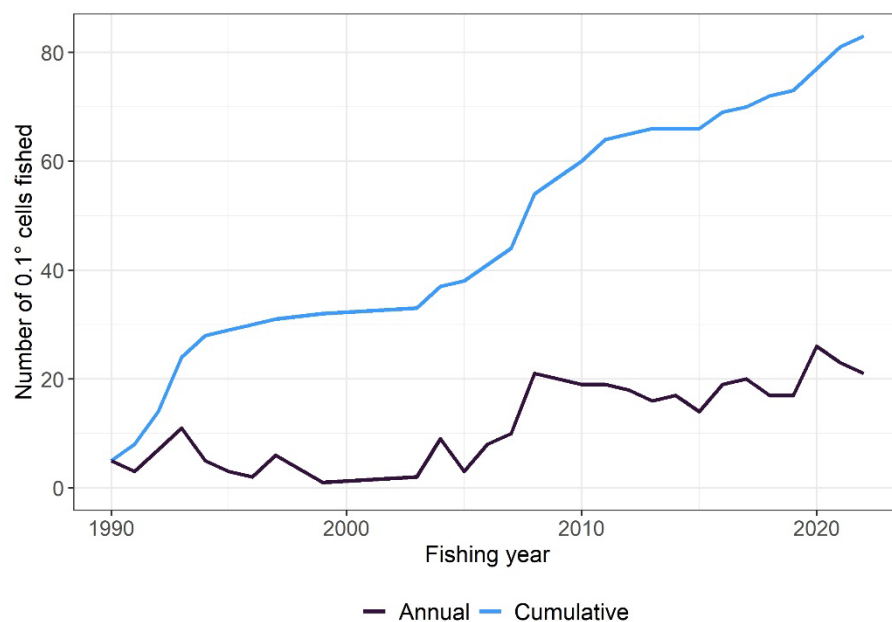


Figure A.12: Distribution of ling catches in the LIN 7WC biological stock area by bottom trawls between 1993 and 2022. Year ranges are fishing years. Areas are plotted at about 0.5° resolution and only where at least three vessels fished in any cell in the period.

Bottom trawl



Bottom longline

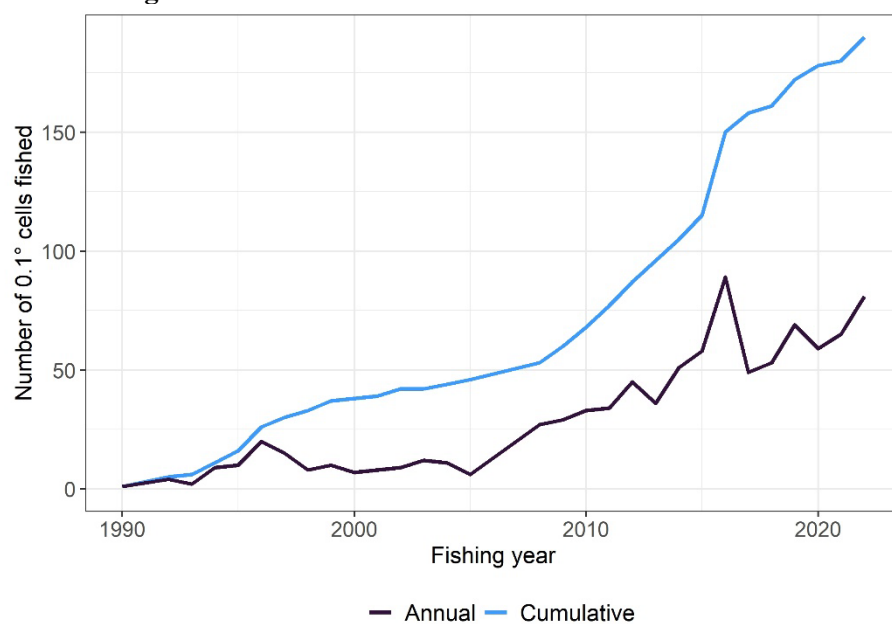


Figure A.13: Spatial distribution of the top 90 percentile catch of the ling target fishery in LIN 7WC: annual total number of cells of 0.1° latitude and longitude that were fished and cumulative number of new cells fished over time.

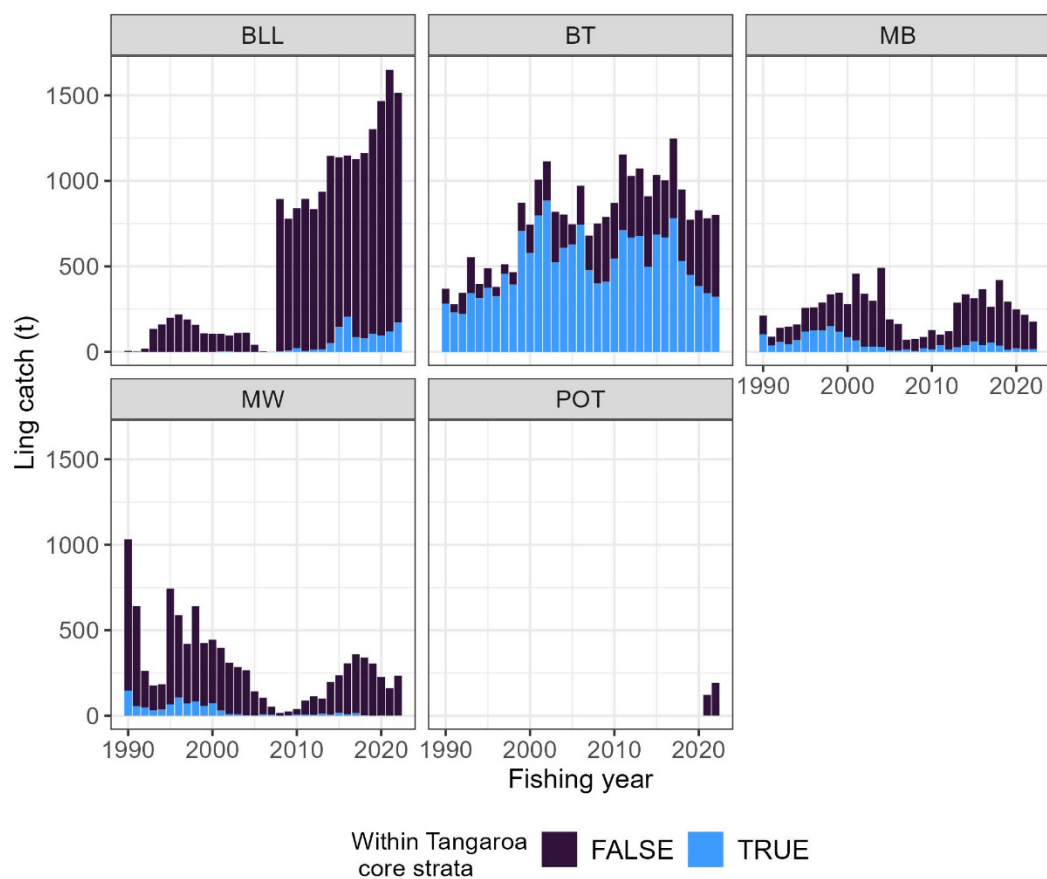


Figure A.14: LIN 7WC distribution of annual ling catch reported in catch and effort forms that fall within the *Tangaroa* survey core strata area for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis above), and all potting methods (POT – code defined within the analysis above).

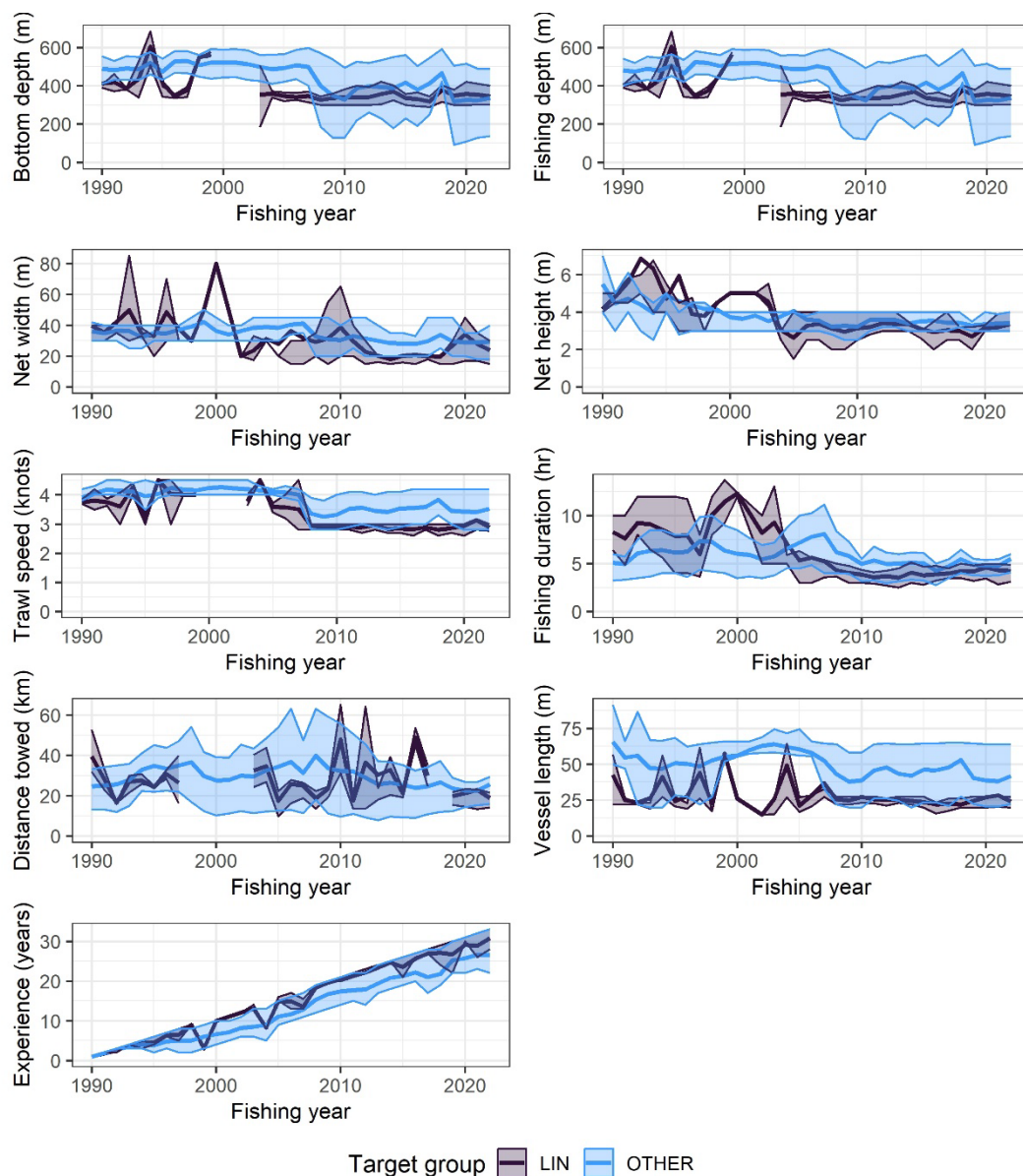


Figure A.15: Change in effort characteristics over time by target species of the bottom trawl ling fisheries in LIN 7WC. Median and interquartile range are shown.

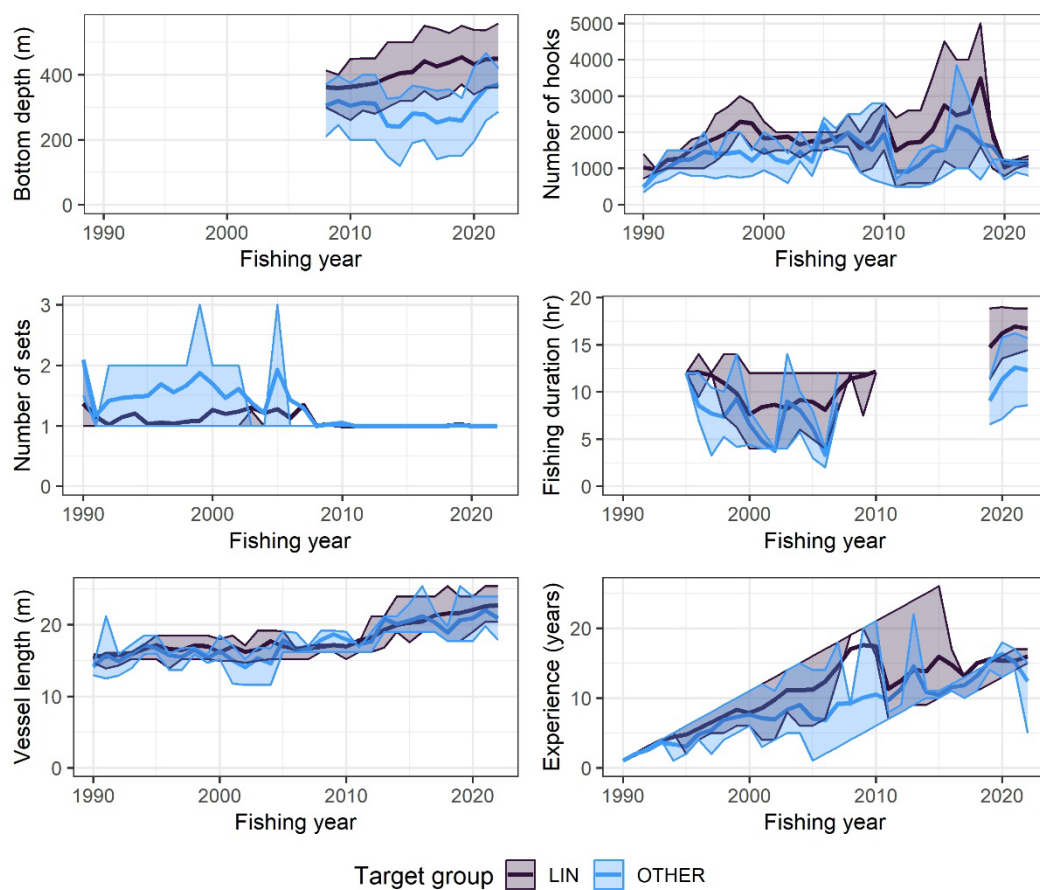


Figure A.16: Change in effort characteristics over time by target species of the longline ling fisheries in LIN 7WC. Median and interquartile range are shown.

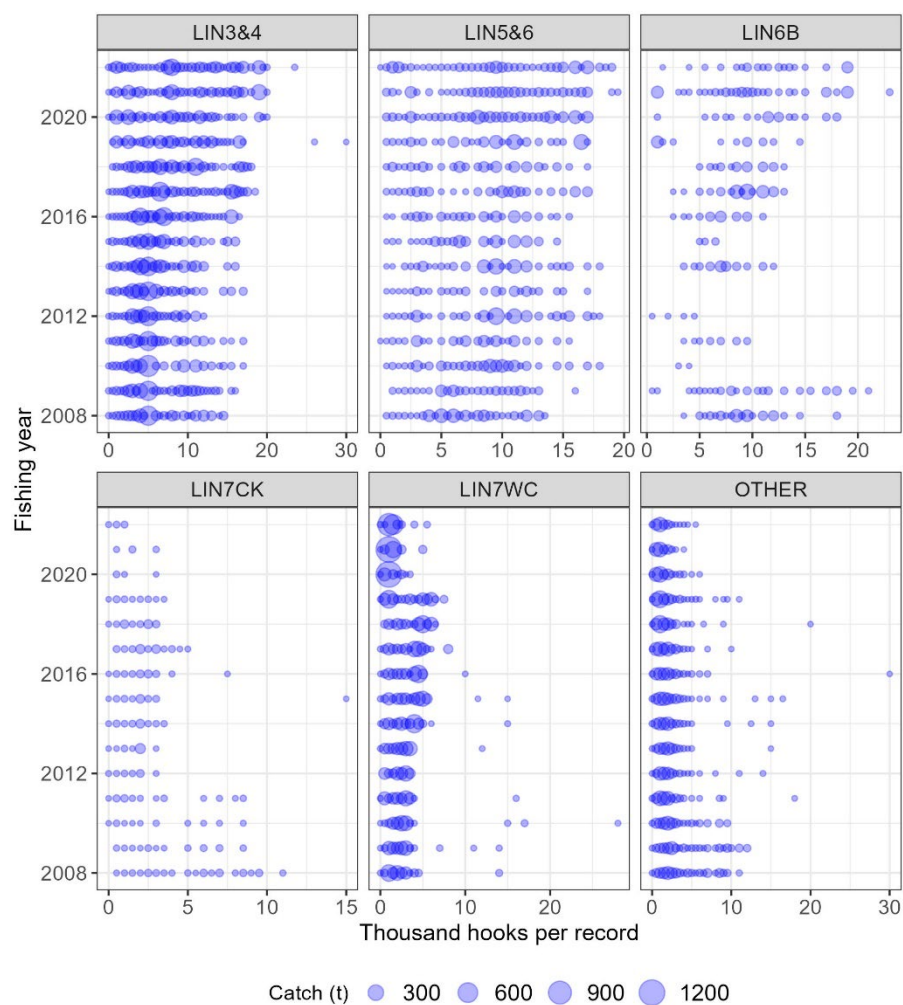


Figure A.17: Annual ling catch reported in catch and effort forms by the number of hooks for vessels per report (discretised in 500 hooks bins) and by year for each ling stock.

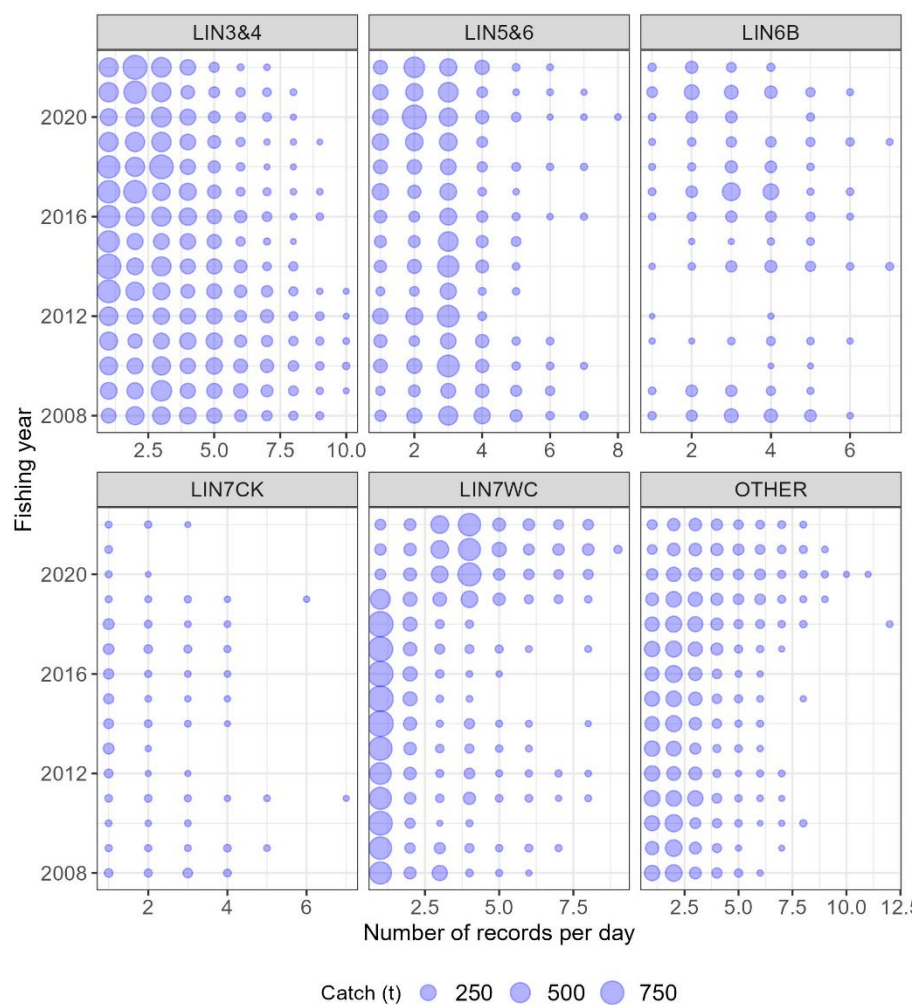


Figure A.18: Annual ling catch reported in catch and effort forms by the number of reports of vessels per day and by year for each ling stock.

12. APPENDIX B – SPATIAL ANALYSIS

Table B.1: Explanatory variables offered to the tree-regression models.

Variable	Type	Description
Month	Categorical	Month of the year
Statistical area	Categorical	Statistical area
Start latitude	Numeric	Start latitude (absolute value)
Start longitude	Numeric	Start longitude (0–360°)
Target	Categorical	Species targeted on the tow
Method	Categorical	Bottom longline or bottom trawl
Bottom depth	Numeric	Depth of the bottom in metres
Spawning	Categorical	Whether during spawning season (July to November) or not

Table B.2: Model comparison deviance information criterion (DIC) and Watanabe-Akaike information criterion (WAIC) for each of the LF model runs. The model term ‘Space’ refers to the INLA SPDE term, and ‘Block’ refers to the three-year time blocks.

Model	DIC	WAIC	Comment
Length ~ Intercept + Space	560 495	560 498	
Length ~ Intercept + Fishing event (random) + Space	560 491	560 491	
Length ~ Intercept + Year + Fishing event (random) + SPDE	553 866	553 870	
Length ~ Intercept + Year + Sex + Fishing event (random) + Space	552 734	552 738	
Length ~ Intercept + Year + Sex + Fishing method + Fishing event (random) + Space	552 734	552 738	
Length ~ Intercept + Year + Sex + Month + Fishing event (random) + Space	551 685	551 686	Chosen model
Length ~ Intercept + Year + Sex + Month + s(Depth,3) + Fishing event (random) + Space	551 951	551 953	
Length ~ Intercept + Year + Sex + Month + Fishing event (random) + (Space * Sex)	540 106	540 170	Best model
Length ~ Intercept + Year + Sex + Fishing method + Fishing event (random) + (Space * Year block)	540 239	540 298	

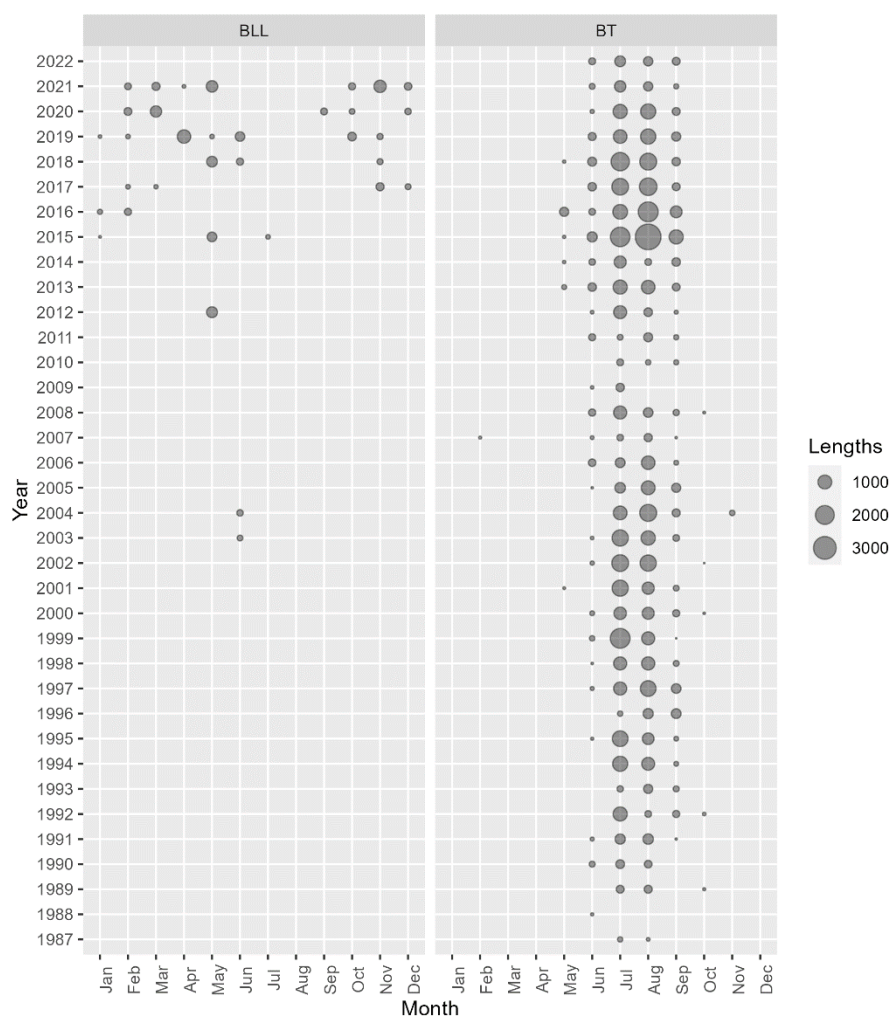


Figure B.1: LIN 7WC distribution of annual ling length data collected by observers for bottom longline (BLL) and bottom trawl (BT) gears separately.

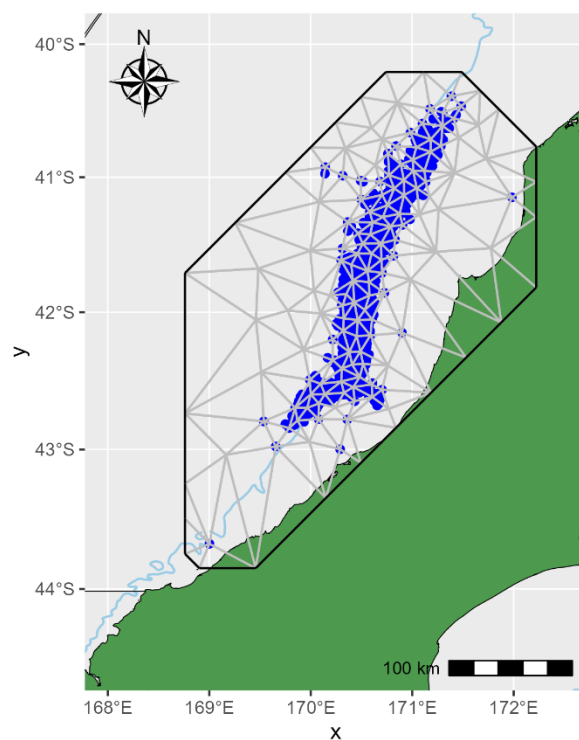


Figure B.2: Spatial mesh for ling spatial-temporal models showing the locations of data (blue points), the spatial mesh (grey lines), the extent of the spatial model (thick black lines), and the New Zealand EEZ (dark grey lines).

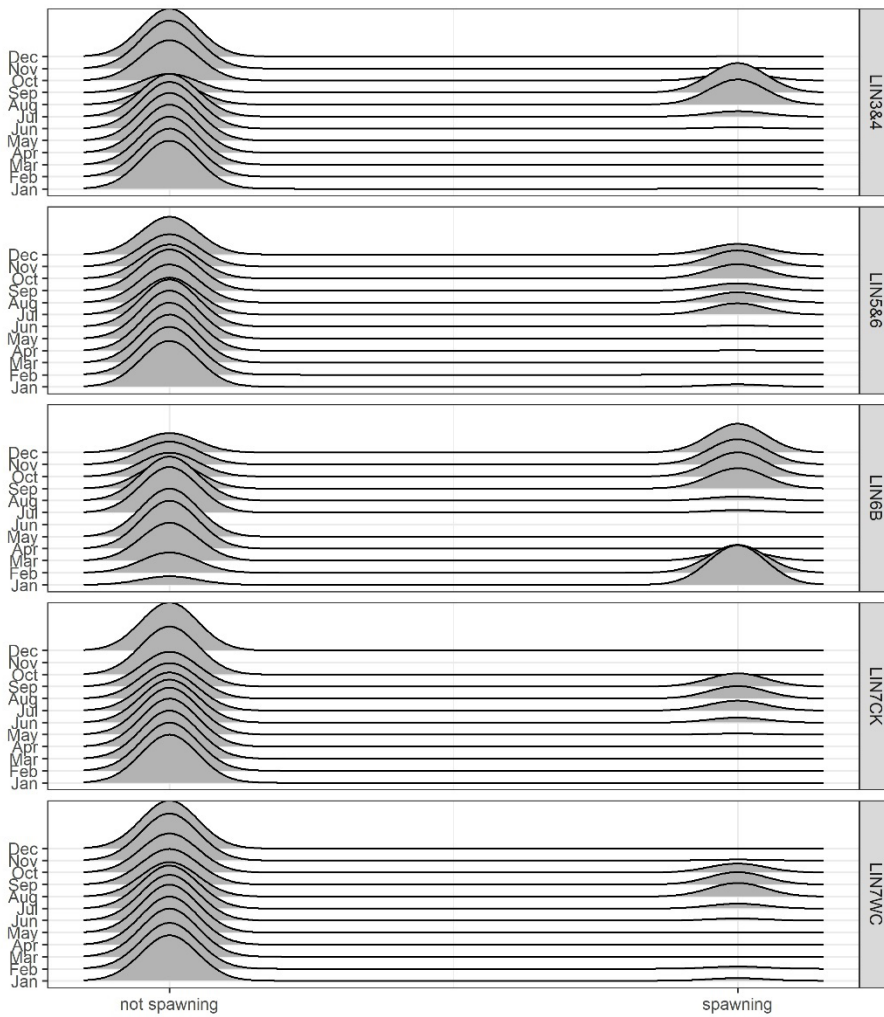


Figure B.3: Proportion of ling spawning by month for the 1900-2022 fishing years in the different ling stocks based on observer data, spawning was defined as stage 3 (mature) or 4 (running ripe).

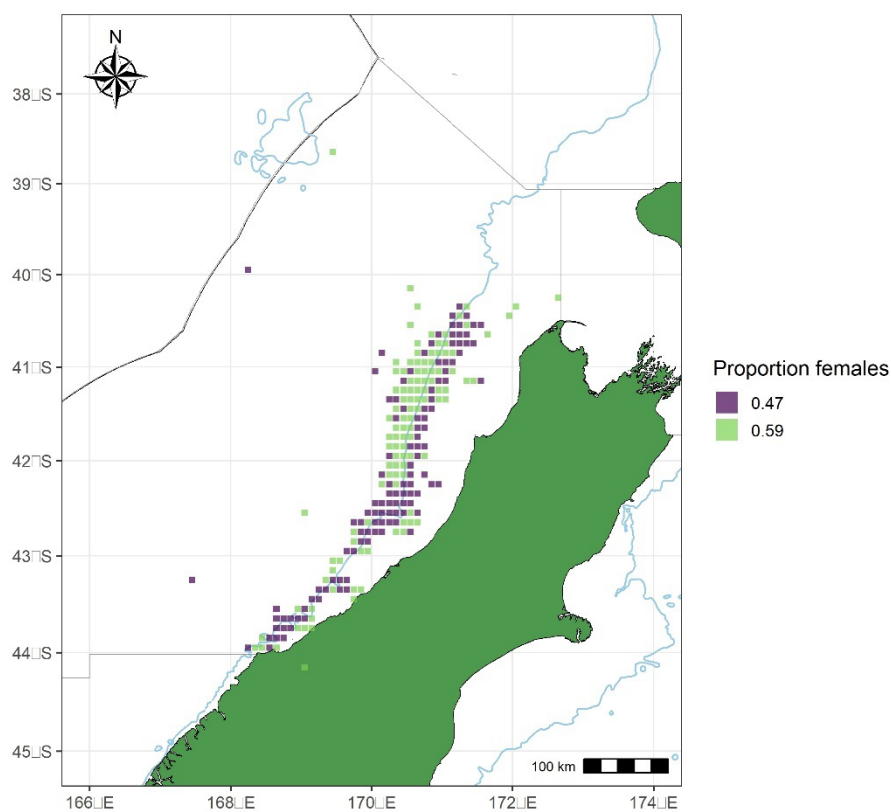


Figure B.4: Potential fisheries strata based on a tree regression analysis of the mean proportion of females by fishing event. The strata were based on statistical areas. Locations have been rounded to 0.1° and are shown only where data were available for three or more vessels.

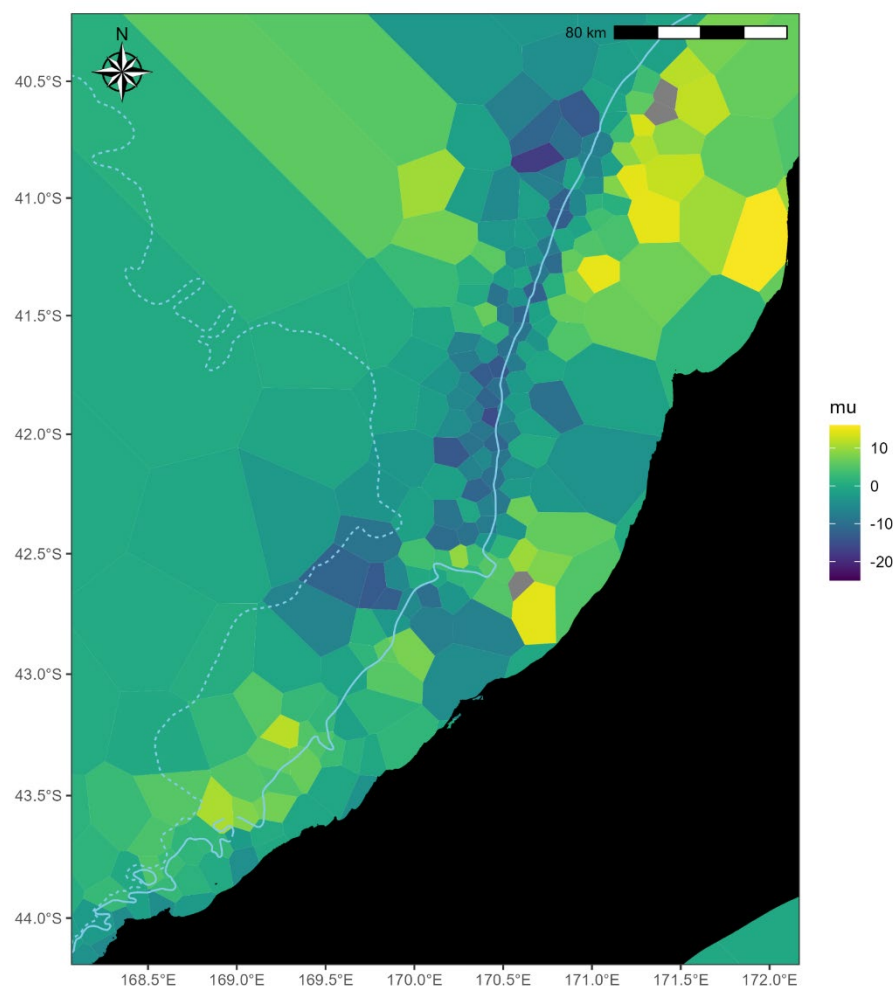


Figure B.5: The spatial effect for the chosen model of $\text{Length} \sim \text{Intercept} + \text{Year} + \text{Sex} + \text{Month} + \text{Fishing event (random)} + \text{Space}$. Mu is the deviance from the mean length.

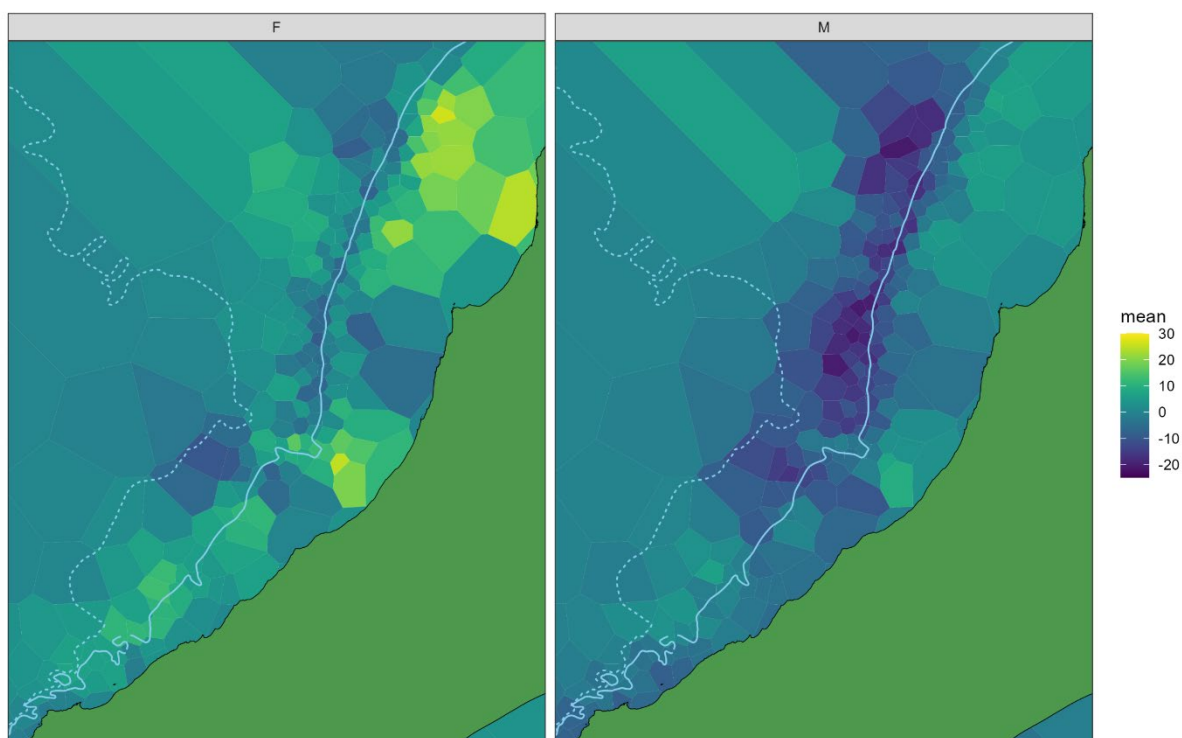


Figure B.6: The spatial effect for the sex-specific model of $\text{Length} \sim \text{Intercept} + \text{Year} + \text{Sex} + \text{Month} + \text{Fishing event (random)} + (\text{Space} * \text{Sex})$. Females (F) and males (M) are shown separately.

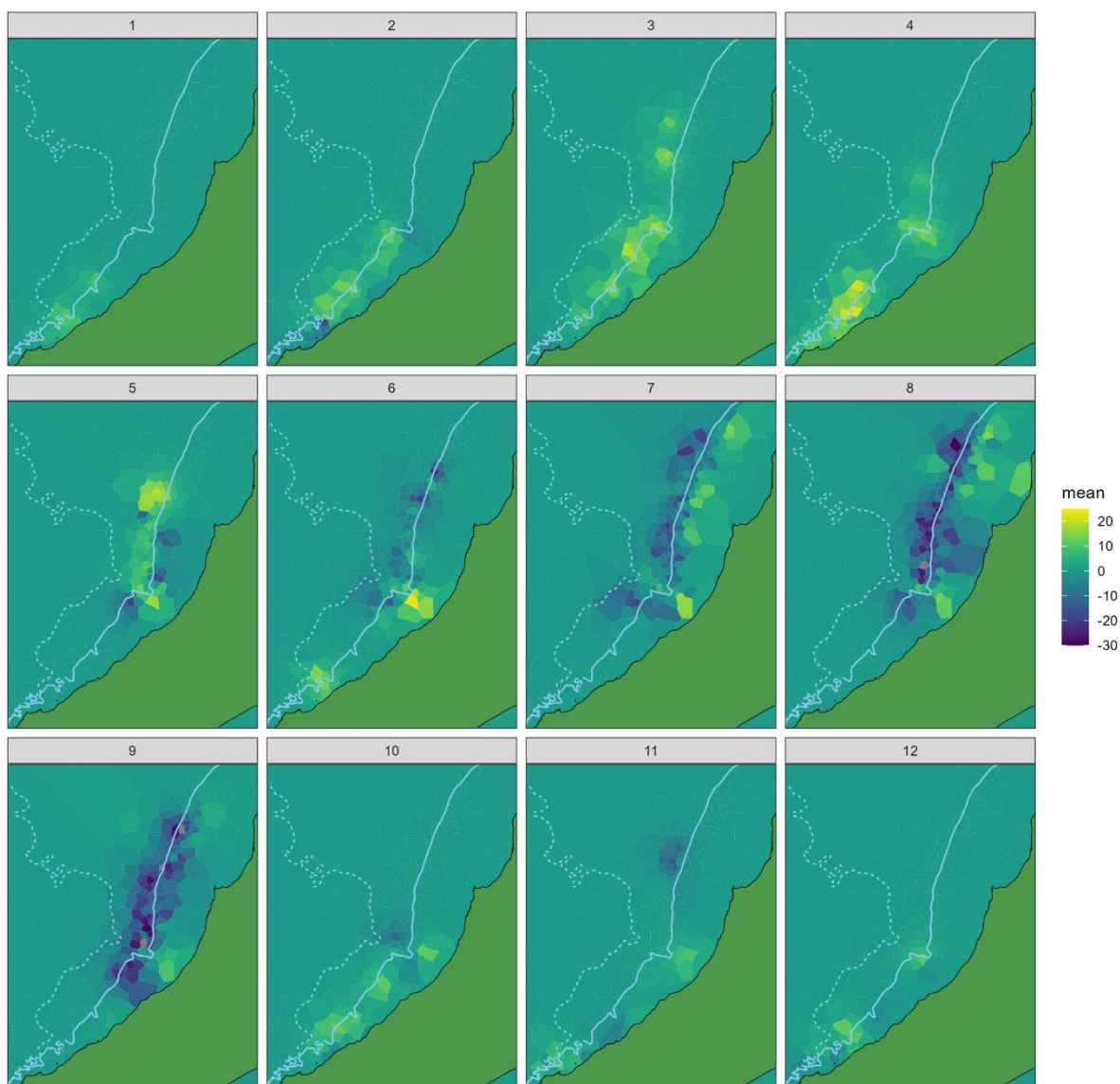


Figure B.7: The spatial effect for model of Length ~ Intercept + Year + Sex + Month + Fishing event + (Space * Month), where 1 is January.

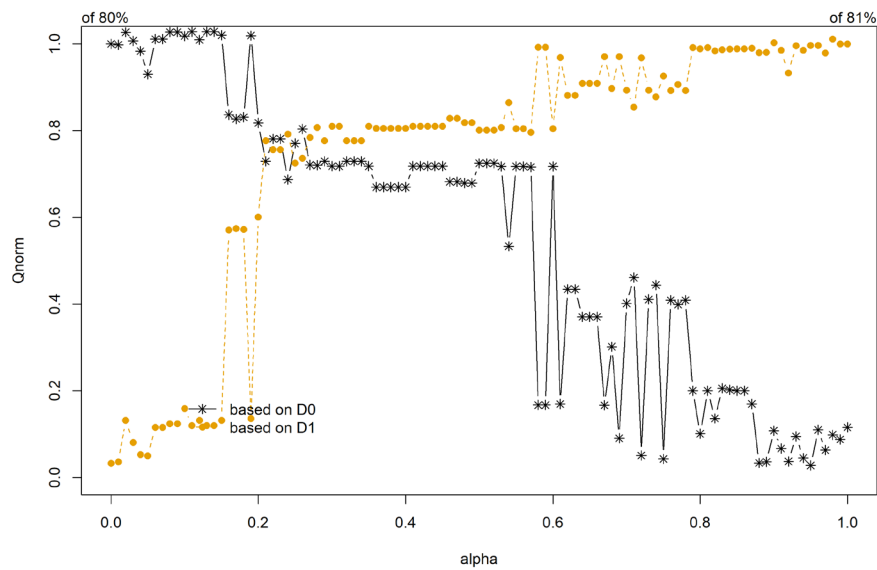


Figure B.8: The proportion of explained inertia of the data (D0) and distance (D1) partitions (in $K = 3$ clusters) for different values of the mixing parameter α for the chosen model of $\text{Length} \sim \text{Intercept} + \text{Year} + \text{Sex} + \text{Month} + \text{Fishing event (random)} + \text{Space}$.

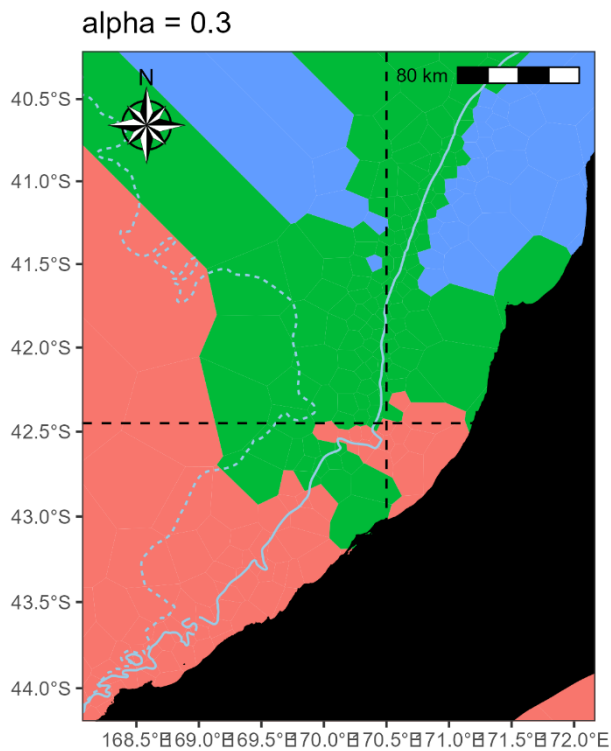
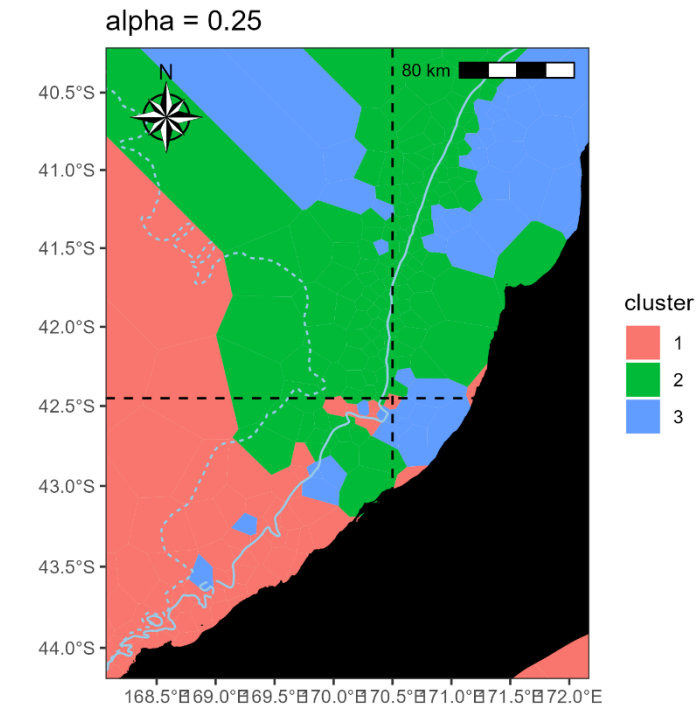


Figure B.9: Clusters (for K = 3 clusters) for different alpha levels for the chosen model of Length ~ Intercept + Year + Sex + Month + Fishing event (random) + Space. The optimum alpha was 0.25.

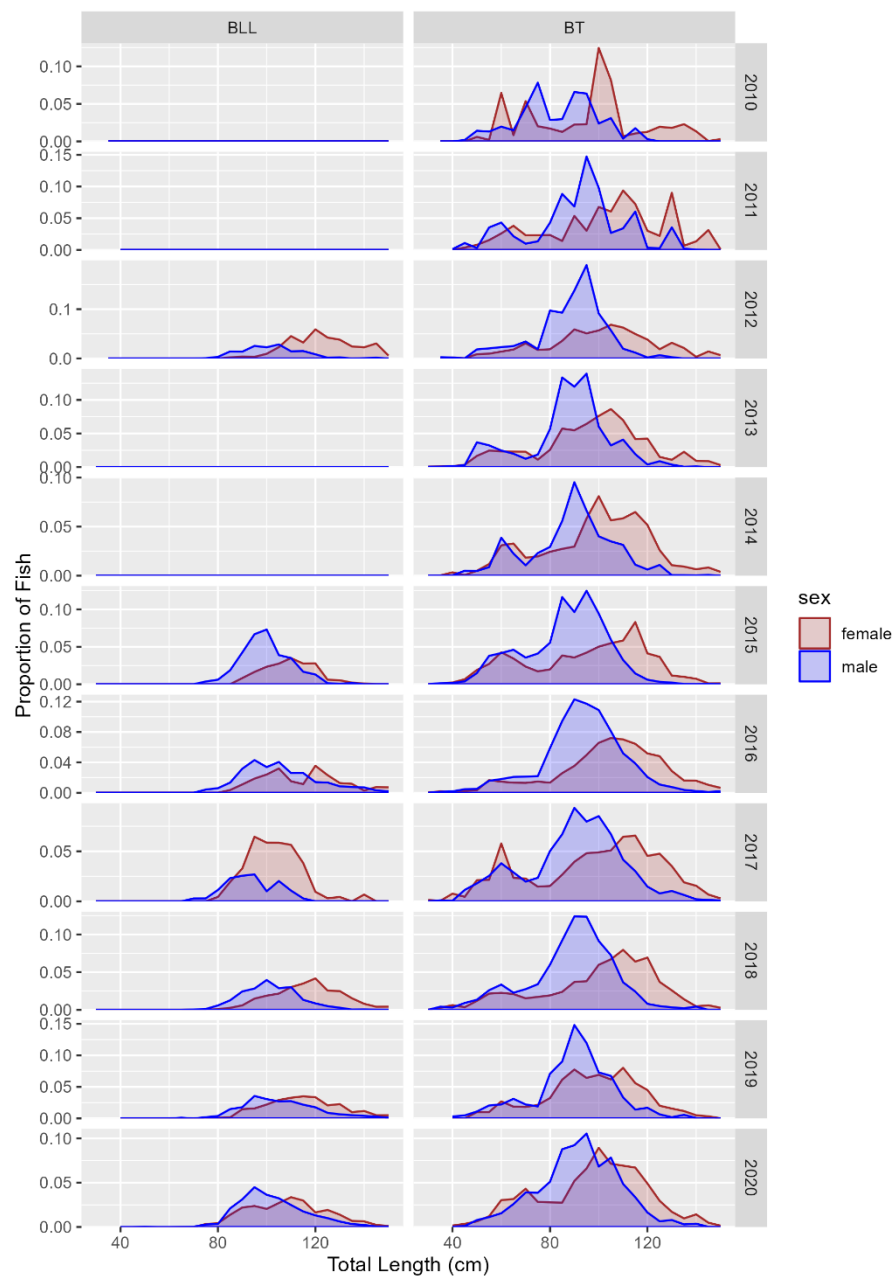


Figure B.10: Trend of scaled length frequency distributions over time of Option 1 (status quo). Year is calendar year.

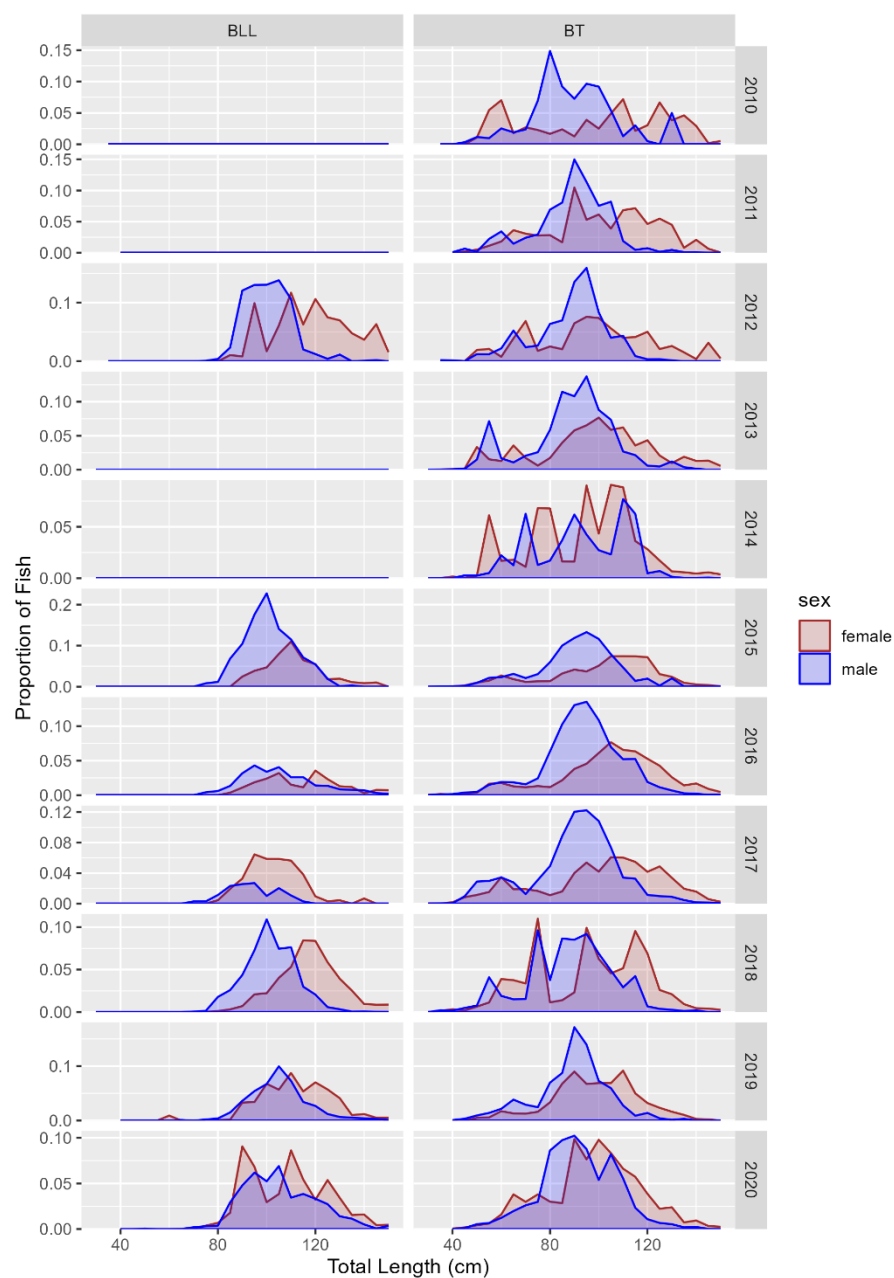


Figure B.11: Trend of scaled length frequency distributions over time of Option 2 (based on INLA). Year is calendar year.

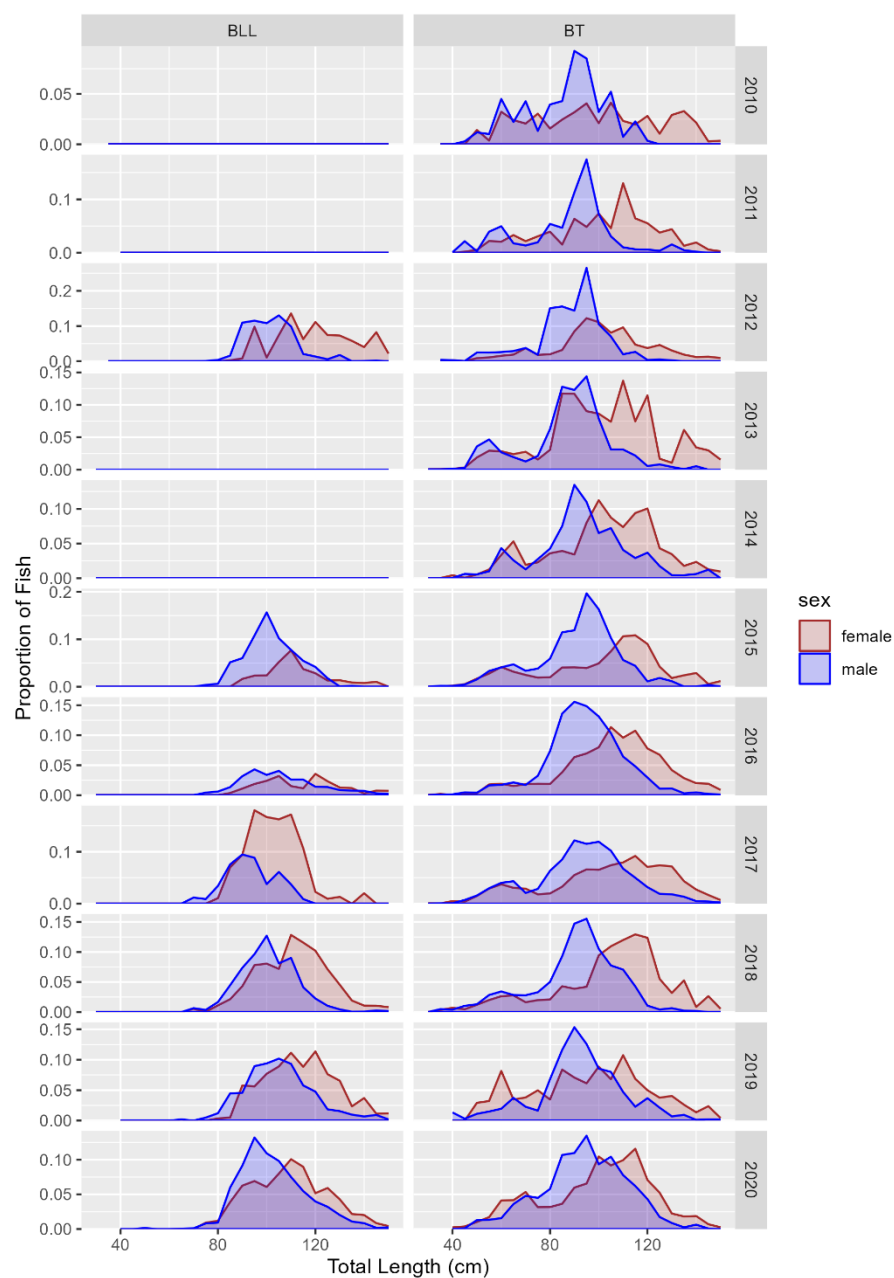


Figure B.12: Trend of scaled length frequency distributions over time of Option 3 (based on tree regression). Year is calendar year.

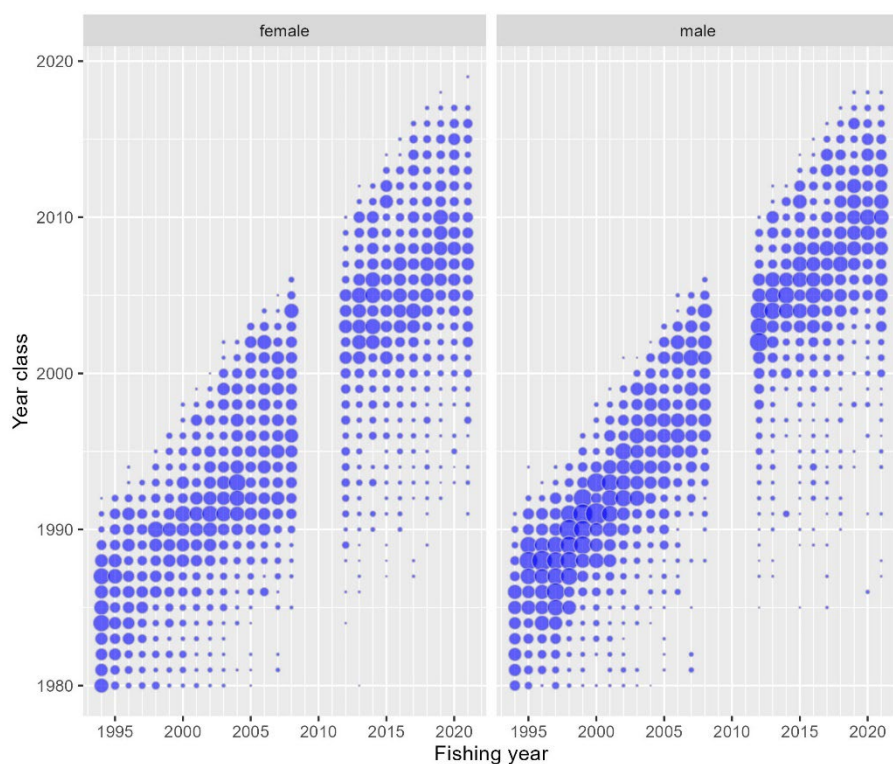


Figure B.13: Progression of year classes in the bottom trawl fishery scaled age frequencies.

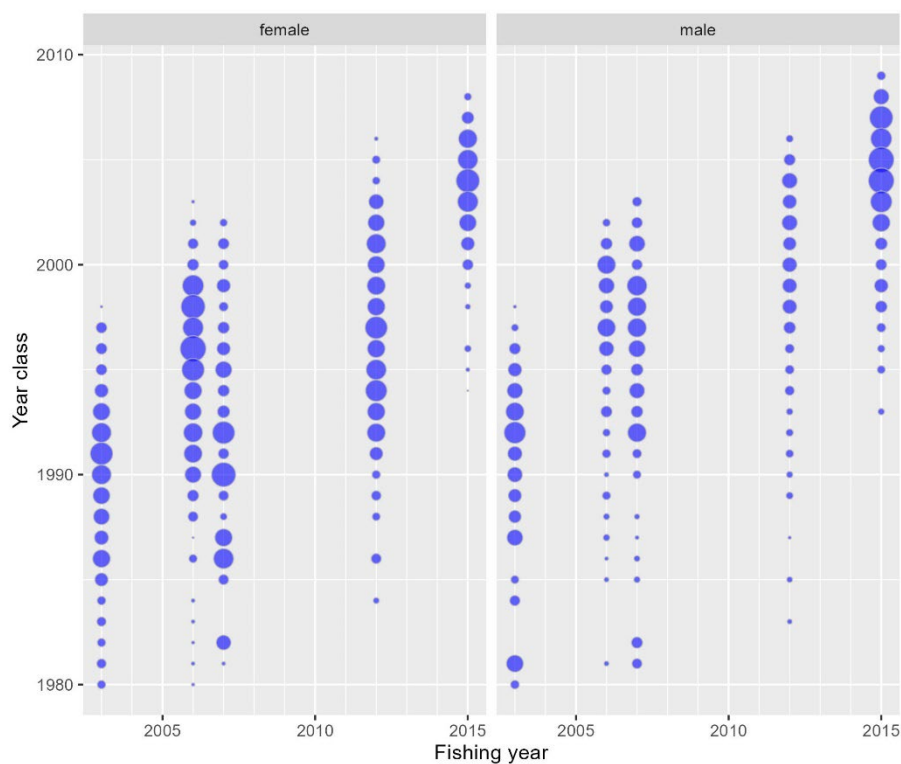


Figure B.14: Progression of year classes in the bottom longline fishery scaled age frequencies.

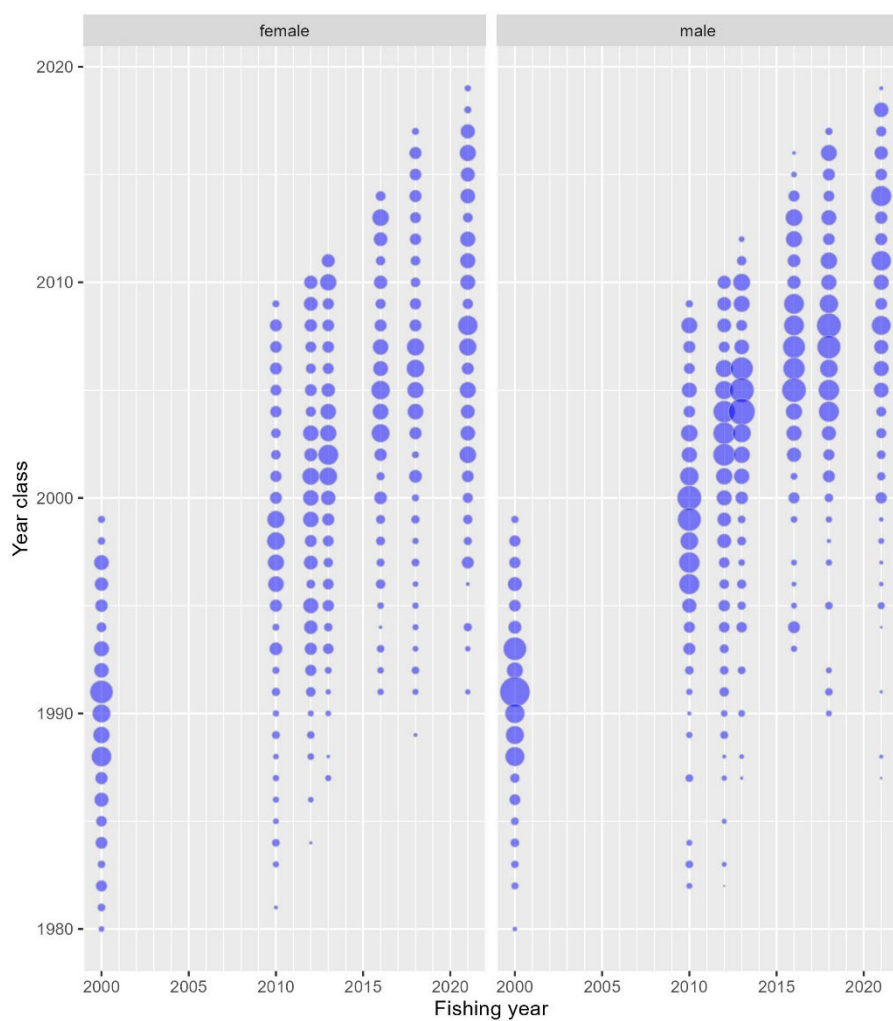


Figure B.15: Progression of year classes in the trawl survey scaled age frequencies.

13. APPENDIX C – UPDATE OF BIOLOGICAL PARAMETERS

Table C.1: Length-weight parameters obtained in this analysis and compared with those reported by Horn (2005) and Edwards (2017).

Sex	Parameter	Horn (2005)	Edwards (2017)	This analysis
Male	a	0.00000115	0.00000135	0.00000131
	b	3.318	3.28	3.292
Female	a	0.93E-06	1.01E-6	0.98E-06
	b	3.368	3.36	3.362

Table C.2: von Bertalanffy growth parameters obtained in this analysis (maximum likelihood estimator – MLE or Bayesian method) and compared to those reported by Horn (2005) and Edwards (2017).

Sex	Parameter	Horn (2005)	Horn (2022)	Edwards (2017)	This analysis	
					MLE	Bayesian
Male	L_{inf}	159.9	134.4	141.00	140.3	140.0
	k	0.067	0.116	0.09	0.096	0.090
	t_0	-2.37	-0.1	-1.18	-1.11	-1.08
Female	L_{inf}	169.3	157.7	164.15	164.7	164.1
	k	0.078	0.098	0.08	0.083	0.080
	t_0	-0.87	-0.1	-0.75	-0.92	-0.86
Both	CV	–			0.08	0.08

Table C.3: Monotonic growth parameters for males and females (CV is 0.08).

Age	Female	Male
2	39.9	37.1
3	47.0	46.9
4	58.7	57.3
5	66.9	66.1
6	73.7	72.6
7	81.2	79.7
8	89.1	86.2
9	95.9	91.0
10	100.7	94.9
11	105.6	98.2
12	110.5	101.4
13	114.8	106.1
14	119.0	108.6
15	121.5	111.6
16	126.2	115.9
17	130.6	118.2
18	132.2	120.6
19	134.7	122.9
20	135.9	126.7
21	142.2	127.9
22	144.0	129.6
23	146.1	132.2
24	148.1	134.2
25	149.1	136.1
26	151.4	137.1
27	153.0	139.3
28	155.2	141.2
29	156.5	142.9
30	157.8	144.7
31	158.7	146.7
32	161.2	148.3
33	163.1	149.8
34	165.7	151.5
35	168.9	152.8

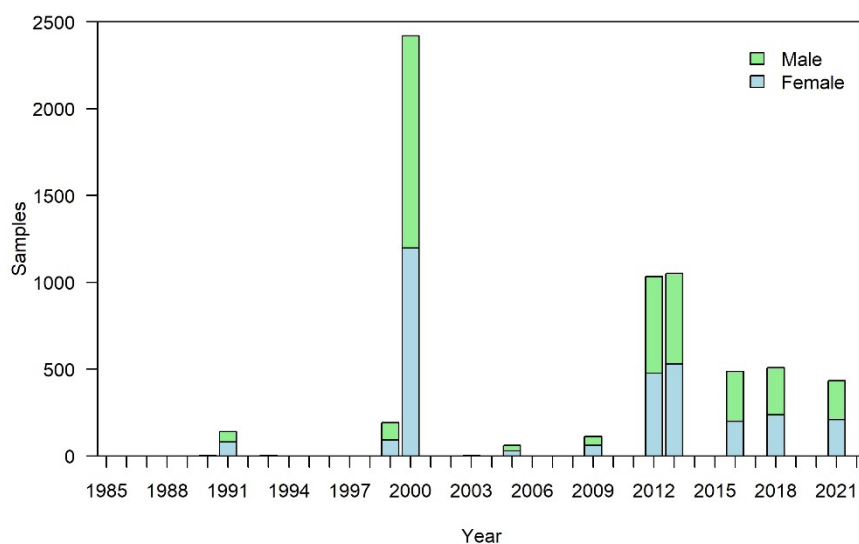


Figure C.1: Number of length-weight samples available by fishing year.

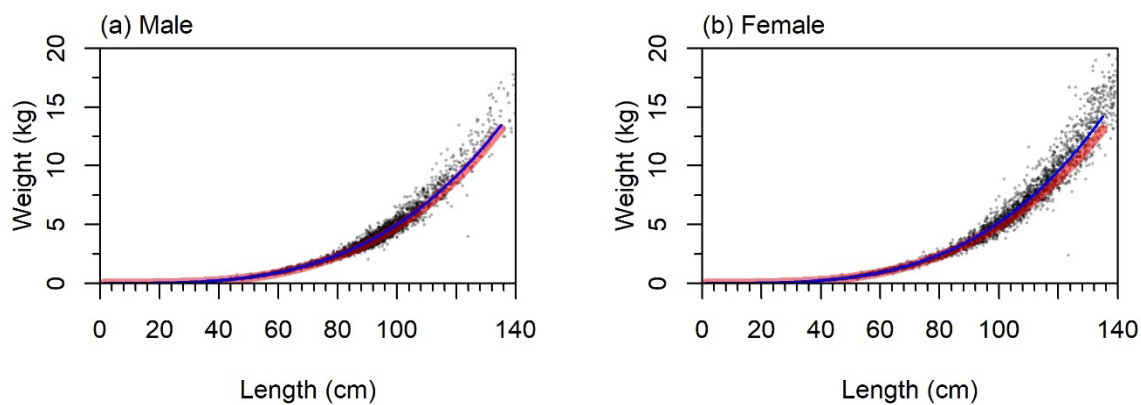


Figure C.2: Estimated length-weight relationships: the red line represents the estimate by Horn (2005), the blue line is the estimated relationship from this analysis, and dots are the data points used .

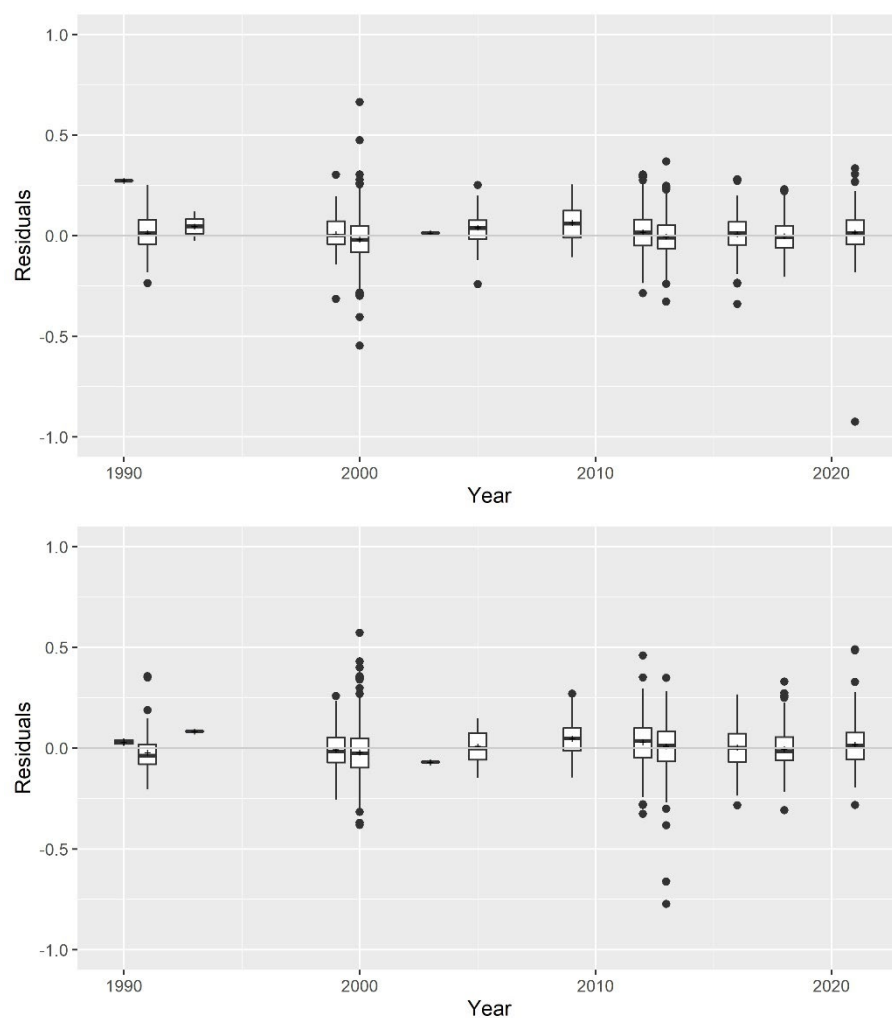


Figure C.3: Residuals by fishing year of the length-weight relationship for males (top) and females (bottom).

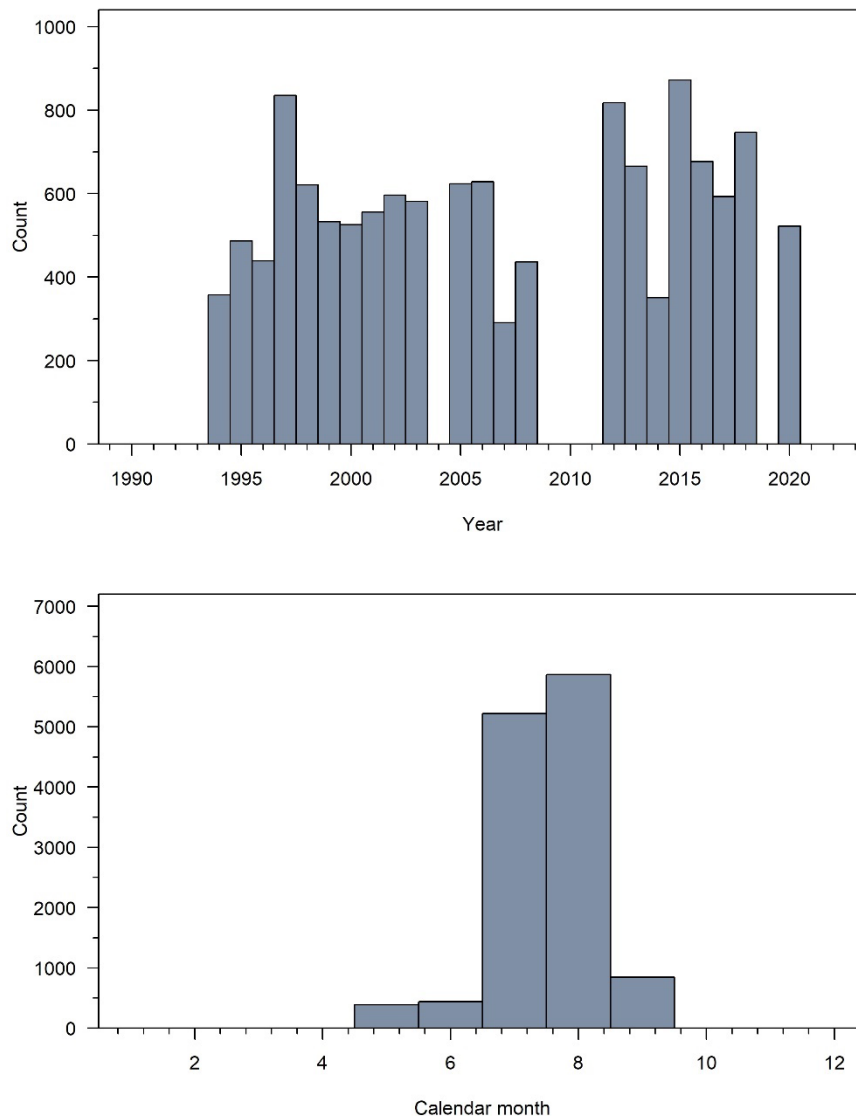


Figure C.4: Available age data, by calendar year (top) and by calendar month over all years (bottom).

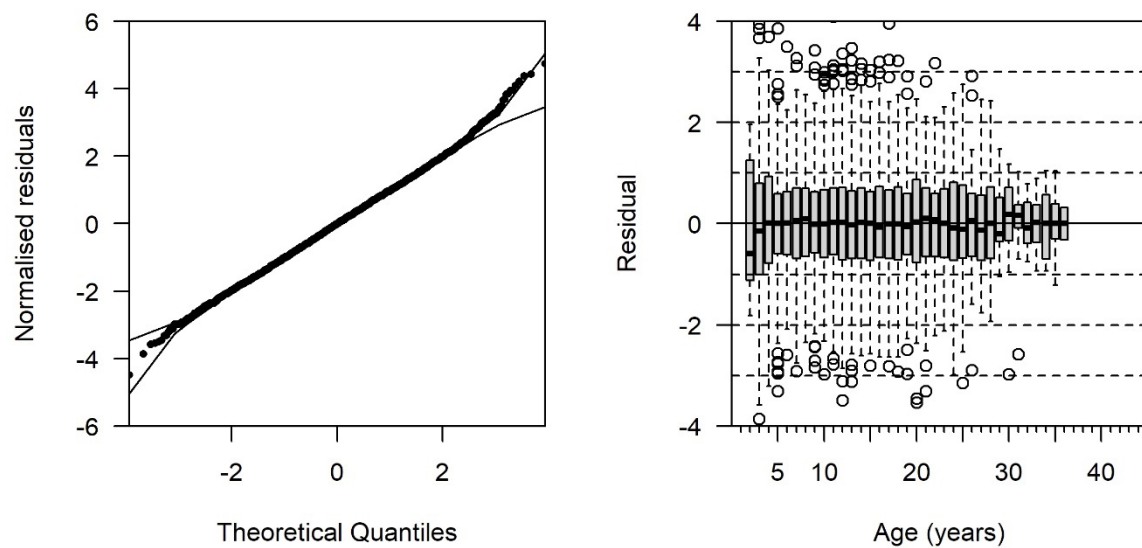


Figure C.5: Residuals of the maximum likelihood estimates for the von Bertalanffy models.

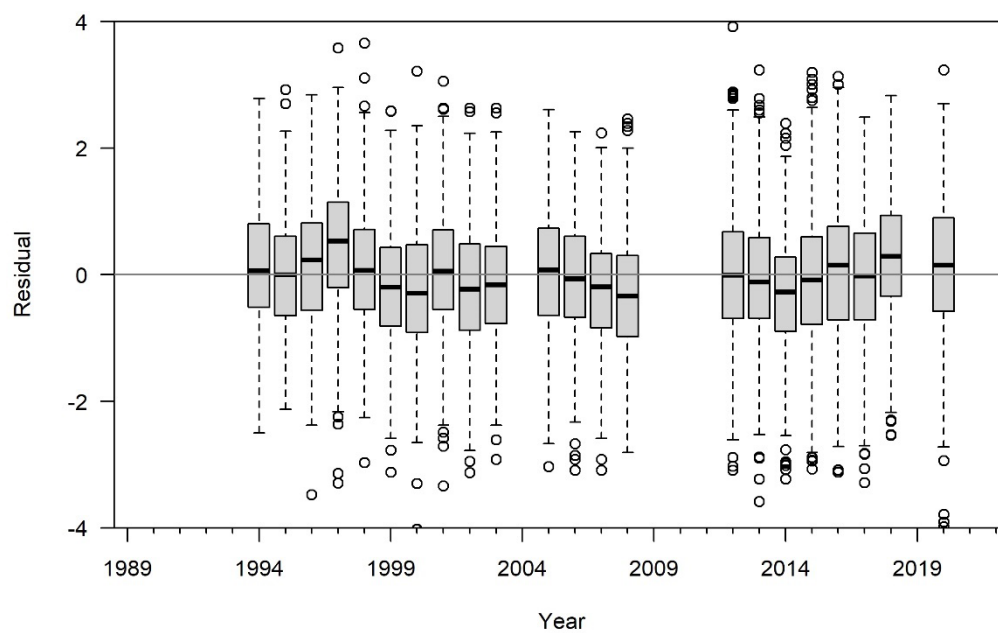
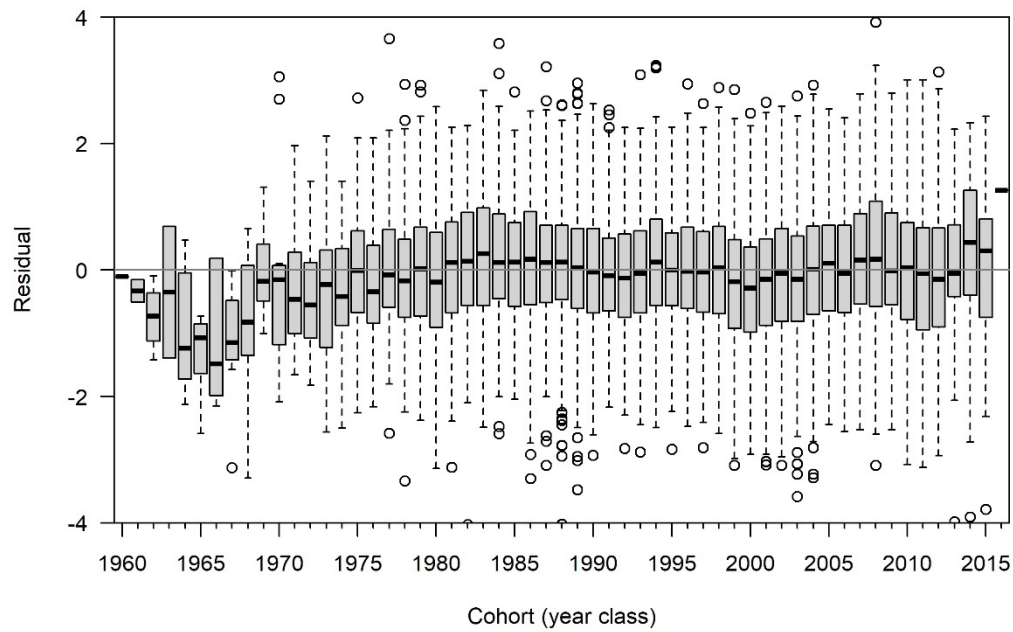


Figure C.6: Residuals of the maximum likelihood estimates for the von Bertalanffy models by cohort (top) or by calendar year (bottom).

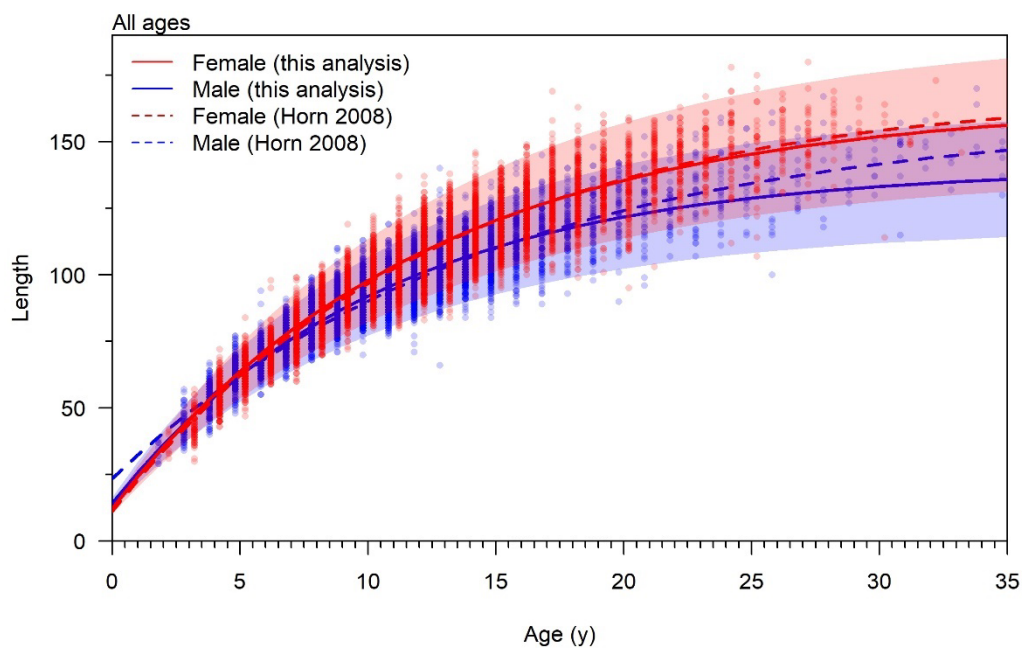


Figure C.7: Comparison of the maximum likelihood estimate for the von Bertalanffy models with the estimates from Horn (2005).

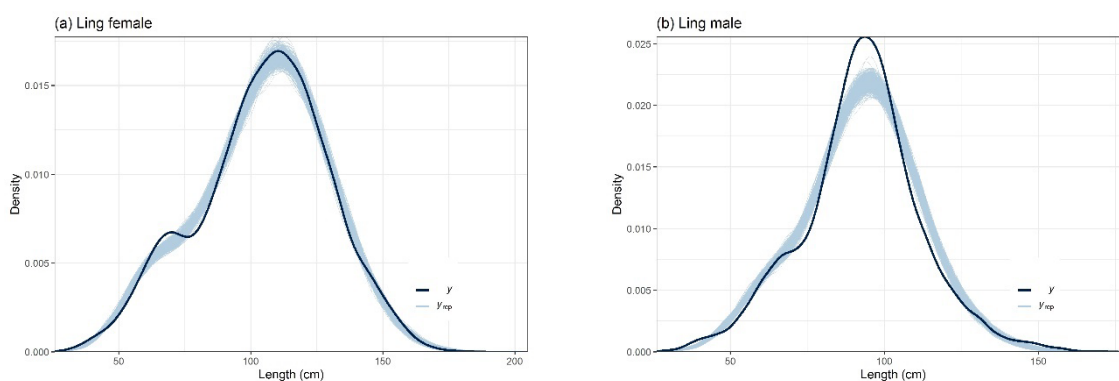


Figure C.8: Comparison of the empirical distribution of the data (y) to the posterior predictive distributions of simulated data (y_{rep}) from the Bayesian von Bertalanffy growth model by sex.

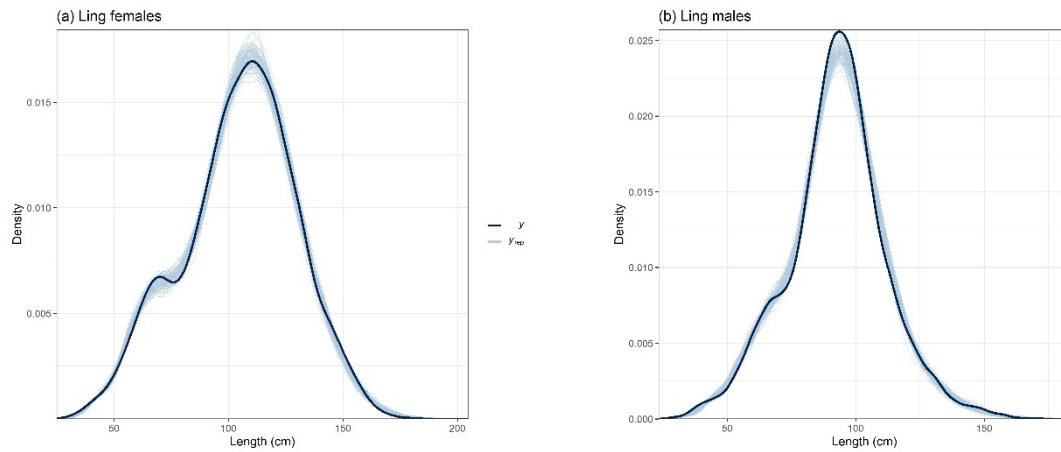


Figure C.9: Comparison of the empirical distribution of the data (y) to the posterior predictive distributions of simulated data (y_{rep}) from the Bayesian mean length-at-age growth model by sex.

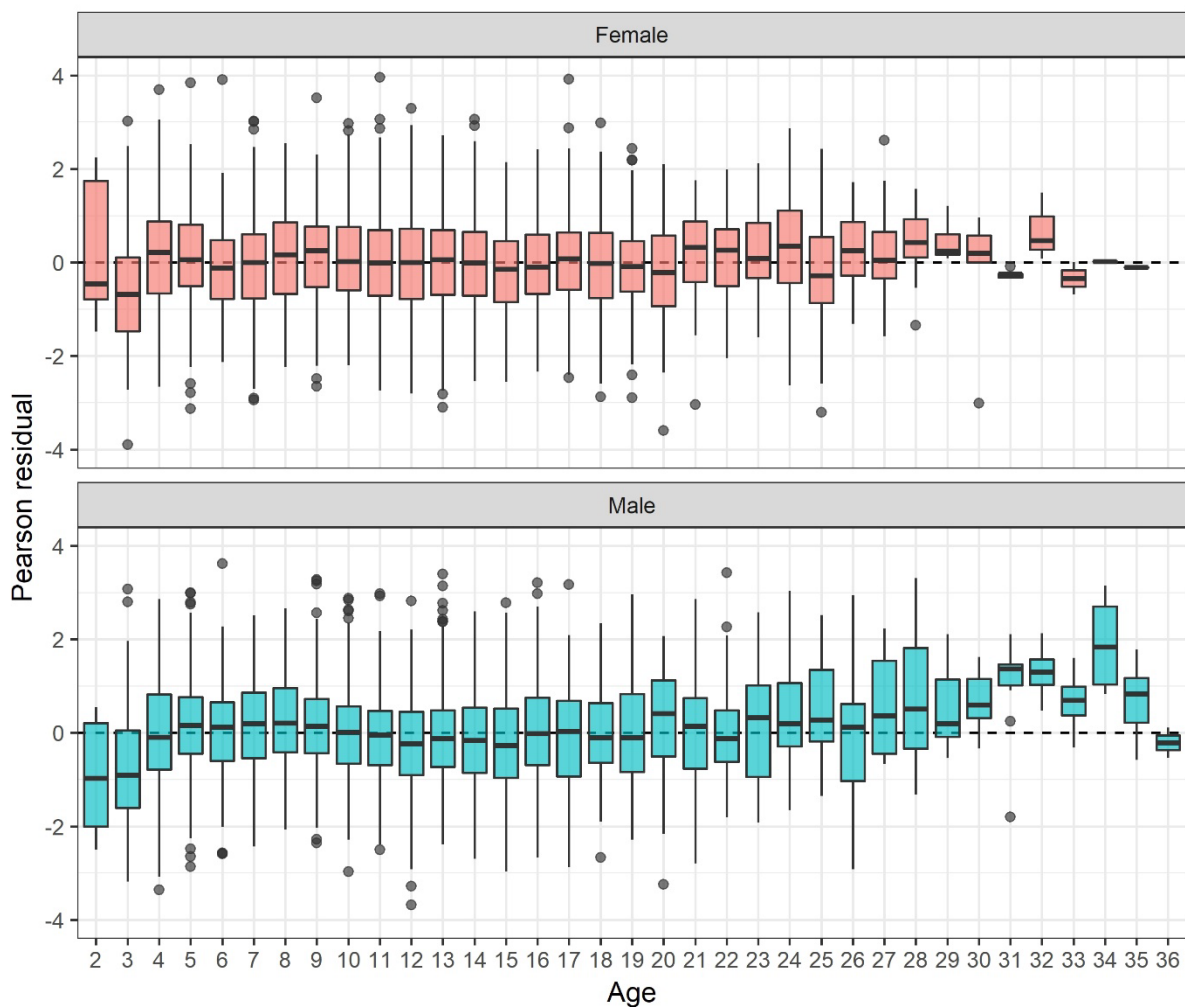


Figure C.10: Pearson residuals by age and sex from the Bayesian von Bertalanffy model .

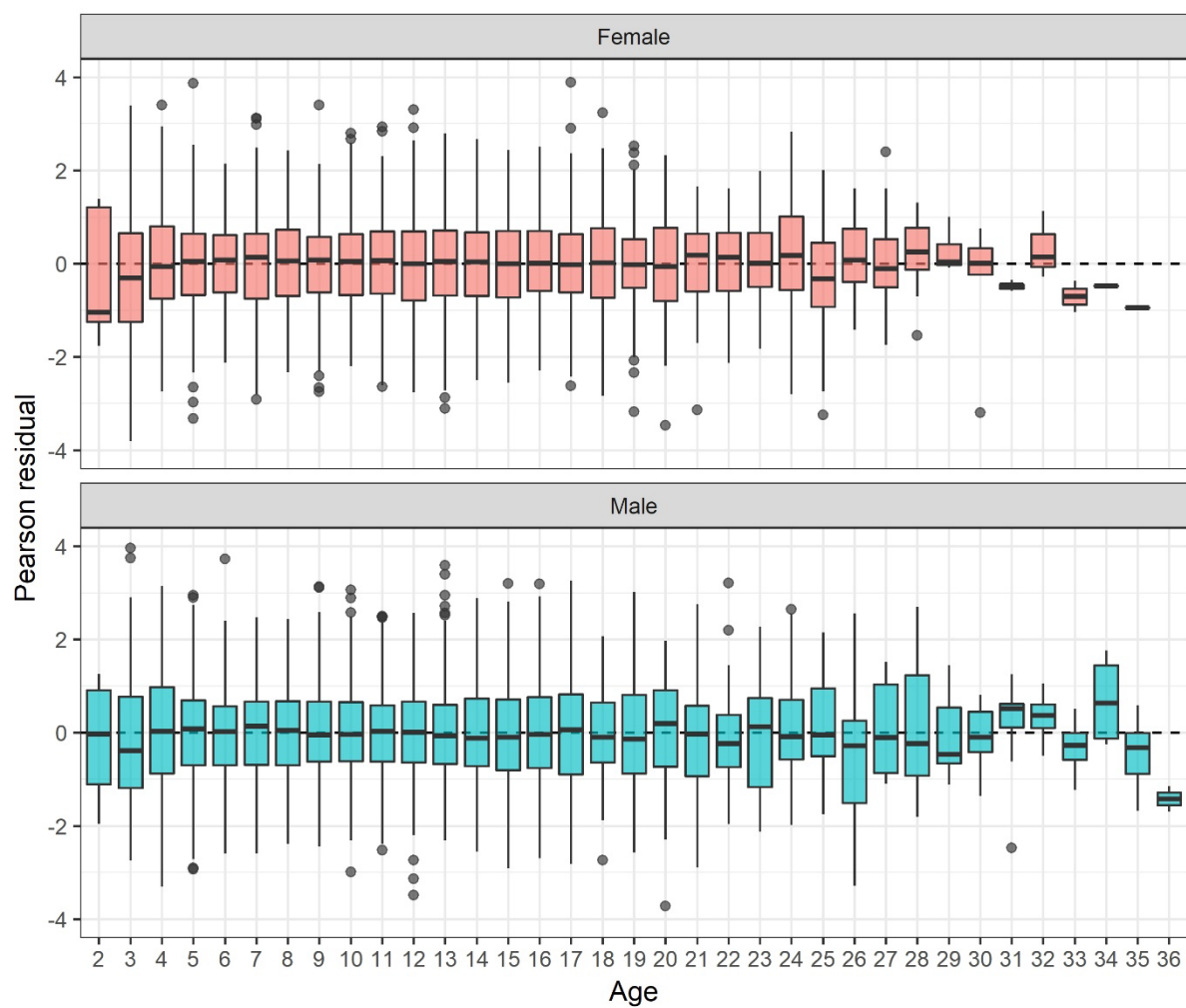


Figure C.11: Pearson residuals by age and sex from the Bayesian mean length-at-age model.

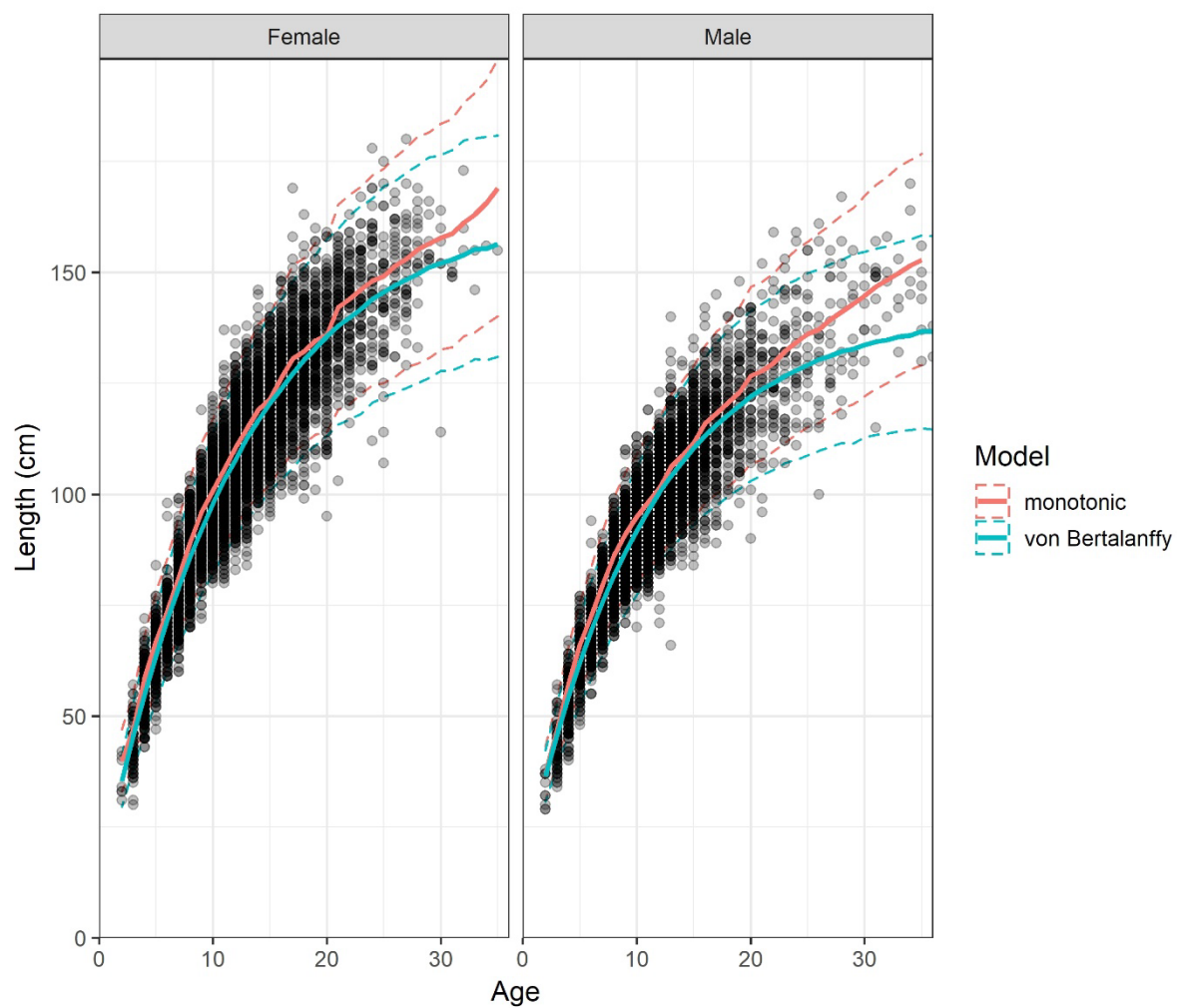


Figure C.12: Comparison of the Bayesian von Bertalanffy versus the mean length-at-age growth models (line is the mean and dashed lines represent the 95% credible interval of the posterior predictive distribution) to length-at-age observations (points) by sex.

14. APPENDIX D – CPUE ANALYSES FOR CHATHAM RISE LING (LIN 7WC)

Table D.1: Explanatory variables offered to the bottom trawl commercial CPUE model.

Variable	Type	Description
Year	Categorical	Model year (January to December)
Month	Categorical	Month of the year
Statistical area	Categorical	Statistical area
Vessel	Categorical	Unique vessel identifier
Day of year	6th degree spline	Julian date, starting on 1 September
Vessel experience	3rd degree spline	Experience of the vessel in number of years
Observed	Categorical	Whether an observer was onboard that day
Effort height	3 rd degree spline	Height of the net (m)
Effort width	3 rd degree spline	Wingspread (m)
Fishing depth	3 rd degree spline	Depth of the fishing gear (m)
Bottom depth	3 rd degree spline	Depth of the bottom (m)
Fishing duration	3 rd degree spline	Fishing duration (decimal hours)
Trawl speed	3 rd degree spline	Speed of towing (kph)
Start latitude	6 th degree spline	Latitude of the start position
Start longitude	6 th degree spline	Longitude of the start position (0–360 degrees)
Start time	3 rd degree spline	Time of the start point of the tow (decimal hours)
Time of mid tow	3 rd degree spline	Time of the mid point of the tow (decimal hours)
Grid	Categorical	Spatial grid of latitude and longitude at 0.5°)
Twin trawl	Categorical	Whether the trawl was a twin trawl or not
Method	Categorical	Whether the trawl was a bottom trawl (BT), midwater trawl (MW) or midwater trawl within 5 m of the bottom (MB)

Table D.2: Data selection for the bottom trawl commercial CPUE model.

Data source	TCEPR, ERS
Year range	1990–2022
Target species	hoki, hake, and ling
Rolling-up method	none
Statistical Areas	Statistical Areas 034–036, 703 (50 or more tows per area)
Catch per tow	< 10 t
Gear type	BT, MW, MB (MB=MW within 5 m of bottom depth)
Time of year	June to September
Vessel experience	Over 6 years in the fishery (~85% of ling catch)
Year definition	Calendar year
Bottom depth	150–900 m
Trawl duration	0.2–15 hours
Catches	Any record where ling is not recorded in the top 5 or top 5 QMS for ERS forms is given a ling catch of 0

Table D.3: Explanatory variables offered to the bottom longline rolled-up CPUE model.

Variable	Type	Description
Year	Categorical	Model year (November to October)
Month	Categorical	Month of the year
Statistical area	Categorical	Statistical area
Vessel	Categorical	Unique vessel identifier
Day of year	6 th degree spline	Julian date, starting on 1 September
Total hooks	4 th degree spline	Number of hooks set per day in a statistical area
Observed	Categorical	Whether an observer was onboard that day

Table D.4: Data selection for the bottom longline rolled-up CPUE model.

Data source	CELR, LTCER, LCER, ERS – lining
Year range	1990–2022
Target species	Ling only
Rolling-up method	By vessel, day, and statistical area
Statistical Areas	50 rolled-up records minimum (Statistical Areas 032–036)
Catch per record	< 15 t
Gear type	Bottom longline only
Number of hooks per line	Between 50 and 15 000
Vessel experience	Over 8 years in the fishery (~84% of ling catch)
Ling catch reporting position	Any record where ling is not recorded in the top 5 or top 5 QMS for ERS forms is given a ling catch of 0 (<0.01% of catch)
Year definition	Model year: January to December

Table D.5: Variables in order of decreasing explanatory value for the lognormal model for the commercial trawl CPUE of ling off the west coast of the South Island (LIN 7WC). The variables which each explain more than 1% of the deviance (r^2) are above the horizontal line and were retained in the model. Df = degrees of freedom.

Step	Df	Deviance	Residual Df	Residual Deviance	r^2	AIC
Year			69 514	78 200	0.01	205 589
Vessel	66	6 240	69 448	71 960	0.09	199 938
Effort height	3	4 710	69 445	67 250	0.15	195 237
Fishing depth	3	1 666	69 442	65 585	0.17	193 498
Fishing duration	3	1 308	69 439	64 277	0.18	192 103
Start latitude	6	1 299	69 433	62 978	0.20	190 696
Start longitude	6	1 377	69 427	61 601	0.22	189 170
Time of mid tow	3	1 018	69 424	60 583	0.23	188 018
Month	3	662	69 421	59 921	0.24	187 259
Grid	37	384	69 384	59 537	0.24	186 886
Time start	3	222	69 381	59 315	0.25	186 632
Vessel experience	3	113	69 378	59 202	0.25	186 505
Day	6	109	69 372	59 093	0.25	186 390
Effort width	3	47	69 369	59 046	0.25	186 340
Twin trawl	2	30	69 368	59 016	0.25	186 307
Bottom depth	3	16	69 365	59 000	0.25	186 293
Statistical area	5	13	69 361	58 987	0.25	186 286
Observed	2	11	69 360	58 976	0.25	186 276
Trawl speed	3	6	69 357	58 970	0.25	186 275
Method	2	3	69 355	58 968	0.25	186 276

Table D.6: Variables in order of decreasing explanatory value for the binomial model for the commercial trawl CPUE of the ling stock off the west coast of the South Island (LIN 7WC). The variables which each explain more than 1% of the deviance (r^2) are above the horizontal line and were retained in the model. Df = degrees of freedom.

Step	Df	Deviance	Residual Df	Residual Deviance	r^2	AIC
Year			132 159	166 276	0.09	166 342
Method	2	9 263	132 157	157 014	0.14	157 084
Vessel	66	10 741	132 091	146 272	0.20	146 474
Fishing depth	3	6 572	132 088	139 700	0.24	139 908
Start latitude	6	3 795	132 082	135 905	0.26	136 125
Month	3	2 021	132 079	133 884	0.27	134 110
Start longitude	6	1 404	132 073	132 479	0.28	132 717
Duration	3	925	132 070	131 555	0.28	131 799
Grid	39	446	132 031	131 109	0.28	131 431
Day	6	275	132 025	130 834	0.28	131 168
Observed	1	235	132 024	130 599	0.29	130 935
Effort width	3	210	132 021	130 389	0.29	130 731
Experience	3	142	132 018	130 247	0.29	130 595
Time of mid tow	3	132	132 015	130 115	0.29	130 469
Bottom depth	3	77	132 012	130 038	0.29	130 398
Twin trawls	1	55	132 011	129 982	0.29	130 344
Time start of tow	3	40	132 008	129 942	0.29	130 310
Statistical area	4	17	132 004	129 925	0.29	130 301
Trawl speed	3	15	132 001	129 910	0.29	130 292
Effort height	3	10	131 998	129 900	0.29	130 288

Table D.7: Variables in order of decreasing explanatory value for the rolled-up longline CPUE for ling off the west coast of the South Island (LIN 7WC). The variables which each explain more than 1% of the deviance (r^2) are above the horizontal line and were retained in the model. Df = degrees of freedom.

Step	Df	Deviance	Residual Df	Residual Deviance	r^2	AIC
Year			13 372	9 618	0.11	33 656
Hooks	4	1 978	13 368	7 640	0.29	30 578
Month	11	976	13 357	6 664	0.38	28 768
Vessel	11	484	13 346	6 180	0.43	27 779
Statistical area	4	22	13 342	6 158	0.43	27 738
Day	6	8	13 336	6 150	0.43	27 733
Observed	1	0	13 335	6 149	0.43	27 735

Table D.8: CPUE standardised indices for the ling stock off the west coast of the South Island (LIN 7WC) rolled-up bottom longline fishery and commercial trawl fishery and CVs as used in the stock assessment. Year is calendar year.

Year	Longline		Trawl	
	CPUE	CV	CPUE	CV
1991	1 450	0.06	—	—
1992	1 590	0.05	—	—
1993	1 220	0.06	—	—
1994	1 260	0.06	—	—
1995	1 290	0.06	—	—
1996	770	0.10	—	—
1997	1 080	0.07	42 964	0.02
1998	1 170	0.06	39 951	0.03
1999	1 210	0.06	43 587	0.02
2000	1 220	0.06	35 601	0.03
2001	1 500	0.05	33 429	0.03
2002	1 390	0.05	30 237	0.03
2003	1 450	0.05	23 348	0.04
2004	1 510	0.05	27 982	0.04
2005	1 090	0.06	24 750	0.04
2006	1 060	0.06	26 303	0.04
2007	1 540	0.04	26 873	0.04
2008	1 440	0.05	25 219	0.05
2009	1 490	0.05	33 698	0.04
2010	1 760	0.04	28 666	0.04
2011	1 620	0.04	30 411	0.03
2012	1 650	0.04	27 911	0.04
2013	1 830	0.04	33 891	0.03
2014	1 760	0.04	31 796	0.03
2015	1 500	0.04	32 743	0.03
2016	1 490	0.04	34 304	0.03
2017	1 600	0.04	34 669	0.03
2018	1 540	0.05	30 621	0.03
2019	1 650	0.04	30 934	0.04
2020	1 520	0.04	30 023	0.04
2021	1 240	0.05	28 896	0.04
2022	1 080	0.06	25 544	0.05

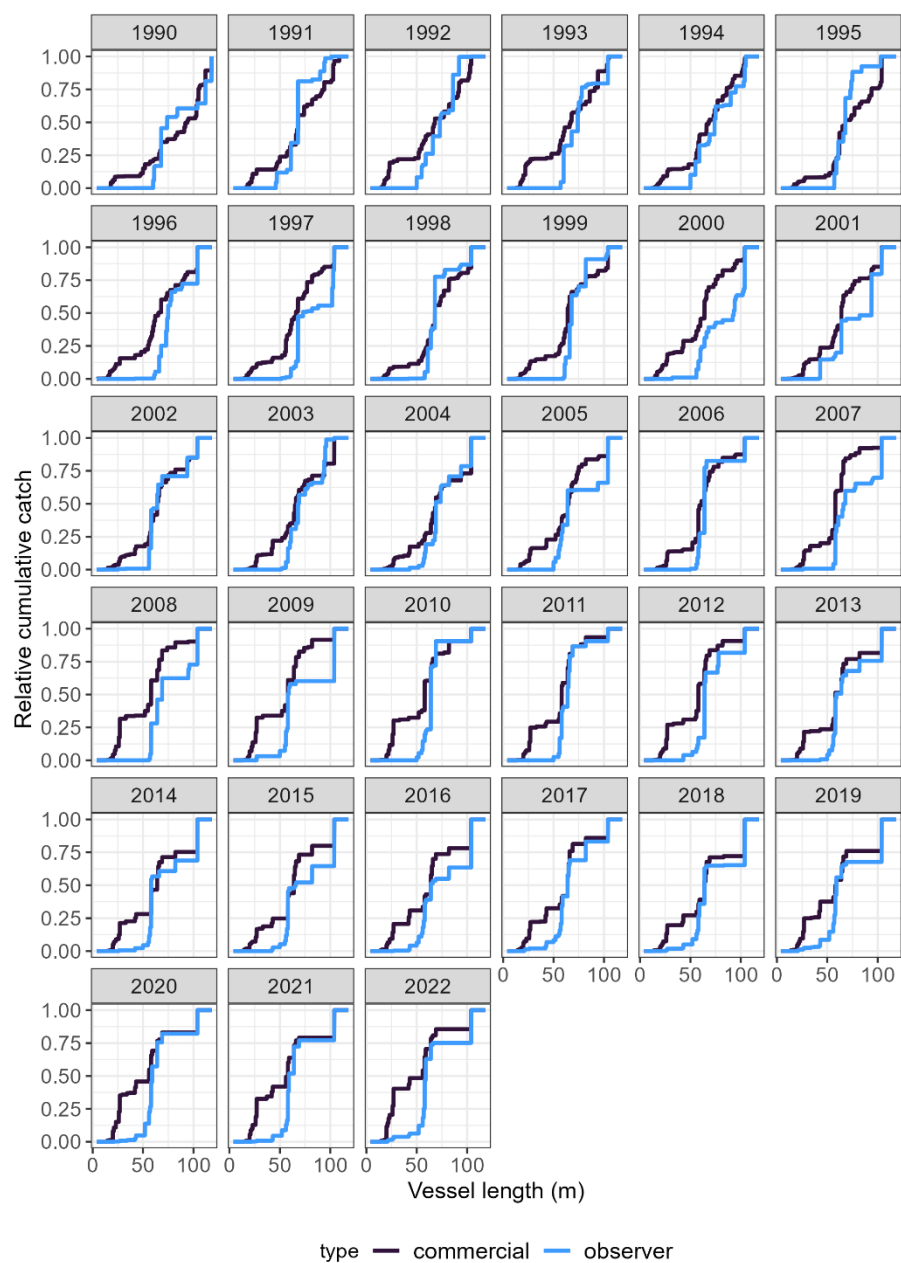


Figure D.1: Relative cumulative catch by calendar year and vessel length of the commercial and observer data.

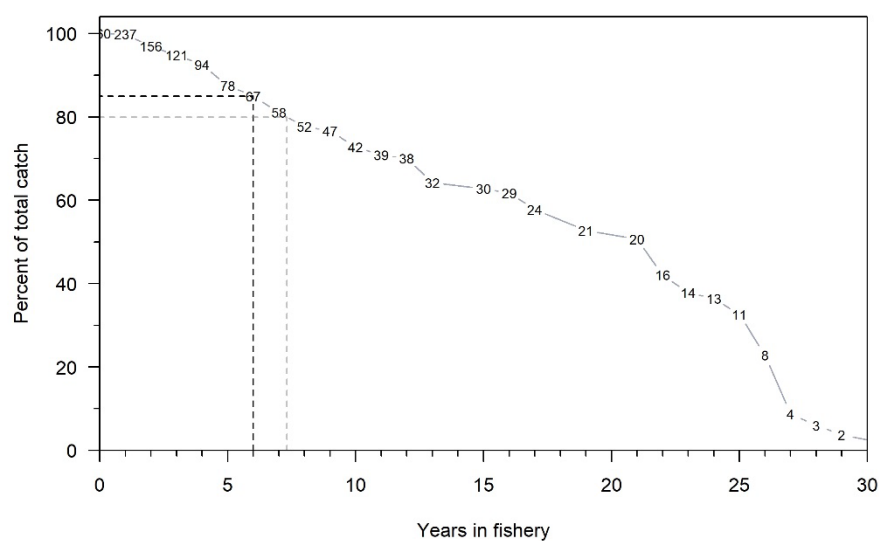
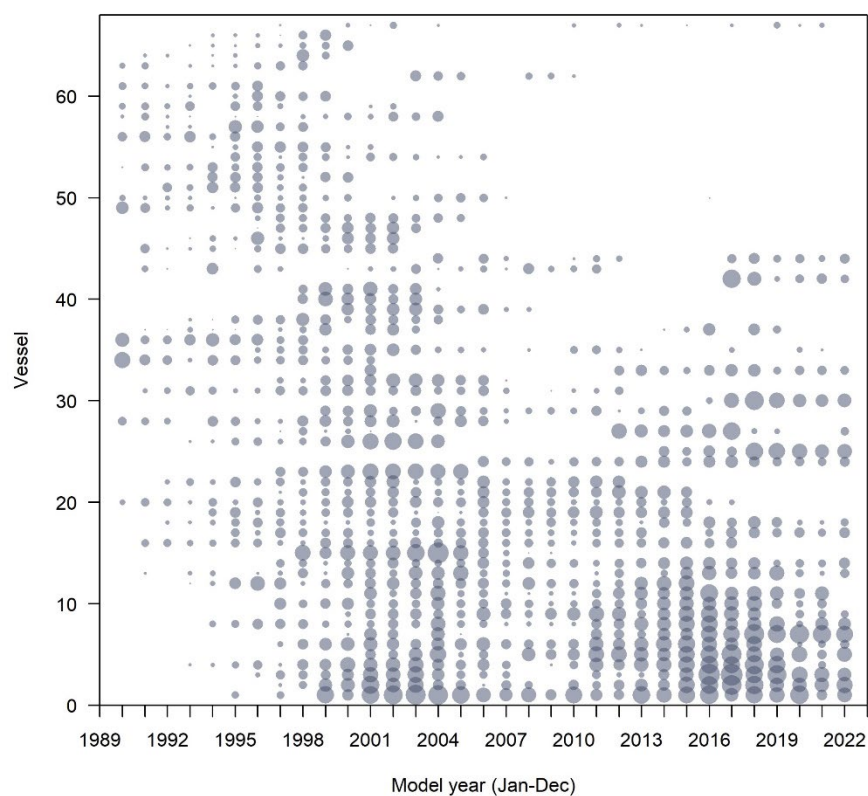


Figure D.2: Core vessel selection for the bottom trawl commercial CPUE model for ling off the west coast of the South Island (LIN 7WC): annual catch per vessel over time (top) and proportion of total catch per vessel experience (bottom).

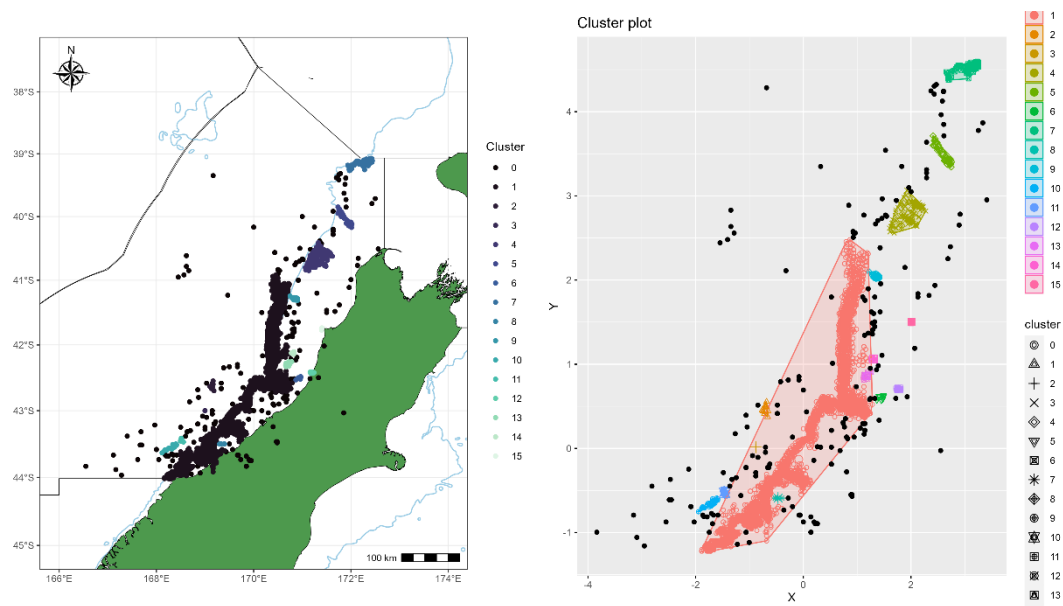


Figure D.3: Clusters of longline effort based on location, plotted spatially in relation to the stock area (left) and in projected space in relation to the clusters (right). Cluster 1 constitutes 94% of the longline effort and 95% of the longline catch.

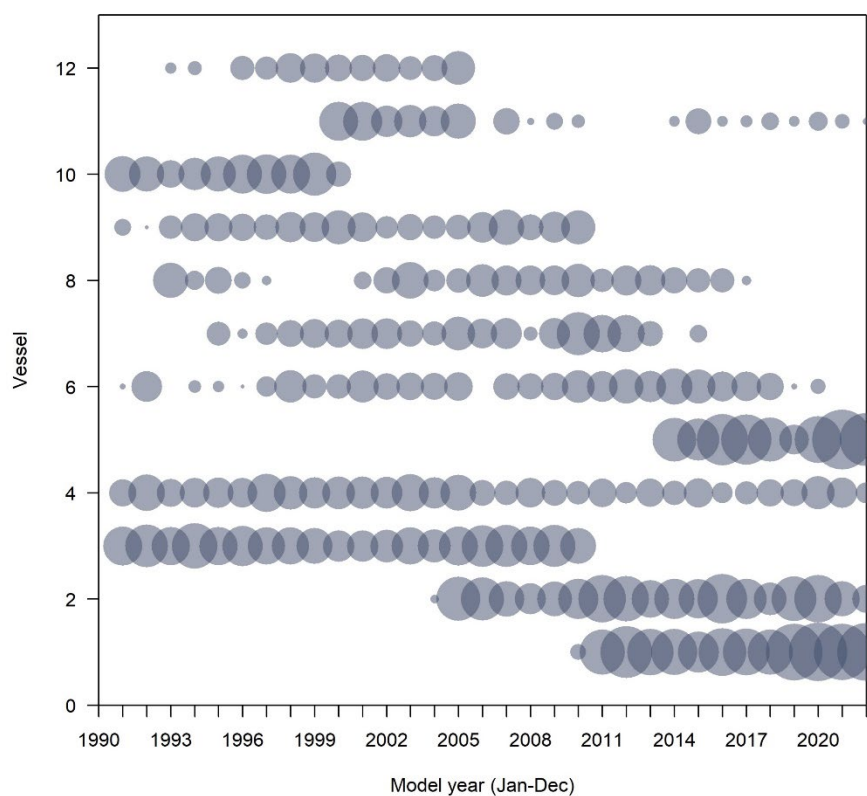


Figure D.4: Core vessel selection for the bottom longline CPUE model for ling off the west coast of the South Island (LIN 7WC): annual catch by vessel over time (top) and proportion of total catch by vessel experience (bottom).

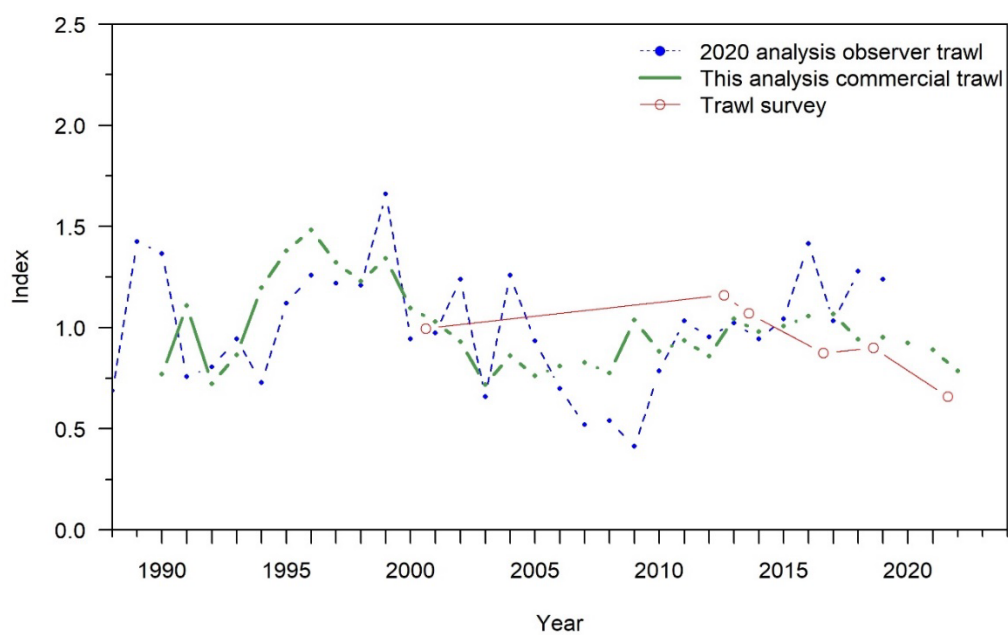


Figure D.5: Year index for the combined model for the bottom trawl CPUE of ling off the west coast of the South Island (LIN 7WC). Also plotted are the 2020 indices (Dutilloy 2021) and the west coast South Island trawl survey biomass series (Fisheries New Zealand 2023). Year was model year which was defined as calendar year.

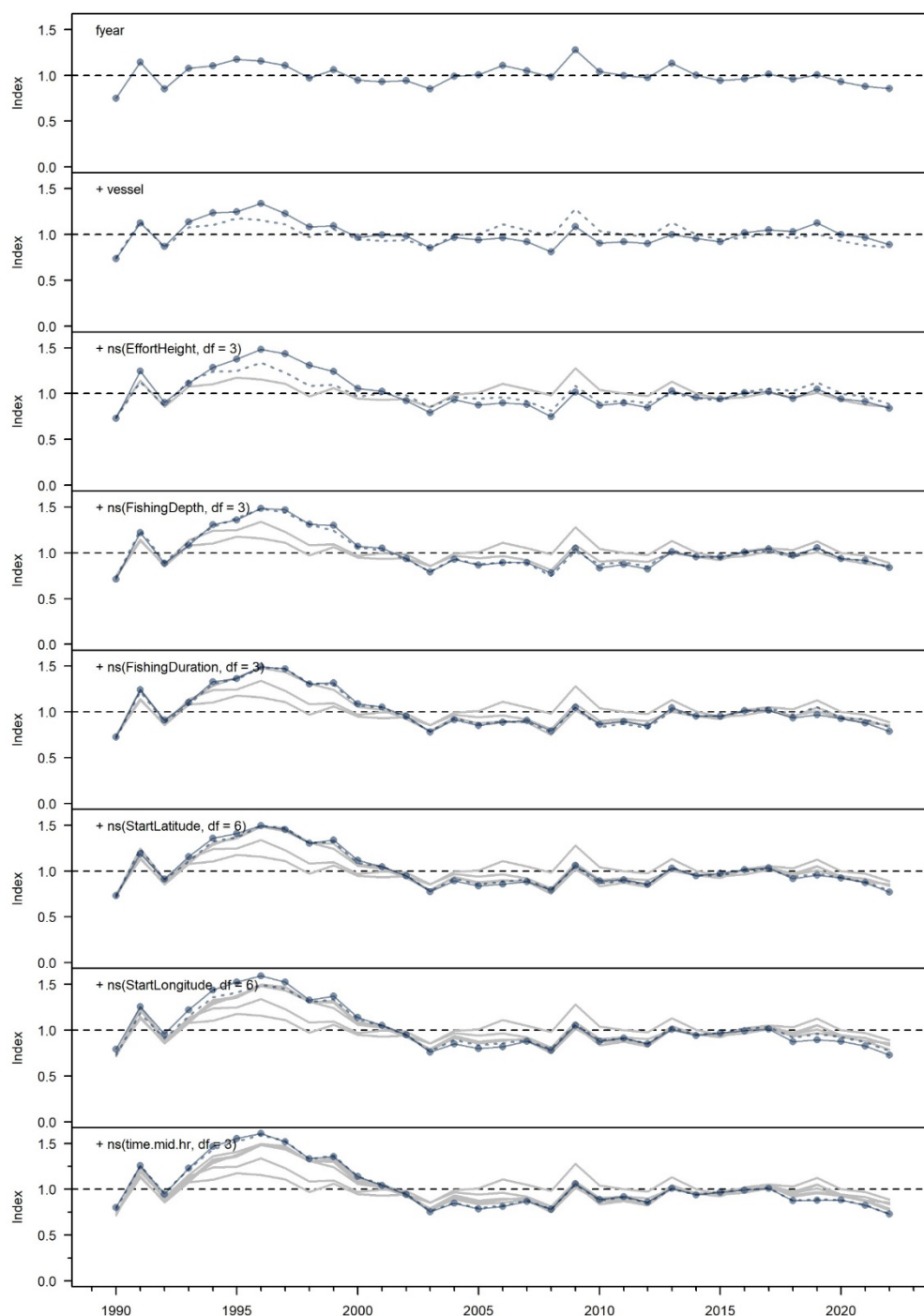


Figure D.6: Influence plots for the lognormal model for the bottom trawl CPUE for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters were constant at their median or modal value. Year is model year which was defined as calendar year.

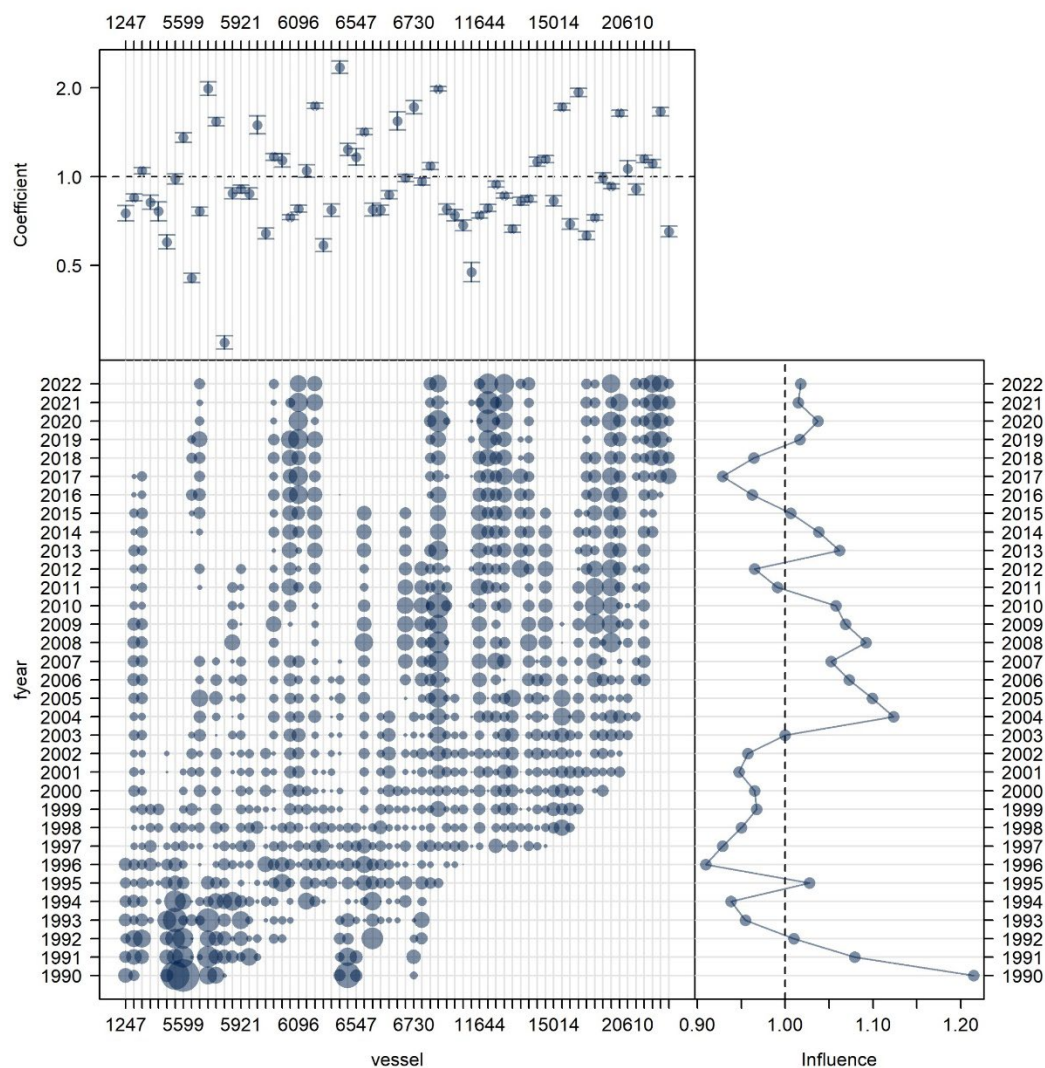


Figure D.7: Influence plots for the lognormal model for the bottom trawl CPUE for vessel identifier in relation to year, assuming all other parameters were constant at their median or modal value. Year is model year which was defined as calendar year.

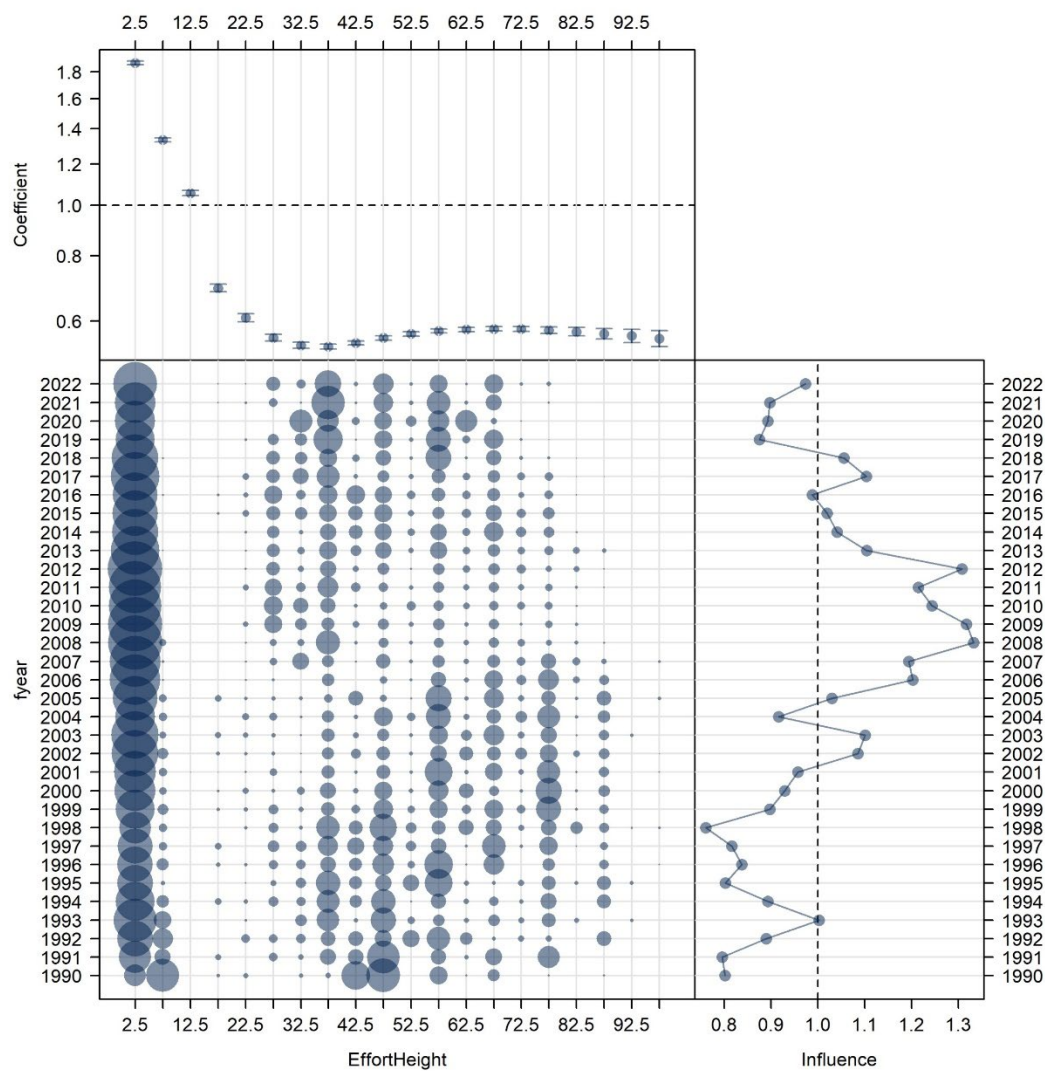


Figure D.8: Influence plots for the lognormal model for the bottom trawl CPUE for effort height (m) in relation to year, assuming all other parameters were constant at their median or modal value. Year is model year which was defined as calendar year.

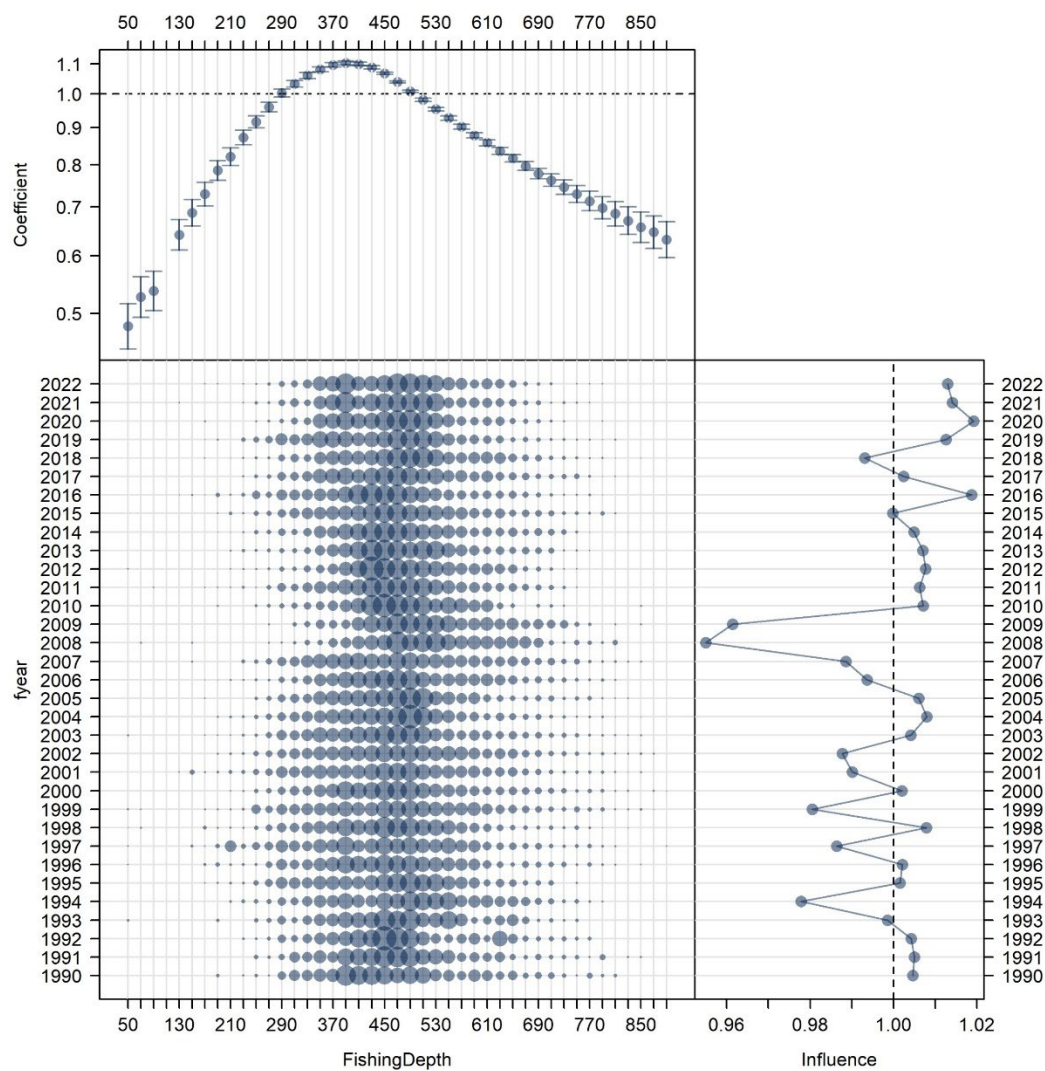


Figure D.9: Influence plots for the lognormal model for the bottom trawl CPUE for fishing depth (m) in relation to year, assuming all other parameters were constant at their median or modal value. Year is model year which was defined as calendar year.

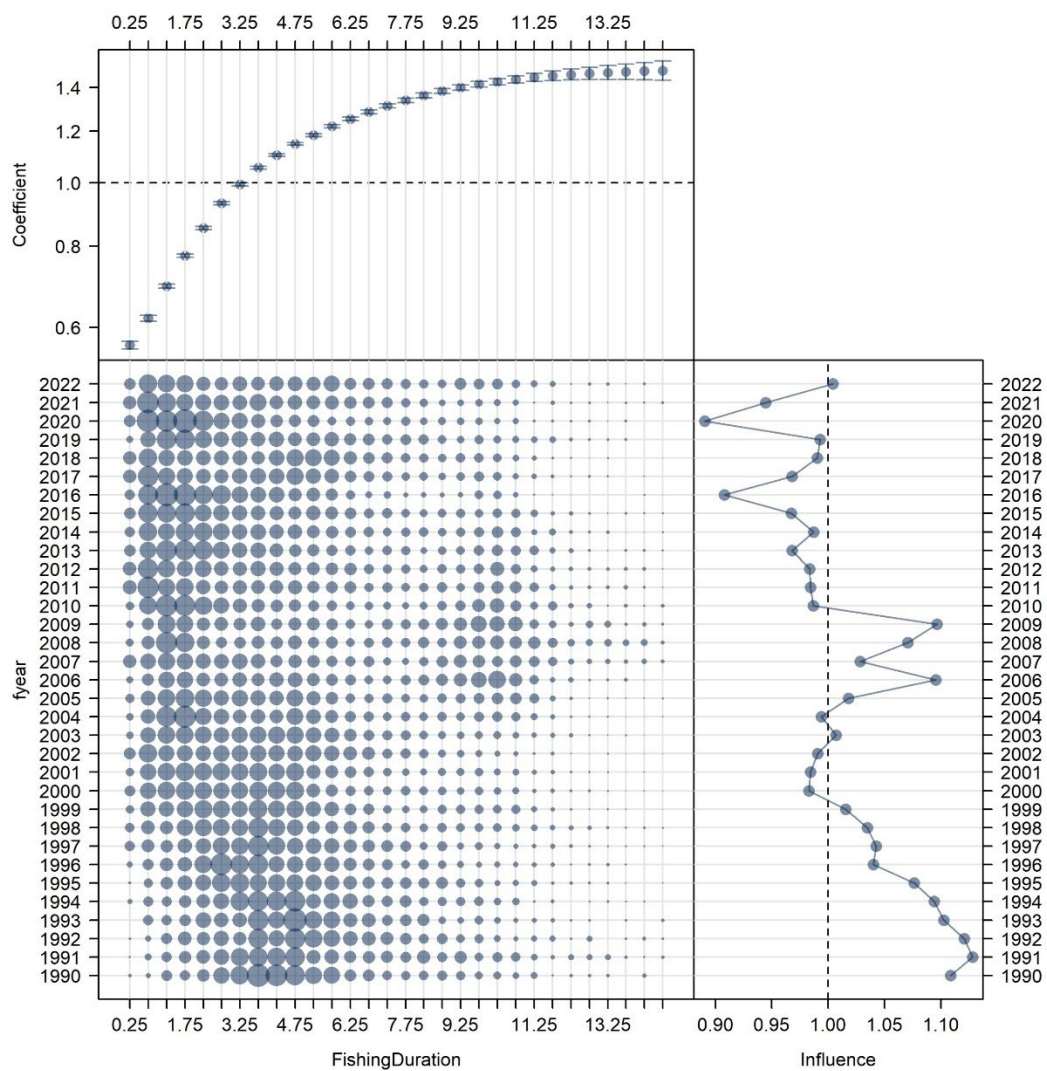


Figure D.10: Influence plots for the lognormal model for the bottom trawl CPUE for fishing duration (hours) in relation to year, assuming all other parameters were constant at their median or modal value. Year is model year which was defined as calendar year.

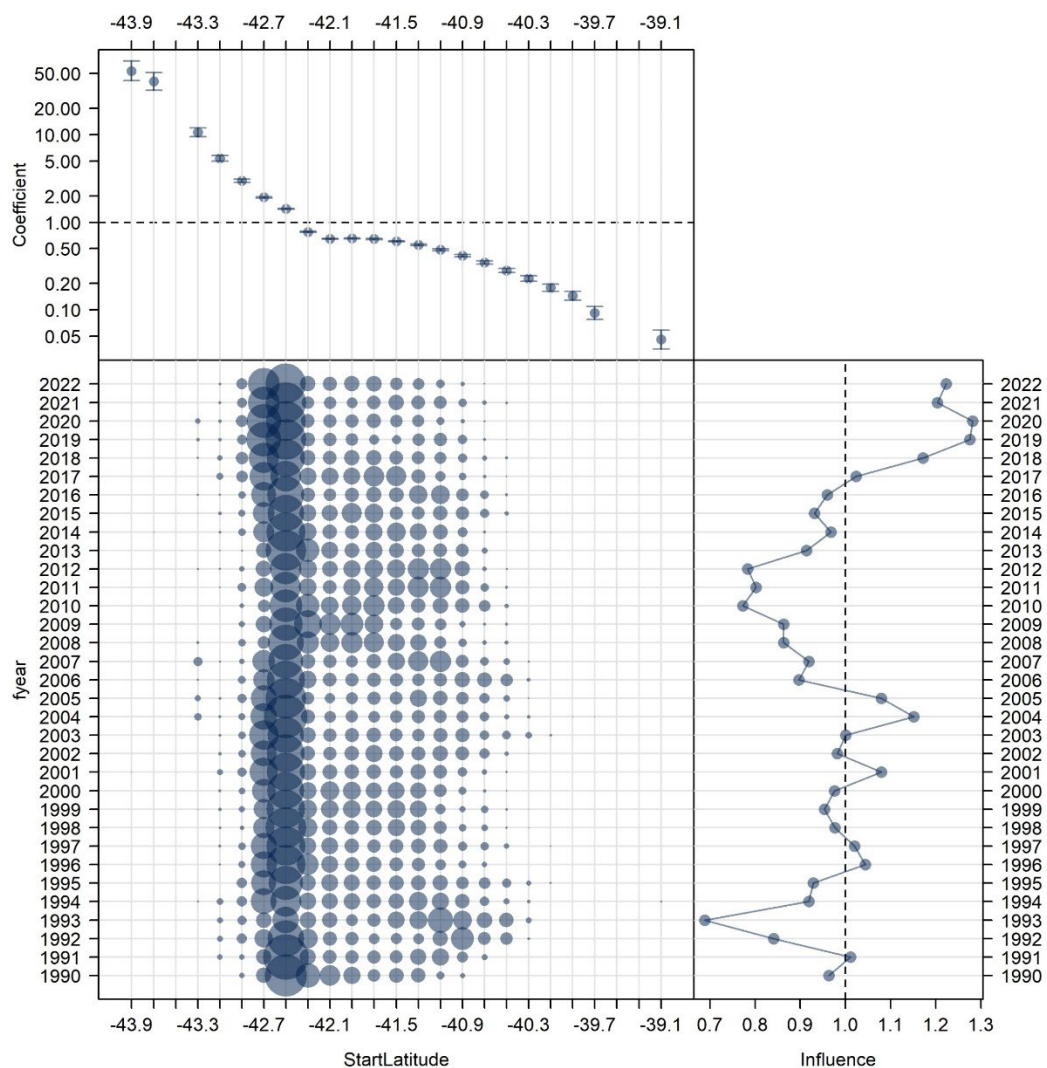


Figure D.11: Influence plots for the lognormal model for the bottom trawl CPUE for the latitude of the start of the tow in relation to year, assuming all other parameters were constant at their median or modal value. Year is model year which was defined as calendar year.

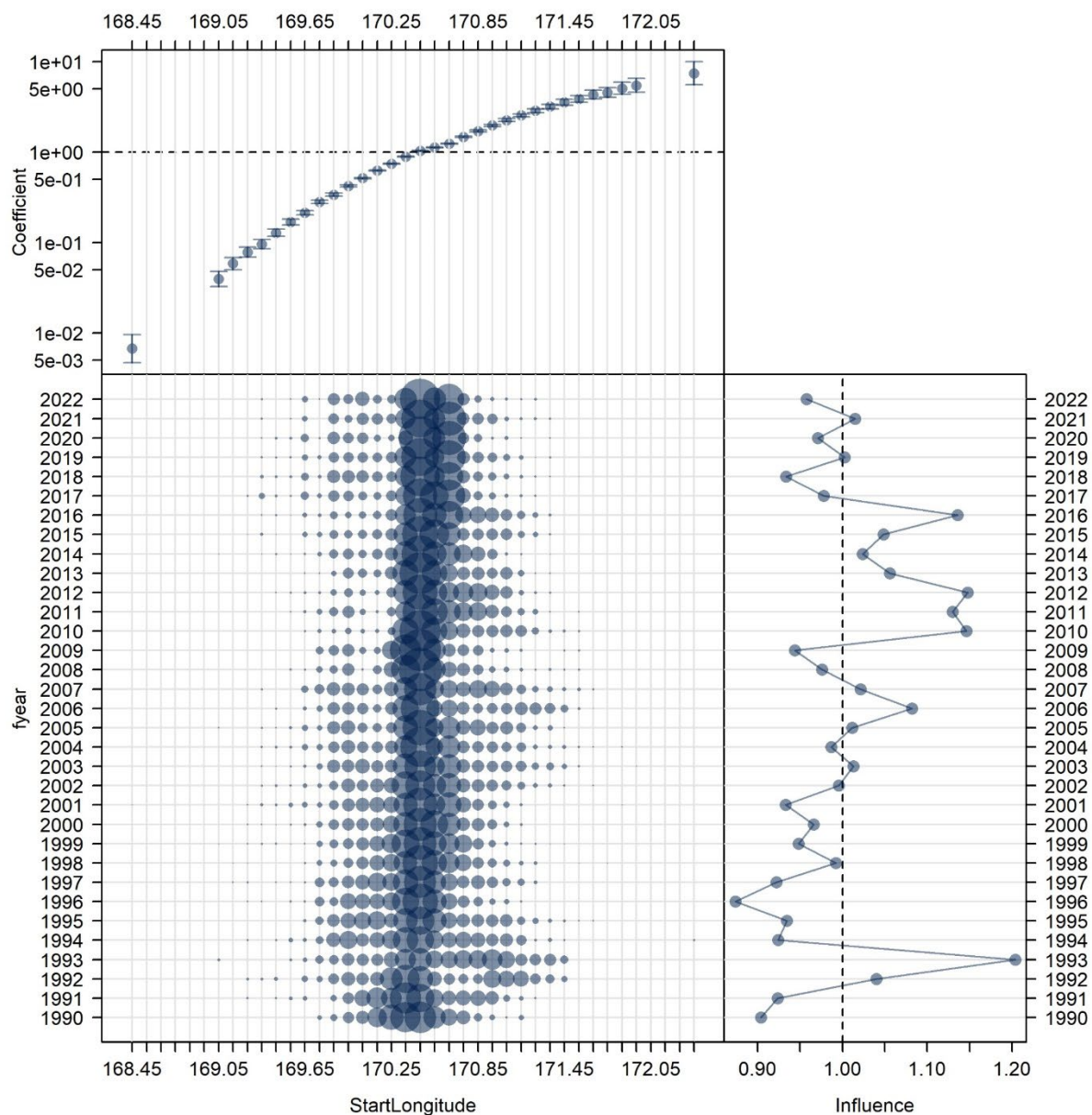


Figure D.12: Influence plots for the lognormal model for the bottom trawl CPUE for the longitude of the start of the tow in relation to year, assuming all other parameters were constant at their median or modal value. Year is model year which was defined as calendar year.

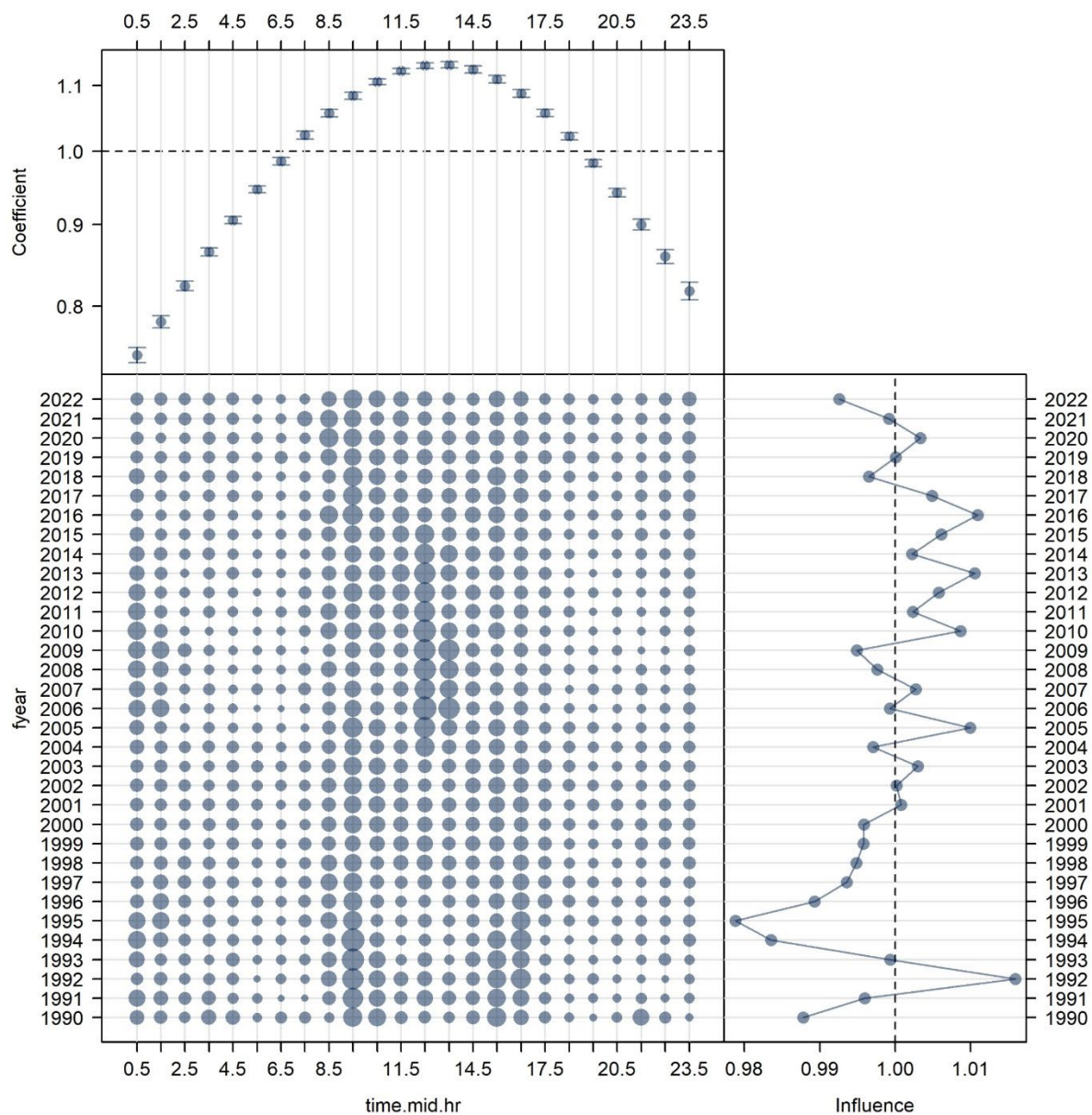


Figure D.13: Influence plots for the lognormal model for the bottom trawl CPUE for the time of mid tow (hours) in relation to year, assuming all other parameters were constant at their median or modal value. Year is model year which was defined as calendar year.

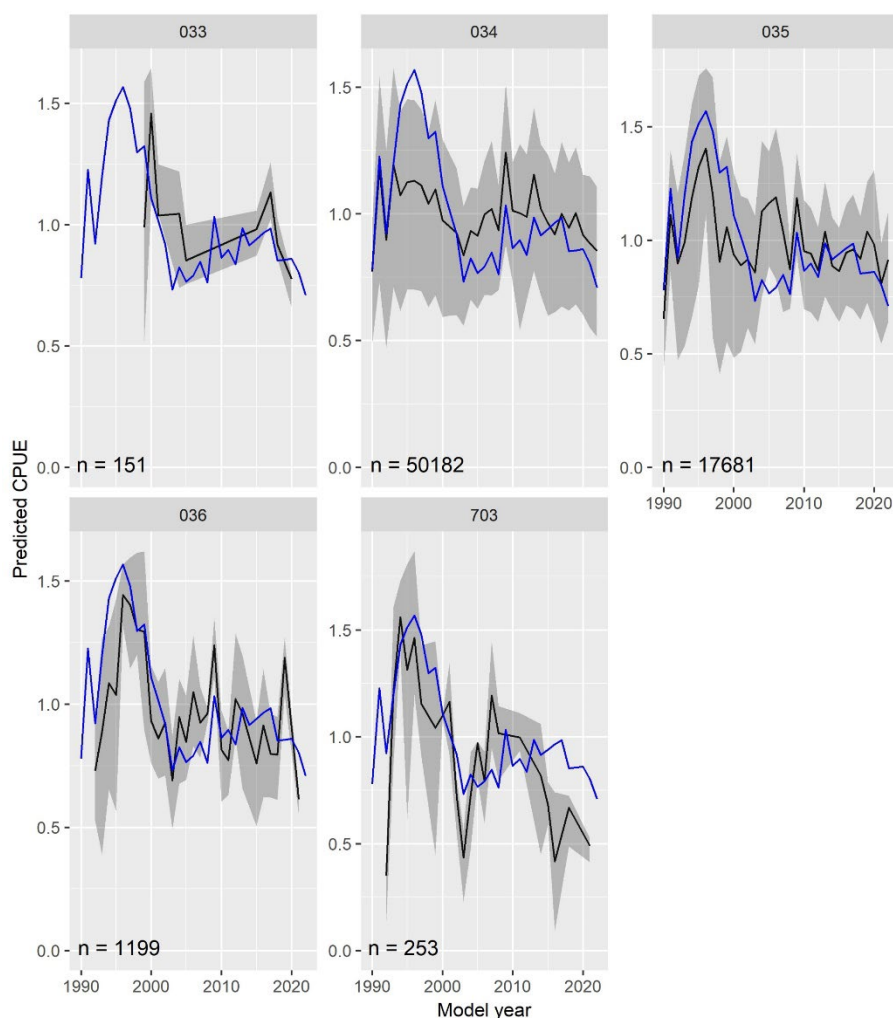


Figure D.14: Implied trends by statistical area for the lognormal model for the bottom trawl CPUE. The black trend and grey band represent the predicted mean standardised catch rate and interquartile range, and the blue trend the predicted year effect of the standardised CPUE. Year was model year which was defined as calendar year. Only years where at least three vessels participated in any statistical area are depicted; n represents the number of rolled-up records where at least three vessels participated in any one year.

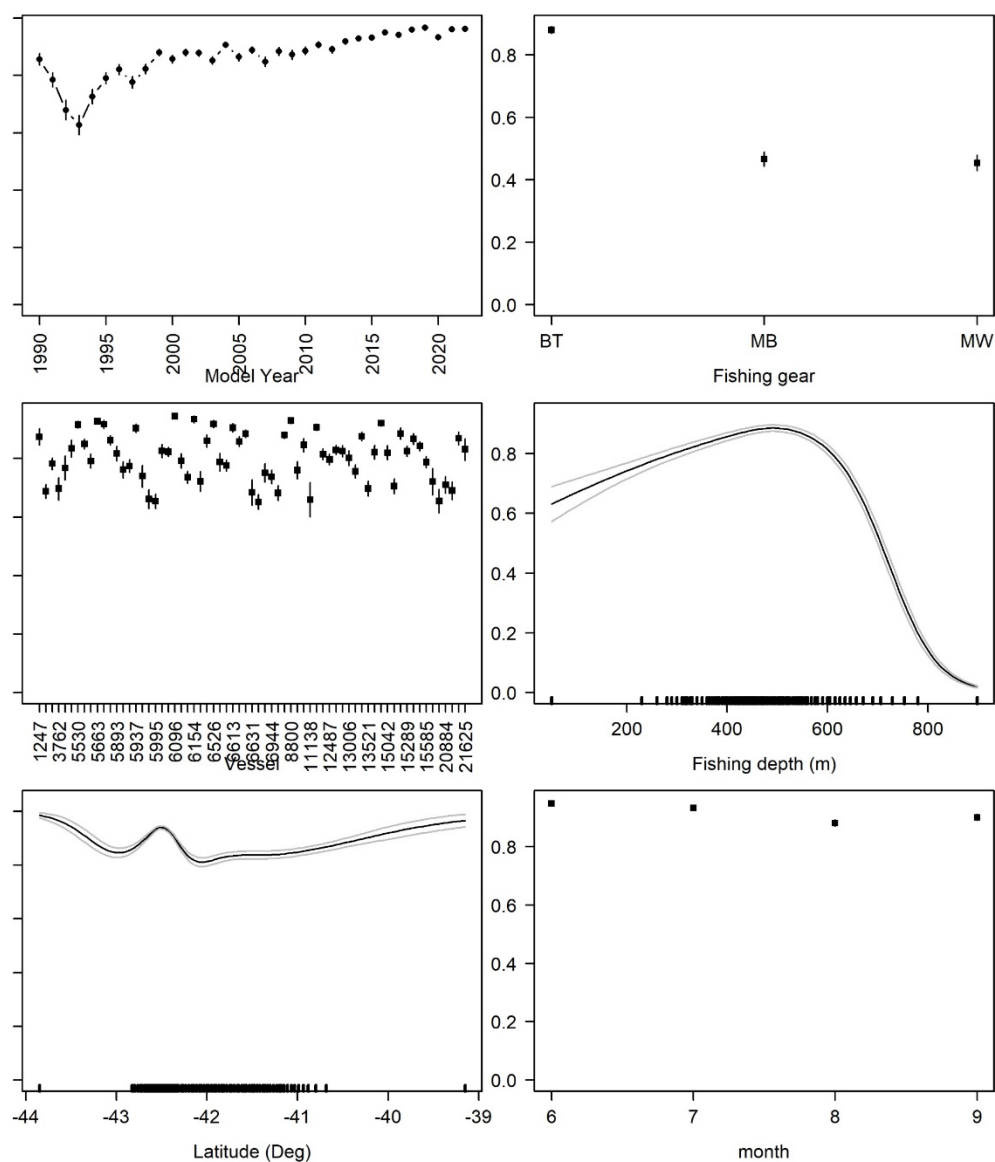


Figure D.15: Effects plots for the binomial model for the bottom trawl CPUE for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters were constant at their median or modal value. Year was model year which was defined as the calendar year. Month 6 is June.

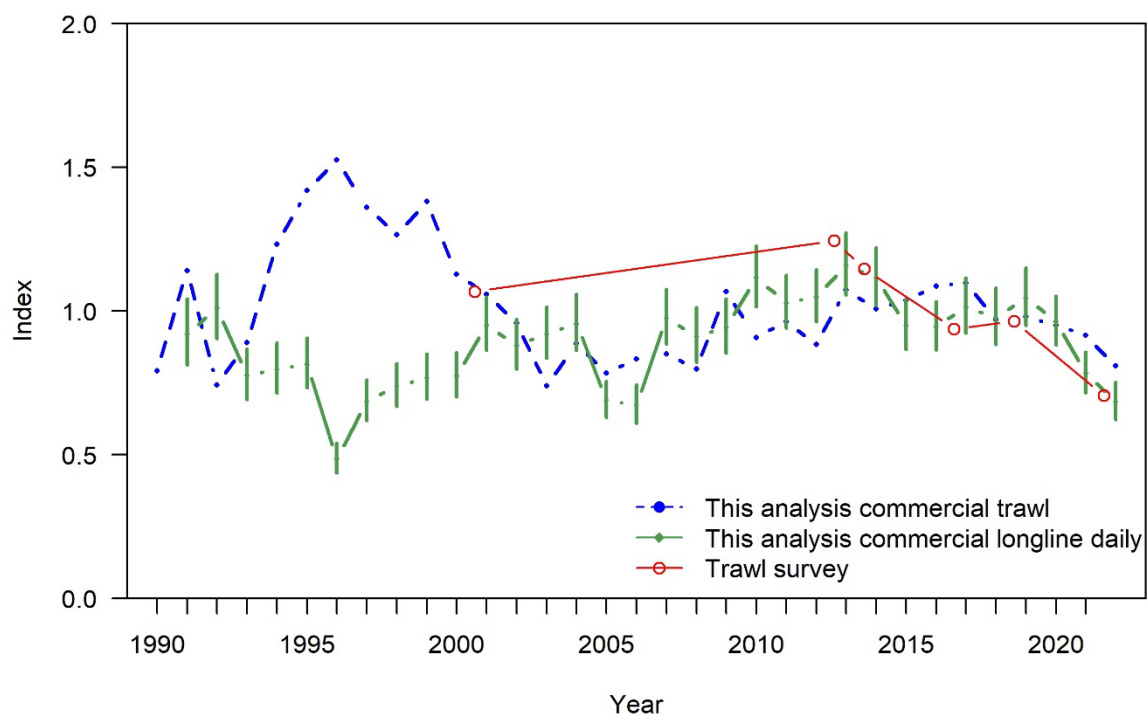


Figure D.16: Year index for the lognormal model for the rolled-up bottom longline CPUE for ling off the west coast of the South Island (LIN 7WC). Also plotted is the bottom trawl CPUE from this analysis and the west coast South Island offshore trawl survey biomass series (Fisheries New Zealand 2023). Year was model year which was defined as the calendar year.

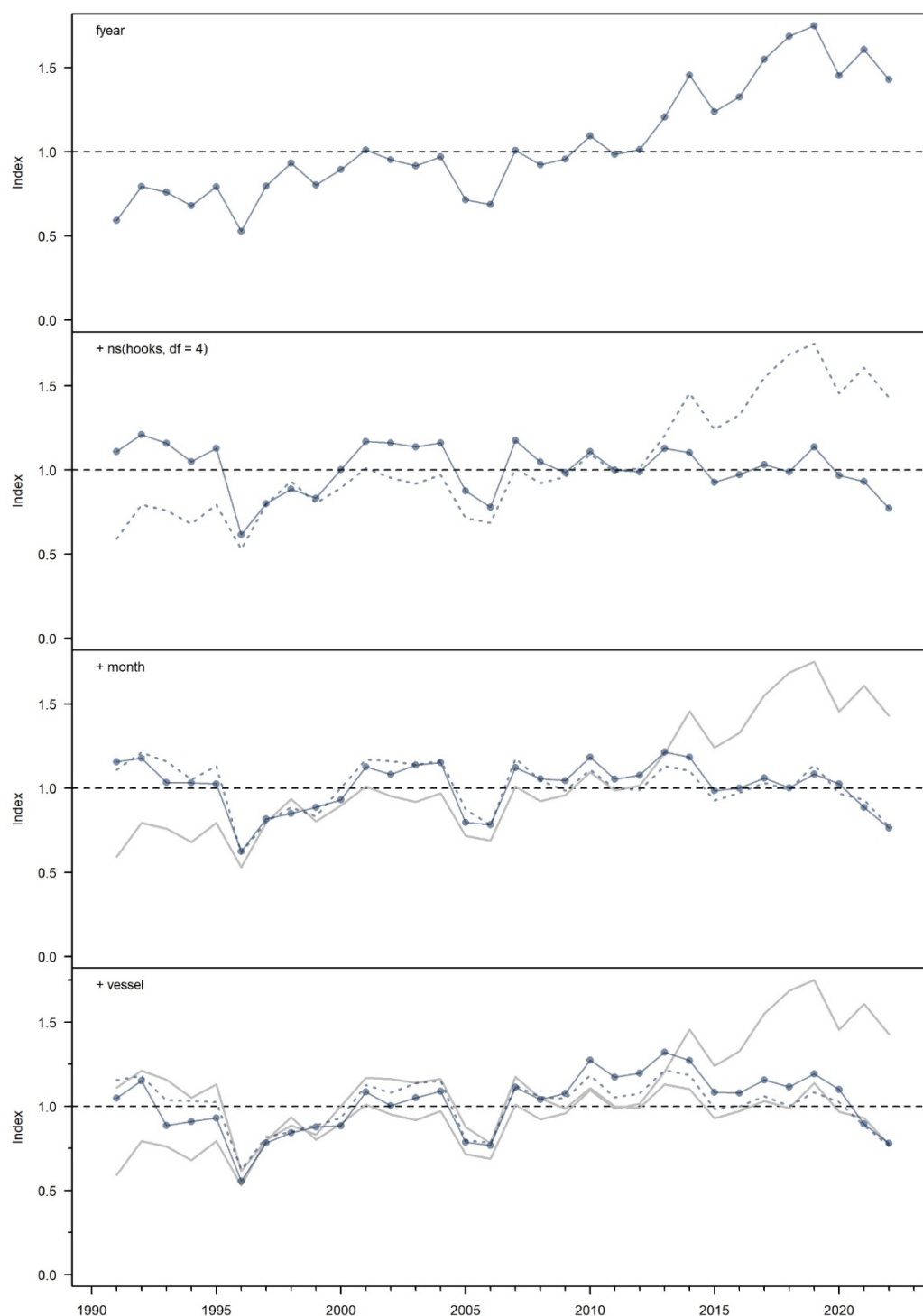


Figure D.17: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters were constant at their median or modal value. Year was model year which was defined as the calendar year.

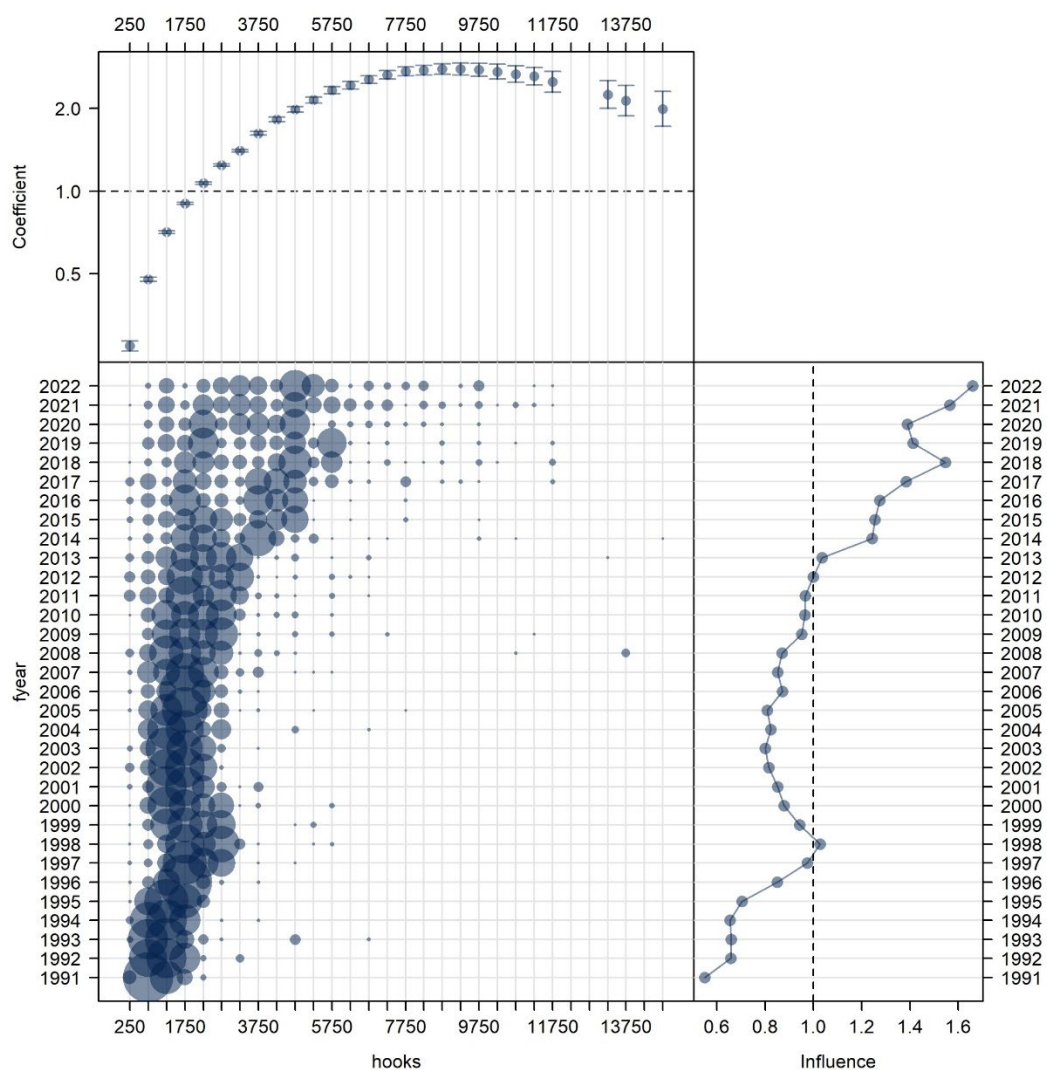


Figure D.18: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for the number of hooks (per set) in relation to year, assuming all other parameters were constant at their median or modal value. Year was model year which was defined as the calendar year.

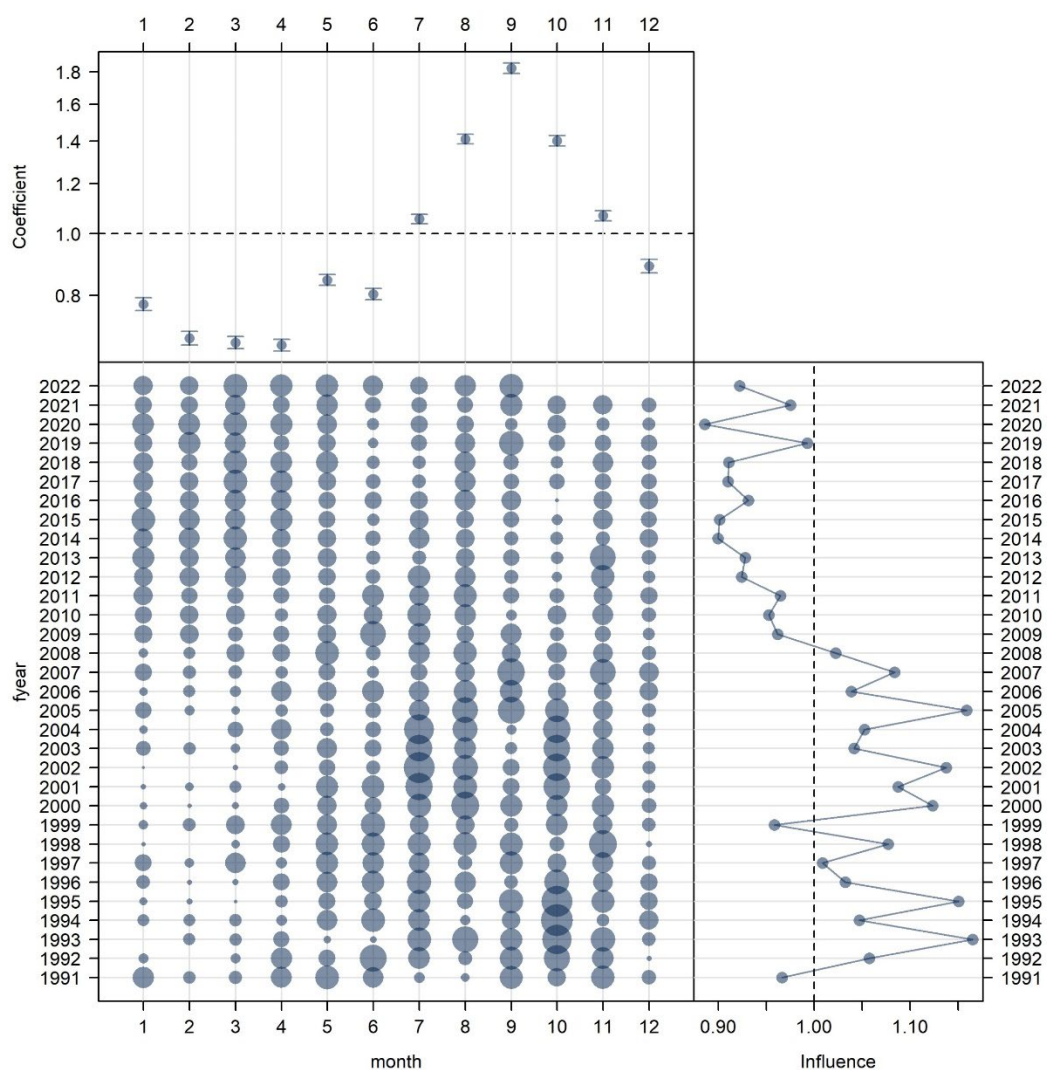


Figure D.19: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for month in relation to year, assuming all other parameters were constant at their median or modal value. Year was model year which was defined as the calendar year, and month 1 is January.

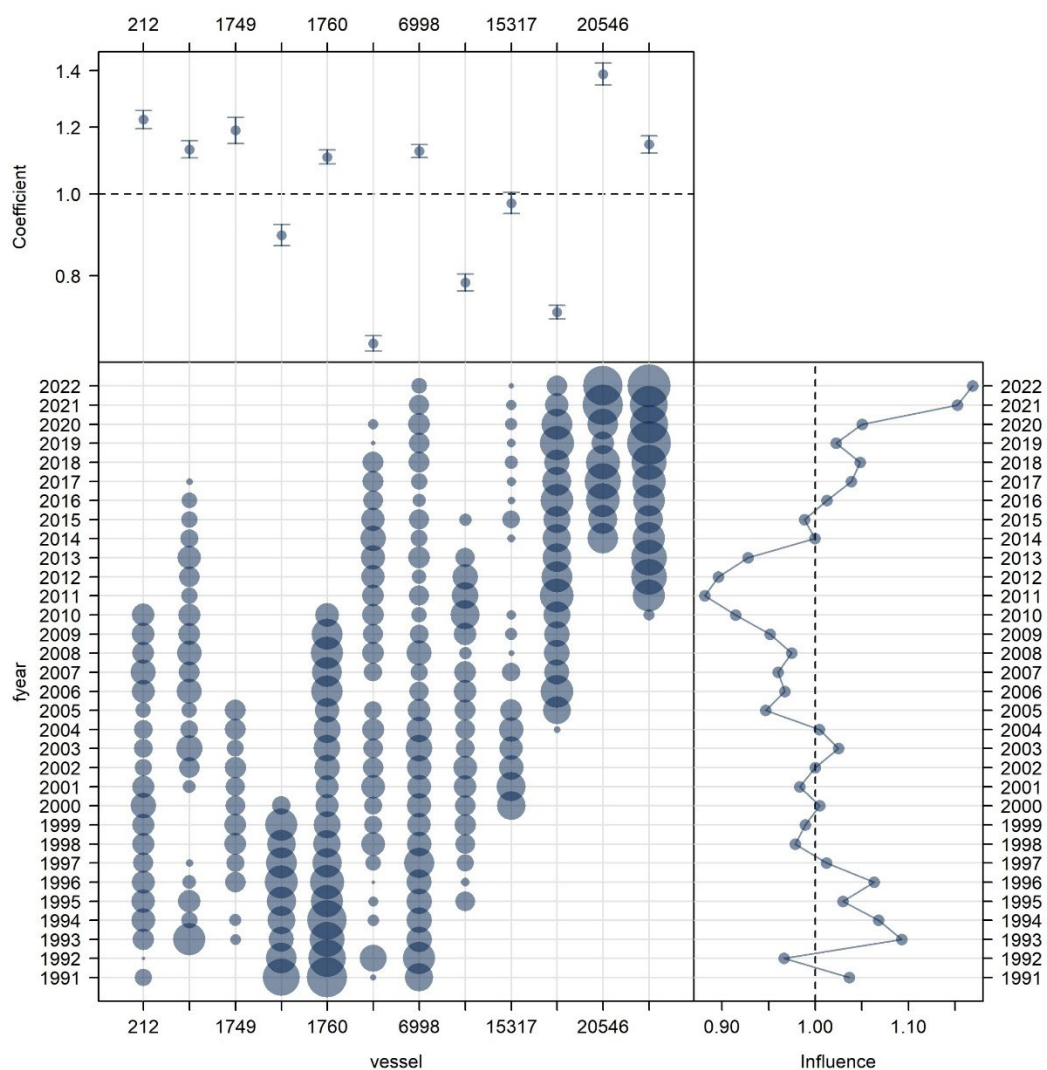


Figure D.20: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for vessel identifier in relation to year, assuming all other parameters are constant at their median or modal value. Year was model year which was defined as the calendar year.

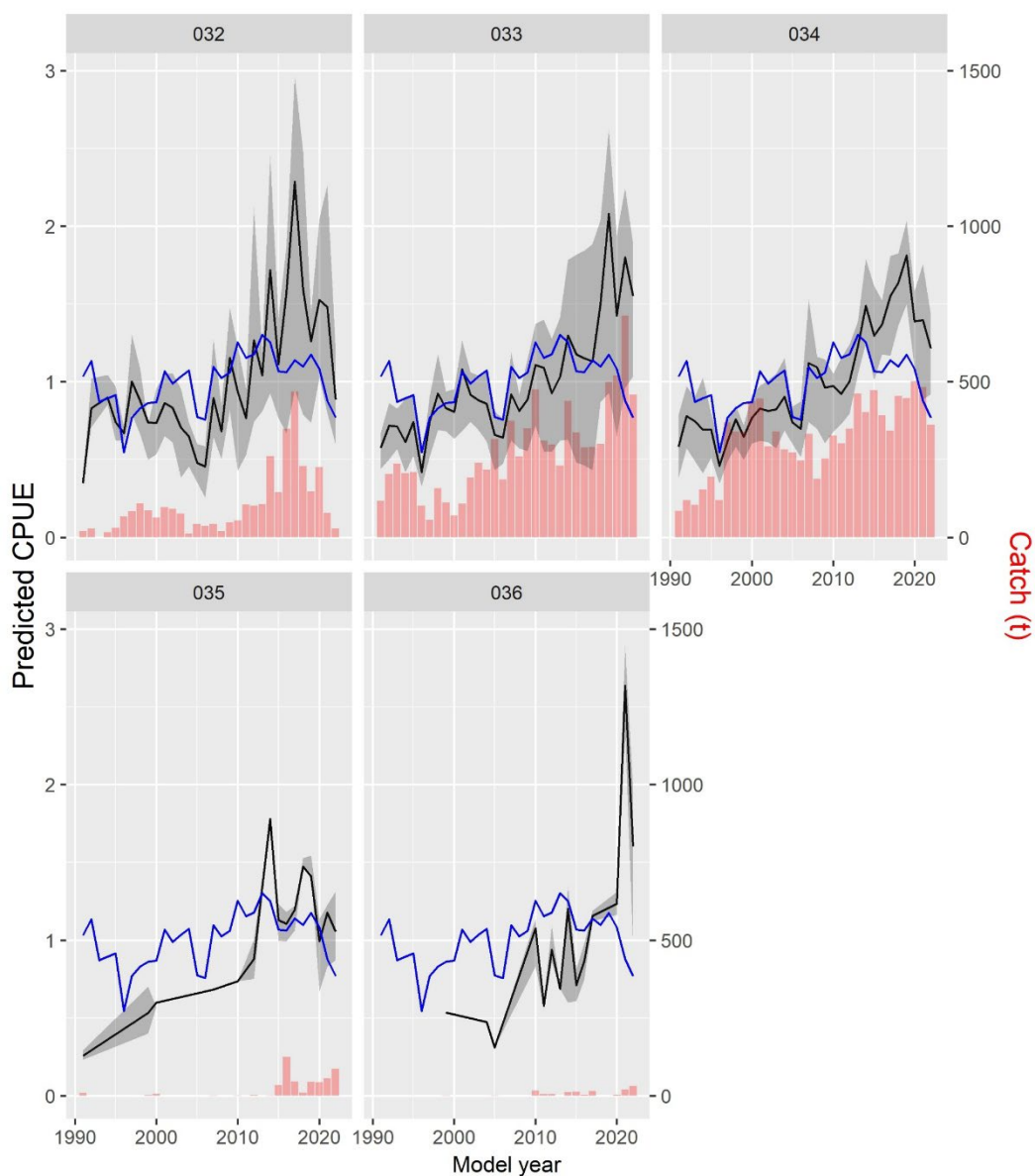


Figure D.21: Implied trends by statistical area for the lognormal model for the rolled-up bottom longline CPUE. The black trend and grey band represent the predicted mean standardised catch rate and interquartile range, and the blue trend the predicted year effect of the standardised CPUE. Year was model year which was defined as the calendar year. Only years where at least three vessels participated in any statistical area are depicted. Catch in tonnes is shown as the red bars using the right-hand axis.

15. APPENDIX E – INPUTS TO THE 2023 STOCK ASSESSMENT

Table E.1: Annual catch in tonnes per fishery used in the 2023 stock assessment (Mormede et al. in prep.).
Year was model year which was defined as the calendar year. Longline includes bottom longline and all potting methods, and trawl represents all other catches.

Year	trawl	longline
1972	0	0
1973	85	20
1974	144	40
1975	401	800
1976	565	2 100
1977	715	4 300
1978	300	323
1979	539	360
1980	540	305
1981	492	300
1982	675	400
1983	1 040	710
1984	924	595
1985	1 156	302
1986	1 082	362
1987	1 105	370
1988	1 428	291
1989	1 959	370
1990	2 173	229
1991	2 025	425
1992	1 572	873
1993	1 590	699
1994	1 312	1 003
1995	1 759	994
1996	2 019	994
1997	2 034	1 323
1998	1 995	1 065
1999	2 389	916
2000	2 479	947
2001	2 400	1 007
2002	2 475	762
2003	2 094	926
2004	2 092	764
2005	1 595	845
2006	1 773	781
2007	1 323	1 161
2008	1 150	1 021
2009	1 216	992
2010	1 386	1 199
2011	1 606	1 143
2012	1 697	1 285
2013	1 959	1 089
2014	1 914	1 444
2015	2 092	1 350
2016	2 159	1 487
2017	2 451	1 470
2018	2 440	1 239
2019	1 834	1 408
2020	1 687	1 752
2021	1 406	2 057
2022	1 440	1 464