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Descriptive analysis of ling (*Genypterus blacodes*) on the Chatham Rise (LIN 3&4) up to 2020–21 and inputs for the 2022 stock assessment

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EXECUTIVE SUMMARY

Mormede, S.[1]; Dunn, A.[2]; Webber, D.N.[3] (2022). Descriptive analysis of ling (*Genypterus blacodes*) on the Chatham Rise (LIN 3&4) up to 2020-21 and inputs for the 2022 stock assessment.

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Ling (*Genypterus blacodes*) are an important species commercially caught mainly by bottom trawls and bottom longlines and also more recently by pots; 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 Chatham Rise stock (LIN 3&4) and fishery up to the 2020–21 fishing year and 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 2022 stock assessment.

Both the ling Total Allowable Commercial Catch (TACC) and catches have been stable in most QMAs recently. The majority of ling was 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 fleet. Recent catches of ling in LIN 3&4 are at about 60% of the TACC. Based on the location of fishing, the bottom trawl fleet showed a rapid increase in the new areas explored up to about 2010, followed by a subsequent plateau. The longline fleet presented the most rapid expansion of the new areas explored up to 1997, followed by a reduction (but not plateau) in the number of new areas investigated.

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

The length-weight relationship for ling in LIN 3&4 was updated with the latest available data. The growth function was updated, including using Bayesian inference, and Bayesian von Bertalanffy growth estimates were used for the stock assessment. A monotonically increasing mean length at age growth model was estimated and used to derive monthly growth increments that were later used in the time steps of the stock assessment model.

The rolled-up longline standardised CPUE for Chatham Rise ling (LIN 3&4) showed a strong decline between 1990 and 1997, followed by a flat and variable trend. In contrast, the survey biomass trend presented a flat and variable trend from 1992 onwards. Because of the disagreement between the longline standardised CPUE index and the survey biomass index between 1992 and 1997, it was uncertain if the longline standardised CPUE represented the underlying biomass of ling.

The annual catches used in the 2022 stock assessment model were re-calculated to account for the increase of importance of the potting fishery and the move to a model year equal to calendar year.

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1. INTRODUCTION

Ling (*Genypterus blacodes*) are an important commercially caught species and are targeted by both bottom trawls and demersal longlines, with an 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 also by demersal longliners (Ballara 2019). Small quantities of ling are also caught by inshore trawls and set nets(Ballara 2019).

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 Cook Strait. Stock assessments have been carried out for ling for the assumed biological stocks of Chatham Rise (LIN 3&4), Sub-Antarctic (including the Campbell Plateau and Stewart-Snares shelf comprising LIN 5 and the part of LIN 6 west of 176º E, labelled LIN 5&6), Bounty Plateau (the part of LIN 6 east of 176º E, labelled LIN 6B), west coast South Island (LIN 7 west of Cape Farewell, labelled LIN 7WC), and Cook Strait (the part of LIN 2 and LIN 7 between latitudes 41º and 42º S and longitudes 174º and 175.4º 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. The catch and Total Allowable Commercial Catch (TACC) for ling in LIN 3 and LIN 4 are shown in Figure 3.

This report fulfils Specific Objective 1 of Project LIN2021-01. The overall Objective was "To carry out stock assessments of ling (*Genypterus blacodes*) on the Chatham Rise (LIN 3 and LIN 4) including estimating biomass and stock status" and Specific Objective 1 was "To carry out a descriptive analysis of the commercial catch and effort data for ling (LIN 3 and LIN 4) on the Chatham Rise, including analyses of standardised catch per unit effort". A descriptive summary of catch and effort data since 1989–90 was provided. A spatial analysis was carried out, and biological parameters were updated. The analysis of the catch per unit of effort data for ling in the Chatham Rise for the fishing years 1990–91 (denoted 1991) to 2020–21 (2021) was also updated.

Table 1: Definition of the biological stocks for ling adapted from Ballara (2019).

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	025–032, 302, 303, 501–504	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	033–036, 701–706	Part of LIN 7	LIN 7WC
Cook Strait	016, 017, 037–040	Parts of LIN 2 & 7	LIN 7CK

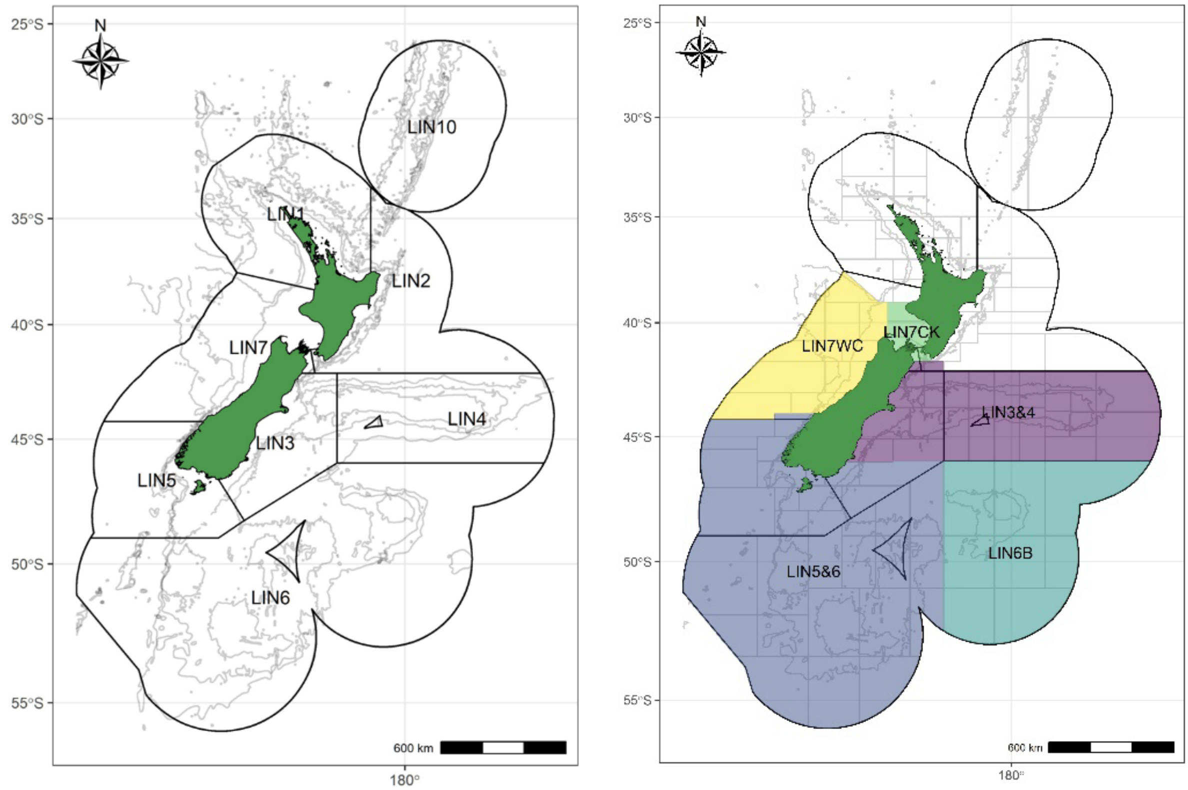

Figure 1: Quota Management Areas (QMAs, left) and biological stock boundaries (right) for ling, as used in this report.

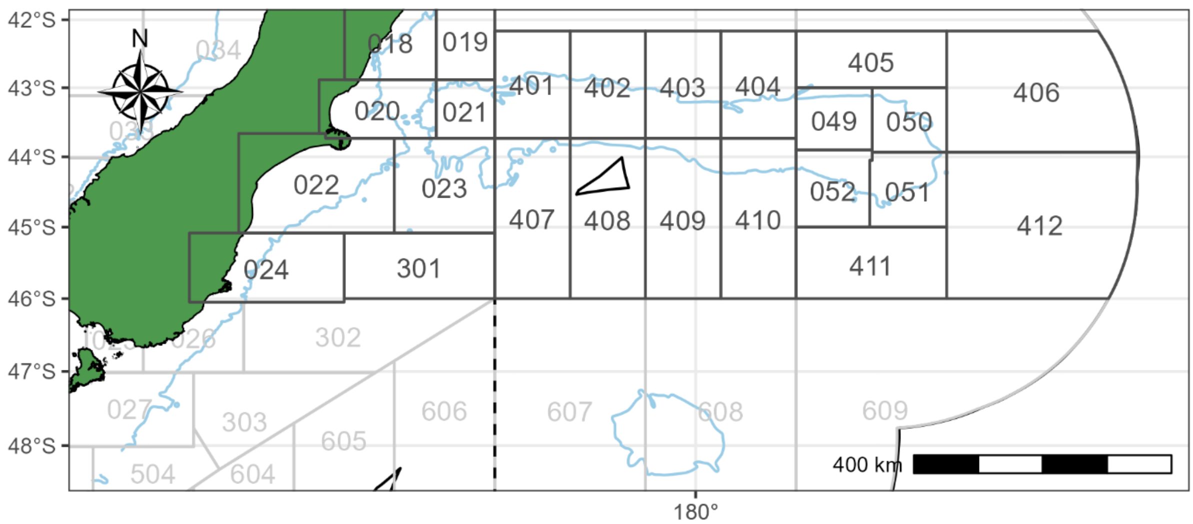

Figure 2: Statistical areas in the LIN 3&4 region are outlined in black.

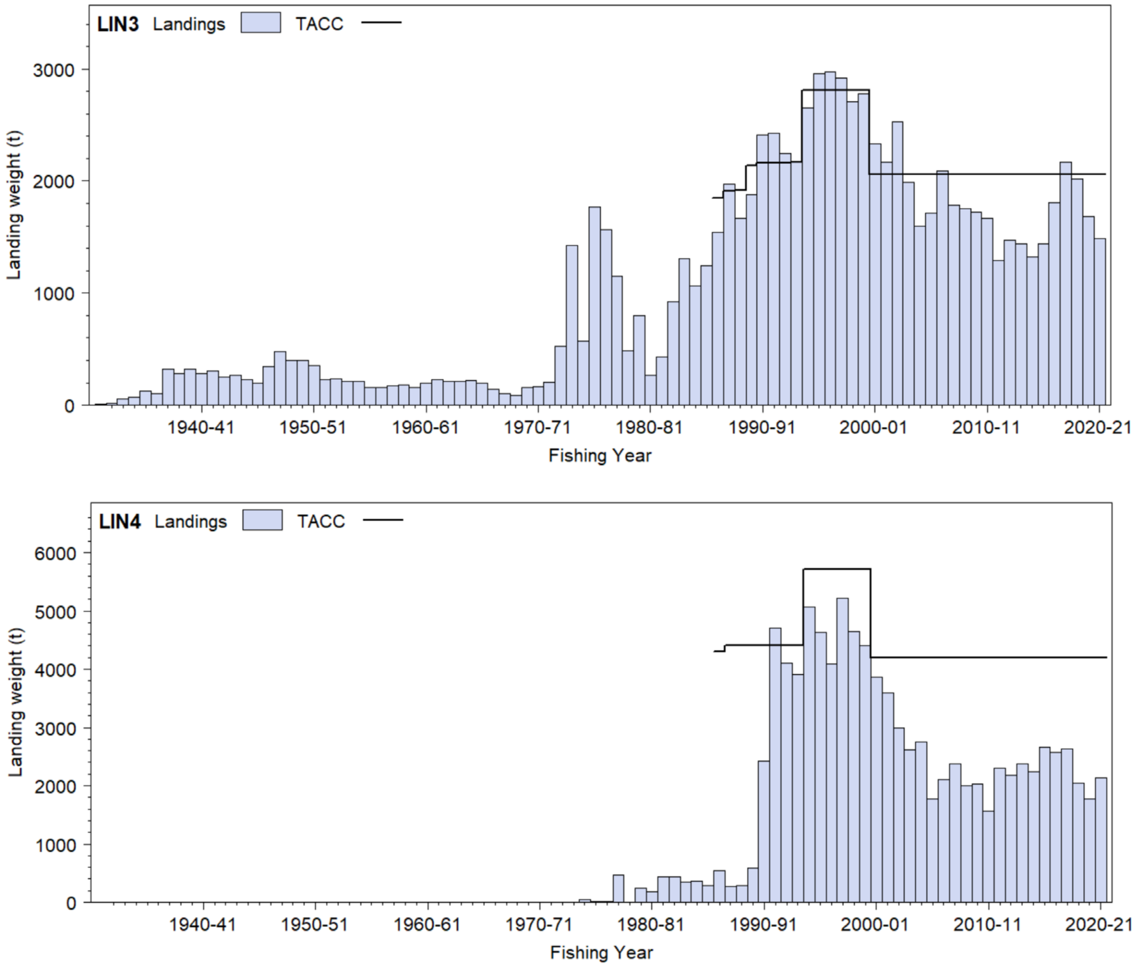

Figure 3: Annual reported catch of ling in LIN 3 and LIN 4 (bars) and the TACC for ling (black line) for fishing years to 2020–21 (Fisheries New Zealand 2022).

2. SUMMARY OF THE LING FISHERY ON THE CHATHAM RISE

2.1 Available data

Data available for Chatham Rise ling 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 to the Chatham Rise was relatively low and was therefore ignored (Dunn 2003).

Catch and effort data were extracted by Fisheries New Zealand for the period from October 1989 to September 2021 that included all available data at the date of the extract (8th December 2021) (REPLOG 14055). 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 8th December 2021 (REPLOG 14055). 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* Chatham Rise standardised trawl survey and any other research voyage that reported ling) were extracted, along with any biological, length frequency information, and associated otolith age readings from these trips (REPLOG 14055).

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 location was available. Longlining events were assigned to either manual baiting or autoline based on vessel name and sometimes year ranges provided by Fisheries New Zealand on 18th February 2021. Vessels were assigned as having a meal plant or not based on vessel identifier number provided by Fisheries New Zealand on 2nd February 2021, noting that no date range was available for this information. Tows carried out with midwater gear (MW) but with fishing depth within 5 m of the bottom were recoded as midwater bottom gear (MB).

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 in LIN 7&8 in 2020 (Table A.1). 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 below the TACC, apart from LIN 5 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 in the Chatham Rise ling stock (LIN 3&4) were similar to those reported by Holmes (2019), as shown in Figure A.1. Ling were caught predominantly by bottom longliners targeting ling followed by bottom trawlers targeting hoki or ling, with no clear trend over time (Table A.6 and Figure A.2 to Figure A.4). Ling have been caught predominantly over the July to October period for longliners and September to January for bottom trawls although the time of the year catches have occurred has been variable over time (Figure A.5). Trawl vessels are dominated by vessels of between 60 and 70 m in length, whereas the most common vessel length for longliners is 28 to 40 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 400 and 500 m; the depths fished has increased slightly over time for bottom trawls but not for longlines (Figure A.9).

The location of catches differs between the bottom trawl and longline fleets (Figure A.10 by statistical area, Figure A.11 to Figure A.14 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 the trawl fleet fishing predominantly in Statistical Areas 020, 401, 023, and 022, and the longline fleet fishing predominantly in Statistical Areas 410, 404, and 020. To represent the expansion or retraction of the area fished over time, the area covered by the fishing fleet targeting ling 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. The bottom trawl fleet showed a continual increase in new areas explored to about 2010, followed by a slowing down (fewer new areas investigated) with a contraction of the area fished. The longline fleet presented a rapid expansion of new areas explored to 1997, followed by a slowing (but not plateau) in the number of new areas investigated (Figure A.15).

The effort characteristics of the bottom trawl and longline fleets have been relatively stable over time except for the depth of longline fishing of the fishery not targeting ling which has dropped over time (Figure A.16 and Figure A.17).

3. SPATIAL-TEMPORAL ANALYSES

Stratifying the catch into fisheries or areas for population modelling allows differences in age frequencies 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.

The strata used in previous analyses of the LIN 3&4 biological stock were derived from a 2005 analysis (Horn 2005) to derive fisheries and, within each fishery, the strata for scaling length frequencies. These have been used to derive the scaled ling age frequencies for LIN 3&4 (Saunders et al. 2021). LIN 3&4 was split in two fisheries as follows:

- bottom longline:
  - single stratum
  - catch, length, and otolith data from 1st June to 31st October
- bottom trawl:
  - four strata:
    - scampi (*Metanephrops challengeri*) target tows
    - coast (longitude ≤ 174° E and target not scampi)
    - north rise (latitude < 43.55° S, longitude > 174° E, target not scampi)
    - south rise (latitude ≥ 43.55° S, longitude > 174° E, target not scampi)
  - catch, length, and otolith data from 1st October to 31st May

However, these strata are not contiguous in time or space; some of the fishing events are not included in the strata due to being outside the time and space defined (18% of trawl catches and 23% of longline catches). The ling birth date was assumed 1st October (Richard Saunders, pers. comm., and Deepwater Working Group on 10 February 2022).

The previous model update for this stock also showed different sex ratios in the longline, trawl, and survey age frequency data (figure 4 of Holmes 2019), indicating that the mean length and also the sex ratio of ling in LIN 3&4 varied over space, time, and/or possibly by fishing method.

Modelling the spatial distribution of mean length or age and correcting for variables such as month and year (like 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

3.1.1 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 3&4 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 concurrently, with potential parameters offered to the regression detailed in Table B.1. A similar tree regression analysis was carried out for the sex ratio (expressed as the proportion of females) in each fishing event.

3.1.2 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.1). The mesh was limited to 1500 nodes (i.e., fewer nodes than data points where N_{LF} = 148 339). 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 sensible 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 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.

3.1.3 Evaluation of the candidate strata

The performance of the candidate strata was evaluated by calculating the scaled age frequencies of ling for these strata and plotting the change in catches and in sex ratio of these candidate strata over time. The ideal strata structure is one where the length frequencies 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. Decadal unscaled length frequency distributions were plotted for each biological stock of ling. They showed no temporal trends or patterns for the LIN 3&4 stock (Figure B.2).

The timing of spawning in the different ling stocks around New Zealand was also investigated using observer data. Using all years combined and gonad stages 4 or 5 as evidence of spawning, the Chatham Rise stock of ling is expected to spawn mostly from August to October (Figure B.3). This was consistent with previous analyses (e.g., Ballara 2019). Only LIN 6B ling 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.

3.2.1 Tree regression analysis

Using mean length per fishing event and the tree regression method, the data split was as follows:

- Longline fleet: mean length of 100.6 cm
- Trawl fleet
    - Latitude < 43.48° S: mean length of 81.3 cm
    - Latitude ≥ 43.48° S: mean length of 89.9 cm

Using the sex ratio per fishing event and the tree regression method, the data split was as follows:

- Statistical Areas 019, 023, 049, 052, 404, 407–410: 45% females
- Statistical Areas 018, 020–022, 024, 050, 051, 401–403, 405, 412: 60% females

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 varied from 45 to 60%, with the highest proportion of females found in the north-eastern part of the stock.

3.2.2 Spatial-temporal analysis

Spatial distribution of lengths

Both the DIC and WAIC suggested the most complex models with sex or time-block specific spatial effects were also 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 sexually specific and/or varied through time. 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 on the northern side of the Chatham Rise, with the exception of one area of large fish on the south-east Chatham Rise (Figure B.5). It appeared that females and males had a similar spatial distribution (Figure B.6) and that the spatial distribution of fish had not changed significantly over the twenty years (Figure B.7). However, the large fish seen in the southeast Chatham Rise were only in the 1992 to 1994 year block.

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 lead 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 0.2 retained the highest level of explained inertia in D0 while maximising the explained inertia in D1 (Figure B.8). The clusters (for K = 2 spatial clusters since fishing method was selected, giving a total of four fisheries) exhibited good spatial contiguity, but there were small components of non-contiguous spatial areas flecked inside the spatial clusters (Figure B.9), which were ignored for the purposes of this analysis. The alpha value of 0.2 was retained for this analysis as it presented slightly fewer non-contiguous areas. The clusters favoured an east-west split rather than a north-south split as found using tree regression analyses.

Spatial distribution of sex ratio

Both the DIC and WAIC suggested the simpler model including fish length and a space was also the most parsimonious model explaining the sex ratio (Table B.3). The model showed that there were more females on the northern and eastern side of the Chatham Rise, with the exception of one area with more females on the north-east Chatham Rise (Figure B.10).

When clustering the sex ratio data, an alpha value of about 0.2 retained the highest level of explained inertia in D0 while maximising the explained inertia in D1 (Figure B.11). The clusters (for K = 2 to be comparable with the tree regression analysis) had good spatial contiguity, but there were small components of non-contiguous clusters flecked throughout other clusters (Figure B.12). The alpha value of 0.2 was retained for this analysis as it presented slightly fewer non-contiguous areas. The clusters favoured an east-west split similar to that found using tree regression analyses (Figure B.4).

3.2.3 Evaluation of the candidate strata

Four new potential fishery structures were investigated:

- Option 1. Three fisheries that were based on the tree regression analysis of mean length: bottom longline, bottom trawl north, and bottom trawl south.
- Option 2. Four fisheries based on the INLA analysis of length: bottom trawl or longline gear, and an east or west split for each fishery (at about 180°, see Figure B.9 with alpha = 0.2).
- Option 3. Two fisheries based on the tree regression of the sex ratio: using a combination of statistical area (see Figure B.4).
- Option 4. Four fisheries with two areas based on the tree regression of the sex ratio (see Figure B.4) but also adding a split for fishing gear in each area: bottom longline or bottom trawl.

All four fishery structure options presented a changing catch over time for each of the strata. The sex ratio was highly variable for all options, but the difference was only significant between strata for Option 3, that was optimised for the sex ratio (Figure B.13 to Figure B.16).

The scaled length frequency distributions for the four options were calculated and are presented for the 2010 to 2021 fishing years in Figure B.17 to Figure B.20. The length frequencies were relatively stable for most options, regardless of whether the Chatham Rise was split by north and south (i.e., Option 1) or east and west (i.e., Option 2). The sex ratios for all options except Option 3 were variable over time. Option 3, that specifically modelled the sex ratio, was the only one that had sex-specific length frequencies that were stable over time.

Because the resulting scaled length frequencies were mostly insensitive to the choice of these four choices of stratification, the existing stratification was kept (bottom longline and bottom trawl, see above) and the age frequencies provided by Saunders et al. (2021) were used, providing continuity and comparison with previous analyses.

4. UPDATE OF BIOLOGICAL PARAMETERS

4.1 Methods

4.1.1 Length-weight parameters

Length-weight parameters for ling used in the stock assessment were calculated in 2005 (Horn 2005). These were recalculated in 2017 (Edwards 2017) but were not used in the 2019 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 and 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.

4.1.2 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 by Edwards (2017) but were not used in the 2019 stock assessment model.

This analysis updates the age-length relationship by applying the von Bertalanffy and Schnute models to all available age data for the Chatham Rise region 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:

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

with:

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

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

4.2.1 Length-weight parameters

Length-weight data were collected only during trawl surveys and as such have a limited temporal coverage within each year as well as a limited number of samples (Figure C.1). 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 3&4.

4.2.2 Growth models

All data available in the ‘t.age’ database provided by Fisheries New Zealand were used whether they were collected during Chatham Rise trawl surveys or by observers. Most of the data available were from January, the month when the survey took place (Figure C.4).

The MLE von Bertalanffy models had poor residuals for ages 2 and 3, and for old ages (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 previously derived (not shown), but note the departure from the growth curve calculated by Edwards (2017) for small females (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 (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).

However, without any constraint, the mean length at age model estimate of length drifted implausibly high for the older fish when compared with either the MLE or Bayesian von Bertalanffy models (Figure C.12, Figure C.13, and Figure C.14). This suggests that this model could be improved by some type of constraint for older fish where there are few data. Despite this, the mean length at age model provided some advantages over the von Bertalanffy model. For example, the model presented is very useful for exploring growth by month (Figure C.15) which can be further developed into the cumulative proportion of growth that occurs throughout a year, a key input for stock assessment.

4.3 Discussion

The length-weight relationship derived using all data up to and including 2021 had very similar values for the parameters to those used previously. The new parameters were used for the 2022 stock assessment and updated in the ling plenary document (Fisheries New Zealand 2022).

The growth curve obtained through three methods (MLE von Bertalanffy, Bayesian von Bertalanffy, and the mean length at age models) all had similar trajectories and the Bayesian von Bertalanffy parameterisation was used for the 2022 update of the stock assessment of ling in biological stock LIN 3&4. The Bayesian mean length at age model was used to calculate monthly growth increments.

5. CPUE ANALYSES (BOTTOM LONGLINE)

5.1 Methods

The catch per unit effort (CPUE) standardisation followed similar methods that have been used for other ling stocks (e.g., Mormede et al. 2021) and in previous analyses (e.g., Dutilloy 2019). Analyses were restricted to calculation of the rolled-up longline standardised CPUE index. The 2019 analyses of the trawl CPUE had concluded that it was not a reliable index of abundance because it was likely influenced by other factors including hoki targeting and the catch limits for hoki (Dutilloy 2019).

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. Of note, the year was defined as calendar year to match the year definition to be used in the model. Starting the model year on 1st January captured the spawning season for all ling stocks apart for LIN 6B which has an extended spawning season (see Figure B.3) and is consistent with assumed ling birth date of 1st October. This also allowed for the highest seasonal fishing catch recorded between June and October to be combined within a single model year.

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). 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 numbers of hooks set on each day in each statistical area.

Details of the data selection for each bottom longline CPUE index are summarised in Table D.2 and were largely consistent with data used previously (Dutilloy 2019), but with the addition of a maximum number of sets per record to remove records where number of sets and number of hooks might have been inverted. Because of the change over time in the reporting requirements, and in particular the number of species that require reporting, fishing events where ling was not recorded in the top five species, or top five Quota Management System (QMS) species for ERS reporting (Figure A.7 and Figure A.8) 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.1).

All the CPUE standardisations 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 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.

5.2 Results

The standardised lognormal CPUE trend for rolled-up bottom longline fishing in Chatham Rise ling (LIN 3&4) was very similar to that obtained in 2019 (Dutilloy 2019). The resulting trend in the CPUE index was different to that for both the raw data and the Chatham Rise trawl survey biomass index over the period 1990 to 1997 (Figure D.2), but similar in trend thereafter. The diagnostic residual plots showed little evidence of departure from model assumptions and were acceptable (Figure D.2). The lognormal model explained 72% of the variance and three parameters were included additional to model year (Table D.3 and Figure D.3 to Figure D.7). The *vessel* parameter had the largest influence on the standardised index (Figure D.4) although the index was almost identical if vessel was removed from the standardisation. The trend was also insensitive to the core vessel selection, with the selection of vessels in the fishery for 4 to 6 years minimum yielding almost identical trends (not shown). The implied trends by statistical area did not show obvious departures from the overall standardised CPUE trend (Figure D.8).

5.3 Discussion

The rolled-up longline standardised CPUE for Chatham Rise ling (LIN 3&4) showed a strong decline between 1990 and 1997 followed by a long flat period, whereas the trawl survey biomass presented a flat and variable trend from 1992 onwards. Longline fishing targets ling (with very few null sets) and did not show evidence of area-specific departure from the standardised trend. However, because of the disagreement between the longline standardised CPUE index and the survey biomass index between 1992 and 1997, it was uncertain if the longline standardised CPUE was an index of the longline vulnerable biomass of ling.

6. INPUTS INTO THE 2022 STOCK ASSESSMENT

6.1 Catches

Three fisheries were defined for the 2022 stock assessment: the trawl and longline fisheries and, for the first time, a pot fishery. The pot fishery used to represent a negligible proportion of the catch until 2016 and has now grown to about 13% of the total catch. For the purposes of catches in the stock assessment model, pot was assumed to comprise all potting methods, and trawl all methods other than bottom longline and potting methods. The model year was defined as the calendar year.

The annual scaled-up catches per fishery and model year are summarised in Table E.1. These are slightly different from those used in the 2019 stock assessment (Holmes 2019), as depicted in Figure E.1. The reasons for those differences were not able to be discerned.

6.2 Age frequencies

The commercial fishery age frequencies for the Chatham Rise ling assessment have traditionally been 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 Saunders et al. (2021) were used.

No age composition data is currently available for the ling potting fishery. Only one potting trip has been observed, in 2020. Length data were available for that trip, but no otoliths have been read to determine the age composition. The unscaled male length frequencies for this trip suggested a length frequency distribution that was between the scaled bottom trawl and bottom longline scaled length frequency distributions for that year and were similar to the bottom longline scaled length frequency distribution for females (Figure E.2). Hence, the same selectivity as for the bottom longline fishery was assumed for the pot fishery. The authors recommend that scaled age frequencies be developed for the pot fishery in the future, especially if this fishery continues to develop and grow. In addition, the authors recommend the addition of observers on those vessels to obtain length frequency observations and otolith samples and to improve the description of the pot gear used in the fishery.

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APPENDIX A – DESCRIPTION OF THE FISHERY

Table A.1: Ling TACC (in tonnes) per QMA by fishing year (from Fisheries New Zealand 2022).

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

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

Fishing year	LIN 1	LIN 2	LIN 3	LIN 4	LIN 5	LIN 6	LIN 7	LIN 10	Total
1990	30	270	870	504	2 040	1 000	1 714	0	6 428
1991	75	374	1 129	2 107	2 261	2 349	1 156	-	9 451
1992	57	231	1 506	4 302	3 527	3 082	930	0	13 636
1993	32	202	1 386	3 455	2 880	5 508	1 067	0	14 531
1994	54	177	1 356	3 665	2 937	3 208	973	-	12 369
1995	53	258	1 334	4 346	3 390	3 788	1 726	-	14 895
1996	70	339	1 999	4 045	4 369	3 752	1 470	-	16 044
1997	140	418	1 675	3 392	4 384	4 762	1 493	0	16 264
1998	140	464	1 845	4 174	3 910	5 418	1 666	0	17 616
1999	109	554	1 633	3 857	3 675	4 277	1 816	0	15 920
2000	190	530	1 737	3 821	3 604	5 272	1 643	0	16 796
2001	170	784	1 552	3 403	3 589	5 196	2 013	-	16 706
2002	174	558	1 431	3 191	3 543	5 379	1 918	-	16 194
2003	125	362	1 622	2 652	3 466	5 237	1 574	0	15 039
2004	109	451	1 216	2 361	3 876	5 541	1 723	-	15 278
2005	73	423	883	2 561	4 709	3 988	1 171	-	13 808
2006	124	450	993	1 655	4 289	2 232	1 267	-	11 009
2007	63	374	1 539	1 925	5 122	2 743	924	-	12 690
2008	340	666	1 559	2 292	5 141	3 251	1 774	-	15 024
2009	295	551	1 483	1 811	3 820	1 704	1 739	-	11 403
2010	351	503	1 445	1 842	3 851	1 490	1 952	0	11 434
2011	387	596	1 389	1 395	4 016	952	2 199	-	10 935
2012	351	422	1 049	2 014	4 285	1 267	2 051	-	11 440
2013	345	498	1 136	1 916	5 801	1 215	2 333	-	13 245
2014	364	543	1 131	2 040	4 926	2 046	2 474	-	13 524
2015	369	555	956	1 875	5 140	1 747	2 581	0	13 224
2016	387	574	1 009	2 266	4 634	1 290	2 715	-	12 874
2017	381	833	1 414	2 209	5 112	2 091	2 720	-	14 760
2018	378	879	1 362	2 371	5 196	3 106	2 695	-	15 987
2019	353	782	1 510	1 842	5 813	2 269	2 545	-	15 114
2020	348	637	1 448	1 590	5 255	2 865	2 760	-	14 902
2021	283	550	1 320	1 895	5 954	2 692	2 815	-	15 508
Total	6 722	15 807	43 916	82 776	134 514	100 717	59 597	1	444 049

Table A.3: Ling catch (in tonnes) per QMA by 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	2 103	4 950	3 916	3 308	16 085
Total	10 127	65 608	94 374	111 186	141 104	92 203	514 602

Table A.4: Ling catch (in tonnes) per stock by fishing year as reported in catch and effort forms and scaled to MHR returns.

Fishing year	LIN 3&4	LIN 5&6	LIN 6B	LIN 7CK	LIN 7WC	OTHER	Total
1990	2 653	3 650	15	883	2 956	608	10 764
1991	5 507	5 469	34	1 152	3 110	902	16 175
1992	7 382	7 068	884	779	3 108	1 058	20 278
1993	6 509	8 666	1 031	849	3 208	1 340	21 603
1994	6 204	6 208	1 083	606	2 882	1 328	18 311
1995	8 247	8 083	455	640	3 799	1 854	23 078
1996	7 995	9 238	607	748	4 152	1 424	24 164
1997	7 426	11 106	435	847	3 942	1 785	25 541
1998	8 338	10 790	401	487	3 911	1 685	25 612
1999	7 702	8 976	615	569	4 381	1 187	23 431
2000	7 688	9 216	1 033	548	4 273	1 186	23 944
2001	6 326	8 831	1 139	536	4 384	1 212	22 429
2002	5 818	9 081	649	439	3 945	1 311	21 243
2003	5 750	8 690	1 029	653	3 649	1 168	20 939
2004	4 835	9 479	995	638	3 578	1 158	20 684
2005	4 652	9 463	49	661	3 373	1 045	19 242
2006	3 616	7 444	72	495	3 237	1 123	15 988
2007	4 294	8 679	256	469	3 129	1 251	18 079
2008	4 115	8 347	447	209	2 442	1 024	16 583
2009	3 649	6 122	233	157	2 361	847	13 368
2010	3 661	5 618	2	99	2 460	927	12 768
2011	2 995	5 338	55	171	2 904	1 043	12 506
2012	3 315	5 796	4	141	2 950	832	13 038
2013	3 505	6 799	4	192	3 154	872	14 526
2014	3 686	6 889	291	199	3 416	933	15 414
2015	3 441	6 965	38	183	3 528	954	15 108
2016	4 169	5 687	214	227	3 585	1 004	14 885
2017	4 296	6 400	803	295	3 797	1 291	16 882
2018	4 989	8 659	263	387	3 869	1 315	19 482
2019	4 068	8 071	222	290	3 278	1 185	17 115
2020	3 263	8 476	254	150	3 292	1 063	16 498
2021	3 500	8 197	645	113	3 458	894	16 807
Total	163 594	247 503	14 257	14 811	109 510	36 809	586 483

Table A.5: Ling catch (in tonnes) for the LIN 3&4 biological stock per form type by fishing year as reported in catch and effort forms.

Fishing year	CELR	LCER	LTCER	ERS - Lining	TCEPR	TCER	ERS - Trawl	Other	Total
1990	6 457	1 709	0	0	0	0	0	0	8 166
1991	8 233	3 717	0	0	0	0	0	0	11 950
1992	9 043	7 076	0	0	0	0	0	0	16 119
1993	9 510	7 555	0	0	0	0	0	0	17 065
1994	6 407	8 315	0	0	0	0	0	0	14 722
1995	8 466	9 690	0	0	0	0	0	0	18 155
1996	10 043	8 694	0	0	0	0	0	0	18 737
1997	9 924	9 347	0	0	0	0	0	0	19 270
1998	11 616	8 529	0	0	0	0	0	0	20 145
1999	10 285	8 046	0	0	0	0	0	0	18 331
2000	11 164	7 982	0	0	0	0	0	0	19 146
2001	11 239	7 345	0	0	0	0	0	0	18 584
2002	11 472	6 402	0	0	0	0	0	0	17 874
2003	11 344	5 726	0	0	0	0	0	0	17 070
2004	11 574	3 556	2 075	0	0	0	0	0	17 204
2005	10 518	2 028	3 318	0	0	0	0	0	15 863
2006	8 605	1 701	2 512	0	0	0	0	0	12 819
2007	10 153	1 818	2 566	0	0	0	0	133	14 670
2008	9 622	206	2 857	0	2 045	0	515	99	15 344
2009	6 721	188	2 591	0	1 462	0	563	108	11 634
2010	6 055	131	2 857	0	1 744	0	698	109	11 593
2011	6 047	75	1 887	0	2 089	0	926	82	11 105
2012	6 260	49	2 356	0	1 975	0	828	54	11 523
2013	8 493	128	1 346	0	2 596	0	843	25	13 431
2014	7 224	165	2 397	0	2 910	0	985	32	13 713
2015	8 045	99	1 694	0	2 596	0	868	28	13 330
2016	6 903	204	2 263	0	2 616	0	1 025	83	13 093
2017	7 960	284	3 029	0	2 703	0	1 030	35	15 041
2018	1 584	715	2 423	8 110	2 900	0	1 002	41	16 775
2019	43	330	1 268	8 791	1 414	2 454	730	457	15 487
2020	0	0	0	8 804	83	5 536	1	520	14 944
2021	0	0	0	9 239	0	5 764	0	581	15 585
Total	251 011	111 811	37 438	34 945	27 132	13 754	10 012	2 387	488 489

Table A.6: Ling catch (in tonnes) for the LIN 3&4 biological stock per gear type, 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).

Fishing	Bottom trawl				Longline		Potting		
year	LIN	HOK	HAK	Other	LIN	Other	LIN	Other	Total
1990	336	517	22	376	167	0	1	1	1 420
1991	551	1 091	9	601	1 227	2	11	2	3 494
1992	345	1 362	65	638	3 449	6	37	2	5 904
1993	124	894	232	674	2 966	9	8	7	4 914
1994	31	679	87	441	3 736	12	1	10	4 997
1995	51	1 075	146	436	4 247	17	5	2	5 979
1996	44	1 298	156	283	4 256	11	0	1	6 049
1997	54	1 386	166	231	3 134	17	32	5	5 025
1998	714	2 221	310	230	2 253	8	37	3	5 776
1999	250	2 066	324	218	2 495	10	41	0	5 404
2000	669	1 716	286	177	2 771	2	20	1	5 642
2001	197	1 826	268	233	2 341	3	2	1	4 871
2002	358	1 476	109	233	2 336	1	1	1	4 515
2003	106	1 941	117	373	1 774	4	0	1	4 316
2004	6	1 447	256	251	1 595	23	3	1	3 582
2005	65	950	216	255	2 069	37	8	2	3 602
2006	151	766	45	259	1 428	51	45	4	2 749
2007	752	716	158	222	1 471	91	51	5	3 466
2008	920	727	135	298	1 561	68	16	3	3 728
2009	176	669	195	197	1 859	25	6	4	3 131
2010	192	657	13	290	1 886	28	37	4	3 107
2011	44	640	3	164	1 581	26	26	7	2 491
2012	98	682	1	282	1 662	42	6	2	2 775
2013	23	714	0	92	1 991	37	23	3	2 883
2014	95	567	1	79	2 205	26	52	5	3 030
2015	130	814	9	99	1 566	32	40	5	2 695
2016	99	706	1	141	2 154	31	133	3	3 268
2017	131	923	0	96	2 200	23	149	9	3 531
2018	104	851	0	143	2 265	13	547	5	3 928
2019	40	573	0	90	1 748	14	613	3	3 081
2020	5	567	0	119	1 602	24	359	1	2 677
2021	4	695	0	116	1 839	14	358	0	3 026
Total	6 865	33 211	3 329	8 335	69 831	705	2 669	102	125 047

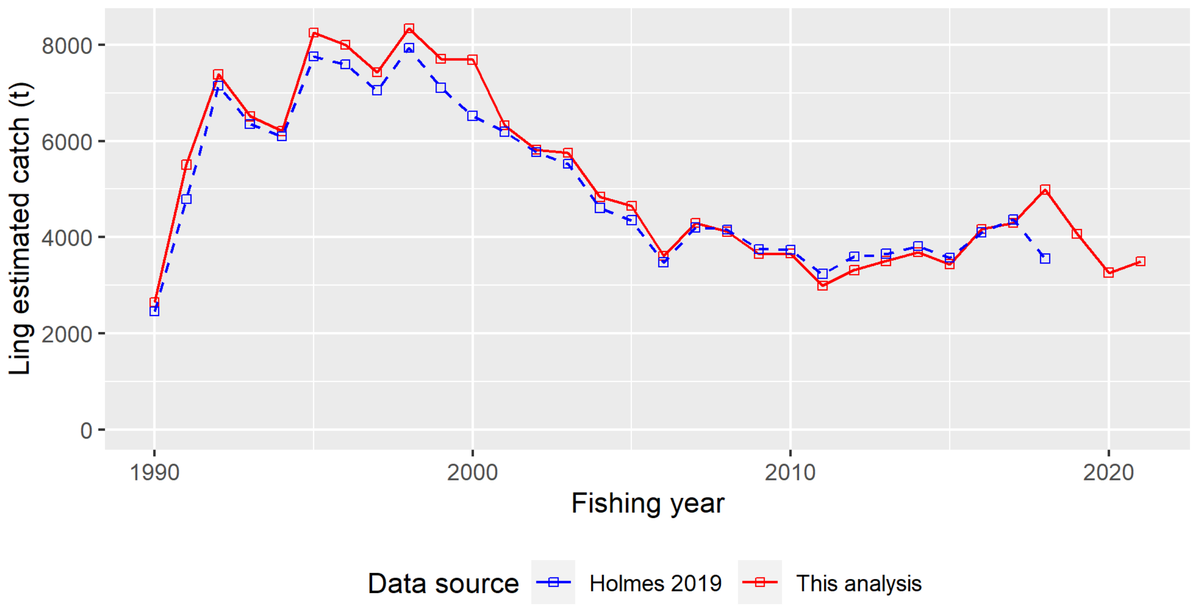


Figure A.1: LIN 3&4 estimated ling catches as reported in the catch and effort forms and scaled to landings and MHR calculated in this analysis and reported in the 2019 analysis (Holmes 2019) by fishing year.

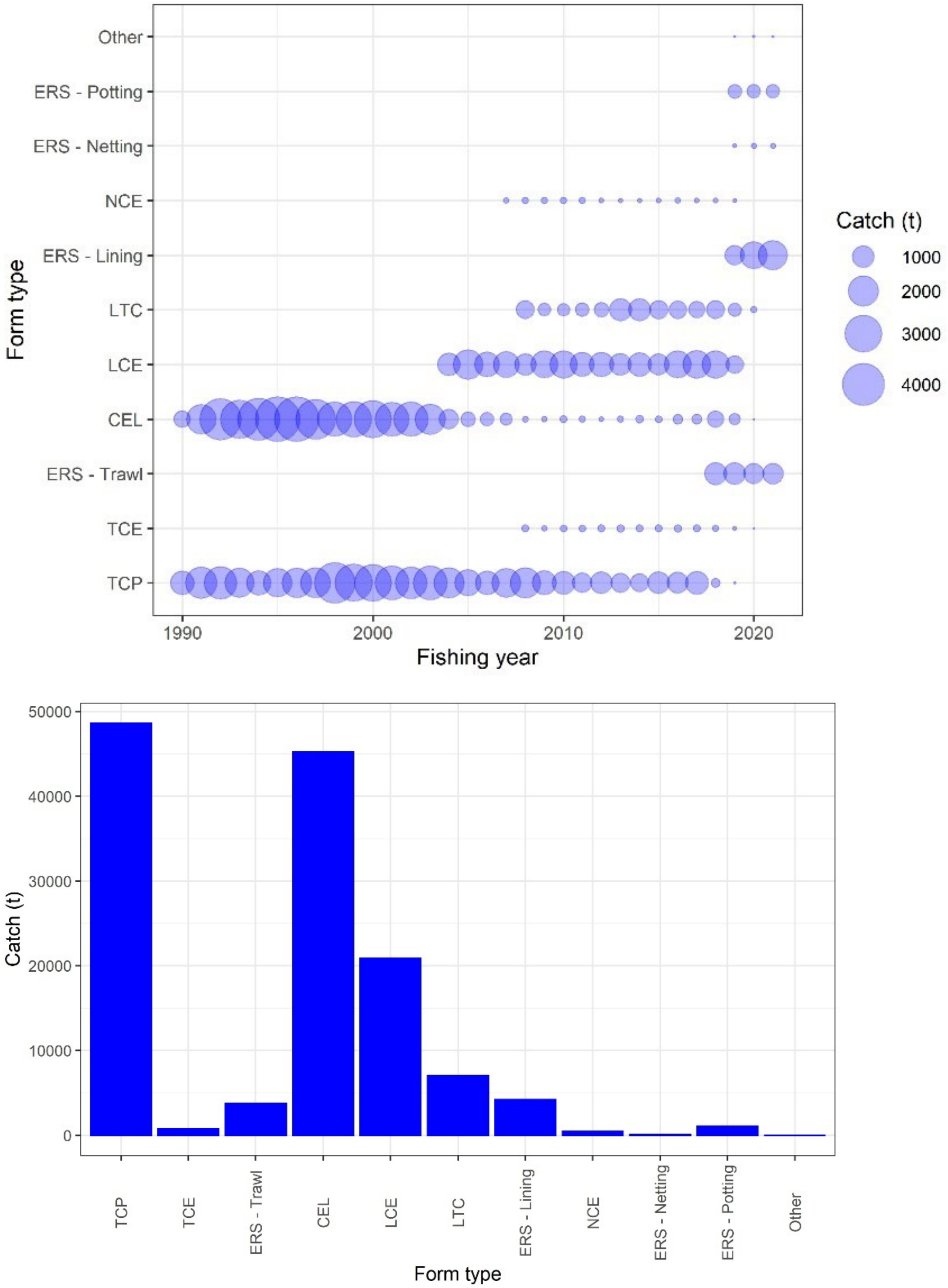
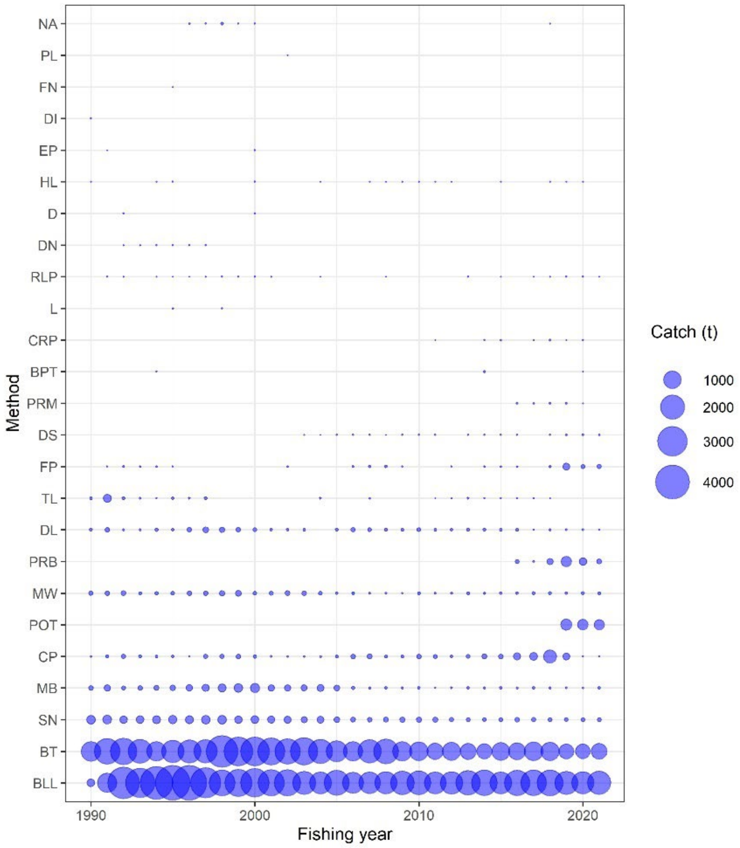


Figure A.2: LIN 3&4 distribution of annual ling catch reported in catch and effort forms by form type: trawl catch effort and processing return (TCP), trawl catch effort return (TCE), electronic reporting system return (ERS), catch effort landing return (CEL), lining catch effort return (LCE), lining trip catch effort return (LTC), and netting catch effort return (NCE).



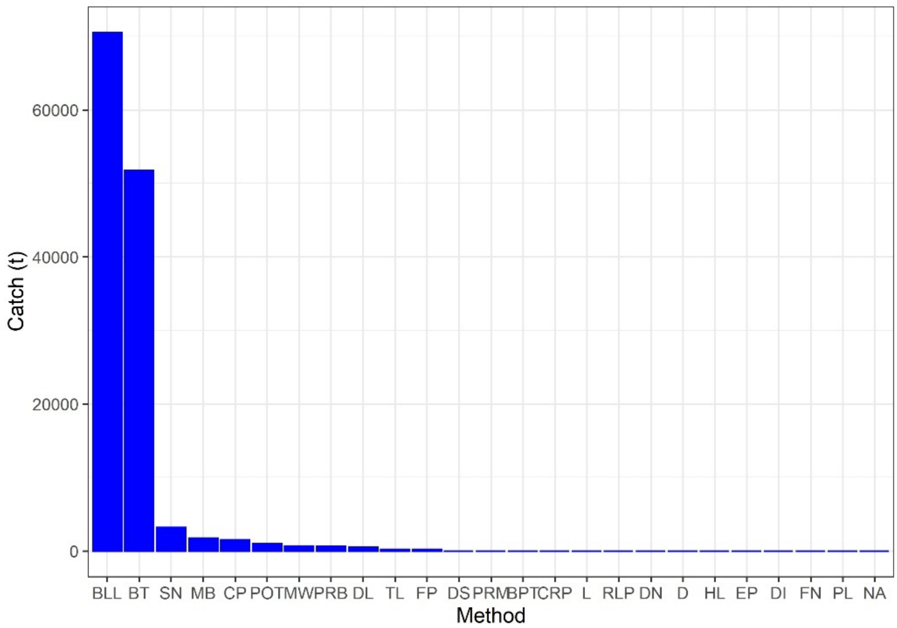


Figure A.3: LIN 3&4 distribution of annual ling catch reported in catch and effort forms by. Model year starts in September (as opposed to fishing year which starts in October). Method includes bottom longlining (BLL), bottom paired trawl (BPT), bottom trawl (BT), crayfish pot (CRP), cod pot (CP), Danish seine (DS), dredge (D), drop/Dahn line (DL), fish pots (FP), handline (HL), mechanical harvesting (MH), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis), not reported (NA), pot (POT), precision bottom trawl (PRB), precision midwater trawl (PRM), rock lobster pot (RLP), set net (SN), troll (T), trot line (TL).

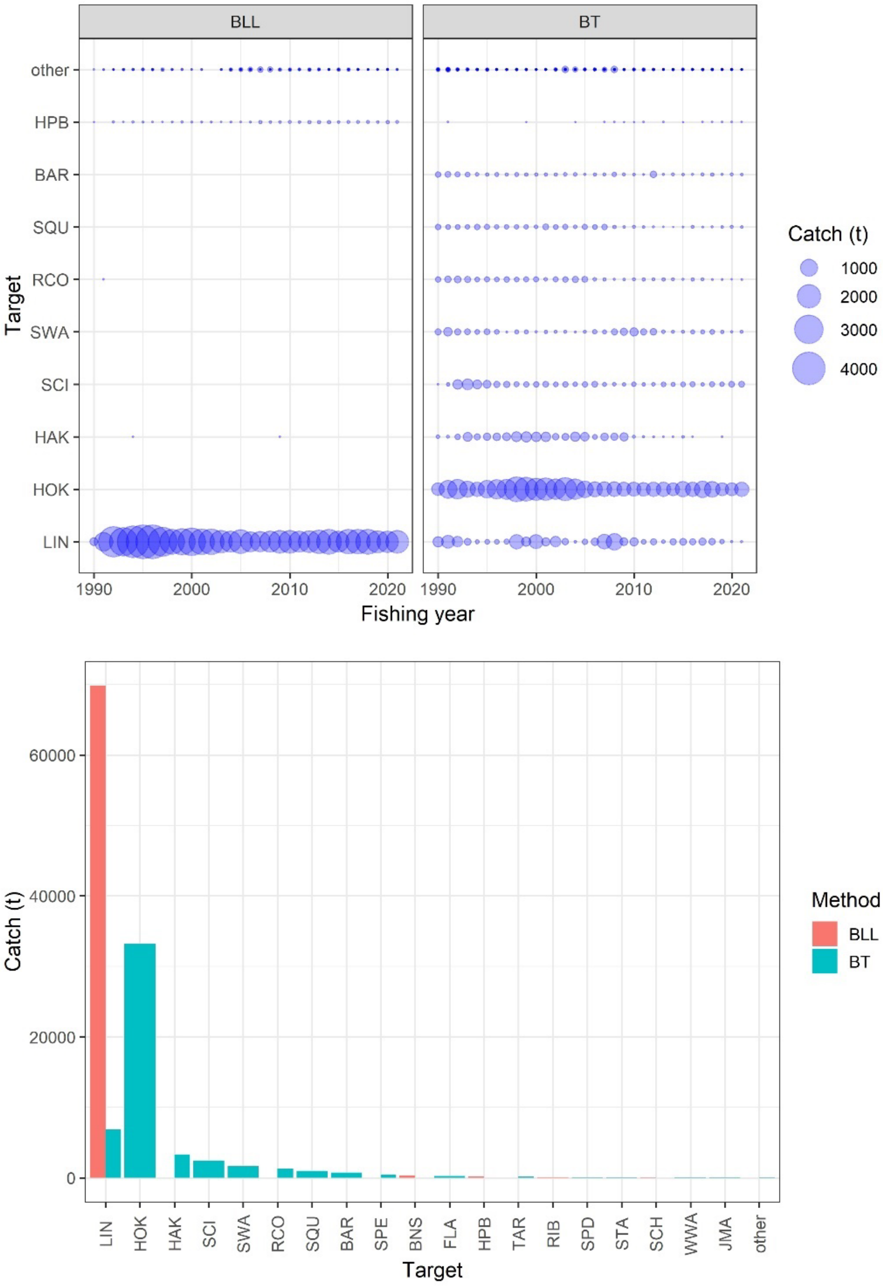


Figure A.4: LIN 3&4 distribution of annual ling catch reported in catch and effort forms by target species for bottom trawl (BT) and bottom longline (BLL) gears separately. Target is barracouta (BAR - *Gigartina* spp.), bluenose (BNS - *Hyperoglyphe antarctica*), flatfish (FLA – mixed species), giant stargazer (STA - *Kathetostoma* spp.), hake (HAK), hāpuku (HAP - *Polyprion oxygeneios*), hāpuku and bass (HPB - *Polyprion oxygeneios, P. americanus*), hoki (HOK), jack mackerel (JMA - *Trachurus declivis, T. murphyi, T. novaezelandiae*), kingfish (KIN - *Seriola lalandi*), lemon sole (LSO - *Pelotretis flavilatus*), ling (LIN), red cod (RCO - *Pseudophycis bachus*), ribaldo (RIB - *Mora moro*), scampi (SCI), school shark (SCH - *Galeorhinus galeus*), sea perch (SPE - *Helicolenus* spp.), silver warehou (SWA - *Seriolella punctata*), southern blue whiting (SBW - *Micromesistius australis*), spiny dogfish (SPD - *Squalus acanthias*), squid (SQU - *Nototodarus sloanii & N. gouldi*), tarakihi (TAR - *Nemadactylus macropterus, Nemadactylus* sp.), white warehou (WWA - *Seriolella caerulea*).

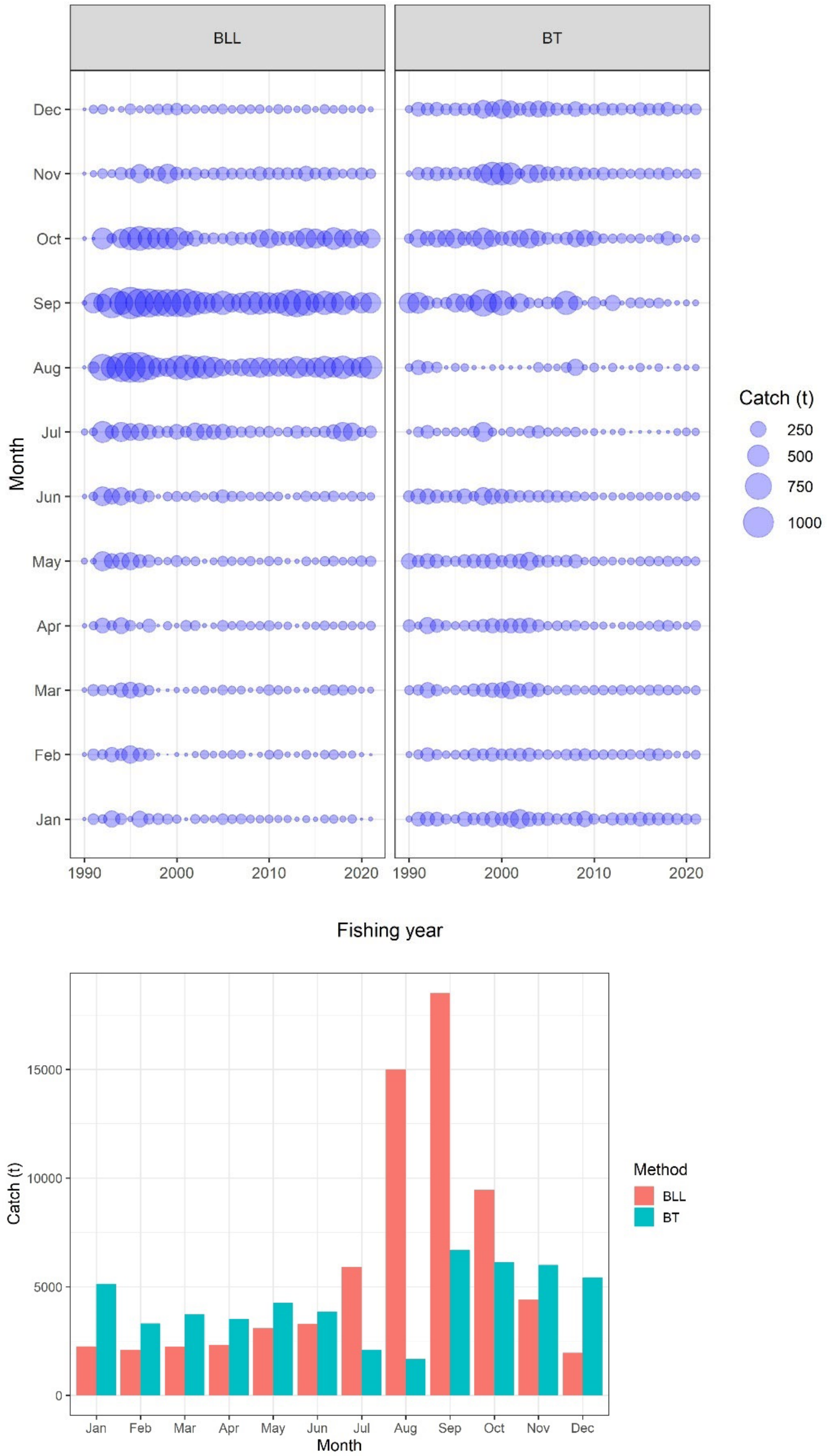


Figure A.5: LIN 3&4 distribution of annual ling catch reported in catch and effort forms by month for bottom trawl (BT) and bottom longline (BLL) gears separately.

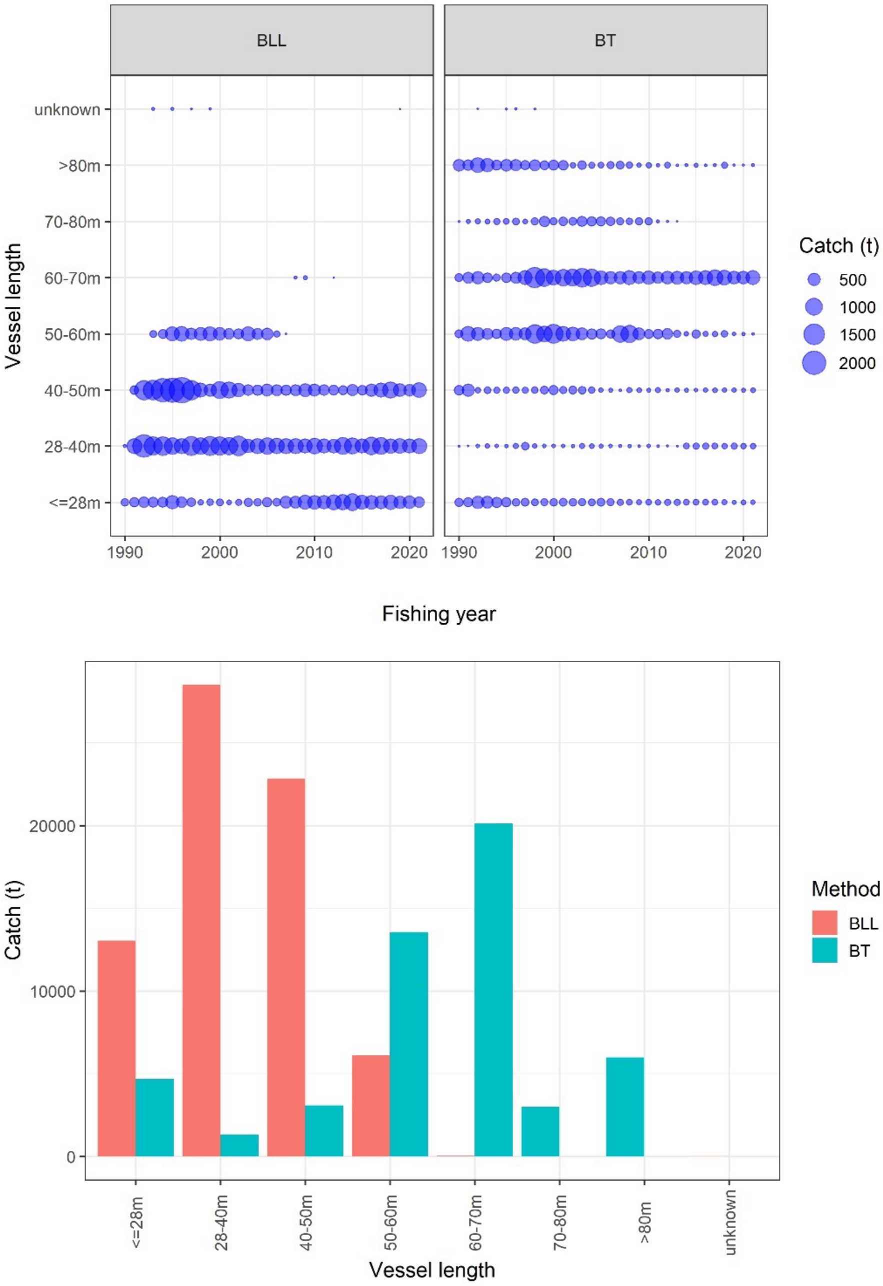


Figure A.6: LIN 3&4 distribution of annual ling catch reported in catch and effort forms by vessel length for bottom trawl (BT) and bottom longline (BLL) gears separately.

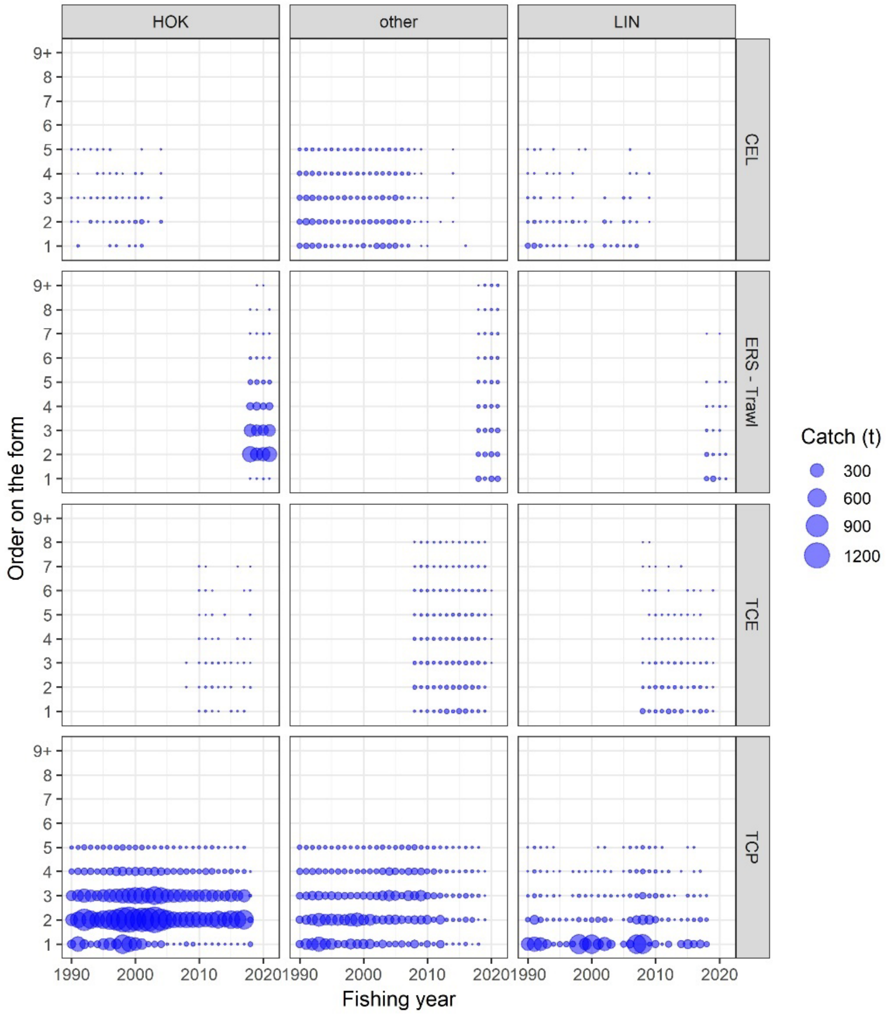


Figure A.7: LIN 3&4 distribution of annual ling catch reported in catch and effort forms by order (where greatest catch is 1) reported in the forms for bottom trawl major target species (ling – LIN, hoki – HOK or other). The order is for QMS species for ERS forms and all species otherwise, matching reporting requirements.

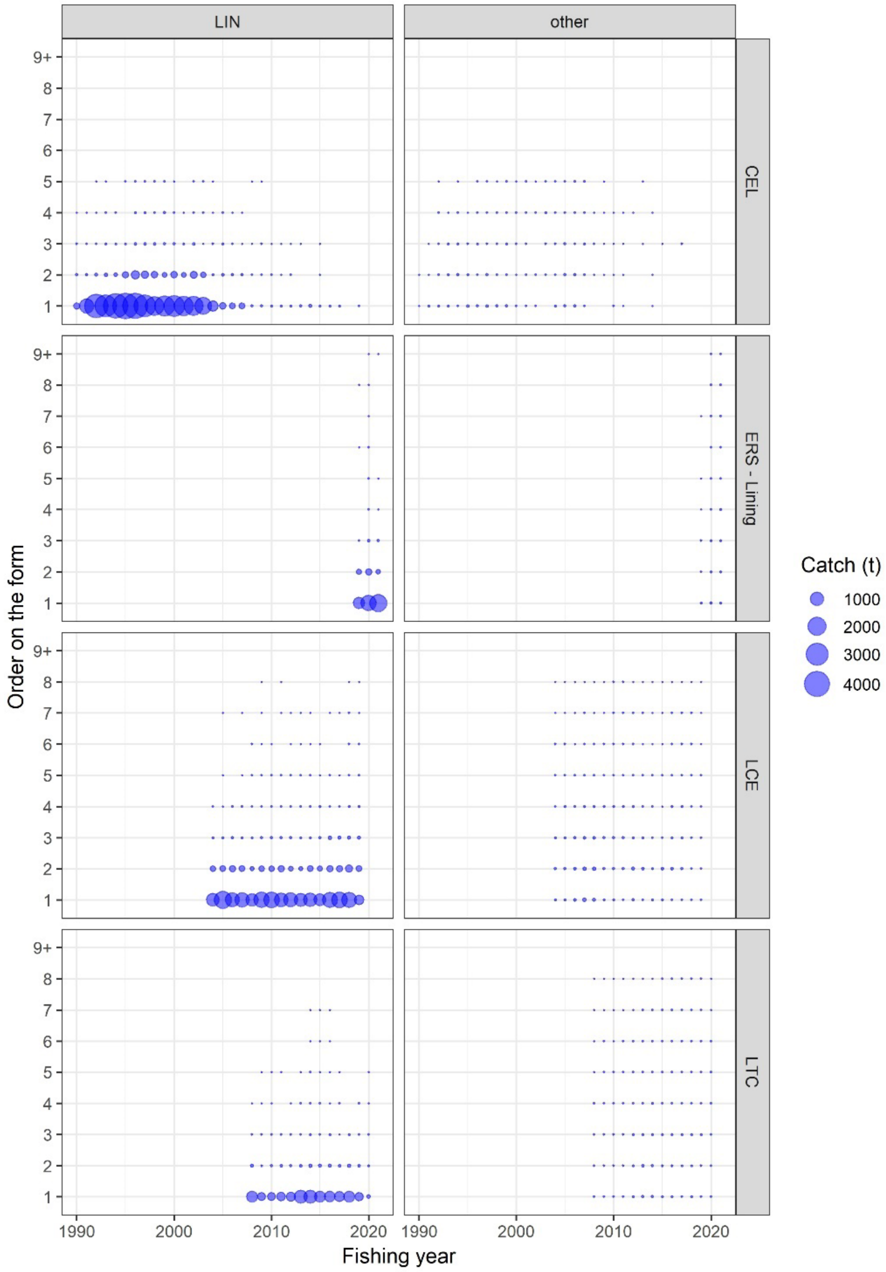


Figure A.8: LIN 3&4 distribution of annual ling catch reported in catch and effort forms by order reported in the forms for longline gears (where greatest catch is 1) and target species (ling – LIN or other). The order is for QMS species for ERS forms and all species otherwise, matching reporting requirements.

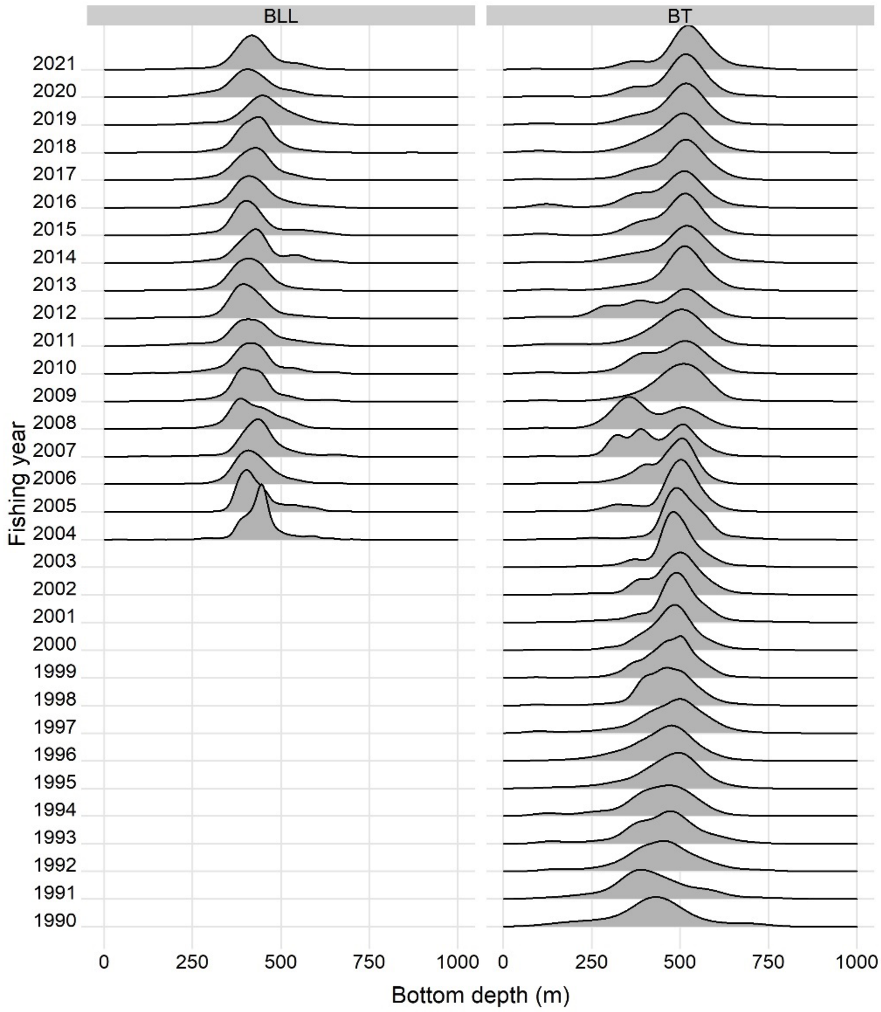
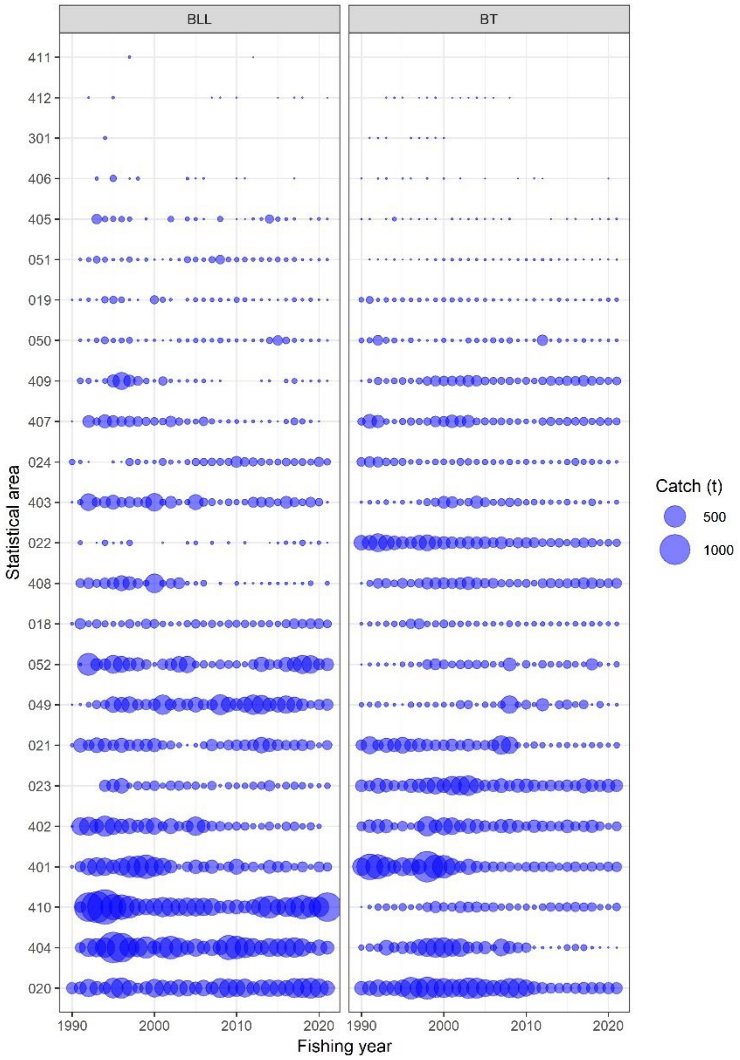


Figure A.9: Catch-weighted LIN 3&4 distribution of bottom depth by fishing year for bottom trawl (BT) and bottom longline (BLL) gears separately.



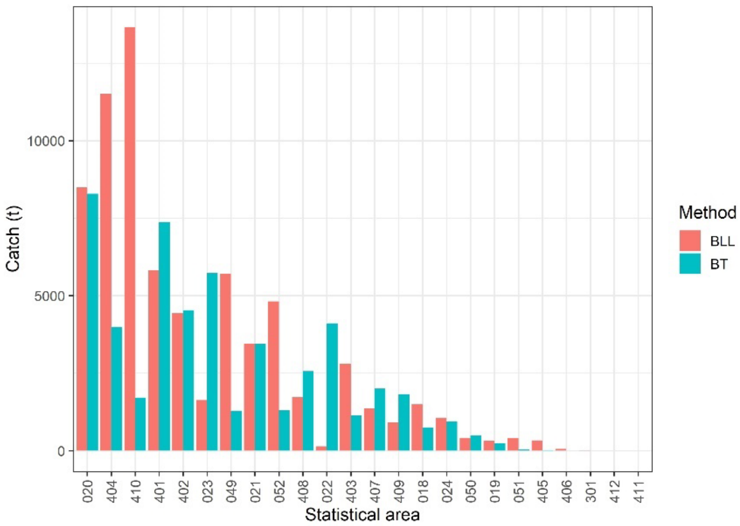


Figure A.10: LIN 3&4 distribution of annual ling catch reported in catch and effort forms by Statistical Area for bottom trawl (BT) and bottom longline (BLL) gears separately.

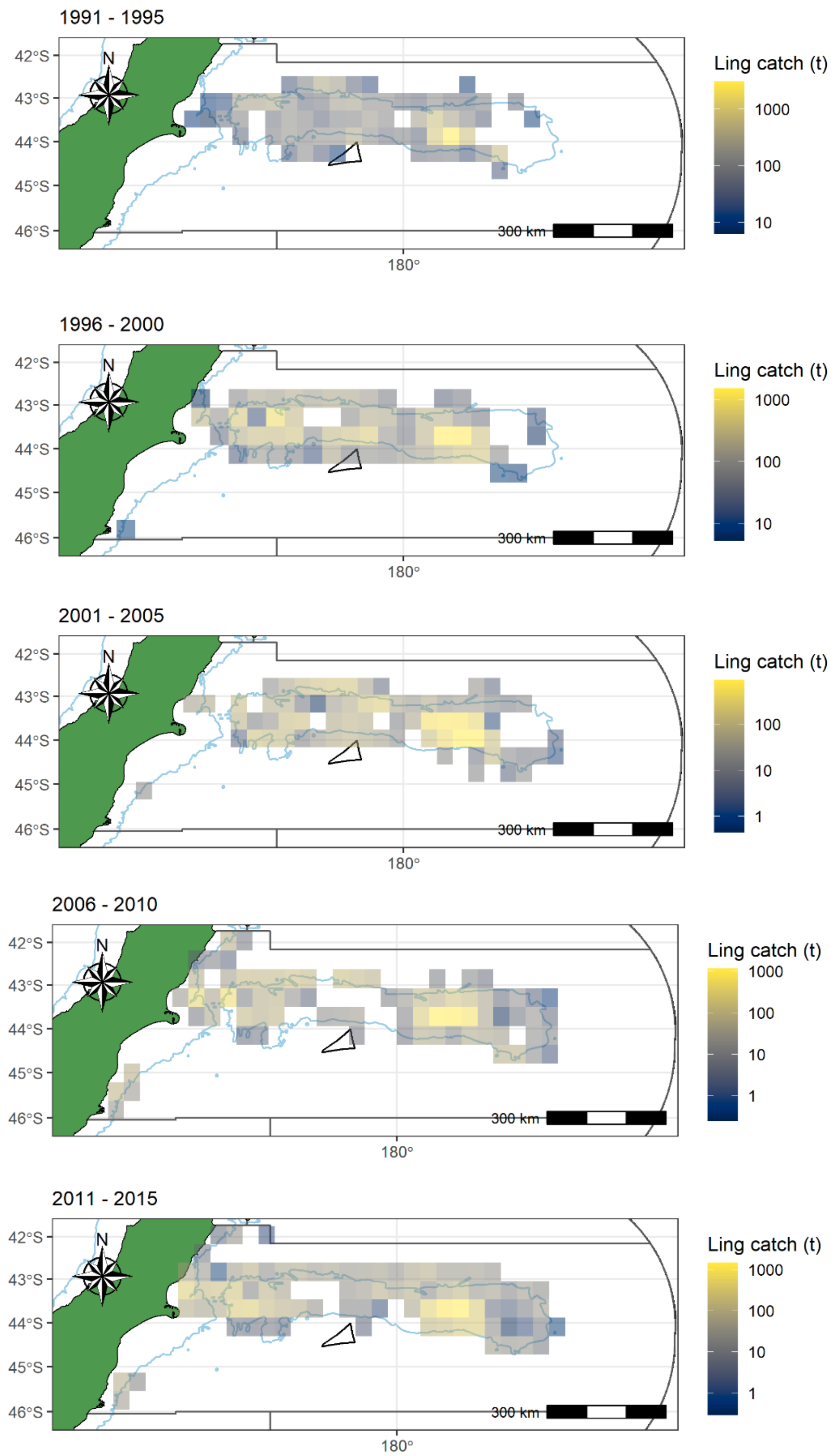


Figure A.11: Distribution of ling catches in the LIN 3&4 biological stock area by bottom longlines between 1991 and 2015. Year ranges are fishing years. Areas are plotted at about 0.5° resolution and only where at least three vessels fished in any cell in the period as per confidentiality rules.

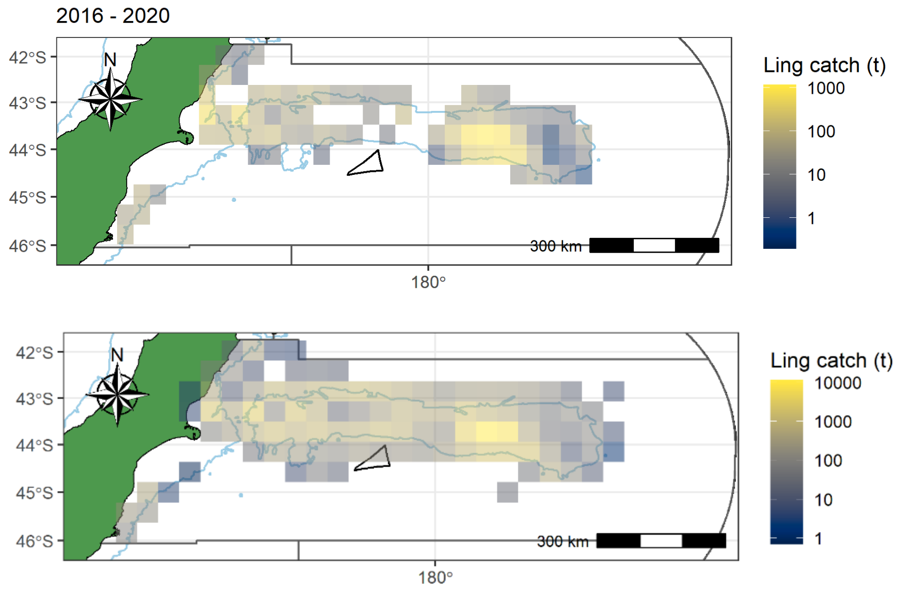


Figure A.12: Distribution of ling catches in the LIN 3&4 biological stock area by bottom longlines between 2016 and 2020, and all years combined (including 2021). Year ranges are fishing years. Areas are plotted at about 0.5° resolution and only where at least three vessels fished in any cell in the period as per confidentiality rules.

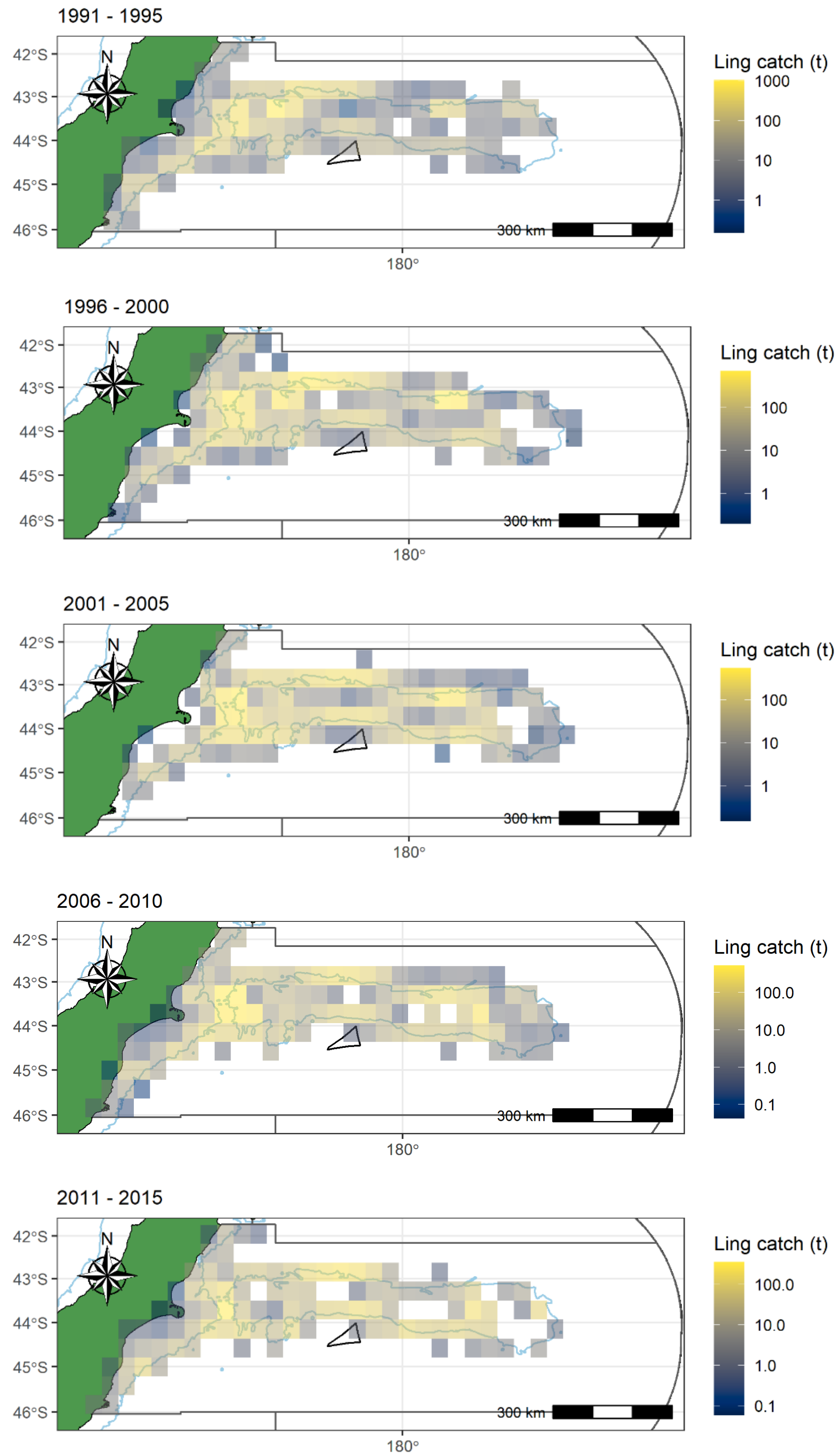


Figure A.13: Distribution of ling catches in the LIN 3&4 biological stock area by bottom trawls between 1991 and 2015. Year ranges are fishing years. Areas are plotted at about 0.5° resolution and only where at least three vessels fished in any cell in the period as per confidentiality rules.

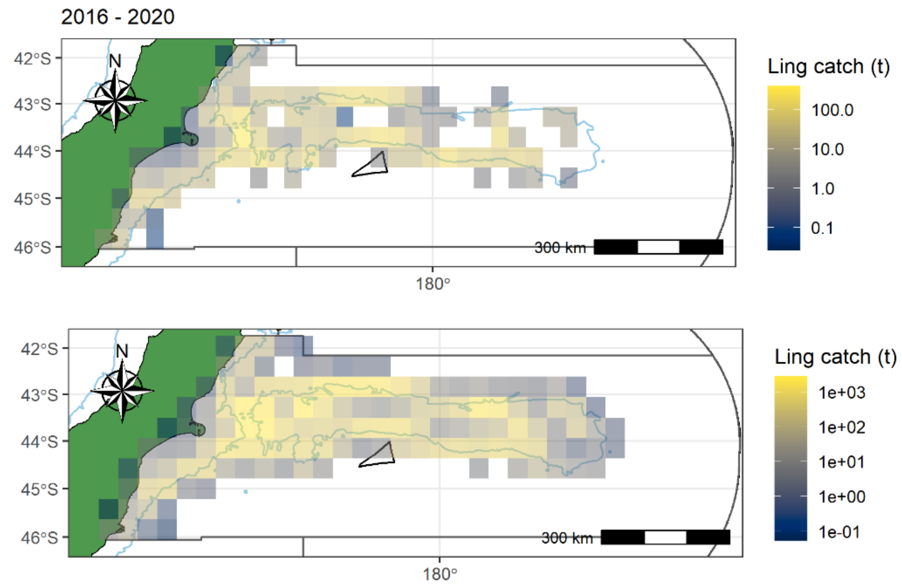
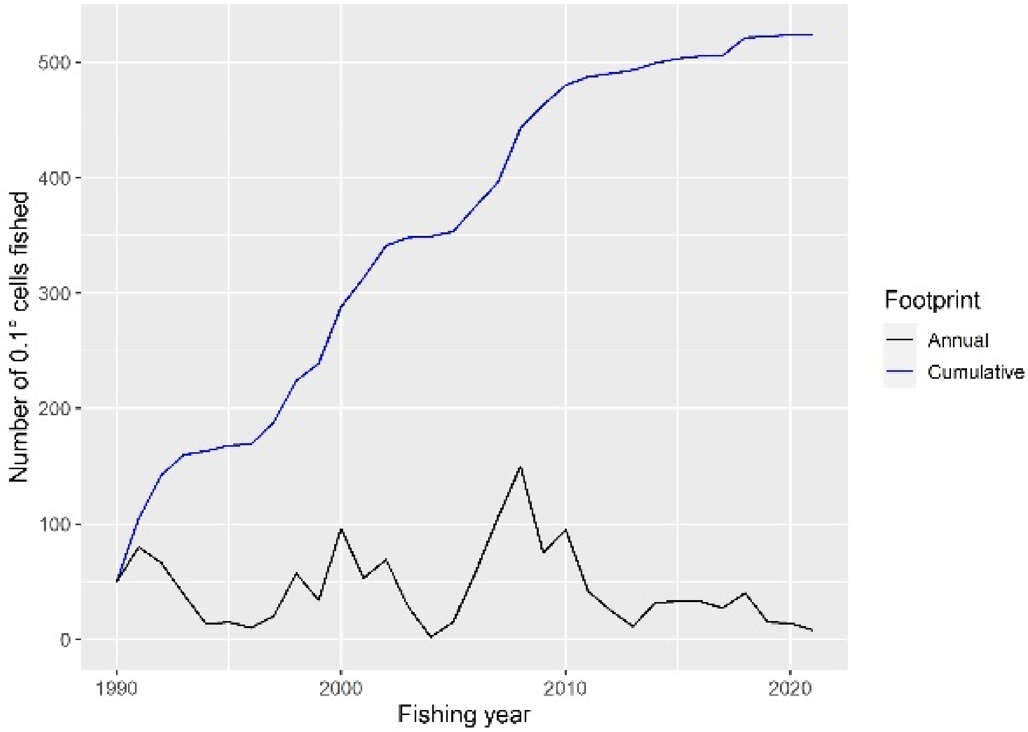


Figure A.14: Distribution of ling catches in the LIN 3&4 biological stock area by bottom trawls between 2015 and 2020, and all years combined (including 2021). Year ranges are fishing years. Areas are plotted at about 0.5° resolution and only where at least three vessels fished in any cell in the period as per confidentiality rules.

Bottom trawl



Bottom longline

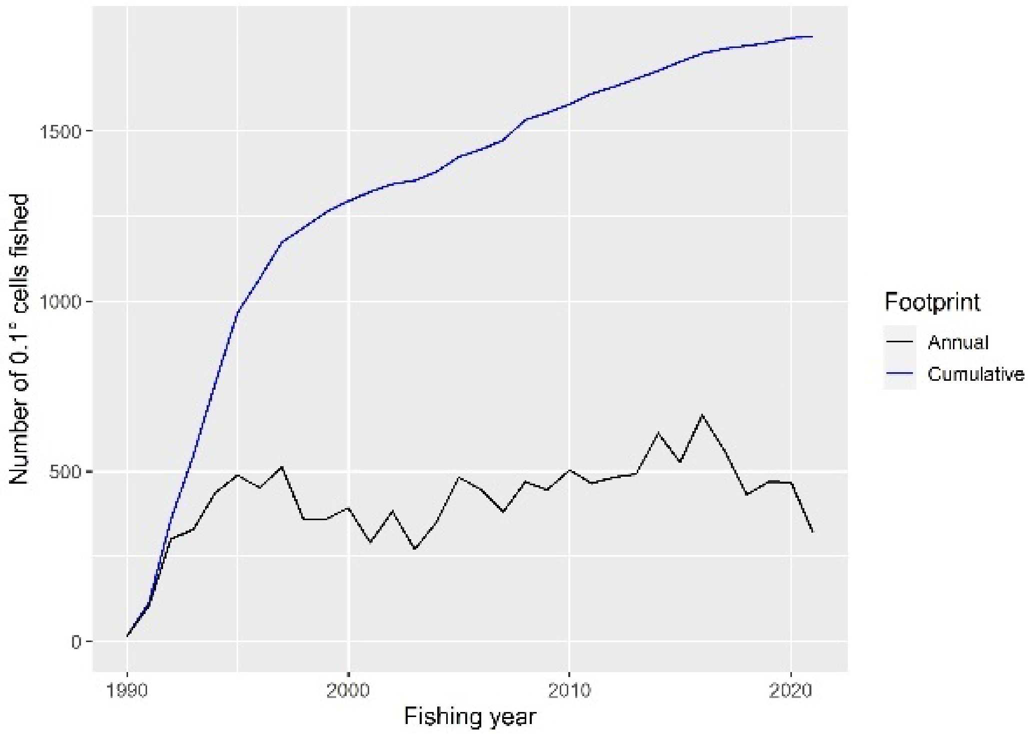


Figure A.15: Spatial distribution of the ling target fishery in LIN 3&4: number of cells of 0.1° latitude and longitude fished in any one year and cumulative number of new cells fished over time.

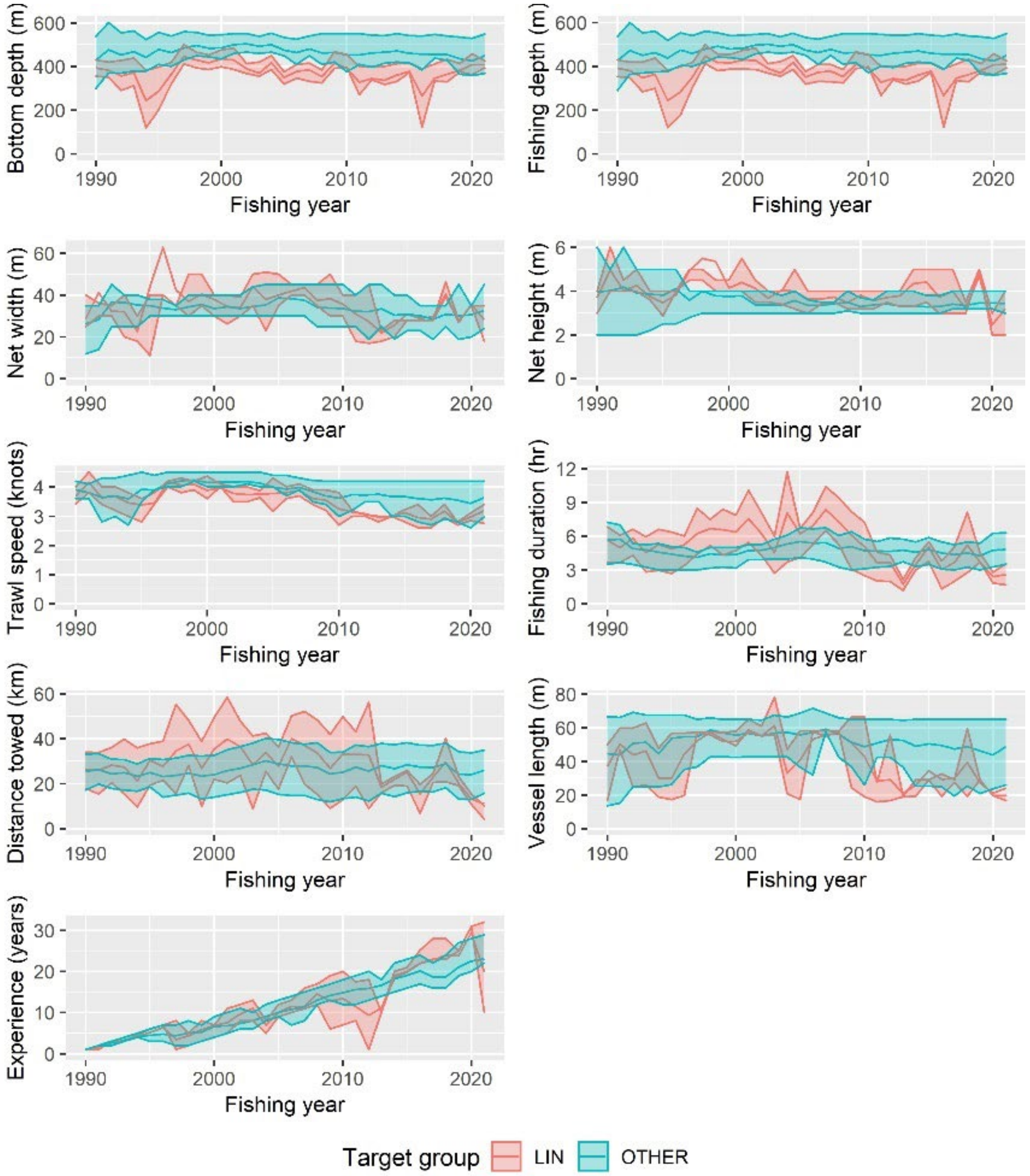


Figure A.16: Change in effort characteristics over time by target species of the bottom trawl ling fisheries in LIN 3&4. Median and interquartile range are showed.

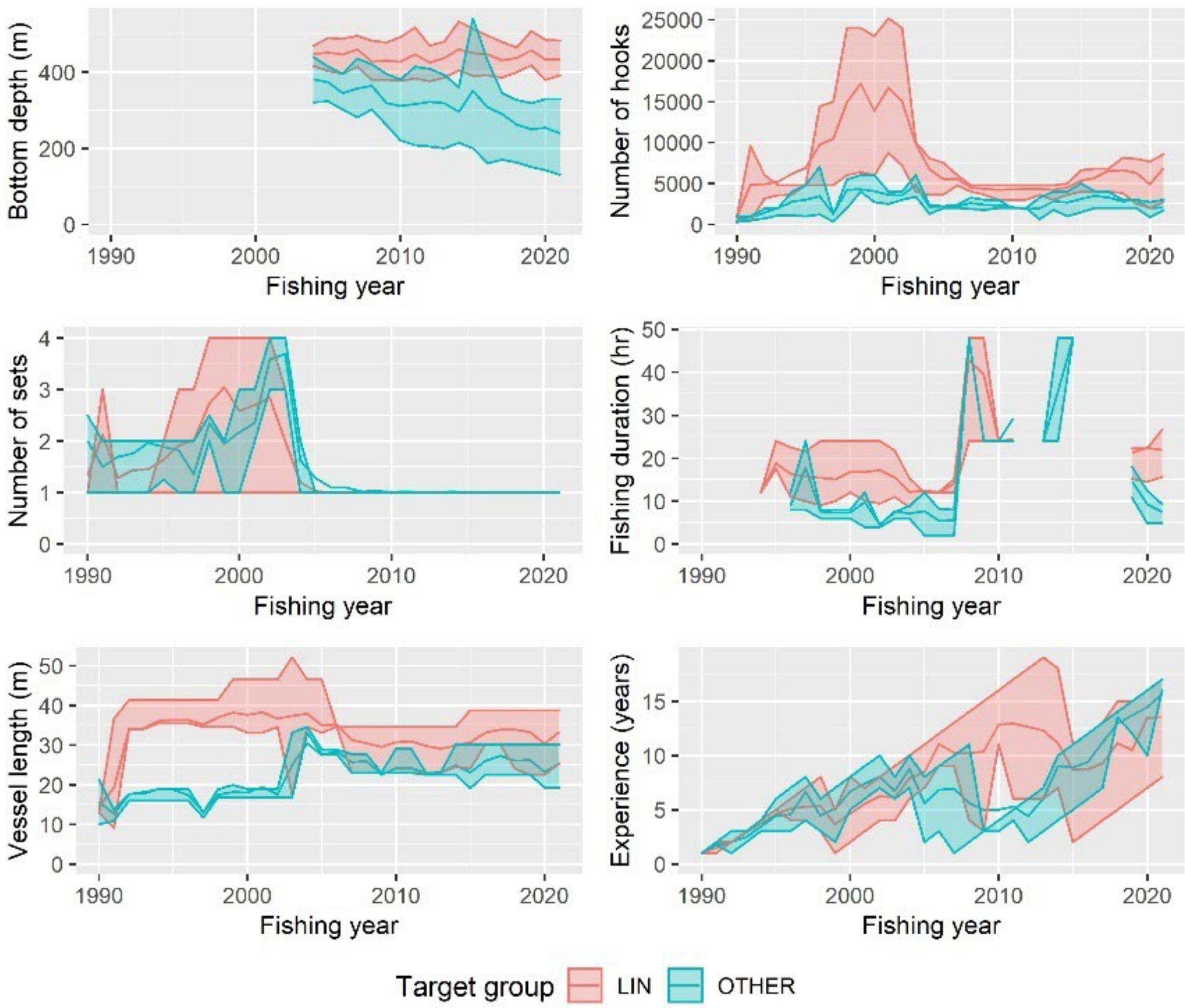


Figure A.17: Change in effort characteristics over time by target species of the longline ling fisheries in LIN 3&4. Median and interquartile range are showed.

APPENDIX B – SPATIAL ANALYSIS

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

Variable	Type	Description
Month	Categorical	Month of the year
QMA	Categorical	LIN 3 or LIN 4
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	1 267 778	1 267 767	
Length ~ Intercept + Fishing event (random) + Space	1 267 721	1 267 703	
Length ~ Intercept + Year + Fishing event (random) + Space	1 244 111	1 244 223	
Length ~ Intercept + Year + Sex + Fishing event (random) + Space	1 229 774	1 229 854	
Length ~ Intercept + Year + Sex + Fishing method + Fishing event (random) + Space	1 229 405	1 229 485	Chosen model
Length ~ Intercept + Year + Sex + Fishing method + Month + Fishing event (random) + Space	1 229 726	1 229 810	
Length ~ Intercept + Year + Sex + Fishing method + s(Depth,3) + Fishing event (random) + Space	1 229 426	1 229 560	
Length ~ Intercept + Year + Sex + Fishing method + Fishing event (random) + (Space * Sex)	1 226 590	1 226 704	Best model
Length ~ Intercept + Year + Sex + Fishing method + Fishing event (random) + (Space * Year block)	1 229 167	1 229 200	

Table B.3: Model comparison deviance information criterion (DIC) and Watanabe-Akaike information criterion (WAIC) for each of the sex ratio model runs. The model term 'Space' refers to the INLA SPDE term.

Model	DIC	WAIC	Comment
Proportion of females ~ Intercept + Space	-3 590	-3 578	
Proportion of females ~ Intercept + s(Length, 3) + Space	-4 357	-4 317	Best model
Proportion of females ~ Intercept + s(Length, 3) + Year + Space	-4 298	-4 278	
Proportion of females ~ Intercept + s(Length, 3) + Fishing method + Space	-4 249	-4 219	
Proportion of females ~ Intercept + s(Length, 3) + Month + Space	-4 233	-4 205	

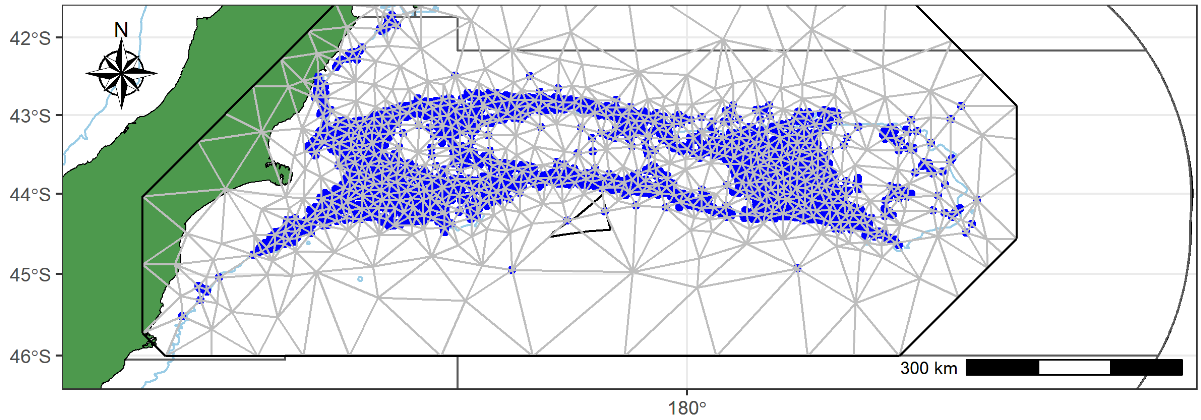


Figure B.1: Spatial mesh for ling spatial-temporal models showing the locations of data (blue points), the spatial mesh (grey lines), the extent of the spatial model (thick black lines), and the New Zealand EEZ (dark grey lines).

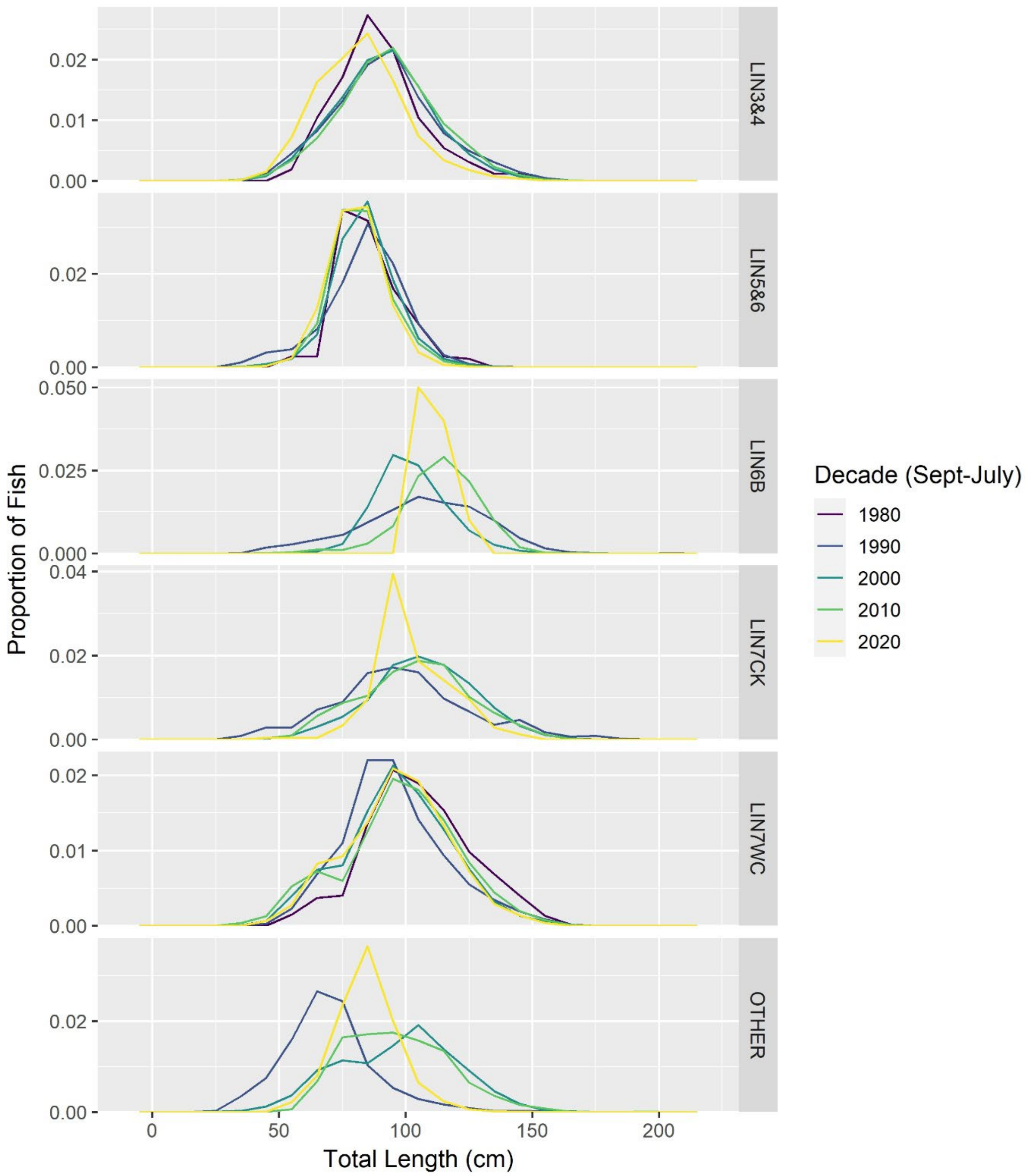


Figure B.2: Unscaled length frequency distribution of ling by biological stock and decade, based on observer data. 1990 represents 1990 to 1999 and 2020 represents the year 2020 only.

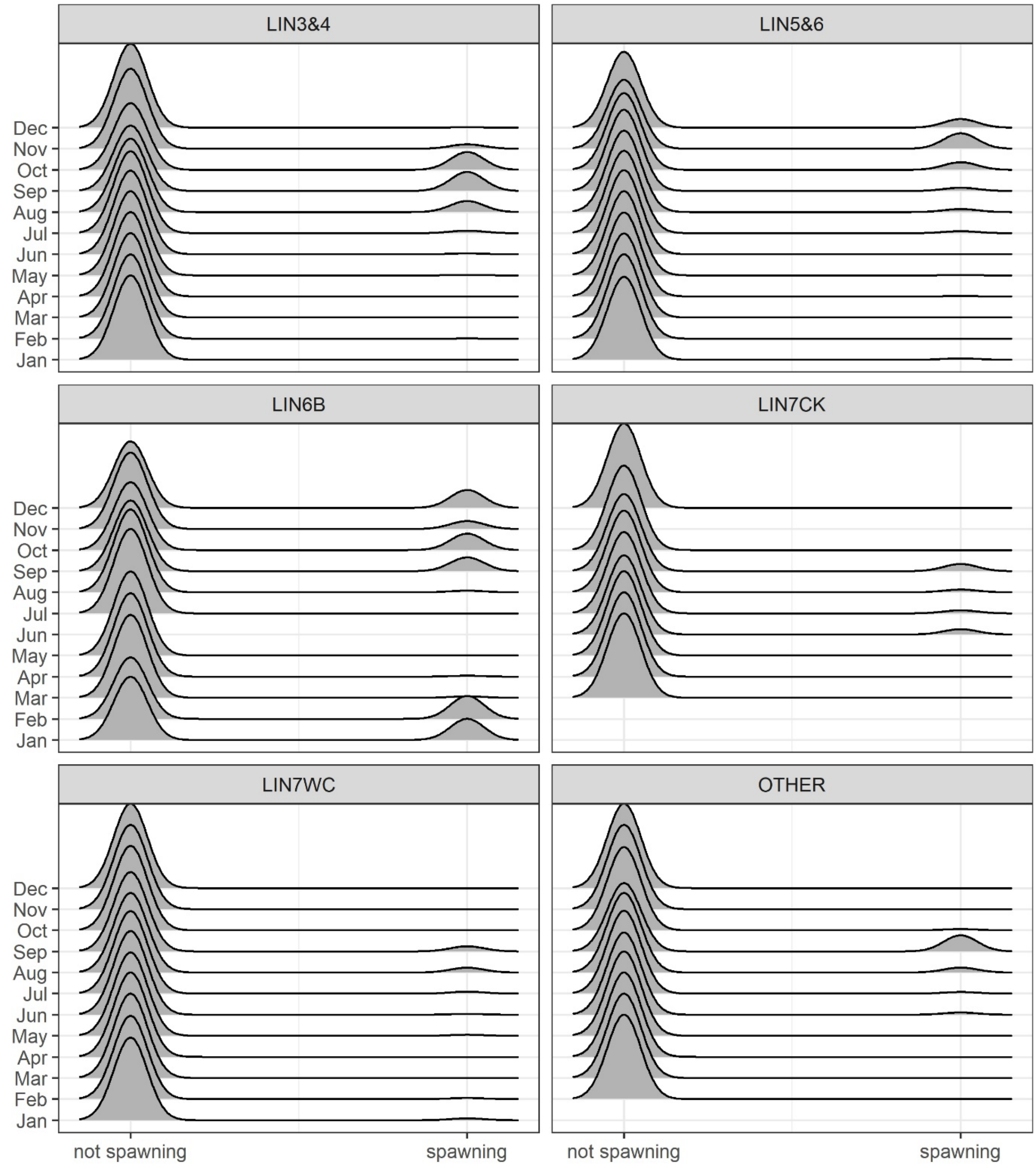


Figure B.3: Proportion of ling spawning by month for all years combined in the different ling stocks based on observer data, spawning is defined as stage 4 or 5.

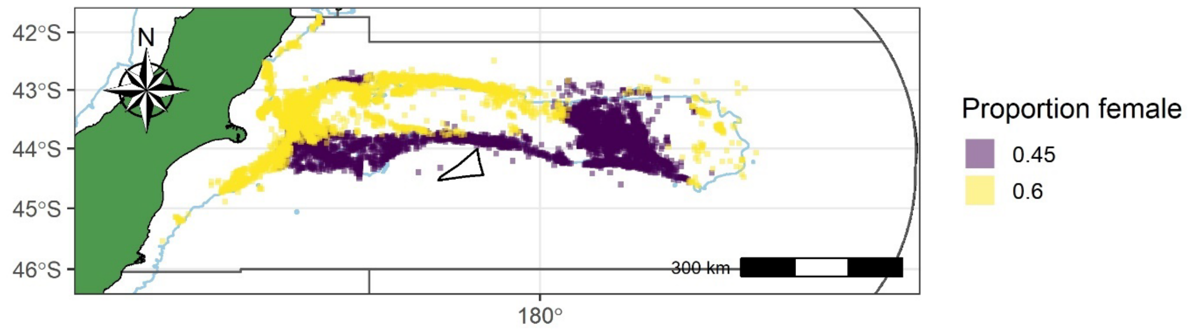


Figure B.4: Potential fisheries strata based on a tree-regression analysis of the mean proportion of females per fishing event. The strata are based on statistical areas. Locations are rounded to 0.1° and shown only where data are available for three or more vessels.

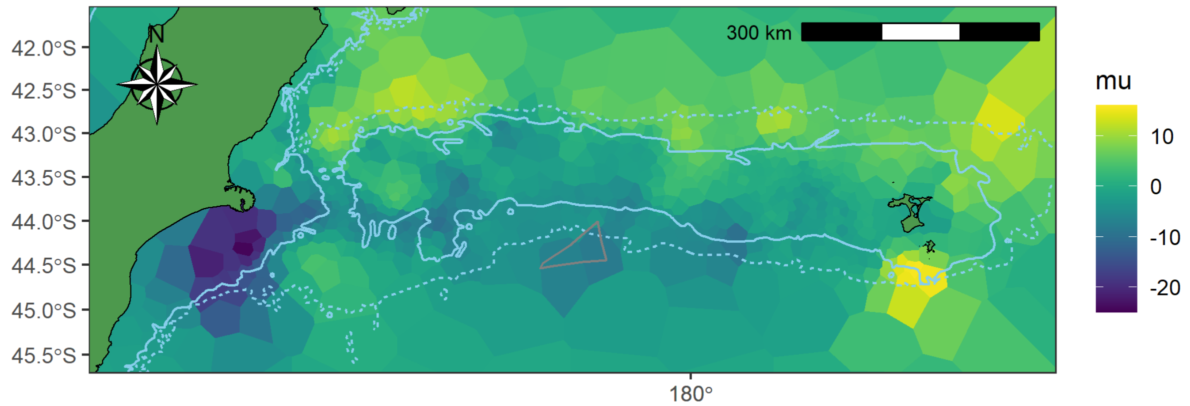


Figure B.5: The spatial effect for the chosen model of Length ~ Intercept + Year + Sex + Fishing method + Fishing event (random) + Space.

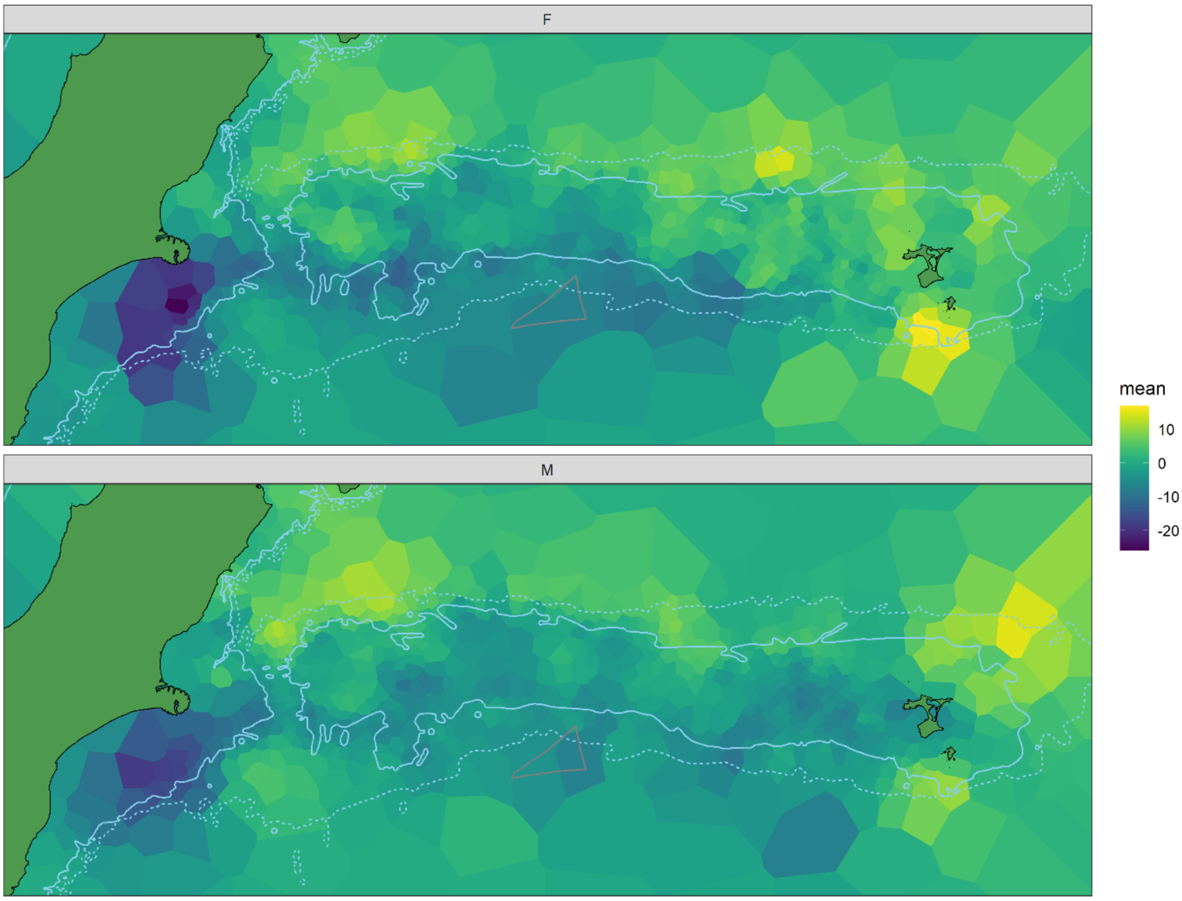


Figure B.6: The spatial effect for the sex-specific model of Length ~ Intercept + Year + Sex + Fishing method + Fishing event (random) + (Space * Sex). Females (F) and males (M) are presented in the top panel and bottom panel, respectively.

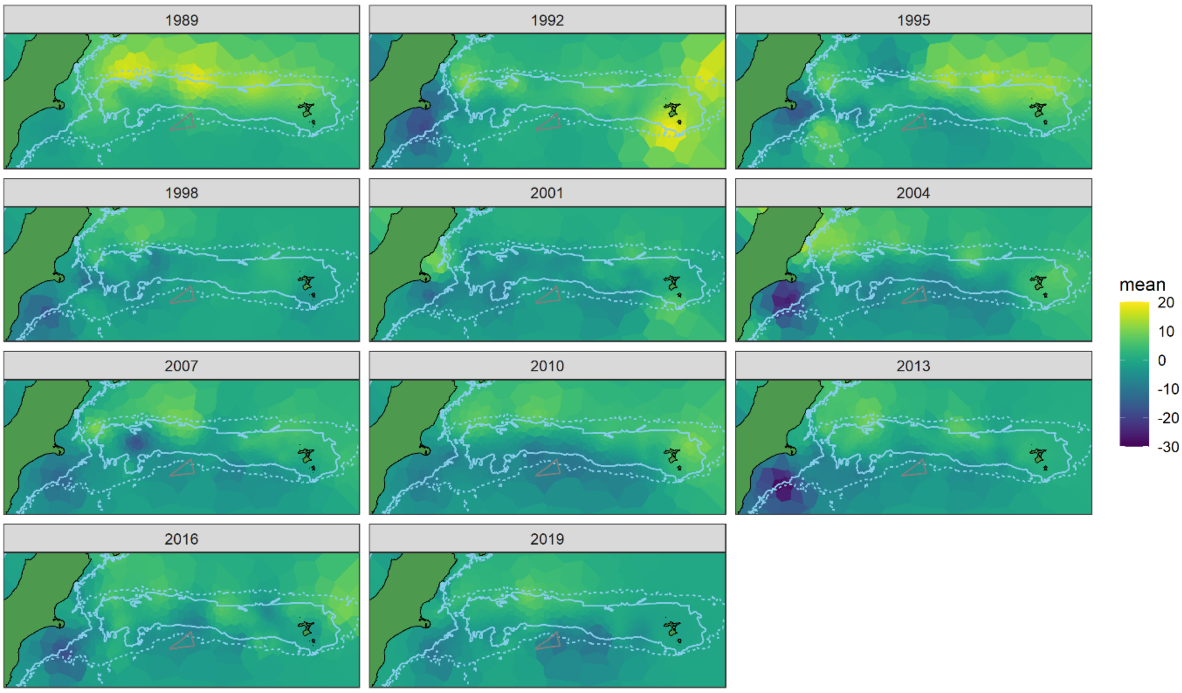


Figure B.7: The spatial effect for the time block model of Length ~ Intercept + Year + Sex + Fishing method + Fishing event + (Space * Year block). The year represents a three-year block where 2019 refers to fishing years from 2019 to 2021.

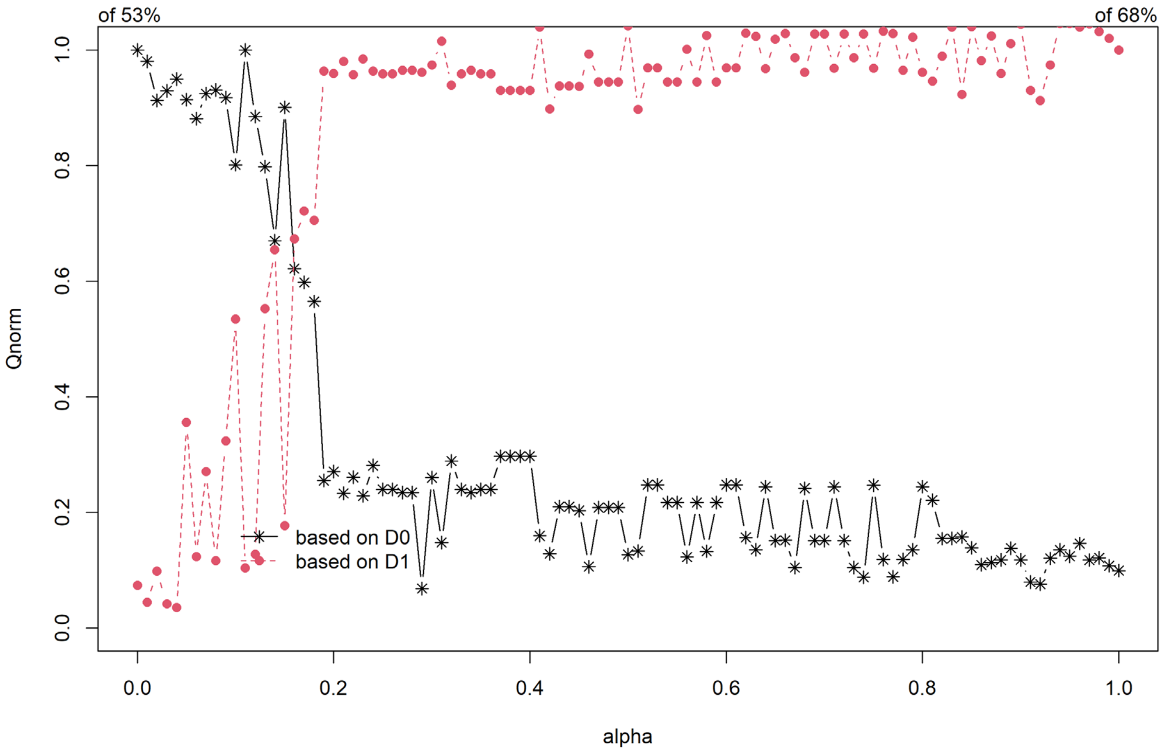


Figure B.8: The proportion of explained inertia of the data (D0) and distance (D1) partitions (in K = 2 clusters) for different values of the mixing parameter alpha for the chosen model of Length ~ Intercept + Year + Sex + Fishing method + Fishing event (random) + Space.

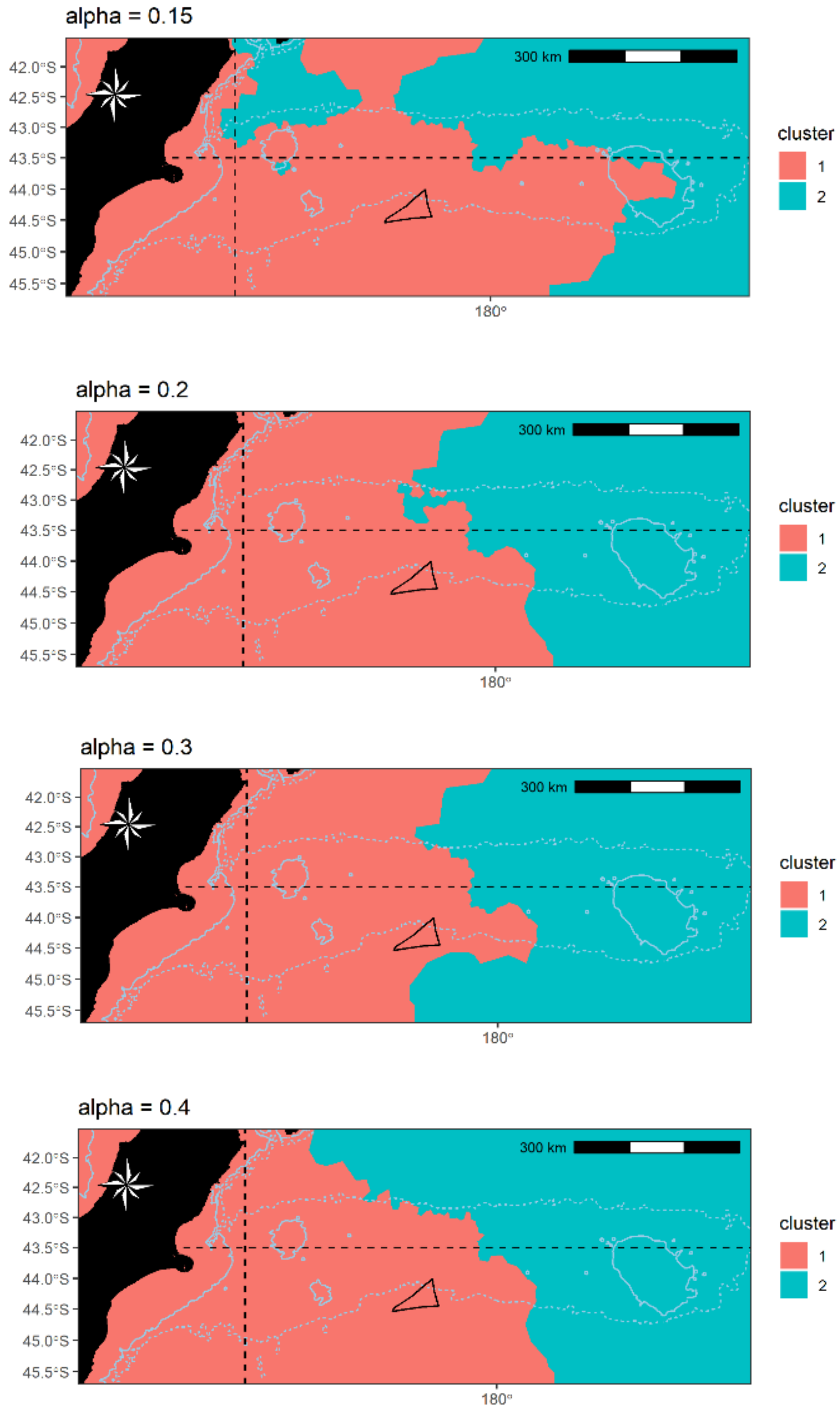


Figure B.9: Clusters (for K = 2 clusters) for different alpha levels for the chosen model of Length ~ Intercept + Year + Sex + Fishing method + Fishing event (random) + Space. The optimum alpha is 0.18.

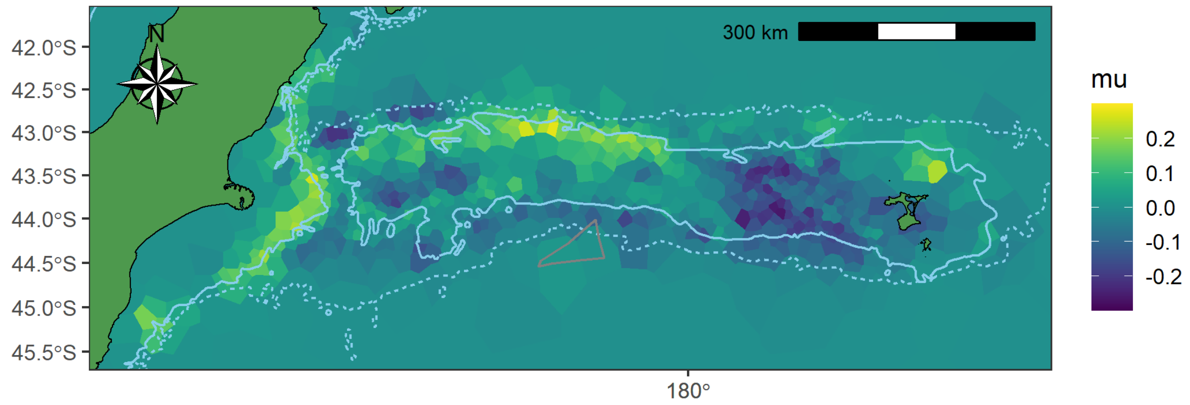


Figure B.10: The spatial effect for the chosen model of Proportion of females ~ Intercept + s(Length, 3) + Space.

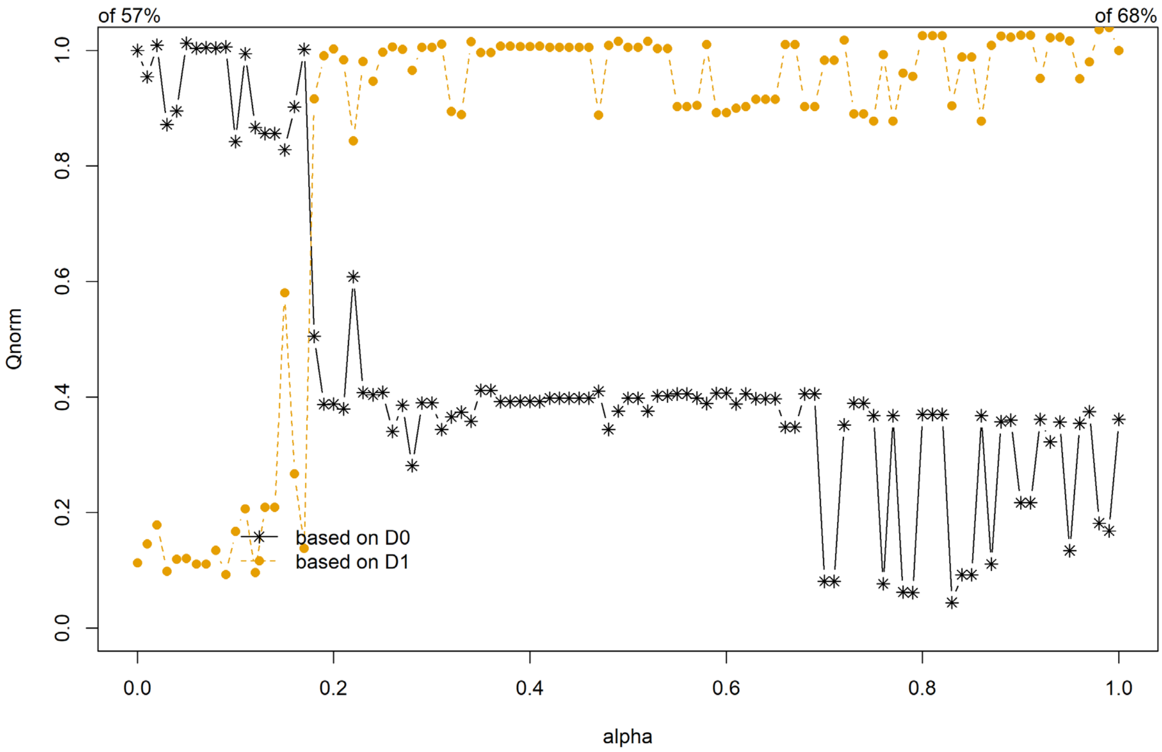


Figure B.11: The proportion of explained inertia of the data (D0) and distance (D1) partitions (in K = 2 clusters) for different values of the mixing parameter alpha for the chosen model of Proportion of females ~ Intercept + s(Length, 3) + Space.

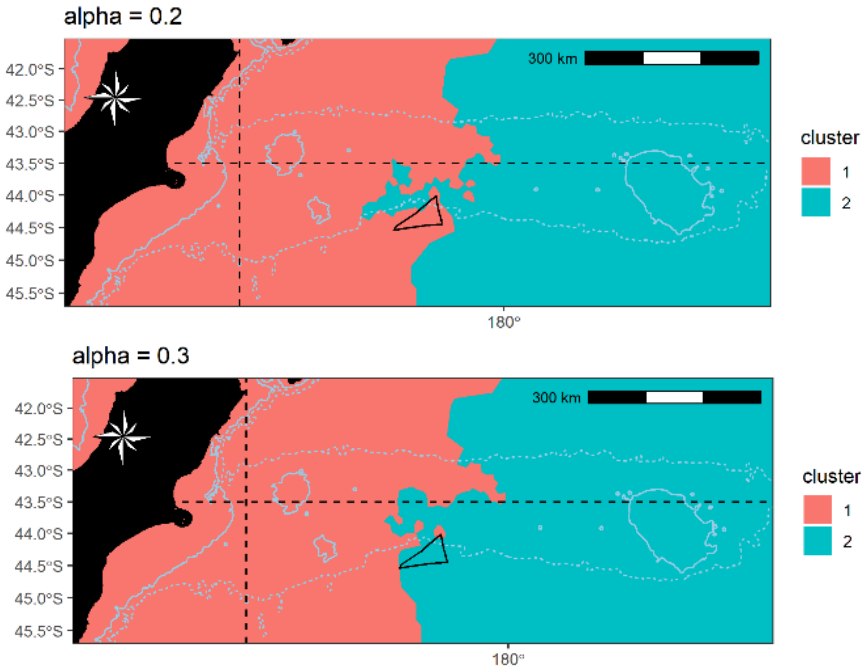


Figure B.12: Clusters (for K = 2 clusters) for different alpha levels for the chosen model of Proportion of females ~ Intercept + s(Length, 3) + Space. The optimum alpha is 0.19.

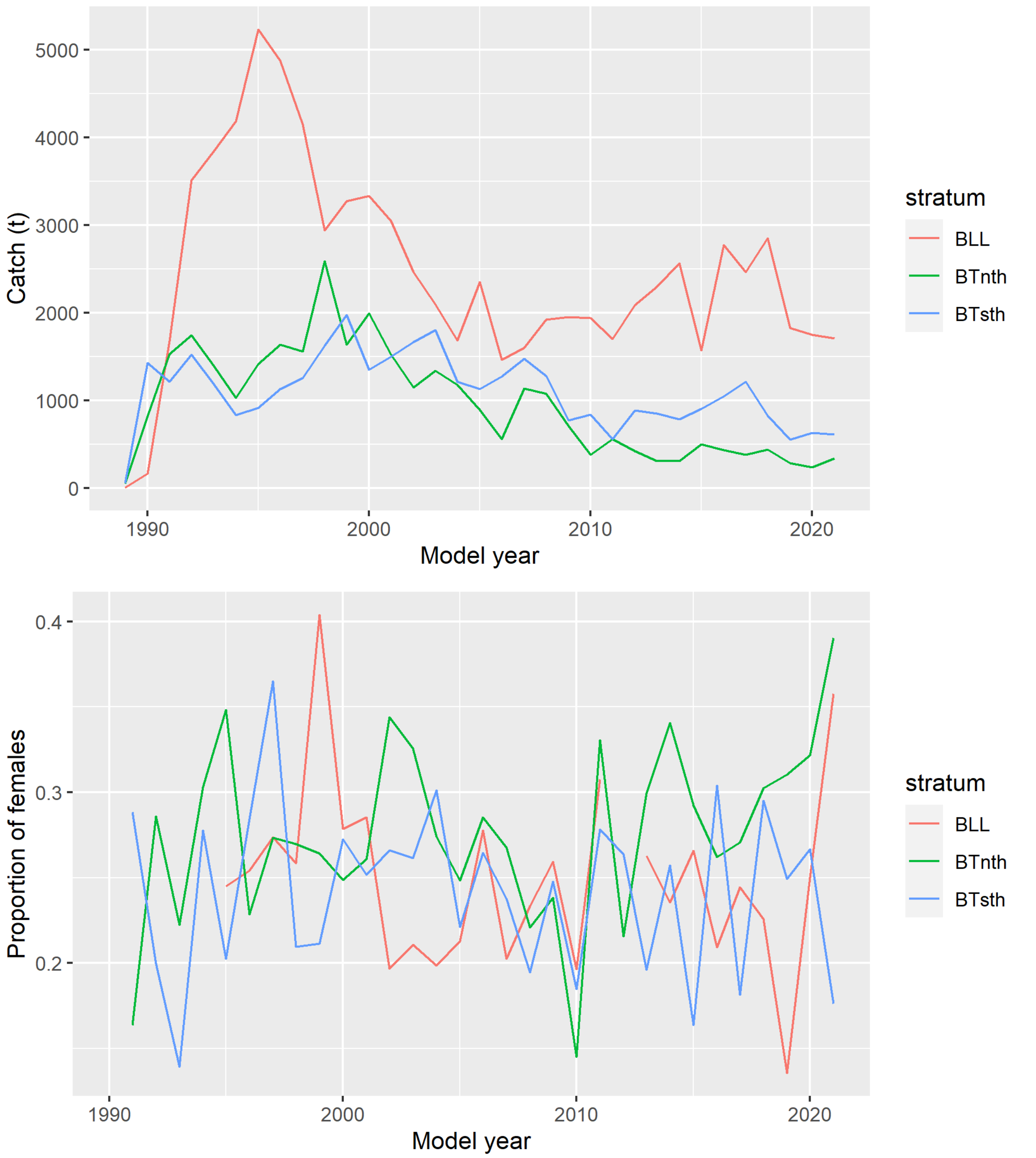


Figure B.13: Trend of catch over time and proportion of females of Option 1 of the four potential fisheries strata: split by fishing method and north / south. Model year is calendar year.

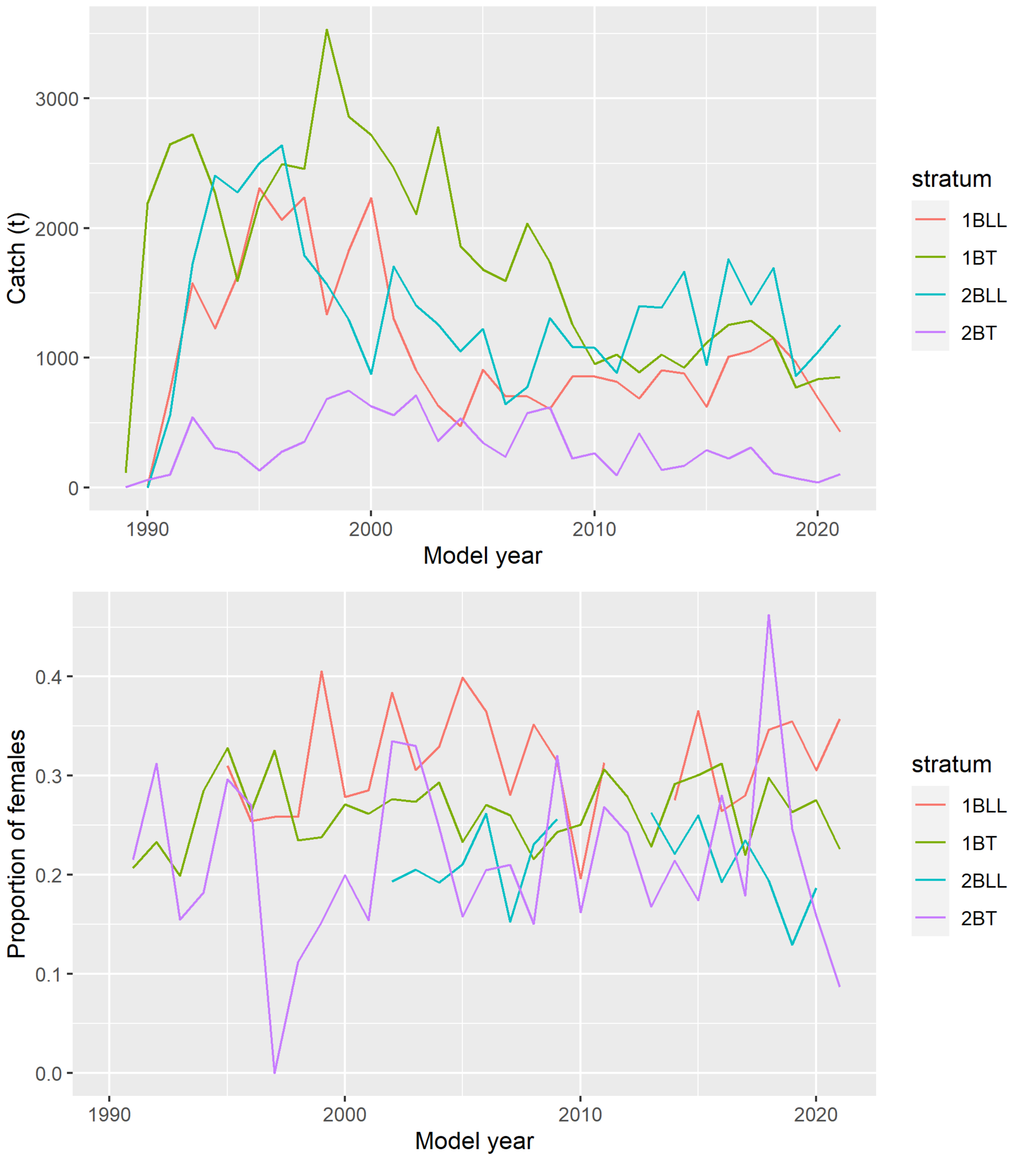


Figure B.14: Trend of catch over time and proportion of females of Option 2 of the four potential fisheries strata: split by fishing method and east / west. Model year is calendar year.

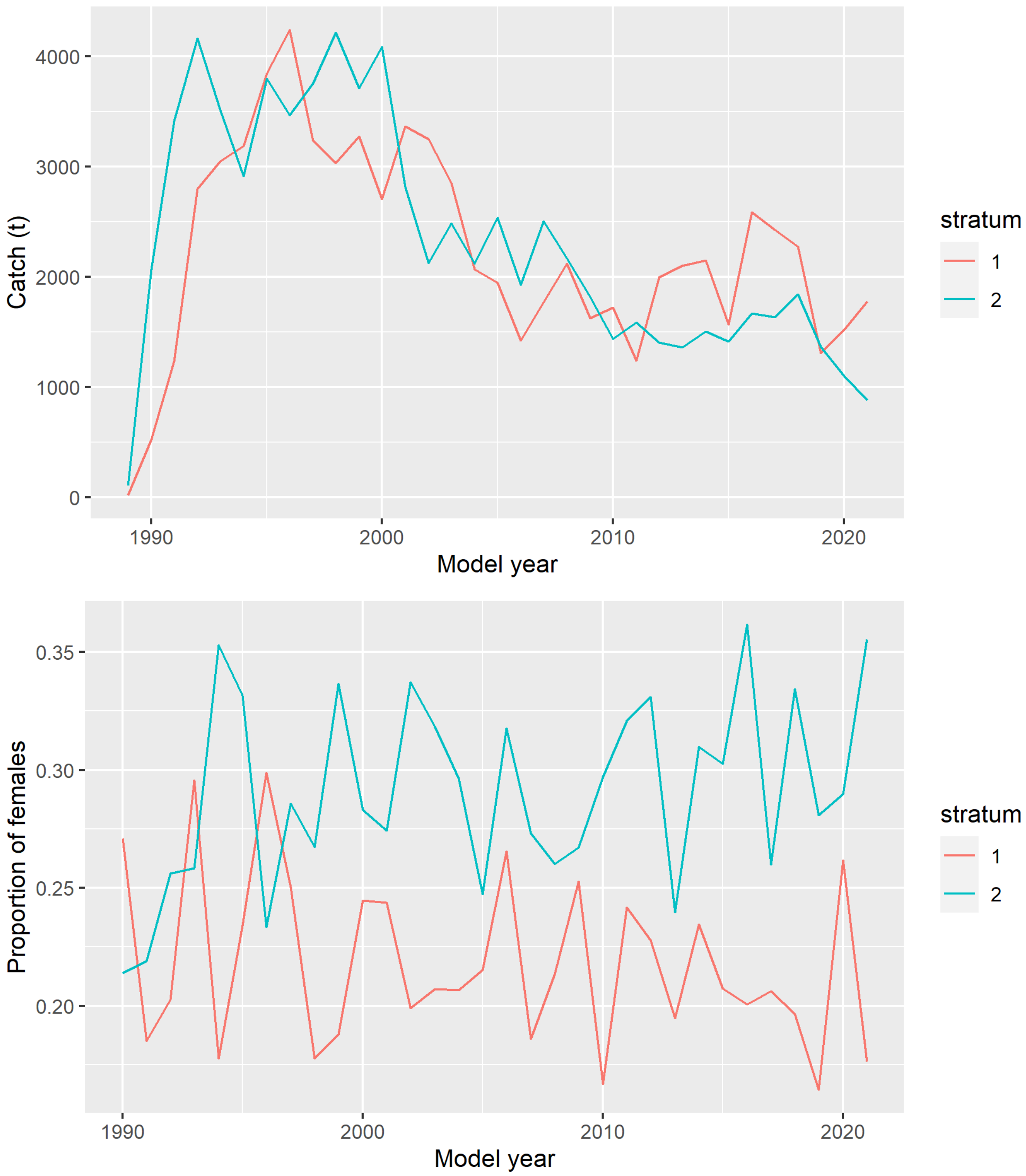


Figure B.15: Trend of catch over time and proportion of females of Option 3 of the four potential fisheries strata: split by statistical area. Model year is calendar year.

Figure B.16: Trend of catch over time and proportion of females of Option 4 the four potential fisheries strata: split by method and statistical area. Model year is calendar year.

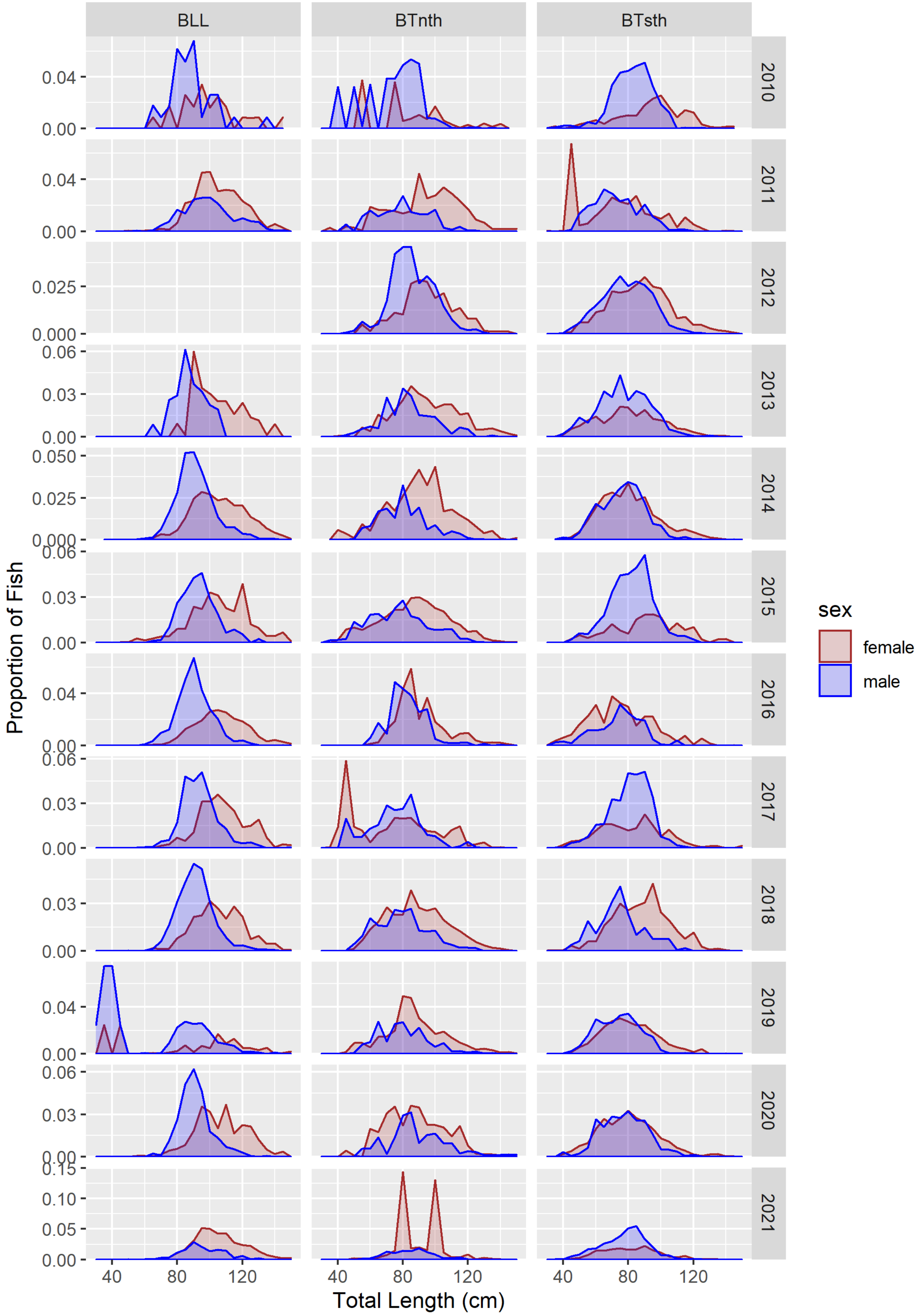


Figure B.17: Trend of scaled length frequency distributions over time of Option 1 of the four potential fisheries strata: split by fishing method and north / south. Year is calendar year.

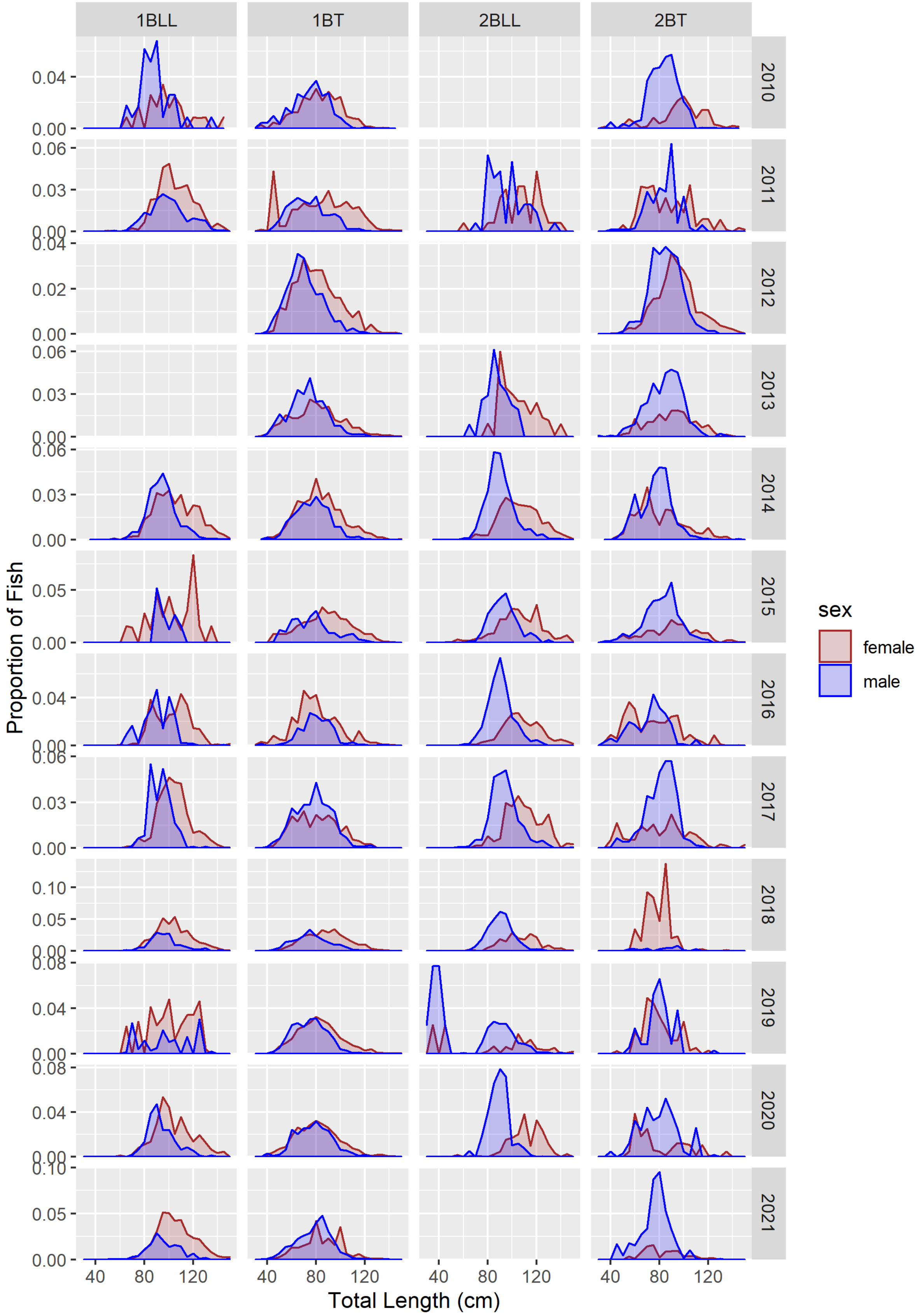


Figure B.18: Trend of scaled length frequency distributions over time of Option 2 of the four potential fisheries strata: split by method and east / west. Year is calendar year.

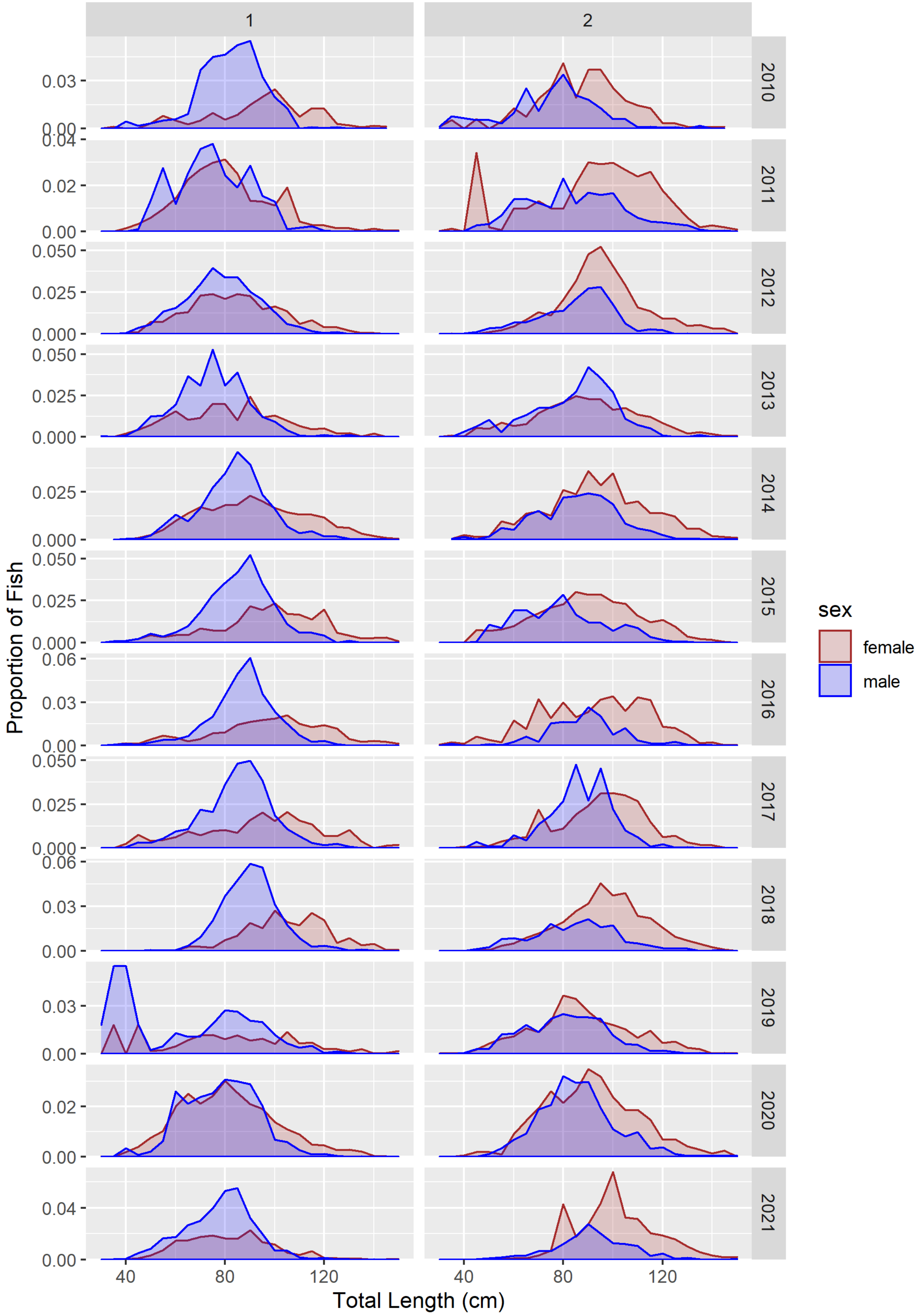


Figure B.19: Trend of scaled length frequency distributions over time of Option 3 of the four potential fisheries strata: split by statistical area. Year is calendar year.

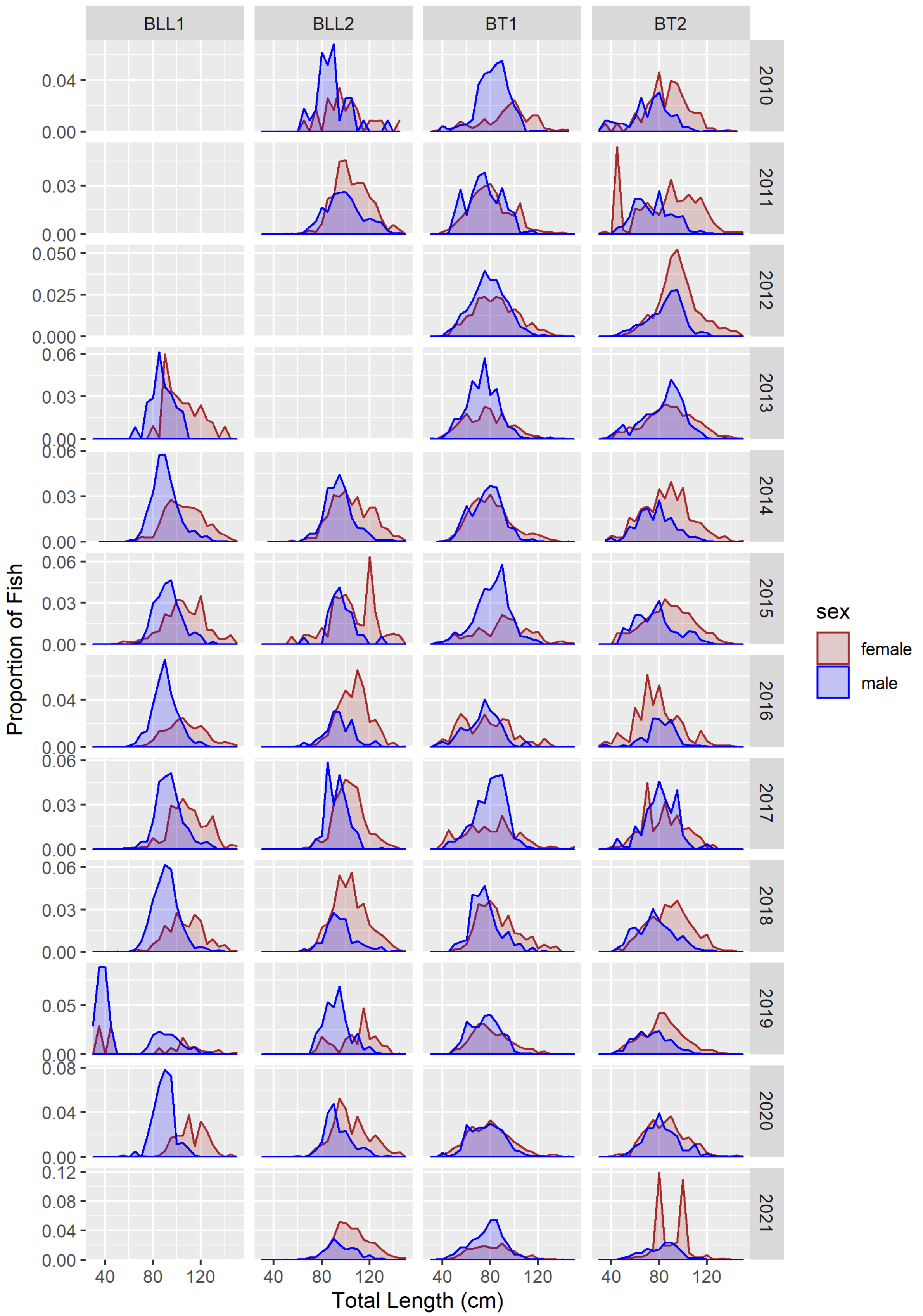


Figure B.20: Trend of scaled length frequency distributions over time of Option 4 of the four potential fisheries strata: split by fishing method and statistical area. Year is calendar year.

APPENDIX C – UPDATE OF BIOLOGICAL PARAMETERS

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

Sex	Parameter	Horn (2005)	Edwards (2017)	This analysis
Male	*a*	0.00000100	0.00000122	0.00000128
	b	3.354	3.30	3.294
Female	*a*	0.00000114	0.00000128	0.00000138
	b	3.318	3.29	3.271

Table C.2: von Bertalanffy growth parameters obtained in this analysis and compared to those reported previously (Horn 2005, Edwards 2017).

Sex	Parameter	Horn (2005)	Edwards (2017)	This analysis	
				All ages	Ages 5+
Male	L_{inf}	113.9	115.16	113.1	115.0
	k	0.127	0.12	0.132	0.118
	t_o	-0.70	-o.86	-0.72	-1.18
Female	L_{inf}	156.4	158.68	154.2	153.9
	k	0.083	0.08	0.09	0.09
	t_o	-0.74	-0.89	-0.78	-0.70
Both	CV	–	–	0.09	0.09

Table C.3: Cumulative proportion of growth by month estimated using the mean age at length growth model.

Month	Female	Male
January	0.00	0.00
February	0.16	0.57
March	0.48	0.71
April	0.67	0.77
May	0.86	0.82
June	0.89	0.85
July	0.91	0.87
August	0.94	0.90
September	0.95	0.92
October	0.97	0.94
November	0.98	0.97
December	1.00	1.00

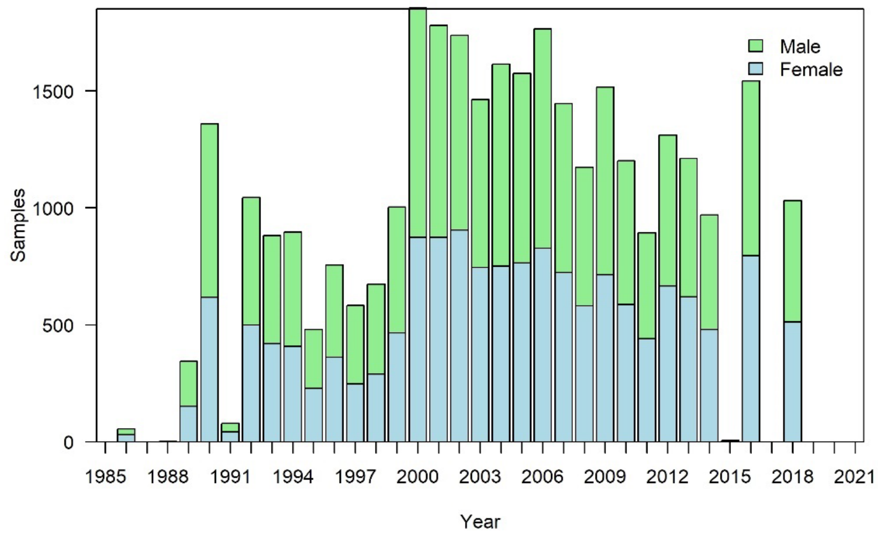


Figure C.1: Number of length-weight samples available by fishing year.

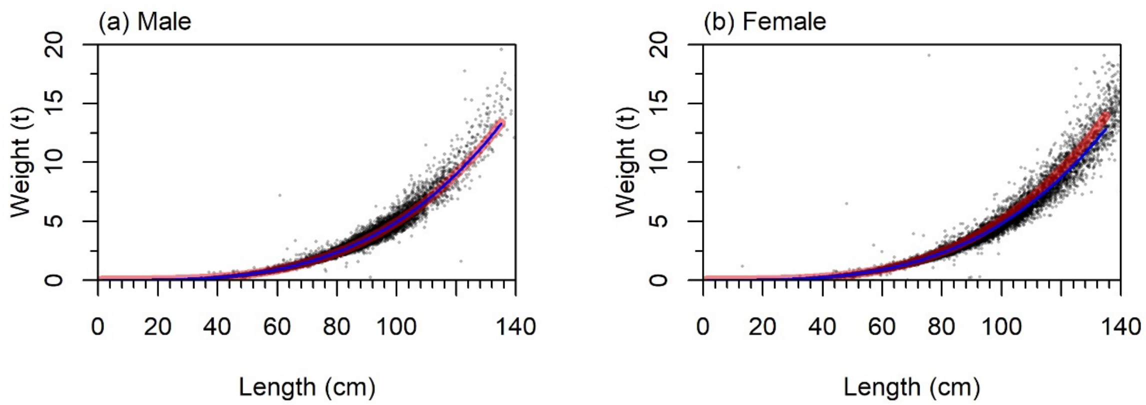


Figure C.2: Estimated length-weight relationships: the red line represents the previous estimate (Horn 2005), the blue line is the estimated relationship, and dots are the actual data points used in this analysis.

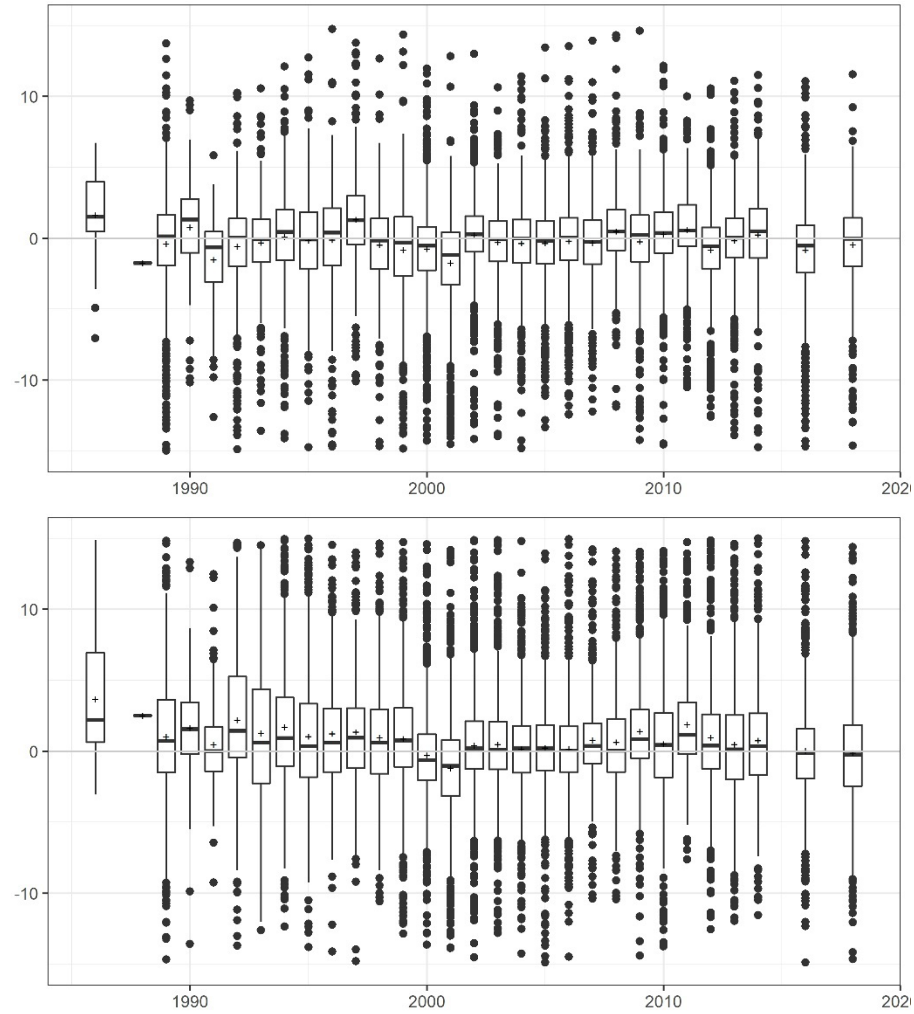


Figure C.3: Residuals by fishing year of the length-weight relationship for males (top) and females (bottom).

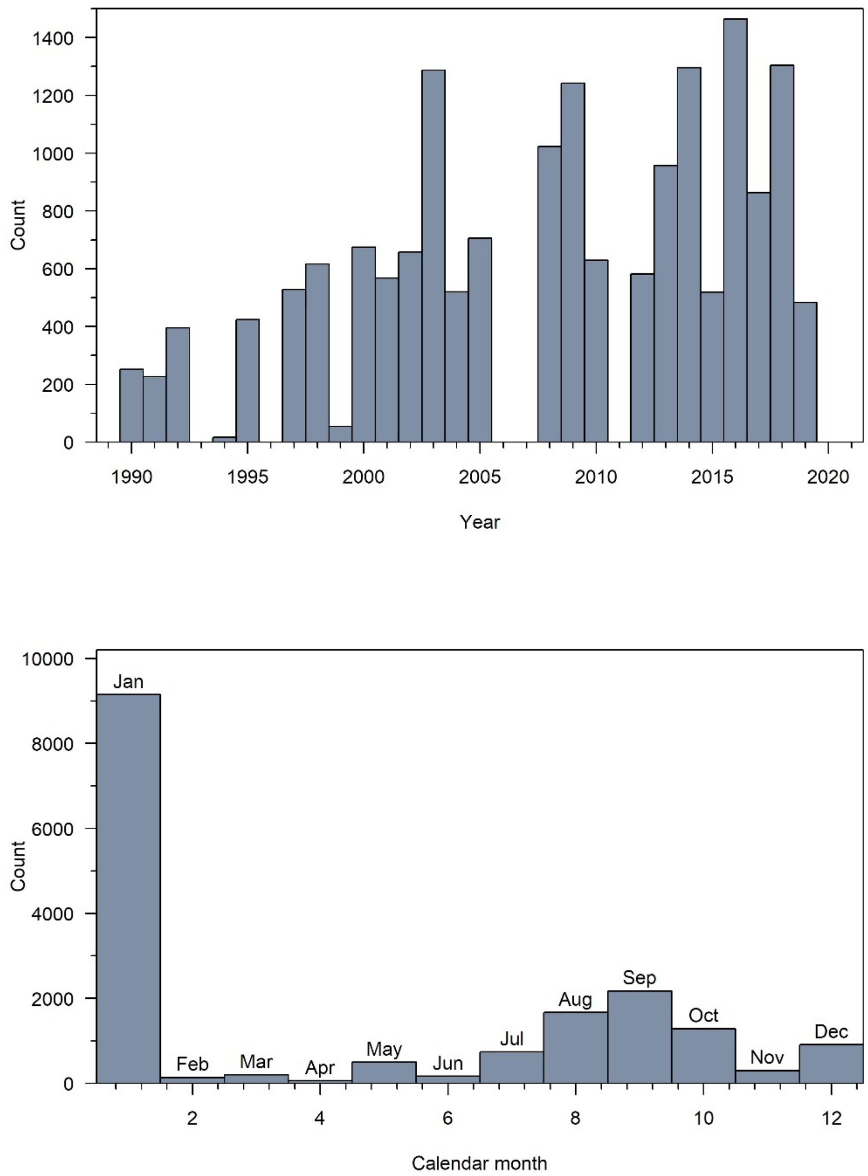


Figure C.4: Available age data, by calendar year (top) and by calendar month over all years (bottom).

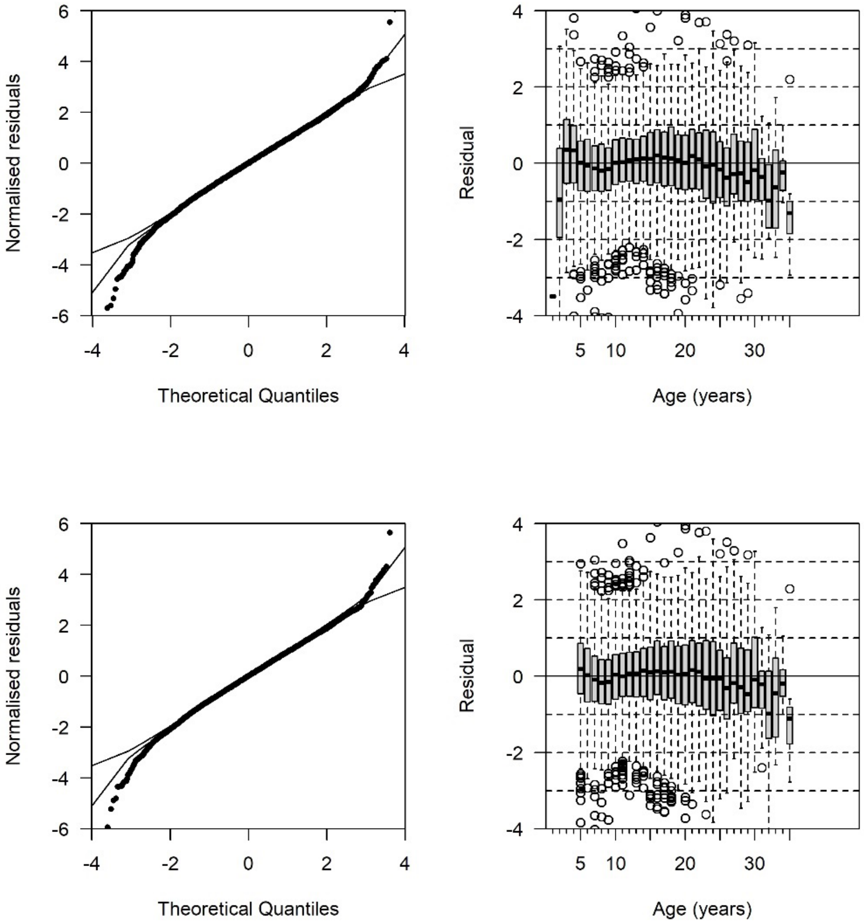
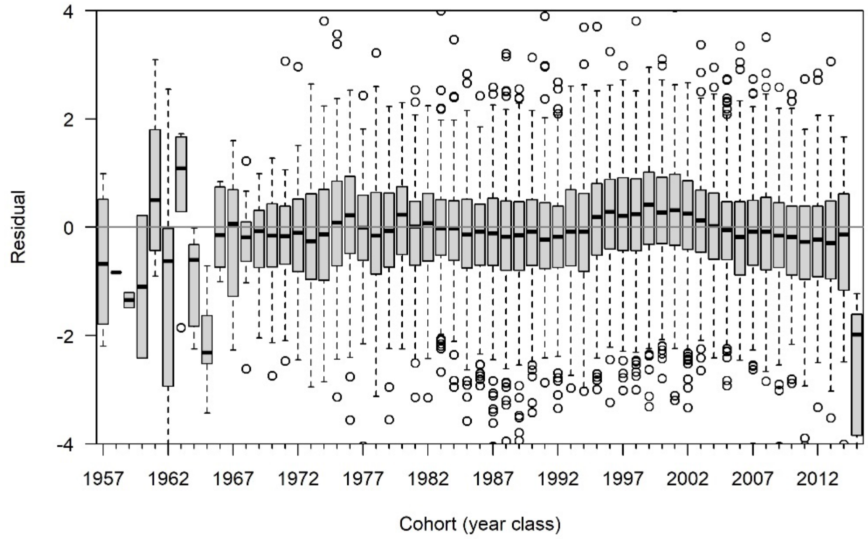


Figure C.5: Residuals of the MLE (maximum likelihood estimation) von Bertalanffy models, using all ages available (top) or ages 5 and over (bottom).



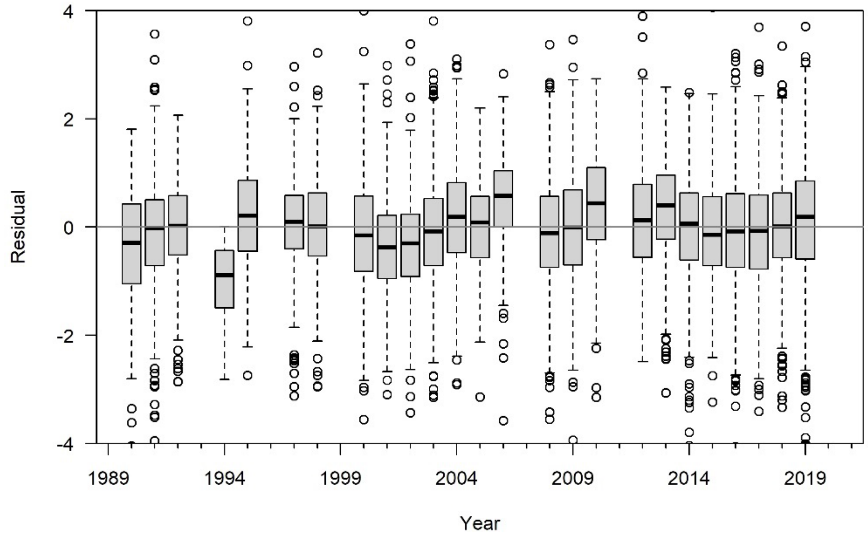


Figure C.6: Residuals of the MLE (maximum likelihood estimation) von Bertalanffy models by cohort (top) or by fishing year (bottom).

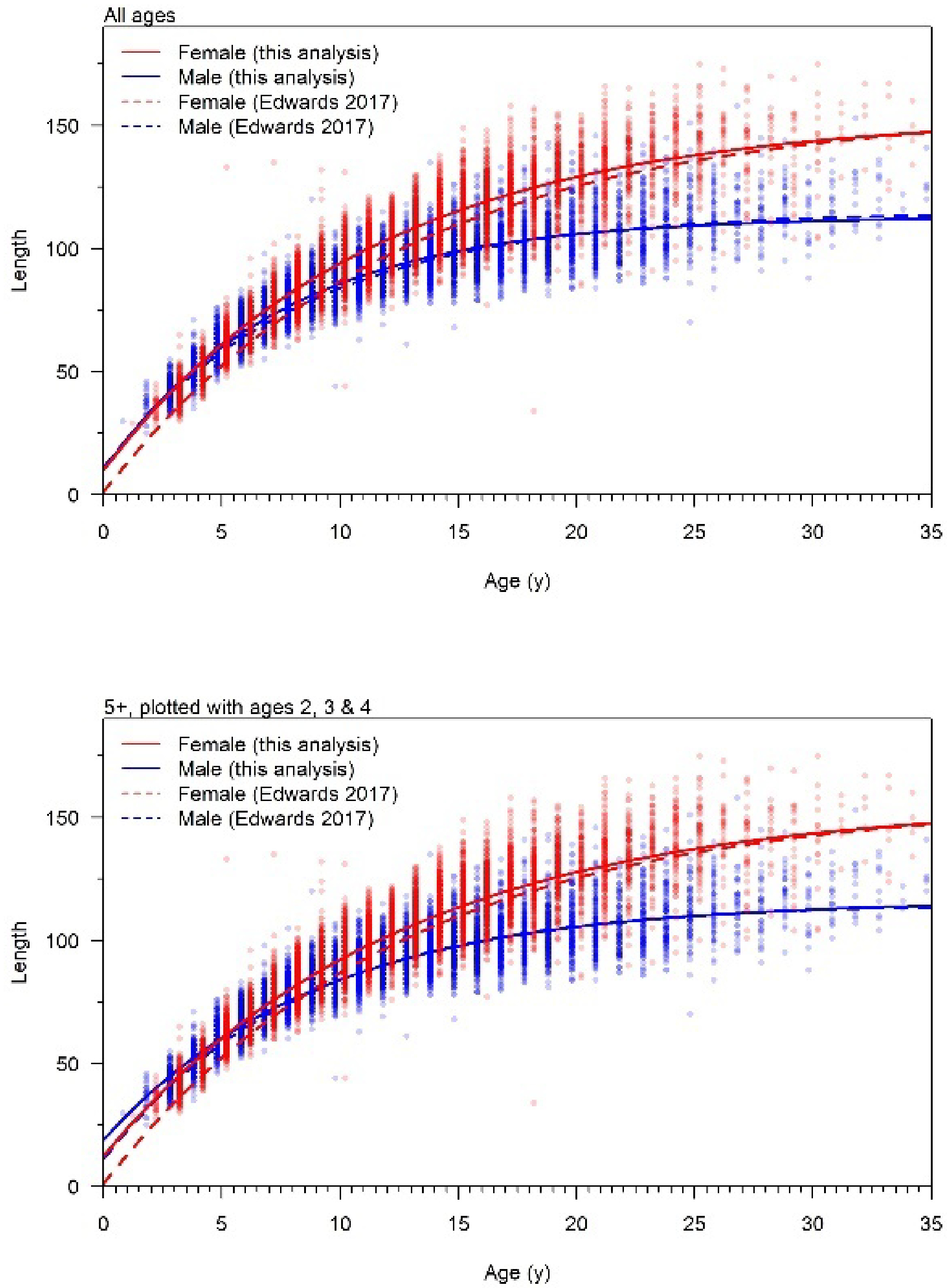


Figure C.7: Comparison of the maximum likelihood estimate (MLE) von Bertalanffy models with the models of Edwards (2017), using all ages available (top) or ages 5 and over (bottom).

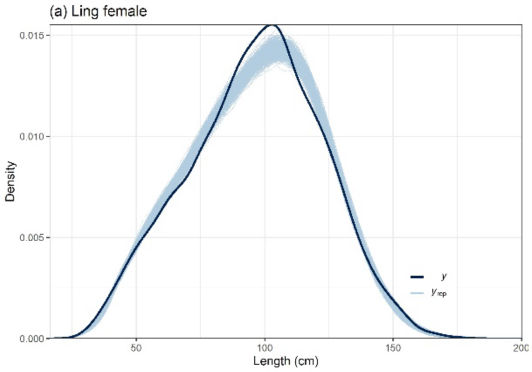


Figure C.8: Comparison of the empirical distribution of the data (y) to the posterior predictive distributions of simulated data (y_{rep}) from the Bayesian von Bertalanffy growth model by sex.

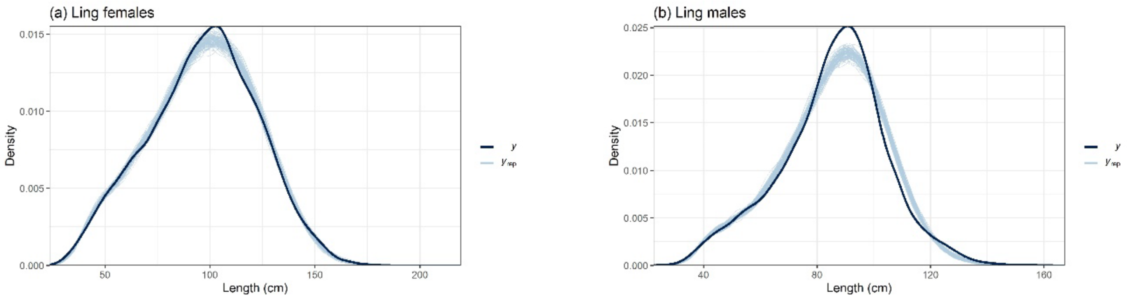


Figure C.9: Comparison of the empirical distribution of the data (y) to the posterior predictive distributions of simulated data (y_{rep}) from the Bayesian mean length at age growth model by sex.

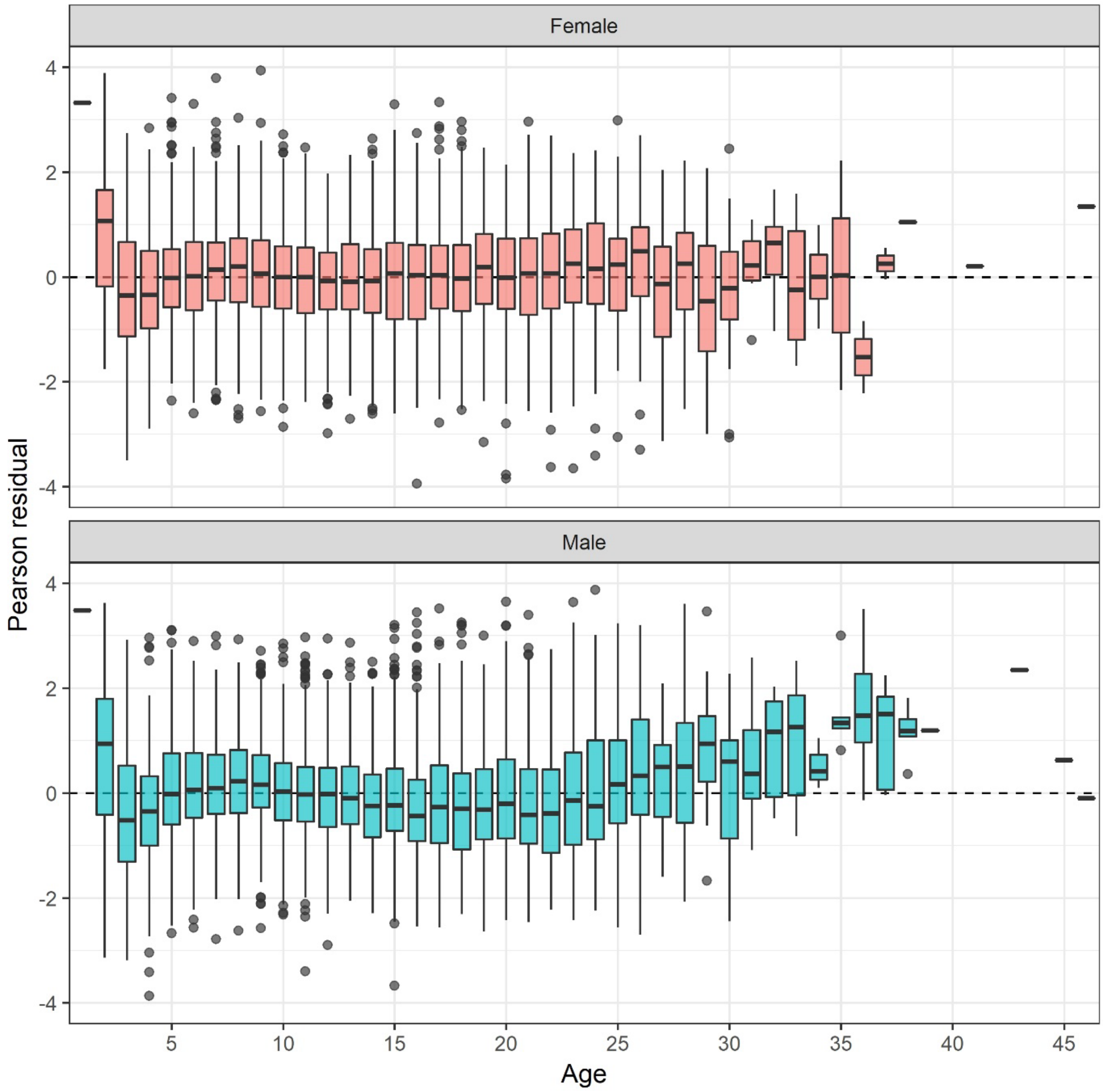


Figure C.10: Pearson residuals by age and sex from the Bayesian von Bertalanffy model fit.

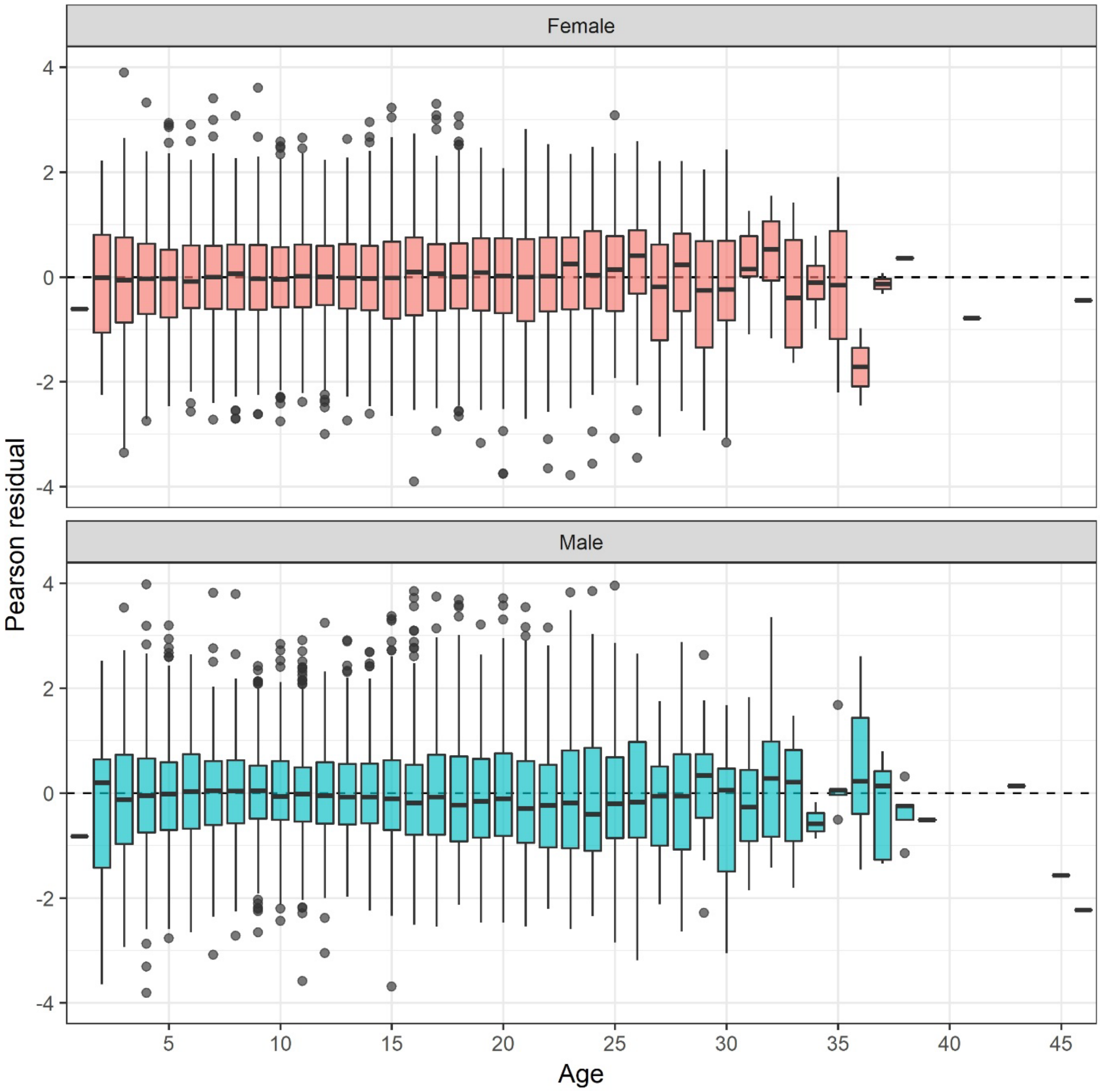


Figure C.11: Pearson residuals by age and sex from the Bayesian mean length at age model fit.

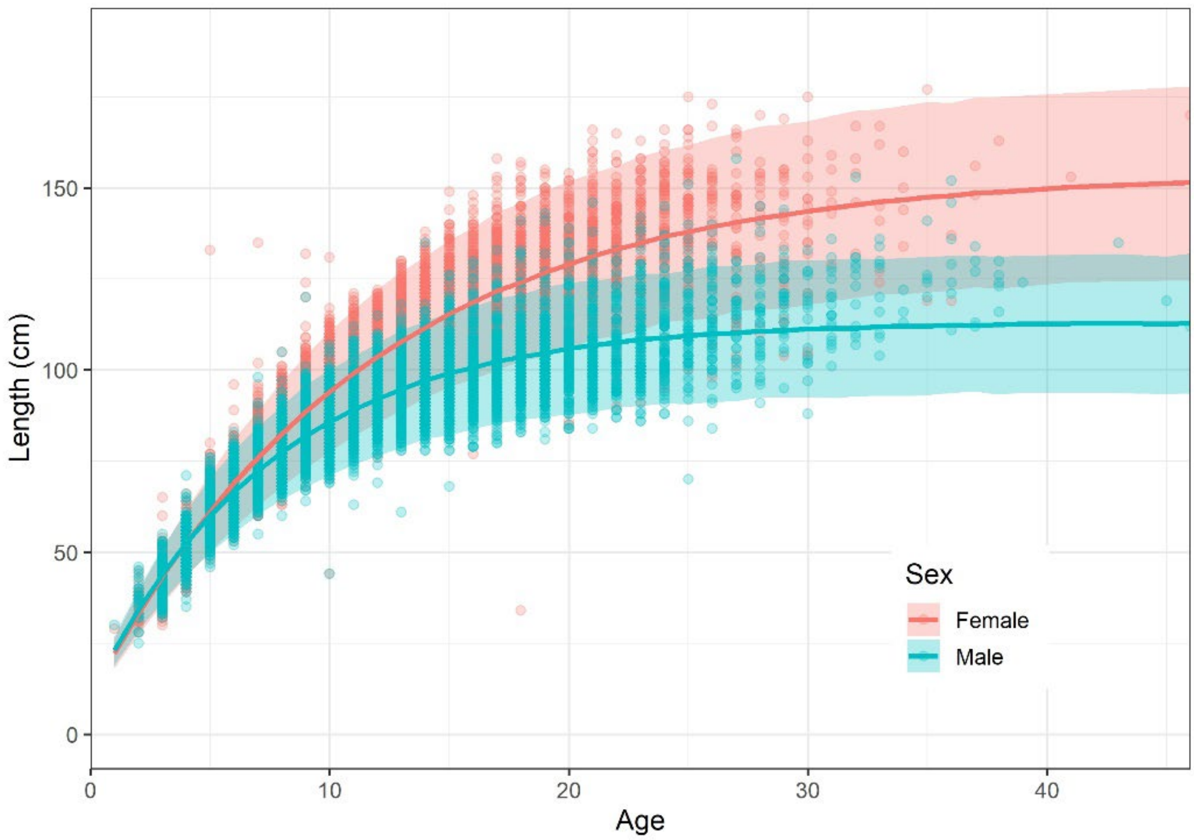


Figure C.12: Fit of the Bayesian von Bertalanffy growth model (line is the mean and shaded region is the 95% credible interval of the posterior predictive distribution) to length at age observations (points) by sex.

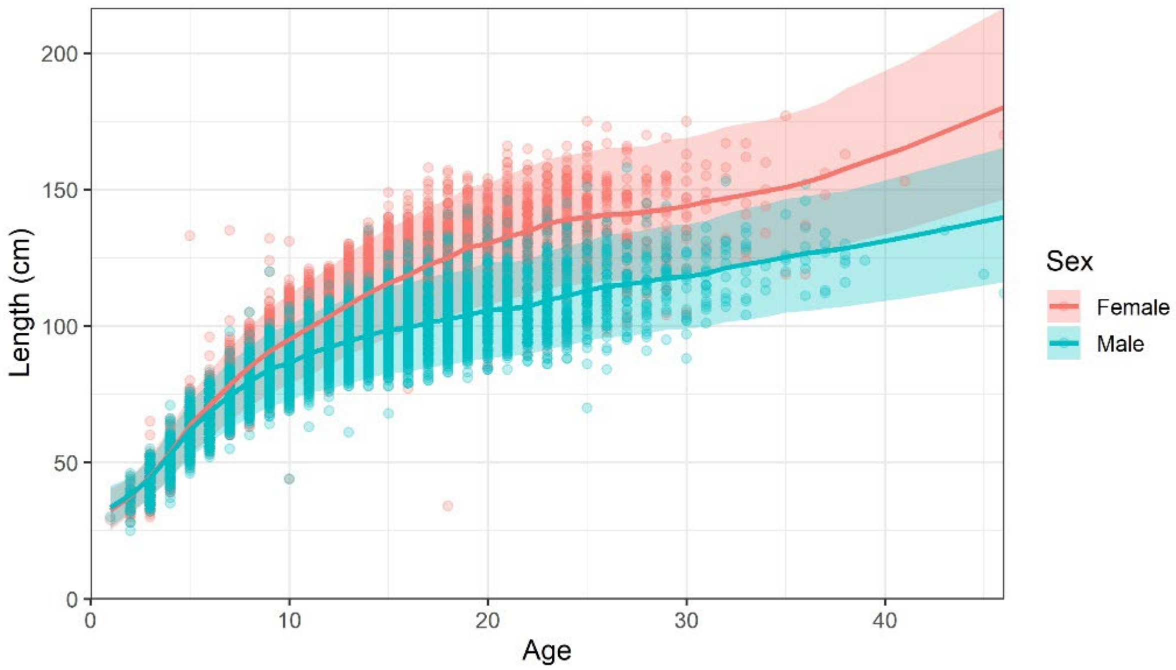


Figure C.13: Fit of the Bayesian mean length at age growth model (line is the mean and shaded region is the 95% credible interval of the posterior predictive distribution) to length at age observations (points) by sex.

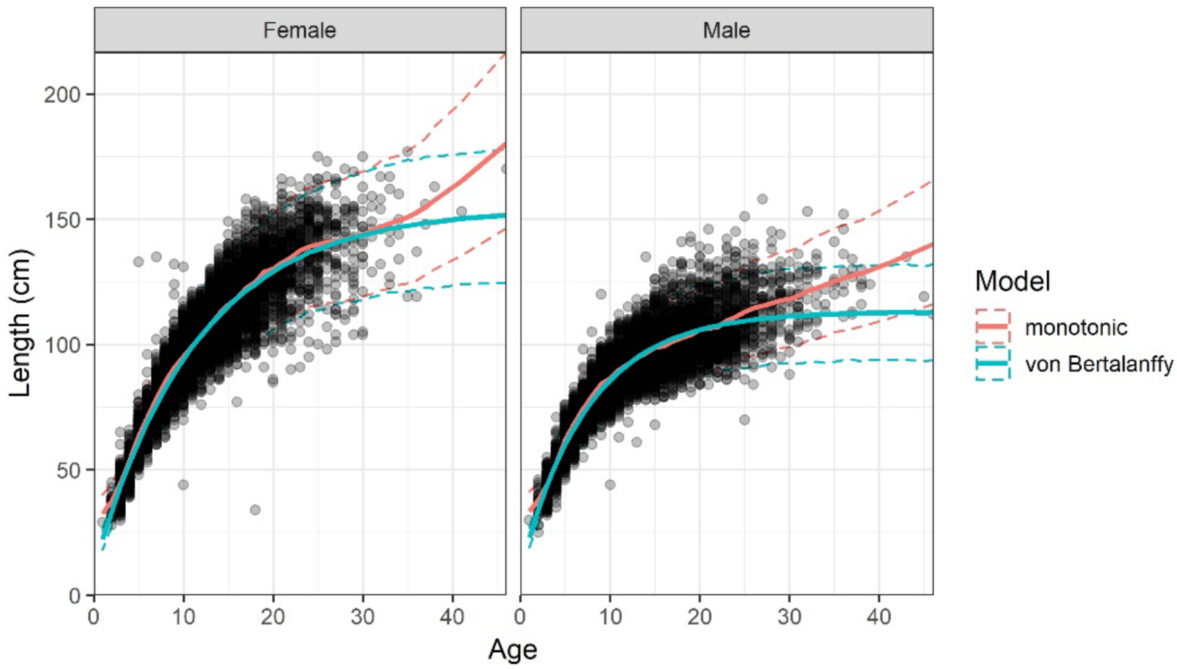


Figure C.14: Comparison of the fit of the Bayesian von Bertalanffy versus the mean length at age growth models (line is the mean and dashed lines represent the 95% credible interval of the posterior predictive distribution) to length at age observations (points) by sex.

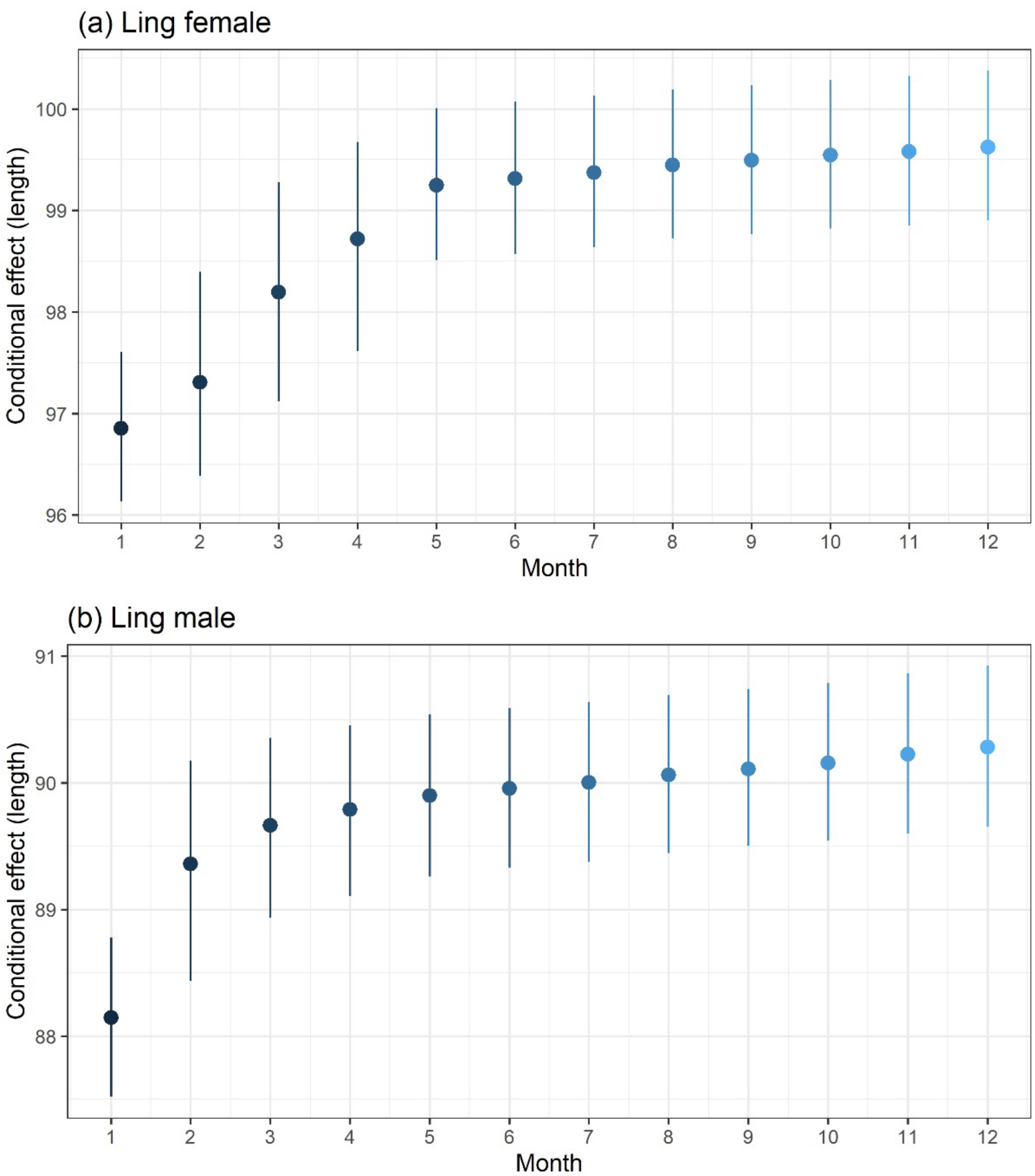


Figure C.15: The conditional effect of the monotonic month term by sex in the Bayesian mean length at age growth model, where 1 is January.

APPENDIX D – CPUE ANALYSES FOR CHATHAM RISE LING (LIN 3&4)

Table D.1: 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	6th degree spline	Julian date, starting on 1 September
Total hooks	4th degree spline	Number of hooks set per day in a statistical area
Vessel experience	3rd degree spline	Experience of the vessel in number of years
Observed	Categorical	Whether an observer was onboard that day
Spawning	Categorical	Whether during spawning season (July to October) or not
Longline type	Categorical	Handline, autoline, or unknown

Table D.2: Data selection for the bottom longline rolled-up CPUE model.

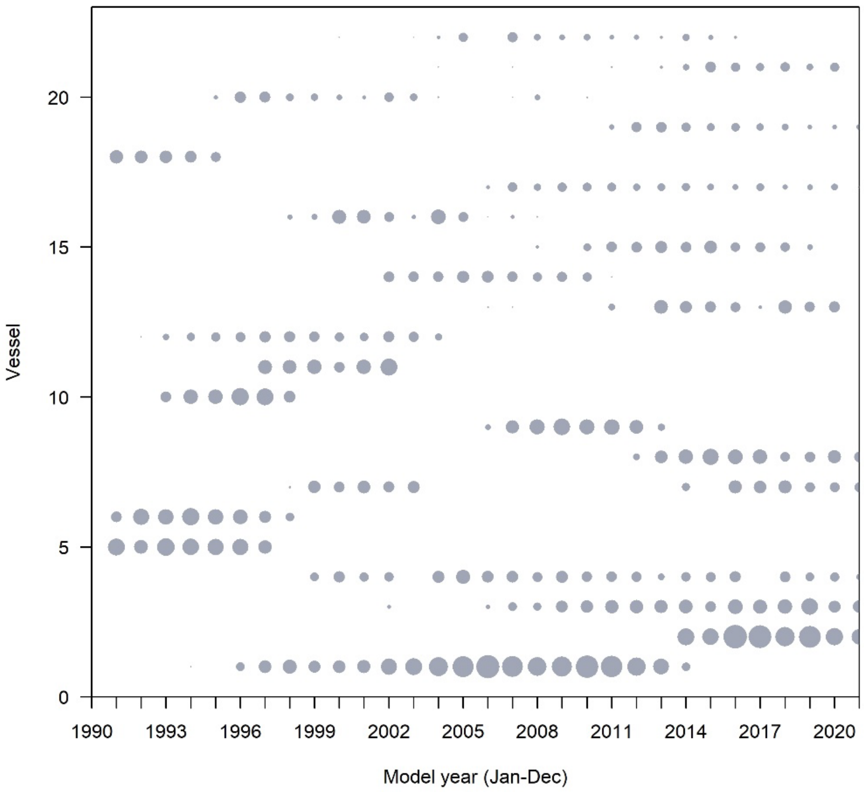
Data source	CELR, LTCER, LCER, ERS – lining
Year range	1991–2021
Target species	Ling only
Rolling-up method	By vessel, day, and statistical area
Statistical Areas	50 rolled-up records minimum (Statistical Area 018–024, 049–052, 401–405, 407–410)
Catch per record	< 35 t
Gear type	Bottom longline only
Baiting method	Autoline, hand baiting, or unknown
Number of hooks per line	Between 50 and 50 000
Number of sets per record	< 10
Vessel experience	Over 6 years in the fishery (~90% 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 (0.002% of catch)
Year definition	Model year: January to December

Table D.3: Variables in order of decreasing explanatory value for the rolled-up longline CPUE for Chatham Rise ling (LIN 3&4). 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			21 518	30 901	0.07	68 985
Vessel	21	14 473	21 497	16 428	0.51	55 413
Hooks	4	5 830	21 493	10 598	0.68	45 975
Month	11	1 214	21 482	9 384	0.72	43 375
Statistical area	19	239	21 463	9 145	0.73	42 858
Vessel experience	3	25	21 460	9 120	0.73	42 804
Longline type	1	20	21 459	9 099	0.73	42 757
Day	6	9	21 453	9 090	0.73	42 747
Observed	1	6	21 452	9 084	0.73	42 736

Table D.4: CPUE standardisation indices for the Chatham Rise ling stock (LIN 3&4) rolled-up bottom longline fishery, 95% credible intervals (CI) and CVs. Only the lognormal model was carried out as null catches were negligible. Year is calendar year.

Year	Index	CI	CV
1991	6.52	5.87-7.23	0.03
1992	9.09	8.21-10.06	0.02
1993	6.52	5.94-7.15	0.02
1994	6.01	5.50-6.57	0.02
1995	5.45	4.98-5.95	0.03
1996	4.35	4.02-4.71	0.03
1997	2.83	2.64-3.03	0.04
1998	2.81	2.61-3.02	0.04
1999	2.43	2.26-2.61	0.05
2000	2.71	2.53-2.90	0.04
2001	2.7	2.52-2.89	0.04
2002	2.36	2.22-2.51	0.04
2003	2.64	2.46-2.83	0.04
2004	2.43	2.28-2.59	0.04
2005	2.6	2.44-2.76	0.04
2006	2.23	2.09-2.38	0.05
2007	2.4	2.26-2.55	0.04
2008	3.1	2.91-3.30	0.03
2009	2.15	2.02-2.28	0.04
2010	2.59	2.45-2.75	0.04
2011	1.9	1.79-2.01	0.05
2012	2.42	2.28-2.56	0.04
2013	2.66	2.50-2.83	0.04
2014	2.4	2.26-2.56	0.04
2015	2.15	2.01-2.30	0.05
2016	2.35	2.21-2.50	0.04
2017	2.38	2.23-2.54	0.04
2018	2.4	2.25-2.56	0.04
2019	2.17	2.03-2.32	0.05
2020	2.26	2.11-2.42	0.05
2021	3.03	2.81-3.28	0.04



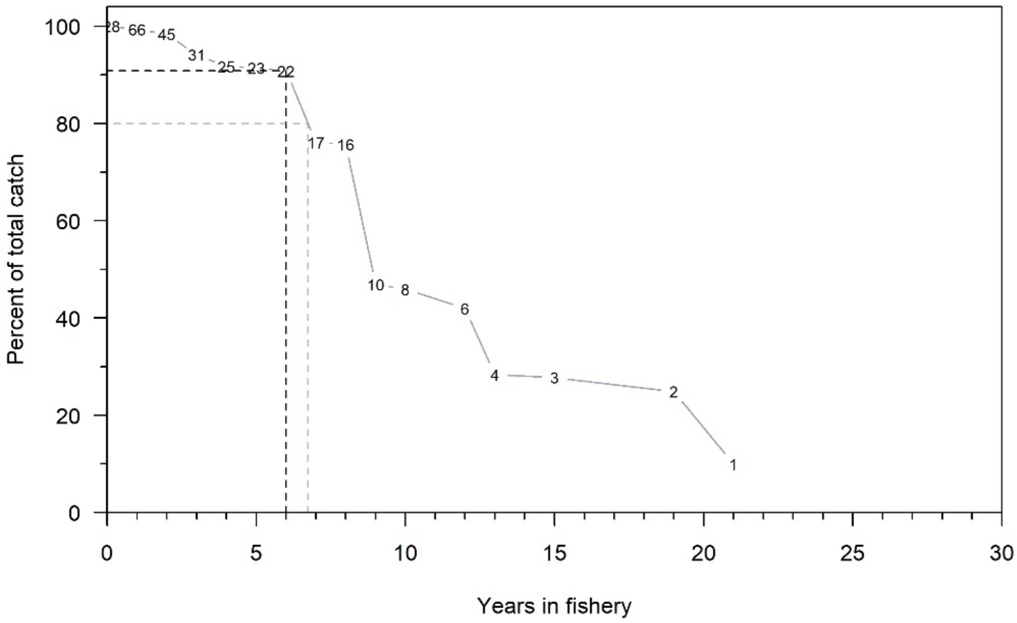
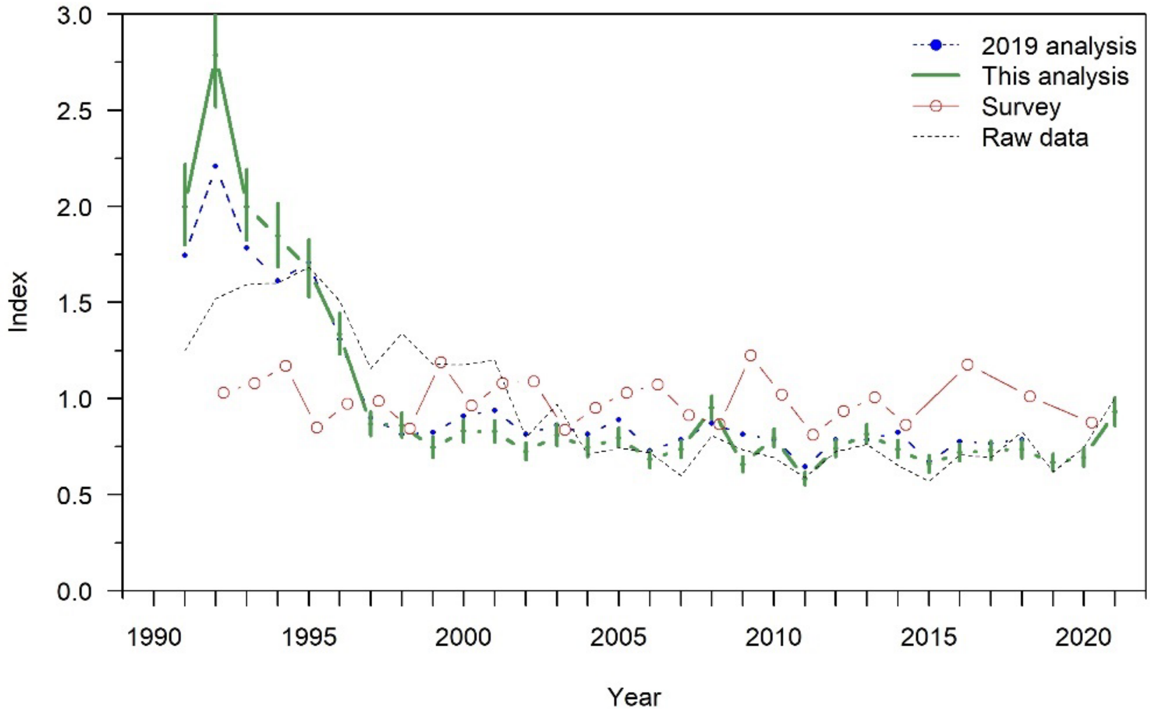


Figure D.1: Core vessel selection for the bottom longline rolled-up CPUE model for Chatham Rise ling (LIN 3&4): annual catch per vessel over time (top) and proportion of total catch per vessel experience (bottom).



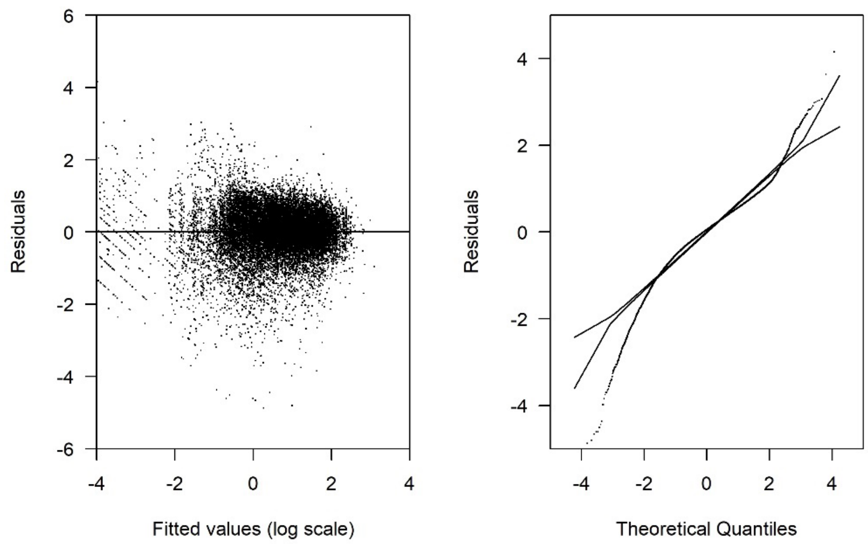


Figure D.2: Year index for the lognormal model for the rolled-up bottom longline CPUE for Chatham Rise ling (LIN 3&4) (top) and residual plots of that model (bottom). The top plot shows the 2019 index (Dutilloy 2019), the Chatham Rise trawl survey biomass series (Fisheries New Zealand 2022), and the raw catch rates. Year is model year which is also calendar year.

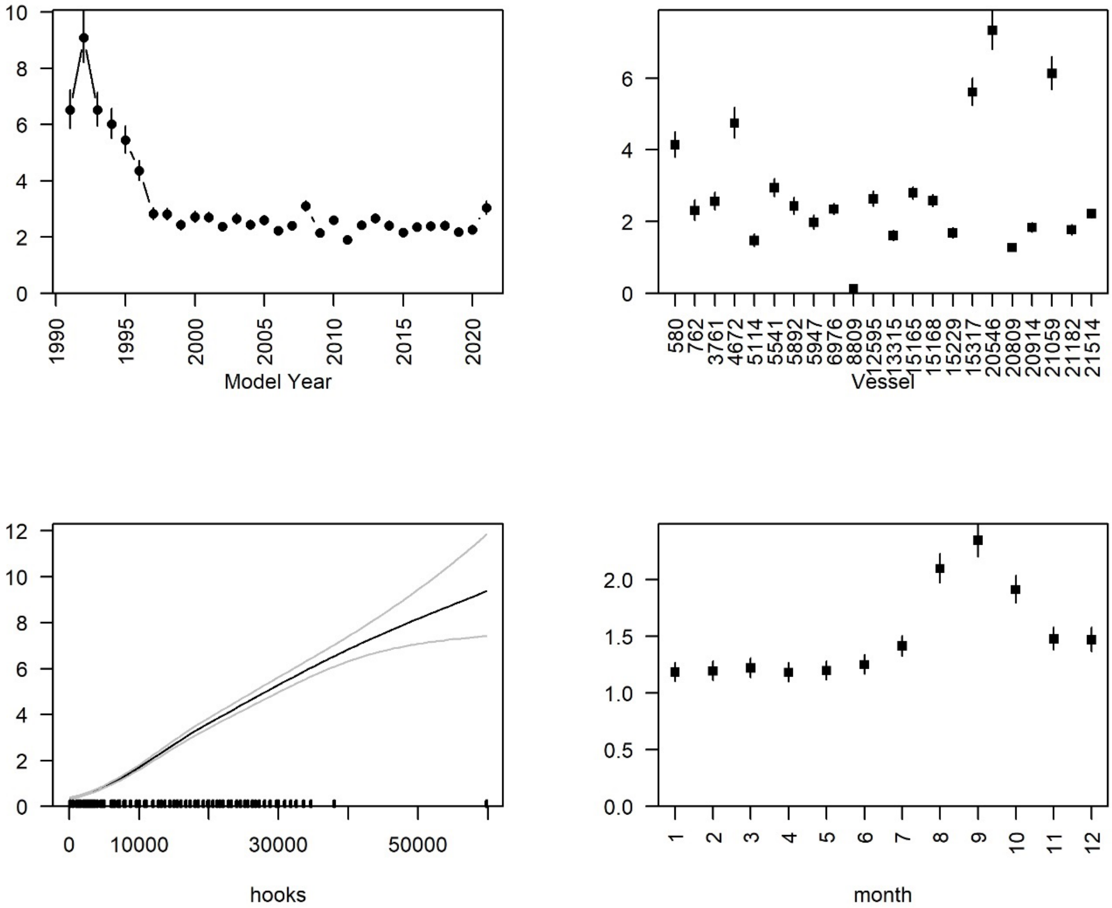


Figure D.3: Effects plots for the lognormal model for the rolled-up bottom longline CPUE for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters are constant at their median or modal value. Model year which is calendar year. Month 1 is January.

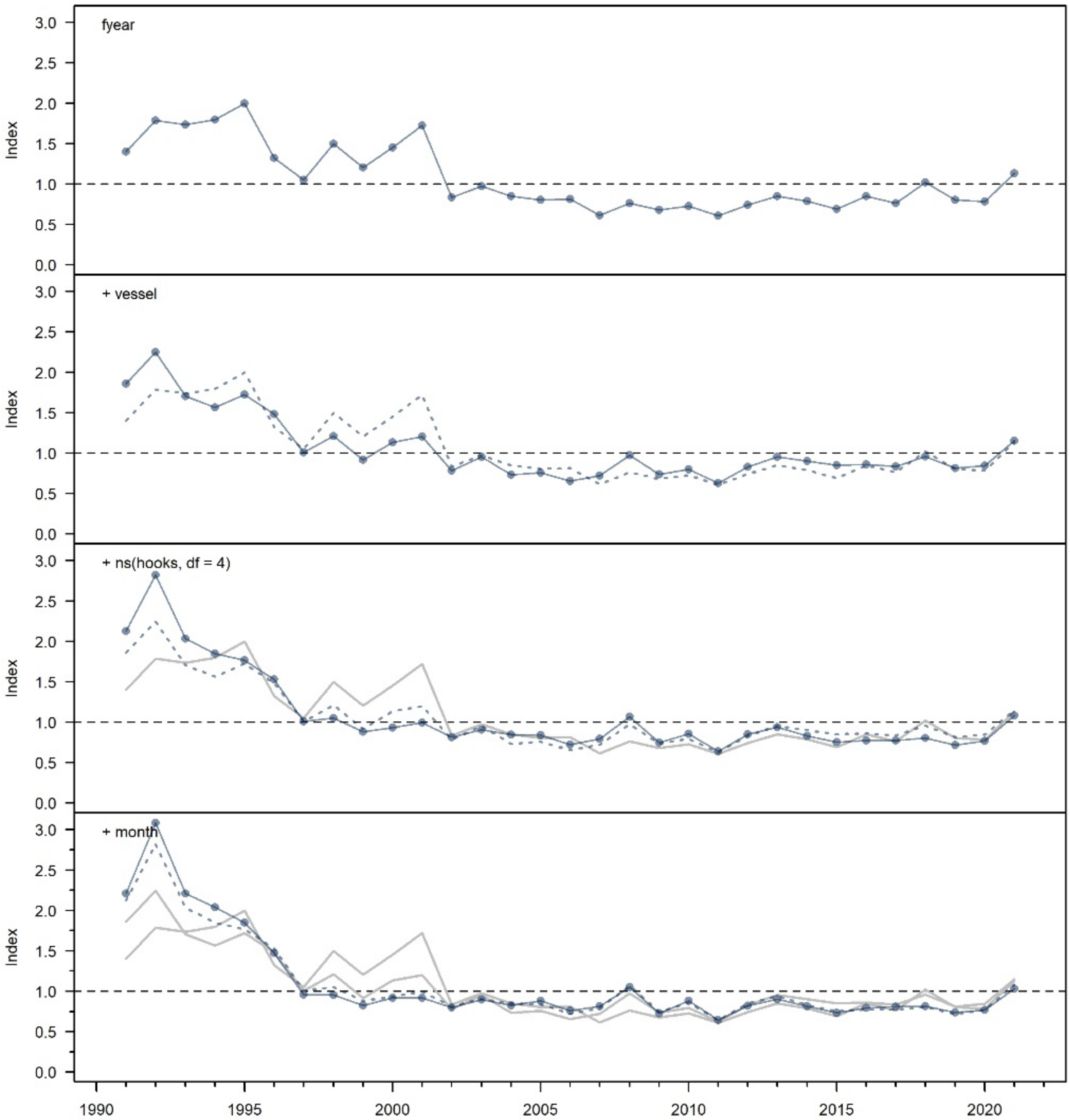


Figure D.4: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters are constant at their median or modal value. Year is model year which is calendar year.

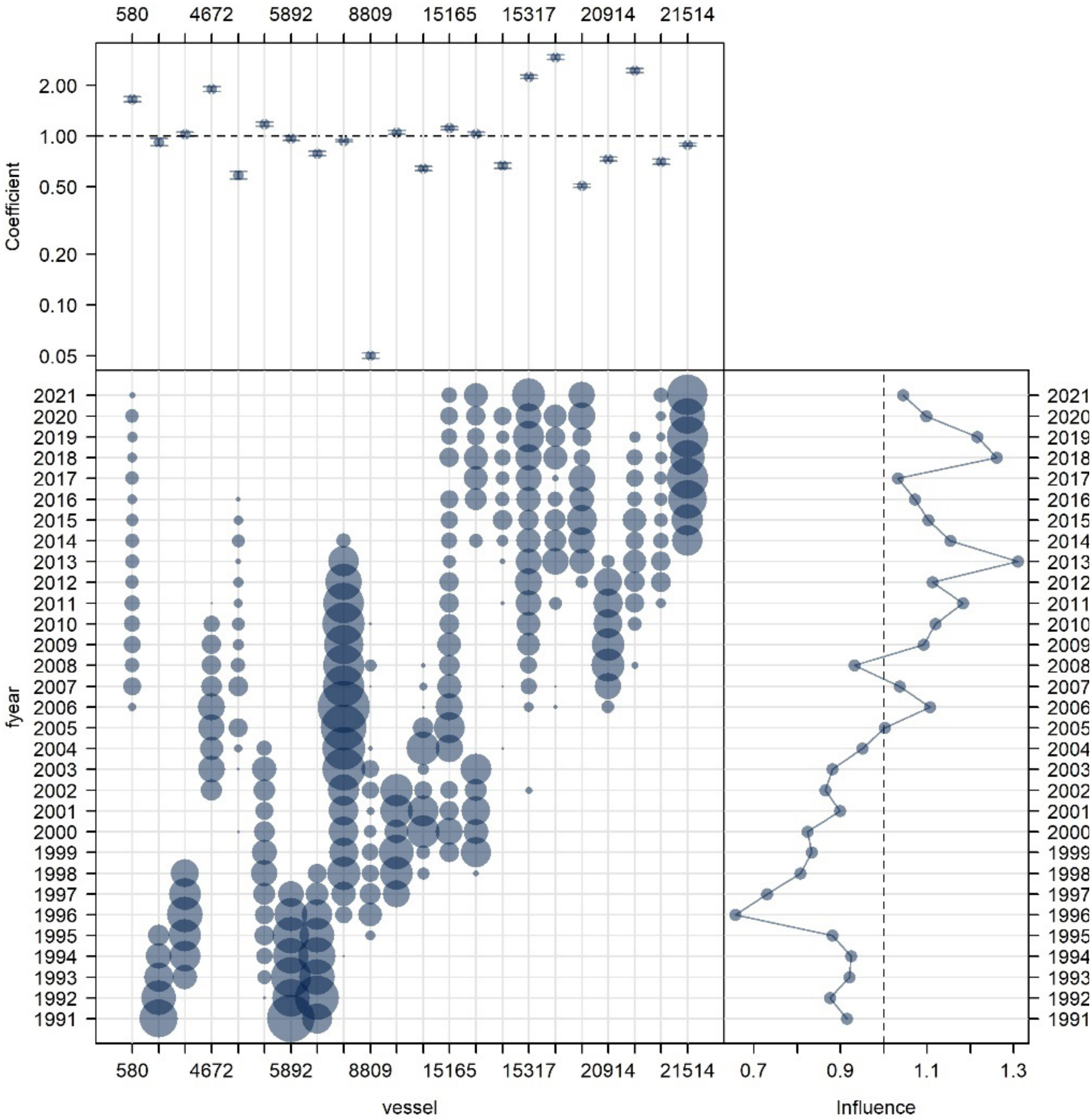


Figure D.5: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for vessel identifier in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year which is calendar year.

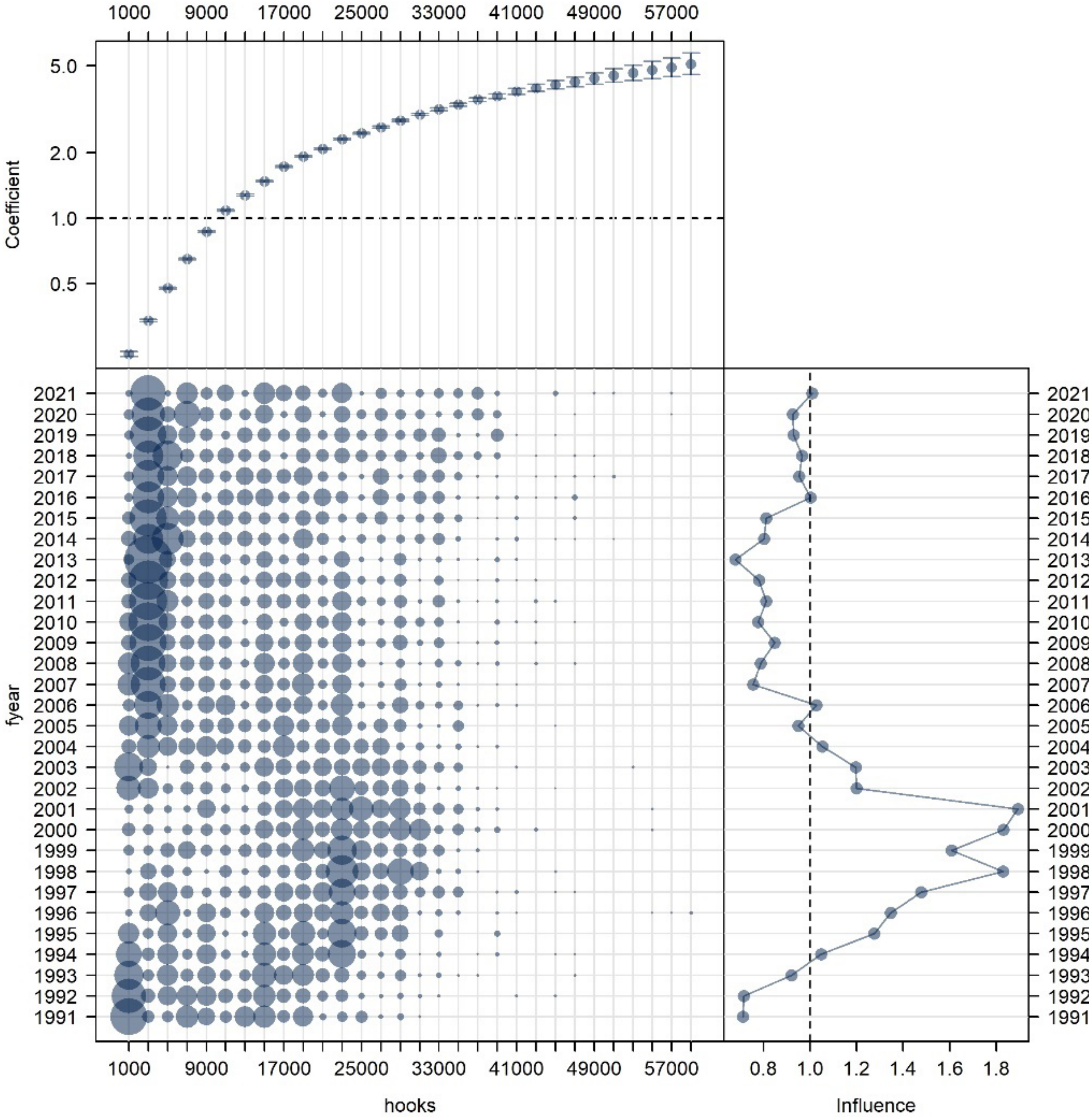


Figure D.6: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for number of hooks in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year which is calendar year.

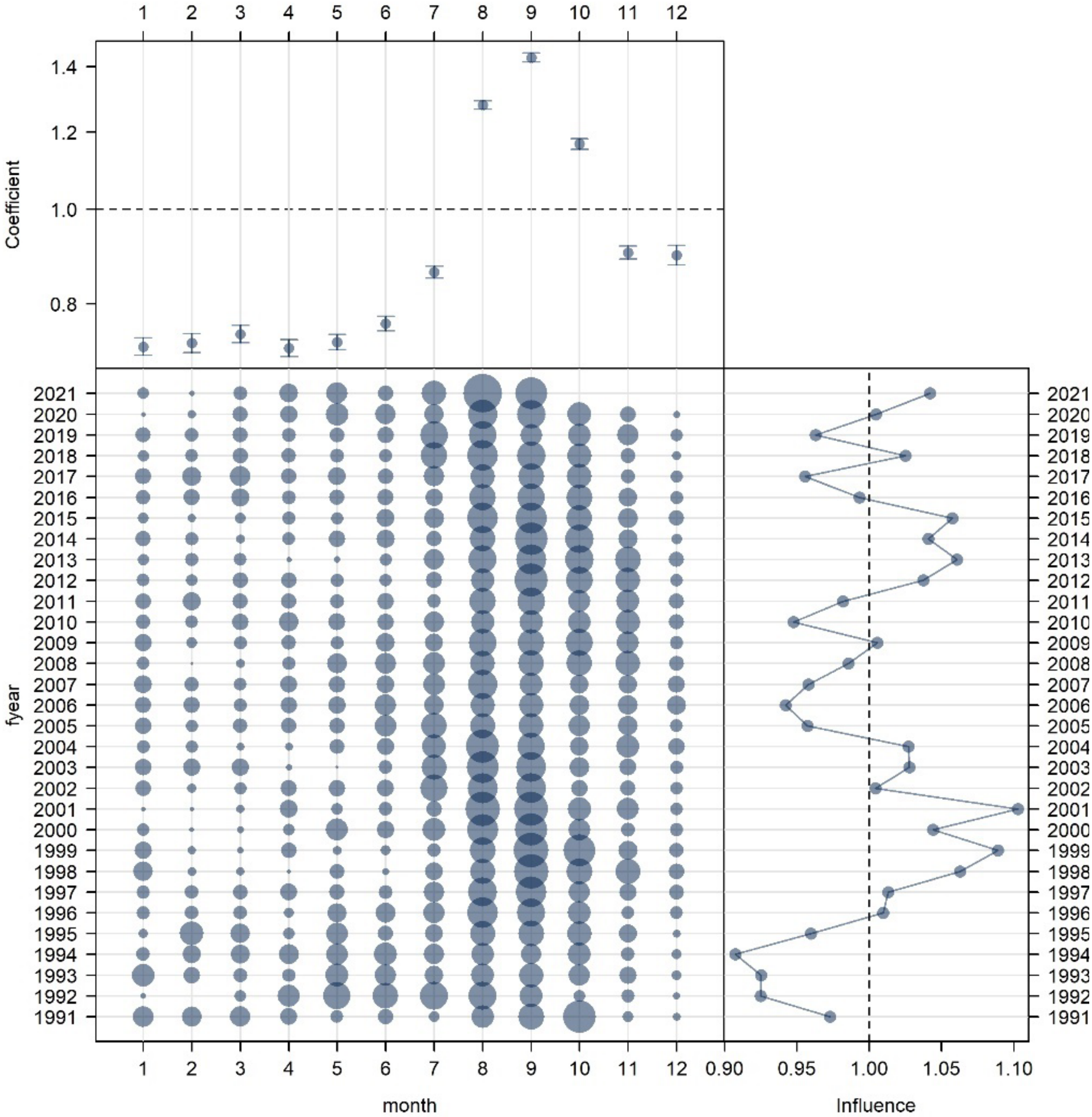


Figure D.7: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for month in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year which is calendar year, and month 1 is January.

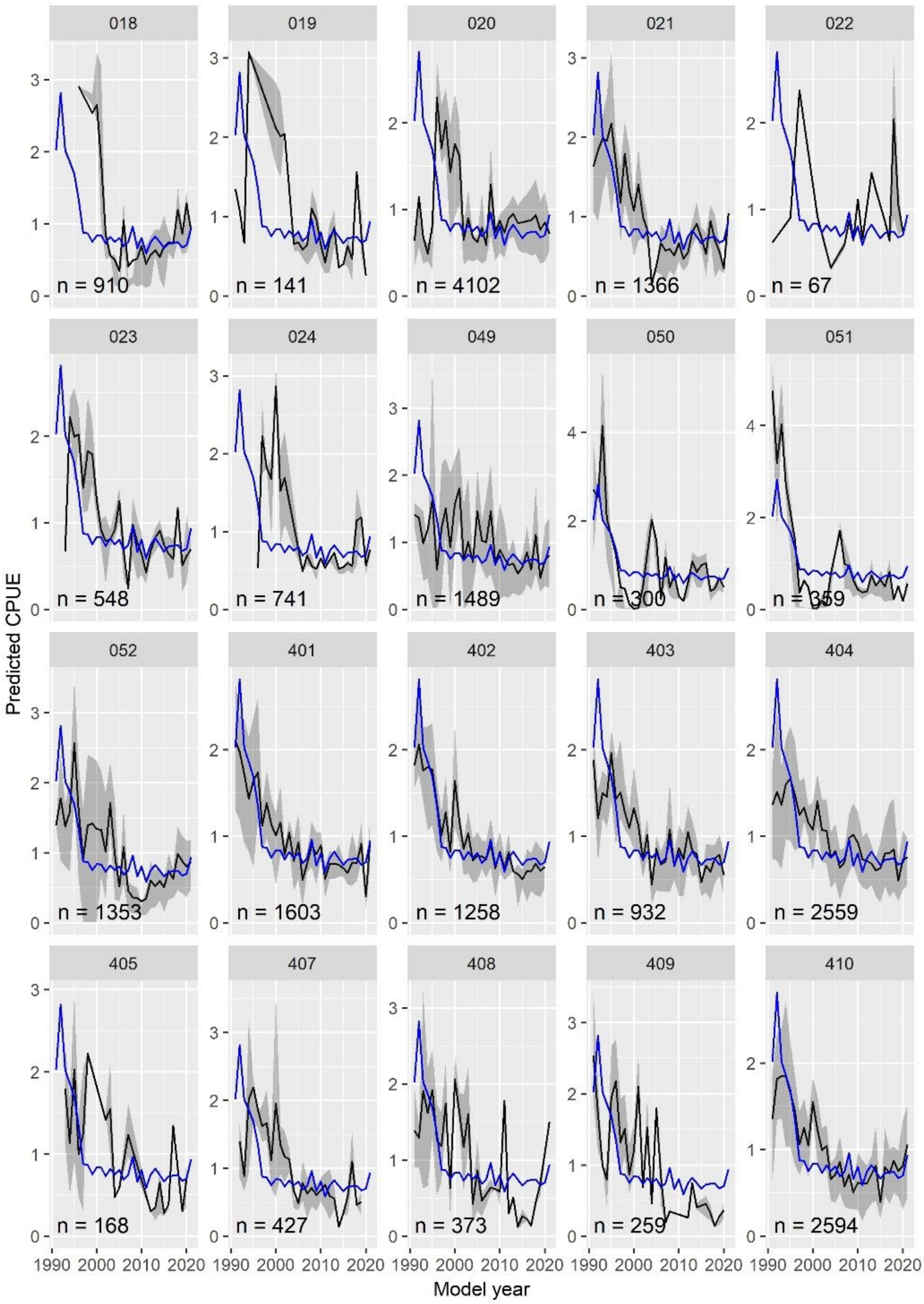


Figure D.8: Implied trends by statistical area for the lognormal model for the rolled-up bottom longline CPUE. The black trend and grey band represent the predicted mean standardised catch rate and interquartile range, and the blue trend the predicted year effect of the standardised CPUE. Year is model year which is 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.

APPENDIX E – INPUTS TO THE 2022 STOCK ASSESSMENT

Table E.1: Annual catch in tonnes per fishery as used in the 2022 stock assessment. Year is model year which is calendar year. Longline is bottom longline, trawl is bottom trawl, and pot is all potting methods combined.

Year	Longline	Trawl	Pot
1990	243	3 170	2
1991	1 786	3 979	16
1992	3 388	3 851	37
1993	3 963	2 836	13
1994	4 241	2 374	11
1995	5 391	2 680	7
1996	4 699	3 375	1
1997	4 182	3 901	38
1998	3 299	5 140	40
1999	2 994	4 306	41
2000	3 228	3 826	23
2001	3 082	2 941	2
2002	2 330	3 637	1
2003	2 150	3 563	1
2004	1 731	2 714	4
2005	2 259	2 250	10
2006	1 489	1 890	54
2007	1 571	2 841	55
2008	2 034	2 432	15
2009	1 897	1 459	12
2010	1 973	1 530	39
2011	1 658	1 030	33
2012	2 087	1 470	11
2013	2 394	1 125	24
2014	2 443	1 349	58
2015	1 685	1 513	46
2016	2 695	1 551	164
2017	2 432	1 811	201
2018	2 870	1 330	543
2019	1 877	1 347	674
2020	1 627	1 060	402
2021	1 598	765	360

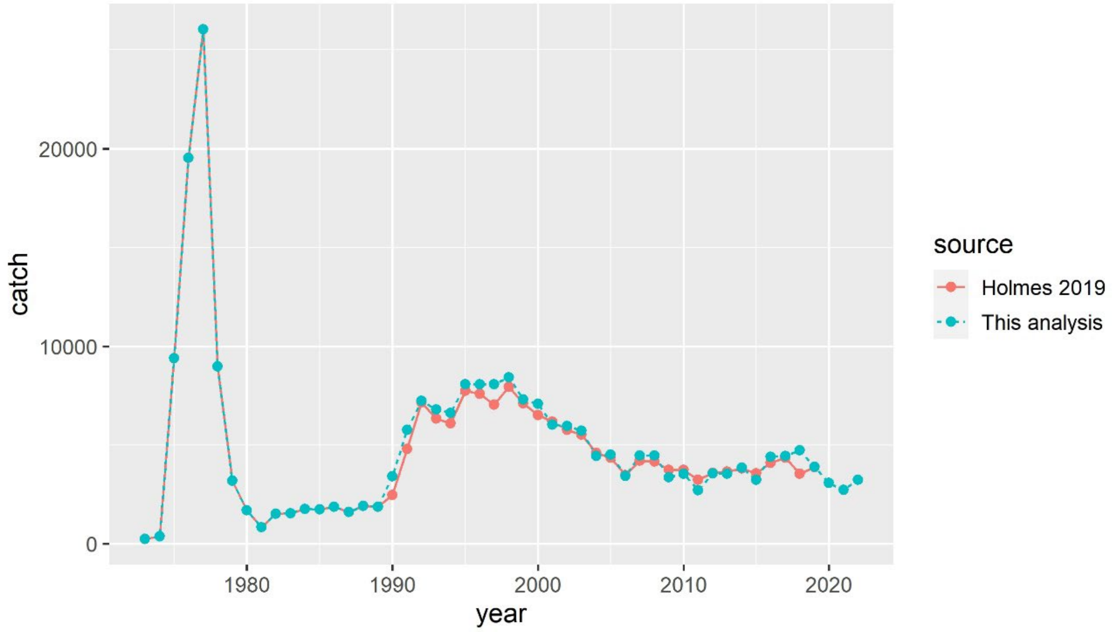


Figure E.1: Comparison of the total catches used in the 2019 assessment (Holmes 2019) base case (with fishing year) with the catches used in this analysis (model year). Model year was changed from fishing year in 2019 to calendar year for this analysis.

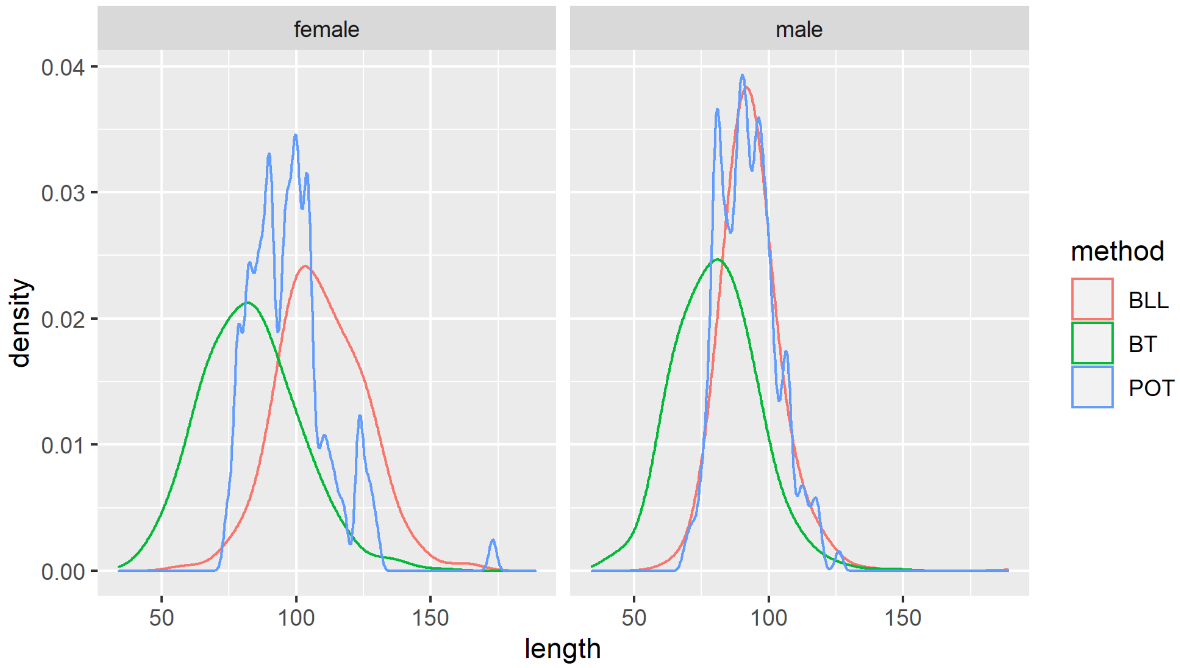


Figure E.2: Comparison of the length frequency distributions in the 2020 calendar year. The bottom longline (BLL) and bottom trawl (BT) length frequencies are scaled up to the entire fishery; the pot length frequency comes from a single trip and is not standardised.