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Tini a Tangaroa

Descriptive analysis and stock assessment model inputs of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5&6) for the 2020–21 fishing year

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Mormede, S.[1]; Dunn, A.[2]; Webber, D.N.[3] (2021). Descriptive analysis and stock assessment model inputs of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5&6) for the 2020–21 fishing year.

***New Zealand Fisheries Assessment Report 2021/60*. 109 p.**

Ling (*Genypterus blacodes*) are an important species commercially caught mainly by bottom trawls and bottom longlines; they are found throughout the middle depths of New Zealand waters. 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 Sub-Antarctic stock (LIN 5&6, excluding LIN 6B) and fishery and provides an updated characterisation of the spatial structure of the stock, revised catch per unit effort (CPUE) indices, and a summary of the input parameters for the 2021 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. Spatially, the bottom trawl fleet showed a rapid increase in the new areas explored up to about 2004, followed by a subsequent plateau. Similarly, the longline fleet presented an expansion of the new areas explored up to 2000, 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. The most parsimonious fishery structure which adequately captured length frequencies and sex ratios was achieved by simply splitting the LIN 5&6 fishery into longline and bottom trawl fisheries. It was more consistent than the previous split that divided spawning or non-spawning longline fisheries.

The length-weight relationship for ling in LIN 5&6 was updated with the latest available data. The growth function was updated, including using Bayesian inference, and the von Bertalanffy parameterisation was used for the update of the stock assessment. A monotonically increasing mean length at age growth model was used to derive monthly growth increments that were later used in the time steps of the stock assessment model.

Standardised CPUE series were derived for the tow-by-tow bottom trawl fishery, daily rolled-up bottom longline fishery, and set-by-set bottom longline fishery (available from 2004 only). The bottom trawl standardised CPUE of ling in the Sub-Antarctic (LIN 5&6) presented a very different trend to that of the Sub-Antarctic trawl survey biomass over time. The bottom trawl standardised CPUE index was not likely to represent an index of ling abundance in the area but rather to represent changing patterns in the fishery driven by changes in hoki TACC over time.

Both rolled-up and set-by-set standardised CPUE for Sub-Antarctic ling (LIN 5&6) presented similar trends and were similar to the Sub-Antarctic trawl survey biomass trend. The standardised CPUE was highly variable over time, with a general decrease to 2016 followed by an increase the last few years of the series. Longline fishing targets ling (with very few null sets) and the data did not show evidence of statistical area-specific departure from the standardised CPUE trend for the stock. It is therefore plausible that the trend in the index represents the trend in the vulnerable biomass of ling. Because the

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rolled-up standardised CPUE provides an index over a much longer time than the set-by-set standardised CPUE, the former was used in the stock assessment in 2021.

The annual catches and scaled age frequencies used in the 2021 stock assessment model were re-calculated to account for the change in the definition of fisheries in the model. They are updated here and are similar to those in the previous stock assessment.

1. INTRODUCTION

Ling (*Genypterus blacodes*) are an important commercially caught species and are targeted by both bottom trawls and demersal longlines. 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, set nets, and pots (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 FMA (LIN 10) (Fisheries New Zealand 2020). The ling biological stocks were defined using statistical areas as described in Table 1 and Figure 1. The catch and TACC for ling in LIN 5 and LIN 6 are shown in Figure 2.

This report fulfils Specific Objective 1 of Project LIN2020-01. The overall Objective was "To carry out stock assessments of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5&6) 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 5&6) in the Sub-Antarctic and update the standardised catch and effort analyses". We provide a descriptive summary of catch and effort data since 1989–90. A spatial analysis was carried out, and biological parameters were updated. We also update and revise the analysis of the catch per unit of effort data for ling in the Sub-Antarctic for the fishing years 1990–91 (denoted 1991) to 2019–20 (2020).

Table 1: Definition of the biological stocks for ling (adapted from Ballara (2019), Statistical Area 032 is assigned to Southland in this analysis).

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	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

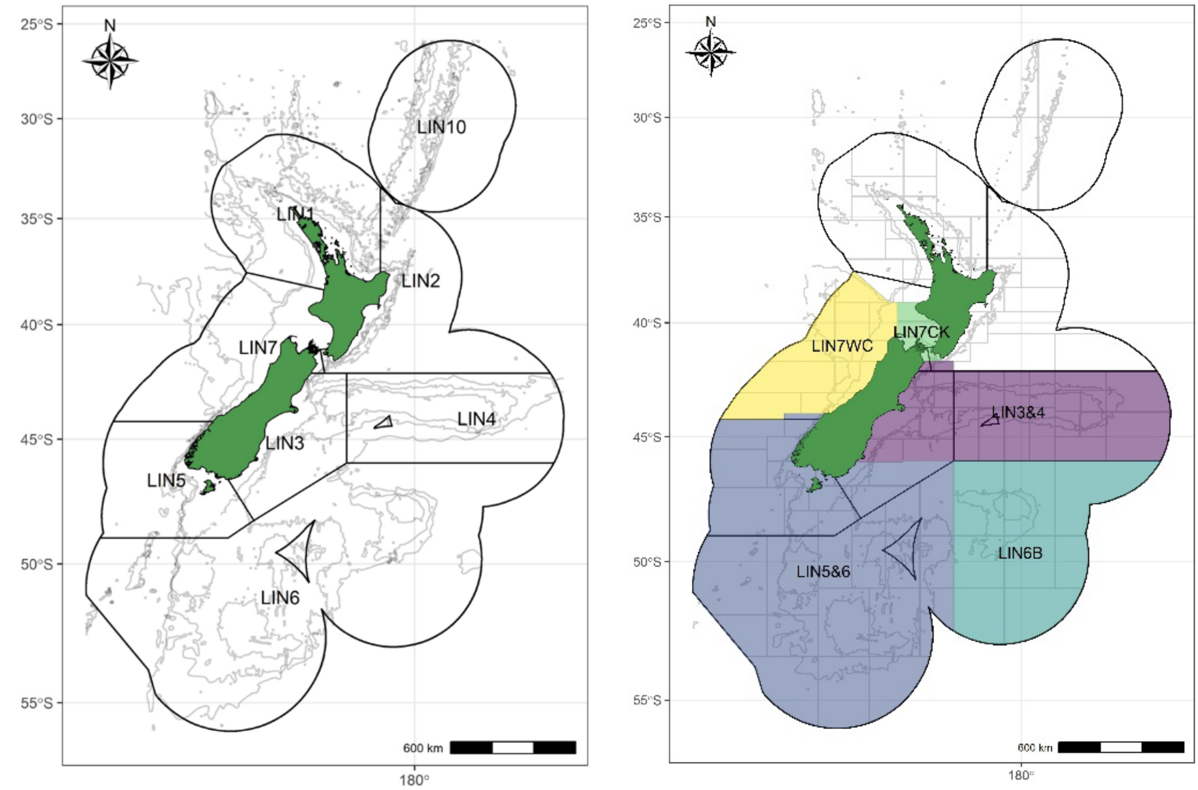

Figure 1: **Quota Management Areas (QMAs, left) and biological stock boundaries (right) for ling, as used in this report.**

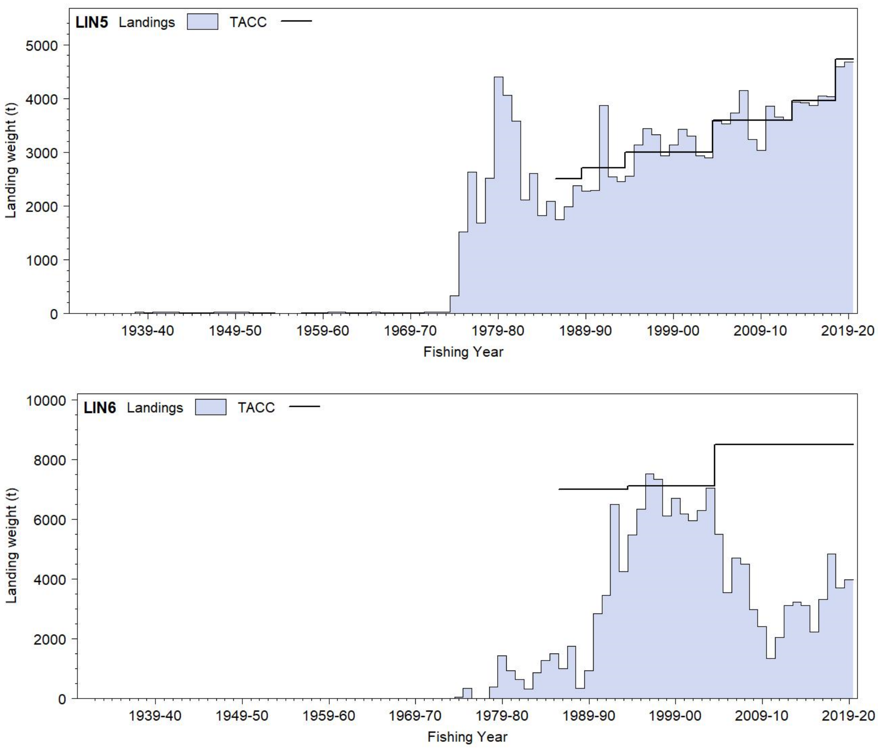

Figure 2: **Annual reported catch of ling in LIN 5 and LIN 6 (bars) and the TACC for ling (black line) for fishing years 1989–90 to 2019–20.**

2. SUMMARY OF THE LING FISHERY IN THE SUB-ANTARCTIC

2.1 Available data

Data available for Sub-Antarctic 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 Sub-Antarctic 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 till September 2020 (REPLOG 13300), and all available observer and resource survey data (REPLOG 13301) on 2nd November 2020. This 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.

Observed catch and effort 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. 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* Sub-Antarctic 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.

2.2 Data checks

Catch and effort data were corrected for errors using simple checking and imputation algorithms similar to those reported by Ballara (2019) 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, 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 total allowable commercial catch (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 which was caught at about the TACC in recent years. The forms ling was reported on have changed over time: from predominantly CELR and TCER to predominantly LCER and TCEPR in the 2000s, and then to ERS forms starting in 2018 (Table A.5).

Catches in the Sub-Antarctic ling stock (LIN 5&6) were similar to those reported by Ballara (2019) (Figure A.1). Ling were caught predominantly by bottom trawlers targeting hoki or ling, followed by longliners targeting 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 September to December period although the time of the year catches have occurred has been variable over time (Figure A.5). Trawl vessels are dominated by 60 to 70 m vessels, whereas the most common vessel size for longliners is 40 to 50 m (Figure A.6). The longline fleet was dominated by New Zealand vessels, whereas the trawl fleet has a mixture of New Zealand, Korean, and Japanese flags (Figure A.7). Ling was the top species caught by longline vessels and was usually within the top three species caught by bottom trawl vessels (Figure A.8 and Figure A.9). Ling have typically been caught at 500 to 750 m depth; the depth of fishing has increased over time in the fleet reporting on LTCER forms but not on other forms (Figure A.10).

The location of catches differs between the bottom trawl and longline fleets (Figure A.11 by statistical area, Figure A.12 to Figure A.14 spatially at about 0.5 degree resolution and three vessels minimum as per confidentiality rules), with the trawl fleet fishing predominantly in Statistical Areas 028, 030, 602, and 603, and the longline fleet fishing predominantly in Statistical Areas 030, 032, 610, and 618. To represent the expansion or retraction of the area fished over time, the area covered by the fleet 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 rapid increase in the new areas explored to about 2004, followed by a subsequent plateau (very few new areas investigated) with a contraction of the area fished in any one year. Similarly, the longline fleet presented an expansion of the new areas explored to 2000, followed by a reduction (but not plateau) in the number of new areas investigated (Figure A.15).

The effort characteristics of the bottom trawl and longline fleets have changed through time, in particular for fishing events not targeting ling (Figure A.16).

3. SPATIAL-TEMPORAL ANALYSES

One of the aims of stratifying the catch into fisheries or areas for population modelling is to capture differences in age frequencies or sex ratios between the different parts of the population; in particular, if there are changes in relative catches between those parts over time (otherwise appropriate scaling up might be sufficient). 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 amount of fish at each age and sex observed as caught in the fishery.

The strata used in previous analyses of the LIN 5&6 biological stock were derived from a 2005 analysis (Horn 2005). The fishery was split in two strata for bottom longline (spawning and non-spawning) and another stratum for bottom trawl (e.g., Horn & Sutton 2019). 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.

The last model update of this stock also showed different sex ratios caught in the spawning and non-spawning longline fisheries (Masi 2019, figure 7), indicating that the mean length and also the sex ratio of ling in LIN 5&6 have varied in 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 standardisations), 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 carried 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 5&6 and LIN 6B concurrently. It was carried out in the software package '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. A similar tree regression analysis was carried out for the sex ratio (expressed as the proportion of females) in each fishing event.

A tree regression was also carried out using age data. Using all ages could introduce a bias due to the non-random selection of fish that were aged, usually a certain predetermined number of fish in length bins per fishery/area/stock rather than representative of the set they came from. The biggest difference in growth between the biological stocks of ling is expected at ages 14 to 18 (Horn 2005), therefore we used the mean length per fishing event of all fish aged from 14 to 18 y as the indicator. Because of the limited dataset, trawl and longline data were analysed together and the gear type was offered as a potential variable.

3.1.2 Spatial-temporal analysis

We used integrated nested Laplace approximation (INLA) (Rue et al. 2009) to develop spatial-temporal models of fish size/age. 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} = 343 424 and N_{age} = 20 306). Each node becomes an estimated model parameter, constrained by the stochastic partial differential equation (SPDE) underpinning INLAs spatial smoothers.

Two different data sets were used in this analysis: length-frequency (LF) data, and ageing (age) data. LF data were combined with the lengths available in the age data set (because length is also recorded in the age data set), records with unknown sex were dropped, length was rounded down to the nearest integer, and eleven three-year blocks were defined. Records with unknown sex were also dropped from the age data, ages were rounded to the nearest integer, and nine four-year blocks were defined.

The length data 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 age data were fitted to assuming a Poisson distribution. The variables year, month, sex, 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 were constructed. Both the deviance information criterion (DIC) and Watanabe-Akaike information criterion (WAIC) were used for model comparison.

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 somewhat 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 frequencies were plotted for each biological stock of ling. They showed no temporal pattern in the LIN 5&6 stock (Figure B.2). However, the LIN 5&6 stock did not contain the larger size classes as seen in other stocks, which might indicate ling do not grow as large in LIN 5&6 as in other stocks or that they are part of a wider stock (including LIN 6B for example). This hypothesis does warrant further investigation in the future.

The timing of spawning in the different ling stocks around New Zealand was also investigated using observer data. Using all years combined and gonad stage 4 or 5 as evidence of spawning, the Sub-Antarctic stock of ling is expected to spawn mostly from October to December (Figure B.3). This was consistent with previous analyses (e.g., Ballara 2019). Only LIN 6B ling were found to spawn at the same time, although over a longer period of time (September to February).

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
  - LIN 5&6
  - LIN 6B
    - 1st September to 31st March
    - 1st April to 31st August
- Trawl fleet
  - LIN 5&6
    - Target hake, hoki, ling, squid (*Nototodarus gouldi, N. sloanii*), white warehou (*Seriolella caerulea*), and silver warehou (*Seriolella punctata*) (representing 97% of the catch)
    - Target orange roughy (*Hoplostethus atlanticus*) and scampi (*Metanephrops challengeri*)
    - Target barracouta (*Thyrsites atun*), southern blue whiting (*Micromesistius australis*), and other species
  - LIN 6B

Using the mean length per fishing event of all fish aged between 14 and 18, the data split was consistent with that determined using length data and was as follows:

- LIN 6B
- LIN 5&6
    - Longline fleet
    - Trawl fleet

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

- Statistical Areas 027–031, 504, 602, 603, 607, 608
- Statistical Areas 025, 026, 032, 302, 303, 501–503, 601, 604–606, 609–625
    - Trawl fleet
    - Longline fleet
        - Statistical Areas 025, 026, 302, 604–606, 610–612, 618, 619, 624, 625
        - Statistical Areas 032, 303, 501–503, 601, 609, 613–617, 620–623

The spatial distribution of the strata based on the sex ratio in the measured catch is depicted in Figure B.9, noting that the strata are not only spatially defined but also by fleet. The mean proportion of females in these strata varies from 34 to 76%, with the highest proportion of females found in the southern part of the stock.

3.2.2 Spatial-temporal analysis

Both the DIC and WAIC suggested the most complex models were also the most parsimonious models (Table B.2 and Table B.3). However, we decided to use a simpler model to define spatially explicit fisheries strata because the more complex models with sex or time-block specific spatial effects would imply that the strata are also sexually explicit or vary through time. This would require sex-specific or time varying selectivities be estimated within the stock assessment. Furthermore, the length models were selected as the models to use to develop spatial strata because they produced less fractured strata, possibly due to the increase in the number of samples and random selection of fish to measure. We present length and age models below, as well as the spatial effects of more complex model structures.

Both the length and the age models produced very similar spatial patterns with small fish generally being found in the same location as young fish (Figure B.4). It appears that females and males had a similar spatial distribution (Figure B.5) and that the spatial distribution of old and young fish has not changed dramatically over the last couple of decades (Figure B.6).

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 0.19 retained the highest level of explained inertia in D0 while maximising the explained inertia in D1 (Figure B.7). The clusters (for K = 4 clusters) that arose from this alpha level exhibited good spatial contiguity, but there were small components of non-contiguous clusters flecked throughout other clusters (Figure B.8). Increasing the alpha value further consolidated the clusters, but much higher alpha levels were required to prevent non-contiguous components of clusters arising on other clusters (Figure B.8). The alpha value of 0.19 was retained for this analysis.

We further note that although there is likely to be high correlation within tows in the LF data, we did not account for this and simply fitted our models to each length measurement independently. It is common in tree-based regression to fit to the mean length per tow; however, this approach ignores the variability in length within tows. A better approach would be to include tow as a random-effect term within the model and will be incorporated in the future. This would properly account for the variability and correlation of individual lengths within tows. This issue does not apply to the age data set as only a small subset of individuals were aged, although they were not sampled randomly, which brings other potential biases.

3.2.3 Evaluation of the candidate strata

Four potential structures of the fishery were investigated:

- Option 1: based on the spatial-temporal analysis (the length model with an alpha of 0.19), four fisheries based on area and irrespective of method or time of the year.
- Option 2a: based on the tree regression of mean length, two fisheries using bottom trawl or longline gear.
- Option 2b: based on the tree regression of the sex ratio, four fisheries based on statistical area and gear type.
- Option 3: based on previous analyses, three fisheries comprising bottom trawl, spawning and non-spawning longline, each with specific areas and periods of the year.

All four options presented a variable catch over time for each of the strata. Option 3 presented the most inconsistent sex ratio over time whereas Option 2b, optimised for sex ratio, had the most consistent sex ratio over time. However, Option 2b also presented very limited length data in one of the strata. One stratum in Option 1 presented low catches and could be combined with another stratum (Figure B.10). Options 1 and 2a presented moderately consistent sex ratios over time.

The scaled age frequency distributions for all four options were calculated and are presented for the 2010 to 2020 model years (Figure B.11), where the 2020 model year is defined as from 1st September 2019 to 31st August 2020 (Masi 2019). Option 1 presented the most consistent age frequencies, supporting the potential of INLA as a very powerful method to use to define strata. However, the sex ratio was variable over time, which is unsurprising because the strata were not optimised for sex ratio. Option 2b presented the most consistent sex ratio, having been optimised for that purpose, and consistent age frequencies but would require grouping some strata due to the paucity of length data in one of the strata. Option 2a presented moderately consistent age frequencies and sex ratios in all strata over time as well as the simplest strata definitions. Option 3, with the most complex strata, presented the most variable sex ratio and rather undefined age frequencies.

The authors proposed that the 2021 stock assessment be updated with two fisheries only: bottom trawl and longline, comprising all the LIN 5&6 area and all times. This was approved by the Deepwater Working Group and is reflected in the May 2021 plenary document for ling (Fisheries New Zealand 2021).

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 2018 stock assessment model.

A log-linear regression was applied to the available length and weight parameters, where $Weight = a \cdot (length)^b$, to estimate the a and b parameters for each sex separately. 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 2018 stock assessment model.

The von Bertalanffy and Schnute models were fitted to all available age data for the Sub-Antarctic region using maximum likelihood estimation (MLE). The coefficient of variation (CV) was assumed constant as a function of mean length and set equal for males and females.

4.1.3 Bayesian growth models

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:

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

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, 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 5&6.

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 Sub-Antarctic trawl surveys or by observers. Most of the data available were from

December, the same time as the November survey (Figure C.4). Fewer ages were available from the Fisheries New Zealand database than had been previously reported (Horn & Sutton 2019), because it appeared that not all historical data had been loaded into the database (Table C.2). This issue is currently being investigated by Fisheries New Zealand.

The 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 growth curve was similar to those previously derived (Table C.3 and Figure C.7).

The Schnute models also had poor residuals for ages 2 and 3, and for old ages (Figure C.8). The resulting parameters are summarised in Table C.4. The growth curves from the von Bertalanffy parameterisation and the Schnute parameterisation were similar, apart from the estimated length at age for ages 2 and 3.

4.2.3 Bayesian growth models

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 MLE von Bertalanffy model (Table C.5). The improvement in model fit is observed when comparing the empirical distribution of the data with the posterior predictive distributions of simulated data for each model run (Figure C.9 and Figure C.10). Further, the standardised residuals suggested that the mean length at age model fits the data better across the full range of observed ages (Figure C.11 and Figure C.12).

However, without any constraint, the mean length at age model estimate of length drifts implausibly high for the older fish when compared with the von Bertalanffy model (Figure C.13, Figure C.14, and Figure C.15). This suggests that this model could be improved by some type of constraint for older fish where there are few data. Despite this fault, the mean length at age model does have some clear advantages over the 'old school' von Bertalanffy model. For example, the model presented is very useful for exploring growth by month (Figure C.16 and Figure C.17) which can be further developed into the cumulative proportion of growth that occurs throughout a year, a key input for stock assessment (Table C.7).

4.3 Discussion

The length-weight relationship derived using all data up to and including 2020 provided very similar parameters to those used previously. The new parameters were used for the 2021 stock assessment and updated in the ling plenary document (Fisheries New Zealand 2021).

The growth curve obtained through three methods (MLE von Bertalanffy, Bayesian von Bertalanffy, and MLE Schnute) provided a similar trajectory and therefore the Bayesian von Bertalanffy parameterisation was chosen for the update of the stock assessment of ling in biological stock LIN 5&6. The Bayesian mean length at age growth curve was used to calculate monthly growth increments.

5. CPUE ANALYSES

5.1 Methods

The catch per unit effort (CPUE) standardisation followed similar methods that have been used previously (e.g., Ballara 2019). Three standardised CPUE indices were calculated: tow-by-tow trawl CPUE, rolled-up longline CPUE, and set-by-set longline CPUE. Following the spatial analysis (see section 3), the longline data were not split between spawning and non-spawning fisheries, although standardisations using this split were carried out to confirm the results were similar to those obtained previously. Only fishing that occurred in the biological stock of LIN 5&6 was considered further.

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, Table D.2, and Table D.3. Of note, the year was defined as 1st September to 31st August to match the year definition used in the model (Masi 2019). Starting the model year on 1st September captured the extended spawning season (September to December, see Figure B.3) within a single time step; it also allowed for the high historic fishing catch recorded in the September month to be combined with similar fishing in October across model years.

Prior to the early 2000s, longline catch and effort data were mostly recorded daily on LCER forms, rather than individually for each set on other form types (Figure A.7). 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., 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 assumed as the total of the numbers of hooks set.

Details of the data selection for each CPUE index are summarised in Table D.4, Table D.5, and Table D.6 and were largely consistent with those used previously (Ballara 2019). Because of the change over time in the reporting requirements, and in particular the number of species that require reporting (Figure A.8 and Figure A.9), fishing events where ling was not recorded in the top five species, or top five 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.1, Figure D.2, and Figure D.3).

All standardisations comprised a lognormal distribution for the positive catches. A binomial model was also conducted for the standardisation of trawl data, because the number of tows with no ling catch was not negligible. This was used in a delta-lognormal standardised CPUE index.

The number of longline sets with no ling catch was negligible, therefore the binomial model was not conducted for those standardised longline CPUE indices. The final models were obtained through the step-wise addition of parameters with highest AIC (Akaike 1974) until the deviance explained by any additional term was less than 1%. Model fits were investigated using standard residual diagnostics.

5.2 Results

5.2.1 Bottom trawl tow-by-tow CPUE

The standardised lognormal CPUE trend for bottom trawl in Sub-Antarctic ling (LIN 5&6) was similar to that obtained in 2019 (Ballara 2019) and had less variation than the raw data (Figure D.4). The residual plots were acceptable (Figure D.4). The lognormal model explained 59% of the variance and seven parameters were included additional to model year (Table D.7 and Figure D.5 to Figure D.13). The parameters *grid* and *target* had the most influence on the standardised index (Figure D.6). The influence plots indicate that fishing might not necessarily happen at the locations or times of highest CPUE (Figure D.6), which was not surprising because the location and times of fishing are not only dictated by the best ling catch rates but a raft of other factors such as the available hoki quota or distance from port, for example. The implied trends by statistical area seemed to indicate that in many statistical areas the bottom trawl CPUE trend was increasing, which was not adequately captured in the standardised model (Figure D.14).

The standardised binomial trend was also similar to that obtained in 2019 (Ballara 2019) and also had less variation than the raw data (Figure D.15). The residual plots were acceptable (Figure D.15). The binomial model explained 29% of the variance and four parameters were included additional to model year (Table D.8 and Figure D.16).

The resulting delta-lognormal model of tow-by-tow bottom trawl CPUE in Sub-Antarctic ling (LIN 5&6) was also similar to that obtained in 2019 (Ballara 2019) and also had less variation than the raw data (Figure D.17). The index, however, was still highly variable over time (Table D.9) and showed little resemblance to the Sub-Antarctic survey trawl biomass index.

5.2.2 Longline rolled-up CPUE

The standardised lognormal CPUE trend for rolled-up bottom longline fishing in Sub-Antarctic ling (LIN 5&6) was similar to that obtained in 2019 (Ballara 2019) and had a similar pattern to the raw data and to the Sub-Antarctic trawl survey biomass (Figure D.18). The residual plots were acceptable (Figure D.18). The lognormal model explained 63% of the variance and four parameters were included additional to model year (Table D.10 and Figure D.19 to Figure D.24). The *number of hooks* had the most influence on the standardised index (Figure D.20). Influence plots indicate that fishing might not necessarily happen at the locations or times of highest CPUE (Figure D.21 to Figure D.24), which was not surprising because the location and times of fishing are not only dictated by best ling catch rates, but by a raft of other factors such as distance from port, for example. The implied trends by statistical area did not show obvious departure from the overall standardised CPUE trend (Figure D.25).

5.2.3 Longline set-by-set CPUE

The standardised lognormal CPUE trend for set-by-set bottom longline fishing in Sub-Antarctic ling (LIN 5&6) was similar to that obtained in 2019 using rolled-up data (Ballara 2019) and had a similar pattern to the raw data and to the Sub-Antarctic trawl survey biomass (Figure D.26). The residual plots were acceptable (Figure D.26). The lognormal model explained 60% of the variance and four parameters were included additional to model year (Table D.11and Figure D.27 to Figure D.32). In this model it was the parameter *vessel* rather than *number of hooks* that had the most influence on the standardised year effect (Figure D.28), although that change was more modest than for the rolled-up longline CPUE. Influence plots indicate that fishing might not necessarily happen at the locations or times of highest CPUE (Figure D.29 to Figure D.32), which was not surprising because the location and times of fishing are not only dictated by best ling catch rates but also by a raft of other factors such as distance from port, for example. The implied trends by statistical area did not show any obvious departure from the overall standardised CPUE trend (Figure D.33).

Both rolled-up and set-by-set standardised CPUE for Sub-Antarctic ling (LIN 5&6) had similar trends, and these were mostly similar to the Sub-Antarctic trawl survey biomass trend (Table D.12 and Figure D.34).

5.3 Discussion

The bottom trawl standardised CPUE of ling in the Sub-Antarctic (LIN 5&6) had a very different trend to that of the Sub-Antarctic trawl survey biomass over time. This CPUE index was not deemed to represent an index of abundance, but rather to represent changing patterns in the fishery driven by changes in available hoki quota over time. A reduction in hoki TACC in the early 2000s meant that vessels focused on ling bycatch to maintain the economic viability of hoki trawlers. Therefore, this index was not used as an index of ling abundance in the stock assessment.

Both rolled-up and set-by-set standardised CPUE for Sub-Antarctic ling (LIN 5&6) had similar trends. Longline fishing targets ling (with very few null sets) and did not show evidence of area-specific departure from the standardised trend. The longline standardised CPUE index was therefore expected to represent the underlying biomass of ling. Because the rolled-up standardised CPUE provides an index over a much longer time period, it was used in the stock assessment in 2021.

6. INPUTS INTO THE 2021 STOCK ASSESSMENT

6.1 Catches

Two fisheries were defined for the 2021 stock assessment: trawl and longline fisheries (see section 3.2.3). For the purposes of catches in the stock assessment model, trawl was assumed to comprise bottom trawls, midwater trawls near the bottom, and midwater trawls. The model year was defined as 1st September to 31st August (see section 3.2).

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 (Masi 2019), as depicted in Figure E.1 where the 2019 base case used model year (as per the definition here) and the 2019 reference case used fishing year. The reasons for those differences with Masi (2019) were not able to be discerned.

6.2 Age frequencies

The commercial fishery age frequencies for the Sub-Antarctic ling assessment have traditionally been calculated under a different Fisheries New Zealand project (e.g., Horn & Sutton 2019), but were recalculated here to generate age frequencies using the updated definition of the fisheries. Even though less age data were available here (Table C.2), the age frequencies were similar to those based on the previous stock assessment, once the different definitions of longline fisheries were accounted for (see the comparison in Figure E.2). The scaled age frequencies are summarised in Table E.2 to Table E.5 and Figure E.3 and Figure E.4.

The Sub-Antarctic trawl survey biomass and age frequencies were also provided through a different Fisheries New Zealand project (e.g., Horn & Sutton 2019). Because the strata of the survey have not changed, these results were used for the 2021 stock assessment. They are summarised in the 2021 ling plenary document (Fisheries New Zealand 2021) and are not replicated here.

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8. REFERENCES

Akaike, H. (1974). A new look at statistical model identification. *IEEE Transactions on Automatic Control AU-19*: 716–722.

Ballara, S.L. (2019). A descriptive analysis of all ling (*Genypterus blacodes*) fisheries, and CPUE for ling fisheries in LIN 5&6, from 1990 to 2017. *New Zealand Fisheries Assessment Report 2019/49*. 88 p.

Chavent, M.; Kuentz-Simonet, V.; Labenne, A.; Saracco, J. (2018). ClustGeo: an R package for hierarchical clustering with spatial constraints. *Computational Statistics 33*: 1799–1822.

Dunn, A. (2003). Investigation of evidence of area misreporting of landings of ling in LIN 3, 4, 5, 6, & 7 from TCEPR records in the fishing years 1989-90 to 2000-01. (Unpublished Final Research Report to the Ministry of Fisheries for Project HAK2001/01 (8) held by Fisheries New Zealand.) 21 p.

Edwards, C.T.T. (2017). Development of natural mortality priors for ling (*Genypterus blacodes*) stock assessments in New Zealand. *New Zealand Fisheries Assessment Report 2017/55*. 32 p.

Fisheries New Zealand (2020). Report from the Fishery Assessment Plenary, May 2020: stock assessments and stock status. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand. 1746 p.

Fisheries New Zealand (2021). Fisheries Assessment Plenary, May 2021: stock assessments and stock status. Compiled by the Fisheries Science Team. 1782 p.

Horn, P.L. (2005). A review of the stock structure of ling (*Genypterus blacodes*) in New Zealand waters. *New Zealand Fisheries Assessment Report 2005/59*. 41 p.

Horn, P.L.; Sutton, C.P. (2019). Catch-at-age for hake (*Merluccius australis*) and ling (*Genypterus blacodes*) in the 2017–18 fishing year and from research trawl surveys in 2018, with a summary of all available data sets from the New Zealand EEZ. *New Zealand Fisheries Assessment Report 2019/63*. 81 p.

Hurst, R.J.; Bagley, N.W.; Anderson, O.F.; Francis, M.P.; Griggs, L.H.; Clark, M.R.; Paul, L.J.; Taylor, P.R. (2000). Atlas of juvenile and adult fish and squid distributions from bottom and midwater trawls and tuna longlines in New Zealand waters. *NIWA Technical Report 84*. 162 p.

Masi, M. (2019). Stock assessment of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5&6) for the 2017–18 fishing year. *New Zealand Fisheries Assessment Report 2019/30*. 35 p.

Mormede, S.; Parker, S.J. (2018). Summary of the toothfish fishery and tagging program in the Ross Sea region (Subarea 88.1 and SSRUs 88.2A-B) through 2017-18. WG-FSA-18/46. CCAMLR, Hobart, Australia. 21 p.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/. Vienna, Austria.

Rue, H.; Martino, S.; Chopin, N. (2009). Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. *Journal of the Royal Statistical Society: Series B (Statistical Methodology) 71*: 319–392. https://doi.org/10.1111/j.1467-9868.2008.00700.x

Stan Development Team (2020). Stan Modelling Language: User's Guide and Reference Manual Version 2.24. Stan Governing Body.(

Starr, P.J. (2008). Procedure for merging MFish landing and effort data. (Unpublished report held by Fisheries New Zealand, Wellington.) 18 p.

Starr, P.J.; Kendrick, T.H. (2016). SCH 1, 2, 3, 4, 5, 7 and 8 fishery characterisation and CPUE report. *New Zealand Fisheries Assessment Report 2016/64*. 255 p.

Vehtari, A.; Gelman, A.; Gabry, J. (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing 27*: 1413–1432. https://doi.org/10.1007/s11222-016-9696-4

von Bertalanffy, R. (1938). A quantitative theory of organic growth (Inquiries on growth laws. II). *Human Biology 10*: 181–213.

APPENDIX A – DESCRIPTION OF THE FISHERY

Table A.1: Ling TACC (in tonnes) per QMA by fishing year.

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

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

Fishing year	LIN1	LIN2	LIN3	LIN4	LIN5	LIN6	LIN7	LIN10	Other	Total
1990	83	563	1 433	512	2 098	1 046	2 428	0	4	8 166
1991	139	833	2 059	2 156	2 383	2 359	2 010	-	11	11 950
1992	183	668	2 108	4 358	3 679	3 232	1 873	0	18	16 119
1993	302	738	1 902	3 546	3 046	5 567	1 957	0	7	17 065
1994	289	637	1 848	3 702	3 121	3 281	1 829	-	14	14 722
1995	405	715	2 072	4 377	3 711	3 839	2 648	-	388	18 155
1996	311	781	2 457	4 077	4 742	3 794	2 484	-	91	18 737
1997	690	740	2 192	3 468	4 751	4 896	2 395	0	139	19 270
1998	339	769	2 244	4 228	4 327	5 493	2 498	0	245	20 145
1999	301	769	2 057	3 905	3 997	4 486	2 738	0	77	18 331
2000	365	778	2 190	3 968	3 846	5 380	2 612	0	6	19 146
2001	312	921	1 831	3 417	3 917	5 208	2 975	-	3	18 584
2002	277	801	1 779	3 214	3 777	5 410	2 614	-	2	17 874
2003	216	746	2 076	2 719	3 748	5 250	2 313	0	2	17 070
2004	200	817	1 607	2 385	4 050	5 699	2 446	-	0	17 204
2005	223	741	1 313	2 570	4 912	4 028	2 077	-	0	15 863
2006	289	702	1 341	1 663	4 535	2 250	2 016	-	22	12 819
2007	228	740	1 815	1 943	5 363	2 786	1 794	-	2	14 670
2008	359	690	1 605	2 307	5 206	3 278	1 899	-	0	15 344
2009	298	560	1 526	1 815	3 863	1 706	1 867	-	0	11 634
2010	354	506	1 524	1 844	3 882	1 494	1 987	0	1	11 593
2011	389	598	1 442	1 398	4 097	959	2 220	-	0	11 105
2012	353	428	1 076	2 016	4 291	1 287	2 072	-	0	11 523
2013	346	514	1 189	1 918	5 863	1 215	2 386	-	0	13 431
2014	365	553	1 218	2 041	4 960	2 046	2 531	-	0	13 713
2015	369	561	1 016	1 877	5 147	1 757	2 602	0	1	13 330
2016	388	599	1 160	2 267	4 640	1 297	2 741	-	2	13 093
2017	382	904	1 571	2 213	5 116	2 110	2 744	-	1	15 041
2018	378	1 006	1 915	2 374	5 216	3 171	2 713	-	1	16 775
2019	354	857	1 747	1 849	5 816	2 308	2 554	-	1	15 487
2020	351	640	1 449	1 597	5 255	2 867	2 782	-	2	14 944
Total	9 837	21 878	52 761	81 724	133 355	99 501	72 806	1	1 042	472 904

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

Fishing year	LIN1	LIN3	LIN4	LIN5	LIN6	LIN7	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	1 684	1 778	4 662	3 967	3 215	15 678
Total	9 808	64 118	92 270	106 220	137 183	88 894	498 494

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	LIN3&4	LIN5&6	LIN6B	LIN7CK	LIN7WC	OTHER	Total
1990	2 212	3 449	13	570	2 291	494	9 030
1991	4 644	5 292	34	729	2 290	697	13 686
1992	6 837	6 767	864	412	2 139	795	17 814
1993	6 032	8 351	1 014	419	2 347	912	19 076
1994	5 765	5 957	1 078	337	2 013	824	15 973
1995	7 543	7 777	451	368	2 764	1 301	20 205
1996	7 499	9 035	607	504	2 875	1 043	21 562
1997	6 868	10 809	403	611	2 785	1 198	22 674
1998	7 920	10 525	400	543	2 638	1 303	23 328
1999	7 237	8 707	550	454	3 238	910	21 096
2000	7 089	9 011	1 018	416	3 158	908	21 599
2001	6 057	8 643	1 139	481	3 245	989	20 554
2002	5 496	8 882	648	384	3 124	1 031	19 565
2003	5 273	8 467	1 029	483	2 793	864	18 910
2004	4 442	9 145	994	465	2 819	892	18 758
2005	4 235	9 219	48	456	2 433	795	17 187
2006	3 300	7 220	72	333	2 416	859	14 200
2007	4 000	8 415	256	281	2 233	916	16 101
2008	4 056	8 381	446	204	2 204	972	16 263
2009	3 609	6 164	232	154	2 144	834	13 137
2010	3 589	5 682	2	100	2 316	921	12 610
2011	2 947	5 468	55	172	2 657	1 038	12 337
2012	3 295	6 018	4	142	2 674	822	12 955
2013	3 466	6 915	4	190	2 909	856	14 339
2014	3 615	7 104	291	197	3 095	923	15 225
2015	3 387	7 207	38	183	3 239	948	15 003
2016	4 026	5 984	214	222	3 239	983	14 668
2017	4 155	6 826	803	285	3 303	1 230	16 601
2018	4 542	8 927	256	378	3 396	1 197	18 695
2019	3 855	8 316	222	278	2 956	1 118	16 743
2020	3 251	8 623	253	149	3 100	1 060	16 436
Total	150 244	237 286	13 439	10 900	84 834	29 630	526 332

Table A.5: Ling catch (in tonnes) 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	1 709	0	0	0	6 457	0	0	0	8 166
1991	3 717	0	0	0	8 233	0	0	0	11 950
1992	7 076	0	0	0	9 043	0	0	0	16 119
1993	7 555	0	0	0	9 510	0	0	0	17 065
1994	8 315	0	0	0	6 407	0	0	0	14 722
1995	9 690	0	0	0	8 466	0	0	0	18 155
1996	8 694	0	0	0	10 043	0	0	0	18 737
1997	9 347	0	0	0	9 924	0	0	0	19 270
1998	8 529	0	0	0	11 616	0	0	0	20 145
1999	8 046	0	0	0	10 285	0	0	0	18 331
2000	7 982	0	0	0	11 164	0	0	0	19 146
2001	7 345	0	0	0	11 239	0	0	0	18 584
2002	6 402	0	0	0	11 472	0	0	0	17 874
2003	5 726	0	0	0	11 344	0	0	0	17 070
2004	3 556	2 075	0	0	11 574	0	0	0	17 204
2005	2 028	3 318	0	0	10 518	0	0	0	15 863
2006	1 701	2 512	0	0	8 605	0	0	0	12 819
2007	1 818	2 566	0	0	10 153	0	0	133	14 670
2008	206	2 857	2 045	0	9 622	515	0	99	15 344
2009	188	2 591	1 462	0	6 721	563	0	108	11 634
2010	131	2 857	1 744	0	6 055	698	0	109	11 593
2011	75	1 887	2 089	0	6 047	926	0	82	11 105
2012	49	2 356	1 975	0	6 260	828	0	54	11 523
2013	128	1 346	2 596	0	8 493	843	0	25	13 431
2014	165	2 397	2 910	0	7 224	985	0	32	13 713
2015	99	1 694	2 596	0	8 045	868	0	28	13 330
2016	204	2 263	2 616	0	6 903	1 025	0	83	13 093
2017	284	3 029	2 703	0	7 960	1 030	0	35	15 041
2018	715	2 423	2 900	0	1 584	1 002	8 110	41	16 775
2019	330	1 268	1 414	2 454	43	730	8 791	457	15 487
2020	0	0	83	5 535	0	1	8 804	520	14 944
Total	111 811	37 438	27 132	7 990	251 011	10 012	25 706	1 806	472 904

Table A.6: Ling catch (in tonnes) for the LIN 5&6 biological stock per gear type, target species by fishing year as reported in catch and effort forms.

Fishing	Bottom trawl				Midwater trawl				Longline		
year	LIN	HOK	HAK	Other	LIN	HOK	HAK	Other	LIN	Other	Total
1990	1 984	605	184	401	0	34	0	27	9	1	3 345
1991	2 662	1 197	77	583	0	15	0	5	253	1	4 844
1992	1 955	2 712	140	667	0	7	0	13	642	1	6 314
1993	3 445	2 307	49	586	0	135	0	6	1 303	11	7 932
1994	2 170	1 010	76	675	0	11	4	5	1 303	16	5 546
1995	2 872	1 099	54	579	0	117	0	1	2 317	8	7 342
1996	4 227	1 356	115	561	0	34	0	2	1 755	6	8 320
1997	3 198	2 317	22	566	0	8	0	6	3 229	11	9 518
1998	2 894	2 571	119	365	0	4	0	3	3 535	20	9 639
1999	2 376	2 085	117	486	0	17	0	5	2 896	37	8 084
2000	2 755	2 906	46	317	0	32	0	11	2 218	8	8 390
2001	1 944	2 897	417	485	60	170	1	28	1 836	19	8 212
2002	1 243	4 449	240	742	124	84	0	54	1 712	5	8 773
2003	1 661	4 062	331	728	179	86	0	15	1 156	8	8 328
2004	2 128	4 290	260	664	269	48	0	30	1 271	7	9 065
2005	3 222	3 196	373	732	0	240	2	21	1 208	13	9 047
2006	3 739	1 106	35	773	15	179	0	9	925	5	6 915
2007	4 660	1 430	105	932	181	79	0	11	714	22	8 162
2008	4 199	1 782	189	676	81	0	0	2	1 158	47	8 144
2009	2 935	782	266	851	0	2	0	3	644	19	5 526
2010	1 645	1 381	287	954	0	4	0	7	1 238	17	5 579
2011	2 182	972	162	940	0	27	0	15	736	25	5 317
2012	2 046	1 159	220	892	0	42	0	2	1 338	9	5 855
2013	4 312	1 278	270	846	0	4	0	4	509	6	7 243
2014	3 040	1 483	281	896	0	0	0	4	1 199	4	6 926
2015	3 738	1 289	290	556	0	30	0	34	1 036	4	7 036
2016	3 268	950	217	488	0	14	0	11	830	3	5 801
2017	3 308	1 208	236	780	0	4	0	6	1 122	8	6 703
2018	4 425	1 976	104	761	0	6	0	7	1 059	13	8 392
2019	4 727	1 135	39	749	0	15	0	3	1 296	23	8 115
2020	4 853	845	91	441	0	3	0	6	1 732	62	8 114
Total	93 813	57 835	5 413	20 668	910	1 451	7	354	42 180	442	226 526

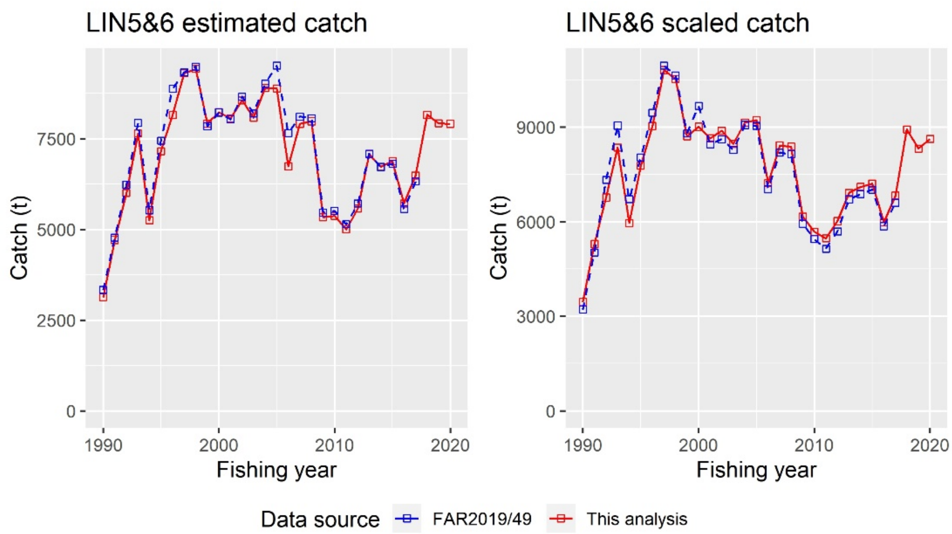


Figure A.1: LIN 5&6 estimated ling catches as reported in the catch and effort forms (left) and scaled to landings and MHR (right) calculated in this analysis and reported in the 2019 analysis (Ballara 2019) by fishing year.

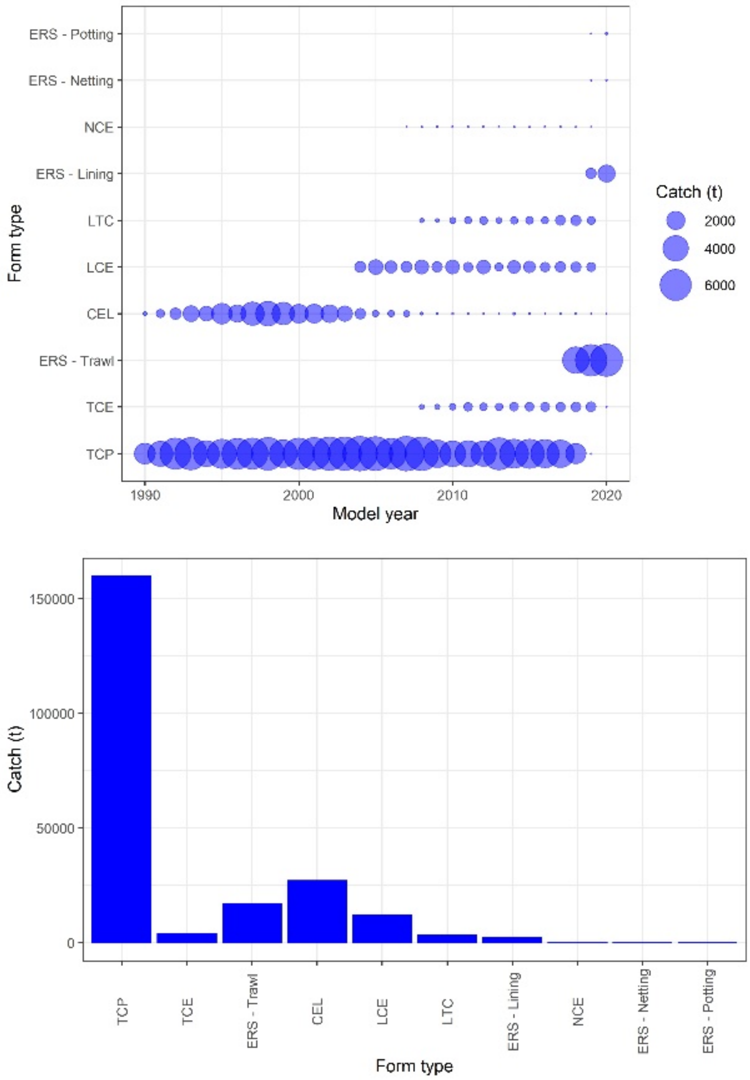


Figure A.2: LIN 5&6 distribution of annual ling catch reported in catch and effort forms by form type for bottom trawl (BT) and bottom longline (BLL) gears separately. Model year starts in September (as opposed to fishing year which starts in October). Form type is trawl catch effort and processing return (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).

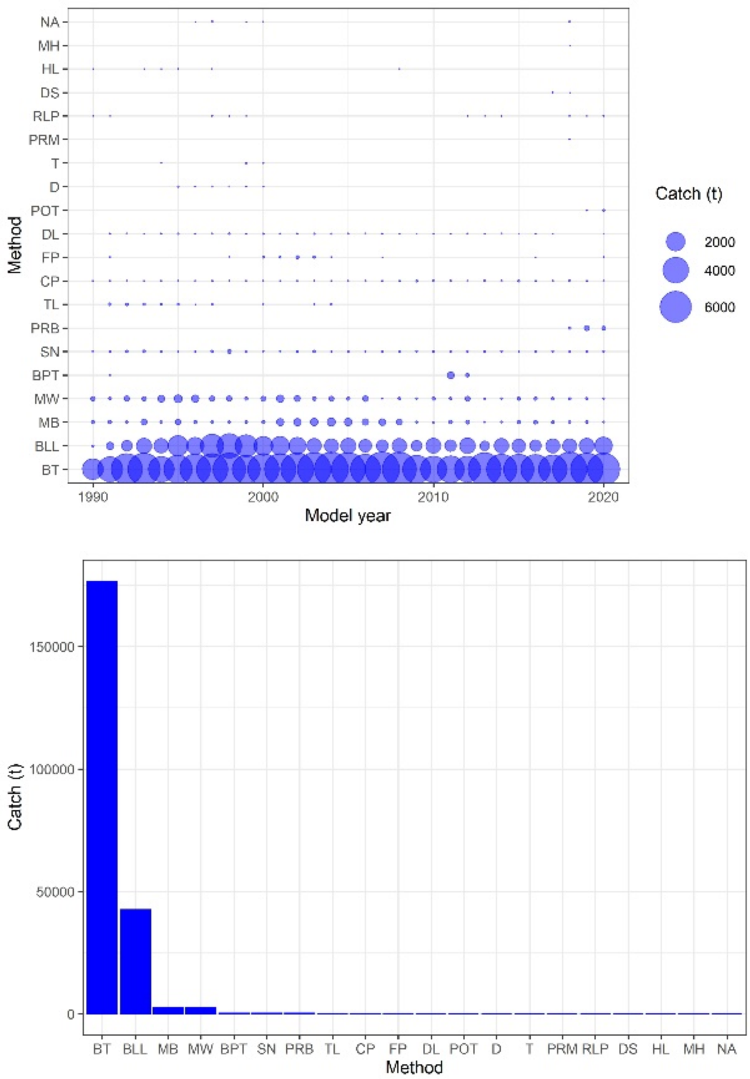


Figure A.3: LIN 5&6 distribution of annual ling catch reported in catch and effort forms by method for bottom trawl (BT) and bottom longline (BLL) gears separately. Model year starts in September (as opposed to fishing year which starts in October). Method is bottom trawl (BT), bottom longlining (BLL), midwater trawl within 5 m of the bottom (MB – code defined within the analysis), midwater trawl (MW), bottom paired trawl (BPT), set-netting (SN), precision bottom trawl (PRB), trot lines (TL), cod potting (CP), fish traps (FP), drop/Dahn lines (DL), potting (POT), dredging (D), trolling (T), precision midwater trawl (PRM), rock lobster potting (RLP), Danish seining (DS), handlining (HL), mechanical harvesting (MH), not reported (NA).

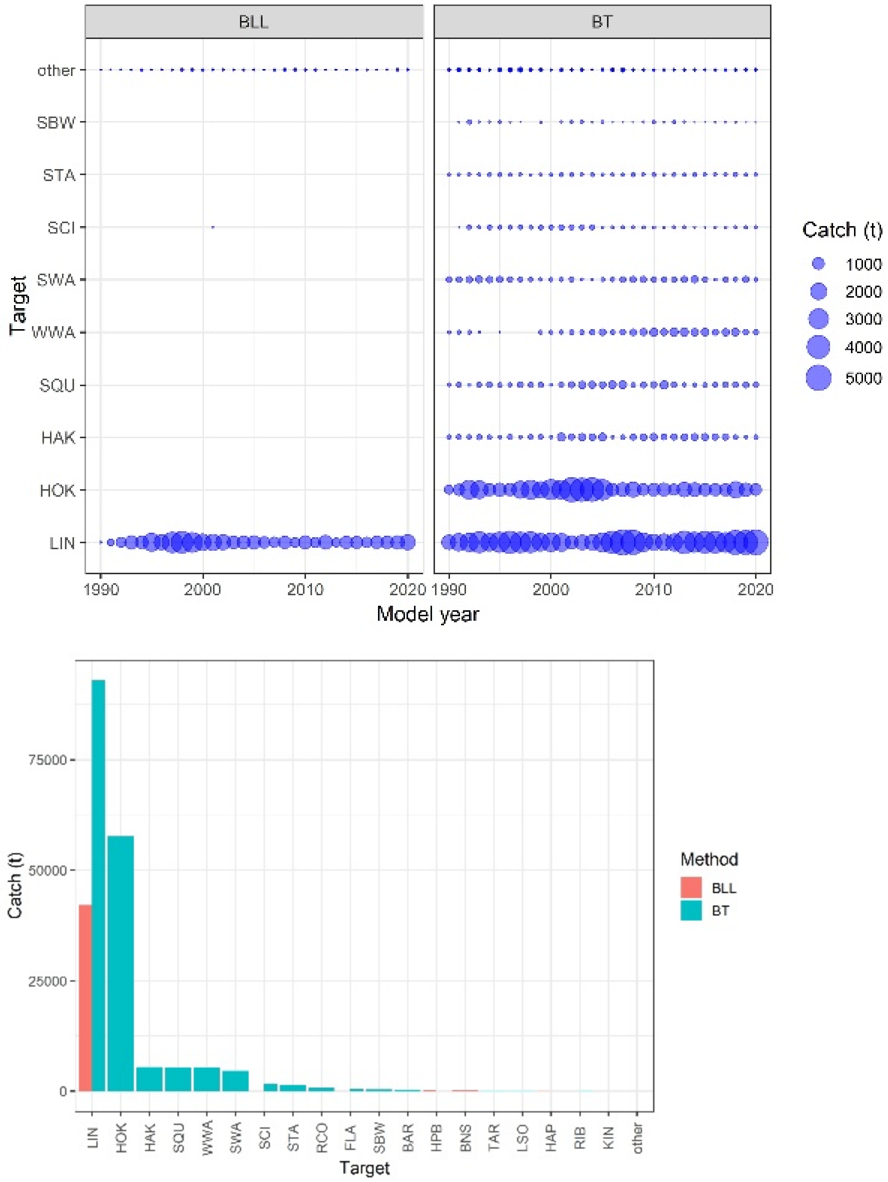


Figure A.4: LIN 5&6 distribution of annual ling catch reported in catch and effort forms by target species for bottom trawl (BT) and bottom longline (BLL) gears separately. Model year starts in September (as opposed to fishing year which starts in October). Target is ling (LIN), hoki (HOK), hake (HAK), squid (SQU), white warehou (WWA), silver warehou (SWA), scampi (SCI), giant stargazer (STA - *Kathetostoma* spp.), red cod (RCO - *Pseudophycis bachus*), flatfish (FLA), southern blue whiting (SBW), barracouta (BAR), hāpuku and bass (HPB - *Polyprion oxygeneios, P. americanus*), bluenose (BNS - *Hyperoglyphe antarctica*), tarakihi (TAR - *Nemadactylus macropterus, Nemadactylus sp.*), lemon sole (LSO - *Pelotretis flavilatus*), hāpuku (HAP - *Polyprion oxygeneios*), ribaldo (RIB - *Mora moro*), kingfish (KIN - *Seriola lalandi*).

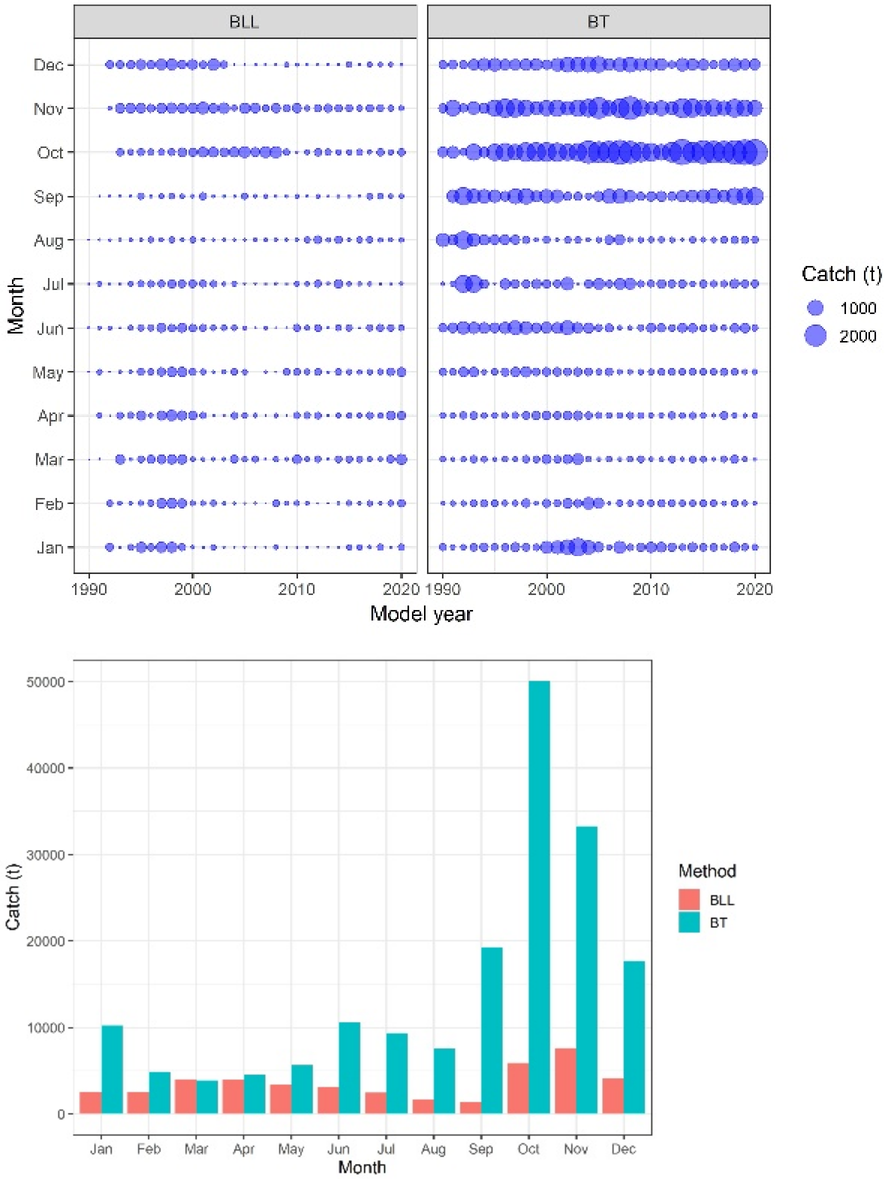


Figure A.5: LIN 5&6 distribution of annual ling catch reported in catch and effort forms by month for bottom trawl (BT) and bottom longline (BLL) gears separately. Model year starts in September (as opposed to fishing year which starts in October).

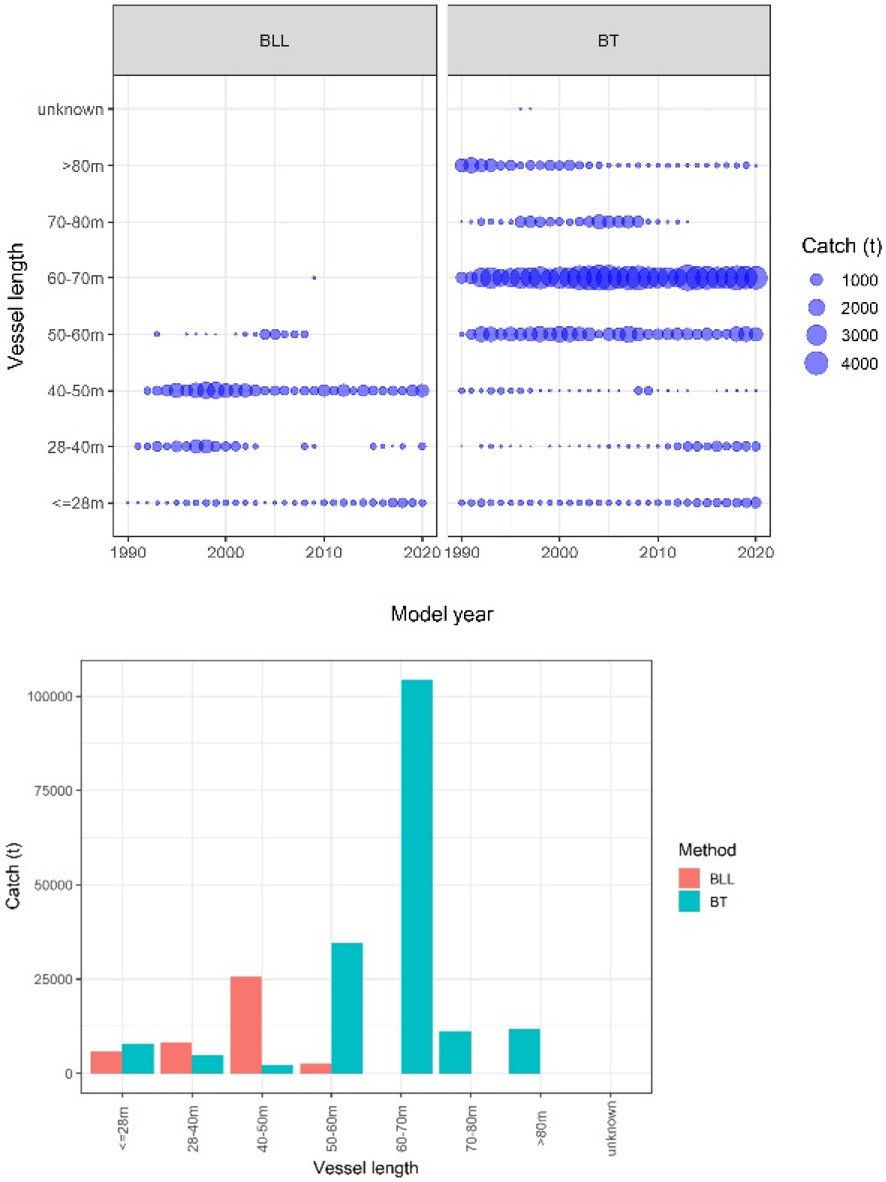


Figure A.6: LIN 5&6 distribution of annual ling catch reported in catch and effort forms by vessel length for bottom trawl (BT) and bottom longline (BLL) gears separately. Model year starts in September (as opposed to fishing year which starts in October).

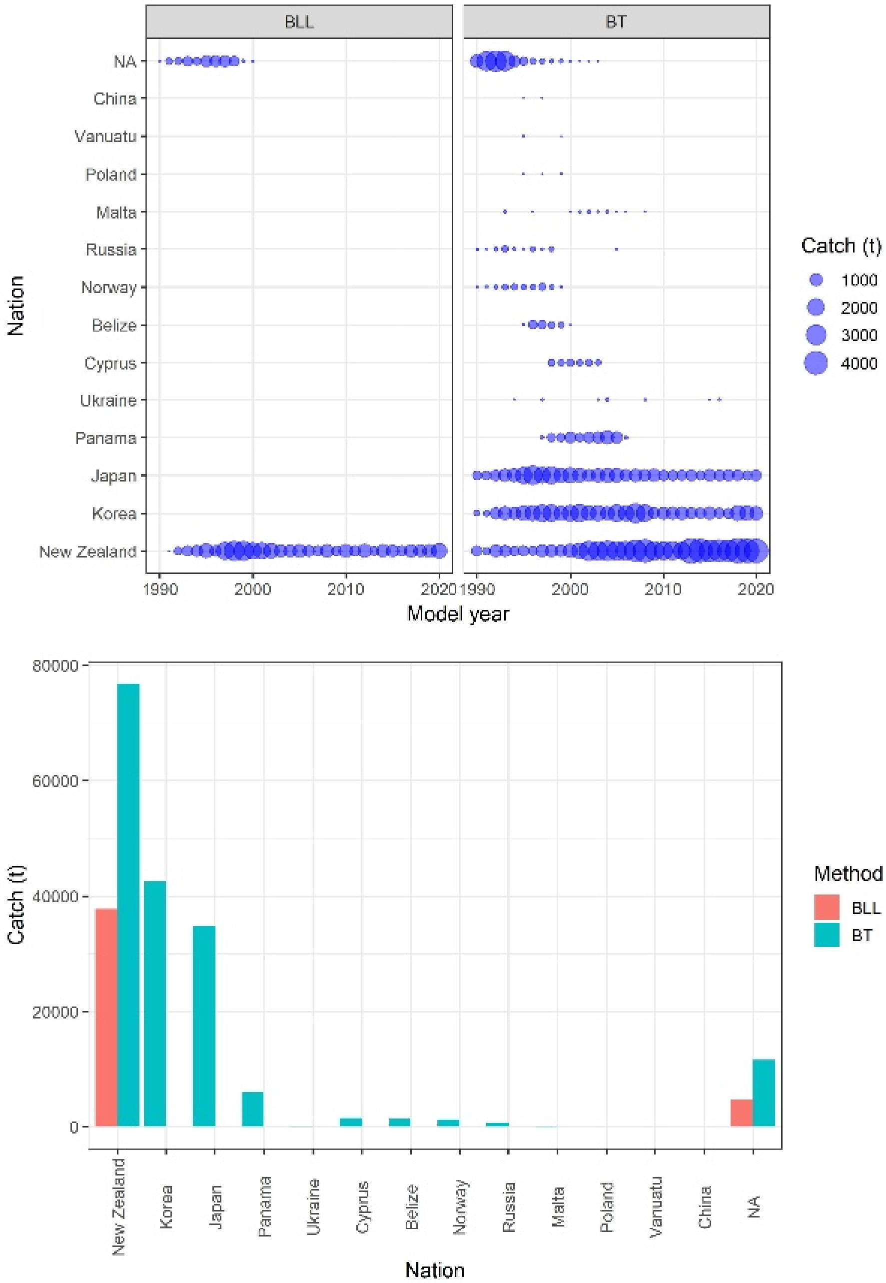


Figure A.7: LIN 5&6 distribution of annual ling catch reported in catch and effort forms by nation for bottom trawl (BT) and bottom longline (BLL) gears separately. Model year starts in September (as opposed to fishing year which starts in October).

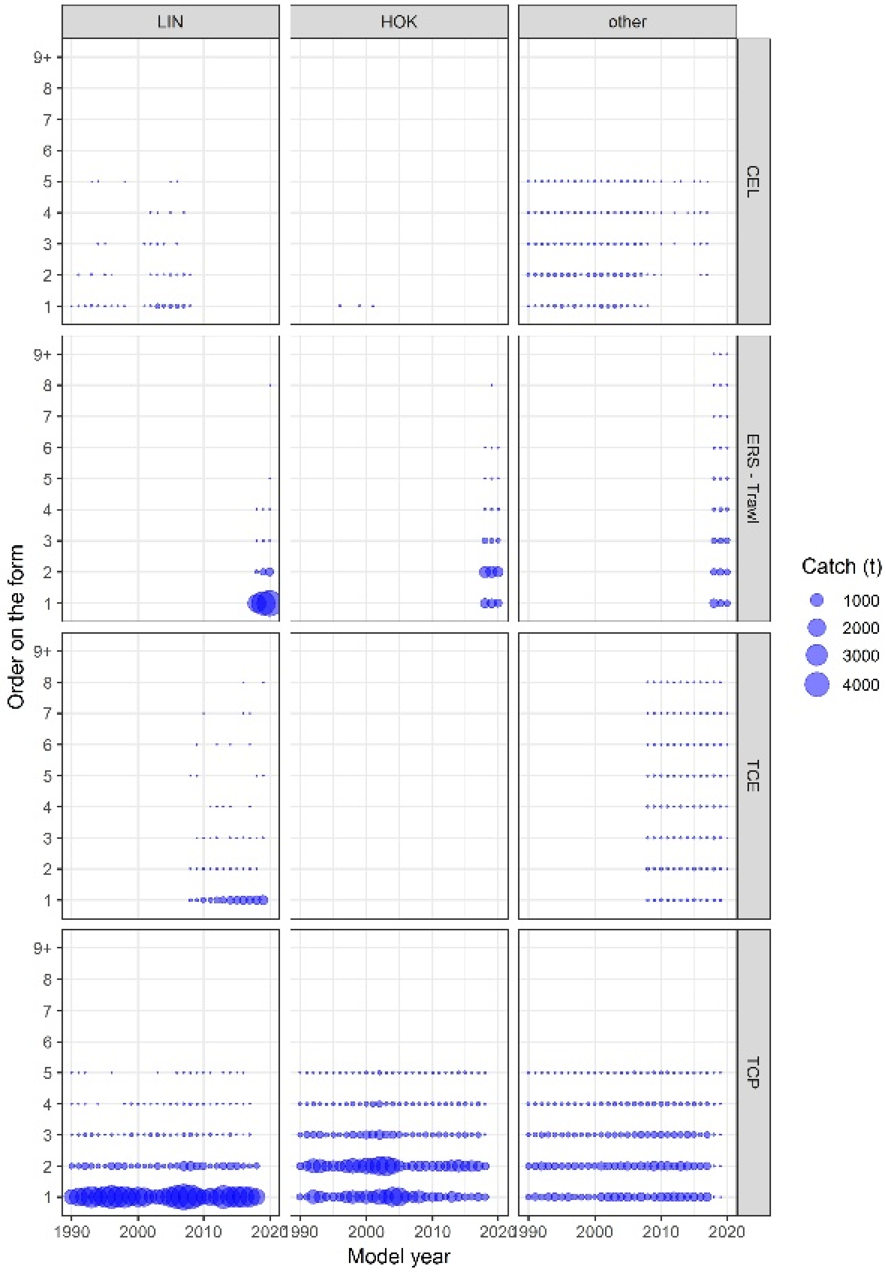


Figure A.8: LIN 5&6 distribution of annual ling catch reported in catch and effort forms by order (where greatest catch is 1) reported in the forms for bottom trawl and major target species (ling – LIN, hoki – HOK, or other).

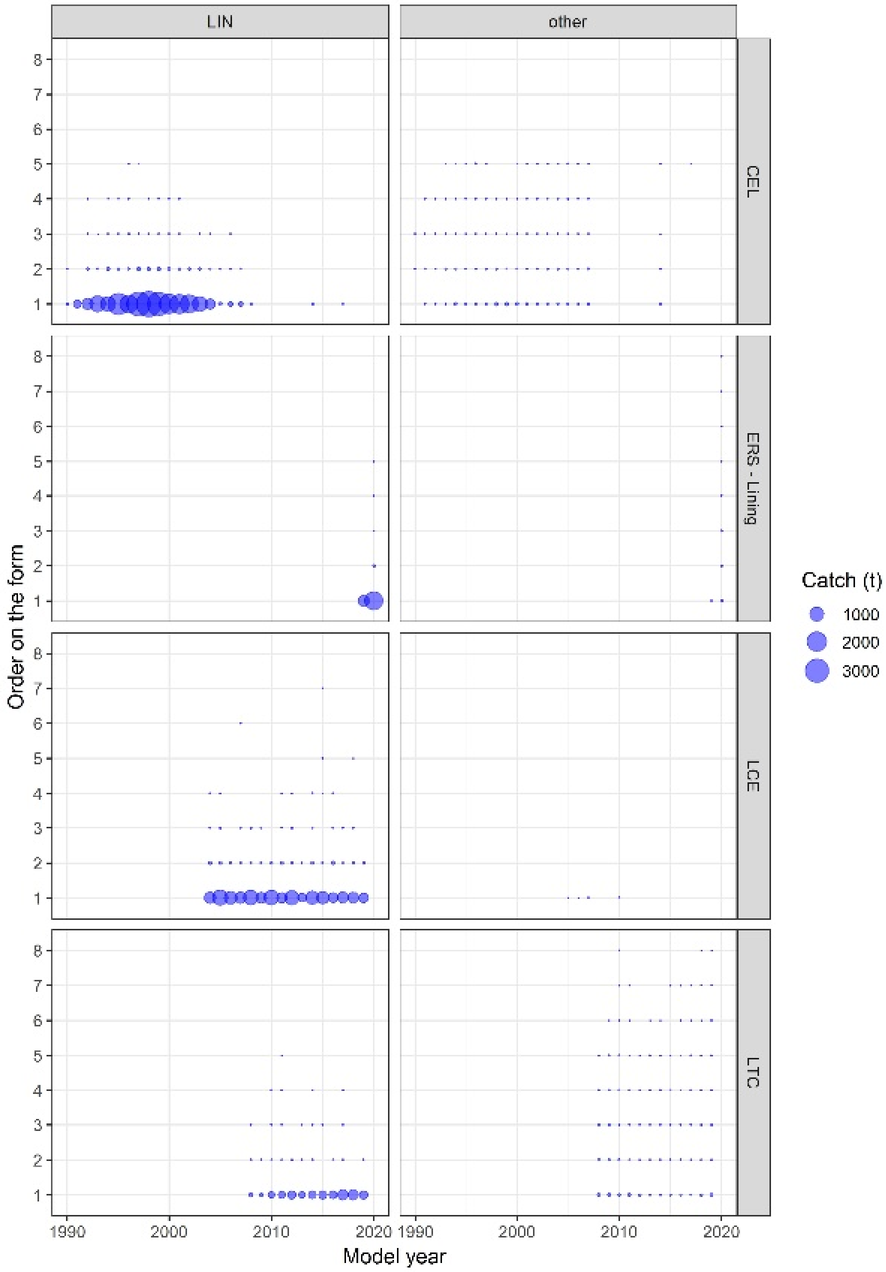


Figure A.9: LIN 5&6 distribution of annual ling catch reported in catch and effort forms by order reported in the forms for longlines gears (where greatest catch is 1) and target species (ling – LIN or other).

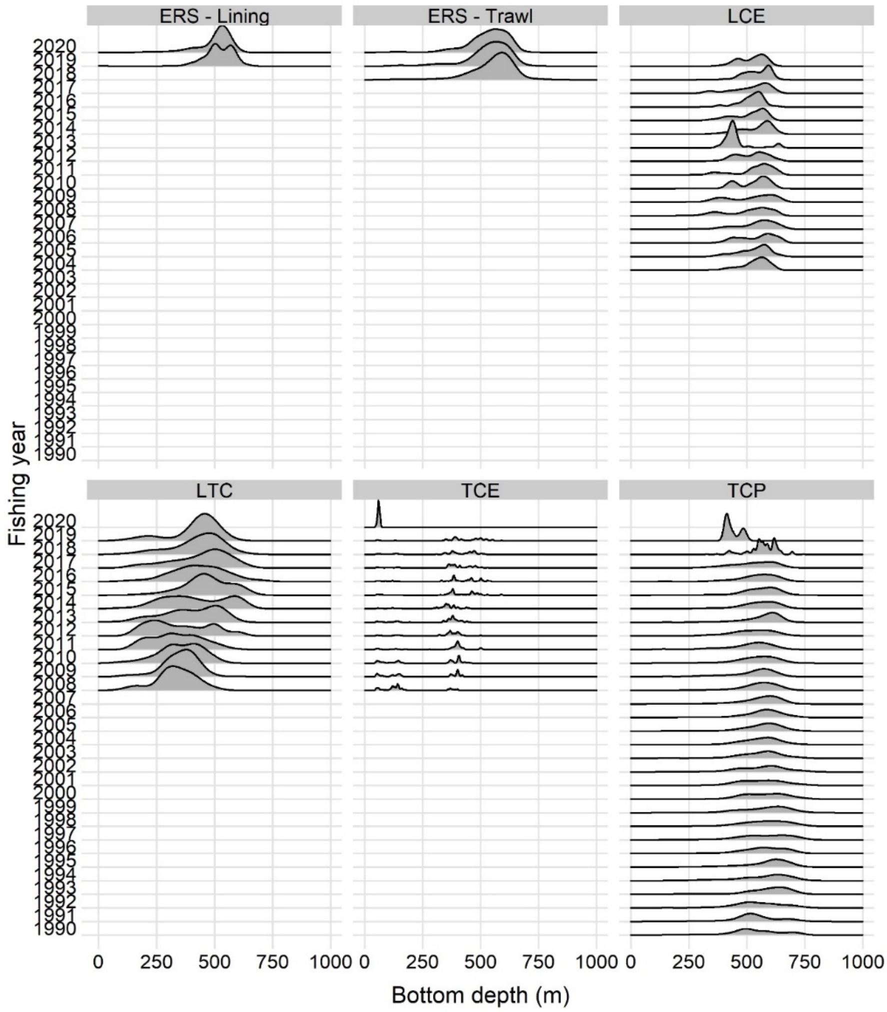
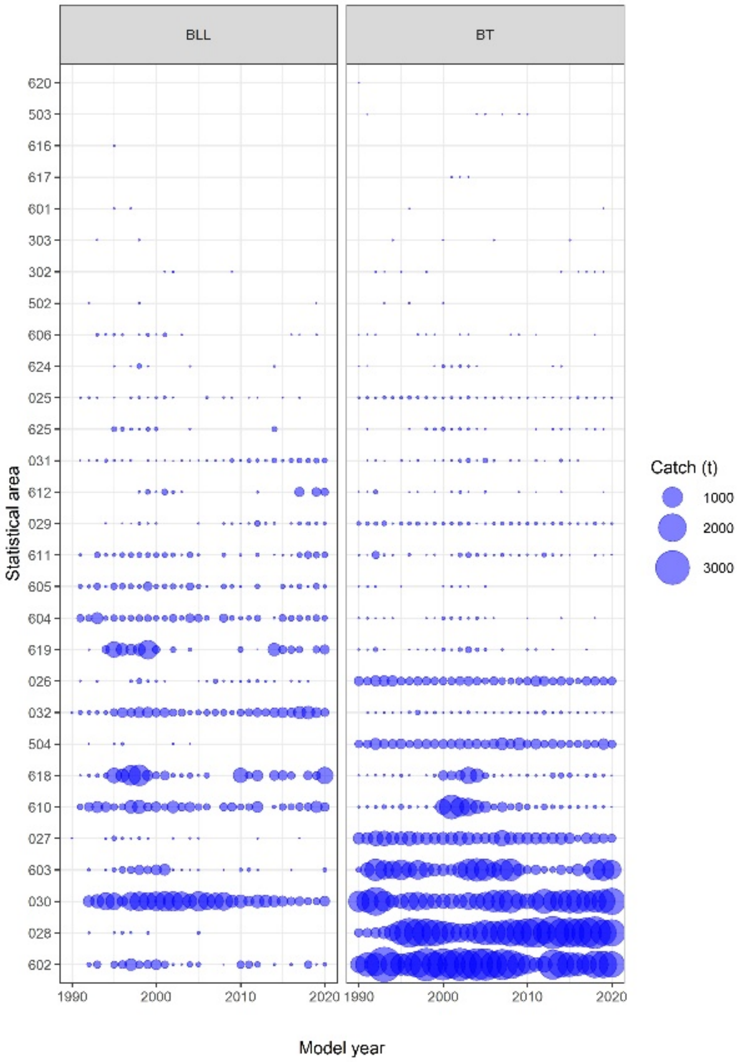


Figure A.10: Catch-weighted LIN 5&6 distribution of bottom depth by fishing year and form type as reported in catch and effort forms. Form type is electronic reporting system return (ERS), lining catch effort return (LCE), trawl catch effort return (TCE) and trawl catch effort and processing return (TCP).



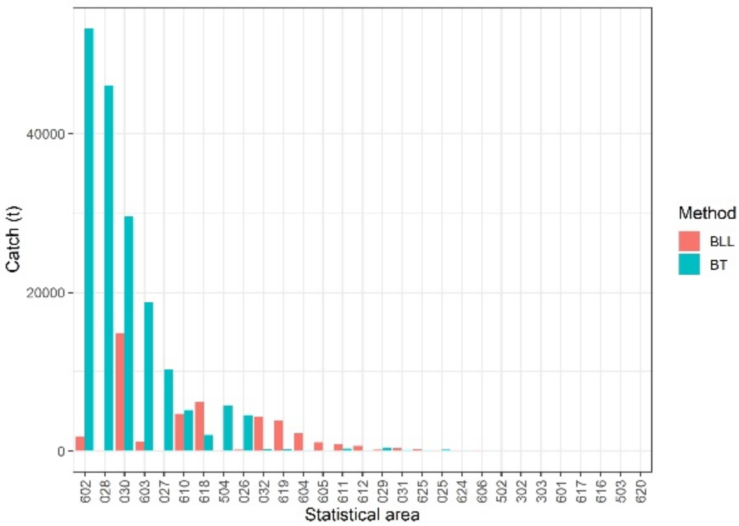


Figure A.11: LIN 5&6 distribution of annual ling catch reported in catch and effort forms by Statistical Area for bottom trawl (BT) and bottom longline (BLL) gears separately. Model year starts in September (as opposed to fishing year which starts in October).

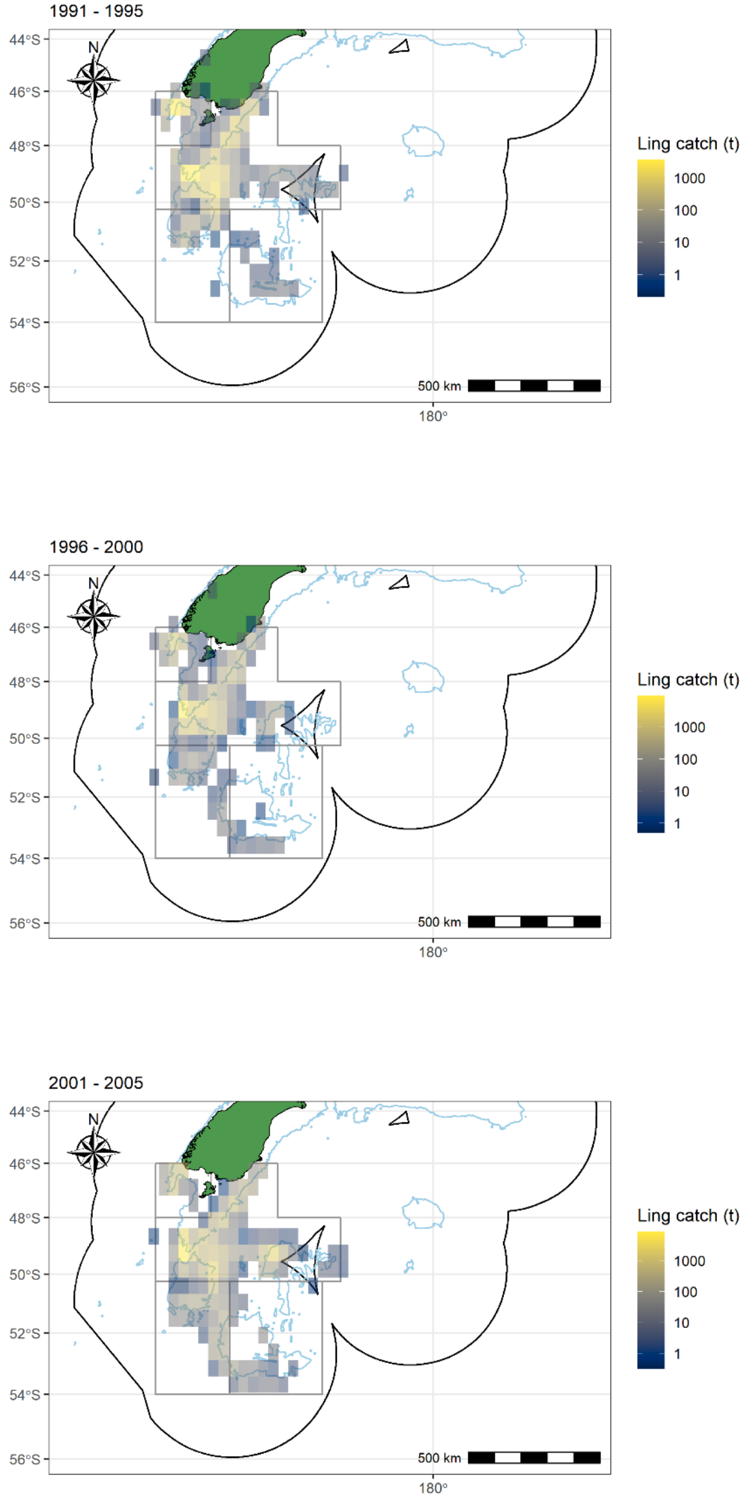


Figure A.12: Distribution of ling catches in QMAs 5 and 6 by bottom trawls between 1991 and 2005. Year ranges are fishing years. The Sub-Antarctic areas historically used to scale up the length frequencies are plotted in grey. Areas are plotted at about 0.5 degree resolution and only where at least three vessels fished in any cell in the period as per confidentiality rules.

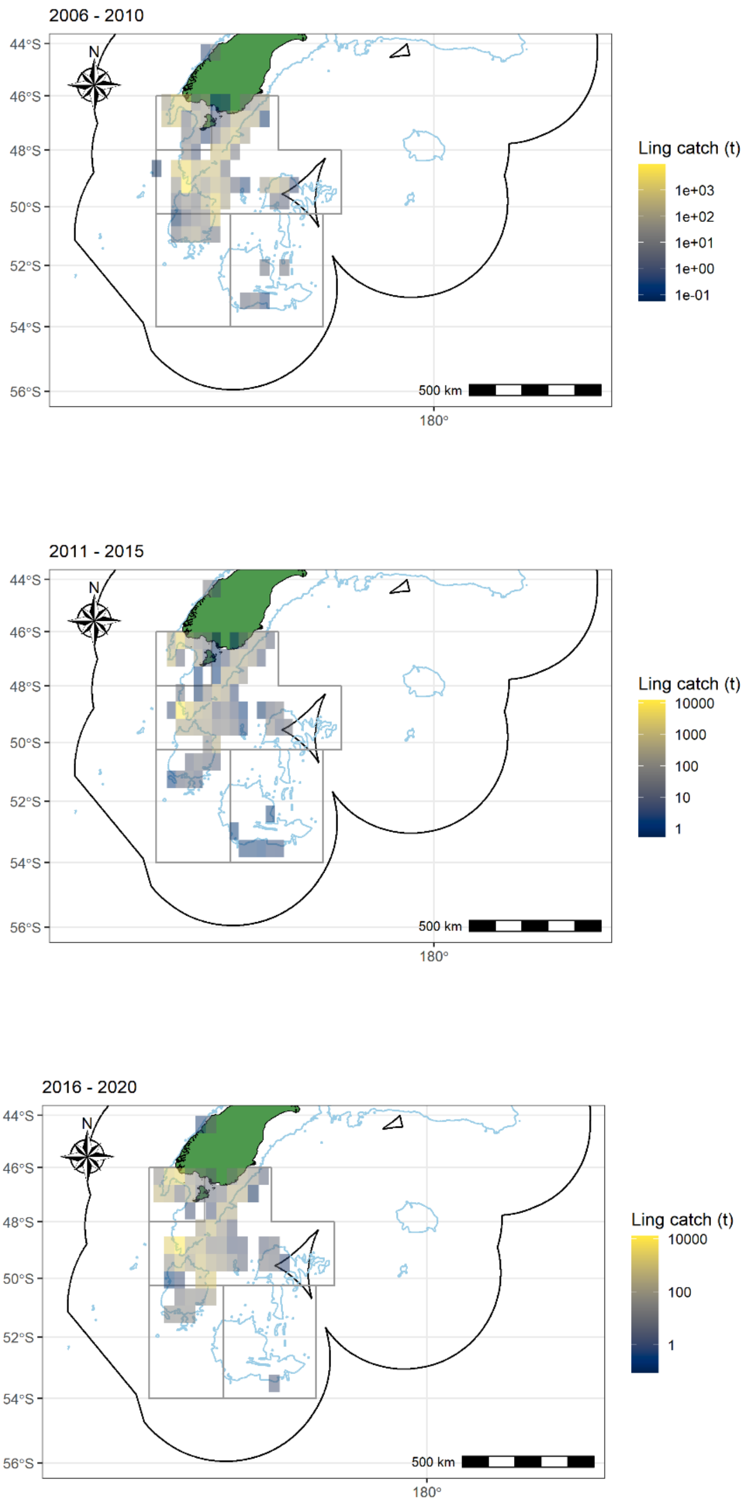


Figure A.13: Distribution of ling catches in QMAs 5 and 6 by bottom trawls between 2006 and 2020. Year ranges are fishing years. The Sub-Antarctic areas historically used to scale up the length frequencies are plotted in grey. Areas are plotted at about 0.5 degree resolution and only where at least three vessels fished in any cell in the period as per confidentiality rules.

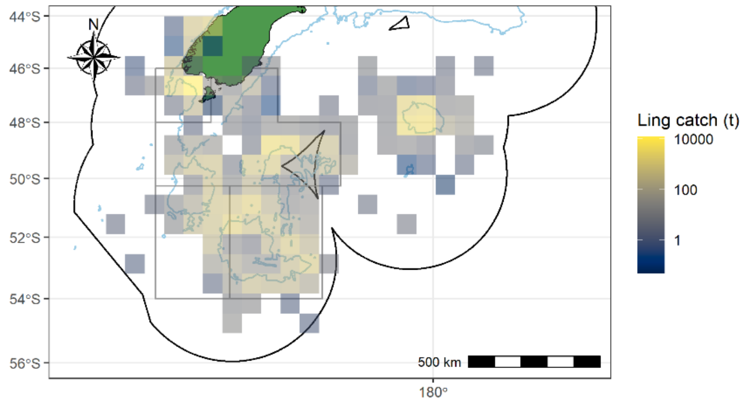
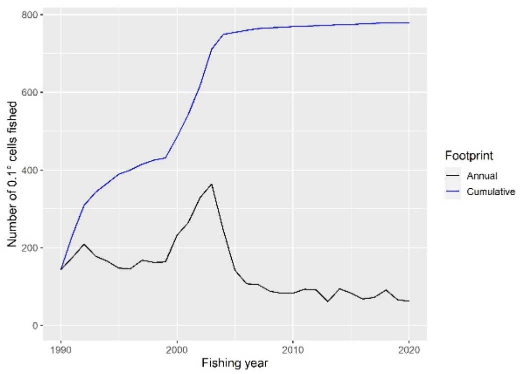


Figure A.14: Distribution of ling catches in QMAs 5 and 6 by longlines between 1991 and 2020. The Sub-Antarctic areas historically used to scale up the length frequencies are plotted in grey. Areas are plotted at about 0.5 degree resolution and only where at least three vessels fished in any cell in the period as per confidentiality rules.

Bottom trawl



Bottom longline

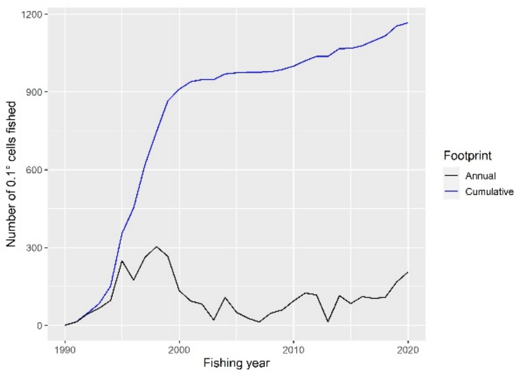
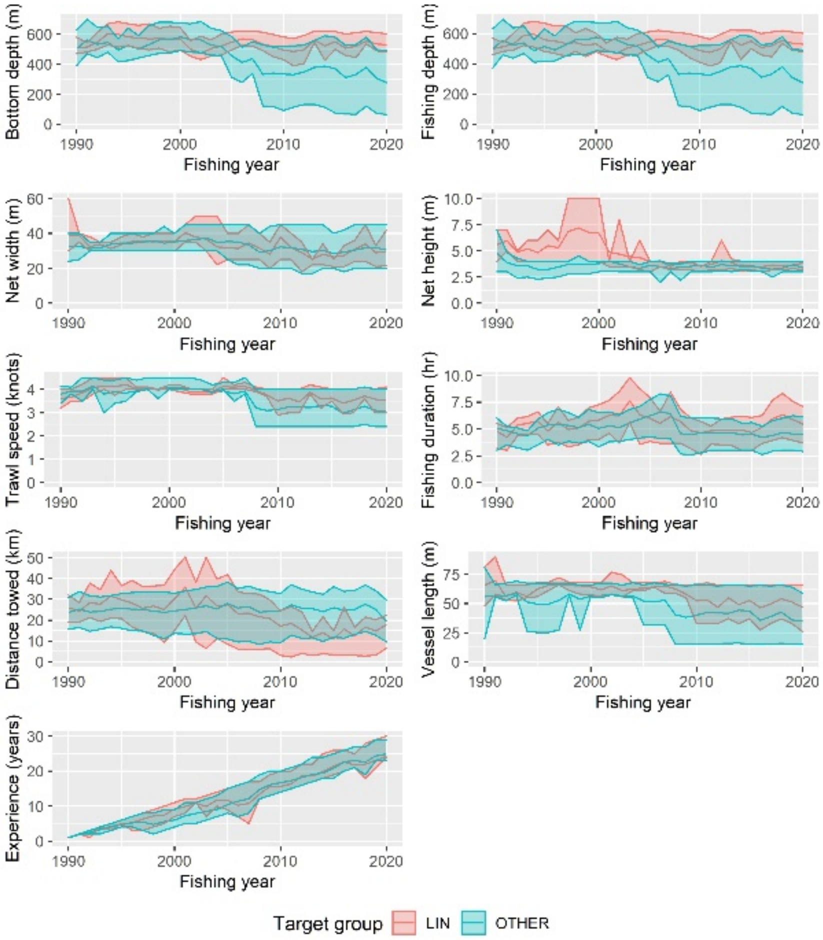


Figure A.15: Spatial distribution of the ling fishery in LIN 5&6: number of cells of 0.1° latitude and longitude fished in any one year and cumulative number of new cells fished over time, using the top 90% of annual effort.

Bottom trawl



Bottom longline

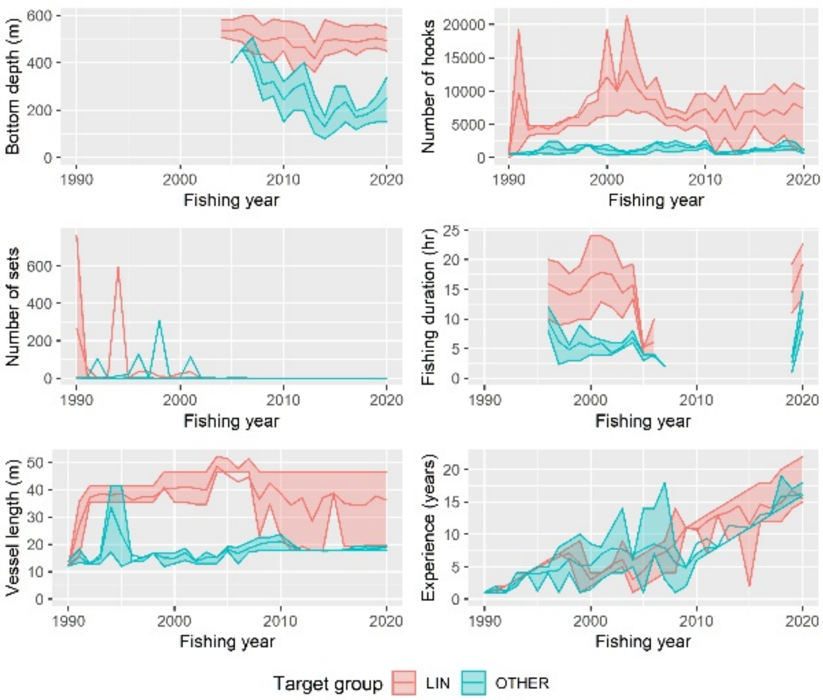


Figure A.16: Change in effort characteristics over time by target species of the bottom trawl (top) and longline (bottom) ling fisheries in LIN 5&6. Median and interquartile range are showed.

APPENDIX B – SPATIAL ANALYSIS

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

Variable	Type	Description
Month	Categorical	Month of the year
Week of year	Numeric	Week of the year, starting on 1 September
Day of year	Numeric	Julian date, starting at 1 on 1 September
Stock	Categorical	LIN 5&6 or LIN 6B
FMA	Categorical	LIN 5 or LIN 6
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
Bottom depth	Numeric	Depth of the bottom in metres
Spawning	Categorical	Whether during spawning season (September to December) or not
Fishing duration	Numeric	Duration of the tow in hours

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	2 643 216	2 643 639	Worst model
Length ~ Intercept + Year + Month + Sex + Space	2 591 957	2 592 441	Chosen model
Length ~ Intercept + Year + Month × Sex + Space	2 590 985	2 591 441	
Length ~ Intercept + Year + Month × Sex + Method + Space	2 642 342	2 642 055	
Length ~ Intercept + Year + Month × Sex + s(Depth) + Space	2 590 552	2 591 041	
Length ~ Intercept + Year + Month + Sex + (Space × Sex)	2 588 132	2 588 699	
Length ~ Intercept + Year + Month × Sex + (Space × Sex)	2 591 833	2 592 120	
Length ~ Intercept + Month + Sex + (Space * Block)	2 570 091	2 571 476	
Length ~ Intercept + Space	2 643 216	2 643 639	
Length ~ Intercept + Year + Month + Sex + Space	2 591 957	2 592 441	Best model

Table B.3: Model comparison deviance information criterion (DIC) and Watanabe-Akaike information criterion (WAIC) for each of the AF 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
Age ~ Intercept + Space	122 980	123 784	Worst model
Age ~ Intercept + Year + Month + Sex + Space	122 487	123 237	Chosen model
Age ~ Intercept + Year + Month × Sex + Space	122 465	123 226	
Age ~ Intercept + Year + Month × Sex + Method + Space	122 409	123 171	
Age ~ Intercept + Year + Month × Sex + s(Depth) + Space	122 419	123 183	
Age ~ Intercept + Year + Month + Sex + (Space × Sex)	121 594	122 737	
Age ~ Intercept + Year + Month × Sex + (Space × Sex)	121 558	122 697	
Age ~ Intercept + Month + Sex + (Space * Block)	121 113	122 236	Best model

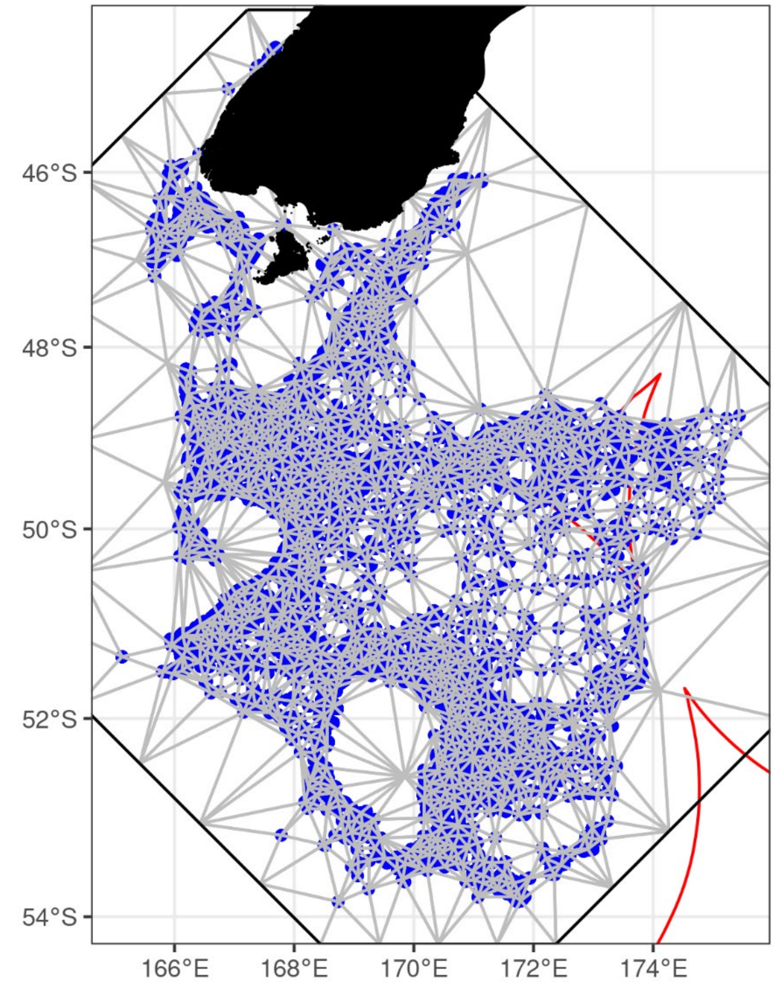


Figure B.1: Spatial mesh for ling spatial-temporal models showing the locations of data (blue points), the spatial mesh (grey lines), the extent of the spatial model (thick black lines), and the New Zealand EEZ (red lines).

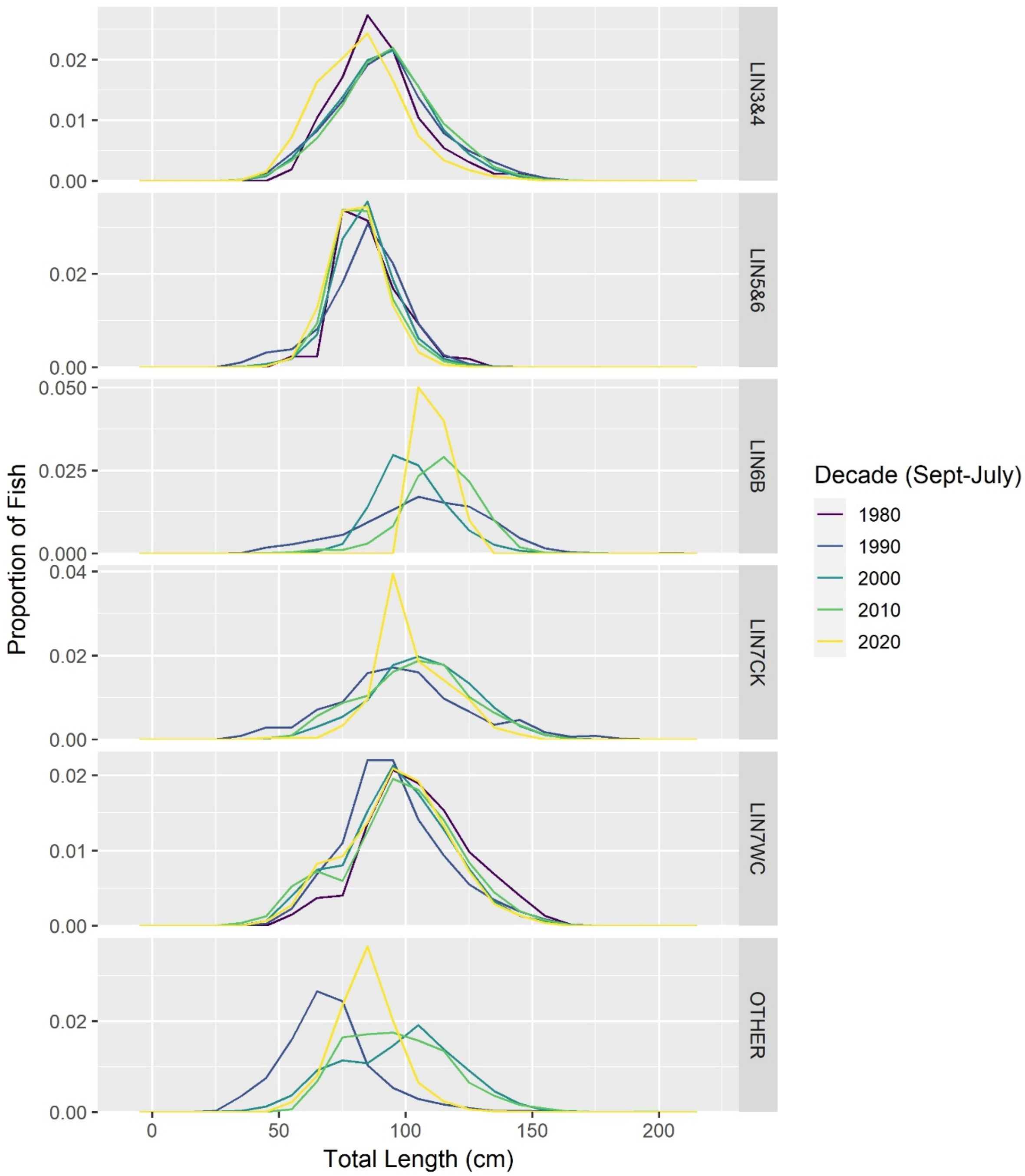


Figure B.2: Unscaled length frequency distribution of ling by biological stock and decade, based on observer data. 1990 represents 1990 to 1999 and 2020 represents the year 2020 only.

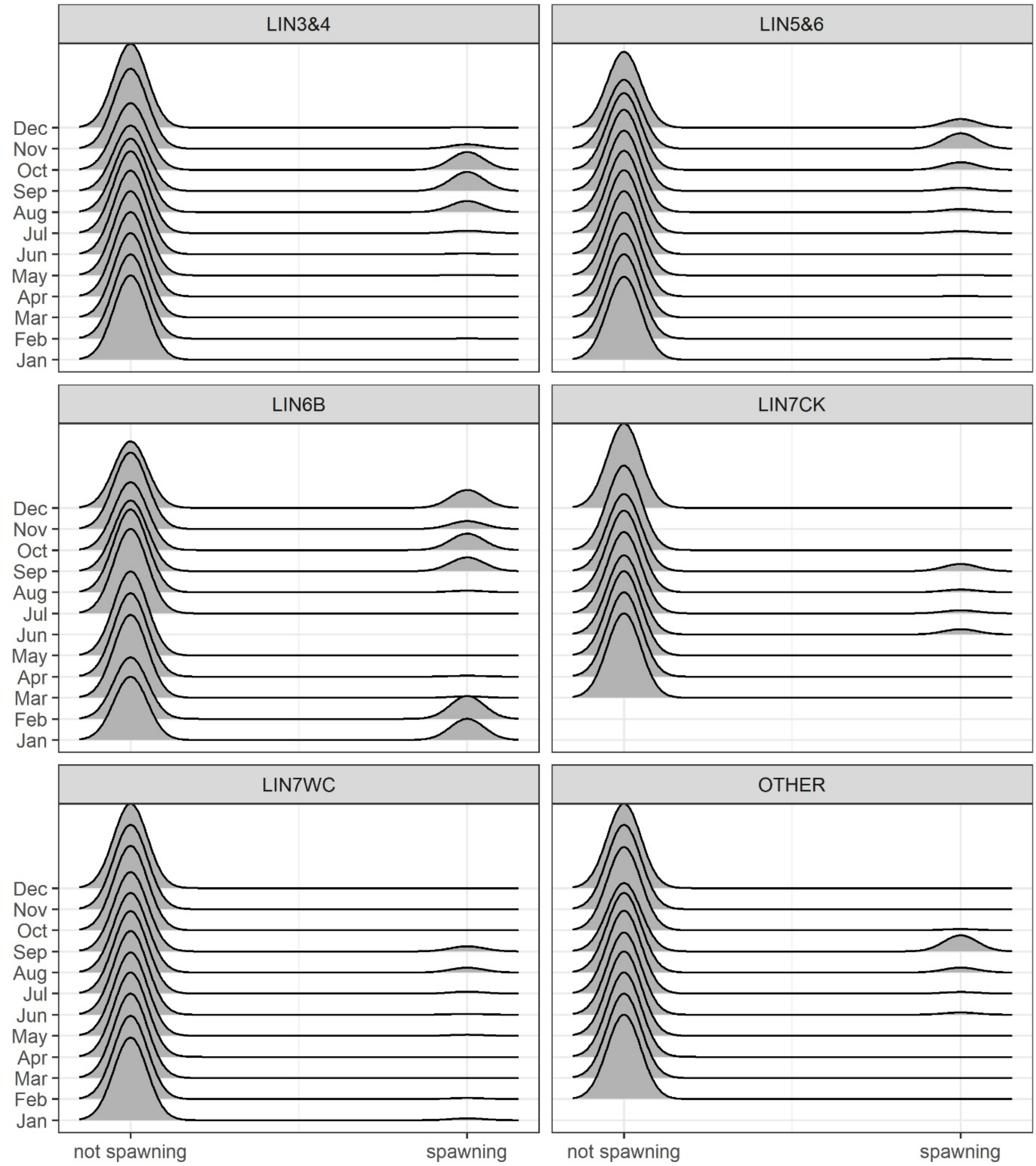


Figure B.3: Proportion of ling spawning by month for all years combined in the different ling stocks based on observer data, spawning is defined as stage 4 or 5.

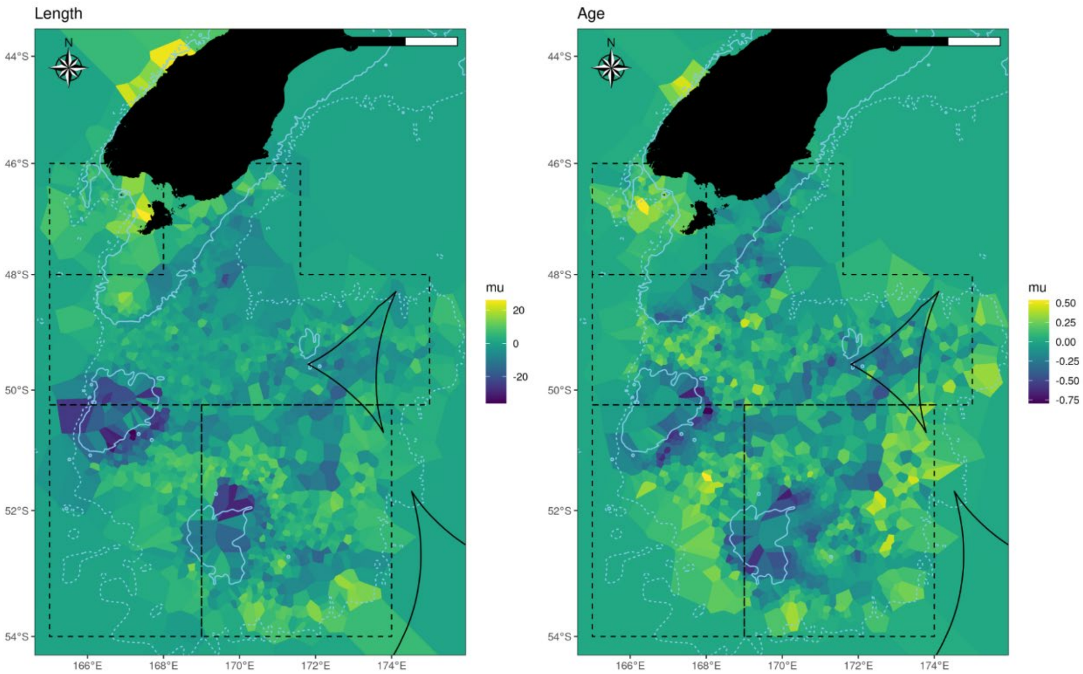


Figure B.4: The spatial effect for the chosen model of mean length (length ~ intercept + year + month + sex + space) and the chosen model of mean age (age ~ intercept + year + month + sex + space).

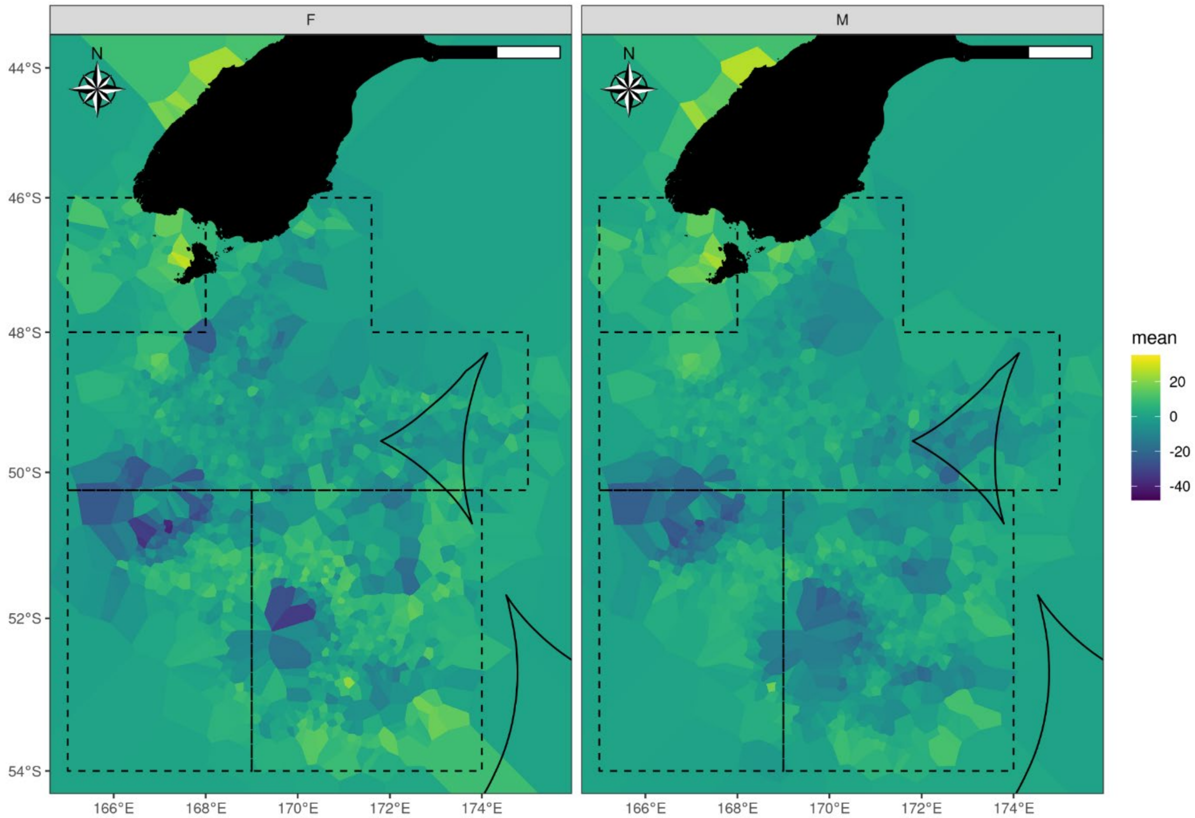


Figure B.5: The spatial effect for the sex-specific model of mean length (length ~ intercept + year + month + sex + (space × sex)). Females (F) and males (M) are presented in the left panel and right panels, respectively.

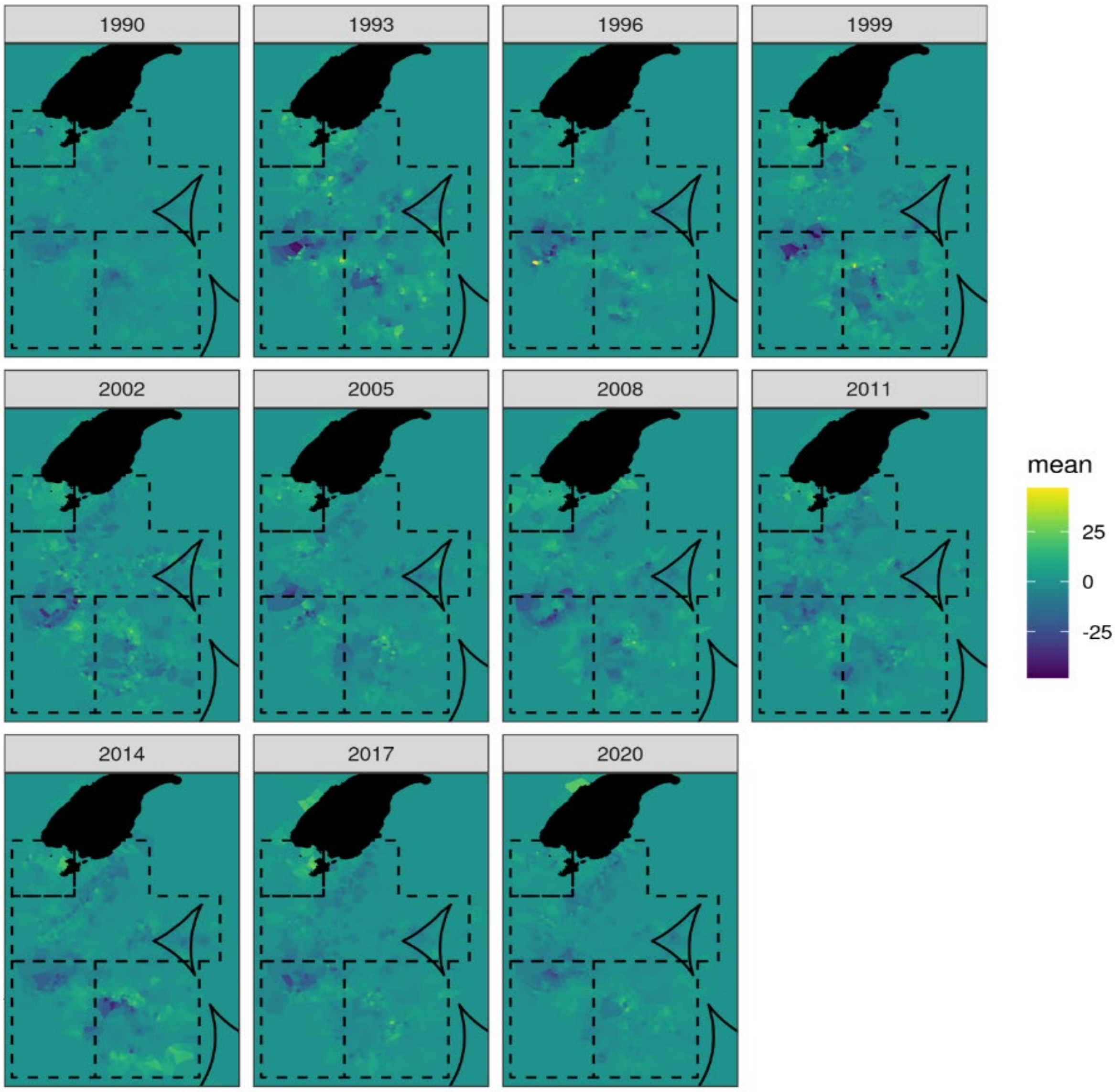


Figure B.6: The spatial effect for the time block model of mean length (length ~ intercept + month + sex + (space × block)). The year represents a three-year block where 2017 refers to fishing years from 2015 to 2017 and 2020 refers to fishing years from 2018 to 2020.

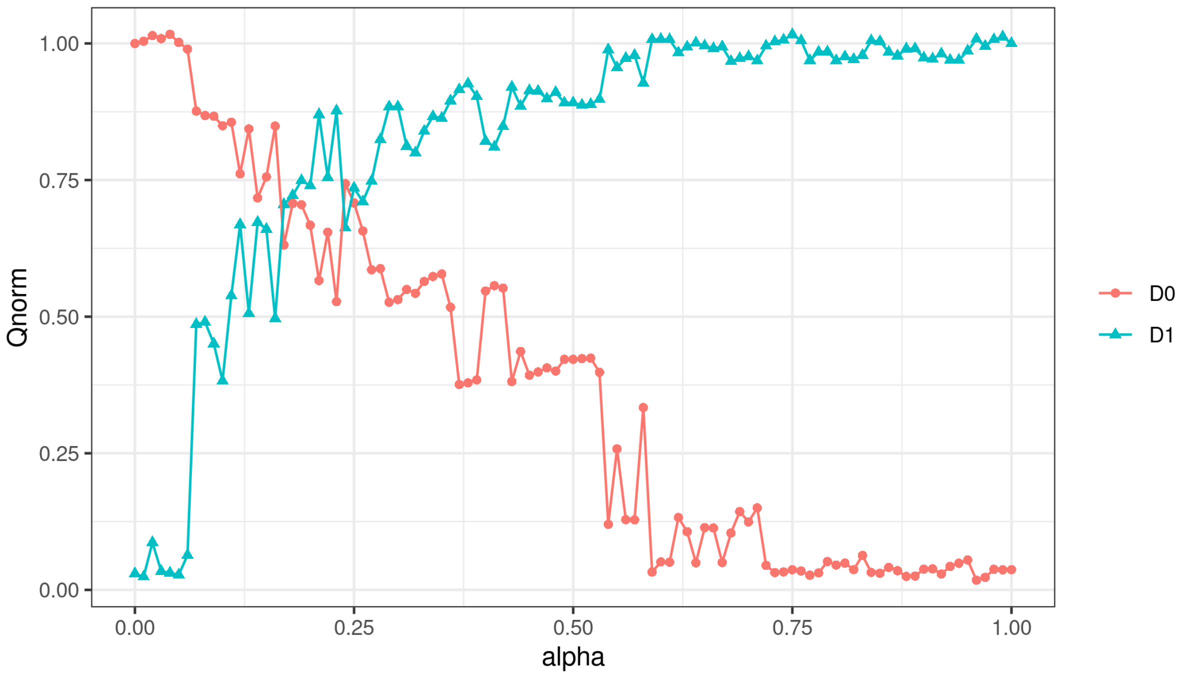


Figure B.7: The proportion of explained inertia of the data (D0) and distance (D1) partitions (in K = 4 clusters) for different values of the mixing parameter alpha for the chosen model of mean length (length ~ intercept + year + month + sex + space).

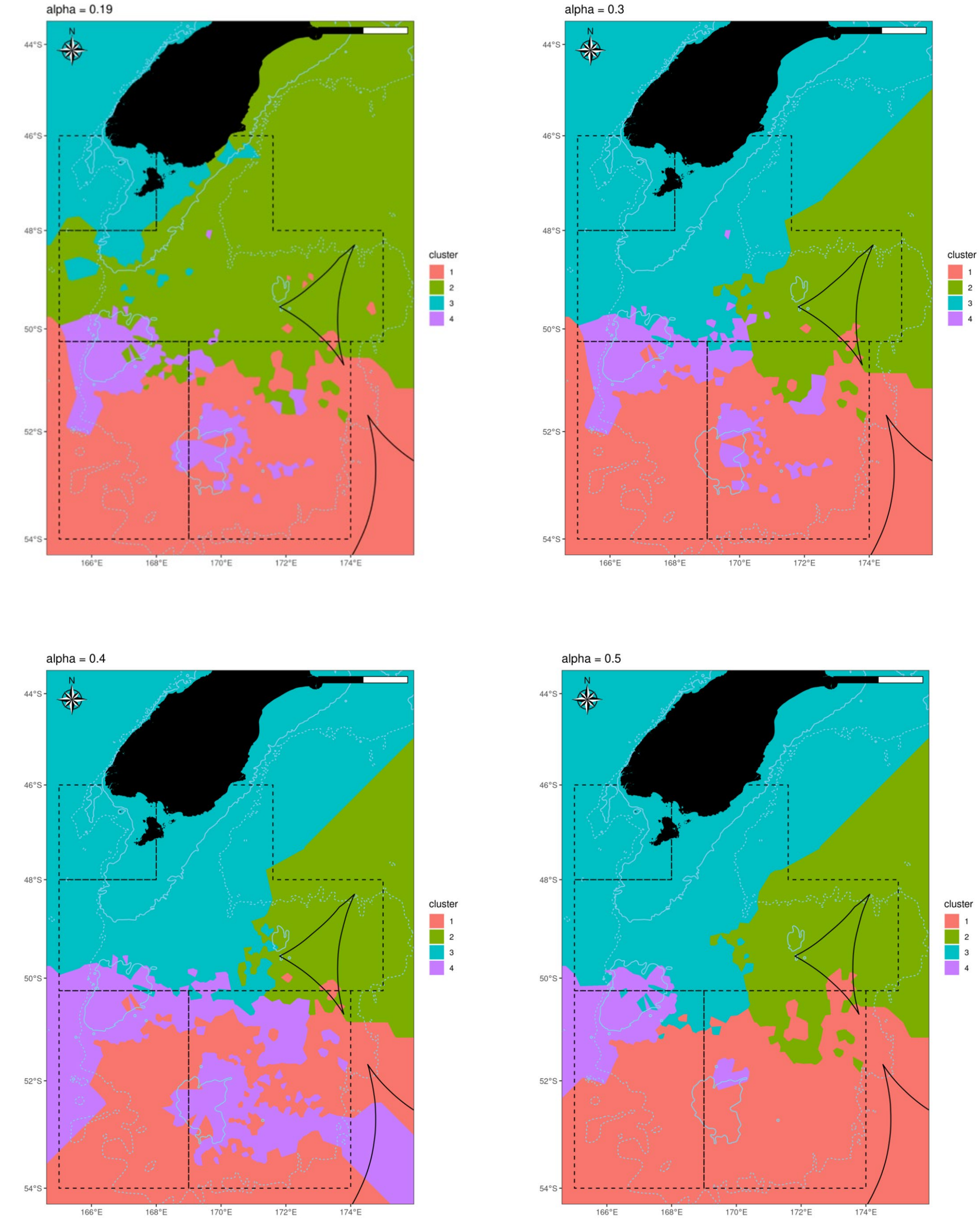


Figure B.8: Clusters (for K = 4 clusters) for different alpha levels for the chosen model of mean length (length ~ intercept + year + month + sex + space).

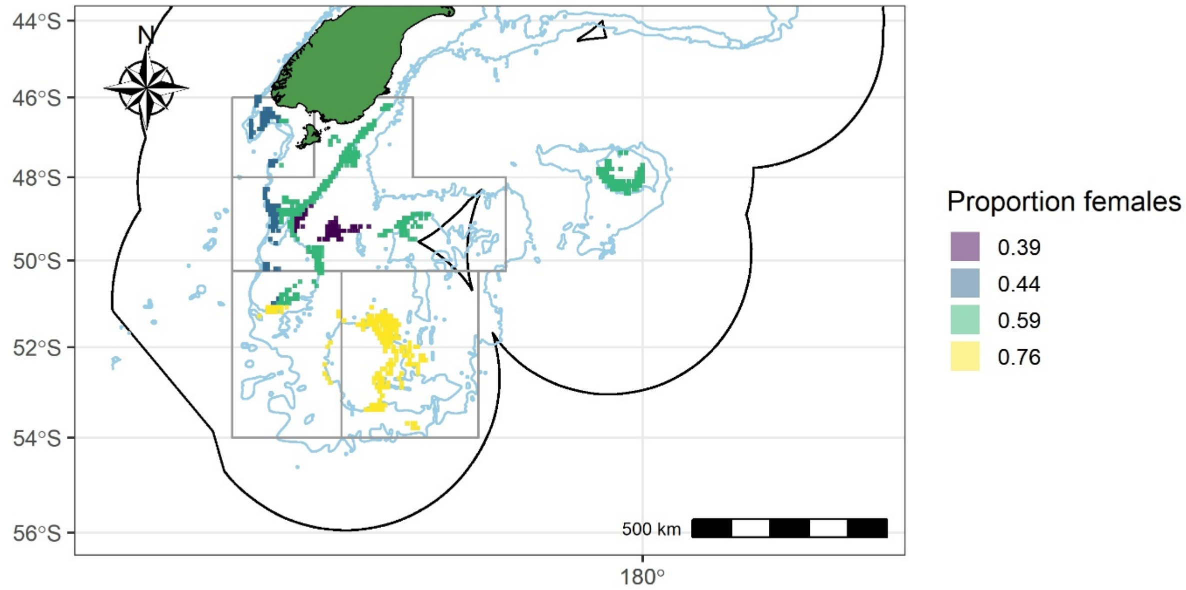
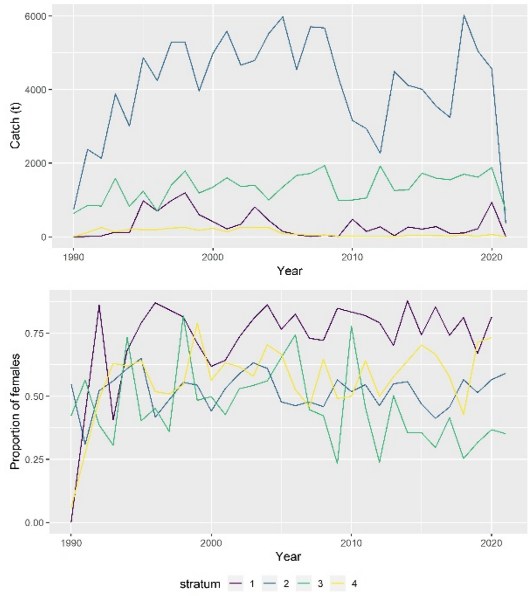
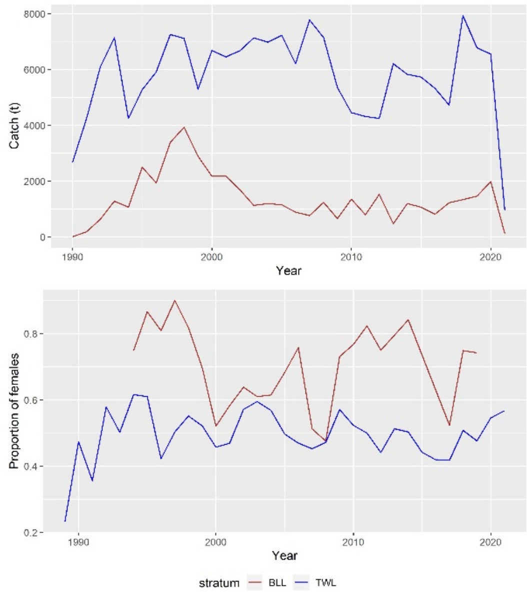


Figure B.9: Potential fisheries strata based on a tree-regression analysis of the mean proportion of females per fishing event. The strata are a combination of statistical area and longline or trawl fleet. Locations are rounded to 0.1 degree and shown only where data are available for three or more vessels.

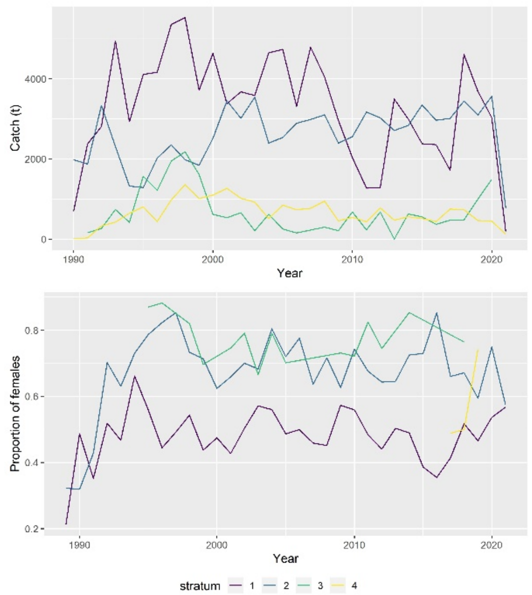
Option 1: 4 fisheries irrespective of method or time of year.



Option 2a: bottom trawl and longline.



Option 2b: 4 fisheries based on statistical area and gear type.



Option 3: bottom trawl, spawning and non-spawning longline with specific times of year.

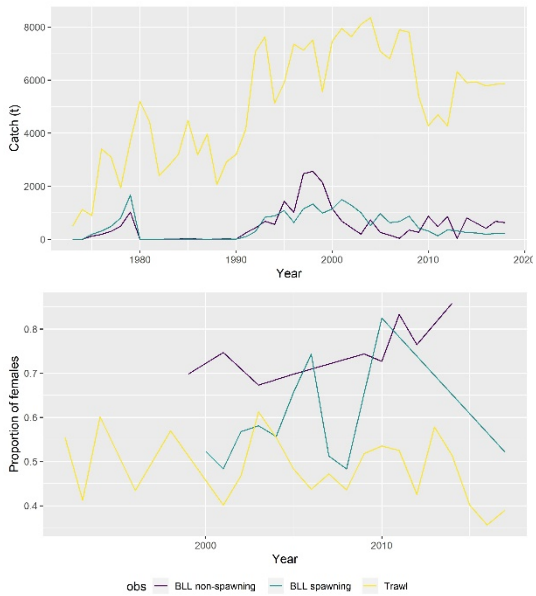
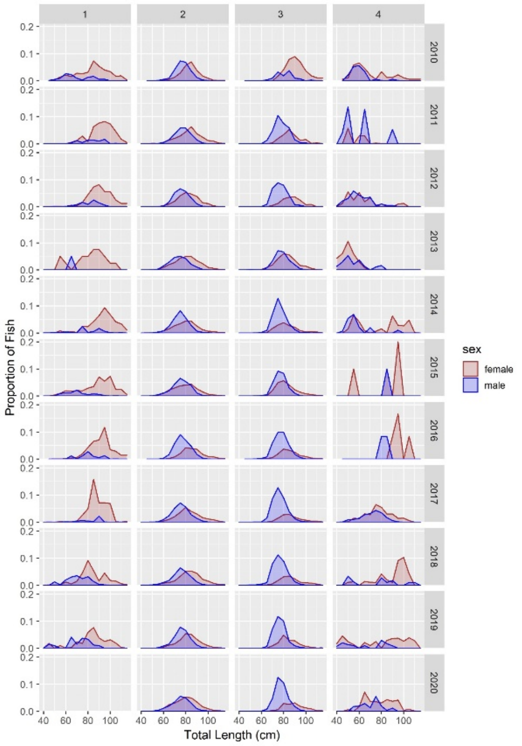
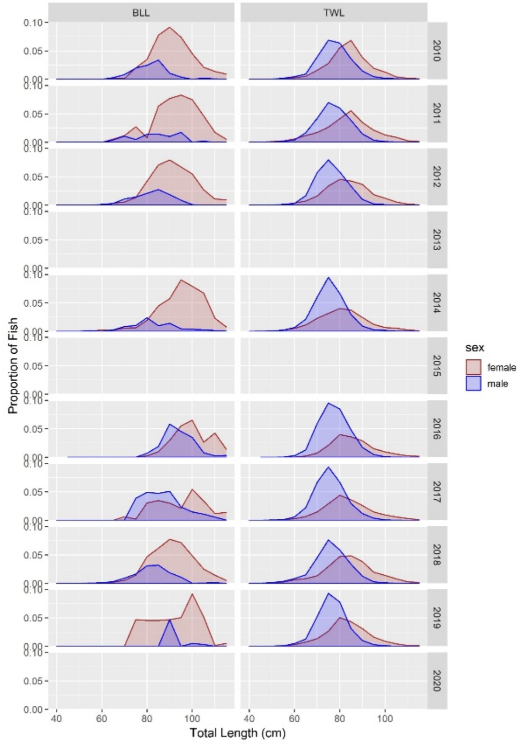


Figure B.10: Trend of catch over time and proportion of females of the four potential fisheries strata. Year is model year (2020 is 1st September 2019 to 31st August 2020).

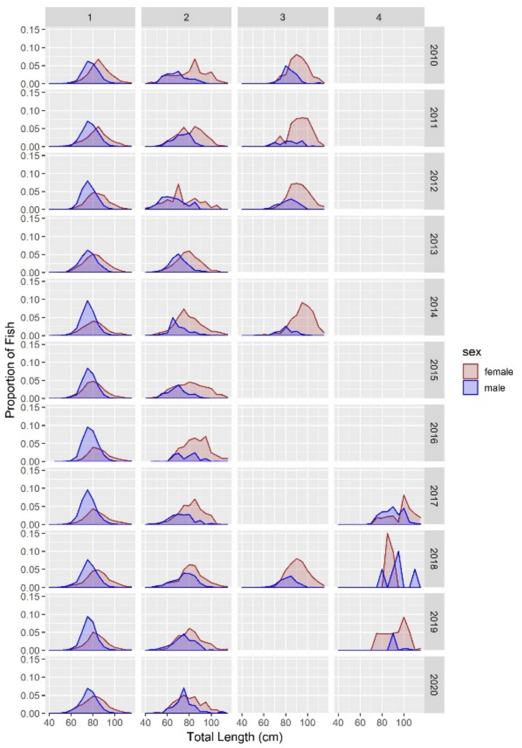
Option 1: 4 fisheries irrespective of method or time of year.



Option 2a: bottom trawl and longline.



Option 2b: 4 fisheries based on statistical area and gear type.



Option 3: bottom trawl, spawning and non-spawning longline with specific times of year.

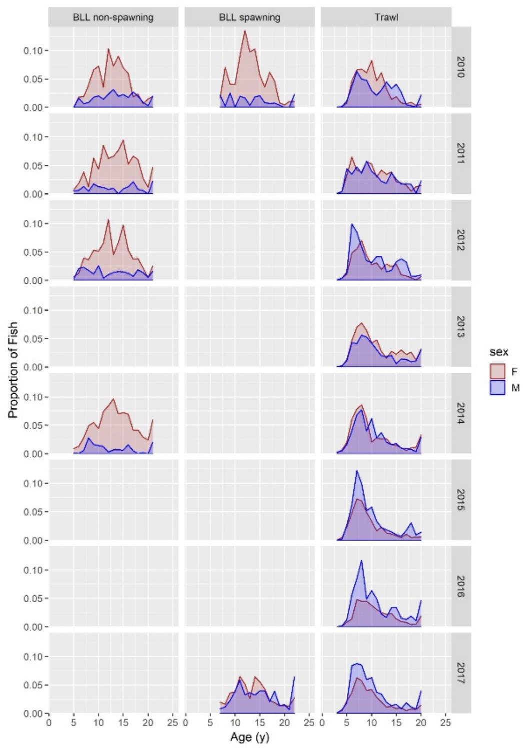


Figure B.11: Trend of scaled age frequency distributions over time of the four potential fisheries strata. Year is model year (2020 is 1st September 2019 to 31st August 2020).

APPENDIX C – UPDATE OF BIOLOGICAL PARAMETERS

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

Sex	Parameter	Horn (2005)	Edwards (2017)	This analysis
Male	*a*	2.08E-06	2.06E-6	2.13E-06
	b	3.190	3.19	3.179
Female	*a*	1.28E-06	1.28E-6	1.32E-06
	b	3.303	3.30	3.293

Table C.2: Number of age data available for this analysis from the database using both survey and observer data, and reported in 2019 from sources unknown (Horn & Sutton 2019). Year is fishing year.

			Females		Males		Total	
Year	Origin	Type	2019	Database	2019	Database	2019	Age
1992	SOP	trawl	667	349	437	202	1104	551
1994	SOP	trawl	357	348	256	247	613	595
1996	SOP	trawl	297	274	366	331	663	605
1998	SOP	trawl	302	292	274	269	576	561
1999	SOP	longline	428	421	214	208	642	629
2000	SOP	longline	278	270	242	234	520	504
2001	SOP	longline	378	378	234	234	612	612
2001	SOP	trawl	351	351	247	244	598	595
2002	SOP	longline	284	279	197	189	481	468
2002	SOP	trawl	327	326	264	268	591	594
2003	SOP	longline	580	579	339	326	919	905
2003	SOP	trawl	625	601	434	401	1059	1002
2004	SOP	trawl	337	332	246	242	583	574
2005	SOP	longline	486	486	202	197	688	683
2006	SOP	longline	345	341	108	105	453	446
2006	SOP	trawl	305	295	288	279	593	574
2007	SOP	longline	217	219	191	189	408	408
2007	SOP	trawl	382	352	225	248	607	600
2008	SOP	longline	62	58	68	66	130	124
2008	SOP	trawl	353	349	229	224	582	573
2009	SOP	longline	196	193	61	52	257	245
2009	SOP	trawl	324	324	245	247	569	571
2010	SOP	trawl	336	387	226	254	562	641
2011	SOP	longline	267	262	60	51	327	313
2011	SOP	trawl	279	221	236	205	515	426
2012	SOP	longline	320	316	109	104	429	420
2012	SOP	trawl	316	319	260	259	576	578
2013	SOP	trawl	317	334	286	315	603	649
2014	SOP	longline	258	253	57	47	315	300
2014	SOP	trawl	311	275	232	191	543	466
2015	SOP	trawl	363	540	264	325	627	865
2016	-	longline	-	29	-	29	-	58
2016	SOP	trawl	306	134	307	263	613	397
2017	SOP	longline	160	129	144	118	304	247
2017	SOP	trawl	404	443	344	380	748	823
2018	SOP	longline	531	521	136	126	667	647
2018	SOP	trawl	358	286	316	234	674	520
2019	-	trawl	-	354	-	254	-	608

Table C.3: 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}	88.8	97.33	92.0	95.9
	k	0.295	0.16	0.198	0.136
	t_o	0.06	-1.16	-0.42	-2.92
Female	L_{inf}	107.3	116.61	111.8	113.0
	k	0.220	0.12	0.137	0.128
	t_o	0.01	-1.3	-0.83	-1.27
Both	CV	–		0.08	0.08

Table C.4: Schnute growth parameters calculated in this analysis.

Sex	Parameter	This analysis	
		All ages	Ages 5+
Male	$y1$	0.00	6.74
	$y2$	90.6	90.8
	a	0.167	0.134
	b	1.667	2.075
Female	$y1$	0.01	0.110
	$y2$	105.8	105.9
	a	0.102	0.089
	b	1.722	1.933
Both	$A1$	1	1
	$A2$	20	20
	CV	0.08	0.07

Table C.5: The leave-one-out information criterion (LOO IC) for the von Bertalanffy and monotonic model runs (smaller LOO IC suggests a more parsimonious model).

	LOO IC	
Model	Female	Male
von Bertalanffy	82 256	50 685
Monotonic	82 065	50 526

Table C.6: Cumulative proportion of growth by month estimated using the mean age at length growth model. Month 9 = September.

Month	Female	Male
9	0.000	0.000
10	0.035	0.046
11	0.043	0.060
12	0.051	0.069
1	0.102	0.227
2	0.205	0.440
3	0.426	0.542
4	0.493	0.682
5	0.509	0.705
6	0.528	0.752
7	0.631	0.860
8	1.000	1.000

Table C.7: Expected length at age (calculated for month 10 - October) using the mean age at length growth model.

	Female						Male					
Age	Estimate	Est Error	2.5%	50%	97.5%	CV	Estimate	Est Error	2.5%	50%	97.5%	CV
2	44.10	3.72	36.75	44.08	51.42	0.0796	41.50	3.02	35.73	41.52	47.53	0.0686
3	46.95	3.77	39.54	47.03	54.53	0.0796	46.52	3.13	40.55	46.41	52.85	0.0686
4	55.34	4.44	46.30	55.48	63.86	0.0796	55.65	3.86	47.97	55.65	63.08	0.0686
5	63.51	5.08	53.92	63.34	73.55	0.0796	62.18	4.35	53.36	62.23	70.51	0.0686
6	70.12	5.47	59.43	69.98	80.78	0.0796	67.95	4.73	58.79	67.94	77.06	0.0686
7	75.66	5.94	63.80	75.53	87.26	0.0796	72.24	5.08	62.71	72.26	81.98	0.0686
8	80.54	6.48	67.67	80.57	92.90	0.0796	75.97	5.13	65.94	75.98	86.09	0.0686
9	84.32	6.64	70.98	84.43	97.22	0.0796	78.06	5.32	68.19	77.95	88.22	0.0686
10	87.01	6.94	72.82	87.02	100.29	0.0796	80.04	5.55	69.16	80.09	90.64	0.0686
11	89.82	7.17	75.55	89.86	103.54	0.0796	82.04	5.48	71.39	82.03	92.71	0.0686
12	92.45	7.44	77.00	92.58	106.50	0.0796	83.87	5.62	73.00	83.82	95.07	0.0686
13	94.96	7.81	78.97	95.14	109.84	0.0796	84.87	5.76	73.88	84.81	96.11	0.0686
14	96.33	7.87	80.78	96.24	112.05	0.0796	86.58	5.78	75.46	86.57	97.72	0.0686
15	98.89	7.83	83.34	99.06	113.51	0.0796	87.33	5.95	75.72	87.37	98.65	0.0686
16	101.41	8.13	85.89	101.47	117.05	0.0796	87.99	6.06	75.71	88.05	100.07	0.0686
17	101.91	8.26	85.65	102.03	117.67	0.0796	88.40	6.21	76.07	88.48	100.21	0.0686
18	103.81	7.99	88.52	103.82	119.53	0.0796	89.07	6.02	77.02	89.10	100.88	0.0686
19	104.65	8.23	88.60	104.53	120.25	0.0796	89.72	6.16	77.50	89.71	101.67	0.0686
20	105.00	8.48	88.62	105.11	122.08	0.0796	90.73	6.29	78.61	90.68	103.00	0.0686
21	106.57	8.75	88.68	106.66	123.58	0.0796	91.50	6.28	78.94	91.37	103.72	0.0686
22	108.05	8.78	90.49	108.08	124.93	0.0796	91.90	6.46	79.15	91.98	104.22	0.0686
23	109.01	8.94	91.60	109.07	126.71	0.0796	92.18	6.46	79.78	92.16	104.92	0.0686
24	109.76	8.83	91.75	109.83	126.67	0.0796	92.54	6.25	80.93	92.60	104.82	0.0686
25	112.42	8.75	95.40	112.37	129.36	0.0796	93.17	6.36	80.29	93.28	105.34	0.0686
26	114.32	9.19	96.35	114.45	131.34	0.0796	93.56	6.40	81.15	93.49	106.15	0.0686
27	115.99	9.53	96.88	116.20	135.00	0.0796	93.79	6.38	81.44	93.70	106.29	0.0686
28	116.53	9.22	98.68	116.51	134.34	0.0796	94.81	6.69	81.69	94.80	107.79	0.0686
30	117.29	9.59	97.55	117.73	135.60	0.0796	95.48	6.66	82.43	95.32	108.84	0.0686

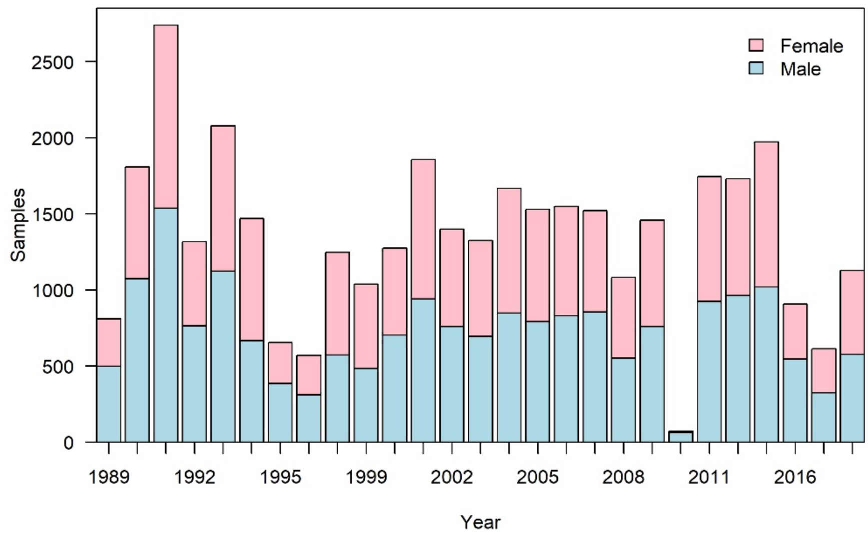


Figure C.1: Number of length-weight samples available by fishing year.

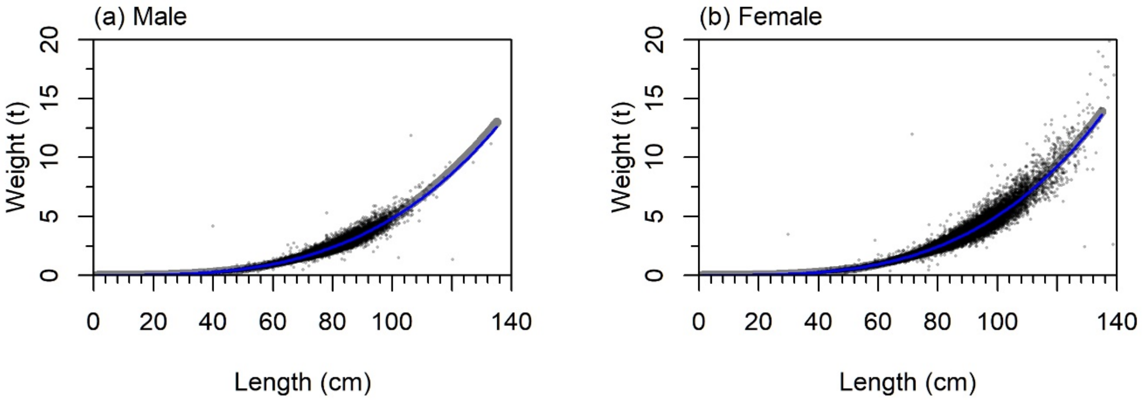


Figure C.2: Estimated length-weight relationships: the grey line represents the previous estimate (Horn 2005), the blue line is the estimated relationship and dots are the actual data points used in this analysis.

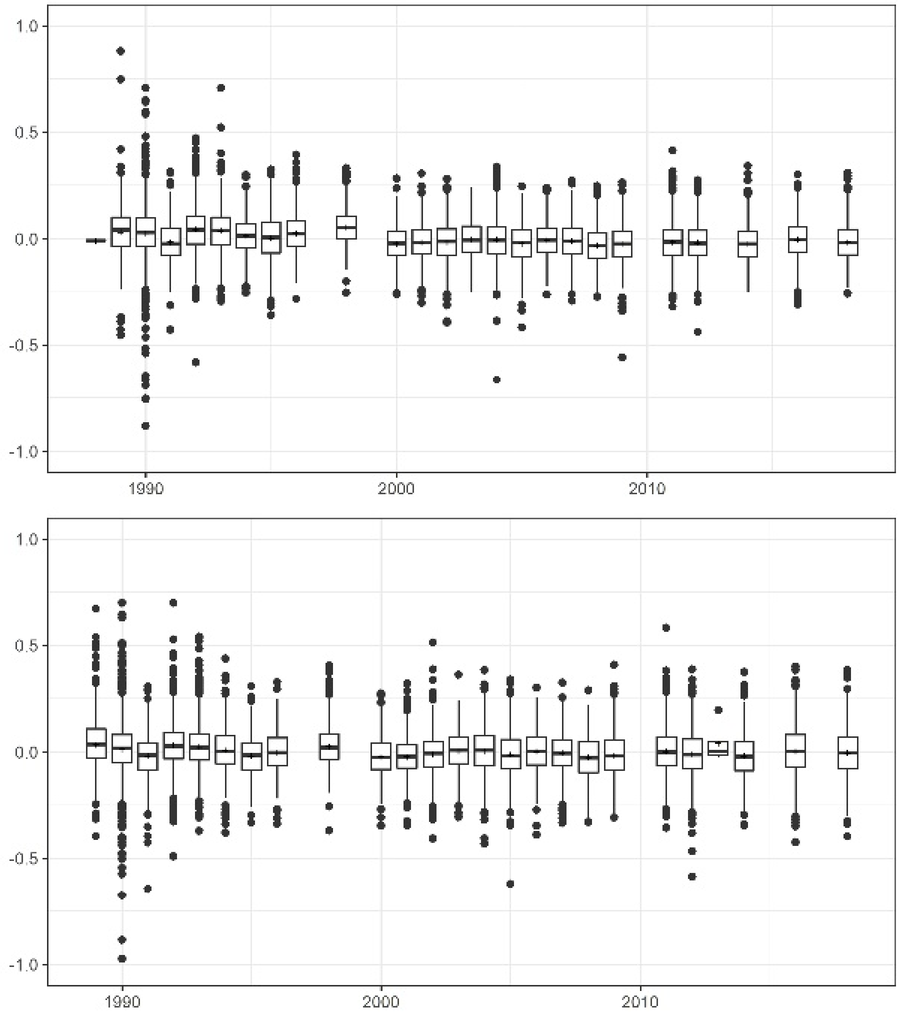


Figure C.3: Residuals by fishing year of the length-weight relationship for males (top) and females (bottom).

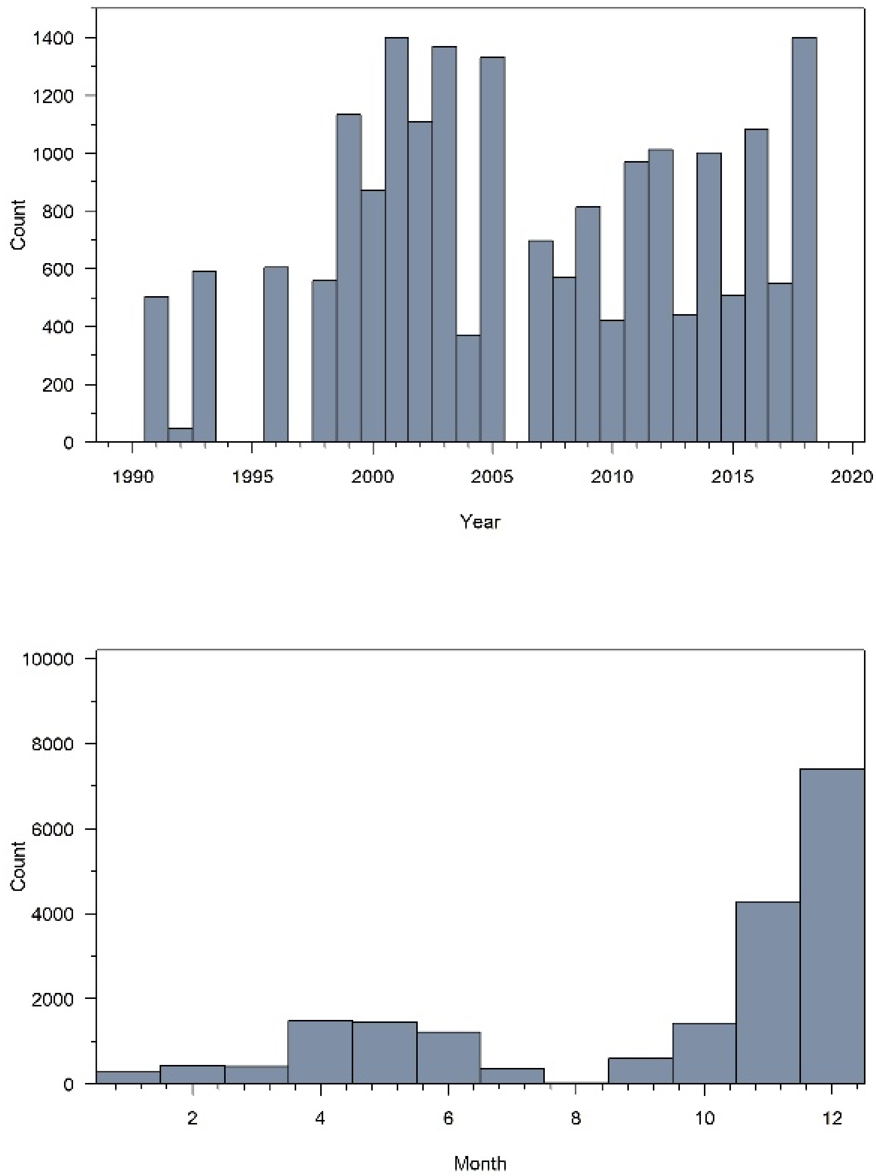


Figure C.4: Available age data, by fishing year (top) and by calendar month over all years (bottom).

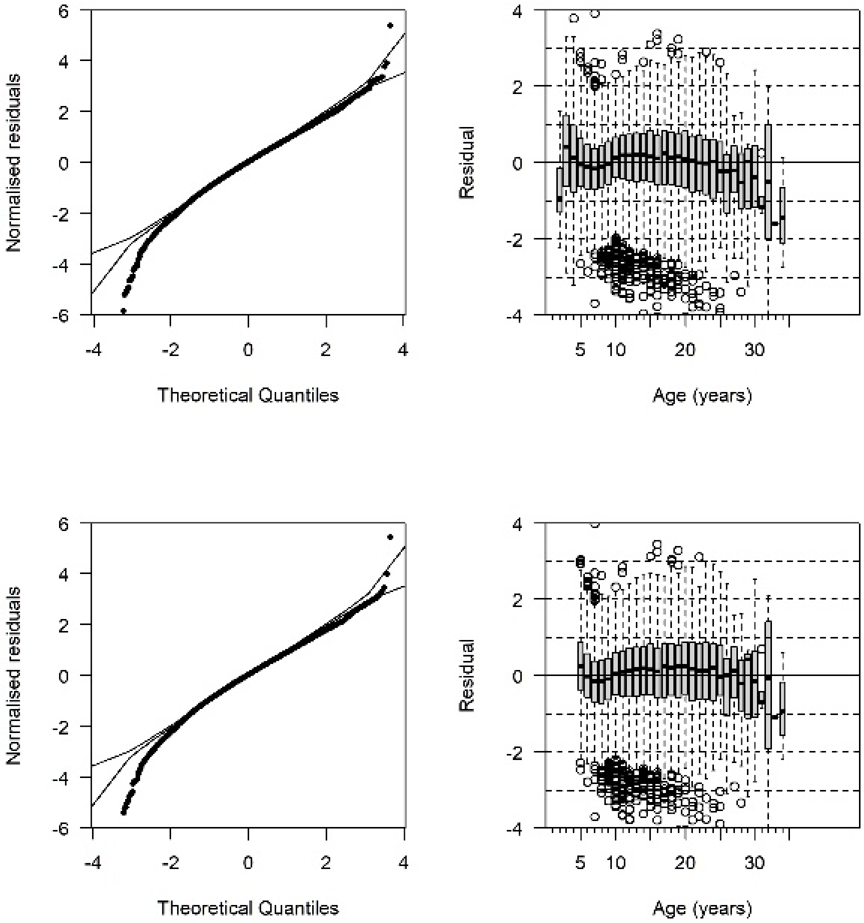


Figure C.5: Residuals of the MLE von Bertalanffy models, using all ages available (top) or ages 5 and over (bottom).

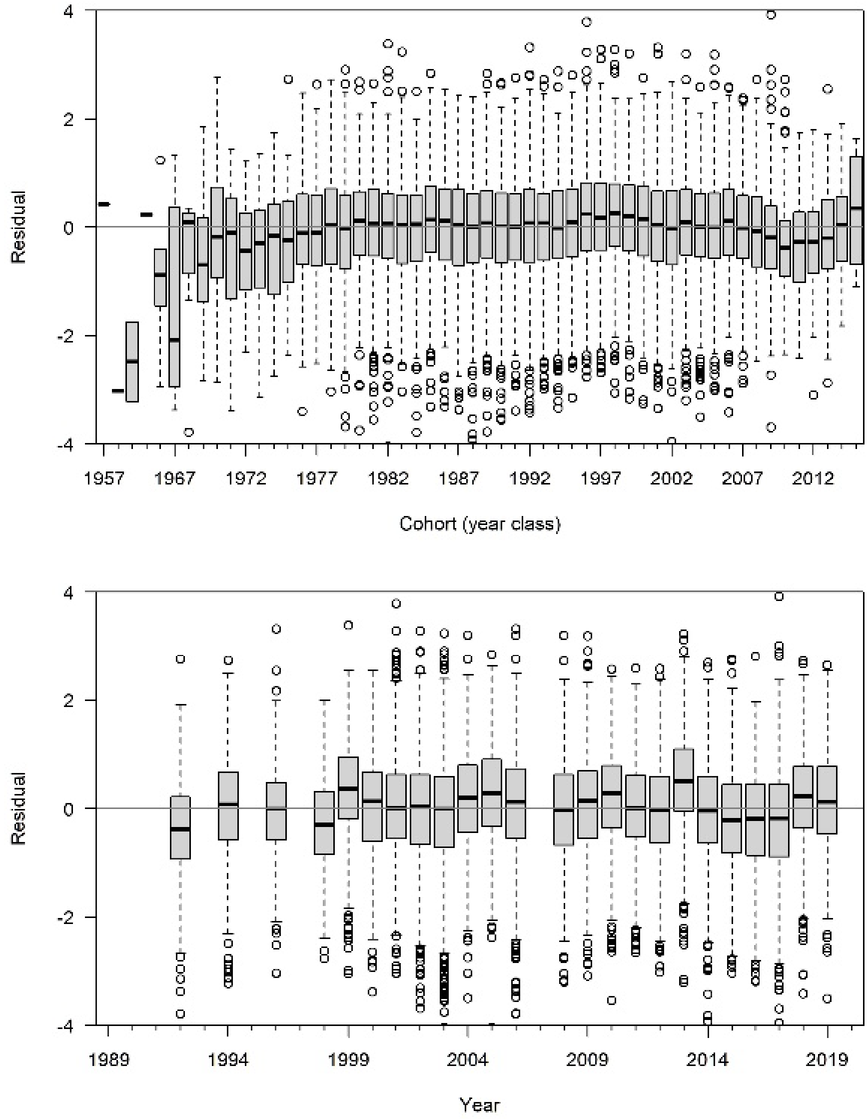


Figure C.6: Residuals of the MLE von Bertalanffy models by cohort (top) or by fishing year (bottom).

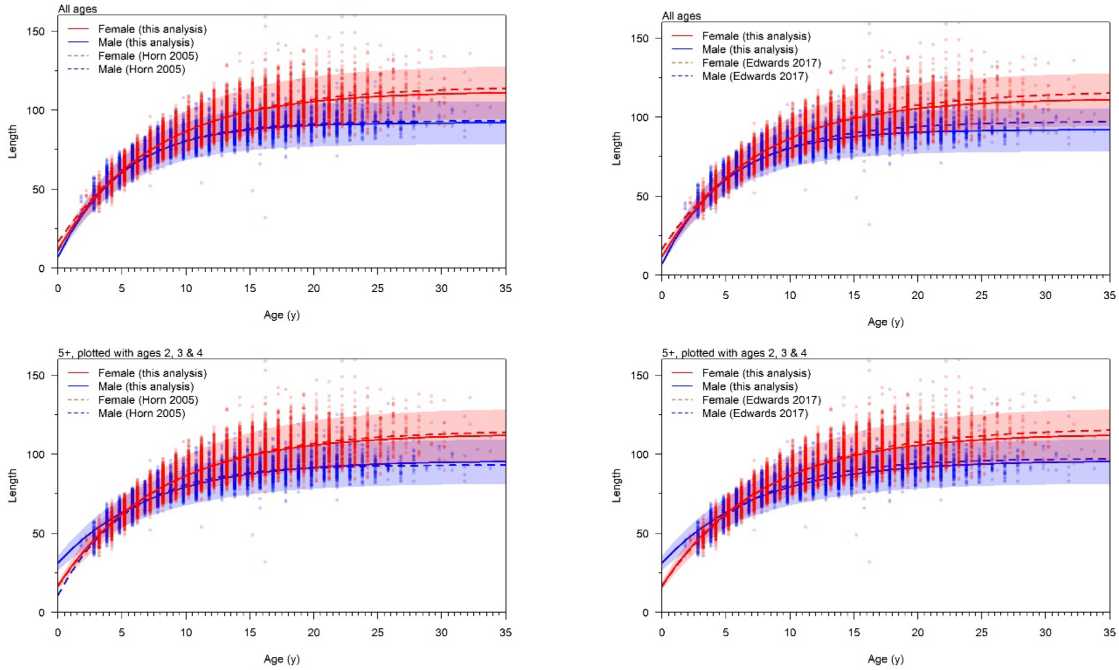


Figure C.7: Comparison of the MLE von Bertalanffy models with the models of Horn (2005, left) or Edwards (2017, right), using all ages available (top) or ages 5 and over (bottom).

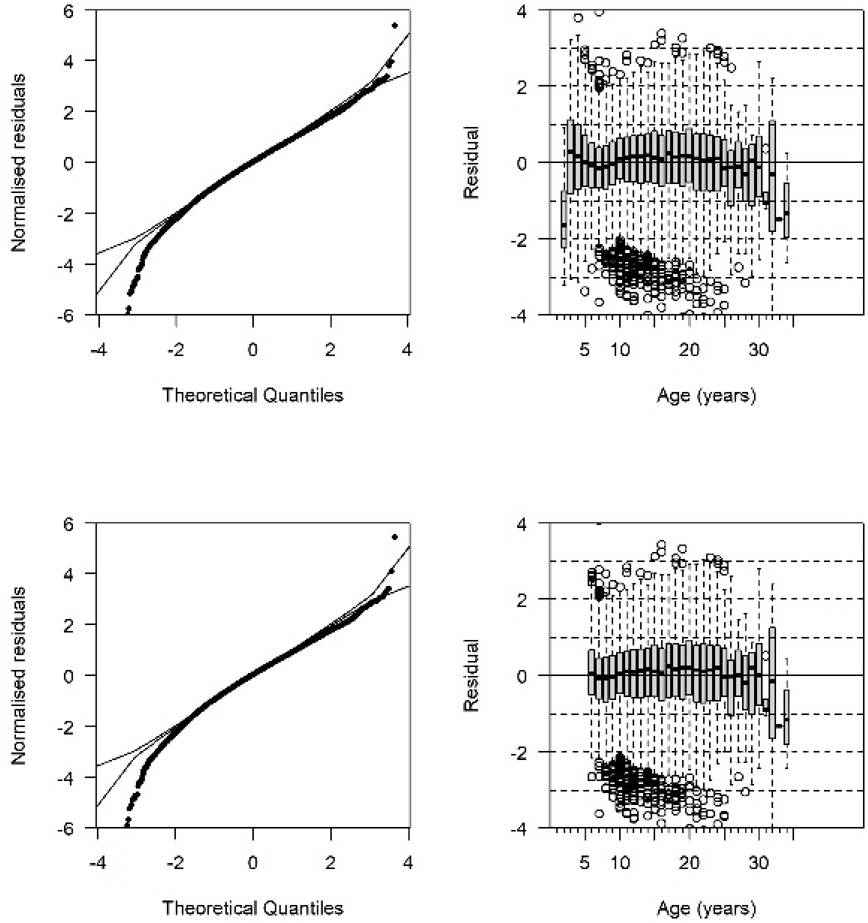


Figure C.8: Residuals of the MLE Schnute models, using all ages available (top) or ages 5 and over (bottom).

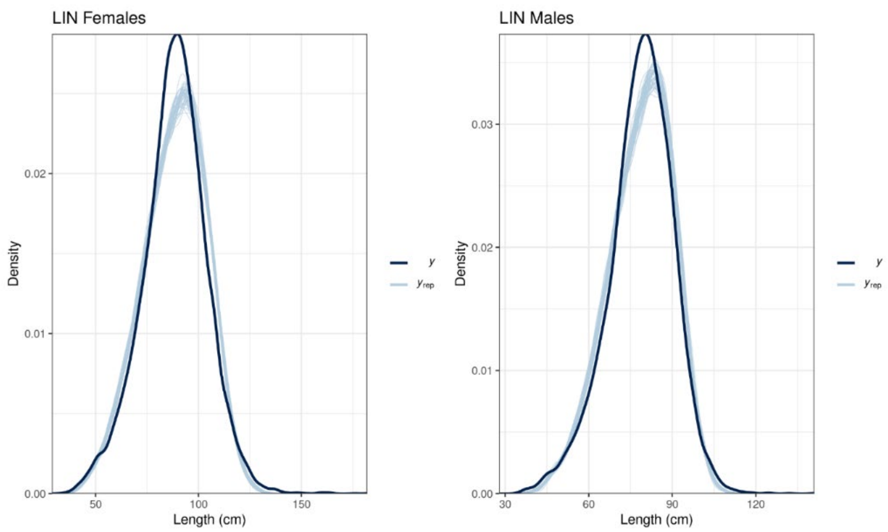


Figure C.9: Comparison of the empirical distribution of the data (*y*) to the posterior predictive distributions of simulated data (y_{rep}) from the Bayesian von Bertalanffy growth model by sex.

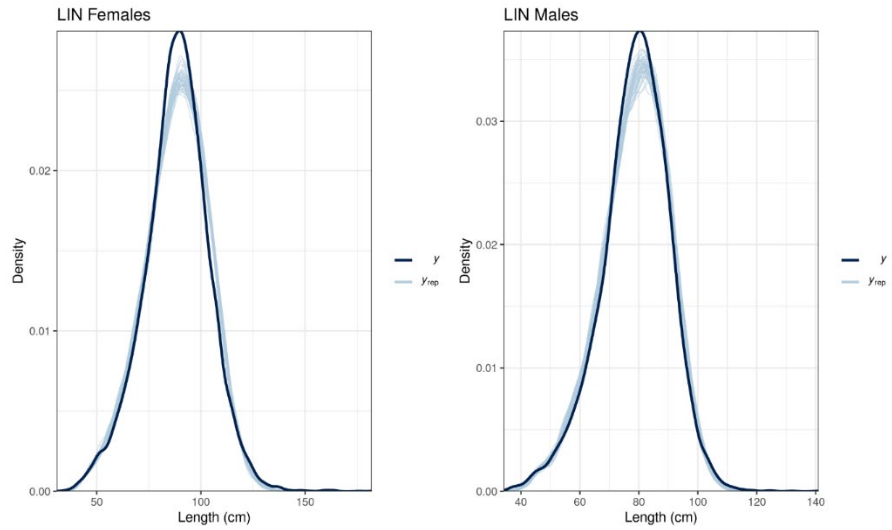


Figure C.10: Comparison of the empirical distribution of the data (*y*) to the posterior predictive distributions of simulated data (y_{rep}) from the Bayesian mean length at age growth model by sex.

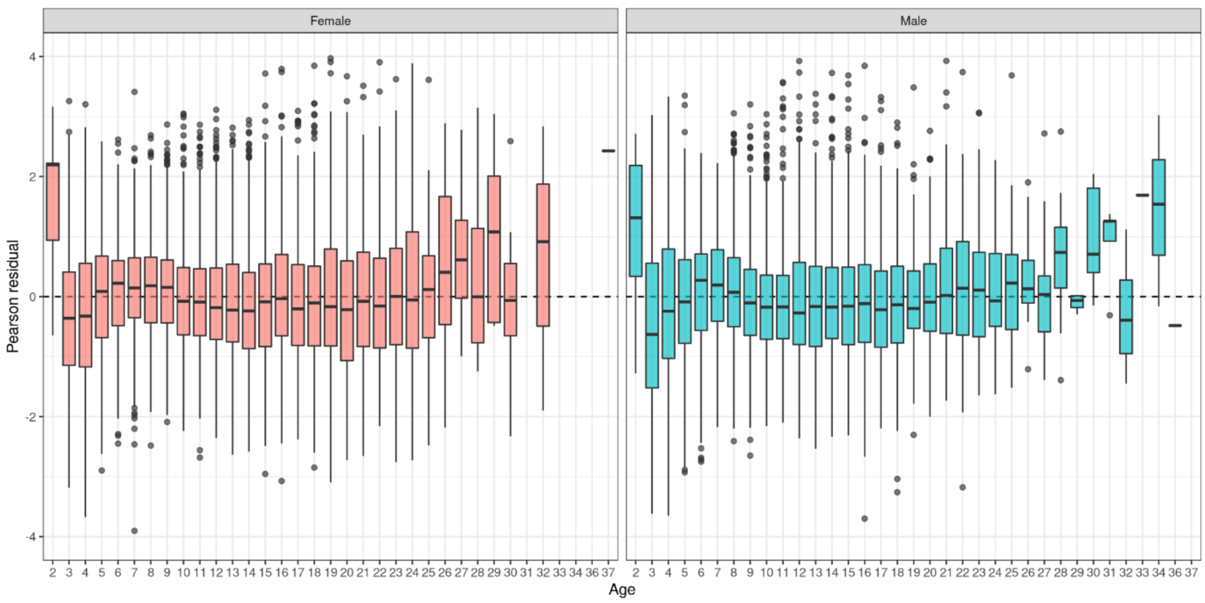


Figure C.11: Pearson residuals by age and sex from the Bayesian von Bertalanffy model fit.

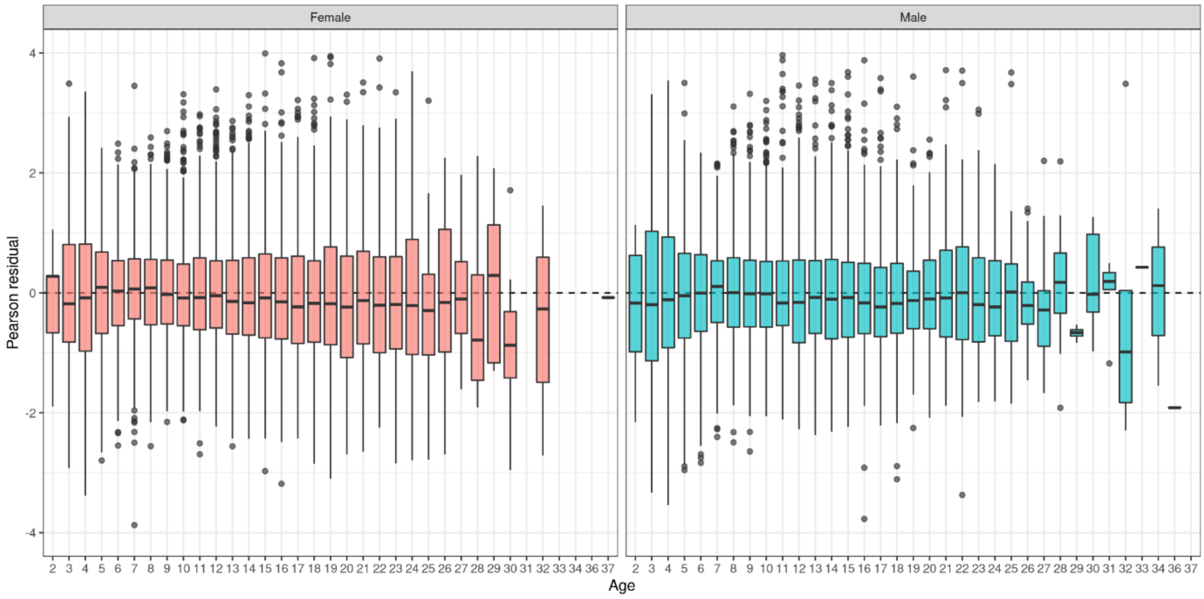


Figure C.12: Pearson residuals by age and sex from the Bayesian mean length at age model fit.

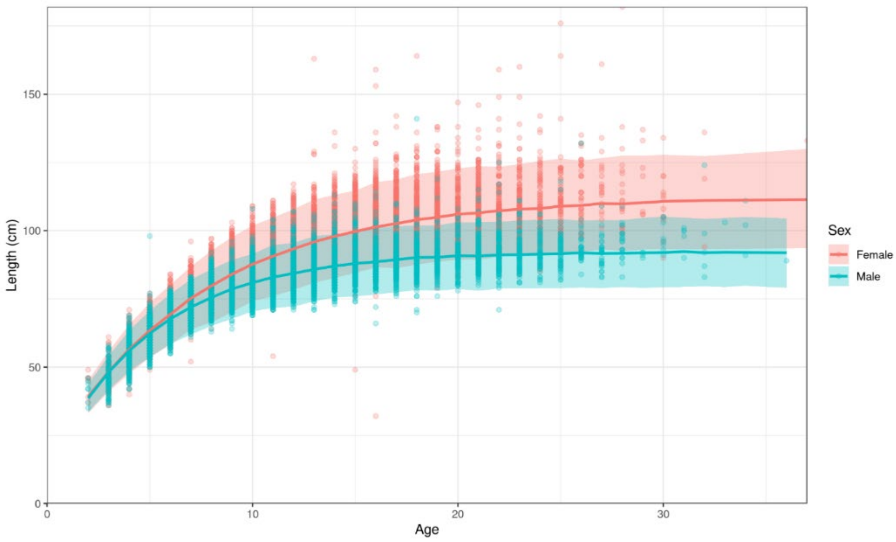


Figure C.13: Fit of the Bayesian von Bertalanffy growth model (line is the mean and shaded region is the 95% credible interval of the posterior predictive distribution) to length at age observations (points) by sex.

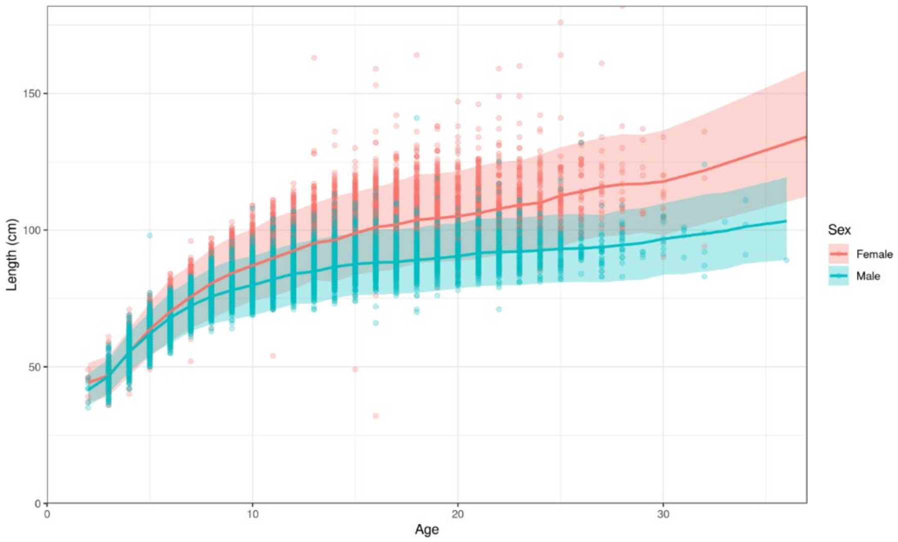


Figure C.14: Fit of the Bayesian mean length at age growth model (line is the mean and shaded region is the 95% credible interval of the posterior predictive distribution) to length at age observations (points) by sex.

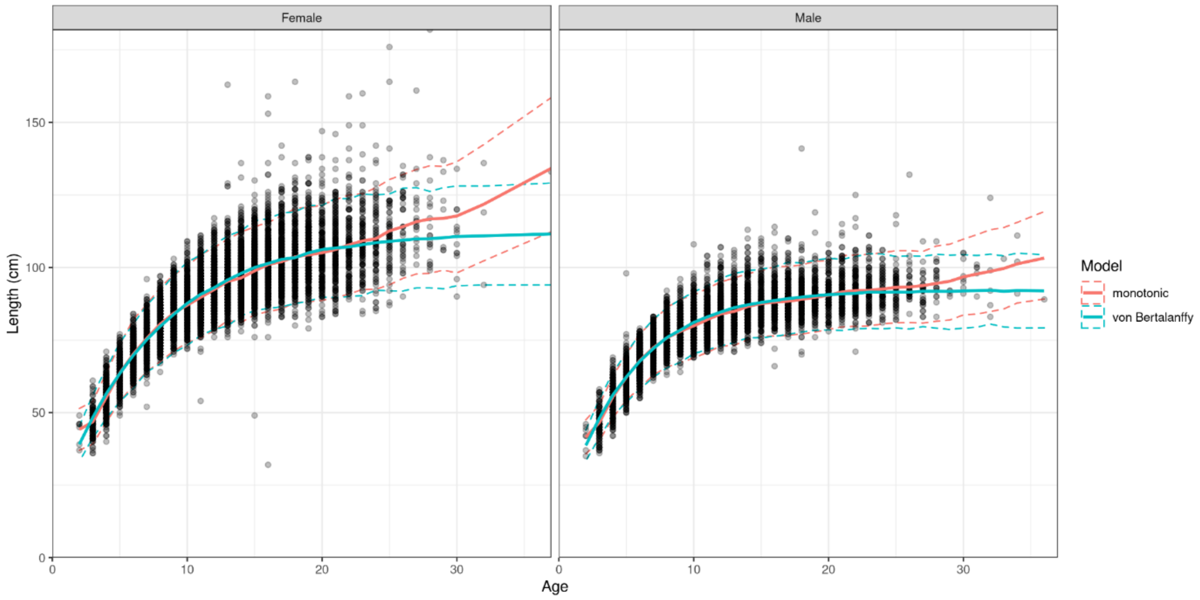


Figure C.15: Comparison of the fit of the Bayesian von Bertalanffy versus the mean length at age growth models (line is the mean and dashed lines represent the 95% credible interval of the posterior predictive distribution) to length at age observations (points) by sex.

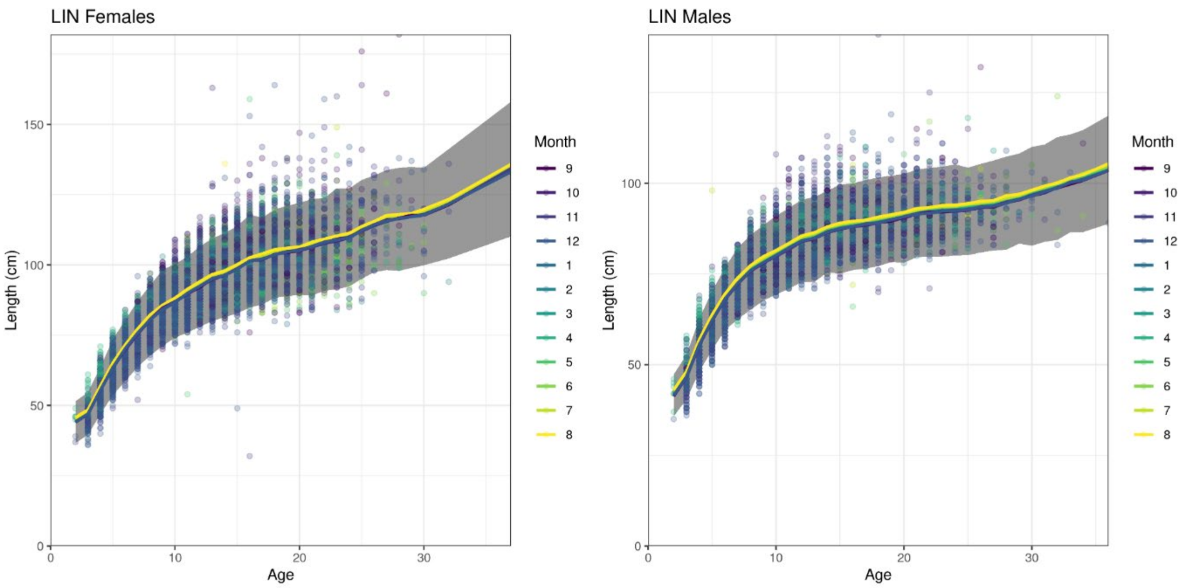


Figure C.16: Fit of the Bayesian mean length at age growth model (line is the mean and shaded region is the 95% credible interval of the posterior predictive distribution) to length at age observations (points) by sex and month (9 is September).

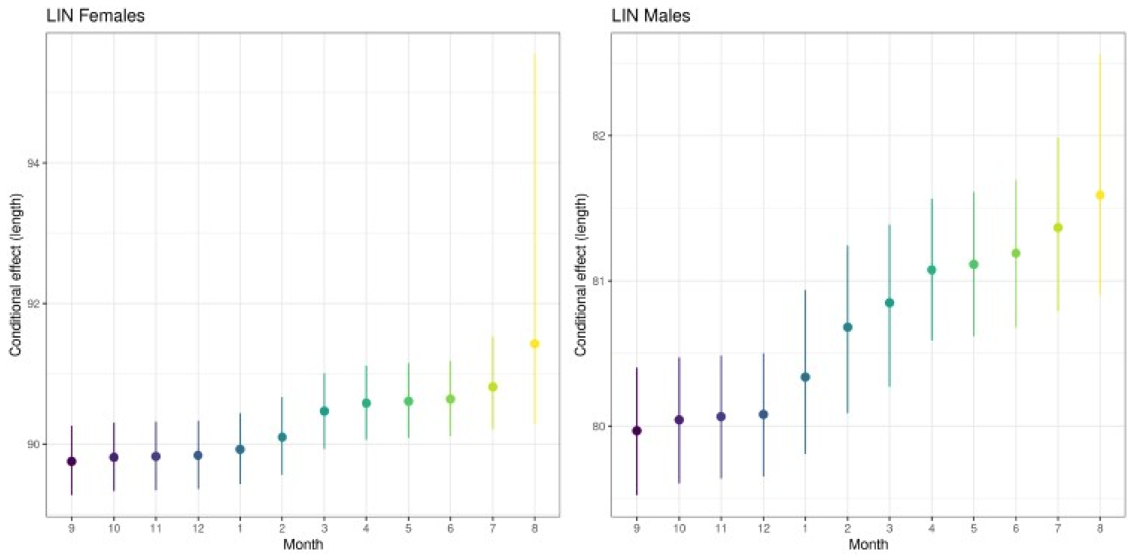


Figure C.17: The conditional effect of the monotonic month term by sex in the Bayesian mean length at age growth model.

APPENDIX D – CPUE ANALYSES FOR SUB-ANTARCTIC LING (LIN 5&6)

Table D.1: Explanatory variables offered to the bottom trawl tow-by-tow CPUE model.

Variable	Type	Description
Year	Categorical	Model year (September to August)
Month	Categorical	Month of the year
Day of year	3rd degree polynomial	Julian date, starting at 1 on 1 September
Statistical area	Categorical	Statistical area
Grid	Categorical	0.5 degree square based on start latitude and longitude of tow
Start latitude	3rd degree polynomial	Start latitude (absolute value)
Start longitude	3rd degree polynomial	Start longitude (0-360)
Vessel	Categorical	Unique vessel identifier
Twin trawl	Categorical	Whether Twin trawl or not
Vessel experience	3rd degree polynomial of log	Experience of the vessel in number of years
Target	Categorical	Species targeted on the tow
Effort width	3rd degree polynomial of log	Width of the net in metres
Effort height	3rd degree polynomial of log	Distance between the trawl headline and groundrope in metres
Trawl speed	3rd degree polynomial of log	Speed of trawling, in knots
Bottom depth	3rd degree polynomial of log	Depth of the bottom in metres
Fishing depth	3rd degree polynomial of log	Depth of the net in metres
Observed	Categorical	Whether an observer was onboard that day
Spawning	Categorical	Whether during spawning season (September to December) or not
Time of start of tow	3rd degree polynomial	Time of day in hours
Time of midpoint of tow	3rd degree polynomial	Time of day in hours, calculated as the midpoint between start and end time
Fishing duration	4th degree polynomial of log	Duration of the tow in hours

Table D.2: Explanatory variables offered to the bottom longline rolled-up CPUE model.

Variable	Type	Description
Year	Categorical	Model year (September to August)
Month	Categorical	Month of the year
Day of year	3rd degree polynomial	Julian date, starting at 1 on 1 September
Statistical area	Categorical	Statistical area
Vessel	Categorical	Unique vessel identifier
Longline type	Categorical	Handline, autoline or unknown
Vessel experience	3rd degree polynomial of log	Experience of the vessel in number of years
Total hooks	4th degree polynomial of log	Number of hooks set per day in a statistical area
Observed	Categorical	Whether an observer was onboard that day
Spawning	Categorical	Whether during spawning season (September to December) or not

Table D.3: Explanatory variables offered to the bottom longline set-by-set CPUE model.

Variable	Type	Description
Year	Categorical	Model year (September to August)
Month	Categorical	Month of the year
Day of year	3rd degree polynomial	Julian date, starting at 1 on 1 September
Statistical area	Categorical	Statistical area
Grid	Categorical	0.5 degree square based on start latitude and longitude of tow
Vessel	Categorical	Unique vessel identifier
Longline type	Categorical	Handline, autoline or unknown
Vessel experience	3rd degree polynomial of log	Experience of the vessel in number of years
Total hooks	4th degree polynomial of log	Number of hooks set
Bottom depth	3rd degree polynomial of log	Depth of the bottom
Observed	Categorical	Whether an observer was onboard that day
Spawning	Categorical	Whether during spawning season (September to December) or not
Time of start of set	3rd degree polynomial	Time of day in hours
Soak time	3rd degree polynomial of log	Difference between start date time and haul start date time

Table D.4: Data selection for the bottom trawl tow-by-tow CPUE model.

Data source	TCEPR, ERS - trawl
Year range	1991–2020
Target species	Hoki, hake and ling only
Statistical Areas (SA)	100 tows minimum (SA 025-031, 504, 602-604, 610-612, 618, 619, 625)
Catch per tow	< 50 t
Bottom depth	Between 150 and 1000m
Tow duration	Between 0.2 and 15 hours
Gear type	Bottom trawl only
Vessel experience	Over 7 years in the fishery (~80% of ling catch)
Ling catch reporting position	Any tow 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.5: Data selection for the bottom longline rolled-up CPUE model.

Data source	CELR, LTCER, LCER, ERS – lining
Year range	1991–2020
Target species	Ling only
Rolling-up method	By vessel, day and statistical area
Statistical Areas (SA)	50 rolled-up records minimum (SA 026, 029-032, 602-605, 610-612, 618, 619, 625)
Catch per rolled-up record	< 35 t
Gear type	Bottom longline only
Baiting method	Autoline and handbait only
Number of hooks per line	Between 50 and 50 000
Vessel experience	Over 4 years in the fishery (~89% of ling catch)
Ling catch reporting position	Any rolled-up 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.6: Data selection for the bottom longline set-by-set CPUE model.

Data source	LCER, LTCER and ERS – lining
Year range	2004–2020
Target species	Ling only
Statistical Areas (SA)	50 sets minimum (SA 026, 029-032, 602-605, 610-612, 618, 619)
Catch per set	< 35 t
Gear type	Bottom longline only
Number of hooks per line	Between 50 and 50 000
Vessel experience	At least 2 years in the fishery (~98% 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

Table D.7: Variables in order of decreasing explanatory value for the tow-by-tow bottom trawl lognormal CPUE for Sub-Antarctic ling (LIN 5&6). 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
Model year (forced)			63 492	126 014	0.10	223 843
Grid	181	37 441	63 311	88 573	0.37	201 809
Target	2	14 412	63 309	74 161	0.47	190 532
Vessel	30	5 210	63 279	68 951	0.51	185 965
Month	11	3 469	63 268	65 482	0.53	182 708
Time of midpoint of tow	3	3 120	63 265	62 361	0.56	179 612
Fishing duration	4	2 855	63 261	59 506	0.58	176 643
Bottom depth	3	1 611	63 258	57 895	0.59	174 906
Time of start of tow	3	194	63 255	57 701	0.59	174 698
Fishing depth	3	143	63 252	57 558	0.59	174 546
Effort width	3	106	63 249	57 452	0.59	174 436
Effort height	3	110	63 246	57 342	0.59	174 320
Start longitude	3	88	63 243	57 254	0.59	174 228
Statistical area	11	65	63 232	57 189	0.59	174 178
Twin trawls	2	17	63 230	57 172	0.59	174 163
Day	3	12	63 227	57 160	0.59	174 156
Observed	1	11	63 226	57 149	0.59	174 146
Vessel experience	3	8	63 223	57 141	0.59	174 143
Trawl speed	3	6	63 220	57 135	0.59	174 142
Start latitude	3	4	63 217	57 131	0.59	174 144

Table D.8: Variables in order of decreasing explanatory value for the tow-by-tow bottom trawl binomial CPUE for Sub-Antarctic ling (LIN 5&6). 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
Model depth (forced)			76 127	65 371	0.04	65 431
Grid	199	13 038	75 928	52 333	0.24	52 791
Vessel	30	1 470	75 898	50 863	0.26	51 381
Bottom depth	3	1 472	75 895	49 391	0.28	49 915
Target	2	851	75 893	48 540	0.29	49 068
Fishing duration	4	683	75 889	47 857	0.30	48 393
Month	11	265	75 878	47 591	0.30	48 149
Time of start of tow	3	259	75 875	47 333	0.31	47 897
Effort height	3	119	75 872	47 213	0.31	47 783
Start latitude	3	72	75 869	47 141	0.31	47 717
Statistical area	11	127	75 858	47 014	0.31	47 612
Effort width	3	66	75 855	46 948	0.31	47 552
Observed	1	34	75 854	46 914	0.31	47 520
Day	3	25	75 851	46 889	0.31	47 501
Vessel experience	3	20	75 848	46 869	0.32	47 487
Fishing depth	3	18	75 845	46 851	0.32	47 475
Twin trawls	2	7	75 843	46 844	0.32	47 472
Start longitude	3	6	75 840	46 838	0.32	47 472
Time of midpoint of tow	3	4	75 837	46 834	0.32	47 474
Trawl speed	3	2	75 834	46 831	0.32	47 477

Table D.9: CPUE standardisation indices for the Sub-Antarctic ling stock (LIN 5&6) tow-by-tow bottom trawl fisheries, including binomial, lognormal and delta lognormal indices, 95% credible intervals (CI) and CVs. Year is model year, from 1st September to 31st August.

	Lognormal			Binomial			Delta lognormal		
Year	Index	CI	CV	Index	CI	CV	Index	CI	CV
1991	1.76	1.57-1.99	0.08	0.87	0.83-0.90	0.02	1.53	1.40-1.65	0.08
1992	2.15	2.00-2.31	0.04	0.93	0.92-0.94	0.01	2.00	1.93-2.07	0.04
1993	2.70	2.52-2.89	0.03	0.95	0.95-0.96	0.00	2.58	2.51-2.65	0.03
1994	2.94	2.73-3.17	0.03	0.95	0.94-0.96	0.01	2.79	2.71-2.86	0.03
1995	2.65	2.48-2.83	0.03	0.93	0.92-0.95	0.01	2.47	2.41-2.54	0.03
1996	2.50	2.34-2.68	0.03	0.90	0.88-0.92	0.01	2.25	2.18-2.32	0.03
1997	2.72	2.56-2.89	0.03	0.89	0.88-0.91	0.01	2.43	2.37-2.50	0.03
1998	2.41	2.28-2.54	0.03	0.93	0.91-0.94	0.01	2.23	2.18-2.28	0.03
1999	2.15	2.03-2.27	0.03	0.93	0.92-0.94	0.01	1.99	1.93-2.05	0.03
2000	1.92	1.83-2.01	0.03	0.92	0.90-0.93	0.01	1.75	1.70-1.80	0.03
2001	2.20	2.09-2.31	0.03	0.90	0.88-0.91	0.01	1.98	1.93-2.03	0.03
2002	2.85	2.72-2.99	0.02	0.95	0.94-0.96	0.00	2.71	2.67-2.76	0.02
2003	2.97	2.82-3.12	0.02	0.94	0.93-0.95	0.00	2.78	2.73-2.83	0.02
2004	2.99	2.84-3.15	0.02	0.94	0.93-0.95	0.01	2.81	2.75-2.86	0.02
2005	3.20	3.02-3.39	0.02	0.95	0.94-0.96	0.01	3.03	2.97-3.09	0.02
2006	2.37	2.21-2.54	0.04	0.90	0.88-0.92	0.01	2.13	2.06-2.2	0.04
2007	2.20	2.07-2.34	0.03	0.94	0.92-0.95	0.01	2.06	2.00-2.12	0.03
2008	2.27	2.14-2.41	0.03	0.91	0.89-0.93	0.01	2.07	2.00-2.13	0.03
2009	2.09	1.97-2.22	0.04	0.93	0.92-0.95	0.01	1.95	1.89-2.01	0.04
2010	2.18	2.05-2.32	0.03	0.94	0.93-0.95	0.01	2.06	1.99-2.12	0.03
2011	2.11	1.98-2.24	0.04	0.95	0.94-0.96	0.01	2.00	1.94-2.07	0.04
2012	2.40	2.26-2.56	0.03	0.96	0.95-0.97	0.00	2.31	2.24-2.37	0.03
2013	2.49	2.35-2.64	0.03	0.97	0.96-0.98	0.00	2.42	2.36-2.47	0.03
2014	2.43	2.30-2.57	0.03	0.96	0.95-0.97	0.00	2.33	2.28-2.39	0.03
2015	2.16	2.04-2.29	0.03	0.96	0.95-0.97	0.00	2.07	2.01-2.13	0.03
2016	2.60	2.44-2.77	0.03	0.97	0.96-0.97	0.00	2.51	2.45-2.57	0.03
2017	2.68	2.52-2.85	0.03	0.96	0.95-0.97	0.00	2.58	2.51-2.64	0.03
2018	2.82	2.66-2.98	0.02	0.99	0.99-0.99	0.00	2.78	2.73-2.84	0.02
2019	2.33	2.19-2.48	0.03	0.99	0.98-0.99	0.00	2.3	2.24-2.36	0.03
2020	2.57	2.41-2.74	0.03	0.98	0.98-0.99	0.00	2.53	2.46-2.59	0.03

Table D.10: Variables in order of decreasing explanatory value for the rolled-up longline CPUE for Sub-Antarctic ling (LIN 5&6). 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.

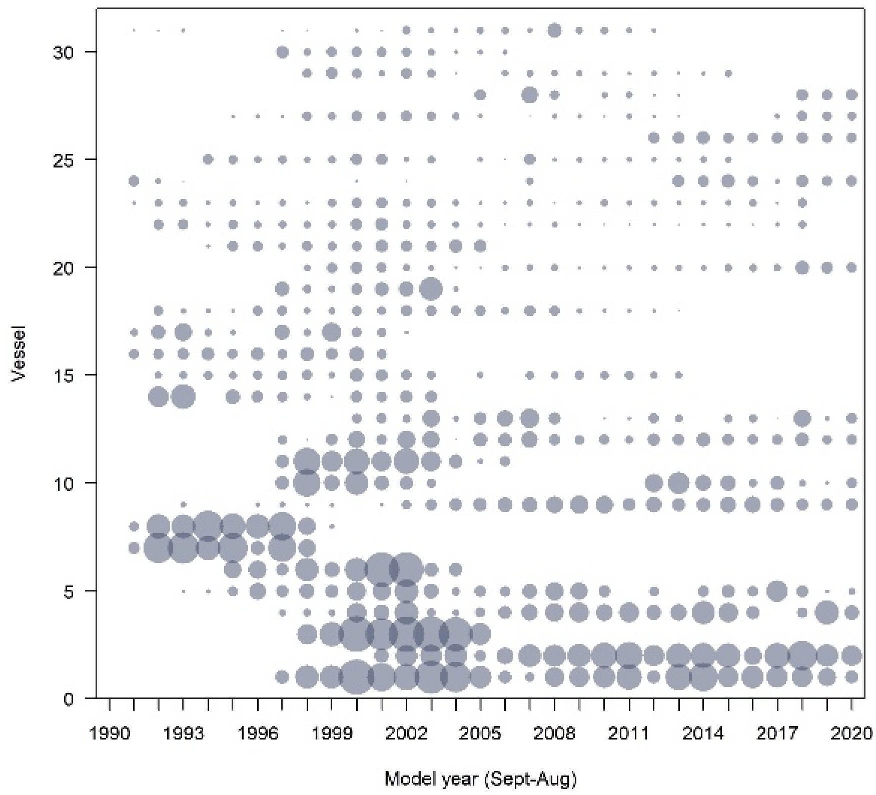
Step	Df	Deviance	Residual Df	Residual Deviance	r^2	AIC
Model year (forced)			8 792	6 961	0.09	23 007
Hooks	4	3 204	8 788	3 757	0.51	17 575
Statistical area	14	620	8 774	3 137	0.59	16 012
Vessel	11	136	8 763	3 001	0.61	15 643
Month	11	138	8 752	2 863	0.63	15 250
Vessel experience	3	41	8 749	2 823	0.63	15 130
Observed	1	10	8 748	2 812	0.63	15 100
Day	3	5	8 745	2 808	0.63	15 091

Table D.11: Variables in order of decreasing explanatory value for the set-by-set longline CPUE for Sub-Antarctic ling (LIN 5&6). 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
Model year (forced)			10 619	8 175	0.05	27 421
Vessel	13	2 916	10 606	5 259	0.39	22 754
Hooks	4	861	10 602	4 398	0.49	20 860
Grid	127	620	10 475	3 778	0.56	19 498
Month	11	324	10 464	3 453	0.60	18 565
Bottom depth	3	42	10 461	3 412	0.60	18 442
Soak time	3	29	10 458	3 383	0.61	18 358
Start time	3	23	10 455	3 360	0.61	18 293
Statistical area	10	22	10 445	3 339	0.61	18 245
Observed	1	14	10 444	3 325	0.61	18 201
Start longitude	3	9	10 441	3 315	0.62	18 177
Vessel experience	3	8	10 438	3 308	0.62	18 159
Day	3	7	10 435	3 300	0.62	18 141
Start latitude	3	3	10 432	3 298	0.62	18 139

Table D.12: CPUE standardisation indices for the Sub-Antarctic ling stock (LIN 5&6) rolled-up and set-by-set bottom longline fisheries, based on rolled-up data, 95% credible intervals (CI) and CVs. Only the lognormal model was carried out as null catches were negligible. Year is model year, from 1st September to 31st August.

	Rolled-up lognormal			Set-by-set lognormal		
Year	Index	CI	CV	Index	CI	CV
1991	6.79	5.62-8.19	0.08			
1992	6.30	5.55-7.15	0.06			
1993	8.20	7.26-9.25	0.04			
1994	8.20	7.29-9.22	0.04			
1995	7.38	6.63-8.21	0.04			
1996	6.37	5.66-7.16	0.05			
1997	7.72	7.00-8.51	0.04			
1998	6.55	5.96-7.19	0.04			
1999	4.99	4.61-5.40	0.05			
2000	5.27	4.88-5.68	0.04			
2001	6.39	5.88-6.95	0.04			
2002	6.06	5.56-6.59	0.04			
2003	6.57	5.94-7.28	0.04			
2004	3.97	3.62-4.36	0.07	1.72	1.58-1.87	0.04
2005	3.76	3.44-4.10	0.07	1.64	1.54-1.76	0.04
2006	4.37	3.99-4.79	0.06	2.17	2.03-2.32	0.03
2007	5.19	4.61-5.84	0.07	2.37	2.19-2.57	0.03
2008	5.78	5.28-6.33	0.05	2.40	2.25-2.56	0.02
2009	5.43	4.89-6.03	0.06	1.97	1.84-2.11	0.03
2010	6.76	6.21-7.36	0.04	2.36	2.21-2.51	0.02
2011	4.52	4.16-4.90	0.05	1.57	1.47-1.67	0.04
2012	5.37	5.00-5.78	0.04	1.78	1.68-1.89	0.03
2013	4.24	3.83-4.70	0.07	1.52	1.41-1.64	0.04
2014	4.86	4.49-5.26	0.05	1.43	1.34-1.52	0.04
2015	4.90	4.47-5.37	0.05	1.62	1.52-1.72	0.04
2016	3.59	3.30-3.92	0.07	1.17	1.10-1.25	0.05
2017	5.03	4.65-5.44	0.04	1.48	1.39-1.58	0.04
2018	5.86	5.34-6.42	0.05	1.84	1.72-1.98	0.03
2019	6.12	5.64-6.64	0.04	2.01	1.88-2.15	0.03
2020	6.30	5.82-6.81	0.04	1.78	1.68-1.90	0.03



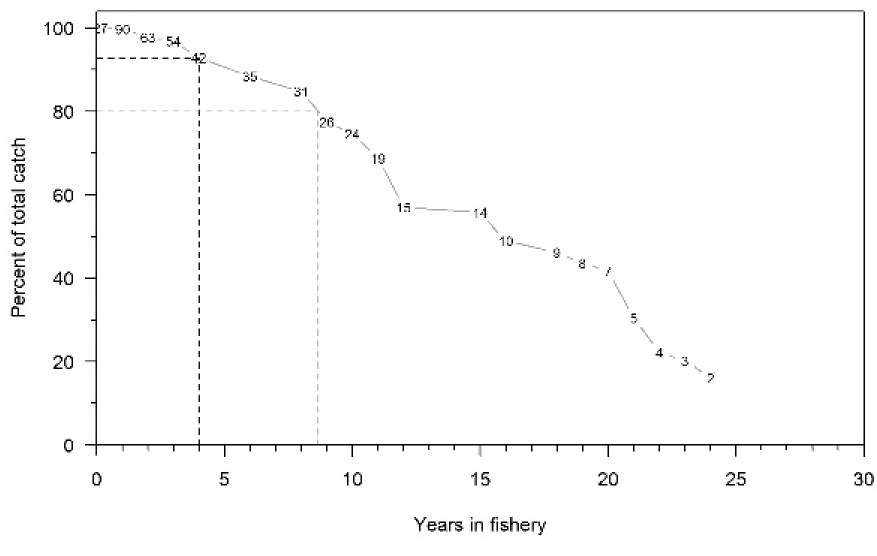
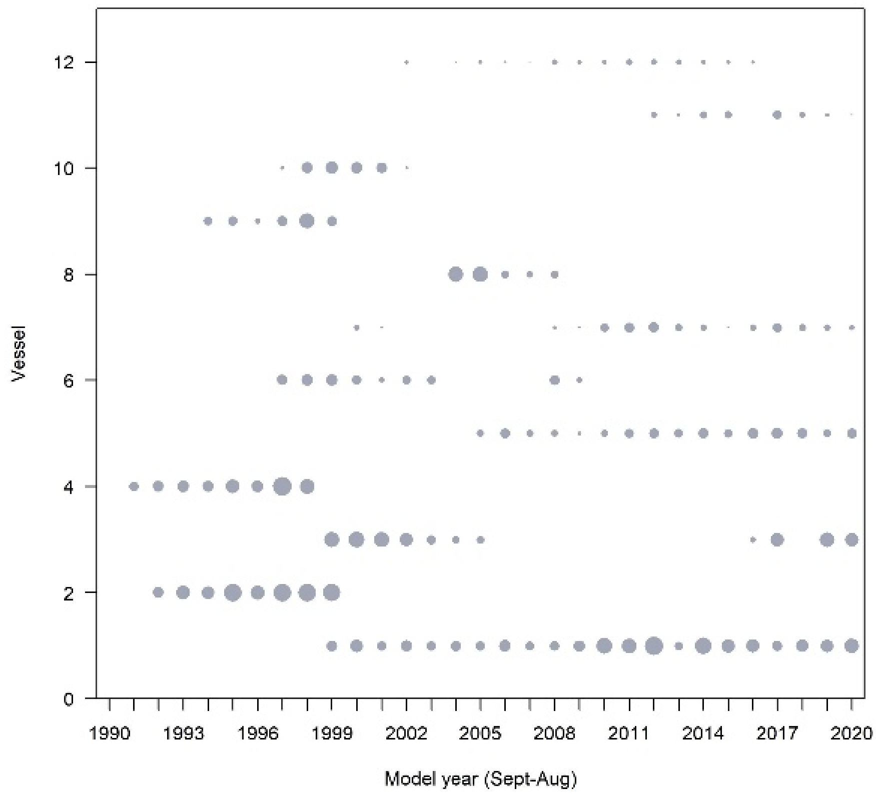


Figure D.1: Core vessel selection for the bottom trawl tow-by-tow CPUE model for Sub-Antarctic ling (LIN 5&6): annual catch per vessel over time (top) and proportion of total catch per vessel experience (bottom).



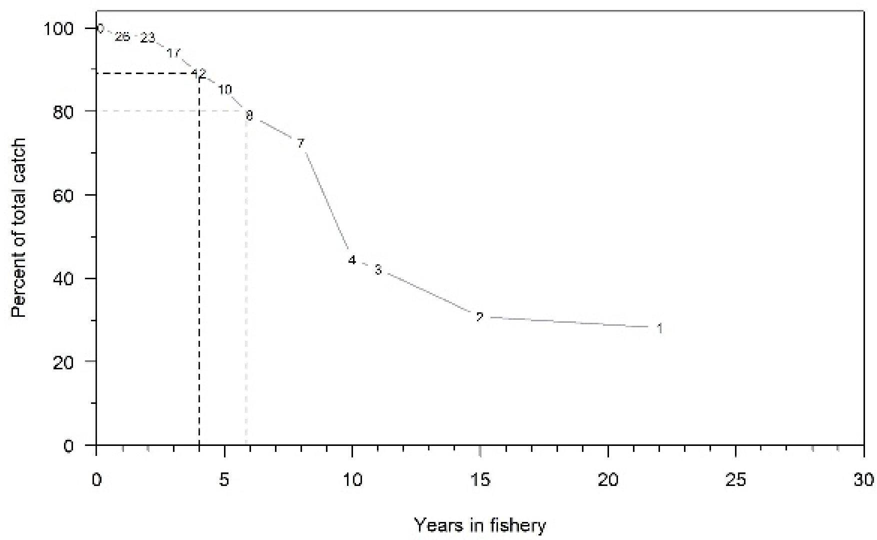


Figure D.2: Core vessel selection for the bottom longline rolled-up CPUE model for Sub-Antarctic ling (LIN 5&6): annual catch per vessel over time (top) and proportion of total catch per vessel experience (bottom).

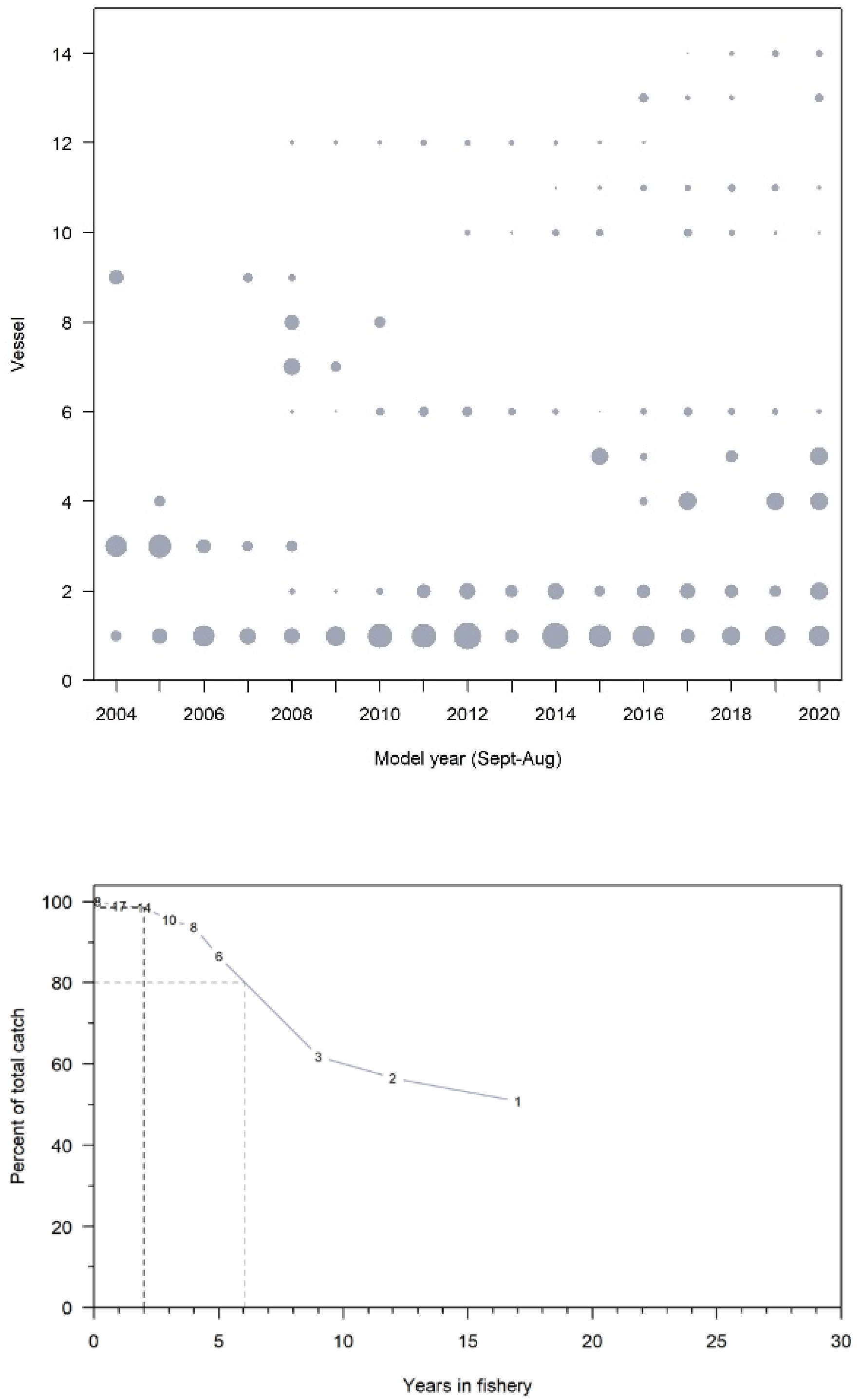
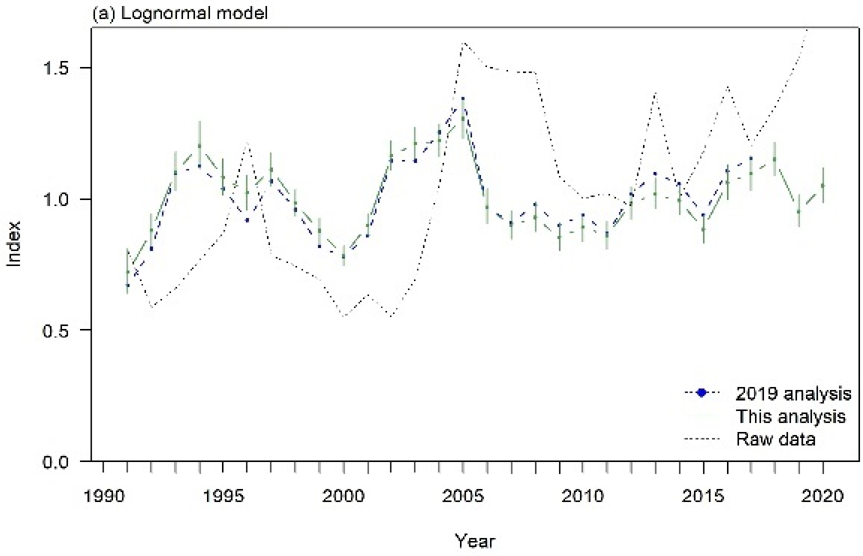


Figure D.3: Core vessel selection for the bottom longline set-by-set CPUE model for Sub-Antarctic ling (LIN 5&6): annual catch per vessel over time (top) and proportion of total catch per vessel experience (bottom).



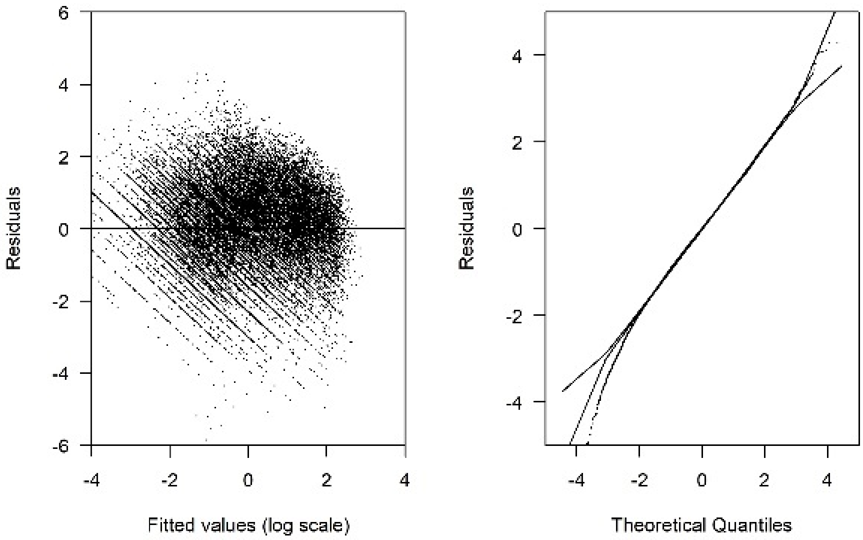


Figure D.4: Year index for the lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6) (top) and residual plots of that model (bottom). Also plotted the 2019 index (Ballara 2019) and the raw catch rates. Year is model year, from 1st September to 31st August.

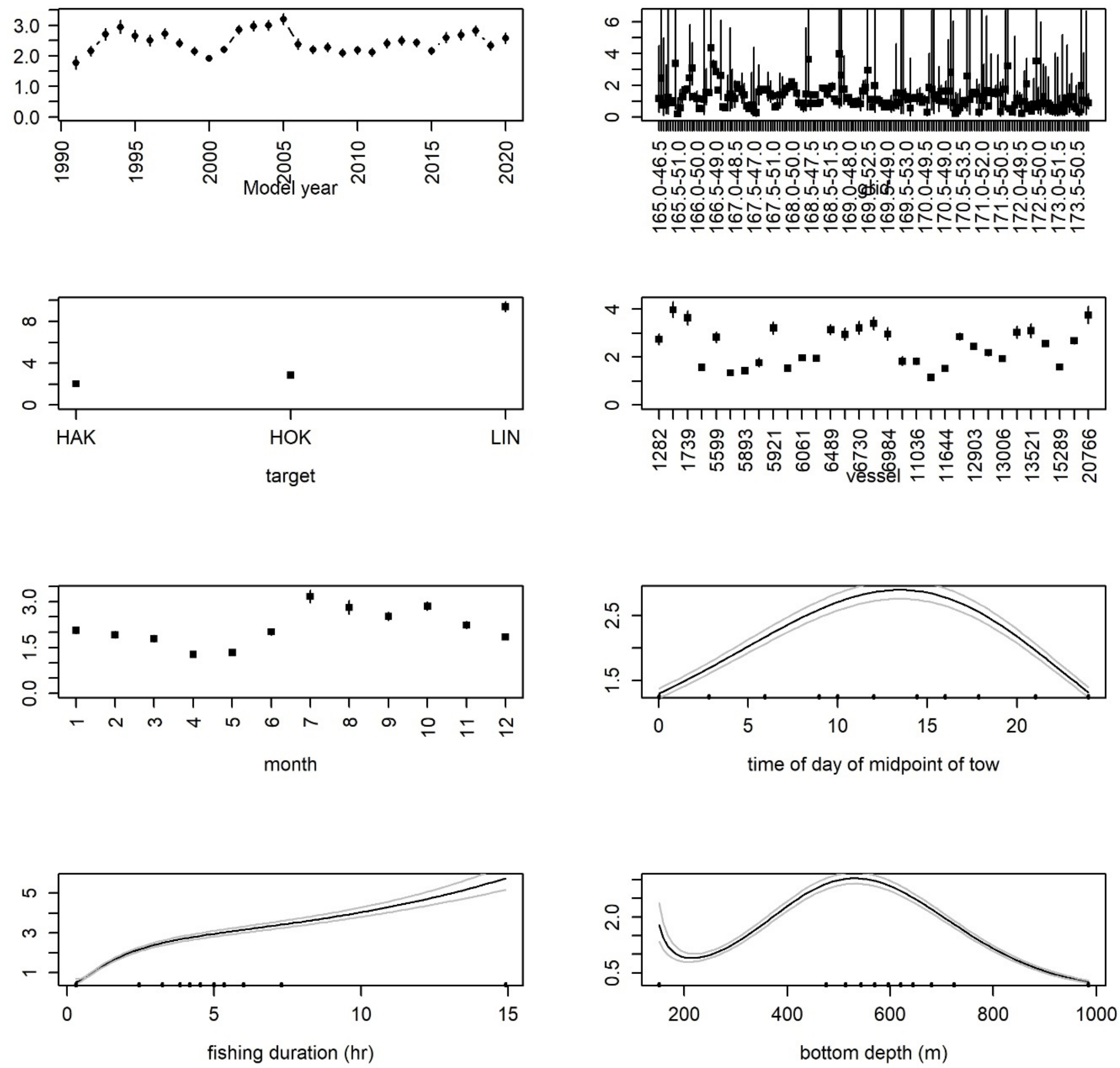


Figure D.5: Effects plots for the lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6) for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August. Month 1 is January.

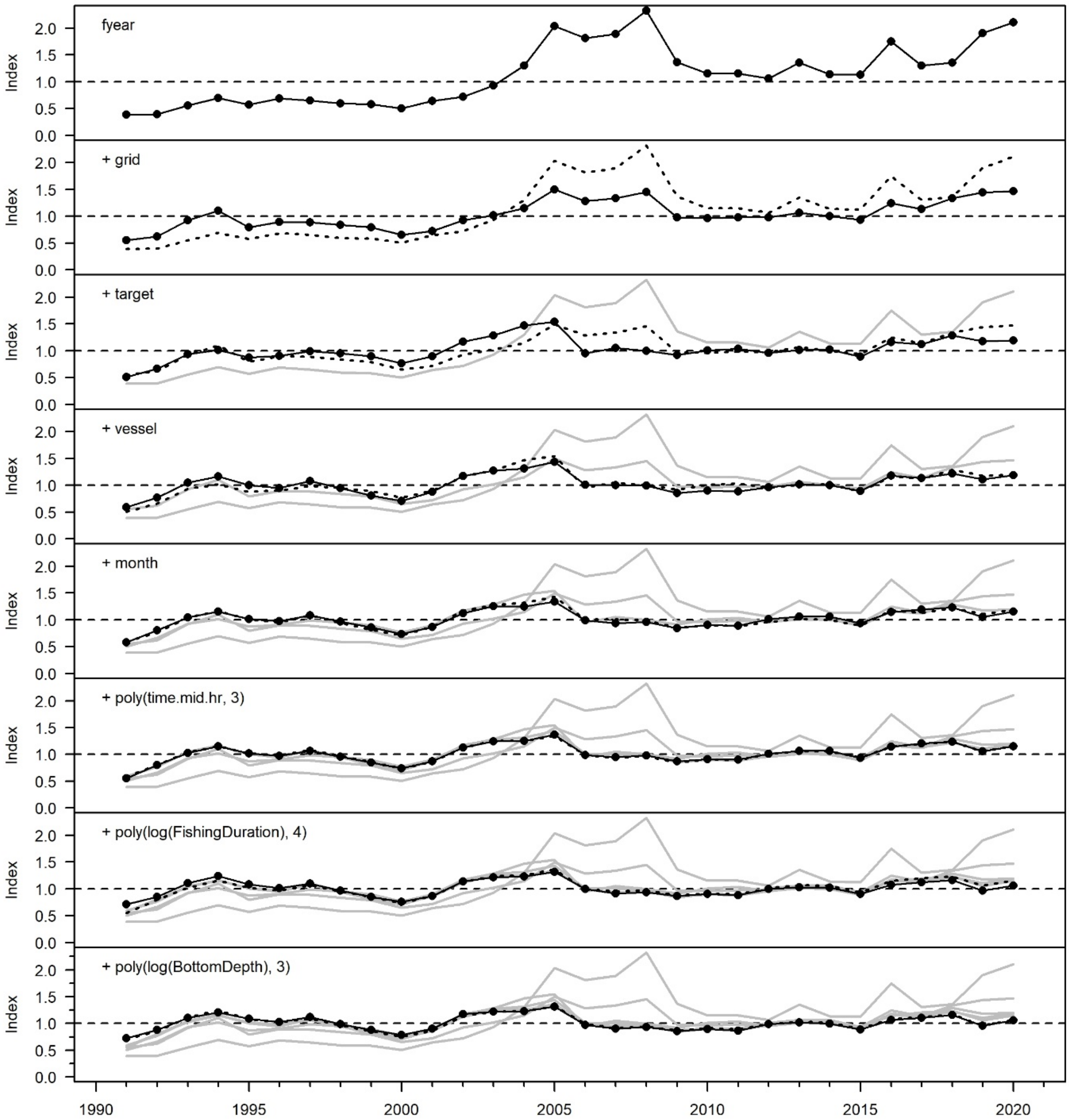


Figure D.6: Influence plots for the lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6) for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

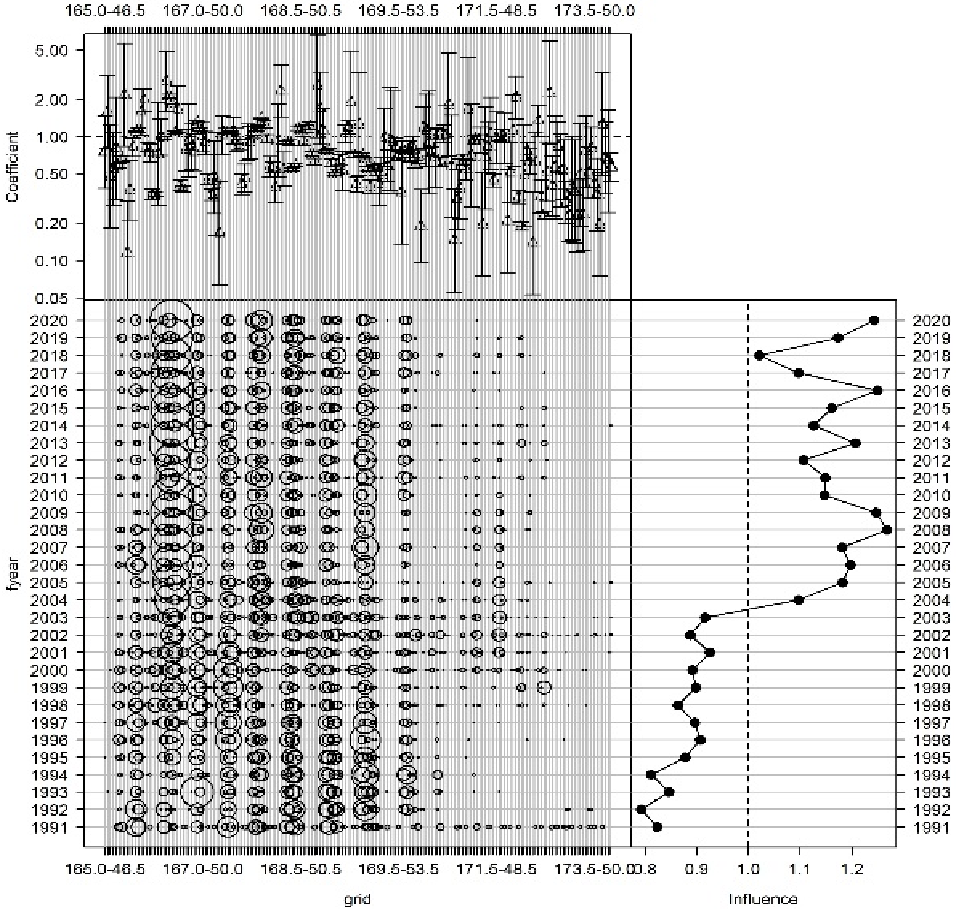


Figure D.7: Influence plots for the lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6) for grid cell in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

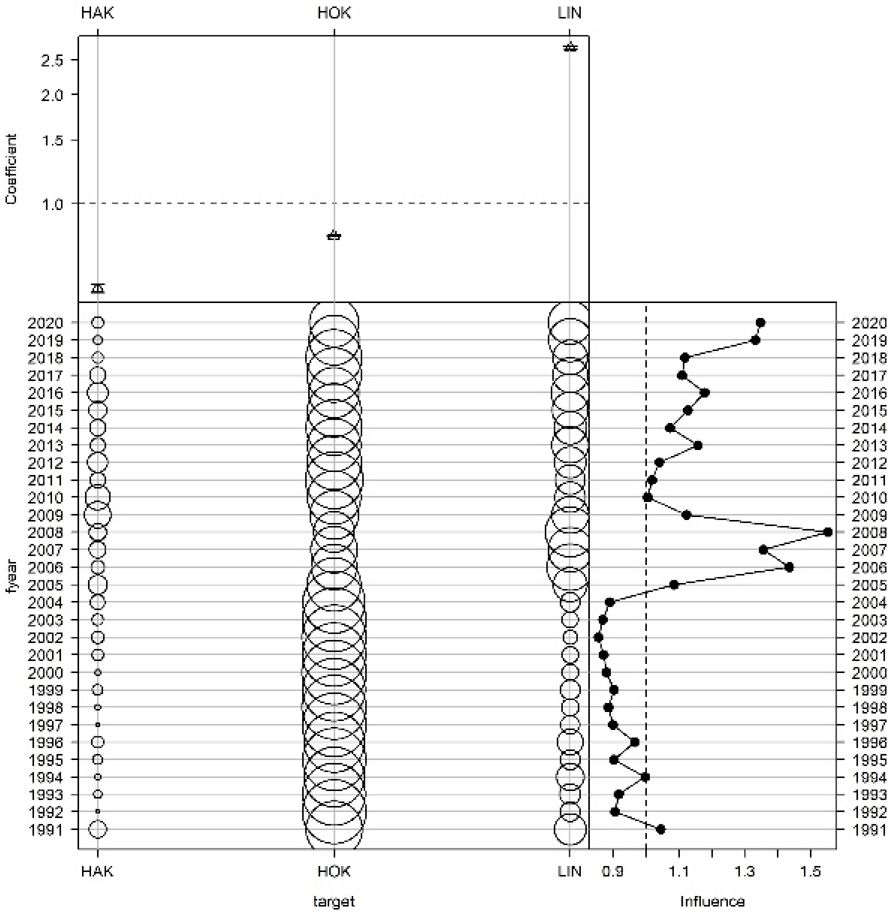


Figure D.8: Influence plots for the lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6) for target species in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

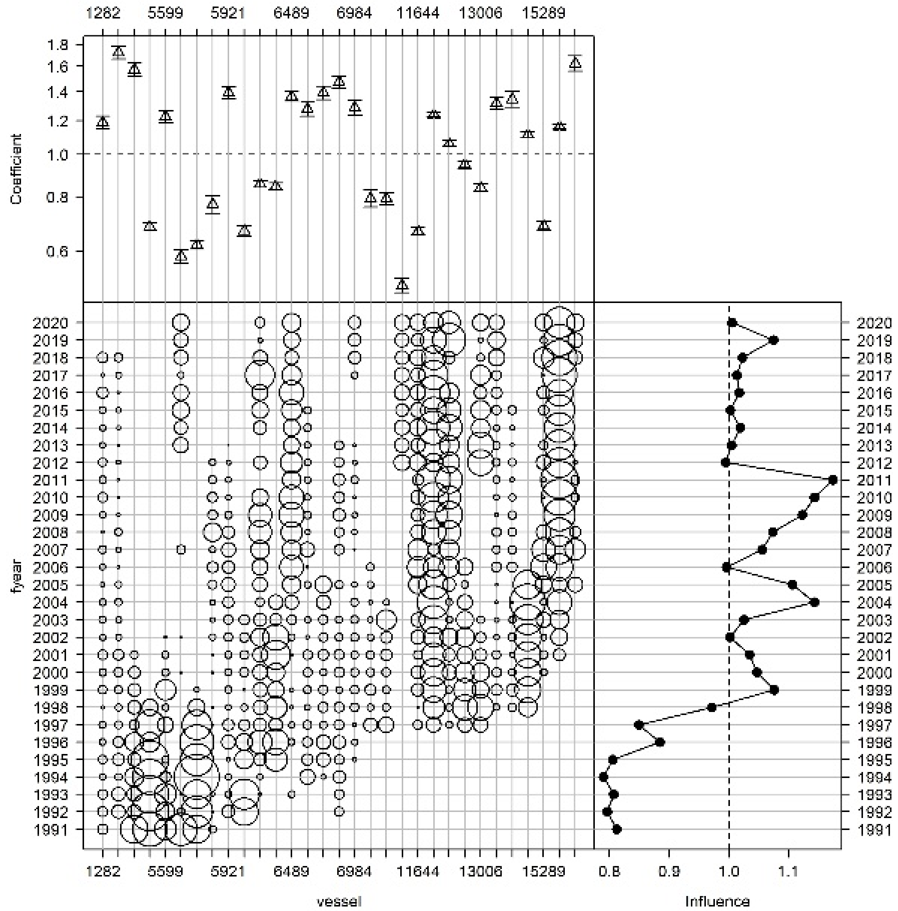


Figure D.9: Influence plots for the lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6) for vessel in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

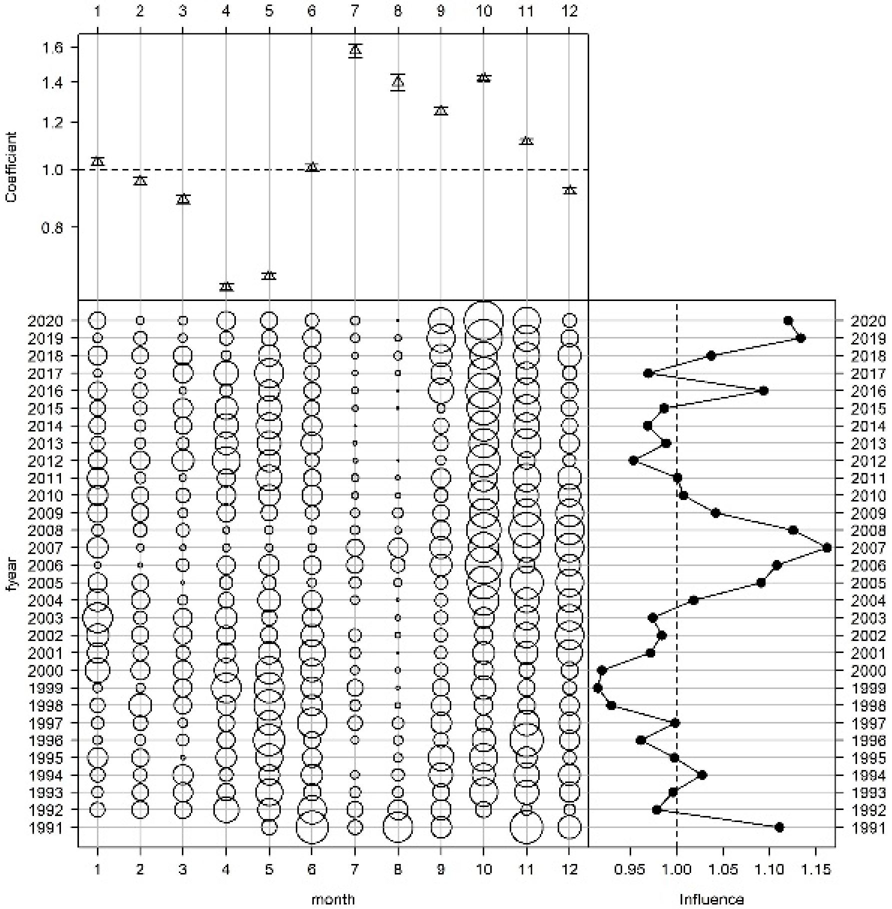


Figure D.10: Influence plots for the lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6) for month in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

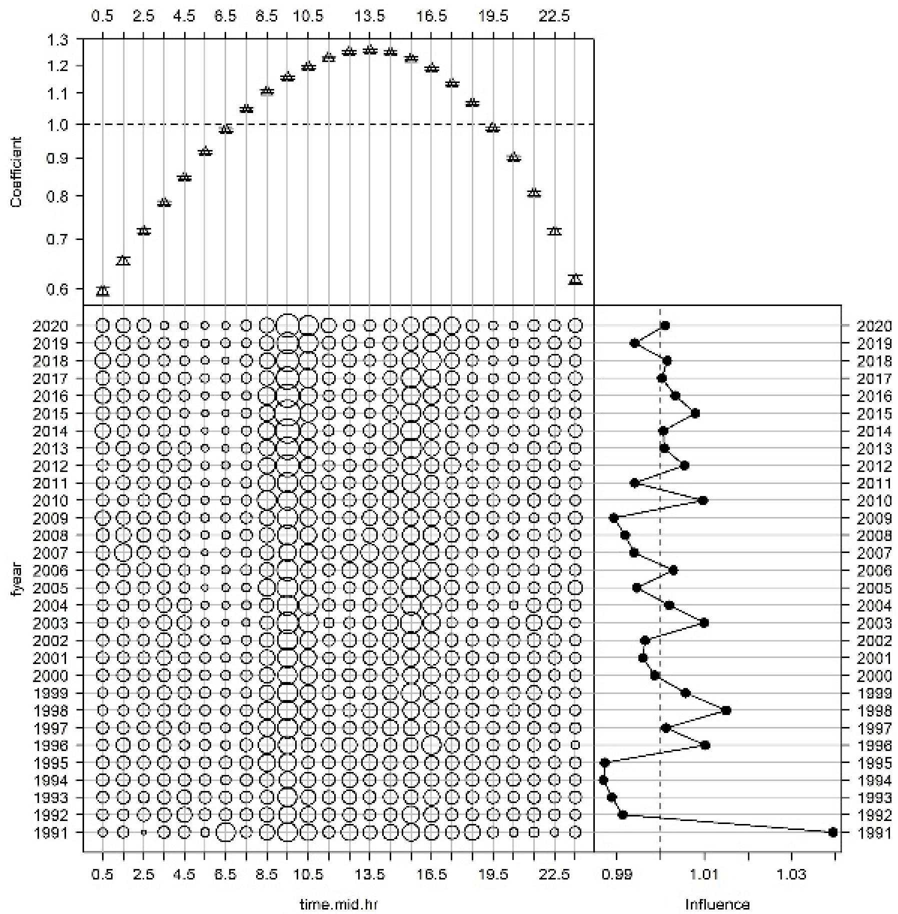


Figure D.11: Influence plots for the lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6) for time of midpoint of the tow in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

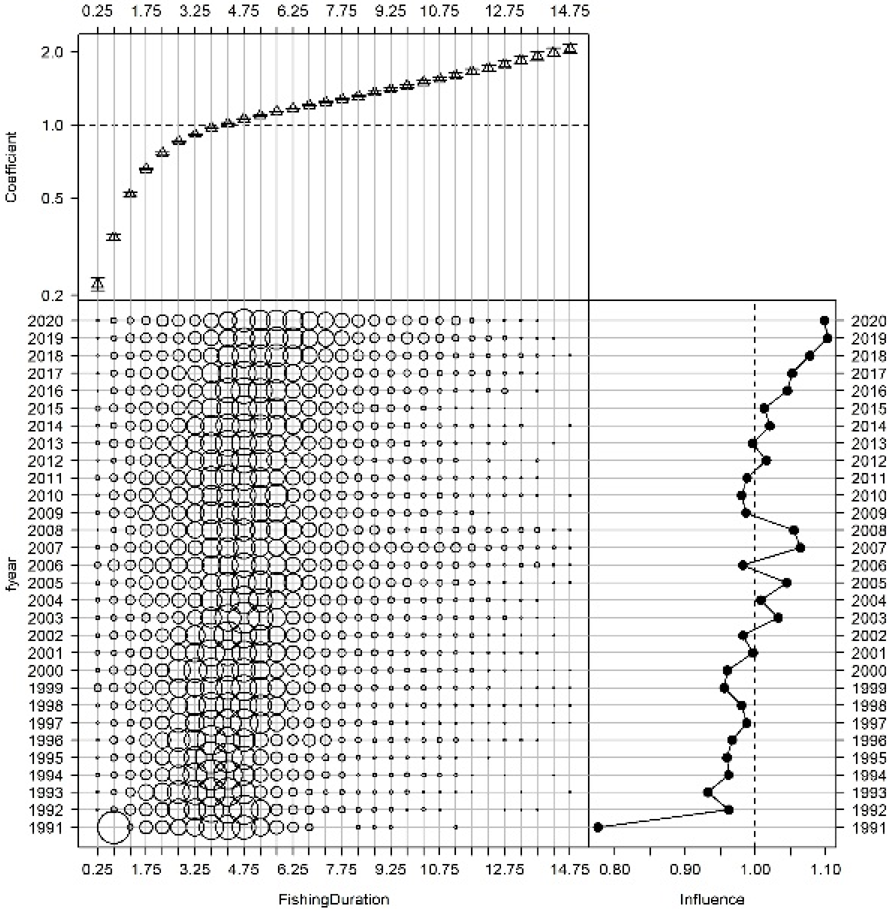


Figure D.12: Influence plots for the lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6) for fishing duration in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

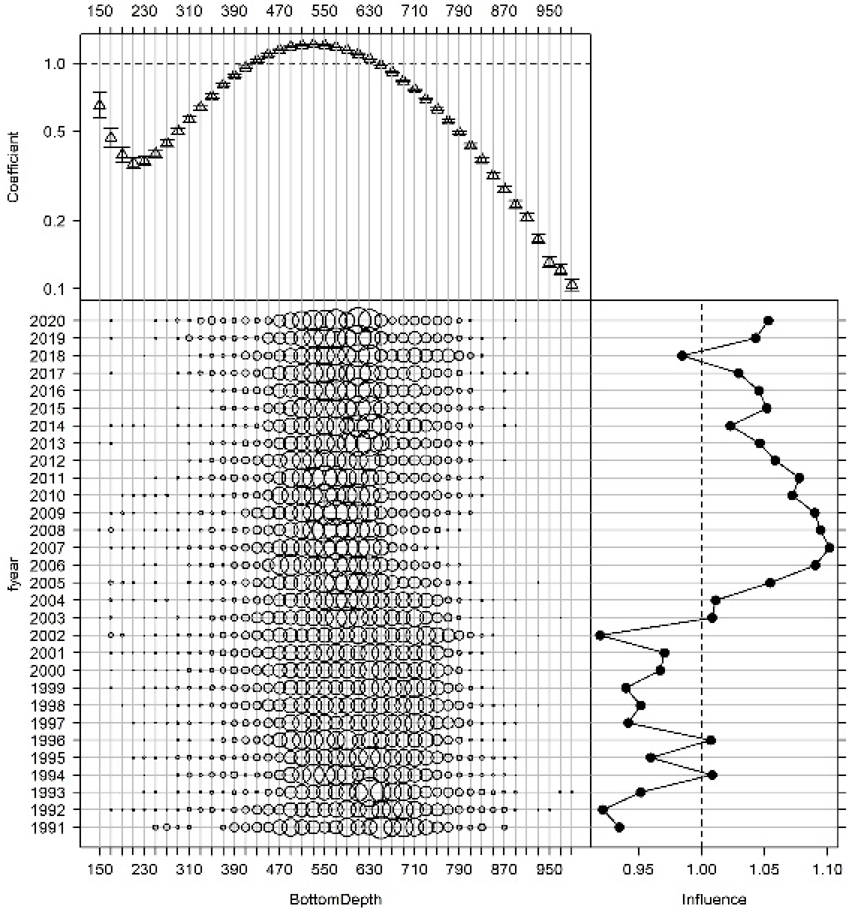


Figure D.13: Influence plots for the lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6) for bottom depth in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

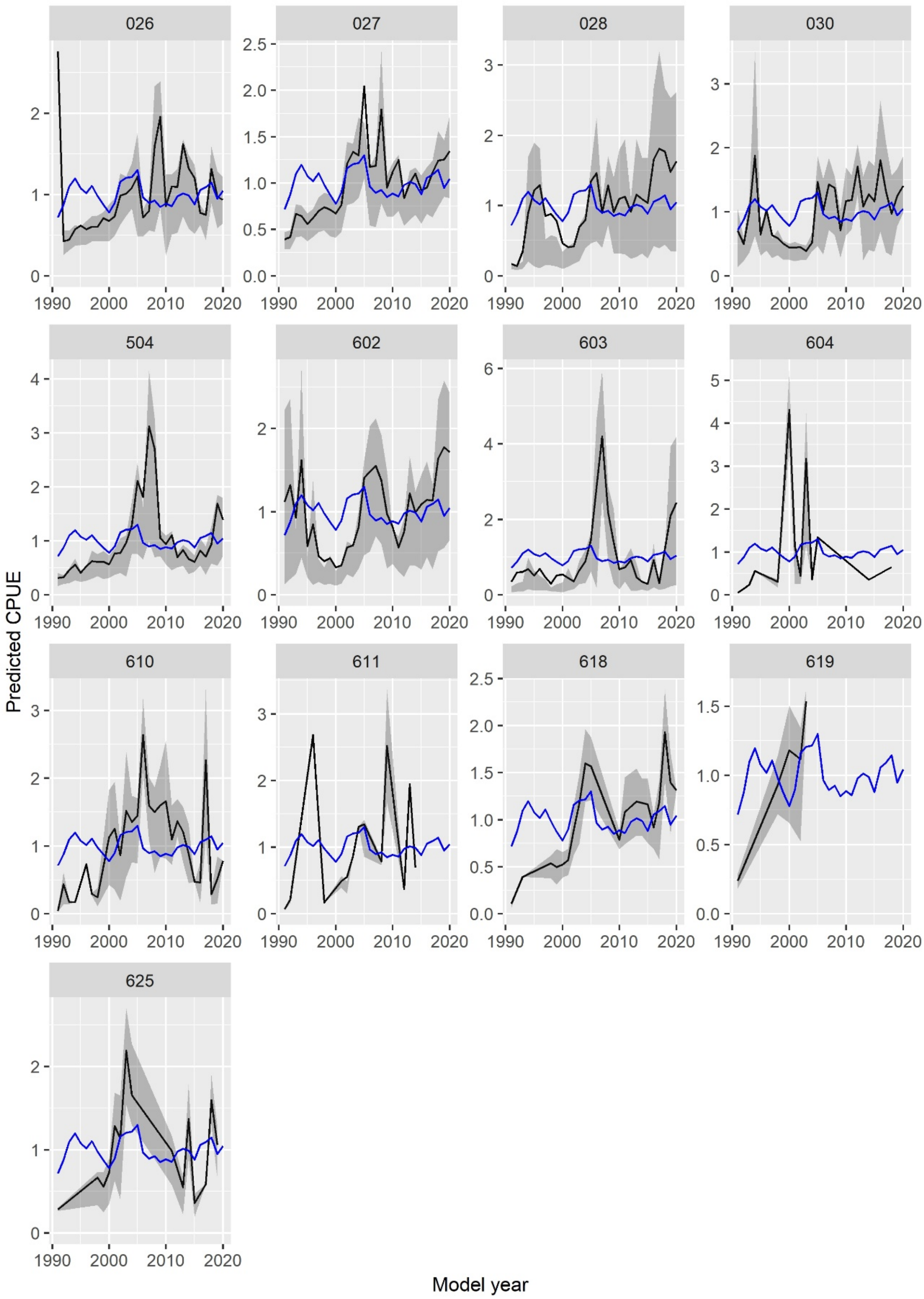
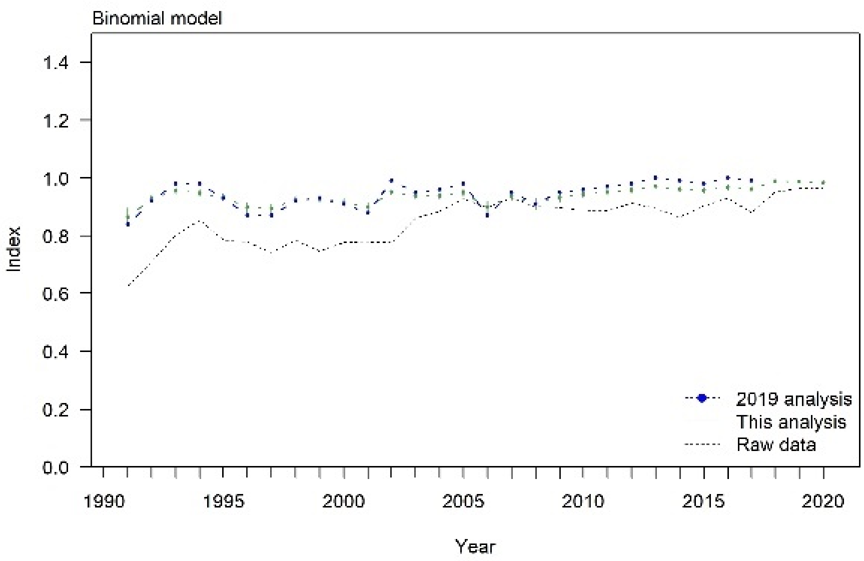


Figure D.14: Implied trends by statistical area for the lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6). The black trend and grey band represent the predicted mean standardised catch rate and interquartile range, and the blue trend the predicted year effect of the standardised CPUE. Year is model year, from 1st September to 31st August.



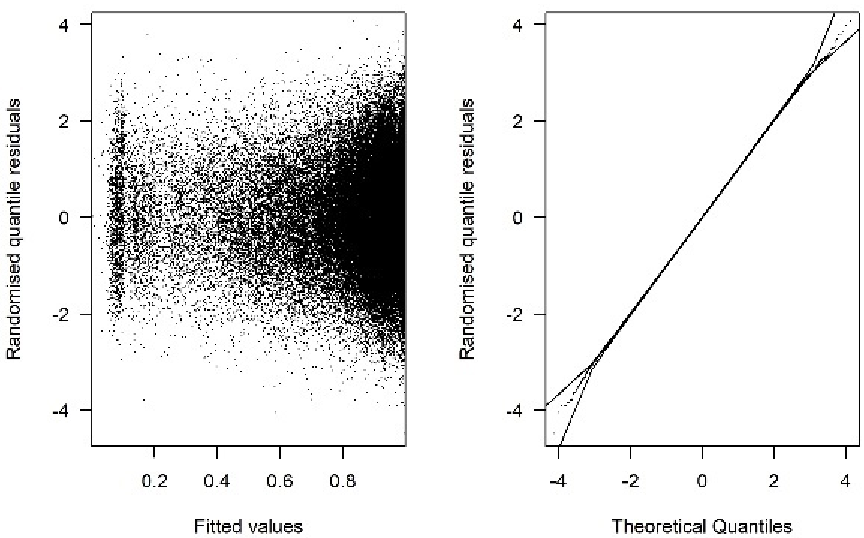


Figure D.15: Year index for the binomial model for the tow-by-tow bottom trawl CPUE (top) and residual plots of that model (bottom). Also plotted the 2019 index (Ballara 2019) and the raw catch rates. Year is model year, from 1st September to 31st August.

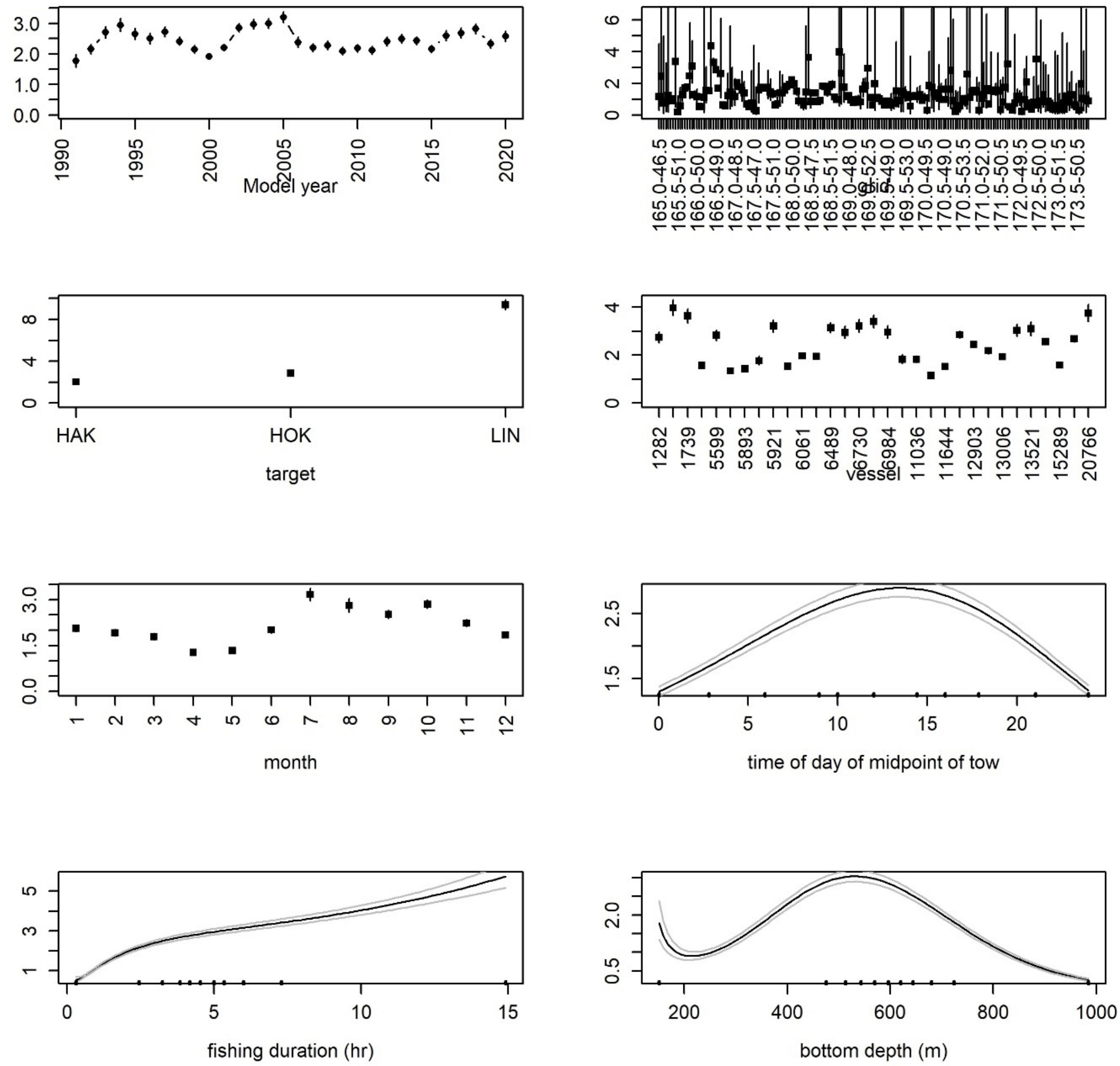


Figure D.16: Effects plots for the binomial model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6) for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August. Month 1 is January.

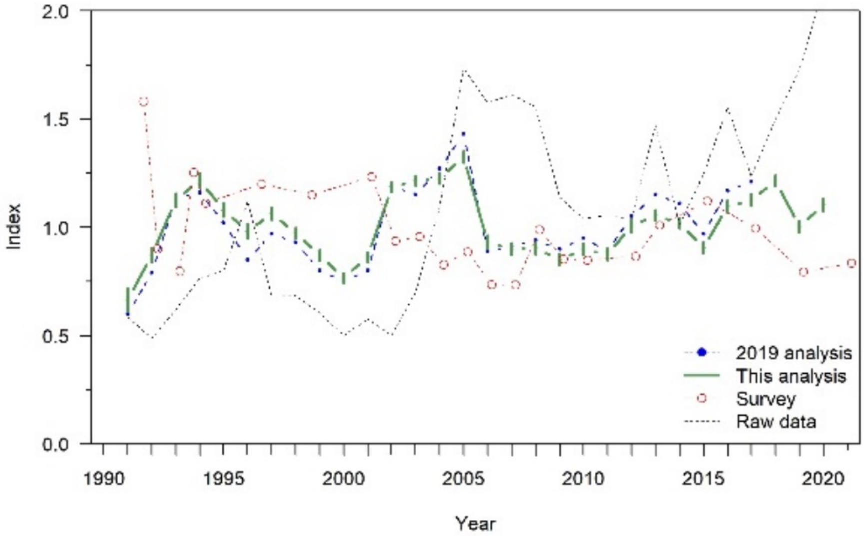


Figure D.17: Year index for the delta lognormal model for the tow-by-tow bottom trawl CPUE for Sub-Antarctic ling (LIN 5&6). Also plotted the 2019 index (Ballara 2019), Sub-Antarctic trawl survey biomass series (Fisheries New Zealand 2021) and the raw catch rates. Year is model year, from 1st September to 31st August.

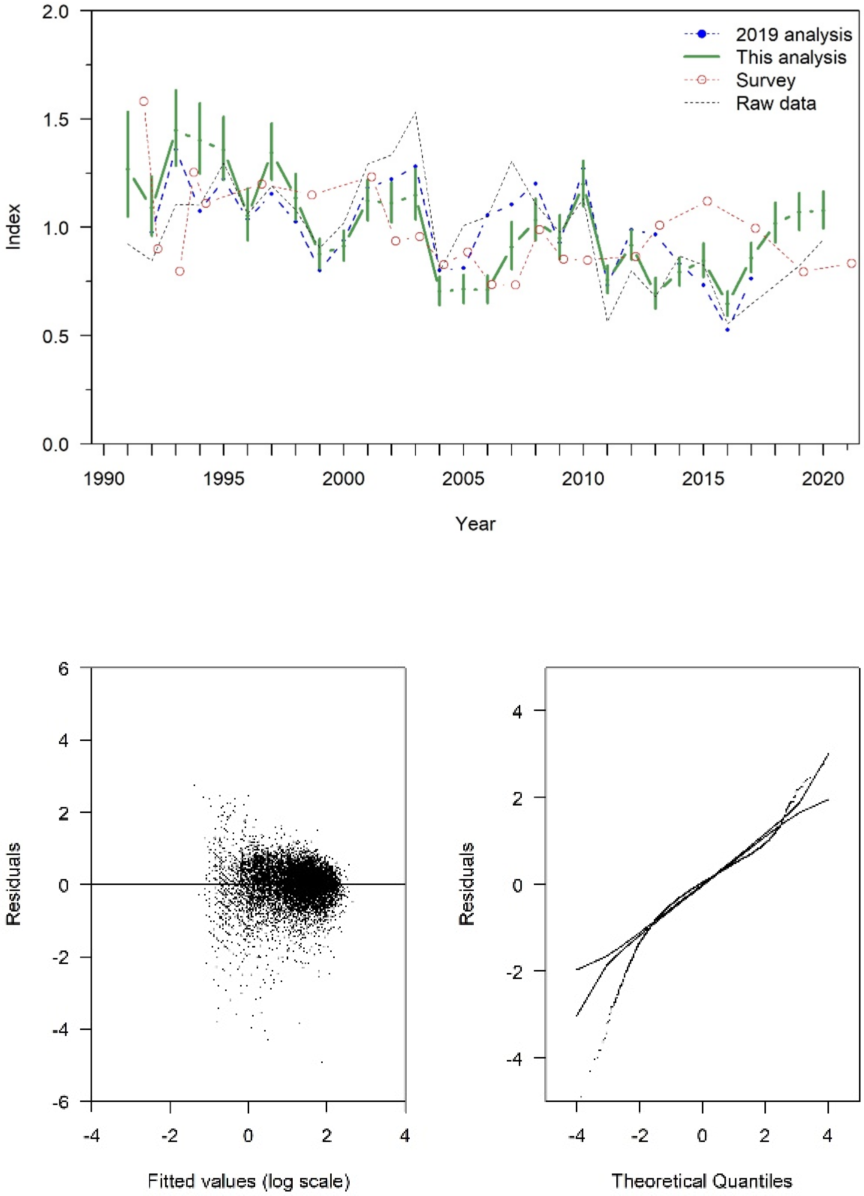


Figure D.18: Year index for the lognormal model for the rolled-up bottom longline CPUE for Sub-Antarctic ling (LIN 5&6) (top) and residual plots of that model (bottom). Also plotted the 2019 index (Ballara 2019), Sub-Antarctic trawl survey biomass series (Fisheries New Zealand 2021) and the raw catch rates. Year is model year, from 1st September to 31st August.

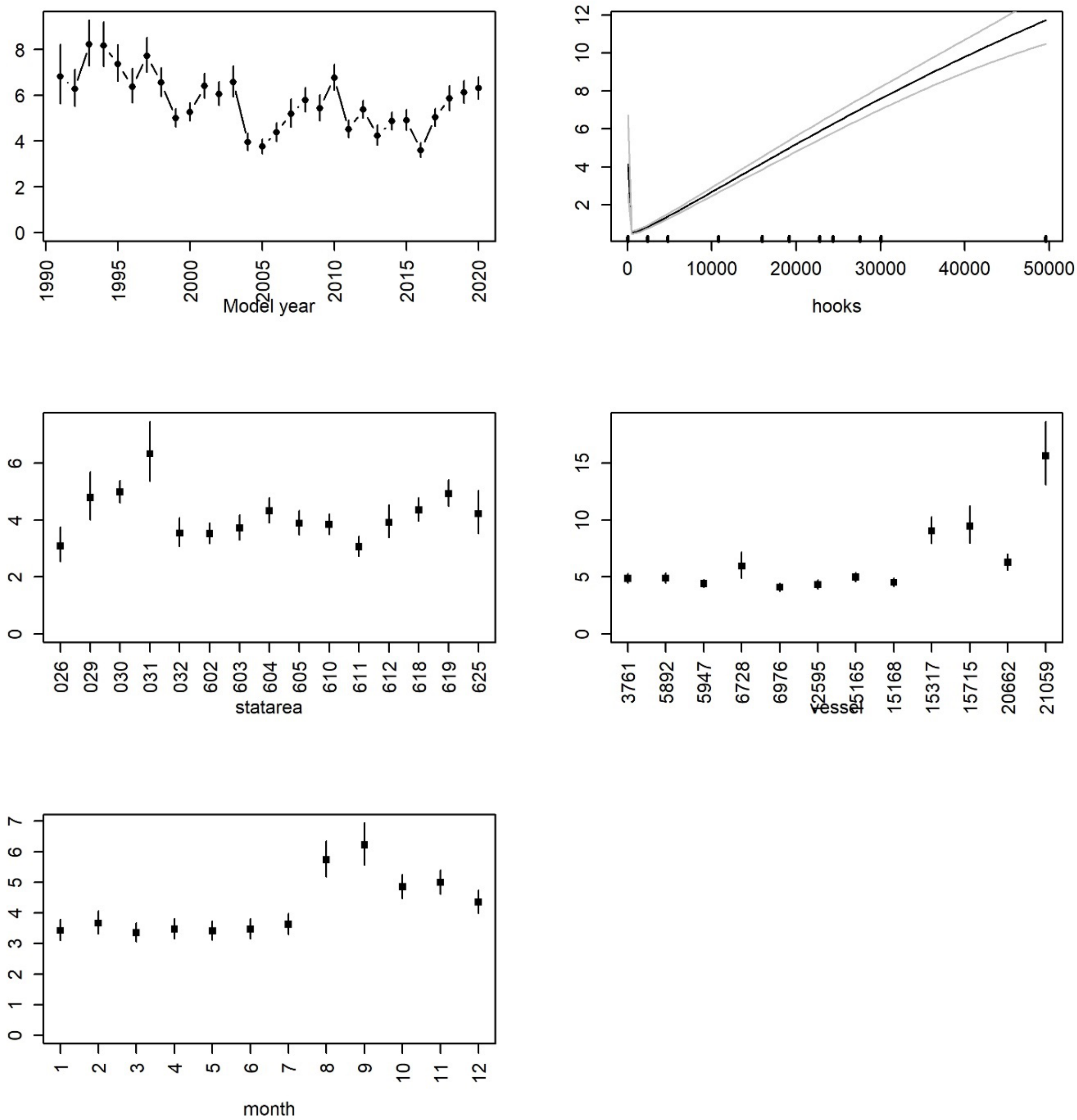


Figure D.19: Effects plots for the lognormal model for the rolled-up bottom longline CPUE for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August. Month 1 is January.

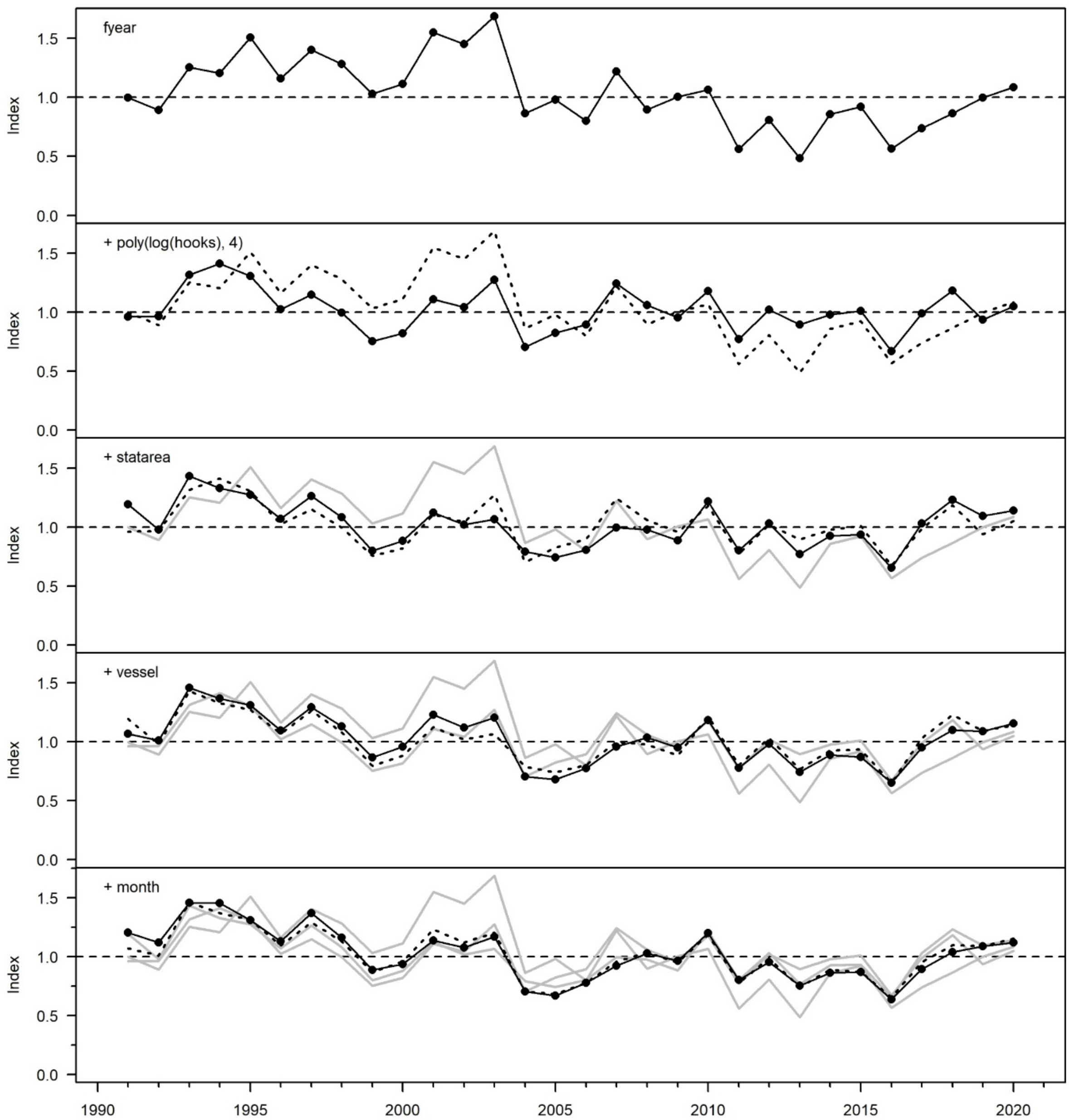


Figure D.20: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

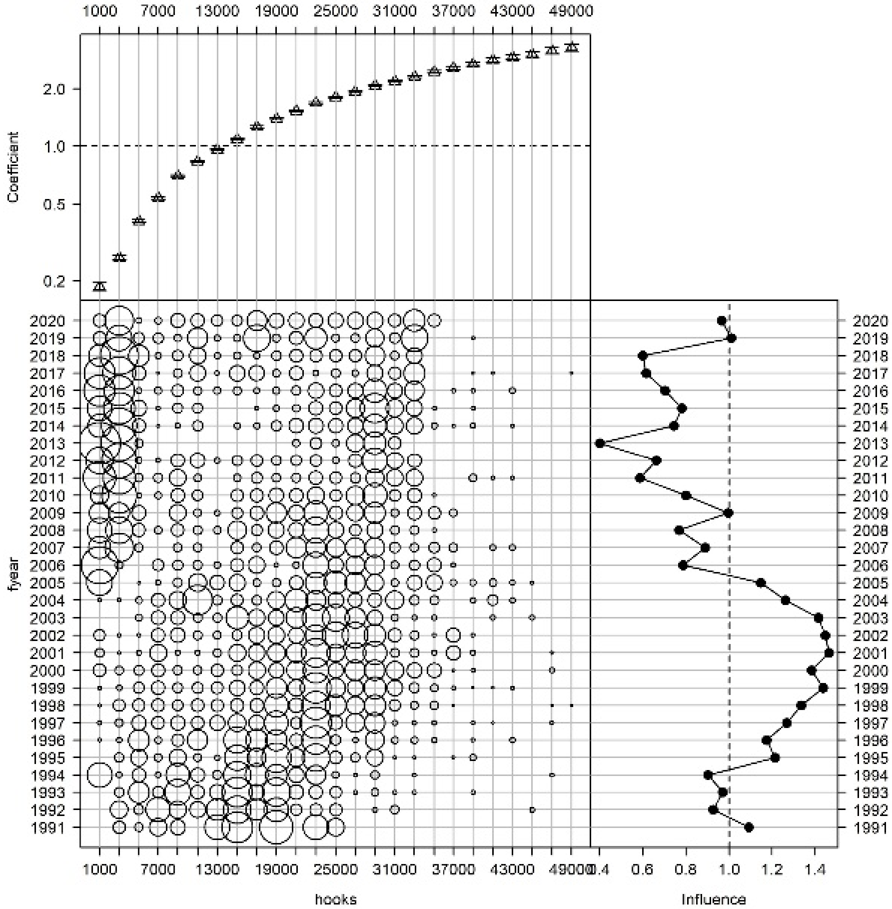


Figure D.21: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for number of hooks in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

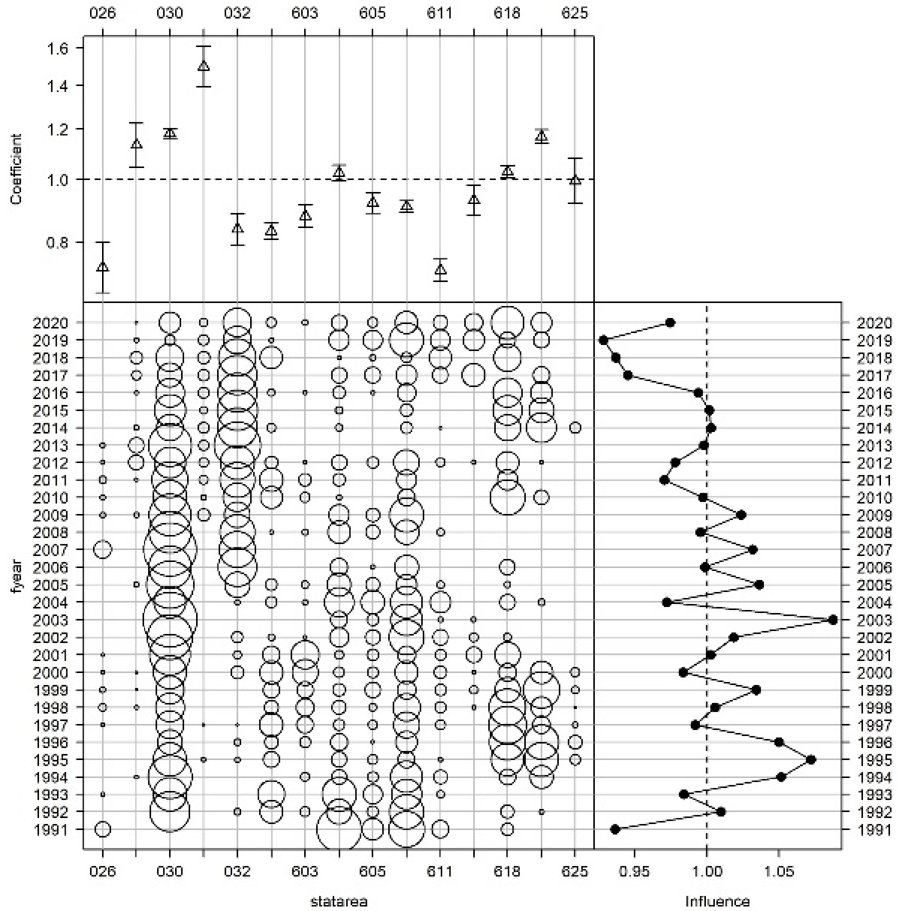


Figure D.22: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for statistical area in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

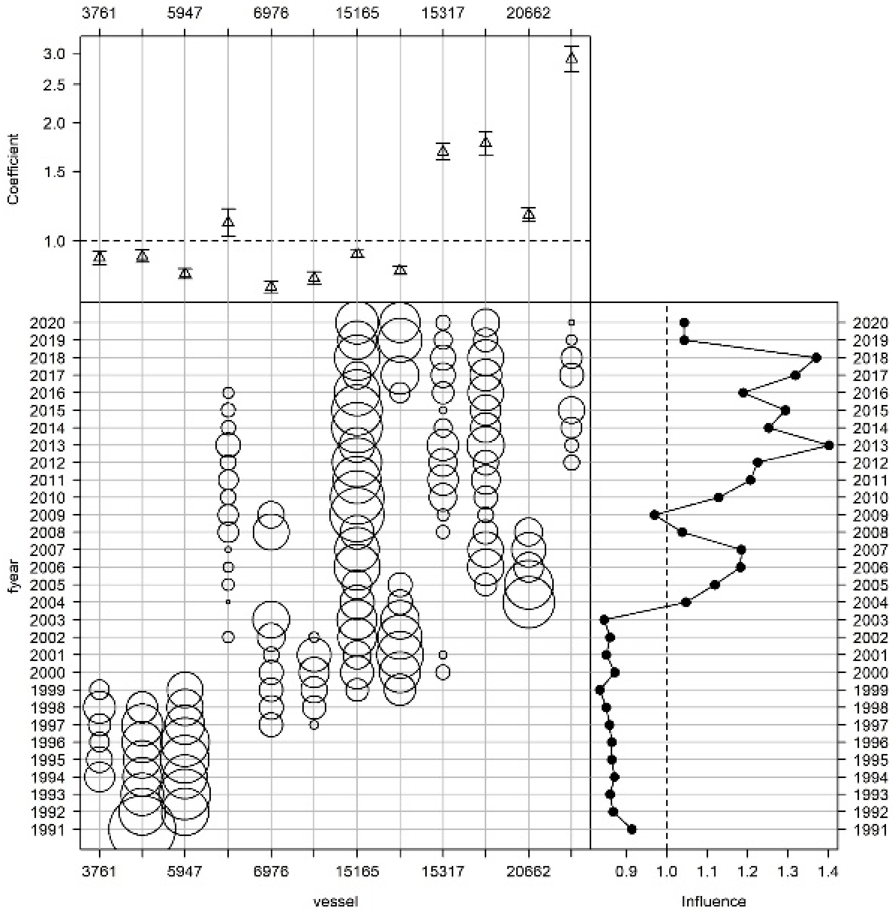


Figure D.23: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for vessel in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

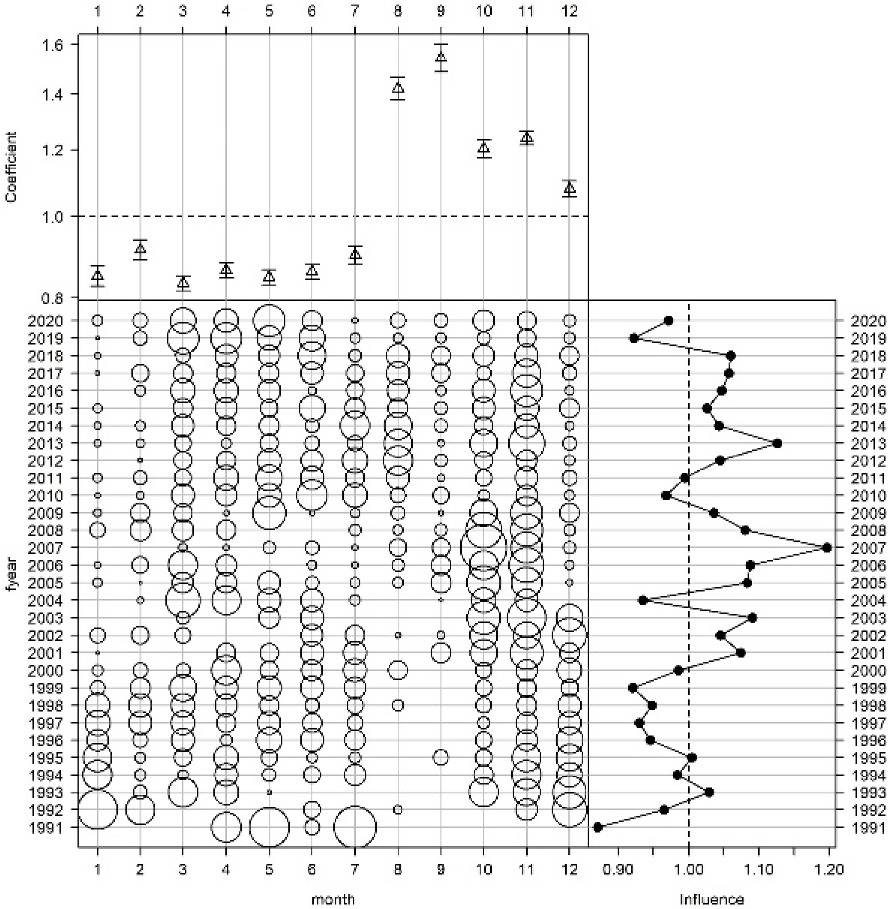


Figure D.24: Influence plots for the lognormal model for the rolled-up bottom longline CPUE for month in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August. Month 1 is January.

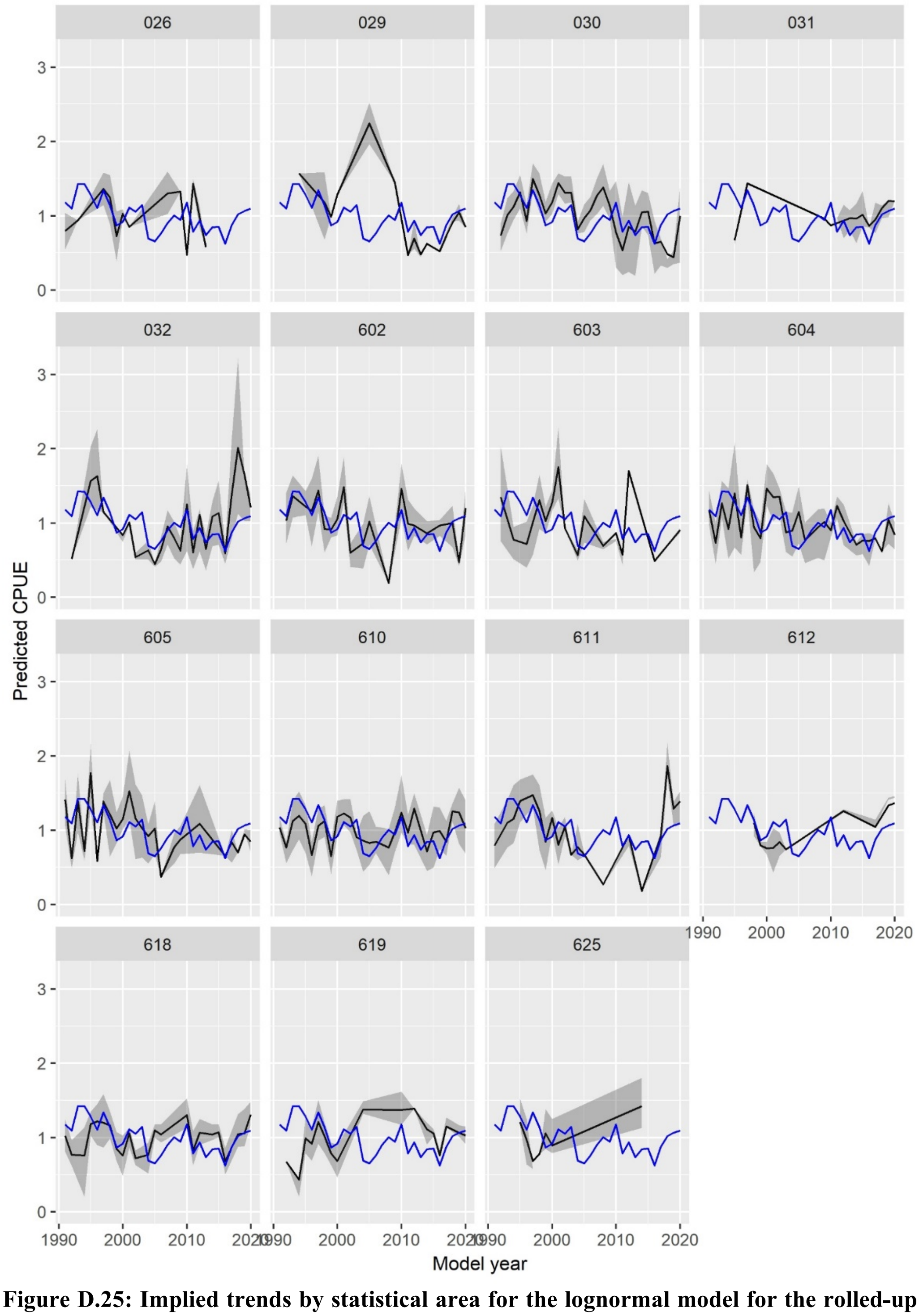
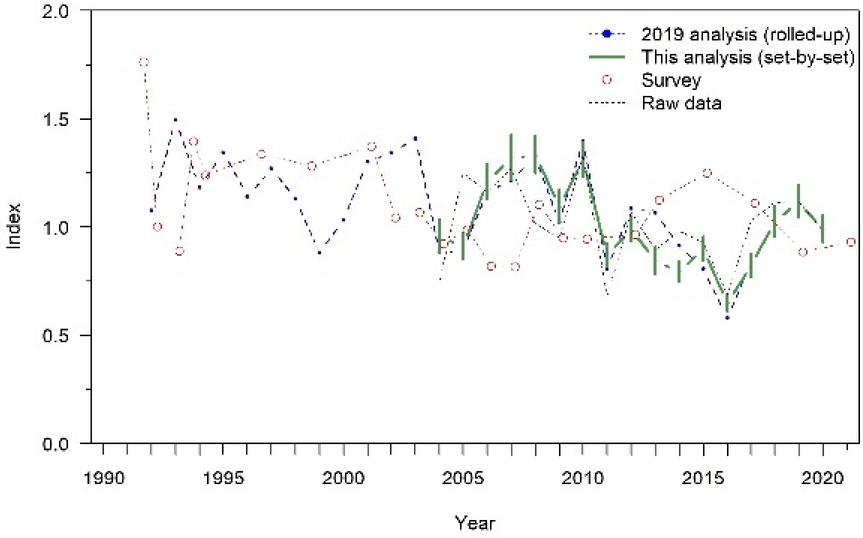


Figure D.25: Implied trends by statistical area for the lognormal model for the rolled-up bottom longline CPUE. The black trend and grey band represent the predicted mean standardised catch rate and interquartile range, and the blue trend the predicted year effect of the standardised CPUE. Year is model year, from 1st September to 31st August.



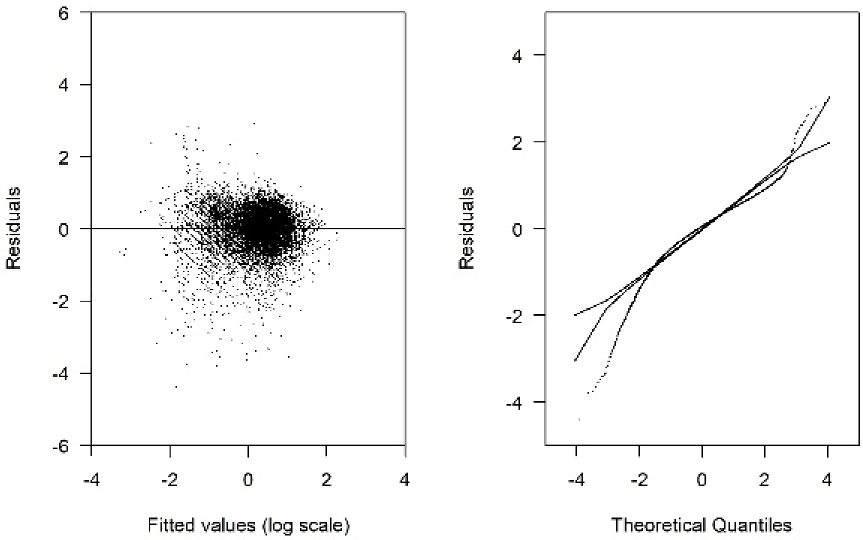


Figure D.26: Year index for the lognormal model for the set-by-set bottom longline CPUE for Sub-Antarctic ling (LIN 5&6) (top) and residual plots of that model (bottom). Also plotted the 2019 index (Ballara 2019), Sub-Antarctic trawl survey biomass series (Fisheries New Zealand 2021) and the raw catch rates. Year is model year, from 1st September to 31st August.

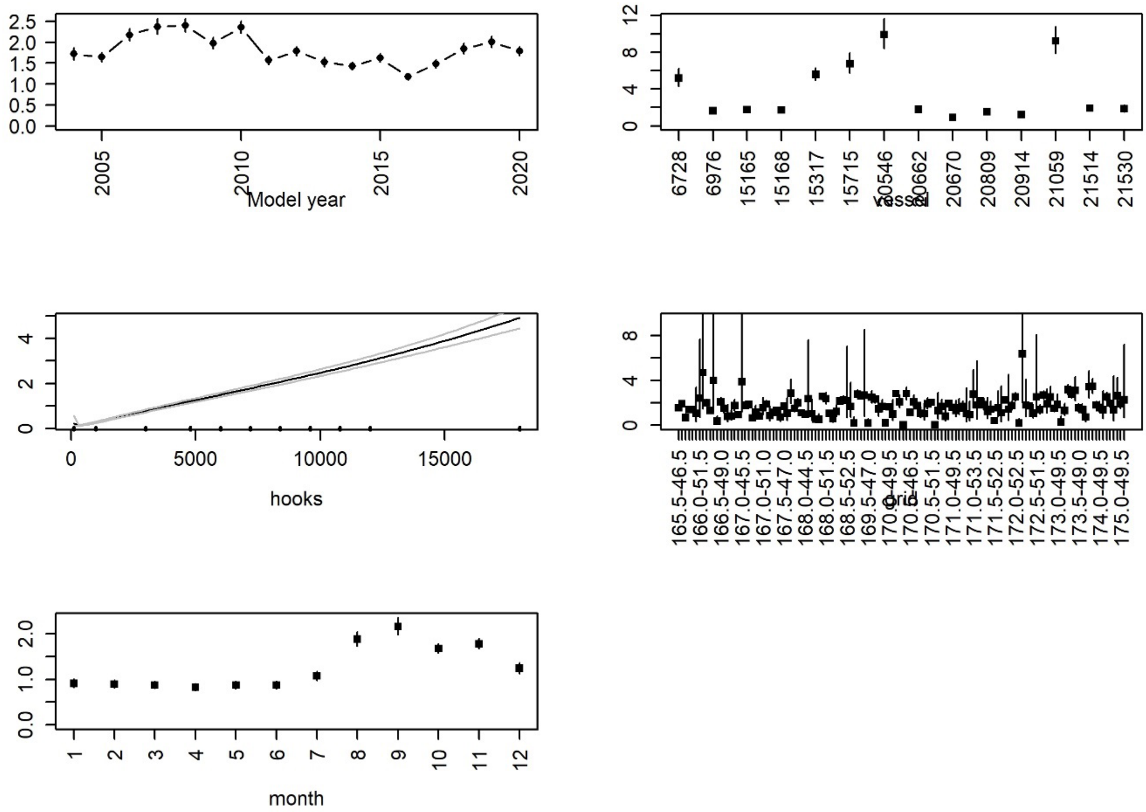


Figure D.27: Effects plots for the lognormal model for the set-by-set bottom longline CPUE for Sub-Antarctic ling (LIN 5&6) for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August. Month 1 is January.

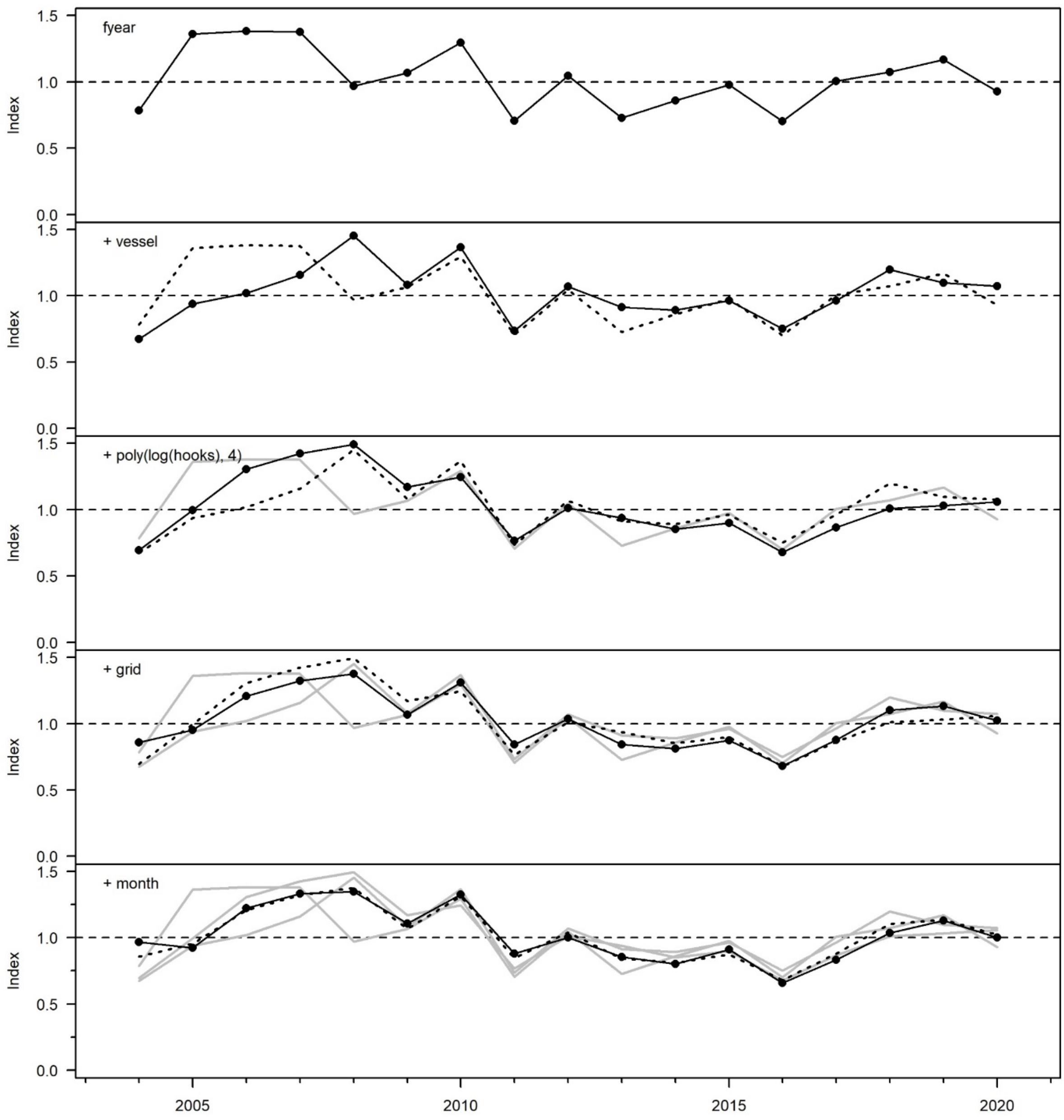


Figure D.28: Influence plots for the lognormal model for the set-by-set bottom longline CPUE for Sub-Antarctic ling (LIN 5&6) for the parameters included in the final model (in order of inclusion in the model), assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

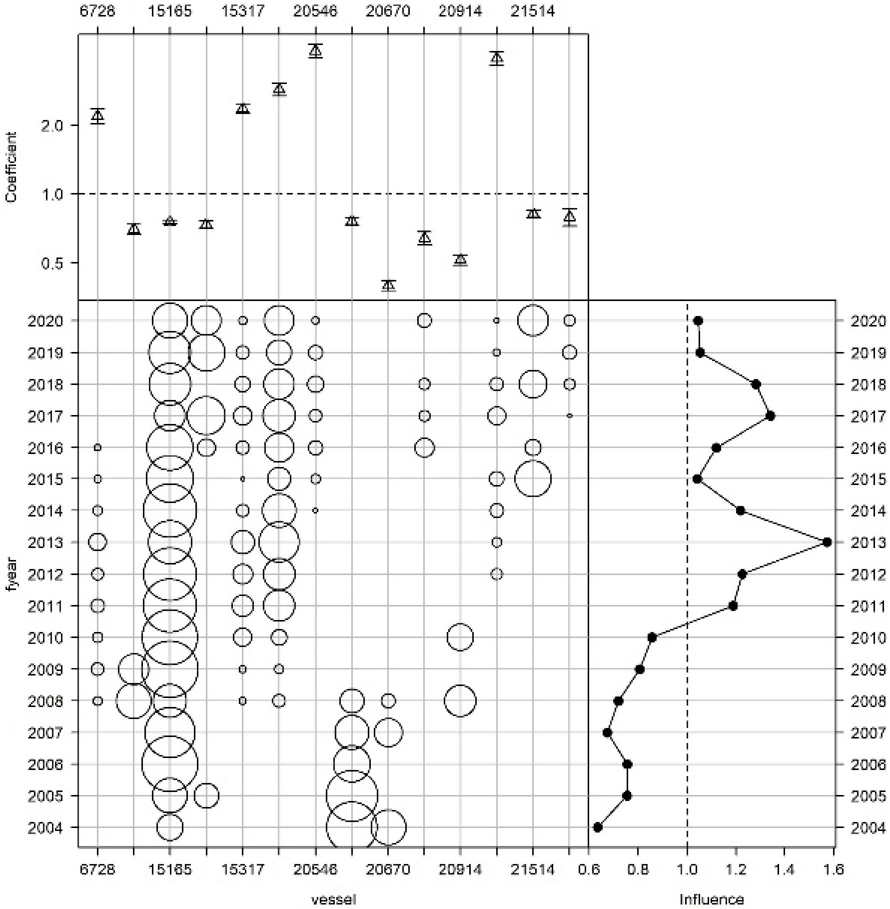


Figure D.29: Influence plots for the lognormal model for the set-by-set bottom longline CPUE for Sub-Antarctic ling (LIN 5&6) for vessel in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

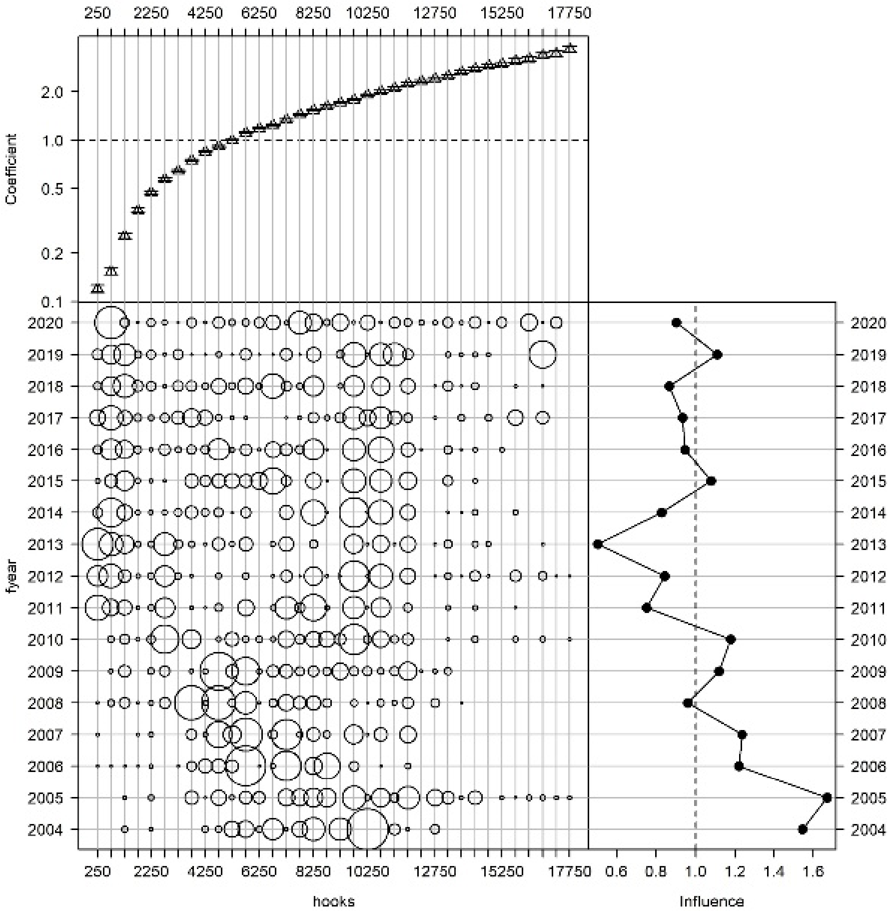


Figure D.30: Influence plots for the lognormal model for the set-by-set bottom longline CPUE for Sub-Antarctic ling (LIN 5&6) for number of hooks in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

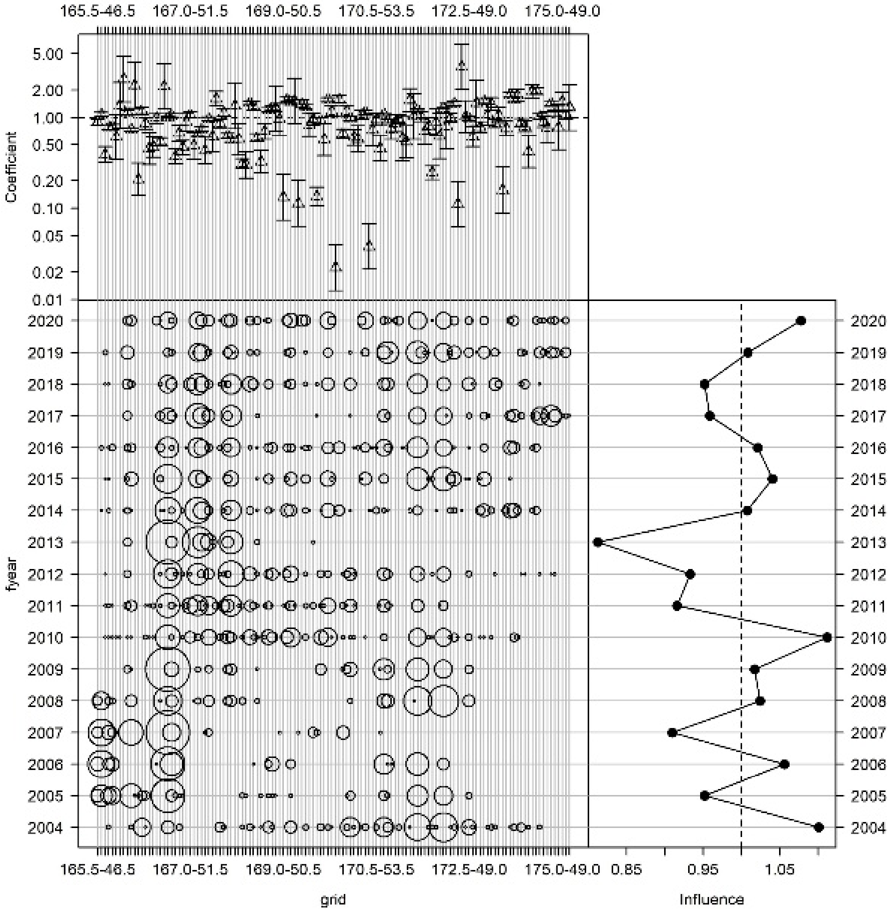


Figure D.31: Influence plots for the lognormal model for the set-by-set bottom longline CPUE for Sub-Antarctic ling (LIN 5&6) for grid in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August.

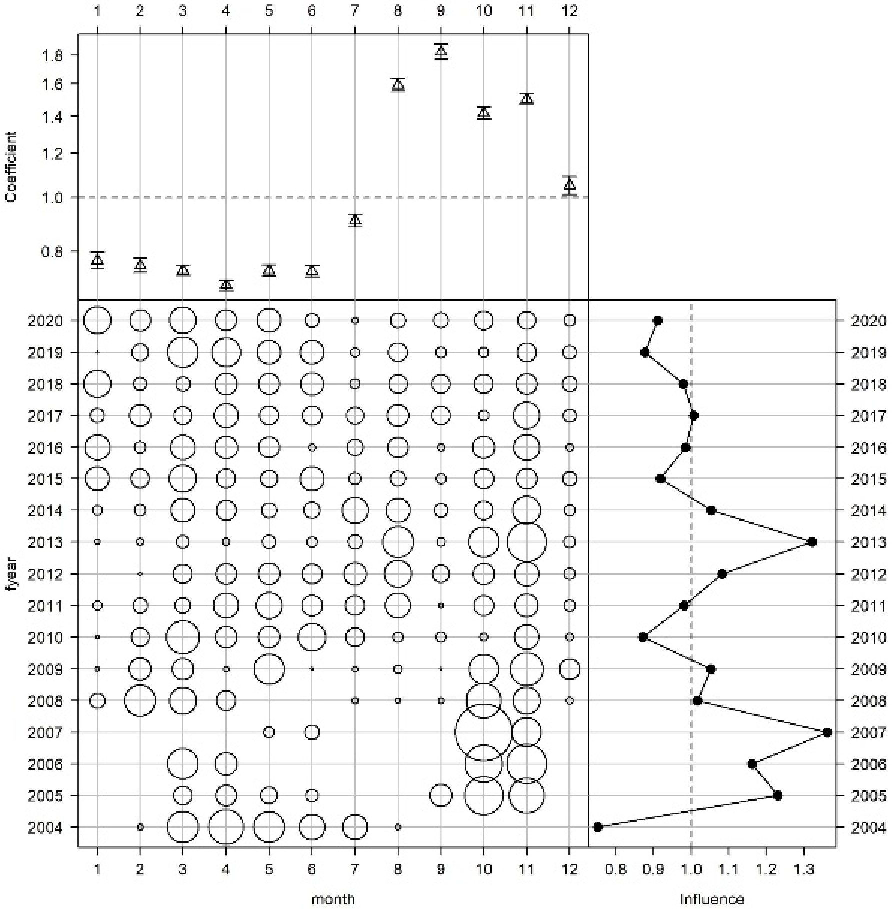


Figure D.32: Influence plots for the lognormal model for the set-by-set bottom longline CPUE for Sub-Antarctic ling (LIN 5&6) for month in relation to year, assuming all other parameters are constant at their median or modal value. Year is model year, from 1st September to 31st August. Month 1 is January.

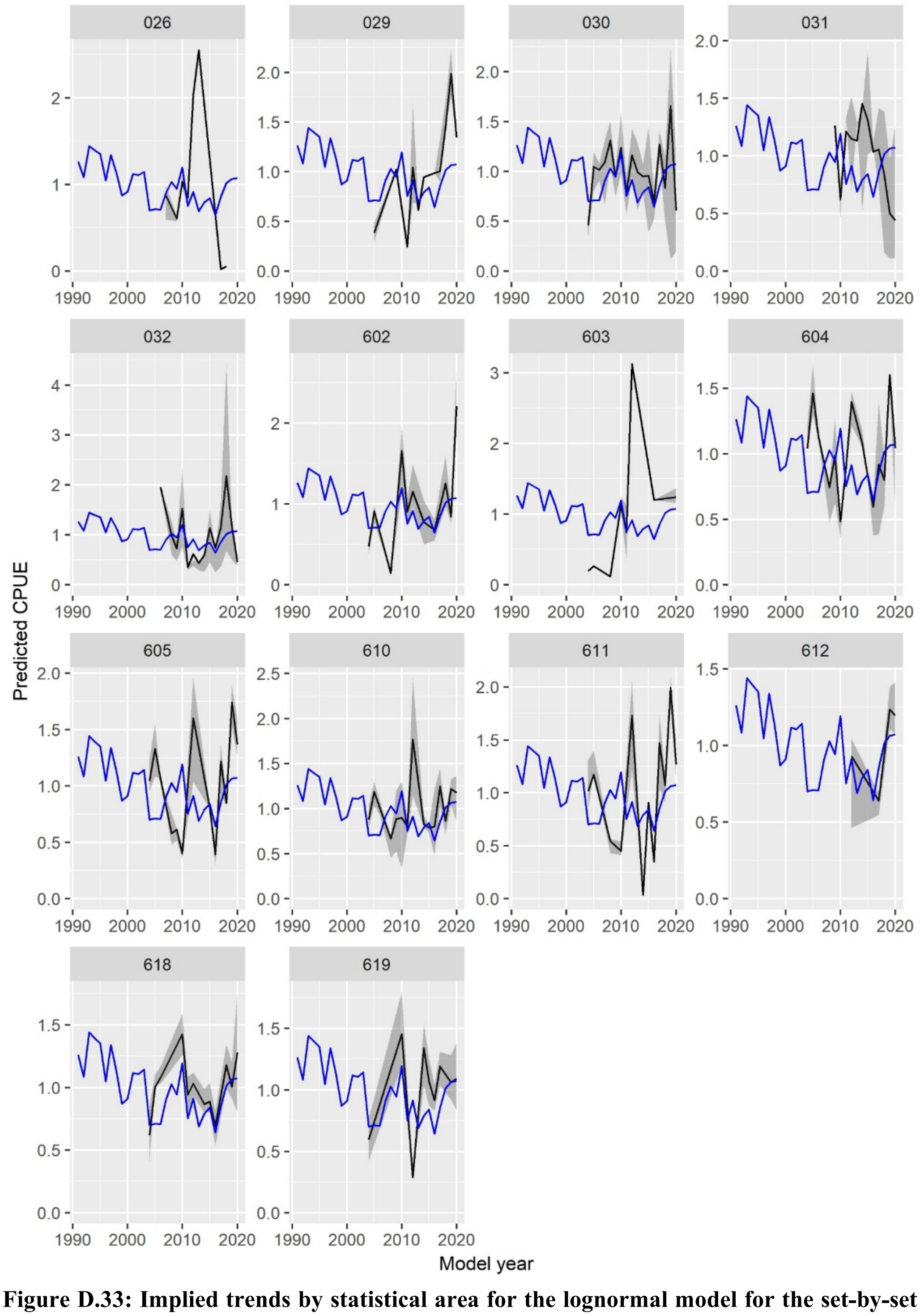


Figure D.33: Implied trends by statistical area for the lognormal model for the set-by-set bottom longline CPUE for Sub-Antarctic ling (LIN 5&6). The black trend and grey band represent the predicted mean standardised catch rate and interquartile range, and the blue trend the predicted year effect of the standardised CPUE. Year is model year, from 1st September to 31st August.

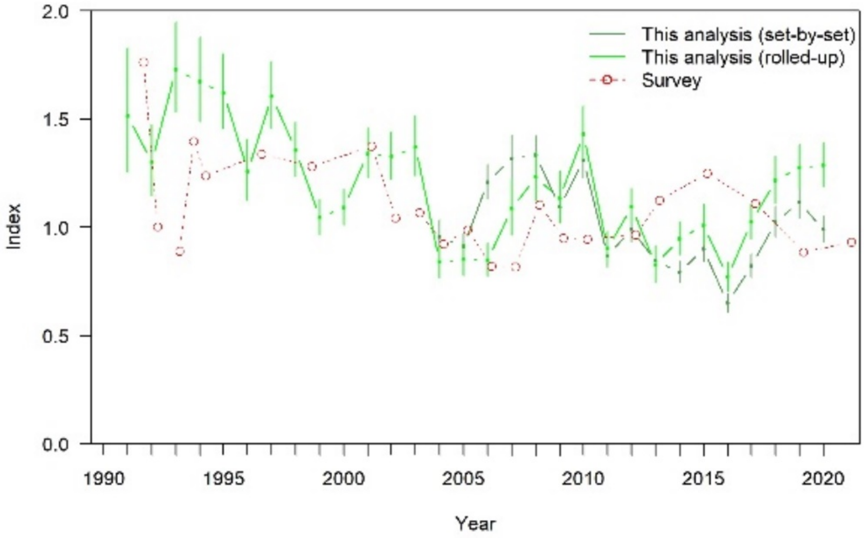


Figure D.34: Comparison of the rolled-up and set-by-set standardised CPUE for bottom longlines for Sub-Antarctic ling (LIN 5&6). Year is model year, from 1st September to 31st August.

APPENDIX E – INPUTS TO THE 2021 STOCK ASSESSMENT

Table E.1: Annual catch in tonnes per fishery as used in the 2021 stock assessment. Year is model year, from 1st September to 31st August.

Year	Trawl	Longline
1990	2 795	11
1991	4 311	187
1992	6 229	637
1993	7 445	1 280
1994	4 475	1 066
1995	6 060	2 497
1996	6 194	1 932
1997	7 394	3 386
1998	7 278	3 932
1999	5 364	2 887
2000	6 839	2 179
2001	7 005	2 181
2002	7 164	1 692
2003	7 513	1 135
2004	7 468	1 195
2005	7 562	1 153
2006	6 517	887
2007	8 021	770
2008	7 295	1 243
2009	5 372	661
2010	4 498	1 358
2011	4 392	795
2012	4 372	1 524
2013	6 222	474
2014	5 856	1 195
2015	5 830	1 067
2016	5 439	816
2017	4 783	1 226
2018	7 971	1 340
2019	6 821	1 465
2020	6 565	1 988

Table E.2: Scaled age frequencies for males in the bottom longline fishery as used in the 2021 stock assessment. Year is model year, from 1st September to 31st August.

age	1992	1994	1996	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
5	0.000	0.000	0.002	0.007	0.005	0.002	0.002	0.001	0.000	0.000	0.002	0.000	0.001	0.001	0.006	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.002	0.000
6	0.000	0.002	0.006	0.004	0.020	0.003	0.010	0.005	0.004	0.006	0.004	0.001	0.003	0.007	0.013	0.002	0.004	0.009	0.000	0.002	0.000	0.000	0.002	0.003	0.000
7	0.000	0.004	0.007	0.004	0.015	0.020	0.026	0.008	0.013	0.010	0.016	0.004	0.012	0.019	0.014	0.007	0.006	0.008	0.000	0.005	0.000	0.000	0.005	0.005	0.000
8	0.000	0.006	0.005	0.007	0.013	0.020	0.021	0.014	0.028	0.017	0.016	0.007	0.017	0.021	0.013	0.007	0.003	0.008	0.000	0.009	0.000	0.000	0.010	0.008	0.000
9	0.000	0.008	0.005	0.005	0.008	0.021	0.019	0.011	0.023	0.014	0.021	0.008	0.018	0.018	0.014	0.010	0.004	0.005	0.000	0.005	0.000	0.000	0.011	0.008	0.000
10	0.000	0.013	0.005	0.004	0.011	0.016	0.015	0.012	0.019	0.023	0.017	0.015	0.024	0.022	0.011	0.004	0.004	0.006	0.000	0.009	0.000	0.000	0.017	0.011	0.000
11	0.000	0.008	0.004	0.006	0.007	0.017	0.017	0.013	0.015	0.015	0.020	0.011	0.037	0.026	0.009	0.002	0.004	0.006	0.000	0.006	0.000	0.000	0.018	0.010	0.000
12	0.000	0.012	0.007	0.007	0.007	0.012	0.009	0.014	0.010	0.013	0.013	0.015	0.026	0.033	0.006	0.006	0.003	0.007	0.000	0.006	0.000	0.000	0.014	0.010	0.000
13	0.000	0.009	0.010	0.003	0.009	0.014	0.010	0.013	0.014	0.015	0.009	0.011	0.011	0.030	0.014	0.014	0.003	0.005	0.000	0.005	0.000	0.000	0.018	0.008	0.000
14	0.000	0.012	0.008	0.006	0.007	0.020	0.008	0.014	0.010	0.013	0.011	0.004	0.017	0.017	0.008	0.010	0.005	0.006	0.000	0.004	0.000	0.000	0.014	0.009	0.004
15	0.000	0.015	0.004	0.007	0.003	0.010	0.010	0.009	0.008	0.017	0.006	0.007	0.011	0.014	0.006	0.014	0.005	0.010	0.000	0.002	0.000	0.000	0.015	0.005	0.000
16	0.000	0.007	0.006	0.007	0.008	0.008	0.007	0.008	0.009	0.012	0.005	0.006	0.007	0.010	0.003	0.011	0.006	0.008	0.000	0.007	0.000	0.000	0.012	0.008	0.026
17	0.000	0.010	0.008	0.006	0.005	0.012	0.009	0.007	0.007	0.012	0.001	0.007	0.011	0.011	0.002	0.003	0.005	0.007	0.000	0.002	0.000	0.000	0.010	0.002	0.000
18	0.000	0.006	0.003	0.003	0.006	0.019	0.011	0.005	0.006	0.012	0.007	0.008	0.011	0.004	0.003	0.003	0.004	0.005	0.000	0.002	0.000	0.000	0.014	0.005	0.000
19	0.000	0.002	0.000	0.002	0.009	0.013	0.009	0.007	0.007	0.011	0.001	0.004	0.005	0.002	0.003	0.001	0.001	0.006	0.000	0.001	0.000	0.000	0.011	0.005	0.005
20	0.000	0.002	0.001	0.002	0.004	0.006	0.011	0.007	0.007	0.004	0.000	0.006	0.007	0.001	0.000	0.001	0.000	0.002	0.000	0.001	0.000	0.000	0.009	0.002	0.000
21	0.000	0.001	0.001	0.001	0.006	0.007	0.003	0.008	0.008	0.010	0.005	0.005	0.002	0.006	0.000	0.000	0.002	0.001	0.000	0.002	0.000	0.000	0.006	0.002	0.000
22	0.000	0.002	0.002	0.003	0.001	0.003	0.006	0.007	0.007	0.002	0.000	0.006	0.000	0.010	0.001	0.002	0.003	0.001	0.000	0.002	0.000	0.000	0.016	0.004	0.000
23	0.000	0.006	0.002	0.000	0.001	0.003	0.003	0.004	0.007	0.005	0.002	0.002	0.003	0.002	0.001	0.003	0.001	0.001	0.000	0.000	0.000	0.000	0.006	0.004	0.000
24	0.000	0.001	0.001	0.000	0.001	0.005	0.002	0.004	0.002	0.000	0.001	0.002	0.003	0.007	0.000	0.000	0.001	0.001	0.000	0.003	0.000	0.000	0.003	0.002	0.026
25	0.000	0.001	0.005	0.001	0.006	0.008	0.006	0.007	0.004	0.004	0.002	0.005	0.007	0.005	0.001	0.006	0.010	0.004	0.000	0.006	0.000	0.000	0.006	0.011	0.000

Table E.3: Scaled age frequencies for females in the bottom longline fishery as used in the 2021 stock assessment. Year is model year, from 1st September to 31st August.

age	1992	1994	1996	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
5	0.000	0.001	0.006	0.010	0.008	0.000	0.002	0.000	0.000	0.000	0.006	0.001	0.000	0.000	0.000	0.001	0.004	0.002	0.000	0.002	0.000	0.000	0.001	0.000	0.000
6	0.000	0.004	0.006	0.011	0.018	0.001	0.008	0.005	0.002	0.002	0.004	0.001	0.001	0.002	0.010	0.003	0.013	0.008	0.000	0.004	0.000	0.000	0.002	0.002	0.017
7	0.000	0.019	0.014	0.015	0.019	0.003	0.024	0.013	0.010	0.006	0.011	0.002	0.006	0.008	0.022	0.009	0.015	0.018	0.000	0.011	0.000	0.000	0.007	0.009	0.026
8	0.000	0.024	0.023	0.021	0.028	0.013	0.022	0.027	0.032	0.020	0.042	0.013	0.012	0.013	0.037	0.019	0.010	0.027	0.000	0.019	0.000	0.000	0.015	0.026	0.017
9	0.000	0.032	0.031	0.031	0.025	0.023	0.028	0.024	0.036	0.034	0.052	0.016	0.024	0.018	0.038	0.029	0.026	0.029	0.000	0.025	0.000	0.000	0.014	0.028	0.032
10	0.000	0.036	0.037	0.025	0.030	0.024	0.022	0.019	0.029	0.020	0.053	0.040	0.026	0.016	0.040	0.051	0.022	0.026	0.000	0.016	0.000	0.000	0.018	0.023	0.018
11	0.000	0.035	0.031	0.036	0.018	0.033	0.031	0.033	0.021	0.021	0.035	0.048	0.042	0.023	0.046	0.028	0.029	0.033	0.000	0.030	0.000	0.000	0.023	0.035	0.032
12	0.000	0.036	0.041	0.029	0.017	0.022	0.024	0.031	0.023	0.026	0.028	0.053	0.028	0.021	0.040	0.061	0.038	0.043	0.000	0.039	0.000	0.000	0.026	0.045	0.052
13	0.000	0.035	0.047	0.035	0.025	0.025	0.022	0.038	0.024	0.026	0.016	0.049	0.021	0.024	0.030	0.037	0.037	0.030	0.000	0.044	0.000	0.000	0.019	0.025	0.026
14	0.000	0.045	0.053	0.031	0.027	0.019	0.021	0.020	0.023	0.024	0.018	0.030	0.022	0.011	0.027	0.020	0.045	0.035	0.000	0.036	0.000	0.000	0.027	0.024	0.023
15	0.000	0.022	0.051	0.034	0.028	0.017	0.018	0.018	0.015	0.027	0.012	0.028	0.019	0.022	0.025	0.044	0.046	0.048	0.000	0.040	0.000	0.000	0.025	0.031	0.033
16	0.000	0.012	0.011	0.035	0.022	0.019	0.010	0.019	0.013	0.015	0.012	0.017	0.013	0.020	0.021	0.021	0.027	0.029	0.000	0.037	0.000	0.000	0.031	0.019	0.016
17	0.000	0.015	0.015	0.039	0.016	0.024	0.012	0.021	0.019	0.008	0.008	0.021	0.009	0.013	0.005	0.011	0.038	0.020	0.000	0.019	0.000	0.000	0.013	0.020	0.022
18	0.000	0.013	0.027	0.029	0.016	0.005	0.008	0.014	0.008	0.010	0.008	0.011	0.003	0.004	0.010	0.022	0.024	0.018	0.000	0.018	0.000	0.000	0.014	0.016	0.001
19	0.000	0.021	0.006	0.011	0.022	0.002	0.009	0.010	0.011	0.010	0.006	0.010	0.012	0.013	0.008	0.011	0.016	0.010	0.000	0.022	0.000	0.000	0.011	0.014	0.027
20	0.000	0.006	0.003	0.006	0.009	0.005	0.004	0.010	0.006	0.007	0.006	0.005	0.005	0.010	0.001	0.015	0.013	0.004	0.000	0.013	0.000	0.000	0.006	0.015	0.034
21	0.000	0.005	0.007	0.012	0.007	0.009	0.008	0.005	0.008	0.007	0.008	0.004	0.006	0.008	0.007	0.003	0.010	0.002	0.000	0.011	0.000	0.000	0.011	0.011	0.001
22	0.000	0.003	0.000	0.000	0.004	0.006	0.004	0.004	0.003	0.014	0.004	0.007	0.007	0.000	0.001	0.002	0.004	0.005	0.000	0.011	0.000	0.000	0.006	0.010	0.040
23	0.000	0.001	0.000	0.003	0.006	0.001	0.005	0.002	0.004	0.004	0.007	0.006	0.001	0.000	0.001	0.004	0.002	0.006	0.000	0.013	0.000	0.000	0.003	0.006	0.014
24	0.000	0.003	0.000	0.002	0.001	0.004	0.003	0.003	0.002	0.005	0.001	0.003	0.004	0.003	0.001	0.000	0.001	0.001	0.000	0.004	0.000	0.000	0.003	0.007	0.003
25	0.000	0.003	0.000	0.000	0.003	0.007	0.003	0.005	0.002	0.003	0.004	0.004	0.000	0.003	0.002	0.002	0.003	0.001	0.000	0.005	0.000	0.000	0.010	0.010	0.004

Table E.4: Scaled age frequencies for males in the bottom trawl fishery as used in the 2021 stock assessment. Year is model year, from 1st September to 31st August.

age	1992	1994	1996	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
5	0.017	0.020	0.007	0.053	0.010	0.008	0.023	0.017	0.020	0.004	0.004	0.008	0.018	0.014	0.022	0.005	0.015	0.008	0.015	0.009	0.026	0.012	0.010	0.015	0.013
6	0.030	0.008	0.013	0.017	0.028	0.010	0.027	0.034	0.024	0.031	0.016	0.009	0.022	0.021	0.029	0.009	0.018	0.051	0.047	0.019	0.060	0.059	0.040	0.019	0.025
7	0.047	0.010	0.025	0.021	0.028	0.035	0.037	0.041	0.030	0.035	0.036	0.023	0.034	0.038	0.025	0.027	0.026	0.046	0.044	0.033	0.123	0.088	0.043	0.031	0.013
8	0.067	0.012	0.016	0.020	0.023	0.033	0.024	0.041	0.037	0.031	0.034	0.028	0.031	0.030	0.026	0.025	0.021	0.033	0.059	0.045	0.100	0.119	0.041	0.037	0.020
9	0.037	0.016	0.016	0.015	0.015	0.023	0.022	0.027	0.024	0.022	0.039	0.034	0.027	0.026	0.026	0.024	0.032	0.017	0.057	0.024	0.052	0.049	0.034	0.023	0.028
10	0.020	0.013	0.020	0.009	0.022	0.021	0.017	0.021	0.014	0.033	0.025	0.036	0.026	0.030	0.017	0.015	0.025	0.022	0.045	0.031	0.057	0.065	0.034	0.032	0.036
11	0.020	0.010	0.014	0.019	0.011	0.020	0.022	0.016	0.010	0.019	0.032	0.029	0.039	0.028	0.017	0.010	0.019	0.016	0.033	0.015	0.033	0.050	0.022	0.019	0.019
12	0.022	0.016	0.019	0.012	0.012	0.013	0.009	0.015	0.005	0.011	0.019	0.029	0.018	0.024	0.010	0.016	0.013	0.016	0.021	0.019	0.022	0.022	0.018	0.017	0.031
13	0.012	0.012	0.031	0.004	0.016	0.010	0.010	0.013	0.006	0.013	0.010	0.020	0.011	0.025	0.020	0.023	0.012	0.010	0.019	0.011	0.017	0.016	0.011	0.012	0.019
14	0.016	0.013	0.023	0.012	0.009	0.016	0.010	0.010	0.004	0.013	0.014	0.006	0.012	0.013	0.012	0.018	0.017	0.013	0.021	0.012	0.015	0.034	0.008	0.011	0.015
15	0.015	0.017	0.015	0.009	0.005	0.007	0.011	0.006	0.003	0.011	0.006	0.009	0.005	0.014	0.007	0.023	0.012	0.014	0.006	0.010	0.011	0.034	0.009	0.004	0.013
16	0.011	0.006	0.009	0.008	0.010	0.005	0.007	0.004	0.003	0.008	0.006	0.008	0.004	0.005	0.004	0.015	0.010	0.012	0.015	0.006	0.007	0.015	0.008	0.006	0.007
17	0.009	0.007	0.016	0.009	0.008	0.007	0.009	0.004	0.002	0.005	0.000	0.007	0.006	0.007	0.002	0.002	0.012	0.012	0.015	0.005	0.017	0.012	0.008	0.002	0.008
18	0.006	0.006	0.011	0.003	0.008	0.013	0.010	0.002	0.001	0.004	0.008	0.004	0.006	0.001	0.004	0.002	0.008	0.006	0.010	0.003	0.031	0.019	0.008	0.006	0.003
19	0.004	0.001	0.000	0.002	0.010	0.008	0.010	0.005	0.002	0.004	0.001	0.004	0.003	0.001	0.003	0.001	0.002	0.005	0.011	0.003	0.009	0.010	0.003	0.004	0.003
20	0.003	0.001	0.002	0.002	0.004	0.004	0.010	0.004	0.002	0.002	0.000	0.003	0.004	0.000	0.000	0.001	0.001	0.002	0.009	0.001	0.001	0.018	0.003	0.002	0.005
21	0.002	0.001	0.004	0.001	0.007	0.004	0.003	0.005	0.003	0.006	0.004	0.004	0.003	0.002	0.001	0.000	0.003	0.001	0.007	0.002	0.003	0.010	0.003	0.002	0.000
22	0.016	0.001	0.002	0.004	0.002	0.001	0.005	0.003	0.002	0.000	0.000	0.003	0.000	0.000	0.001	0.005	0.002	0.001	0.003	0.004	0.005	0.013	0.006	0.002	0.003
23	0.003	0.003	0.003	0.001	0.002	0.002	0.003	0.001	0.002	0.001	0.001	0.002	0.001	0.002	0.000	0.004	0.002	0.001	0.006	0.000	0.001	0.000	0.002	0.003	0.001
24	0.001	0.001	0.003	0.000	0.001	0.002	0.001	0.001	0.001	0.000	0.001	0.002	0.002	0.002	0.000	0.000	0.000	0.001	0.004	0.000	0.000	0.004	0.001	0.003	0.005
25	0.000	0.002	0.000	0.000	0.008	0.004	0.006	0.002	0.001	0.002	0.003	0.003	0.004	0.002	0.000	0.003	0.003	0.001	0.002	0.004	0.001	0.002	0.002	0.007	0.001

Table E.5: Scaled age frequencies for females in the bottom trawl fishery as used in the 2021 stock assessment. Year is model year, from 1st September to 31st August.

age	1992	1994	1996	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
5	0.020	0.025	0.012	0.053	0.018	0.000	0.022	0.023	0.024	0.008	0.009	0.006	0.018	0.005	0.015	0.005	0.012	0.007	0.016	0.010	0.025	0.008	0.010	0.009	0.014
6	0.036	0.018	0.016	0.024	0.033	0.005	0.023	0.035	0.035	0.009	0.004	0.006	0.017	0.012	0.024	0.016	0.022	0.018	0.047	0.025	0.046	0.012	0.015	0.009	0.015
7	0.049	0.021	0.022	0.026	0.020	0.013	0.031	0.031	0.047	0.021	0.011	0.012	0.018	0.022	0.031	0.024	0.019	0.027	0.069	0.035	0.074	0.047	0.029	0.018	0.016
8	0.095	0.021	0.027	0.027	0.031	0.014	0.019	0.037	0.063	0.039	0.035	0.018	0.029	0.024	0.037	0.032	0.016	0.028	0.075	0.043	0.072	0.045	0.027	0.034	0.021
9	0.079	0.022	0.023	0.032	0.022	0.041	0.020	0.022	0.037	0.045	0.038	0.020	0.026	0.027	0.032	0.029	0.031	0.020	0.062	0.030	0.052	0.045	0.019	0.026	0.023
10	0.085	0.025	0.021	0.017	0.024	0.022	0.013	0.014	0.024	0.023	0.035	0.032	0.026	0.020	0.028	0.047	0.025	0.016	0.040	0.013	0.035	0.037	0.021	0.020	0.029
11	0.042	0.021	0.017	0.017	0.013	0.030	0.017	0.014	0.014	0.016	0.023	0.030	0.026	0.025	0.026	0.024	0.021	0.016	0.043	0.017	0.017	0.030	0.016	0.024	0.021
12	0.063	0.025	0.014	0.015	0.012	0.018	0.014	0.010	0.012	0.017	0.016	0.026	0.017	0.021	0.022	0.036	0.019	0.017	0.025	0.012	0.024	0.024	0.011	0.023	0.020
13	0.034	0.025	0.019	0.012	0.013	0.020	0.011	0.010	0.010	0.014	0.010	0.024	0.011	0.015	0.015	0.020	0.015	0.011	0.015	0.013	0.013	0.022	0.005	0.013	0.014
14	0.031	0.036	0.026	0.013	0.014	0.016	0.010	0.005	0.009	0.012	0.009	0.013	0.010	0.012	0.012	0.008	0.018	0.013	0.025	0.008	0.011	0.022	0.007	0.012	0.009
15	0.025	0.018	0.021	0.009	0.014	0.012	0.010	0.005	0.005	0.013	0.009	0.014	0.007	0.010	0.011	0.012	0.014	0.015	0.020	0.008	0.008	0.014	0.005	0.013	0.008
16	0.024	0.010	0.004	0.009	0.010	0.012	0.005	0.005	0.005	0.008	0.009	0.006	0.005	0.006	0.007	0.005	0.008	0.008	0.028	0.006	0.005	0.010	0.005	0.007	0.009
17	0.004	0.013	0.006	0.008	0.007	0.019	0.005	0.006	0.007	0.004	0.004	0.006	0.003	0.003	0.002	0.004	0.008	0.005	0.020	0.005	0.011	0.008	0.003	0.007	0.007
18	0.018	0.010	0.013	0.007	0.008	0.003	0.004	0.004	0.002	0.005	0.005	0.004	0.001	0.002	0.004	0.005	0.005	0.005	0.024	0.006	0.005	0.004	0.003	0.005	0.005
19	0.008	0.012	0.003	0.003	0.010	0.002	0.004	0.002	0.003	0.003	0.004	0.004	0.004	0.003	0.003	0.003	0.004	0.002	0.012	0.003	0.005	0.005	0.003	0.004	0.004
20	0.003	0.006	0.000	0.001	0.004	0.003	0.003	0.003	0.002	0.001	0.004	0.002	0.001	0.004	0.000	0.002	0.003	0.001	0.009	0.003	0.002	0.008	0.001	0.006	0.005
21	0.008	0.009	0.005	0.002	0.003	0.007	0.005	0.001	0.002	0.003	0.004	0.001	0.002	0.002	0.003	0.001	0.003	0.000	0.004	0.003	0.001	0.002	0.002	0.004	0.003
22	0.009	0.002	0.000	0.000	0.001	0.005	0.002	0.001	0.001	0.003	0.004	0.001	0.002	0.000	0.001	0.000	0.001	0.001	0.003	0.002	0.001	0.001	0.001	0.003	0.001
23	0.004	0.001	0.000	0.001	0.002	0.000	0.002	0.000	0.001	0.001	0.004	0.002	0.000	0.000	0.000	0.001	0.000	0.001	0.003	0.001	0.001	0.005	0.000	0.002	0.002
24	0.005	0.002	0.000	0.000	0.001	0.003	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.003
25	0.002	0.002	0.000	0.000	0.001	0.006	0.001	0.001	0.001	0.001	0.003	0.002	0.000	0.000	0.000	0.000	0.001	0.000	0.009	0.000	0.001	0.000	0.001	0.003	0.002

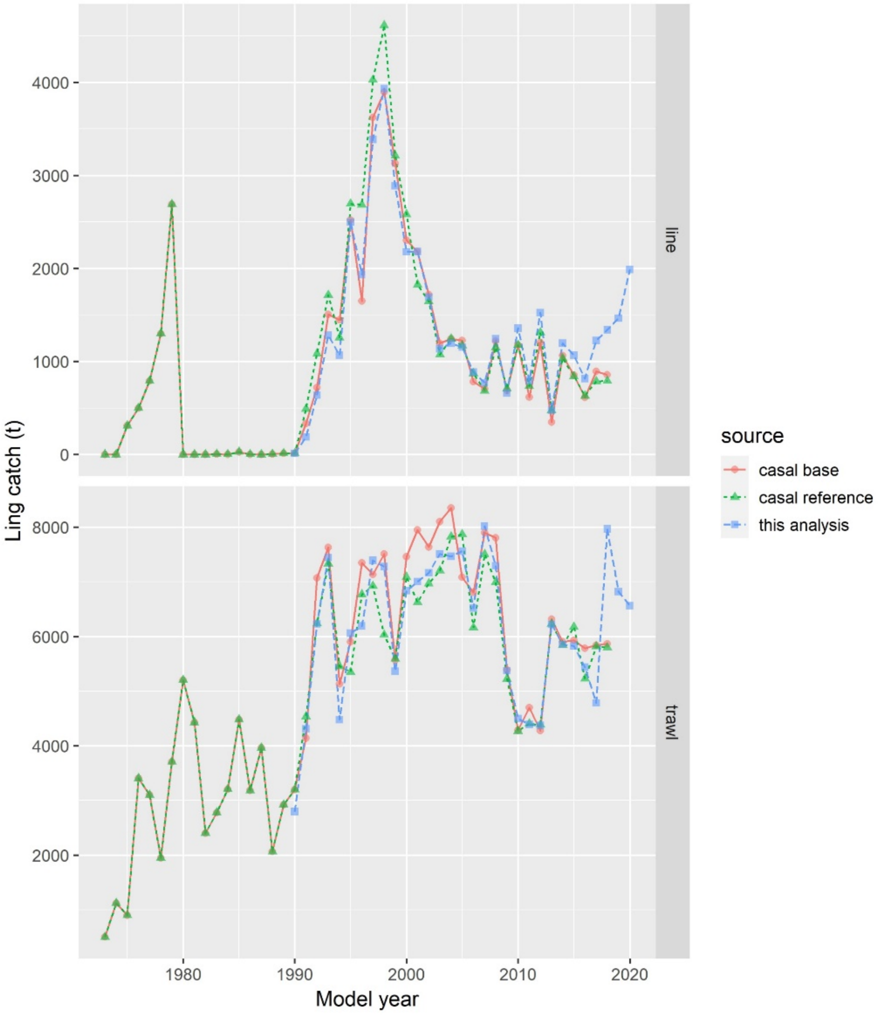


Figure E.1: Comparison of the bottom trawl and bottom longline catches used in the 2019 assessment (Masi 2019) base (CASAL base – with fishing year) and reference case (CASAL reference – with model year) with the catches used in this analysis. Model year is from 1st September to 31st August.

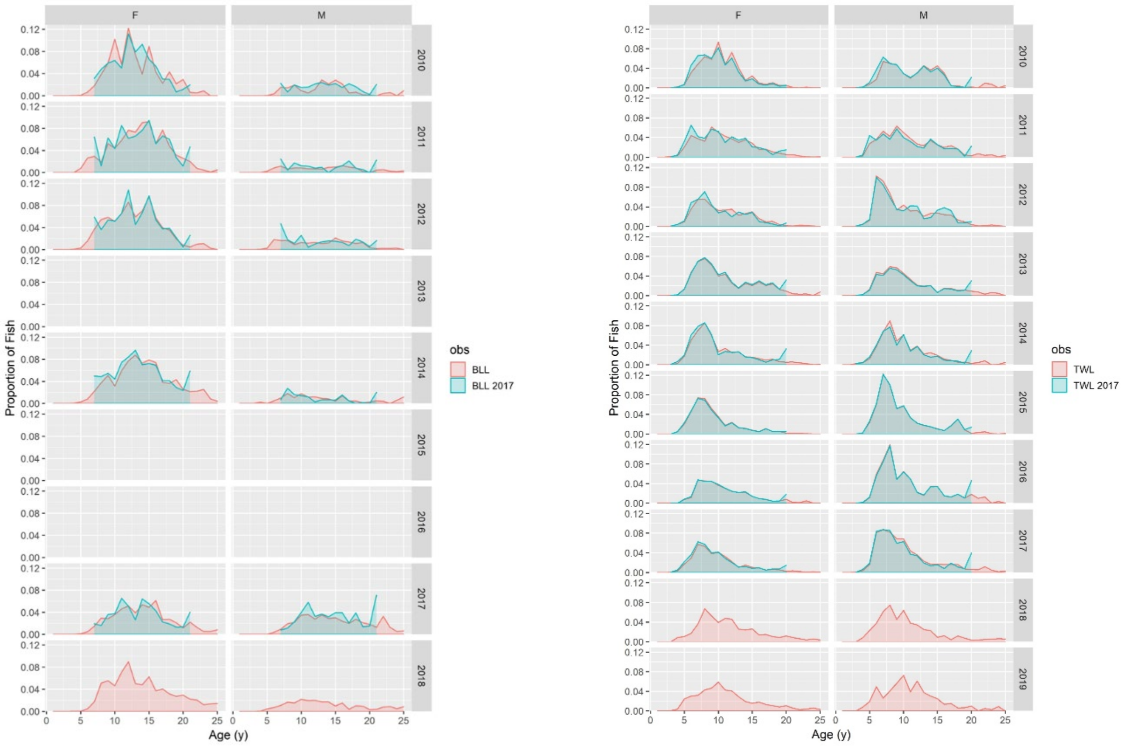


Figure E.2: Comparison of the age frequency distributions used in the 2019 assessment (Masi 2019) with the age frequency distributions calculated in this analysis. The 2019 longline age frequency is a weighted sum of the 2019 spawning and non-spawning age frequencies. Model year is from 1st September to 31st August.

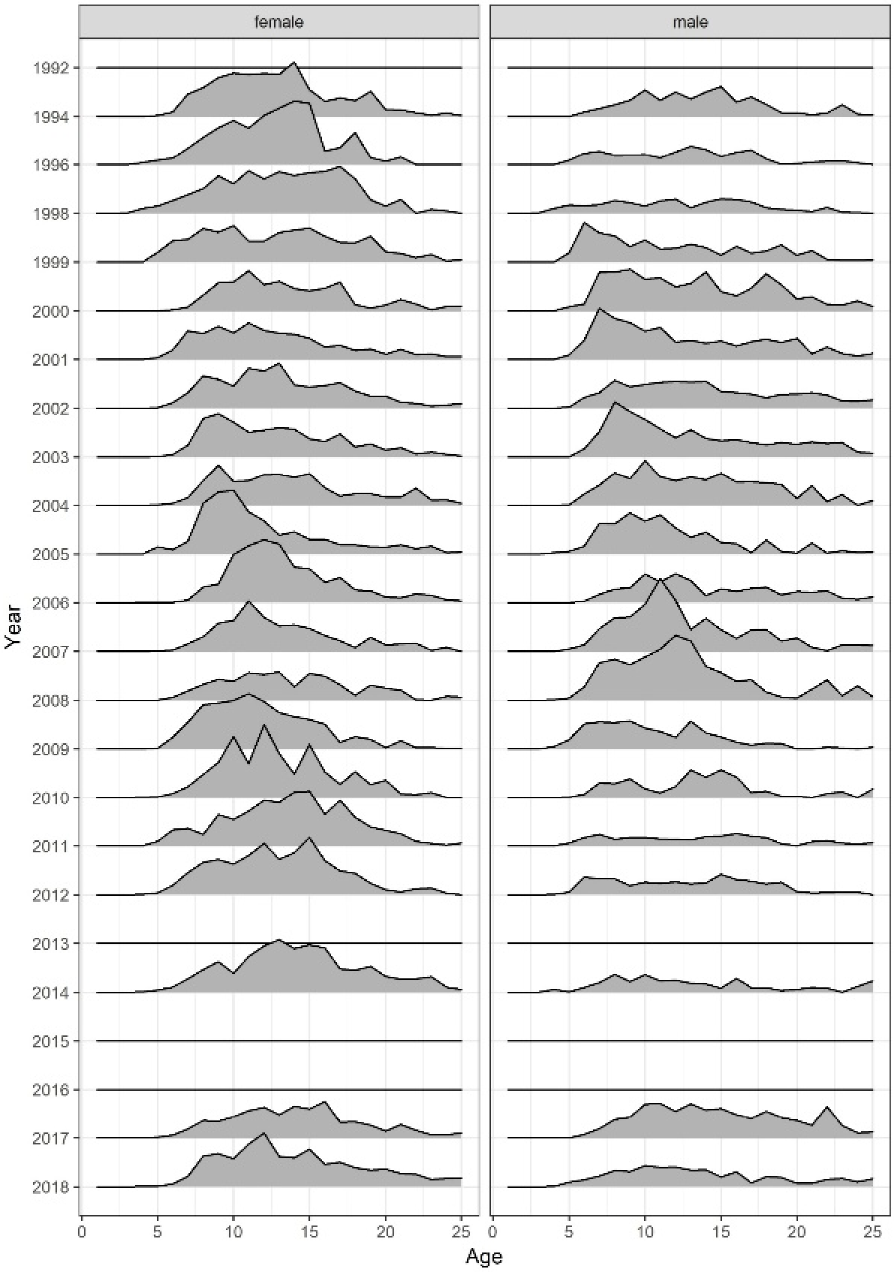


Figure E.3: Age frequency distributions used in the 2021 assessment for bottom longline. Model year is from 1st September to 31st August.

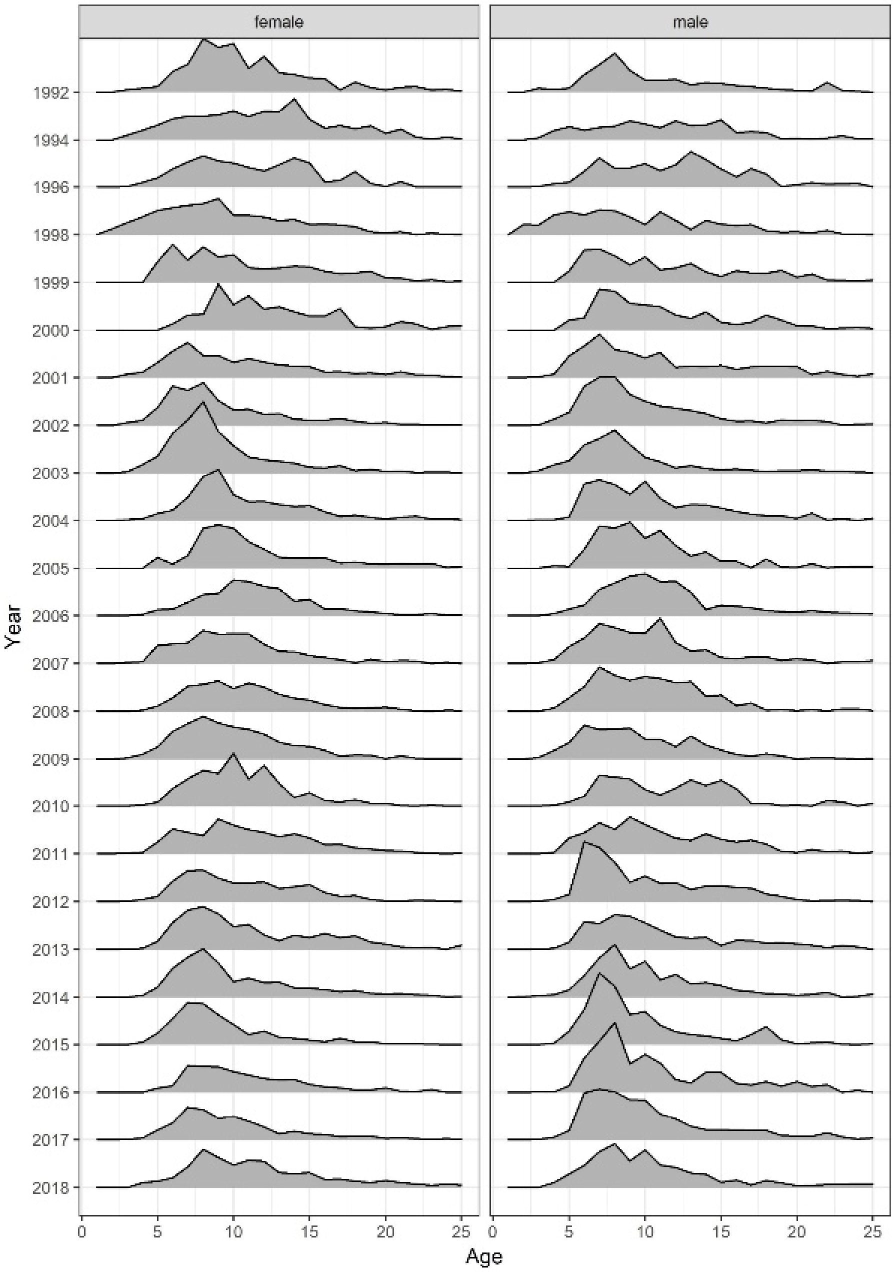


Figure E.4: Age frequency distributions used in the 2021 assessment for bottom trawl on the right. Model year is from 1st September to 31st August.