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Tini a Tangaroa

Descriptive analysis of ling in the Sub-Antarctic (LIN 5&6 and LIN 6B) up to 2023 and inputs for the 2024 stock assessment

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PLAIN LANGUAGE SUMMARY

Ling (*Genypterus blacodes*) is an important commercial fish species in New Zealand middle depths waters and is caught mainly by bottom trawls, bottom longlines, and increasingly by potting.

This report summarises the 2024 characterisation of one of the five main ling stocks managed under the Quota Management System: Sub-Antarctic ling (LIN 5&6 and LIN 6B). The Total Allowable Commercial Catch (TACC) in LIN 5&6 is generally caught whilst that in LIN 6B has not been caught since 2005.

The bottom longline standardised catch per unit effort (CPUE) was updated for LIN 5&6 and for LIN 6B. Spatio-temporal CPUE indices were also developed and were in general agreement with the non-spatially explicit CPUE indices.

Length-weight relationships, von Bertalanffy growth curves, and maturity curves were updated for LIN 5&6. The maturity ogive for LIN 5&6 indicated some level of inter-annual variability. Only von Bertalanffy growth curves were updated for LIN 6B due to the paucity of data.

Inputs to the 2024 stock assessment of Sub-Antarctic ling are summarised.

EXECUTIVE SUMMARY

Mormede, S.[1]; Dunn, A.[2]; Webber, D.N.[3] (2024). Descriptive analysis of ling in the Sub-Antarctic (LIN 5&6 and LIN 6B) up to 2023 and inputs for the 2024 stock assessment.

New Zealand Fisheries Assessment Report **2024/82. 94 p.**

Ling (*Genypterus blacodes*) are an important commercial species caught mainly by bottom trawls and bottom longlines and more recently by potting; they are found throughout the middle depths of New Zealand waters. 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 Platform (which might be an offshoot of the Sub-Antarctic stock), the west coast of the South Island, and Cook Strait.

This report summarises a characterisation of Sub-Antarctic ling fisheries (LIN 5&6 and LIN 6B separately) up to the 2022–23 fishing year. It provides updated biological parameters for LIN 5&6 and for LIN 6B, revised catch per unit effort (CPUE) indices for the longline fisheries, and a summary of the input parameters for the 2024 stock assessment of Sub-Antarctic ling.

Both the ling Total Allowable Commercial Catch (TACC) and catches have been stable in most QMAs recently. The majority of ling has been caught in LIN 5, which is also the QMA where the catch is closest to the TACC, by a combination of bottom trawl and longline fleets. The TACC in LIN 6B has not been caught since 2005. In 2023, Statistical Area 032 was reassigned from the Sub-Antarctic stock (LIN 5&6) to the west coast of the South Island stock (LIN 7WC).

The spatio-temporal structure of the length data was investigated. Although length data indicated three potential strata, the age frequency distributions yielded similar results to the previous simpler split between longline and trawl fisheries. Therefore, the scaled age frequency distributions developed in previous analyses were used in this update.

The length-weight relationship for ling in LIN 5&6 and in LIN 6B were updated with the latest available data. The growth functions were also updated, and the Bayesian von Bertalanffy growth estimates were used for the stock assessment. These did not indicate inter-annual variability. The maturity ogive for LIN 5&6 was updated and showed some level of inter-annual variability.

The rolled-up longline standardised CPUE series for ling in LIN 5&6 and in LIN 6B was updated. CPUE in LIN 5&6 was variable and generally declining, whilst the CPUE for LIN 6B was very limited, with only an additional four data points since 2005. Spatio-temporal indices were developed using a model of LIN 3&4, LIN 5&6, LIN 6B concurrently. Resulting indices indicated spatio-temporal variability, yet similar annual indices to the rolled-up indices.

The annual catches used in the 2024 stock assessment model were re-calculated to account for all fishing methods, the exclusion of Statistical Area 032 from LIN 5&6, the inclusion of LIN 6B in the Sub-Antarctic stock, and the change of the definition to the model year to be the calendar year.

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[3] Quantifish Ltd., Tauranga, New Zealand.

1. INTRODUCTION

Ling (*Genypterus blacodes*) are an important commercial species with adults found throughout the middle depths of the New Zealand Exclusive Economic Zone (EEZ) typically in depths of 100 m to 800 m (Mormede et al. 2021a, 2022a, 2023). Ling are managed as eight administrative Quota Management Areas (QMAs, Figure 1), with five (LIN 3, 4, 5, 6, and 7) reporting about 95% of landings.

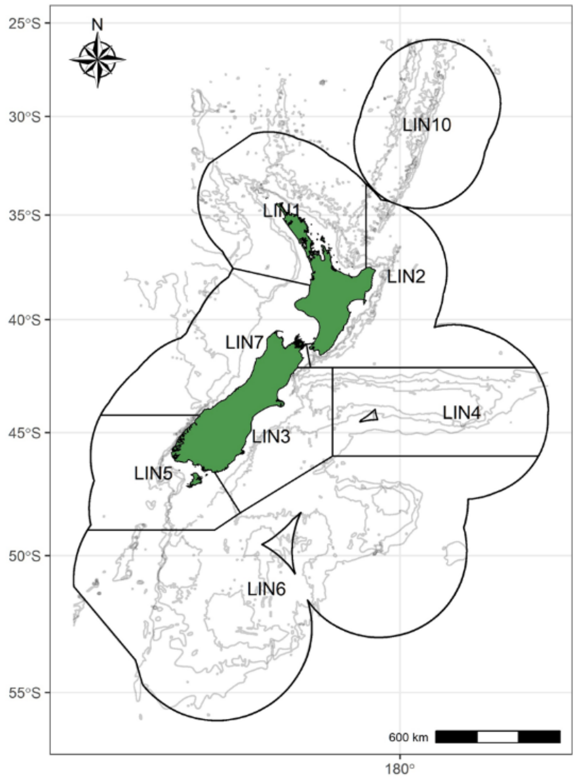
Ling are caught mainly by deepwater trawlers, often as bycatch in hoki (*Macruronus novaezelandiae*) target fisheries, by demersal longliners, and more recently by potting. LIN 5&6 contributes the highest ling catches, followed by LIN 3&4 then LIN 7WC. Between 2020 and 2023, 15 to 50% of the total annual catch in each stock has been caught by bottom longliners. Catches of ling by potting have increased in all areas in 2023.

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 Platform, the west coast of the South Island, and Cook Strait. Recent analyses have indicated that the Bounty Platform might be an offshoot of the Sub-Antarctic stock (Mormede et al. 2024a), and these two areas were assessed as a single stock in 2024 (Mormede et al. 2024b).

In this analysis, catches from Statistical Area 032 were removed from the Sub-Antarctic ling stock as they were added to the west coast of the South Island based on the continuity of catches along the depth contour along Statistical Areas 032, 033, and 034 (Mormede et al. 2023). Based on the difference in growth between LIN 7WC and LIN 5&6, this stock boundary was corroborated (Mormede et al. 2024a). The ling biological stocks were defined using statistical areas as described in Figure 1.

The catch and Total Allowable Commercial Catch (TACC) for ling in LIN 5 and LIN 6 are shown in Figure 2. The catch has been near the TACC for LIN 5 since the inception of the Quota Management System in 1986 but has not been caught in LIN 6 since 2005. Of note, the QMA and stock boundaries do not align for Sub-Antarctic ling: part of LIN 5 is in the LIN 7WC stock and part of LIN 3 is in the LIN 5&6 stock.

This report fulfils part of Specific Objective 1 of Project LIN2023-01 funded by Fisheries New Zealand. The overall objective was 'to carry out stock assessments of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5, 6, & 6B) including estimating biomass and stock status.' Specific Objective 1 was 'To carry out a descriptive analysis of the commercial catch and effort data for ling (LIN 5, 6, and 6B) in the Sub-Antarctic, and update the standardised catch and effort analyses.' This report provides a descriptive summary of catch and effort data since 1989–90, a spatio-temporal analysis, updated biological parameters, and an analysis of the catch per unit of effort (CPUE) data for Sub-Antarctic ling for the 1991 to 2023 calendar years. Stock hypotheses for Sub-Antarctic ling were investigated as part of Specific Objective 1 of LIN2023-01 and are reported separately (Mormede et al. 2024a).



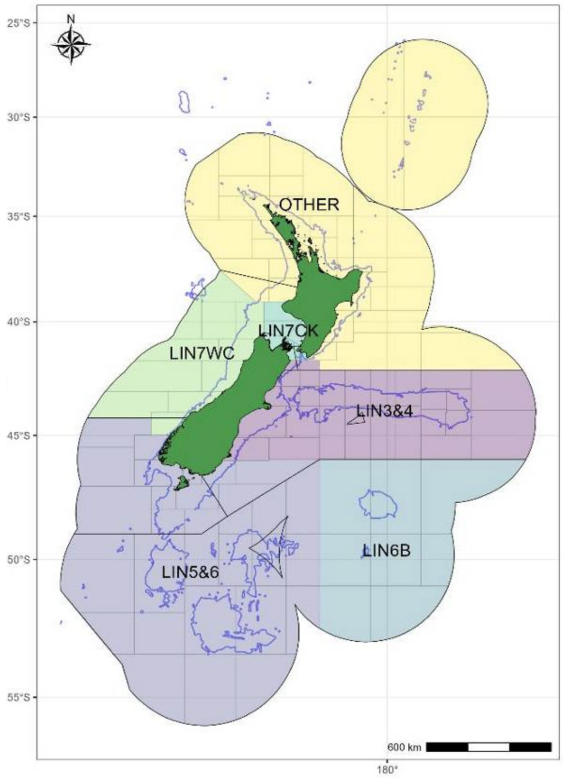


Figure 1: Quota Management Areas (QMAs, left) and biological stock boundaries (right) for ling, as used in this analysis. In 2024, LIN 5&6 and LIN 6B were assessed as a single Sub-Antarctic stock.

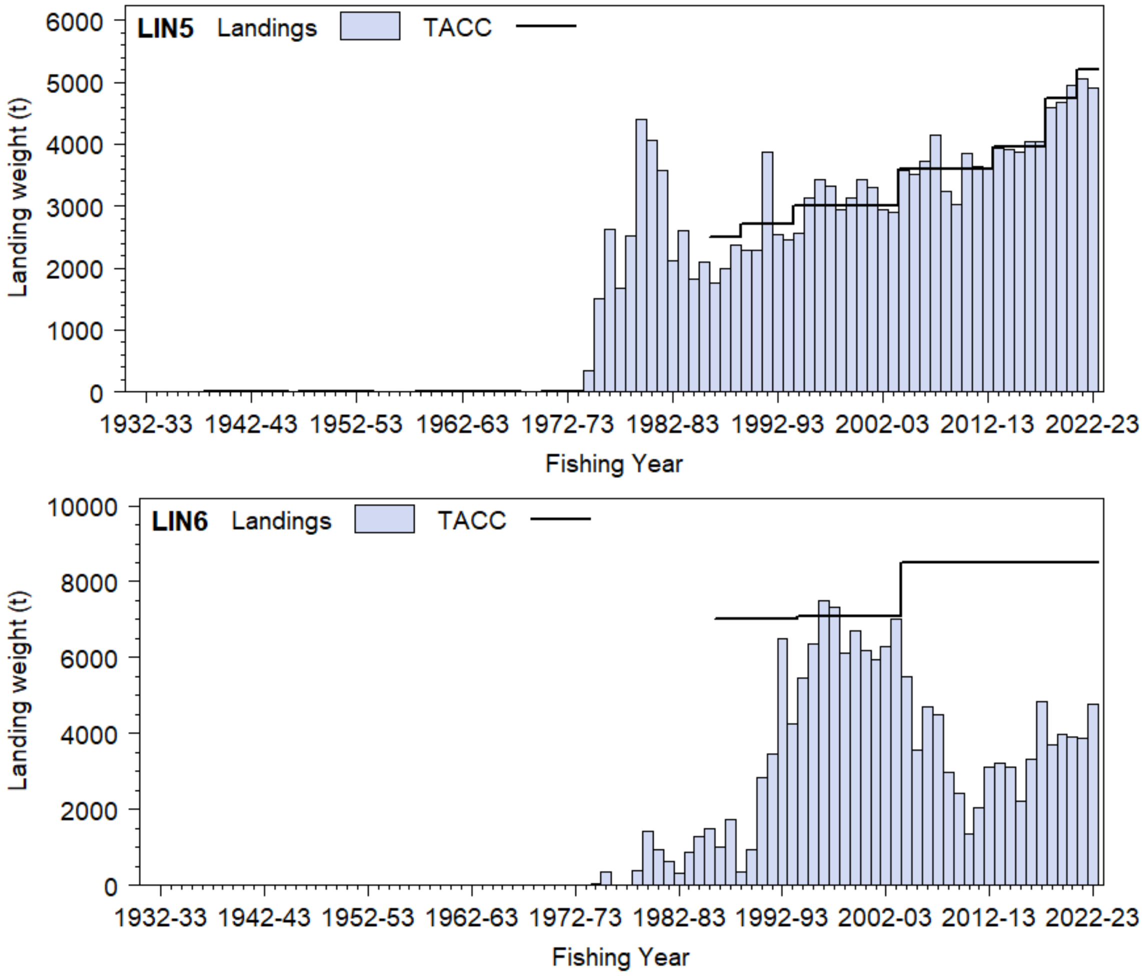


Figure 2: Annual reported catch of ling (bars) and the TACC (black line) for ling in LIN 5 (top) and LIN 6 (bottom) for fishing years to 2022–23 (Fisheries New Zealand 2024).

2. SUMMARY OF THE LING FISHERY IN LIN 5&6 and LIN 6B

2.1 Available data

Data available for ling include catch and effort data from trips that caught or targeted ling, 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. Catch and effort data and landings of ling have been misreported in the past; however, the amount of catch misreported in this area was low (Dunn 2003) and was therefore not considered in the stock assessment.

Catch and effort data were extracted by Fisheries New Zealand for the period from 1st October 1989 to 31st December 2023 including all available data at the date of the extracts (4th December 2023 and updated on 12th February 2024, REPLOG 15450 and update 15557). The data extract included all data from trips where hoki, hake (*Merluccius australis*), or ling were reported as either caught, processed, or landed and all fishing recorded on trawl catch, effort and processing returns (TCEPRs); trawl catch and effort returns (TCERs); catch, effort and landing returns (CELRs); lining catch and effort returns (LCERs); lining trip catch and effort returns (LTCERs); netting catch, effort and landing returns (NCELRs); electronic reporting system returns for all methods (ERS); as well as any high seas reports.

Observer data for ling from the Fisheries New Zealand observer sampling programme were also extracted, including all observer trips that reported hoki, hake, or ling (extracts on 4th December 2023 and updated on 12th February 2024, REPLOG 15450 and update 15557). 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 voyages that reported ling) were extracted, along with any biological, length frequency information, and associated otolith age readings from these trips (REPLOG 15450).

2.2 Data checks

Catch and effort data were corrected for errors using checking and imputation algorithms similar to those reported by Mormede et al. (2023) and implemented in the software package *R* (R Core Team 2019). Individual tows were investigated, and errors were corrected using median imputation for start/finish latitude or longitude, fishing method, target species, tow speed, net depth, bottom depth, wingspread, duration, number of events, and headline height for each fishing day for a vessel. Range checks were defined for the remaining attributes to identify potential outliers in the data. The outliers were checked and corrected with median or mean imputation on larger ranges of data such as vessel, target species, and fishing method for a year or month.

Fish biological stocks and statistical areas were assigned based on the corrected positions or the reported statistical area where no specific location was available. Longlining events were assigned to either manual baiting or autoline based on vessel name and, where available, year ranges provided by Fisheries New Zealand on 18th February 2021 (Dave Foster, Fisheries New Zealand, pers. comm.). Tows were classified as bottom trawl (BT), midwater trawl (MW), or midwater trawl fished within 5 m of the seafloor (MB) for the purposes of this analysis.

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

2.3 Results

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

In LIN 5&6, ling were caught predominantly by bottom trawlers targeting ling, followed by bottom trawlers targeting hoki and bottom longliners targeting ling. Potting targeting ling has become a more important method starting in 2023. On the other hand, in LIN 6B ling were caught almost exclusively by bottom longliners targeting ling (Table A.7, Table A.8 and Figure A.1 to Figure A.6). Catches of ling in LIN 6B have been highly variable over the years.

Ling have been caught predominantly between September and December by bottom trawl in LIN 5&6, and from October to May by bottom longlines in both LIN 5&6 and LIN 6B (Figure A.7 and

Figure A.8). Trawl vessels were dominated by larger vessels, between 50 m and 70 m in length. Longliners were dominated by 40–50 m vessels in LIN 5&6, and a mixture of vessel sizes in LIN 6B, from 28m to 60m in length, with a changing composition over time (Figure A.9 and Figure A.10). Ling was predominantly the top species caught by longline vessels and was usually within the top three species caught by bottom trawl vessels (Figure A.11 to Figure A.13). Ling have typically been caught at bottom depths of between 250 and 750 m in LIN 5&6 (Figure A.14); and shallower at depths of between 100 and 500 m in LIN 6B (Figure A.15).

The location of the catches differed between the bottom trawl and longline fleets, with the bottom longline fishery concentrating mostly closer to the mainland New Zealand than bottom trawls in LIN 5&6 (Figure A.16 and Figure A.17 by statistical area, Figure A.18 and Figure A.19 at about 0.5° resolution but only showing locations with a minimum of three vessels as per the Fisheries New Zealand data confidentiality requirements).

To represent the expansion or retraction of the area fished over time, the area covered by the fishing fleet targeting 90% of the ling catches was investigated at the 0.1° cell resolution, by summarising the number of those 0.1° cells where fishing occurred based on location of fishing in any one year as well as the cumulative number of cells fished for the first time each year (Figure A.20 and Figure A.21). The bottom trawl footprint seems well established whilst the longline fleet showed a slow continued increase in the number of new areas explored to date, consistent with the spatial plots (Figure A.18 and Figure A.19), noting that before the early 2000s, longline catch and effort data were mostly recorded daily on CELR forms rather than individually for each set. The area covered by the research survey encompassed most ling catches by both the bottom trawl and bottom longline fisheries, indicating that the survey adequately covered both the trawl and longline fishing grounds (Figure A.22).

The effort characteristics of the bottom trawl and longline fleets have been relatively stable over time except for the distance towed which has decreased over time (Figure A.23 to Figure A.25). The number of hooks reported per fishing event in LIN 7WC between 2020 and 2022 dropped dramatically (Figure A.26), with an associated increase in the number of fishing events recorded per vessel and day (Figure A.27), which may be attributable to the move from LTCER to reporting form to ERS. This pattern was not seen in the other stocks, including the Sub-Antarctic stocks.

3. SPATIO-TEMPORAL ANALYSES

Modelling the spatial distribution of mean length or age and correcting for variables such as month and year (as in a CPUE standardisation), can help better understand the spatial and temporal patterns in fish size/age. Looking at the data alone can result in biased conclusions because spatio-temporal patterns of fish size/age could be different depending on when and where fishing occurred.

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

Population models for LIN 5&6 defined two fisheries: bottom longline and bottom trawl. The age frequency distributions were calculated using time and location stratifications for both fisheries (Kienzle 2021), derived from a 2005 analysis (Horn 2005). Potential strata for LIN 5&6 were thoroughly investigated in 2021 but were shown to be inconsequential in their resulting age frequency distributions (Mormede et al. 2021a). Subsequently, the age frequency distributions were simplified to use all data, with no stratification, therefore maintaining the two fisheries.

The observer coverage of the bottom longline fishery in LIN 5&6, but particularly in LIN 6B, has been limited over time, with few length data observations collected (Figure B.1 and Figure B.2 of Appendix B).

3.1 Methods

Integrated Nested Laplace Approximation (INLA) (Rue et al. 2009) was used to develop spatio-temporal models of fish length for bottom longline and bottom trawl fisheries separately for LIN 5&6 and LIN 6B combined. A spatial mesh was developed using constrained Delaunay triangulation (Figure B.3 for the bottom trawl fishery and Figure B.4 for the bottom longline fishery). The mesh was limited to 1500 nodes (i.e., fewer nodes than data points). Each node becomes an estimated model parameter, constrained by the Stochastic Partial Differential Equation (SPDE) underpinning the INLA spatial smoothers. Records with unknown sex were dropped, length was rounded down to the nearest integer, and three-year blocks were defined.

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

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 (i.e., the sizes of fish), and D1 is a matrix containing the distance in space (in metres) between all data points. The alpha parameter (a real value between 0 and 1) stipulates the relative importance of the data (D0) compared to space (D1).

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

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

The performance of the candidate strata was evaluated by calculating the scaled age frequency distributions of ling for these strata and plotting the change in catches and in sex ratio of these candidate strata over time. The ideal stratum structure is one where the length frequency distributions and sex ratios remain constant over time and data are available for all strata.

3.2 Results

Bottom trawl fishery

For ling in LIN 5&6 and LIN 6B combined caught by the bottom trawl fishery, both the DIC and WAIC suggested that the most complex models with month specific spatial effects were the most parsimonious models for explaining length (Table B.1). However, a simpler model was used to define spatially explicit fisheries strata because the more complex models would imply that the strata also varied over time, requiring additional complexity to be added to the assessment model.

The length model for the bottom trawl fishery suggested that larger fish were in the shallow areas off the South Island and in LIN 6B, though the clusters exhibited poor spatial contiguity (Figure B.5). Partial effects plots indicated a significant year effect for 1994 and 1995 only, a significant depth and sex effect, and a smaller significant month effect for most months (Figure B.6). The month × year effect seemed to be driven by August (Figure B.7) which is outside the main fishing season (September to January, Figure A.7).

Bottom longline fishery

For ling in LIN 5&6 and LIN 6B combined caught by the bottom longline fishery, both the DIC and WAIC suggested that the most complex models with month-specific spatial effects were the most parsimonious models for explaining length (Table B.2). This result was similar to that of ling caught by the bottom trawl fishery, although fishing event was not a significant factor for the bottom longline fishery.

The length model for the bottom longline fishery suggested that larger fish were caught in the shallow areas off the South Island and in LIN 6B. The clusters exhibited good spatial contiguity with three main clusters: LIN 6B with the largest ling, near the South Island with the intermediate-sized ling, and the southern part of LIN 5&6 with the smallest ling (Figure B.8). Partial effects plots indicated a significant year effect for 1994 only, a significant depth and sex effect, and a smaller significant month effect for March to September (Figure B.9). The month × year effect seemed to be driven by smaller fish caught in February and March (Figure B.7).

Evaluation of the candidate strata

Results of the spatio-temporal investigation indicated that there could potentially be three length strata for Sub-Antarctic ling and a small but significant month effect at play. A single stratum with all data was used for LIN 6B using bottom longlines only. Two options were investigated for LIN 5&6:

- Option 1. Status quo: one stratum for bottom longline and one stratum for bottom trawl, both using all data available
- Option 2. Three strata based on the bottom longline strata for each fishery, and data limited to October to January for bottom longlines, and October to May for bottom trawls.

The scaled age frequency distributions were calculated and are presented in Figure B.11 to Figure B.14. Option 2 resulted in the loss of multiple years of data due to the data selection criteria. The age frequency distributions for the different strata were almost identical within years.

3.3 Discussion

Because the resulting scaled age frequency distributions were generally insensitive to the choice of these options of stratification, the existing process was kept (bottom longline and bottom trawl with no strata or time constraints), providing continuity and comparison with previous analyses. This analysis highlighted that the makeup of this stock is highly complex, both spatially and temporally. The scaled age frequencies showed a weak pattern of year-class strength progression (Figure B.15 to Figure B.18). This is partly attributed to the variability in the makeup of the stock and the limited sampling of the longline fishery. Of note is how sparse the data for LIN 6B was, limiting the usefulness of that information.

4. UPDATE OF BIOLOGICAL PARAMETERS

4.1 Methods

Length-weight parameters

Length-weight parameters for ling used in the LIN 5&6 stock assessment were calculated in 2005 (Horn 2005) and updated in 2021 (Mormede et al. 2021a).

This analysis updated the length-weight relationship for LIN 5&6 and LIN 6B separately by applying a log-linear regression to the available length and weight data, where $Weight = a \cdot (length)^b$, to estimate the *a* and *b* parameters for each sex separately—assuming a bias correction resulting from the transformation from log-space for *a*. Plots of residuals were checked for any evidence of fitting issues or trends over time.

Growth models

Age-length parameters for ling used in the stock assessment were calculated in 2005 (Horn 2005) assuming a von Bertalanffy curve. These were updated in 2021 for LIN 5&6 to a Bayesian von Bertalanffy analysis; monotonic growth was also investigated (Mormede et al. 2021a). The Bayesian von Bertalanffy parameters were adopted for the 2021 stock assessment (Fisheries New Zealand 2021).

This analysis updated the age-length relationship by applying the von Bertalanffy models to all available age data for LIN 5&6 and LIN 6B separately using Bayesian inference. Due to the lack of small ling caught in LIN 6B, the von Bertalanffy parameter t_0 was fixed at -0.1 following Horn (2022). The monotonic growth model was not investigated as it resulted in a similar result to the von Bertalanffy model and was not taken forward in 2021 (Fisheries New Zealand 2021).

Bayesian growth models were developed using the R package *brms* which uses Stan (Stan Development Team 2020) to run Bayesian GLMMs and non-linear models. A von Bertalanffy model (von Bertalanffy 1938) was developed to describe the length *L* at age *t*:

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

with:

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

where L_∞ is asymptotic length (cm), *k* is the Brody growth coefficient, t_0 is the age at which the length is zero, μ_t is the expected length at age, and L_t is the predicted length at age.

Maturity ogive

The maturity ogive for LIN 5&6 was updated. Maturity at age was determined based on the maturity status of aged fish collected during the Sub-Antarctic resource surveys since 2000. Following the method of Horn (2005), stage 1 animals were assumed to be immature, stage 3–7 animals were assumed mature, and stage 2 animals were removed from the analysis as they represent a mixture of immature and mature fish.

Bayesian maturity models were developed using the R package *brms* which uses Stan (Stan Development Team 2020) to run Bayesian GLMs and non-linear models. The model was defined as *mature ~ age* with a Bernoulli distribution. The year effect was tested to investigate if maturity has changed over time.

A maturity ogive for LIN 6B was not calculated due to the lack of survey data for this area. Furthermore, observer maturity data indicated that most fish were mature, limiting the ability to determine a maturity ogive. It has been assumed equal to that of LIN 3&4 in the past (Horn 2005; Fisheries New Zealand 2024).

4.2 Results

Length-weight parameters

Length-weight data were collected only during trawl surveys and as such only cover LIN 5&6, have a limited temporal coverage within each survey year, and have a limited number of samples. The length-weight parameters derived in this analysis were similar to those reported previously and used in the previous stock assessments (Table C.1 and Figure C.1). There were few differences in the pattern of residuals over time (Figure C.2), indicating no clear inter-annual pattern of weight at length for ling in LIN 5&6.

Growth models

All data available in the 't.age' database provided by Fisheries New Zealand were used whether they were collected during the Sub-Antarctic trawl surveys or by observers for LIN 5&6. The Sub-Antarctic survey does not cover LIN 6B so for this area all data were collected by observers.

The patterns of residuals per cohort and year did not show any indication of trends in growth over time; the lower growth rates for very early and late years were likely to be confounded by the lack of a full range of fish for those cohorts (Figure C.3 for LIN 5&6 and Figure C.4 for LIN 6B). The resulting von Bertalanffy growth curves were similar to those estimated previously (Table C.2 and Figure C.5 for LIN 5&6 and Table C.3 and Figure C.6 for LIN 6B).

Partial effects plots were carried out by Statistical Area to investigate potential spatial patterns in growth. These did not show any specific patterns that would warrant investigating spatially explicit growth for ling in that area.

Maturity at age

Maturity at age for ling in LIN 5&6 derived in this analysis was to the right of the 2005 estimate (Horn 2005) for females, but to the left of the 2005 estimate for males (Figure C.7). The potential for a temporally varying maturity was tested by offering year as a random effect. The effect was only significant for female ling, driven by an older age at maturity in 2018 in particular (Figure C.8).

4.3 Discussion

The length-weight relationship derived using all data up to and including 2023 had very similar values for the parameters to those used previously. No change in length-weight with time was found. The existing parameters were used for the 2024 stock assessment.

The updated von Bertalanffy growth curve for LIN 5&6 was almost identical to that estimated in 2021 (Mormede et al. 2021a) and therefore not updated for the 2024 model or in the species summary. The von Bertalanffy growth curve for LIN 6B had not been updated since 2005 and the species summary was updated with the 2024 values (Fisheries New Zealand 2024). There was no evidence of time-varying or spatially varying growth in LIN 5&6 or LIN 6B.

The maturity curves for ling in LIN 5&6 were updated for the first time since 2005 and found to be slightly different to previous estimates. The updated values were used for the 2024 stock assessment and updated in the species summary (Fisheries New Zealand 2024). Estimates of female maturity indicated some differences among years, in particular for 2018. As new data become available, these estimates should continue to be updated.

5. CPUE ANALYSES

5.1 Methods

Non-spatial CPUE standardisation

The trawl CPUE was not considered to be likely to be an index of abundance for ling stocks as the indices are more likely to reflect changes in hoki abundance and changes in hoki operational practice and management requirements rather than ling abundance (Fisheries New Zealand 2024). Therefore, trawl CPUE was not calculated for ling in the Sub-Antarctic.

The longline standardised CPUE for ling in LIN 5&6 was not included in the base case stock assessment model in 2019 (Masi 2019). It was, however, used in the base case model in 2021 (Mormede et al. 2021a, 2021b) as the CPUE trend was generally consistent with the survey biomass trend and its inclusion was expected to add some additional information not otherwise reflected in the stock assessment model.

Before the early 2000s, longline catch and effort data were mostly recorded daily on CELR forms, rather than individually for each set as on other form types (Figure A.1 for LIN 5&6 and Figure A.2 for LIN 6B). To obtain as much of a time series of longline CPUE as possible, all longline data that were available on a set-by-set basis were 'rolled-up' into daily equivalents by vessel, day, and statistical area (e.g., using the approach of Starr 2008; Starr & Kendrick 2016). The catch was assumed to be the sum of all catches reported by each vessel in each day and statistical area and the number of hooks was assumed to be the total of the number of hooks set on each day in each statistical area.

A CPUE standardisation was carried out for LIN 5&6 and LIN 6B bottom longline fisheries separately. The CPUE standardisation followed similar methods that have been used for other ling stocks (e.g., Mormede et al. 2021a). Year was defined as the calendar year to match the year definition used in the assessment model (Fisheries New Zealand 2024). All explanatory variables offered to the models are detailed in Table D.1. Because the longline fishery operates year-round (Figure A.7 and Figure A.8), data from all months were used. Details of the data selection for the bottom longline CPUE indices are summarised in Table D.2. Because of the change over time in the reporting requirements, and in particular the number of species that require reporting (Figure A.11 to Figure A.13), fishing events where ling was not recorded in the top five species, or top five Quota Management System (QMS) species for ERS reporting, were assumed to have caught no ling; they were kept for the analysis but assigned a catch of 0 kg. This allows for comparability of the data reported over the entire time series.

CPUE analyses were carried out on the 'core' fleet for each of the indices, aiming to keep at least 80% of the ling catch in each instance and cover the duration of the fishery with overlaps between fishing vessels over the entire time series (Figure D.1 and Figure D.2). Where vessels stopped fishing for at least 10 years, they were split into two pseudo-vessels to account for potential changes in vessel behaviour and hence catchability. Fishing in LIN 6B has been patchy, and only years where at least two vessels fished were kept for the analysis.

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

Spatio-temporal CPUE

Methods such as Vector Autoregressive Spatio-Temporal models (VAST, Thorson & Barnett 2017) apply a smoother to catch data in both time and space. Maunder et al. (2020) showed that spatio-temporal models were useful to derive indices of abundance and composition data when sampling intensity varies across the spatial domain — better accounting for variability in sampling over space and time that otherwise would violate the assumptions of time-invariant catchability and selectivity in stock assessment models. Similar results were reported elsewhere; for example, comparing Generalised Additive Model (GAM) and VAST performance (Grüss et al. 2019; Mormede et al. 2020). The performance of VAST has also been tested using simulations (e.g., Brodie et al. 2020; Mormede & Lyon 2023).

VAST was used in this study to account for the spatial and spatio-temporal relationships in the data, and to allow the development of CPUE trends for LIN 3&4, LIN 5&6, and LIN 6B concurrently. The catch per event from bottom longlines with location was modelled from commercial data starting in 2004 and excluding daily CELR forms. Covariates tested in the models were: space, vessel, number of hooks set, month, and depth. The model predictions were run in equal area space grid cells of 16 km × 16 km (Mormede et al. 2022b). Only cells that had at least 10 events over the entire duration of the model were used to avoid the undue influence of outliers.

The model build and variable selection followed recommendations by Thorson and others (Thorson 2019; Thorson et al. 2021):

- The model distribution chosen was a gamma only with bias correction given that there are virtually no sets with a zero catch of ling in the data.
- The method used was *Barrier* to ensure that no spatial correlation was carried across land.
- The number of knots used was 50 for investigations, then increased to 200 for the final models.
- Fine scale extrapolation smoothing was applied for the final models.

5.2 Results

Non-spatial bottom longline CPUE of LIN 5&6

The standardised lognormal CPUE indices for rolled-up bottom longline fishing data for ling in LIN 5&6 were similar to those calculated previously, although more variable, and partly consistent with the survey biomass series (Figure D.3). The index was noisy but generally declining from the early 1990s to 2023.

The lognormal model explained 58% of the variance and three parameters were included in addition to model year (Table D.3 and Figure D.4 to Figure D.7). The *number of hooks* parameter had the largest influence on the standardised index, followed by *Statistical Area* and *vessel*. The implied trends by statistical area showed a limited departure from the overall standardised CPUE trend, most pronounced in statistical areas with little catch such as Statistical Areas 018 and 019 (Figure D.8).

Non-spatial bottom longline CPUE of LIN 6B

The standardised lognormal CPUE indices for rolled-up bottom longline fishing data for ling in LIN 6B has not been updated since 2007, with the last index point in 2005. This was due to the low level of fishing in the intervening years. This update provided only four new data points: 2017 and 2021–2023. The results were similar to those calculated previously apart from a clear difference in 1995 (Figure D.9).

The lognormal model explained 42% of the variance and three parameters were included in addition to model year (Table D.4 and Figure D.10 to Figure D.13). The *number of hooks* parameter had the largest influence on the standardised index, followed by *month* and *vessel*. The implied trends by statistical area showed a limited departure from the overall standardised CPUE trend (Figure D.14).

Spatially explicit bottom longline CPUE

The standardised bottom longline CPUE annual indices for the different ling stocks showed generally variable trends from 2004, with no consistent pattern between stocks (Figure D.15). Spatio-temporal patterns highlight the need to consider space in this standardisation (Figure D.16). Only the *number of hooks* parameter was influential after space, and the final model explained 72.9% of the deviance (Table D.5 and Figure D.17 and Figure D.18). Diagnostic plots were satisfactory (Figure D.19).

5.3 Discussion

All the derived standardised CPUE series are provided in Table D.6. The 2024 non-spatial standardised CPUE of LIN 5&6 was slightly more variable than the one derived in 2021. The data selection in 2024 was slightly different from that in 2021, in that Statistical Area 032 was excluded, and as a result, the core vessel selection was slightly different. These differences are thought to have contributed to the change in the CPUE index since the 2021 analysis. The resulting index was more variable and therefore deemed to be less likely to represent ling abundance. There was also a concern that such a long index might not have captured technological changes (i.e. effort creep) over time adequately (Fisheries New Zealand 2024). It was used only in sensitivity runs for the stock assessment (Mormede et al. 2024b).

The last LIN 6B standardised CPUE provided an index to 2005 only. An update provided another four data points: in 2017 and from 2021 onwards. This index was highly uncertain and showed no trend. Fishing in LIN 6B has been sporadic, and often carried out by only one or two vessels in any single year, making CPUE standardisation difficult.

A spatially explicit standardisation of ling CPUE from the bottom longline fleet in LIN 3&4, LIN 5&6, and LIN 6B was carried out. It allowed the use of all data available, and therefore a derivation of a full LIN 6B index, although some of that was extrapolated in the years when no fishing was carried out. It also allowed the derivation of indices for LIN 5&6 and LIN 6B combined, which was used as an alternative index for the stock assessment (Mormede et al. 2024b). The spatially explicit annual ling CPUE indices were similar to the non-spatially explicit CPUE series (Figure D.20).

6. INPUTS INTO THE 2024 STOCK ASSESSMENT

The 2021 Sub-Antarctic stock assessment of ling covered LIN 5&6 only (Mormede et al. 2021b). At that time LIN 6B was assumed to be a separate stock and had not been assessed since 2007 (Fisheries New Zealand 2024). In 2024, following a review of the stock hypothesis for ling, the Sub-Antarctic stock assessment of ling included LIN 5&6 and LIN 6B (Mormede et al. 2024a). This was a practical decision based on the similarity between LIN 5&6 and LIN 6B and the lack of data to drive a separate assessment for LIN 6B (Fisheries New Zealand 2024).

6.1 Catches

Three fisheries were defined for the 2024 stock assessment: the trawl and longline fisheries in LIN 5&6 and the longline fishery in LIN 6B. The pot fishery is increasingly important in LIN 5&6, representing 12% of catches in the 2022–23 fishing year (Fisheries New Zealand 2024). There was no length data for the pot fishery in this region as there had been no observer sampling of ling on these trips, and for the stock assessment it was added to the longline fishery, which is similar to the approach used for ling on the Chatham Rise (Mormede et al. 2022a). The year was defined as the calendar year.

The annual scaled-up catches per fishery and model year are summarised in Table E.1 of Appendix E. These were slightly different from those used in the 2021 stock assessment (Mormede et al. 2021a) as LIN 5&6 now excludes catches in Statistical Area 032.

6.2 Age frequencies

The ling birth date was assumed to be 1st October (Richard Saunders, pers. comm., and Deepwater Working Group on 10th February 2022).

The commercial fishery age frequency distributions for the Sub-Antarctic were recalculated using a single stratum per fishery and no time restriction (Figure B.11 to Figure B.14). Only the age frequency distributions for LIN 5&6 were used in the stock assessment models, as the observer coverage of LIN 6B was deemed too limited to be representative of the underlying stock (Mormede et al. 2024c), leading to sparse and highly variable age frequency distributions (Figure B.14).

6.3 Indices of abundance

The bottom longline non-spatially explicit bottom longline CPUE was deemed too variable to be representative of the underlying abundance of ling. There was also a concern that such a long index might not have captured technological changes over time, and hence changes in catchability, adequately (Fisheries New Zealand 2024). Therefore, it was only used in sensitivity analyses for the stock assessment model in 2024. The spatially explicit CPUE standardisation was deemed plausible, although the index only started in 2004, and the CPUE index for LIN 5&6 and LIN 6B was used as a sensitivity analysis, as it represented the entire stock definition for the Sub-Antarctic ling population models developed. All sets of CPUE indices developed are given in Table D.6.

7. POTENTIAL RESEARCH

Observer coverage of the bottom longline fisheries is limited, in particular for LIN 6B where the paucity of data precludes a separate stock assessment. Increased representative coverage would help inform the management of ling (see also Mormede et al. 2024c).

The potting fishery has been increasing since 2021 in the various ling fisheries around New Zealand. Potting for ling in LIN 3&4 represented less than 1% of the catch up until 2013; but since then the use of this method has increased, and potting represented 10–16% of the catch in that area per year between 2018 and 2022 and 31% of total catches in the 2023 fishing year. The use of potting has also increased more recently in other ling stocks: in the 2023 fishing year, it represented 22% of total catches in LIN 7WC and 12% of total catches in LIN 5&6. Observer length data and age readings are required to develop age frequency distributions and associated selectivities for this fishery.

Scaled age frequency distributions for the various ling fisheries have been calculated based on data collected at certain times of the year, representing historical catch patterns, and do not necessarily reflect the current seasonality of the fisheries. Furthermore, analyses have shown that the stratified historical age frequency estimates gave similar results as when the stratification was ignored (Mormede et al. 2022a, 2023, and herein) despite some small month effects seen in the spatio-temporal analyses (Figure B.9). One way forward could be to age otoliths from the months when the top 80% of ling catches occurred in each fishery. This would result in the following months for otolith selection (Figure E.1):

- LIN 3&4
    - Bottom longline: July to November
    - Bottom trawl: November to May
- LIN 5&6
    - Bottom longline: March to June and could be extended
    - Bottom trawl: September to November
- LIN 6B
    - Bottom longline: whenever there is information
- LIN 7WC
    - Bottom longline: January to October (it is a very protracted season)
    - Bottom trawl: August and September
- LIN 7CK
    - Bottom longline and bottom trawl: whenever there is information

8. FULFILLMENT OF BROADER OUTCOMES

As required under Government Procurement rules[4], Fisheries New Zealand considered broader outcomes (secondary benefits such as environmental, social, economic or cultural benefits) that would be generated by this project. The following broader outcomes were delivered:

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

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

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10. REFERENCES

Brodie, S.J.; Thorson, J.T.; Carroll, G.; Hazen, E.L.; Bograd, S.; Haltuch, M.A.; Holsman, K.K.; Kotwicki, S.; Samhouri, J.F.; Willis-Norton, E.; Selden, R.L. (2020). Trade-offs in covariate selection for species distribution models: a methodological comparison. *Ecography 43*: 11–24. https://doi.org/10.1111/ecog.04707

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). Stock assessment of hake (Merluccius australis) for the 2002–03 fishing year. *New Zealand Fisheries Assessment Report 2003/38*. 57 p.

Fisheries New Zealand (2021). Fisheries Assessment Plenary, May 2021: stock assessments and stock status. Ministry for Primary Industries.

Fisheries New Zealand (2024). Fisheries Assessment Plenary, May 2024: stock assessments and stock status. Compiled by the Fisheries Science Team. Ministry for Primary Industries, 1941 p.

Grüss, A.; Drexler, M.D.; Chancellor, E.; Ainsworth, C.H.; Gleason, J.S.; Tirpak, J.M.; Love, M.S.; Babcock, E.A. (2019). Representing species distributions in spatially-explicit ecosystem models from presence-only data. *Fisheries Research 210*: 89–105. https://doi.org/10.1016/j.fishres.2018.10.011

Horn, P. (2007). Stock assessment of ling (*Genypterus blacodes*) on the Bounty Plateau and in Cook Strait for the 2007--08 fishing year. Unpublished report held by the Ministry of Primary Industries Final Research Report for Ministry of Fisheries Research Project LIN2005-01, Objective 3. 51 p.

Horn, P. (2021). Age determination protocol for ling (*Genypterus blacodes*). *New Zealand Fisheries Assessment Report 2021/31*. 23 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.

[4] https://www.procurement.govt.nz/procurement/principles-charter-and-rules/government-procurement-rules/planning-your-procurement/broader-outcomes/

Horn, P.L. (2022). A synopsis of the biology of ling (*Genypterus blacodes*) and a history of its fishery and assessment in New Zealand. *New Zealand Fisheries Assessment Report 2022/27*. 82 p.

Kienzle, M. (2021). Stock assessment for ling off the west coast South Island (LIN 7WC) to the 2018-19 fishing year. *New Zealand Fisheries Assessment Report 2021/18*. 26 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.

Maunder, M.N.; Thorson, J.T.; Xu, H.; Oliveros-Ramos, R.; Hoyle, S.D.; Tremblay-Boyer, L.; Lee, H.H.; Kai, M.; Chang, S.-K.; Kitakado, T.; Albertsen, C.M.; Minte-Vera, C.V.; Lennert-Cody, C.E.; Aires-da-Silva, A.M.; Piner, K.R. (2020). The need for spatio-temporal modeling to determine catch-per-unit effort based indices of abundance and associated composition data for inclusion in stock assessment models. *Fisheries Research 229*: 105594. https://doi.org/10.1016/j.fishres.2020.105594

Mormede, S.; Dunn, A.; Webber, D.N. (2021a). 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*. 113 p.

Mormede, S.; Dunn, A.; Webber, D.N. (2021b). Stock assessment of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN5&6) for the 2020–21 fishing year. *New Zealand Fisheries Assessment Report 2021/61*. 36 p.

Mormede, S.; Dunn, A.; Webber, D.N. (2022a). Descriptive analysis of ling (*Genypterus blacodes*) on the Chatham Rise (LIN 3&4) up to 2020–21 and inputs for the 2022 stock assessment. *New Zealand Fisheries Assessment Report 2022/64*. 85 p.

Mormede, S.; Dunn, A.; Webber, D.N. (2023). Descriptive analysis of ling off the west coast of the South Island (LIN 7WC) up to 2021–22 and inputs for the 2023 stock assessment. *New Zealand Fisheries Assessment Report 2023/51*. 91 p.

Mormede, S.; Dunn, A.; Webber, D.N. (2024a). Stock hypotheses for ling in the Sub-Antarctic (LIN 5&6 and LIN 6B). *New Zealand Fisheries Assessment Report 2024/83*. 13 p.

Mormede, S.; Dunn, A.; Webber, D.N. (2024b). The 2024 stock assessment of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN5&6 and LIN 6B). *New Zealand Fisheries Assessment Report 2024/84.* 28 p..

Mormede, S.; Dunn, A.; Webber, D.N. (2024c). Longline observer data coverage in ling fisheries and their use in stock assessments. *New Zealand Fisheries Assessment Report 2024/85*. 30 p.

Mormede, S.; Lyon, W.S. (2023). Development and testing of spatial distribution models for selected shark and turtle species. *New Zealand Aquatic Environment and Biodiversity Report 311.* 78 p.

Mormede, S.; Parker, S.J.; Pinkerton, M.H. (2020). Comparing spatial distribution modelling of fisheries data with single-area or spatially-explicit integrated population models, a case study of toothfish in the Ross Sea region. *Fisheries Research 221*: 105381. https://doi.org/10.1016/j.fishres.2019.105381

Mormede, S.; Webber, D.N.; Edwards, C. (2022b). Creating standardised grids for New Zealand marine science outputs. *New Zealand Aquatic Environment and Biodiversity Report 283*. 11 p.

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

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). CmdStan: User's Guide. Version 2.24.

Starr, P.J. (2008). Procedure for merging MFish landing and effort data. Unpublished report held by the Ministry of Primary Industries. Ministry for Primary Industries, 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.

Thorson, J.T. (2019). Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments. *Fisheries Research 210*: 143–161. https://doi.org/10.1016/j.fishres.2018.10.013

Thorson, J.T.; Barnett, L.A.K. (2017). Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat. *ICES Journal of Marine Science 74*: 1311–1321.

Thorson, J.T.; Cunningham, C.J.; Jorgensen, E.; Havron, A.; Hulson, P.-J.F.; Monnahan, C.C.; von Szalay, P. (2021). The surprising sensitivity of index scale to delta-model assumptions: Recommendations for model-based index standardization. *Fisheries Research 233*: 105745. https://doi.org/10.1016/j.fishres.2020.105745

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

11. APPENDIX A – DESCRIPTION OF THE FISHERY

Table A.1: Ling TACC (in tonnes) per QMA by fishing year (Fisheries New Zealand 2024).

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

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

Fishing year	LIN 1	LIN 2	LIN 3	LIN 4	LIN 5	LIN 6	LIN 7	OTHER	Total
1990	54	523	1 231	443	1 459	802	2 370	21	6 903
1991	138	829	2 062	2 153	2 382	2 360	2 010	16	11 950
1992	183	672	2 101	4 346	3 674	3 238	1 875	29	16 119
1993	302	738	1 894	3 530	3 055	5 558	1 969	18	17 065
1994	289	636	1 842	3 701	3 121	3 248	1 844	40	14 722
1995	405	717	2 062	4 376	3 658	3 860	2 646	433	18 155
1996	311	782	2 453	4 085	4 731	3 804	2 474	108	18 748
1997	690	741	2 189	3 469	4 721	4 921	2 397	144	19 272
1998	339	770	2 240	4 229	4 303	5 511	2 506	248	20 147
1999	301	770	2 054	3 906	3 992	4 492	2 738	80	18 332
2000	366	778	2 188	3 969	3 834	5 391	2 614	7	19 146
2001	312	922	1 830	3 415	3 915	5 206	2 975	9	18 584
2002	277	801	1 779	3 217	3 774	5 419	2 614	4	17 885
2003	216	746	2 076	2 719	3 747	5 257	2 313	2	17 075
2004	200	817	1 605	2 385	4 052	5 698	2 446	1	17 204
2005	223	741	1 314	2 570	4 911	4 029	2 077	0	15 863
2006	289	702	1 341	1 663	4 519	2 250	2 016	39	12 819
2007	228	740	1 814	1 942	5 380	2 770	1 792	4	14 670
2008	359	690	1 604	2 306	5 192	3 275	1 899	18	15 344
2009	298	560	1 525	1 815	3 867	1 706	1 866	3	11 640
2010	354	506	1 524	1 844	3 882	1 494	1 987	1	11 593
2011	389	598	1 445	1 398	4 086	968	2 220	0	11 105
2012	353	428	1 076	2 016	4 291	1 287	2 071	2	11 523
2013	346	514	1 188	1 918	5 860	1 218	2 386	0	13 431
2014	365	553	1 218	2 041	4 945	2 061	2 531	0	13 713
2015	369	561	1 016	1 877	5 147	1 757	2 602	1	13 330
2016	388	599	1 160	2 267	4 647	1 290	2 741	2	13 093
2017	382	904	1 572	2 213	5 114	2 110	2 743	4	15 041
2018	378	1 006	1 914	2 375	5 204	3 183	2 713	2	16 776
2019	354	857	1 747	1 849	5 816	2 308	2 552	5	15 488
2020	348	640	1 449	1 601	5 255	2 867	2 782	2	14 944
2021	283	551	1 321	1 914	5 954	2 695	2 830	36	15 585
2022	327	494	1 022	2 324	5 965	2 661	2 918	0	15 711
2023	253	429	1 191	1 690	5 321	3 894	3 176	0	15 953
Total	10 669	23 315	56 047	87 566	149 774	108 588	81 693	1 279	518 929

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

Fishing year	LIN 1	LIN 3	LIN 4	LIN 5	LIN 6	LIN 7	Total
1990	97	1 618	534	1 553	885	2 416	7 102
1991	207	2 410	2 420	2 291	2 845	2 534	12 708
1992	241	2 423	4 710	3 867	3 461	2 262	16 964
1993	253	2 247	4 100	2 546	6 504	2 475	18 125
1994	234	2 167	3 917	2 459	4 248	2 155	15 179
1995	261	2 654	5 072	2 558	5 477	2 946	18 967
1996	245	2 962	4 632	3 137	6 341	3 103	20 420
1997	313	2 976	4 087	3 438	7 510	3 024	21 348
1998	326	2 943	5 215	3 321	7 331	2 955	22 091
1999	208	2 706	4 642	2 937	6 112	3 345	19 949
2000	313	2 779	4 402	3 136	6 707	3 274	20 611
2001	296	2 330	3 861	3 430	6 177	3 352	19 446
2002	303	2 164	3 602	3 295	5 945	3 219	18 529
2003	246	2 529	2 997	2 939	6 283	2 918	17 912
2004	249	1 990	2 618	2 899	7 032	2 926	17 713
2005	283	1 597	2 758	3 584	5 506	2 522	16 250
2006	364	1 711	1 769	3 522	3 553	2 479	13 398
2007	301	2 089	2 113	3 731	4 696	2 295	15 226
2008	381	1 778	2 383	4 401	4 246	2 282	15 471
2009	320	1 751	2 000	3 232	2 977	2 223	12 503
2010	386	1 718	2 026	3 034	2 414	2 446	12 024
2011	438	1 665	1 572	3 856	1 335	2 800	11 667
2012	384	1 292	2 305	3 649	2 047	2 771	12 449
2013	383	1 475	2 181	3 610	3 102	3 010	13 761
2014	380	1 442	2 373	3 935	3 221	3 200	14 551
2015	374	1 325	2 246	3 924	3 115	3 344	14 329
2016	422	1 440	2 659	3 868	2 222	3 351	13 963
2017	404	1 808	2 565	4 051	3 323	3 428	15 579
2018	415	2 171	2 636	4 034	4 846	3 487	17 589
2019	383	2 016	2 044	4 596	3 706	3 059	15 804
2020	371	1 685	1 778	4 678	3 972	3 216	15 701
2021	319	1 489	2 129	4 949	3 916	3 308	16 109
2022	353	1 175	2 604	5 049	3 881	3 325	16 388
2023	270	1 366	1 892	4 906	4 780	3 540	16 755
Total	10 723	67 891	98 842	120 415	149 716	98 990	546 581

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

Fishing year	LIN 3&4	LIN 5&6	LIN 6B	LIN 7CK	LIN 7WC	OTHER	Total
1990	1 954	2 606	13	537	2 240	416	7 767
1991	4 644	5 218	34	719	2 375	703	13 691
1992	6 838	6 654	870	409	2 246	808	17 824
1993	6 020	8 207	1 162	414	2 359	925	19 087
1994	5 765	5 890	1 082	280	2 078	903	15 999
1995	7 543	7 666	455	366	2 876	1 345	20 250
1996	7 476	8 790	608	509	3 143	1 053	21 579
1997	6 850	10 526	434	565	3 100	1 205	22 679
1998	7 920	10 208	401	355	3 140	1 307	23 331
1999	7 233	8 383	596	444	3 520	923	21 099
2000	7 090	8 827	1 017	416	3 342	908	21 601
2001	6 056	8 443	1 139	480	3 447	994	20 560
2002	5 502	8 744	640	382	3 264	1 034	19 567
2003	5 275	8 298	1 029	483	2 960	865	18 910
2004	4 442	9 093	994	465	2 871	893	18 759
2005	4 236	9 115	48	461	2 536	789	17 187
2006	3 299	7 112	72	334	2 525	875	14 216
2007	4 001	8 329	256	281	2 318	918	16 103
2008	4 056	8 265	446	205	2 320	990	16 281
2009	3 608	6 074	232	154	2 235	837	13 140
2010	3 589	5 573	2	100	2 425	921	12 610
2011	2 947	5 242	55	172	2 882	1 038	12 337
2012	3 293	5 764	4	142	2 930	823	12 956
2013	3 460	6 730	4	190	3 101	856	14 339
2014	3 615	6 840	290	197	3 360	923	15 225
2015	3 387	6 940	38	182	3 508	948	15 003
2016	4 026	5 665	214	222	3 559	983	14 668
2017	4 155	6 345	815	285	3 773	1 233	16 604
2018	4 542	8 475	252	378	3 851	1 198	18 696
2019	3 855	8 000	222	278	3 271	1 122	16 747
2020	3 251	8 473	254	150	3 270	1 060	16 458
2021	3 505	8 190	637	113	3 451	893	16 790
2022	3 719	8 795	218	109	3 346	733	16 920
2023	3 225	9 624	98	153	3 533	580	17 212
Total	160 377	257 104	14 631	10 930	101 155	32 002	576 195

Table A.5: Ling catch (in tonnes) for LIN 5&6 by form type and fishing year as reported on catch and effort forms.

Fishing year	TCP	ERS - Trawl	CEL	LCE	ERS - Lining	TCE	Other	Total
1990	2 358	0	40	0	0	0	0	2 398
1991	4 490	0	285	0	0	0	0	4 775
1992	5 551	0	669	0	0	0	0	6 221
1993	6 495	0	1 415	0	0	0	0	7 910
1994	4 099	0	1 339	0	0	0	0	5 438
1995	4 890	0	2 309	0	0	0	0	7 199
1996	6 490	0	1 556	0	0	0	0	8 046
1997	6 139	0	3 130	0	0	0	0	9 269
1998	5 989	0	3 371	0	0	0	0	9 360
1999	5 066	0	2 777	0	0	0	0	7 843
2000	6 099	0	2 121	0	0	0	0	8 220
2001	6 219	0	1 810	0	0	0	0	8 029
2002	6 943	0	1 716	0	0	0	0	8 660
2003	6 955	0	1 244	0	0	0	0	8 199
2004	7 642	0	605	771	0	0	0	9 018
2005	7 685	0	138	1 158	0	0	0	8 980
2006	5 855	0	118	840	0	0	0	6 813
2007	7 319	0	109	678	0	0	2	8 108
2008	6 803	0	2	1 112	0	109	25	8 051
2009	4 726	0	11	580	0	121	23	5 462
2010	4 127	0	7	1 103	0	180	92	5 509
2011	4 151	0	5	504	0	368	113	5 141
2012	4 213	0	2	1 074	0	288	136	5 713
2013	6 465	0	4	331	0	249	39	7 087
2014	5 307	0	6	923	0	399	86	6 721
2015	5 591	0	7	757	0	395	60	6 810
2016	4 500	0	2	487	0	460	114	5 563
2017	5 161	0	3	602	0	404	155	6 325
2018	1 385	5 479	9	564	0	441	146	8 023
2019	3	6 252	3	412	527	527	130	7 854
2020	0	6 306	0	0	1 634	0	14	7 954
2021	0	6 900	0	0	1 111	0	23	8 033
2022	0	7 258	0	0	1 245	0	4	8 508
2023	0	6 647	0	0	1 475	0	1 031	9 152
Total	158 714	38 842	24 814	11 895	5 992	3 942	2 193	246 391

Table A.6: Ling catch (in tonnes) for LIN 6B by form type and fishing year as reported on catch and effort forms.

Fishing year	CEL	LCE	ERS - Lining	TCP	ERS - Trawl	TCE	Other	Total
1990	0	0	0	12	0	0	0	12
1991	7	0	0	27	0	0	0	34
1992	834	0	0	79	0	0	0	913
1993	965	0	0	18	0	0	0	983
1994	1 142	0	0	8	0	0	0	1 150
1995	389	0	0	4	0	0	0	393
1996	378	0	0	4	0	0	0	382
1997	340	0	0	1	0	0	0	341
1998	388	0	0	8	0	0	0	396
1999	549	0	0	14	0	0	0	564
2000	984	0	0	8	0	0	0	991
2001	1 063	0	0	0	0	0	0	1 064
2002	627	0	0	2	0	0	0	629
2003	921	0	0	1	0	0	0	922
2004	835	15	0	3	0	0	0	853
2005	0	34	0	15	0	0	0	49
2006	0	38	0	5	0	0	0	43
2007	0	234	0	2	0	0	0	236
2008	0	502	0	1	0	0	0	503
2009	0	222	0	10	0	0	0	232
2010	0	1	0	1	0	0	0	1
2011	0	51	0	2	0	0	0	53
2012	0	1	0	1	0	0	0	2
2013	0	0	0	3	0	0	0	3
2014	0	265	0	11	0	0	0	277
2015	0	23	0	0	0	0	0	23
2016	0	220	0	0	0	0	0	220
2017	0	739	0	0	0	0	0	739
2018	0	228	0	0	0	0	0	228
2019	0	45	155	0	0	0	0	200
2020	0	0	209	0	1	0	0	209
2021	0	0	593	0	0	0	0	594
2022	0	0	189	0	0	0	0	189
2023	0	0	91	0	1	0	0	92
Total	9 422	2 618	1 237	239	2	0	0	13 519

Table A.7: Ling catch (in tonnes) in LIN 5&6 by gear type and target species (LIN: ling, HOK: hoki, HAK: hake, or other) by fishing year as reported on catch and effort forms for the main gear types. Potting is defined as catches from the following forms: CP (cod pot), CRP (cray pot), OCP (octopus pot), POT (unspecified pot), FP (fish pot), and RLP (rock lobster pot). Bottom trawl also includes midwater trawl within 5 m of the bottom.

Fishing	Bottom and midwater trawl				Bottom longline		Potting		Other	Total
year	LIN	HOK	HAK	Other	LIN	Other	LIN	Other		
1990	1 356	589	119	334	0	0	0	0	0	2 398
1991	2 659	1 226	77	592	219	1	0	0	2	4 775
1992	1 956	2 825	140	684	613	1	0	0	1	6 221
1993	3 432	2 509	49	596	1 302	7	0	1	15	7 910
1994	2 143	1 270	79	685	1 244	16	0	1	0	5 438
1995	2 842	1 500	54	578	2 216	6	0	1	3	7 199
1996	4 224	1 639	115	562	1 499	3	0	2	1	8 046
1997	3 198	2 441	22	534	3 069	1	0	1	3	9 269
1998	2 894	2 634	119	372	3 336	0	2	1	2	9 360
1999	2 376	2 148	116	492	2 707	2	0	0	2	7 843
2000	2 755	3 016	46	330	2 063	0	9	1	0	8 220
2001	2 000	3 383	418	515	1 685	2	24	0	0	8 029
2002	1 367	4 621	240	804	1 611	0	16	0	1	8 660
2003	1 832	4 218	331	742	1 063	1	13	0	1	8 199
2004	2 397	4 419	260	703	1 235	2	0	0	2	9 018
2005	3 222	3 467	375	757	1 158	0	0	0	2	8 980
2006	3 754	1 391	35	782	846	2	0	3	1	6 813
2007	4 841	1 510	105	961	678	8	1	2	2	8 108
2008	4 260	1 785	189	677	1 113	21	0	2	3	8 051
2009	2 941	788	266	853	590	8	3	8	6	5 462
2010	1 645	1 417	287	958	1 183	8	2	5	5	5 509
2011	2 160	1 022	162	955	607	4	0	5	225	5 141
2012	2 046	1 296	220	893	1 204	2	0	1	50	5 713
2013	4 311	1 284	270	850	366	1	1	3	4	7 087
2014	3 033	1 484	281	908	1 009	0	1	2	2	6 721
2015	3 738	1 364	290	594	815	0	0	7	2	6 810
2016	3 268	978	217	496	598	0	0	1	4	5 563
2017	3 308	1 223	236	799	748	6	0	1	4	6 325
2018	4 425	1 987	104	768	699	7	7	1	26	8 023
2019	4 727	1 160	39	753	1 040	20	5	3	108	7 854
2020	4 853	857	91	448	1 619	15	6	3	62	7 954
2021	5 328	971	187	414	1 100	11	18	2	4	8 033
2022	5 114	1 537	189	419	1 189	56	1	2	1	8 508
2023	5 640	593	79	331	1 467	8	1 028	2	4	9 152
Total	110 044	64 547	5 808	22 139	41 889	217	1 137	64	547	246 391

Table A.8: Ling catch (in tonnes) in LIN 6B by gear type (BLL: bottom longline, BT: bottom trawl, MW: midwater) and target species (LIN: ling, SBW: southern blue whiting) by fishing year as reported on catch and effort forms for the main gear types. Bottom trawl also includes midwater trawl within 5 m of the bottom.

Fishing year	BLL-LIN	BT	MW-SBW	Other-LIN	Total
1990	0	9	3	0	12
1991	7	18	8	0	34
1992	834	67	11	0	913
1993	965	15	3	0	983
1994	1 142	8	1	0	1 150
1995	381	1	3	7	393
1996	378	2	2	0	382
1997	340	0	0	0	341
1998	388	4	3	0	396
1999	549	9	6	0	564
2000	984	3	4	0	991
2001	1 063	0	0	0	1 064
2002	627	1	0	0	629
2003	921	1	0	0	922
2004	850	3	0	0	853
2005	34	14	1	0	49
2006	38	4	1	0	43
2007	234	2	0	0	236
2008	502	0	1	0	503
2009	222	10	0	0	232
2010	1	0	0	0	1
2011	51	2	0	0	53
2012	1	1	0	0	2
2013	0	3	0	0	3
2014	265	10	1	0	277
2015	23	0	0	0	23
2016	220	0	0	0	220
2017	739	0	0	0	739
2018	228	0	0	0	228
2019	200	0	0	0	200
2020	209	0	0	0	209
2021	593	0	0	0	594
2022	189	0	0	0	189
2023	91	0	0	0	92
Total	13 270	191	50	7	13 519

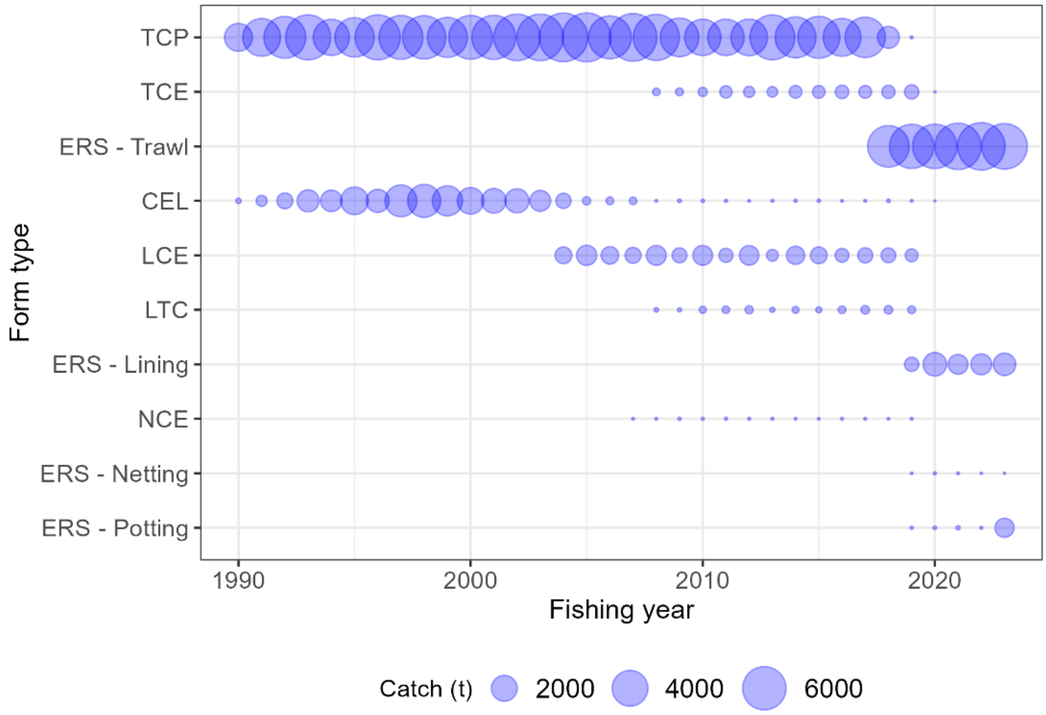


Figure A.1: LIN 5&6 distribution of annual ling catch reported on catch and effort forms by form type: trawl catch effort and processing return (TCP), trawl catch effort return (TCE), electronic reporting system return (ERS), catch effort landing return (CEL), lining catch effort return (LCE), lining trip catch effort return (LTC), and netting catch effort return (NCE).

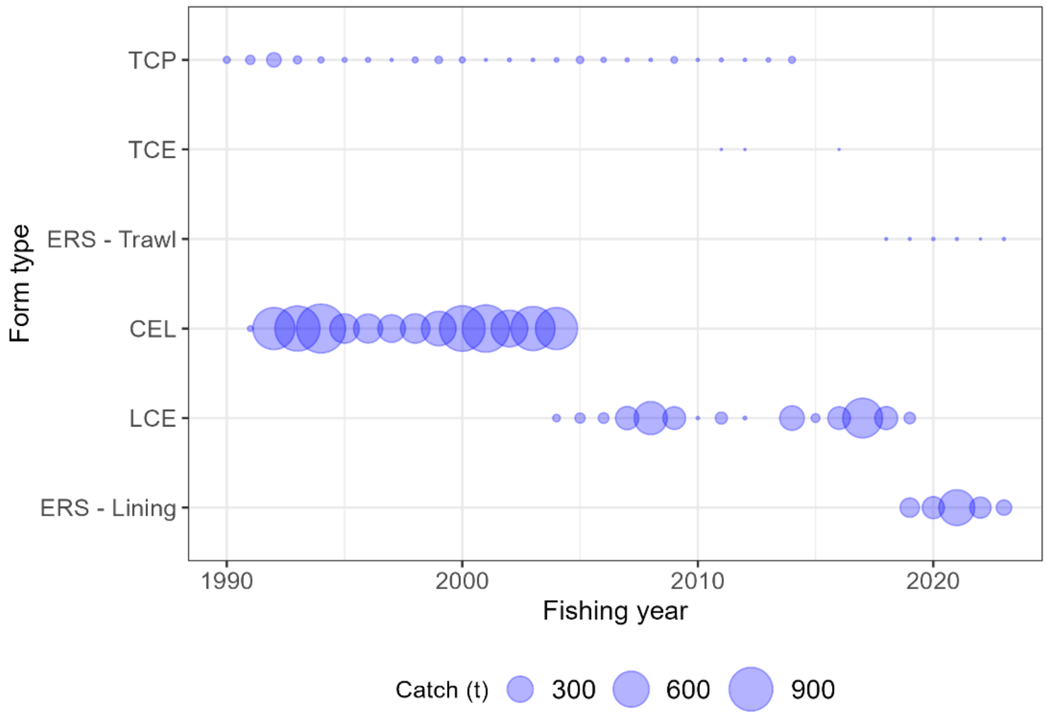


Figure A.2: LIN 6B distribution of annual ling catch reported on catch and effort forms by form type: trawl catch effort and processing return (TCP), trawl catch effort return (TCE), electronic reporting system return (ERS), catch effort landing return (CEL), lining catch effort return (LCE), and lining trip catch effort return (LTC).

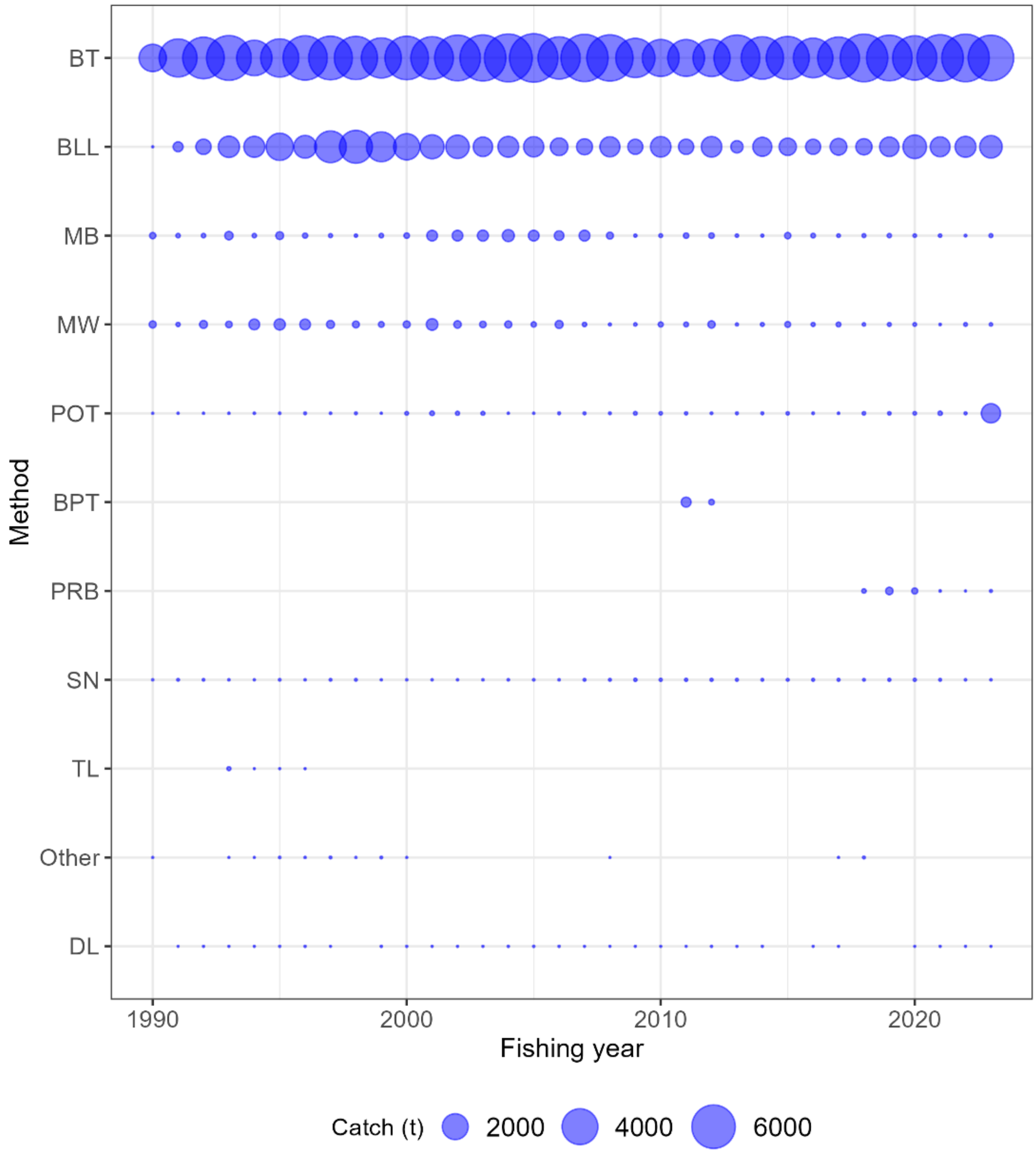


Figure A.3: LIN 5&6 distribution of annual ling catch reported on catch and effort forms by method and fishing year. Method is bottom longlining (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis), set net (SN), all potting methods (POT – code defined within the analysis), trot line (TL), precision bottom trawl (PRB), precision midwater trawl (PRM), drop/Dahn line (DL), and all other codes (Other).

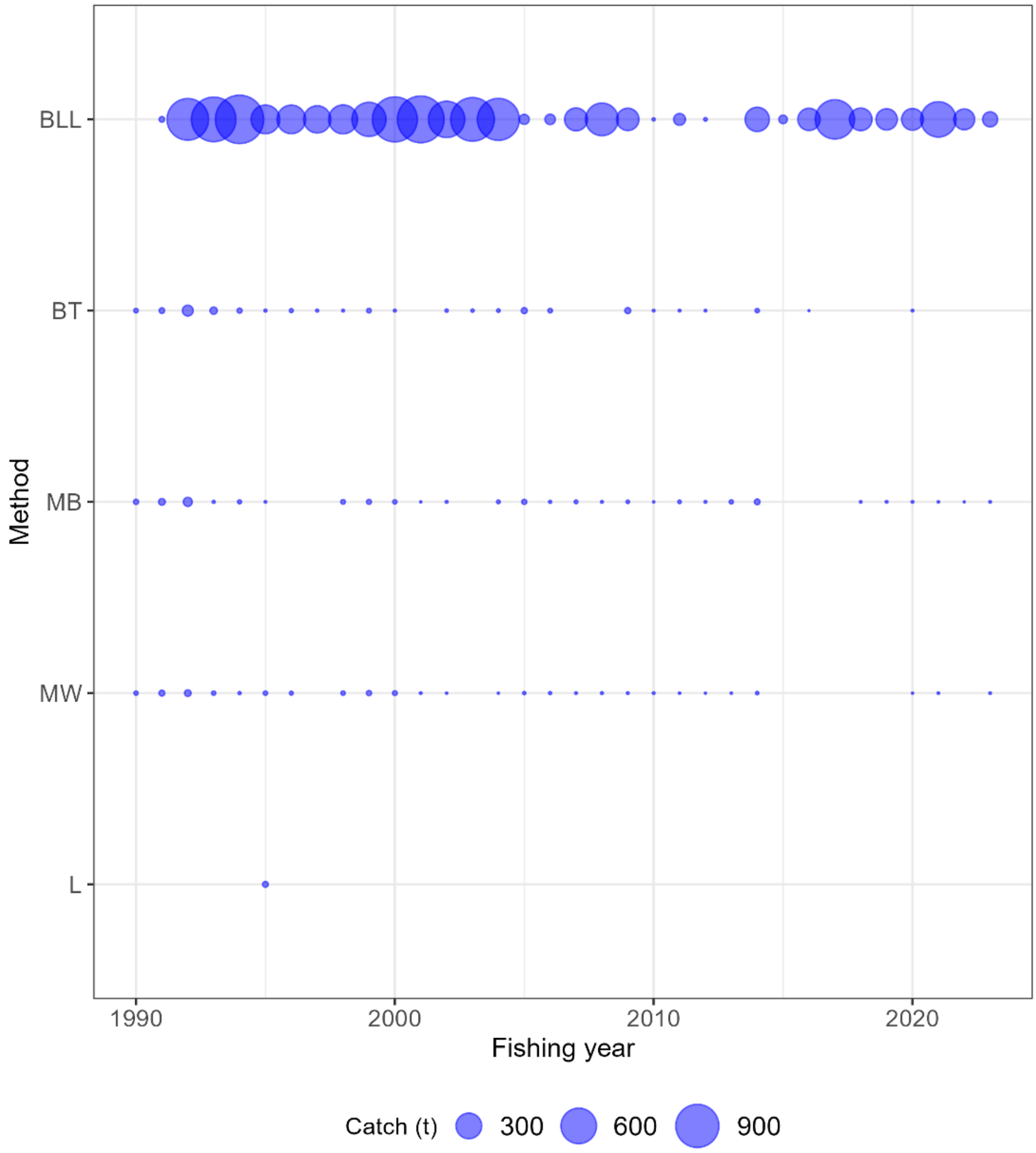


Figure A.4: LIN 6B distribution of annual ling catch reported on catch and effort forms by method and fishing year. Method is bottom longlining (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis), line (L).

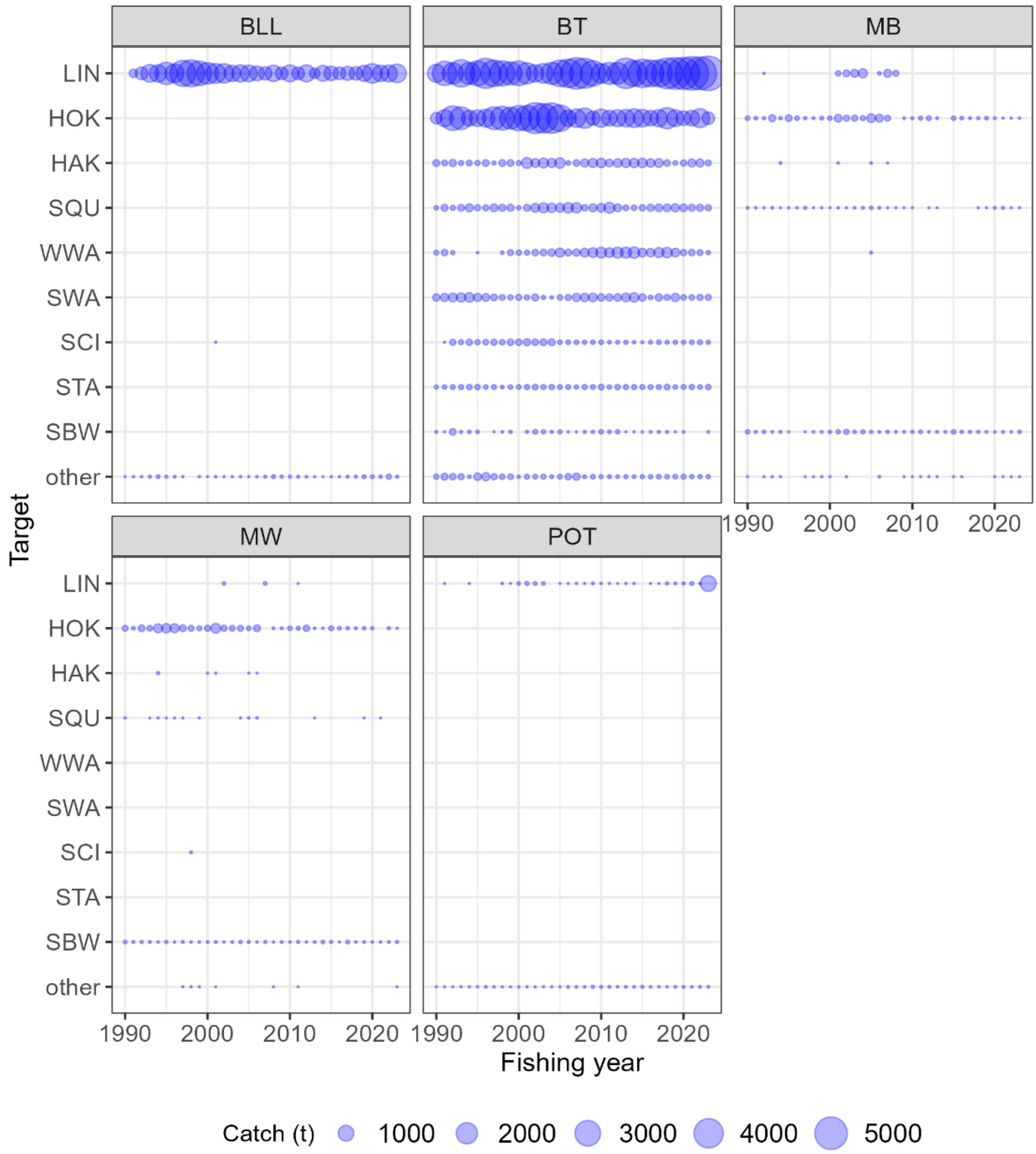


Figure A.5: LIN 5&6 distribution of annual ling catch reported on catch and effort forms by target species for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawls within 5 m of the bottom (MB – code defined within the analysis above), and all potting methods (POT – code defined within the analysis) gears separately. Target is hake (HAK), hoki (HOK), ling (LIN), giant stargazer (STA – *Kathetostoma* spp.), scampi (SCI – *Metanephrops challenger*), silver warehou (SWA – *Seriolella punctata*), squid (SQU – *Nototodarus sloanii* and *N. gouldi*), white warehou (WWA – *Seriolella caerulea*), and all other targets combined (other).

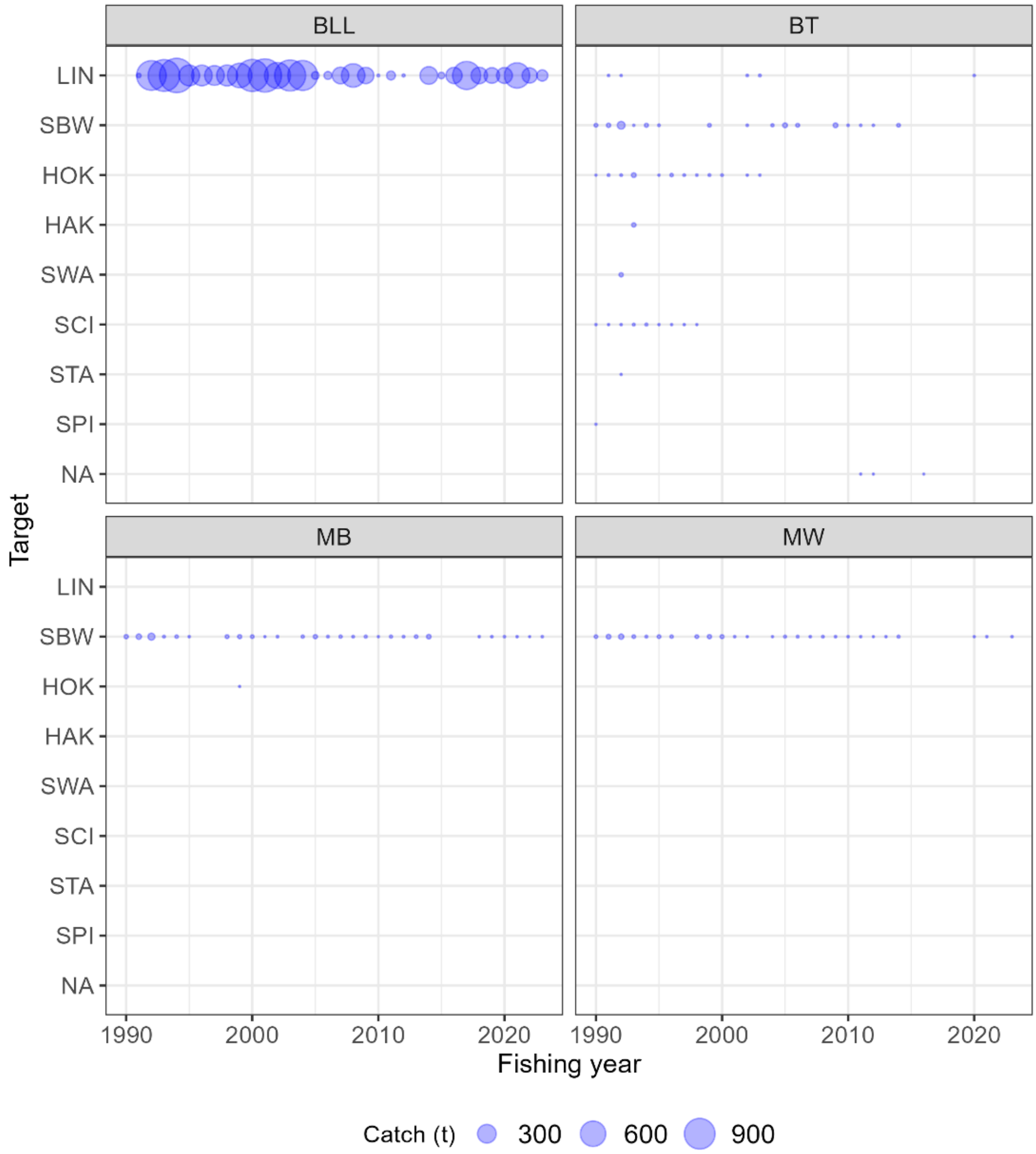


Figure A.6: LIN 6B distribution of annual ling catch reported on catch and effort forms by target species for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawls within 5 m of the bottom (MB – code defined within the analysis above), and all potting methods (POT – code defined within the analysis) gears separately. Target is hake (HAK), hoki (HOK), ling (LIN), giant stargazer (STA), scampi (SCI), silver warehou (SWA), southern blue whiting (SBW), spider crab (SPI) and not reported (NA).

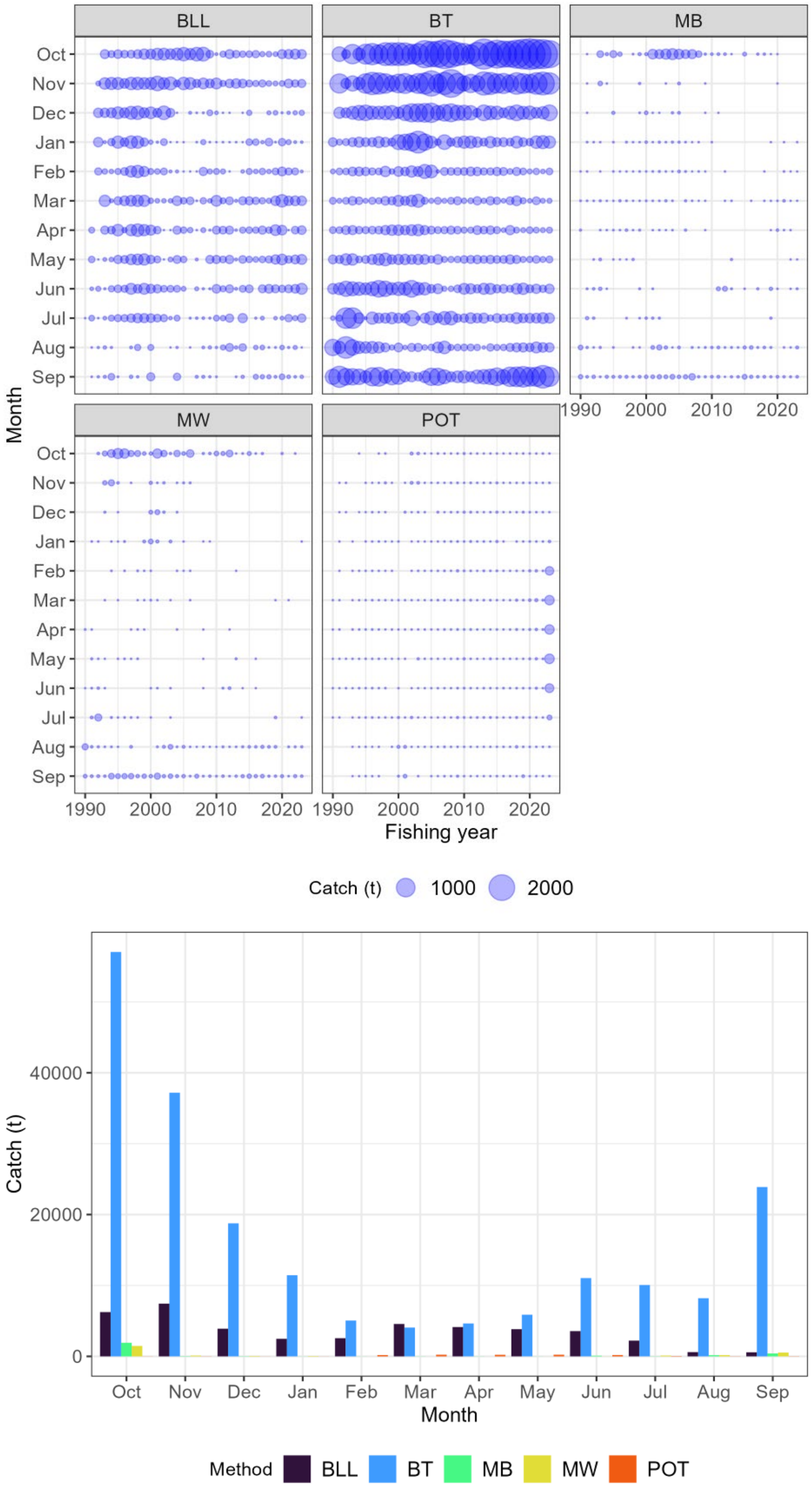


Figure A.7: LIN 5&6 distribution of annual ling catch reported on catch and effort forms by month for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis), and all potting methods (POT – code defined within the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

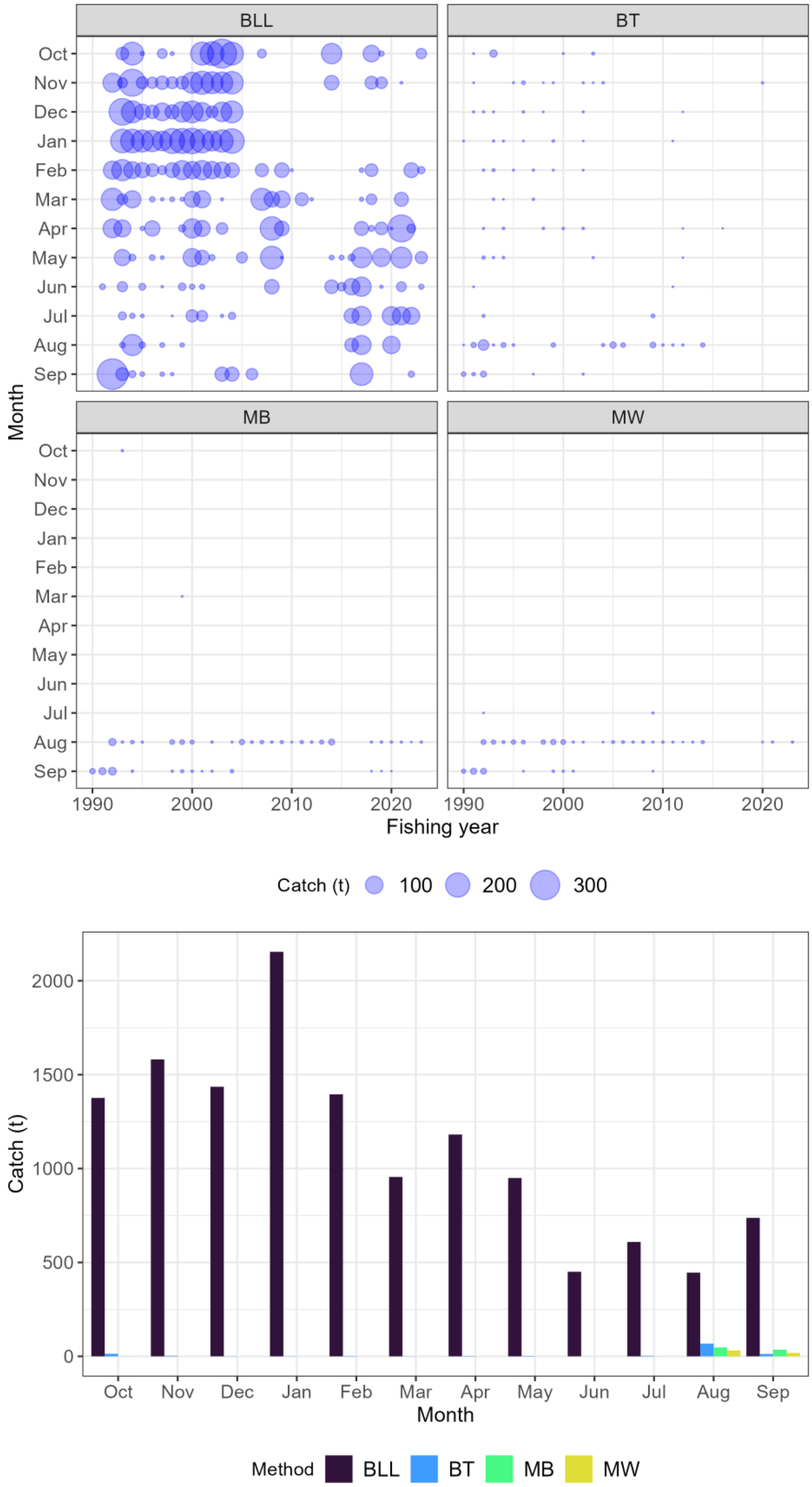


Figure A.8: LIN 6B distribution of annual ling catch reported on catch and effort forms by month for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis), and all potting methods (POT – code defined within the analysis above) gears separately.

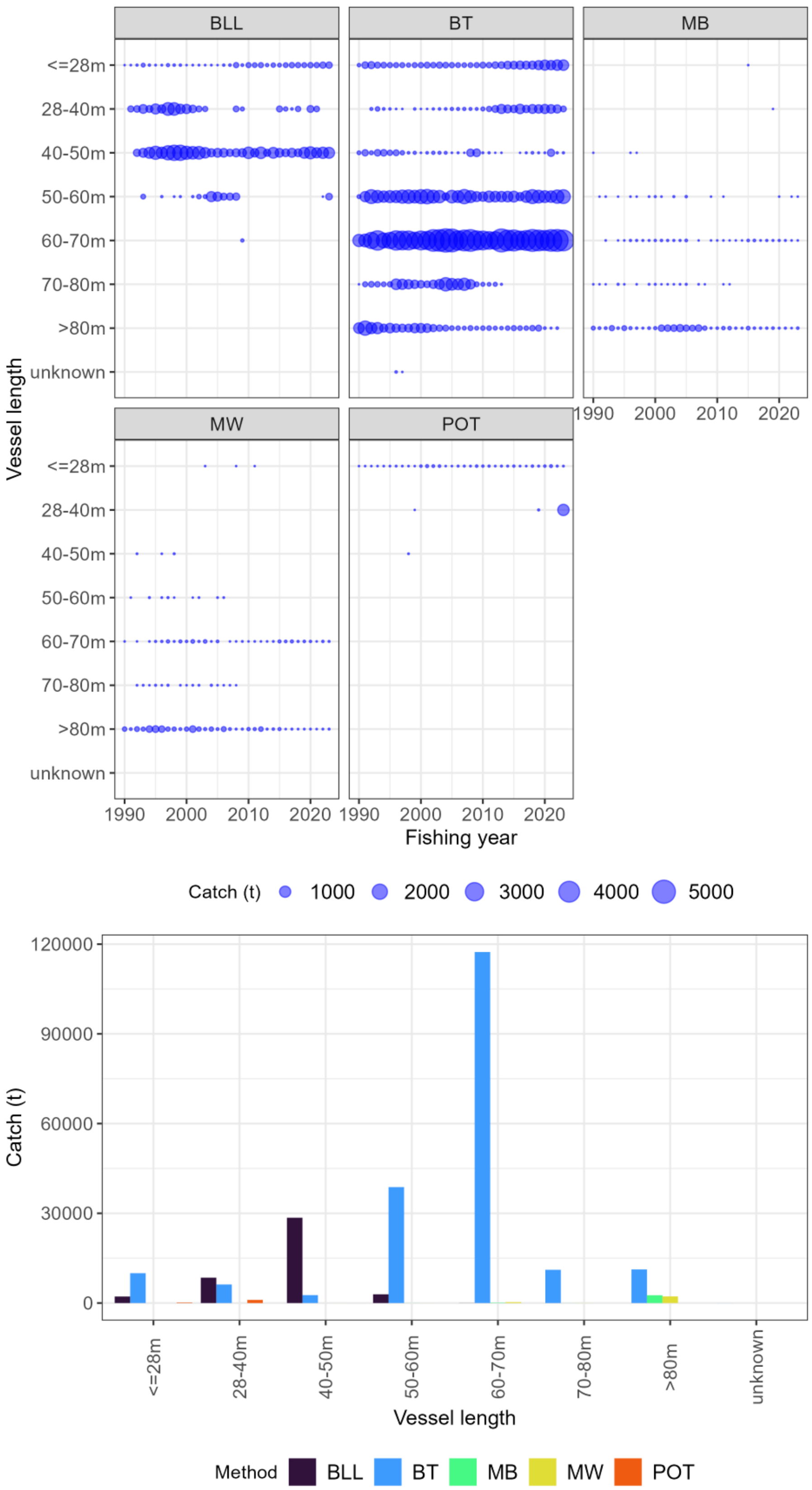


Figure A.9: LIN 5&6 distribution of annual ling catch reported on catch and effort forms by vessel length for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis above), and all potting methods (POT – code defined within the analysis) gears separately.

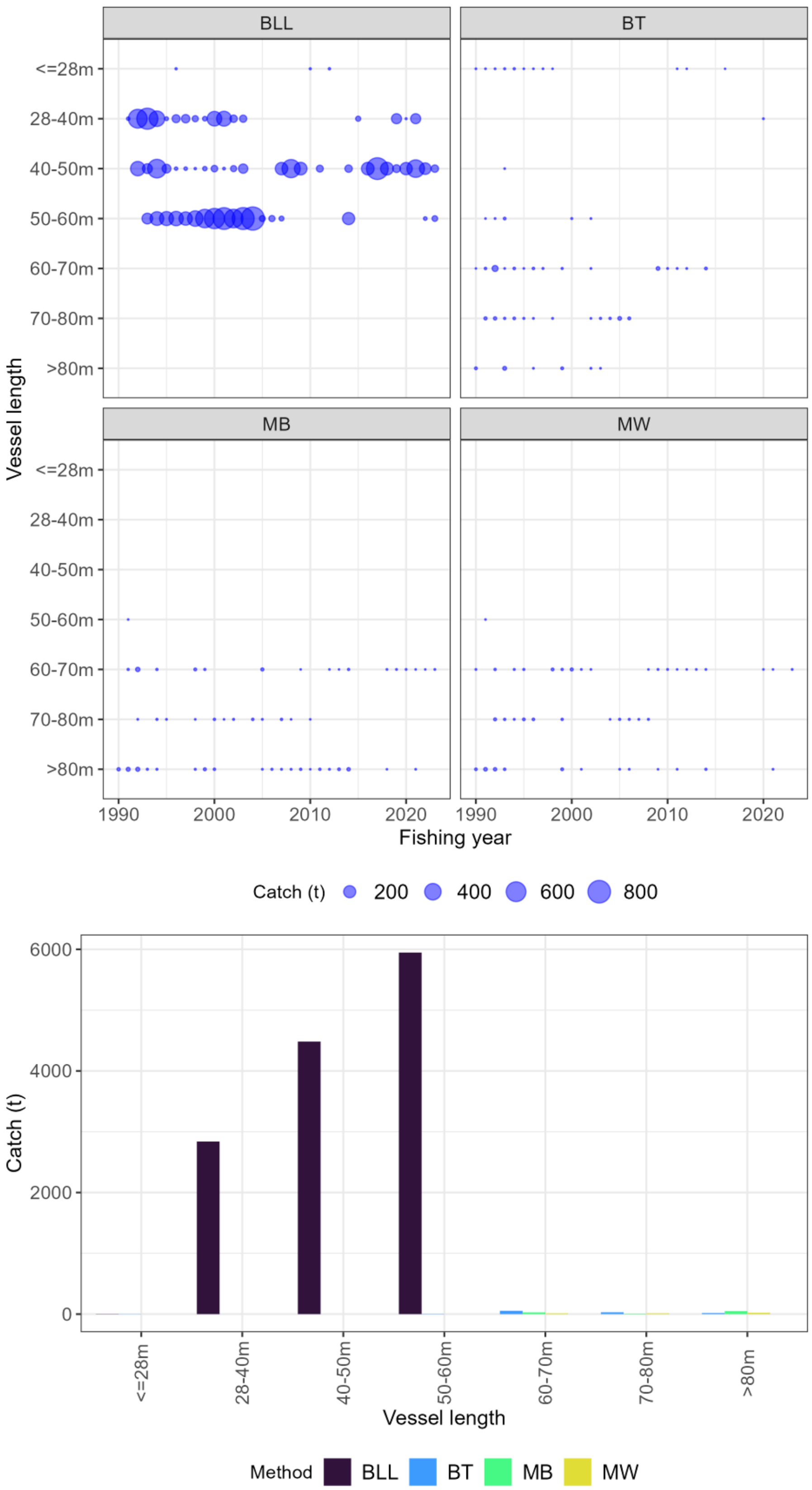


Figure A.10: LIN 6B distribution of annual ling catch reported on catch and effort forms by vessel length for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis above), and all potting methods (POT – code defined within the analysis) gears separately.

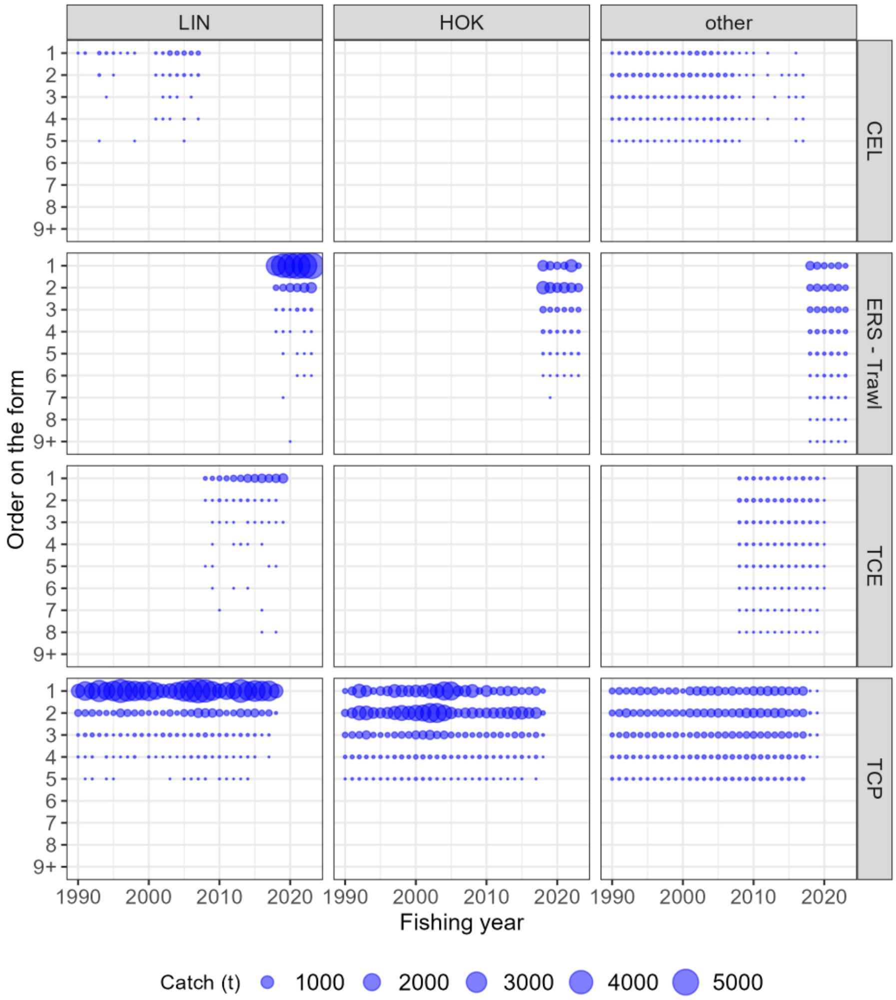


Figure A.11: LIN 5&6 distribution of annual ling catch reported on catch and effort forms by order (where greatest catch is 1) reported on the forms for bottom trawl major target species (ling – LIN, hoki – HOK, or other). The order is for QMS species for ERS forms and all species otherwise, matching the reporting requirements. Form type is trawl catch effort and processing return (TCP), trawl catch effort return (TCE), electronic reporting system return (ERS), and catch effort landing return (CEL).

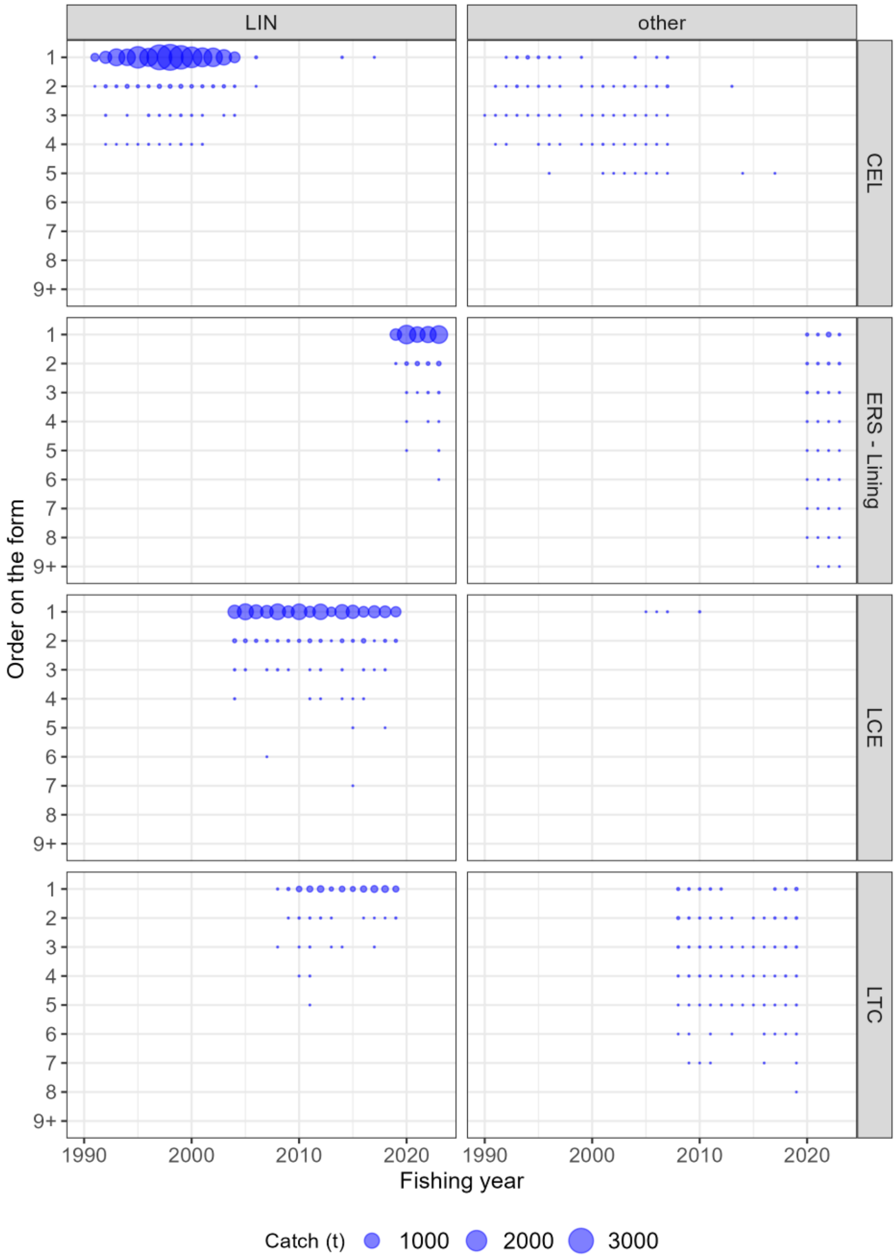


Figure A.12: LIN 5&6 annual ling catch reported on catch and effort forms by order reported on the forms for longline gears (where greatest catch is 1) and target species (ling – LIN or other). The order is for QMS species for ERS forms and all species otherwise, matching the reporting requirements. Form type is electronic reporting system return (ERS), catch effort landing return (CEL), lining catch effort return (LCE), and lining trip catch effort return (LTC).

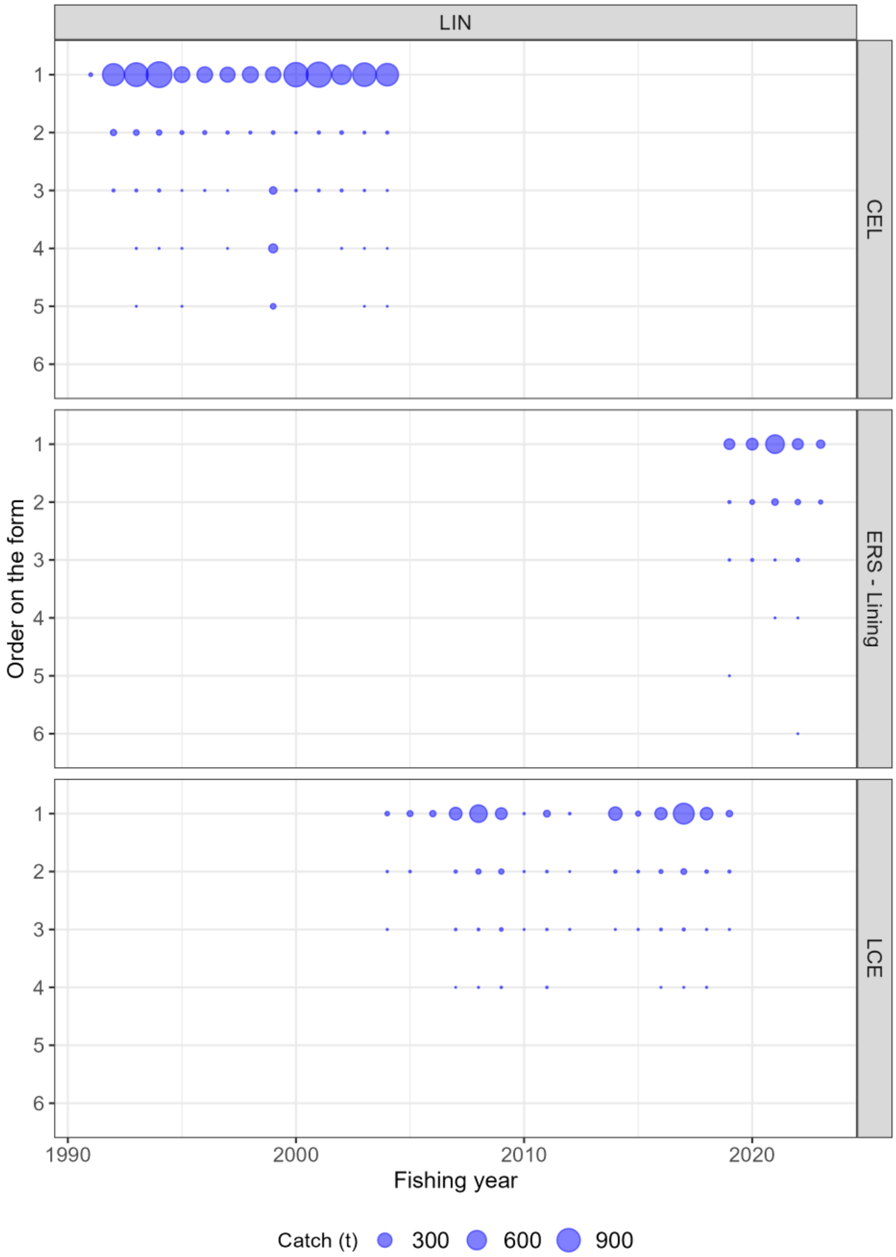


Figure A.13: LIN 6B annual ling catch reported on catch and effort forms by order reported on the forms for longline gears (where greatest catch is 1) and target species (ling – LIN or other). The order is for QMS species for ERS forms and all species otherwise, matching the reporting requirements. Form type is electronic reporting system return (ERS), catch effort landing return (CEL), lining catch effort return (LCE), and lining trip catch effort return (LTC).

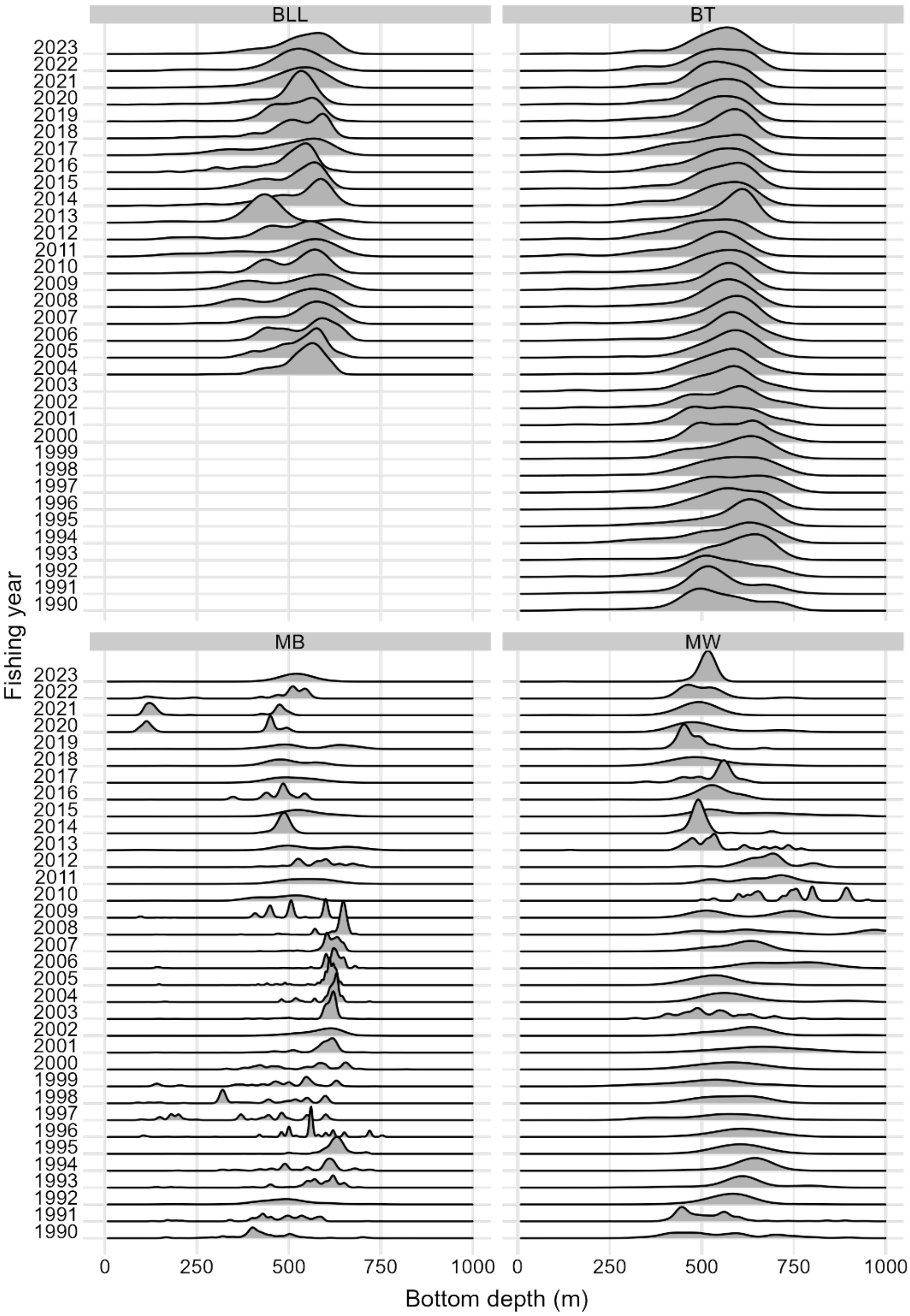


Figure A.14: Catch-weighted LIN 5&6 distribution of bottom depth by fishing year for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), and midwater trawl within 5 m of the bottom (MB – code defined within the analysis above).

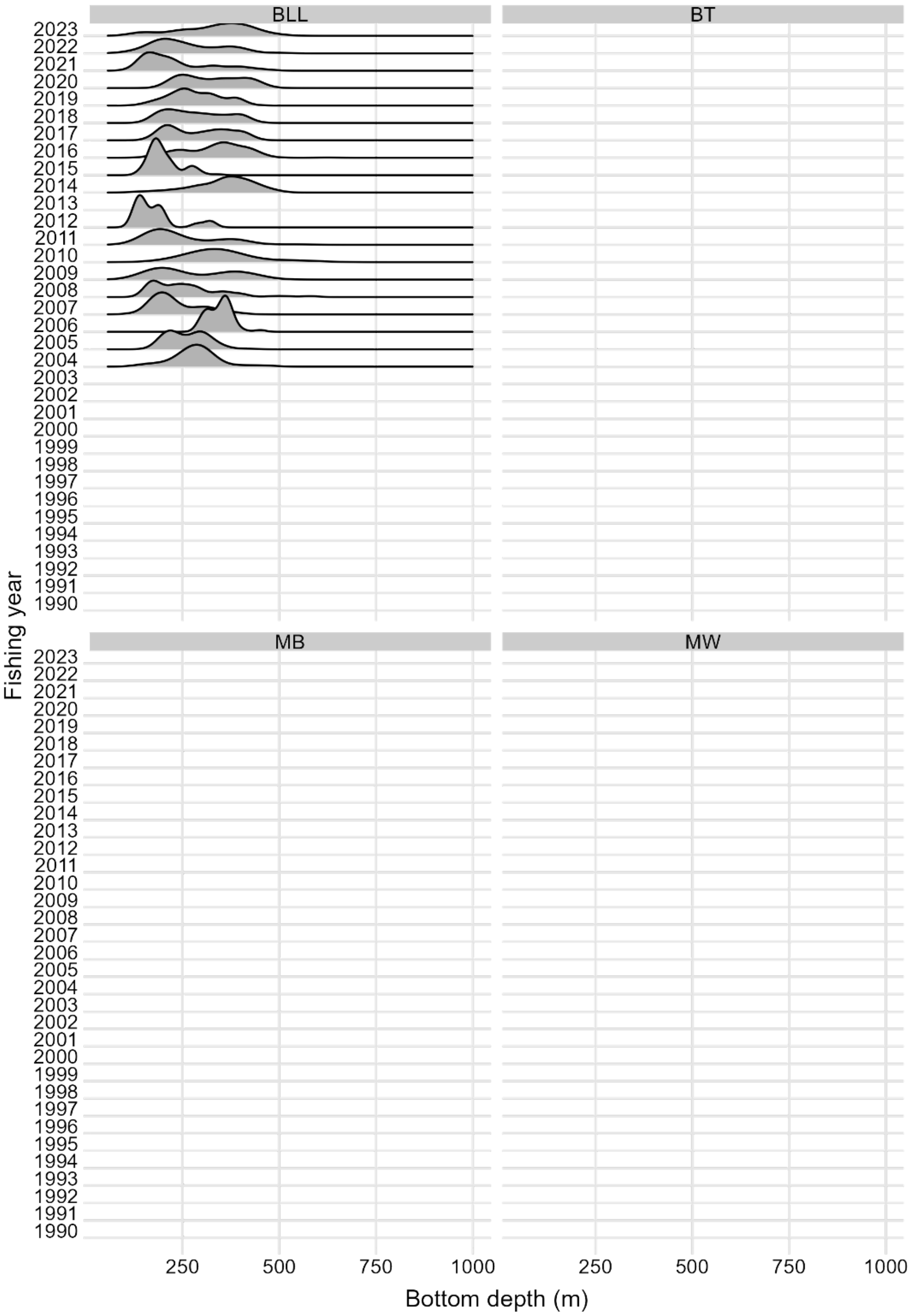


Figure A.15: Catch-weighted LIN 6B distribution of bottom depth by fishing year for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), and midwater trawl within 5 m of the bottom (MB – code defined within the analysis above). The majority of the ling catch in LIN 6B is by bottom longline, hence the lack of data in the other methods, which are kept in the plot for completeness.

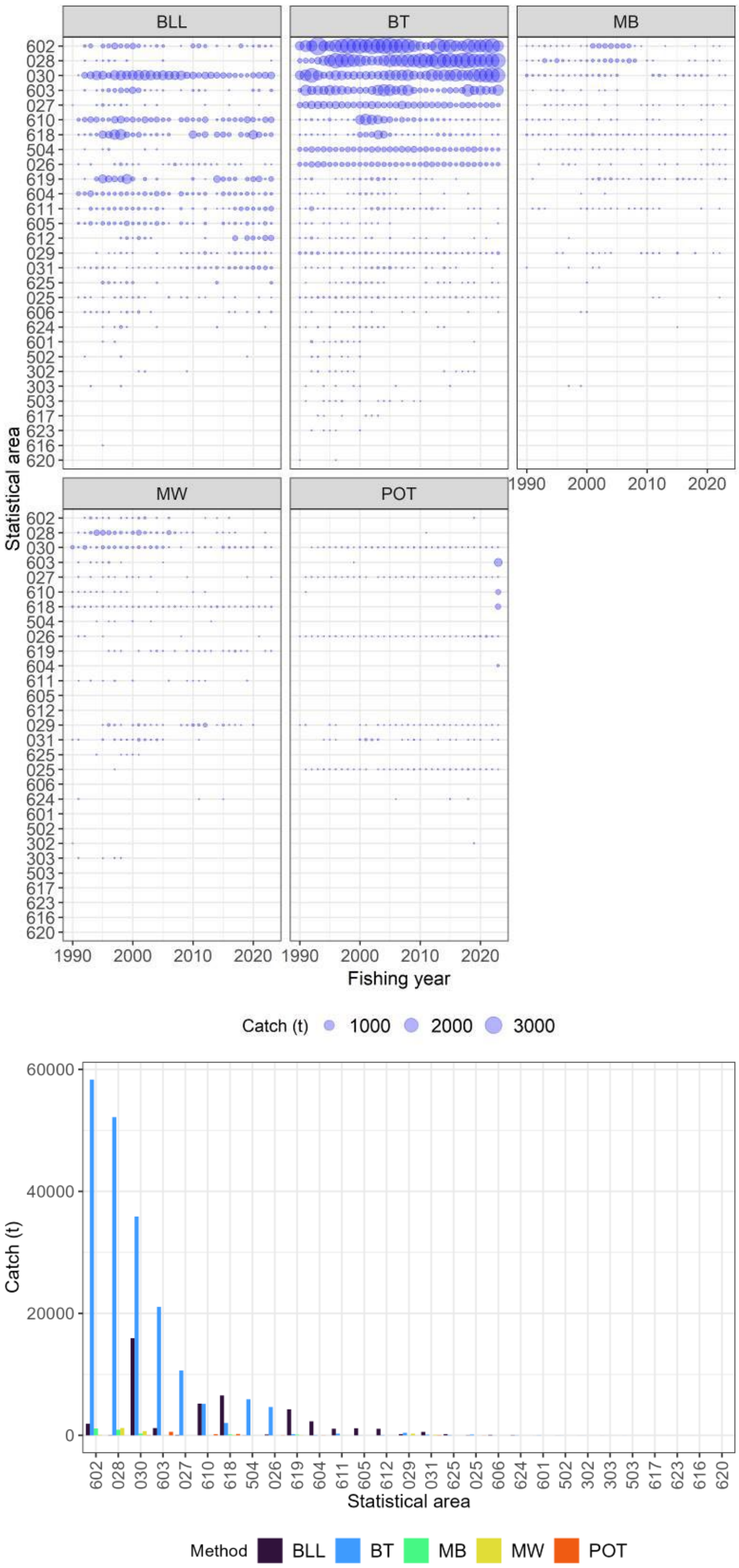


Figure A.16: LIN 5&6 distribution of annual ling catch reported on catch and effort forms by Statistical Area for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis above), and all potting methods (POT – code defined within the analysis above).

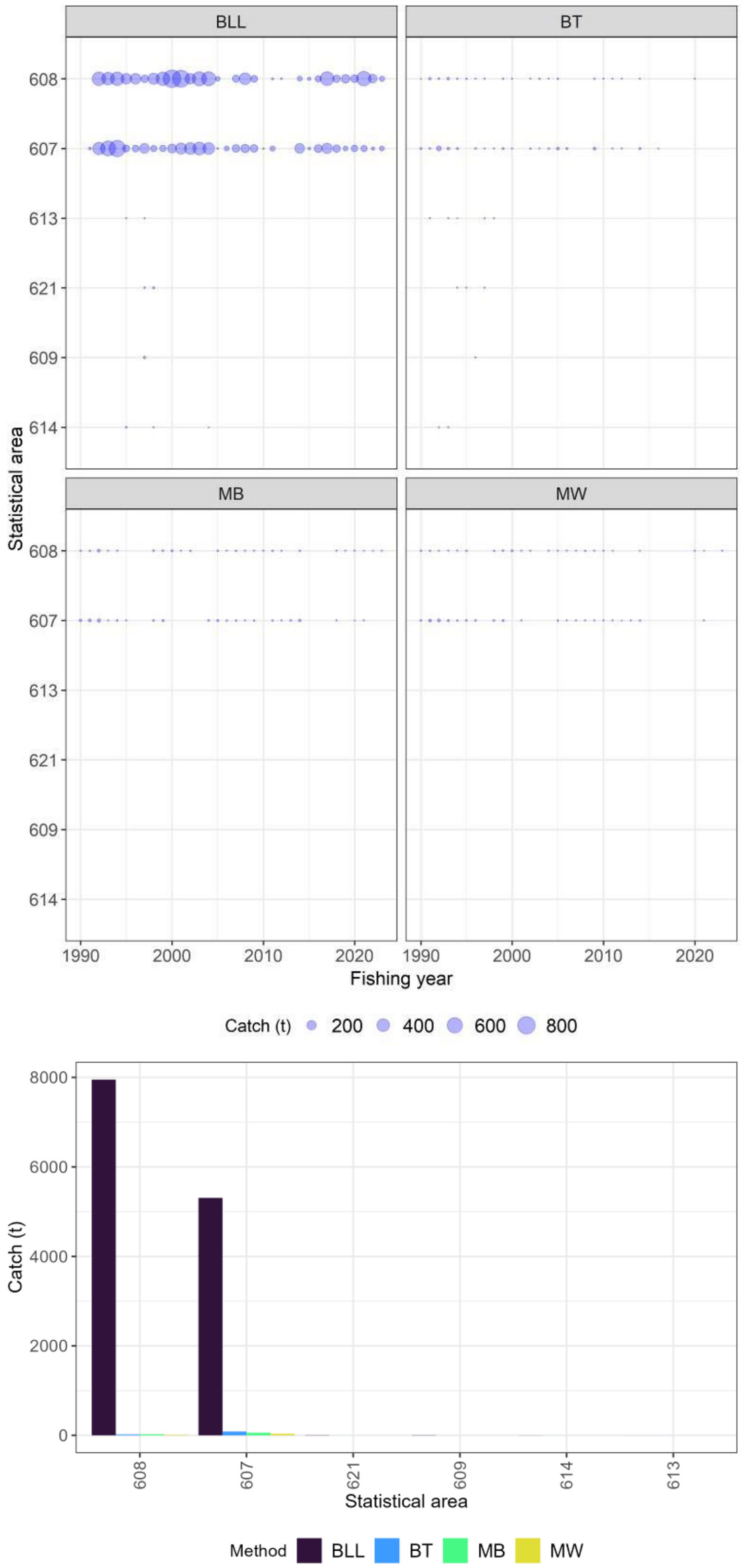


Figure A.17: LIN 6B distribution of annual ling catch reported on catch and effort forms by Statistical Area for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), and midwater trawl within 5 m of the bottom (MB – code defined within the analysis above.

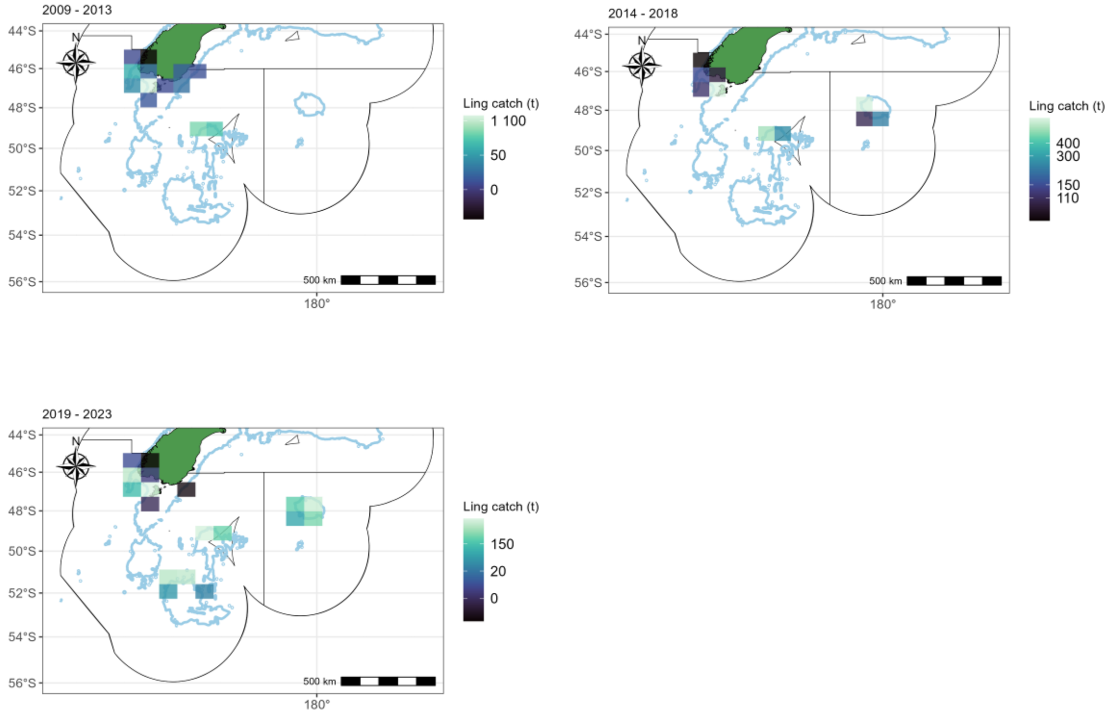


Figure A.18: Distribution of ling catches in the Sub-Antarctic (LIN 5&6 and LIN 6B) by bottom longlines between 2008 and 2023. Year ranges are fishing years. Areas are plotted at about 0.5° resolution and only where at least three vessels fished in any cell in the period. Data prior to 2008 are not shown as they were recorded on daily forms.

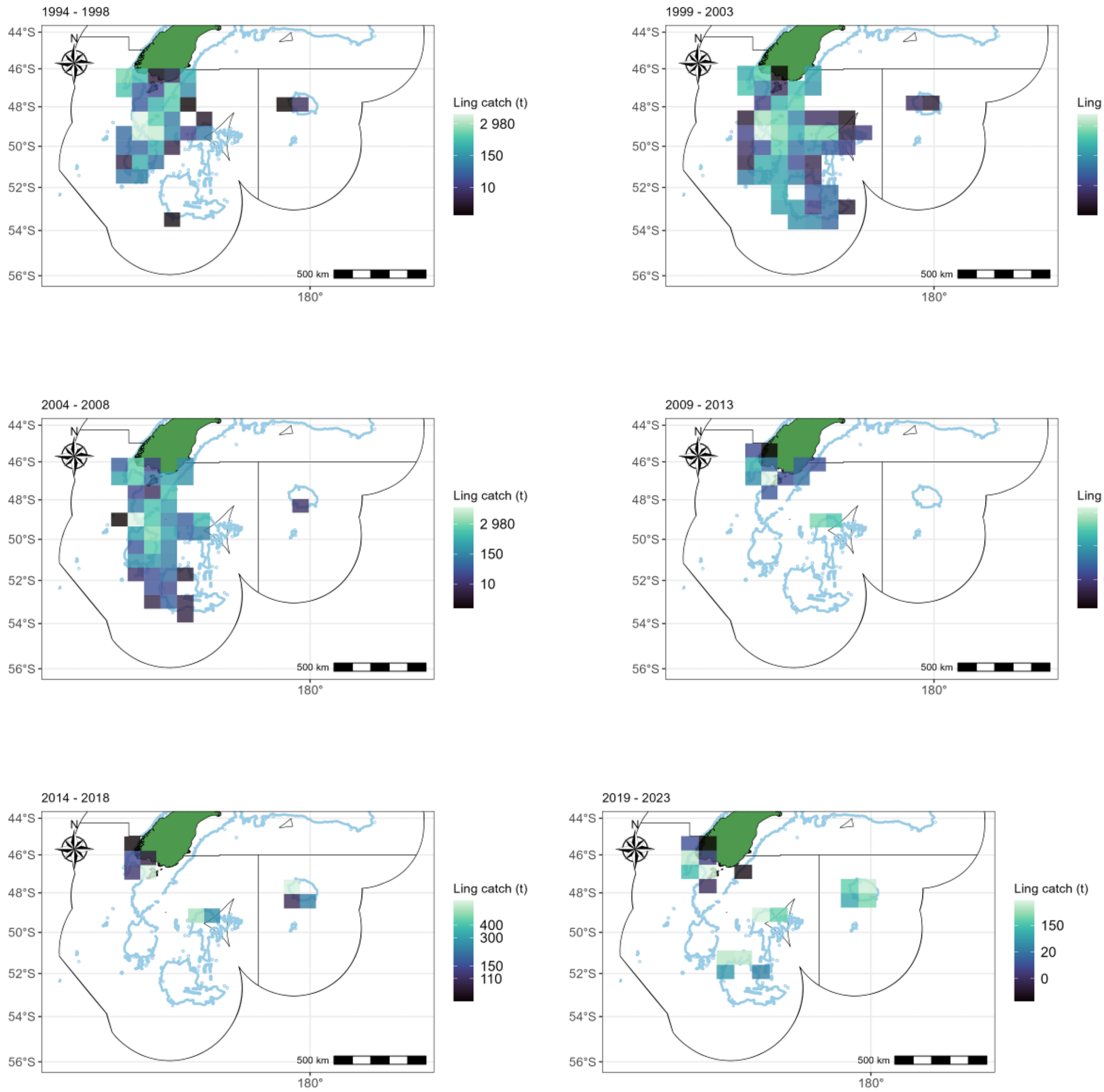
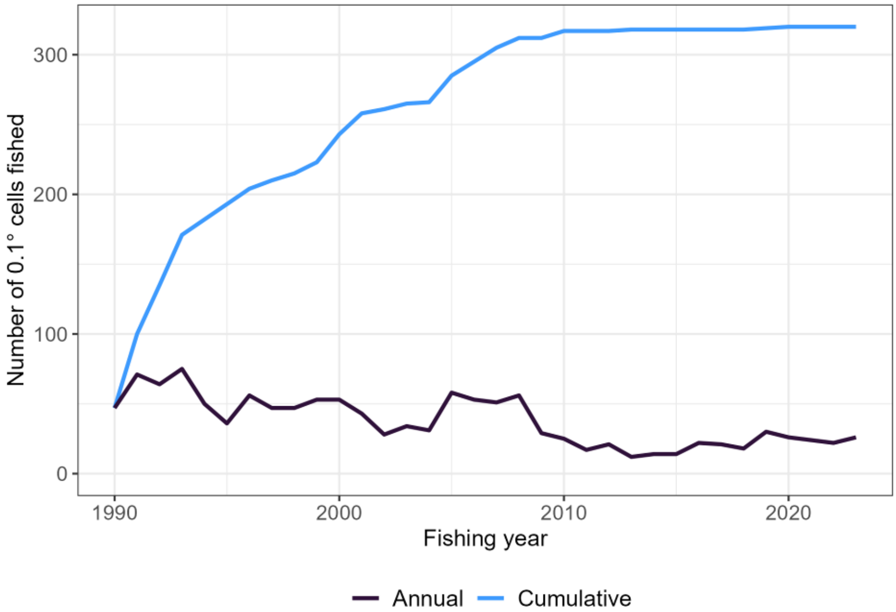


Figure A.19: Distribution of ling catches in the Sub-Antarctic (LIN 5&6 and LIN 6B) by bottom trawls between 1994 and 2023. Year ranges are fishing years. Areas are plotted at about 0.5° resolution and only where at least three vessels fished in any cell in the period.

Bottom trawl



Bottom longline

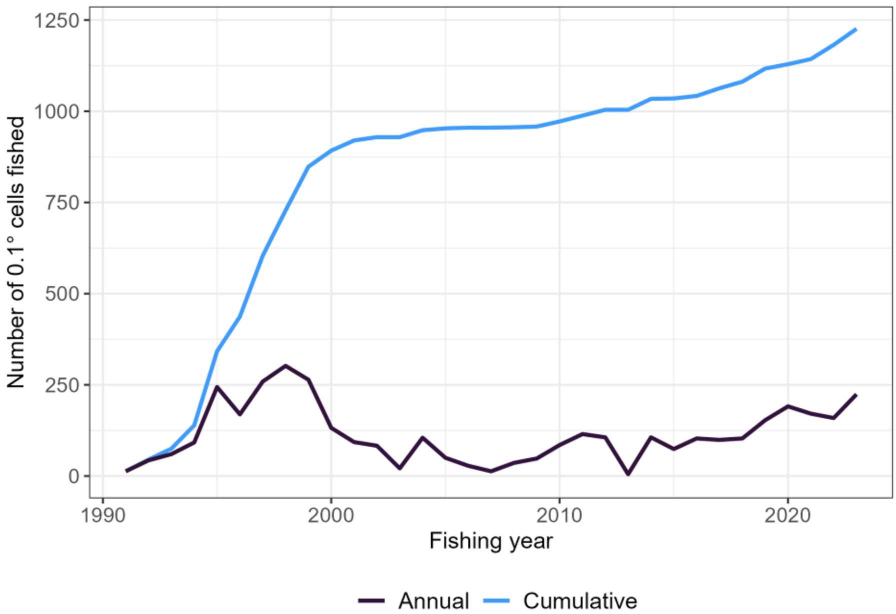


Figure A.20: Spatial distribution of the top 90% of catch of the ling target fishery in LIN 5&6: annual total number of cells of 0.1° latitude and longitude that were fished and cumulative number of new cells fished over time.

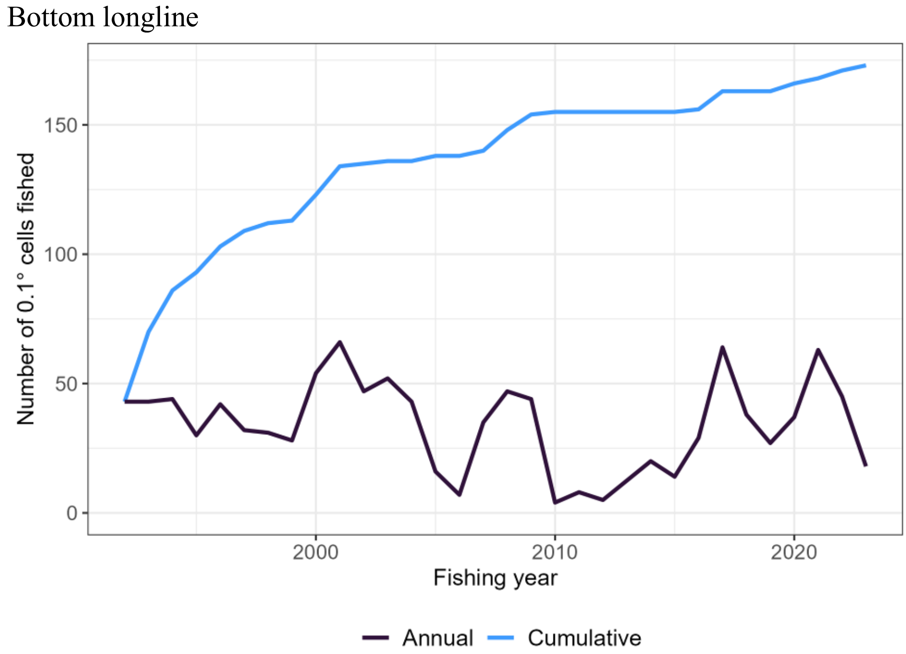


Figure A.21: Spatial distribution of the top 90% of catch of the ling target fishery in LIN 6B: annual total number of cells of 0.1° latitude and longitude that were fished and cumulative number of new cells fished over time.

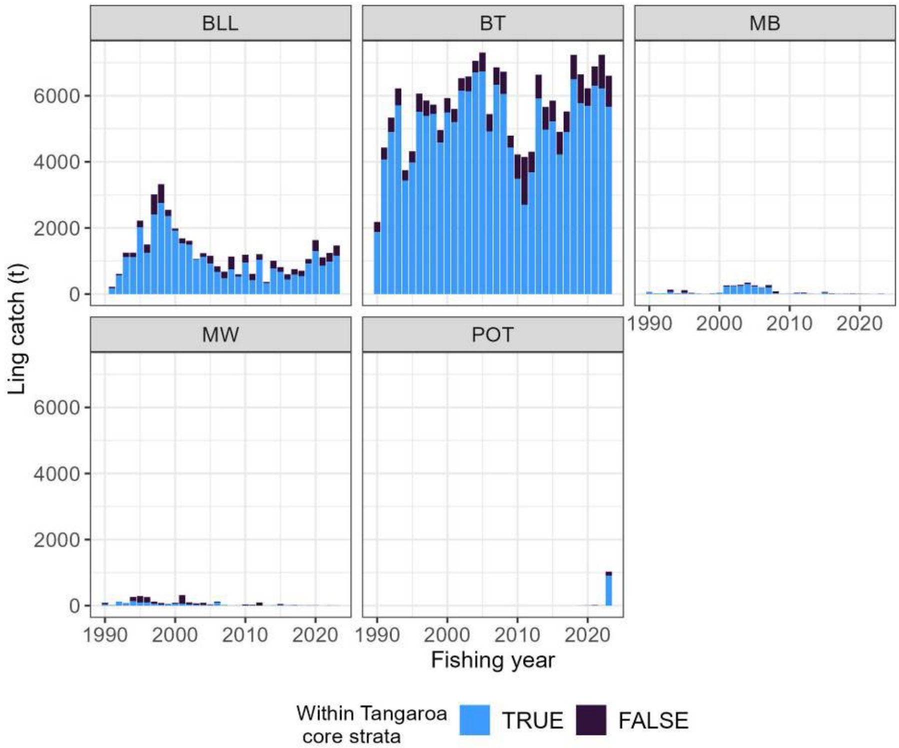


Figure A.22: LIN 5&6 distribution of annual ling catch reported on catch and effort forms that fall within the *Tangaroa* survey core strata area for bottom longline (BLL), bottom trawl (BT), midwater trawl (MW), midwater trawl within 5 m of the bottom (MB – code defined within the analysis above), and all potting methods (POT – code defined within the analysis above).

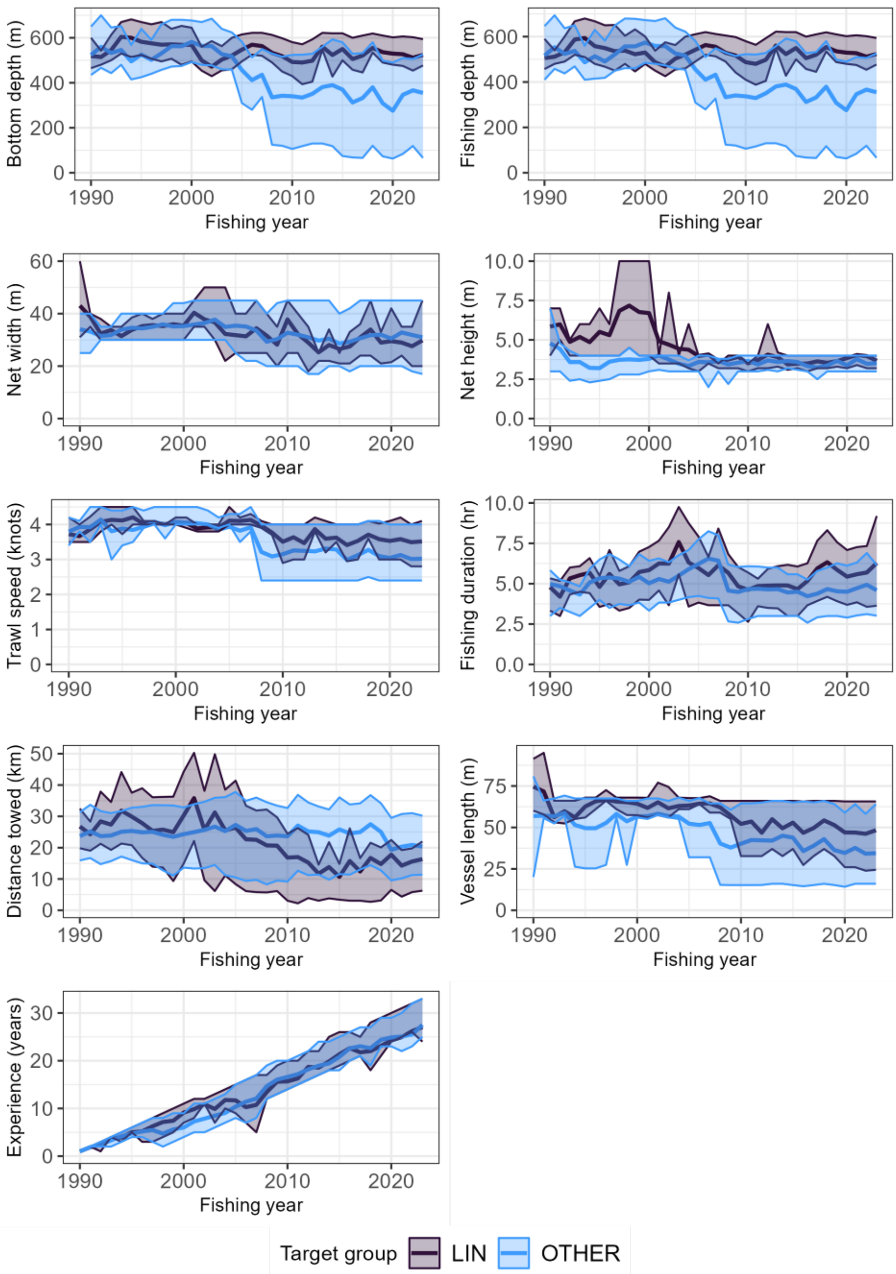


Figure A.23: Change in effort characteristics over time by target species of the bottom trawl ling fisheries in LIN 5&6. Median and interquartile range are shown.

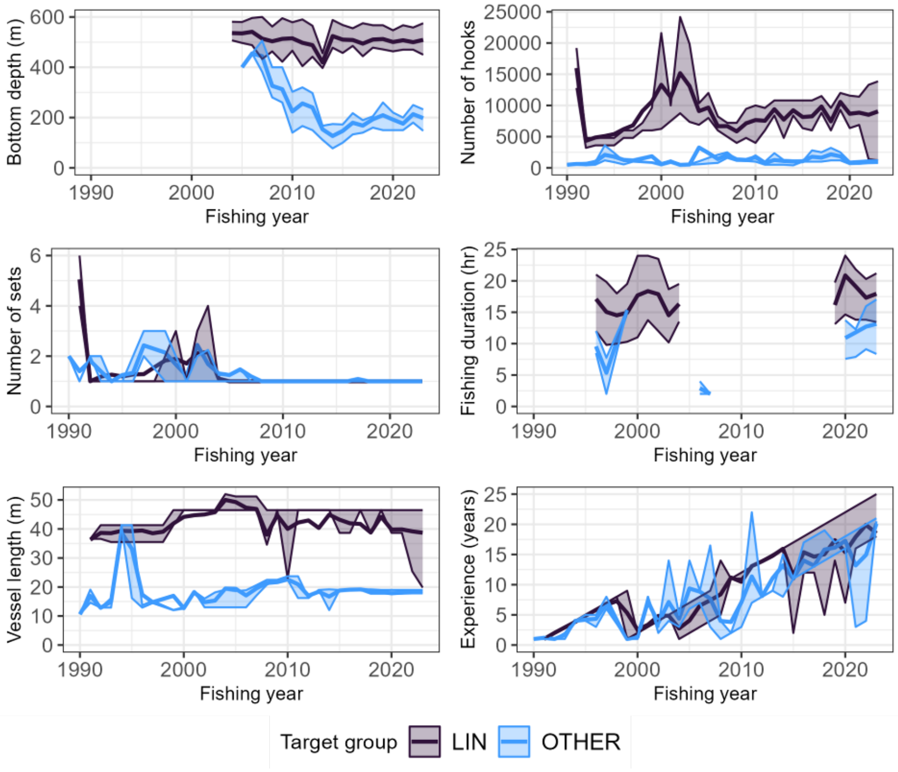


Figure A.24: Change in effort characteristics over time by target species of the longline ling fisheries in LIN 5&6. Median and interquartile range are shown.

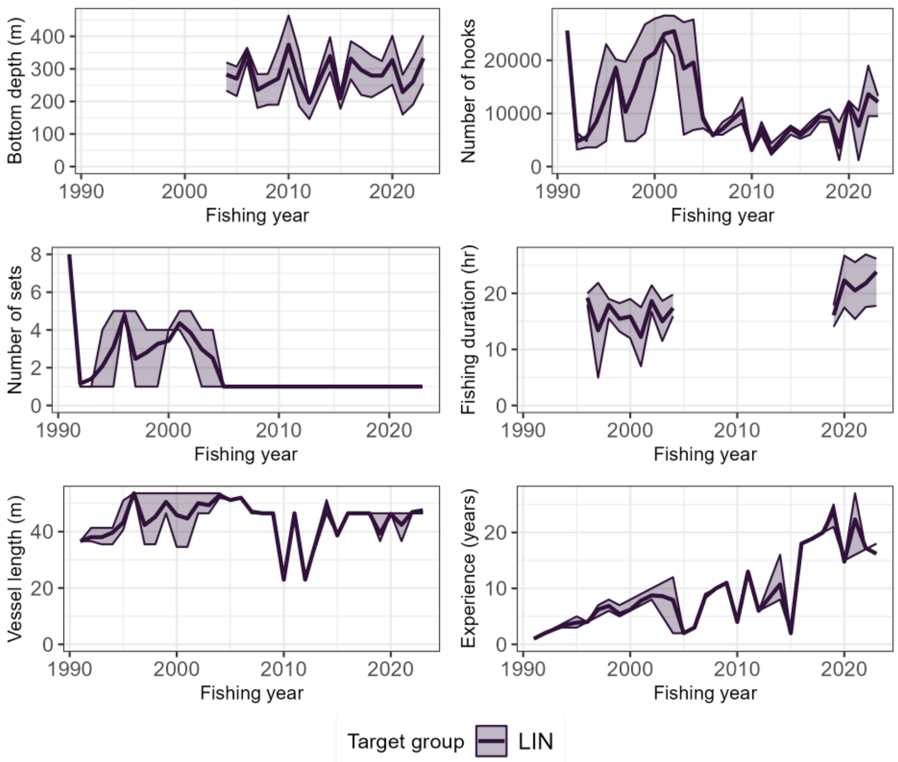


Figure A.25: Change in effort characteristics over time by target species of the longline ling fisheries in LIN 6B. Median and interquartile range are shown.

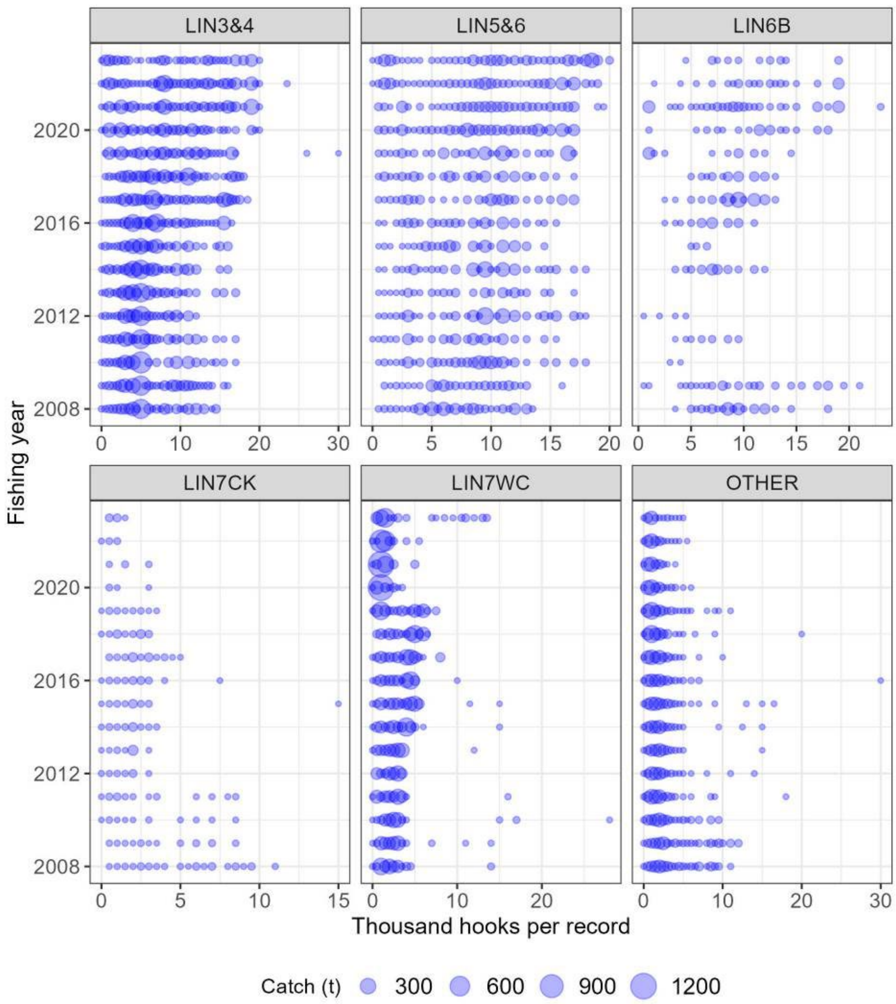


Figure A.26: Annual ling catch reported on catch and effort forms by the number of hooks for vessels per report (discretised in 500 hook bins) and by year for each ling stock.

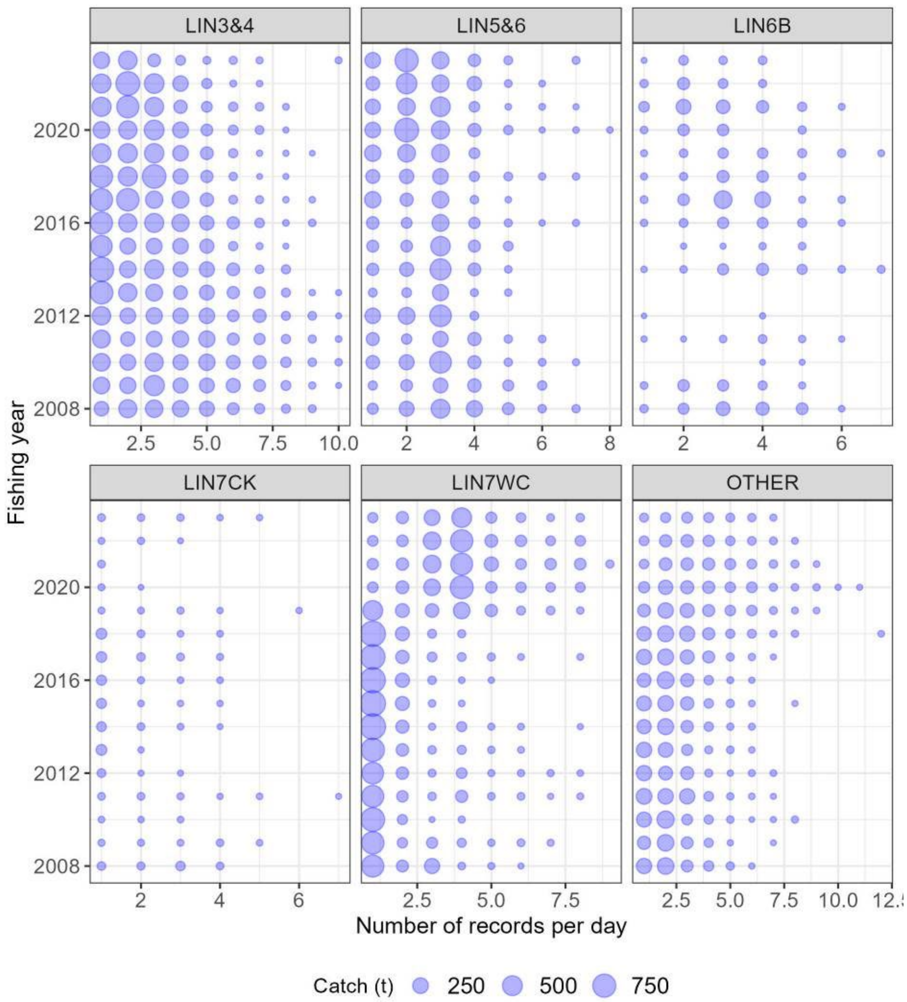


Figure A.27: Annual ling catch reported on catch and effort forms by the number of reports of vessels per day and by year for each ling stock.

12. APPENDIX B – SPATIAL ANALYSIS

Table B.1: Model comparison Deviance Information Criterion (DIC) and Watanabe-Akaike Information Criterion (WAIC) for each of the model runs of mean length of ling caught by bottom trawl vessels. The model term 'Space' refers to the INLA SPDE term.

Model	DIC	WAIC	Comment
Length ~ Intercept + Space	1 623 211	1 623 406	
Length ~ Intercept + Fishing event (random) + Space	1 623 170	1 623 368	
Length ~ Intercept + Fishing event (random) +Year + Space	1 619 332	1 619 536	
Length ~ Intercept + Fishing event (random) +Year + Sex + Space	1 592 110	1 592 335	
Length ~ Intercept + Fishing event (random) +Year + Sex + Month + Space	1 590 902	1 591 125	
Length ~ Intercept + Fishing event (random) +Year + Sex + Month + s(Depth,3) + Space	1 590 584	1 590 801	Chosen model
Length ~ Intercept + Fishing event (random) +Year + Sex + s(Depth,3) + Space × Month	1 581 223	1 581 708	Best model

Table B.2: Model comparison Deviance Information Criterion (DIC) and Watanabe-Akaike Information Criterion (WAIC) for each of the model runs of mean length of ling caught by bottom longline vessels. The model term 'Space' refers to the INLA SPDE term.

Model	DIC	WAIC	Comment
Length ~ Intercept + Space	586 419	586 428	
Length ~ Intercept + Fishing event (random) + Space	586 420	586 428	
Length ~ Intercept +Year Space	584 575	584 584	
Length ~ Intercept +Year + Sex + Space	576 003	576 015	
Length ~ Intercept +Year + Sex + Month + Space	575 826	575 827	
Length ~ Intercept +Year + Sex + Month + s(Depth,3) + Space	575 820	575 831	Chosen model
Length ~ Intercept +Year + Sex + s(Depth,3) + Space × Month	574 356	574 390	Best model

Figure B.1: LIN 5&6 distribution of the annual number of ling length measurements collected by observers for bottom longline (BLL) and bottom trawl (BT) gears separately.

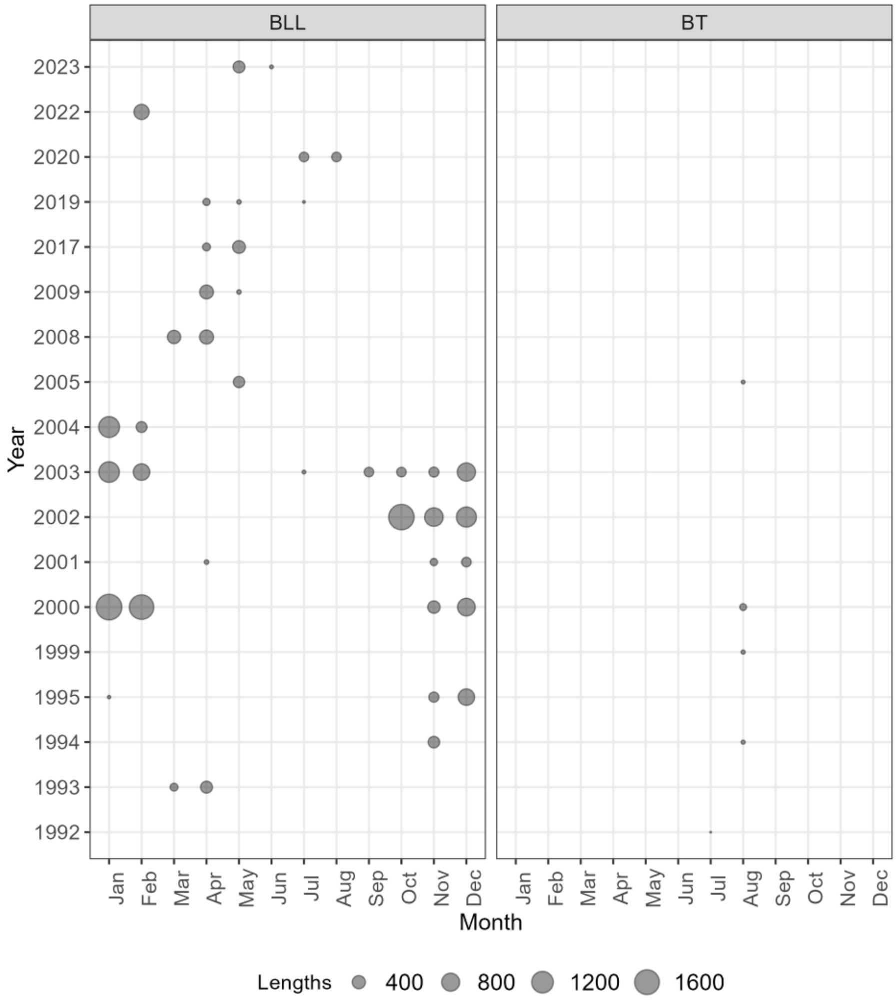


Figure B.2: LIN 6B distribution of annual number of ling length measurements collected by observers for bottom longline (BLL) and bottom trawl (BT) gears separately.

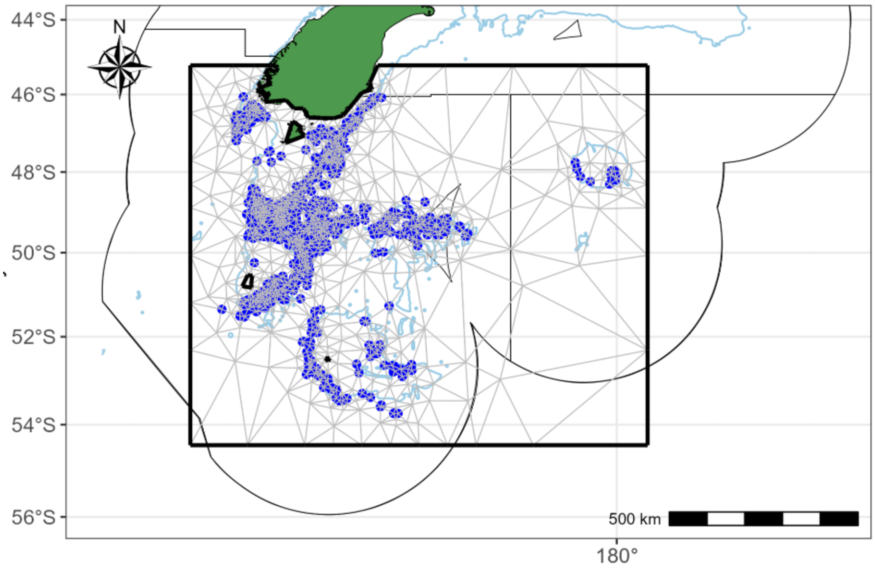


Figure B.3: Spatial mesh for ling spatio-temporal models for the bottom trawl ling fishery showing the locations of length data (blue points), the spatial mesh (grey lines), the extent of the spatial model (thick black lines), and the ling stocks (black lines).

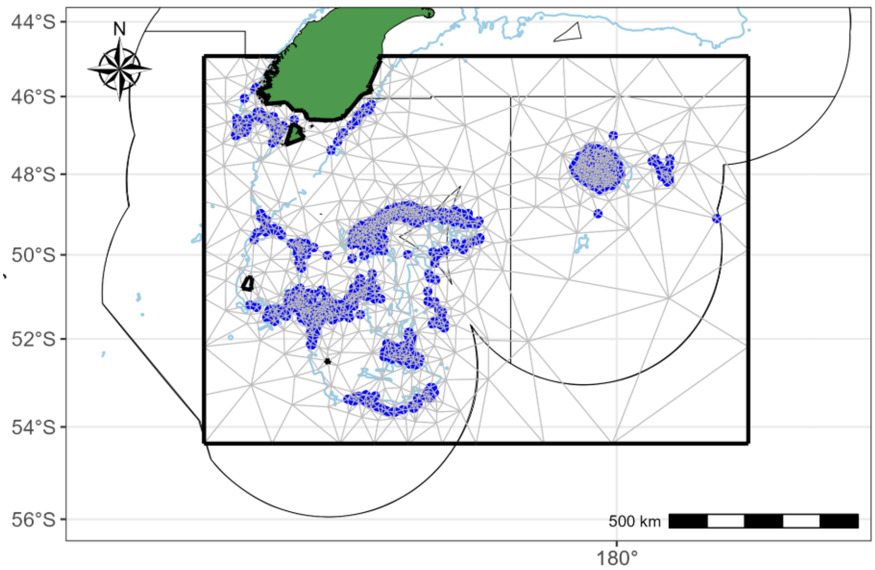


Figure B.4: Spatial mesh for ling spatio-temporal models for the bottom longline ling fishery showing the locations of length data (blue points), the spatial mesh (grey lines), the extent of the spatial model (thick black lines), and the ling stocks (black lines).

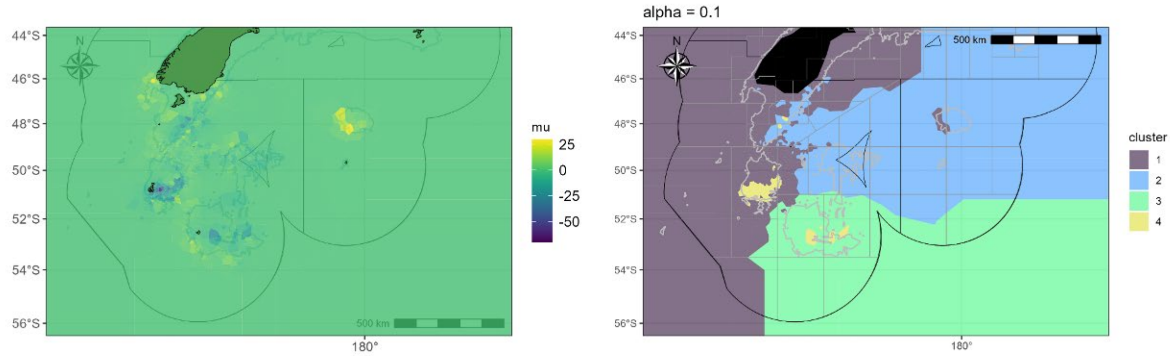


Figure B.5: The bottom trawl fleet spatial effect for the chosen model of Length ~ Intercept + Fishing event (random) + Year + Sex + Month + s(Depth,3) + Space (left) and resulting optimum clusters (alpha = 0.1). Mu is the deviance from the mean length.

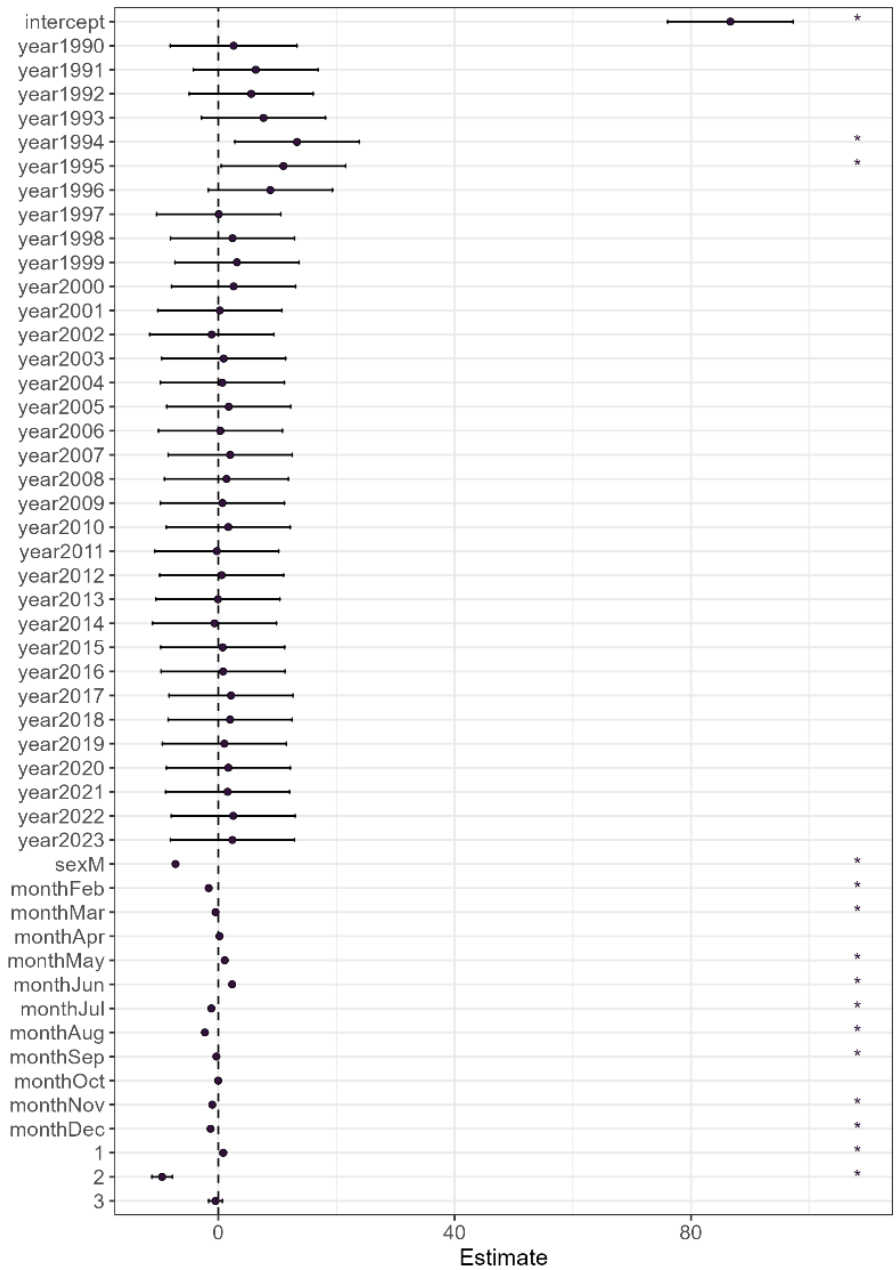


Figure B.6: The bottom trawl fleet partial effects plots for the chosen model of Length ~ Intercept + Fishing event (random) + Year + Sex + Month + s(Depth,3) + Space. * denotes a statistically significant parameter.

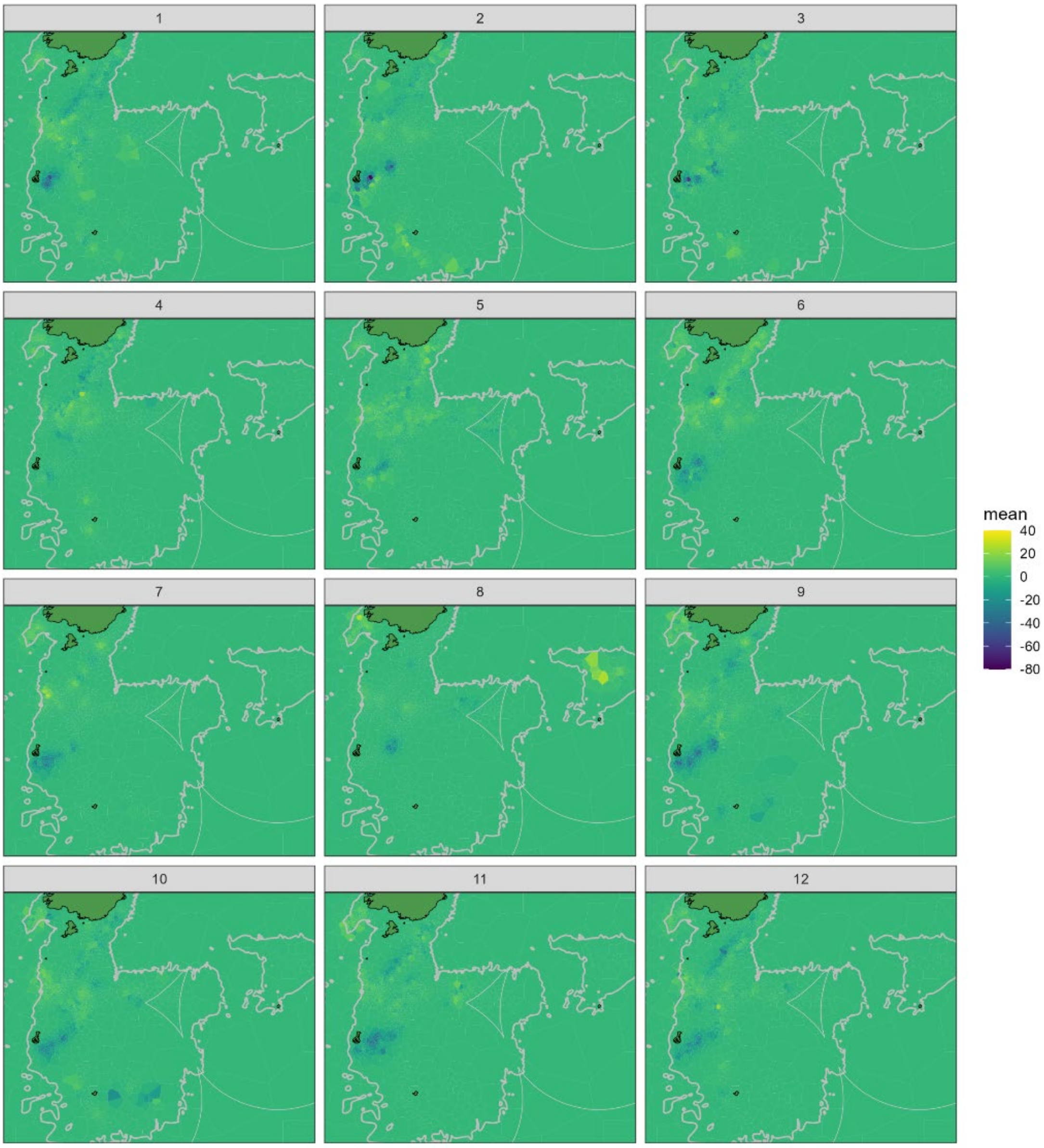


Figure B.7: The bottom trawl fleet spatial effect for model of Length ~ Intercept + Fishing event (random) + Year + Sex + s(Depth,3) + SPDE × Month, where 1 is January. 'mean' is the deviation from the mean length.

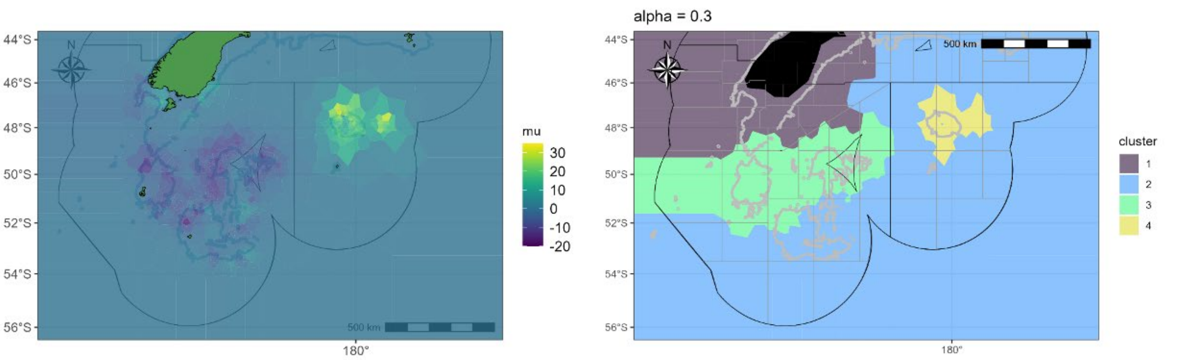


Figure B.8: The bottom longline fleet spatial effect for the chosen model of Length ~ Intercept + Year + Sex + Month + s(Depth,3) + Space (left) and resulting optimum clusters (alpha = 0.3). Mu is the deviance from the mean length.

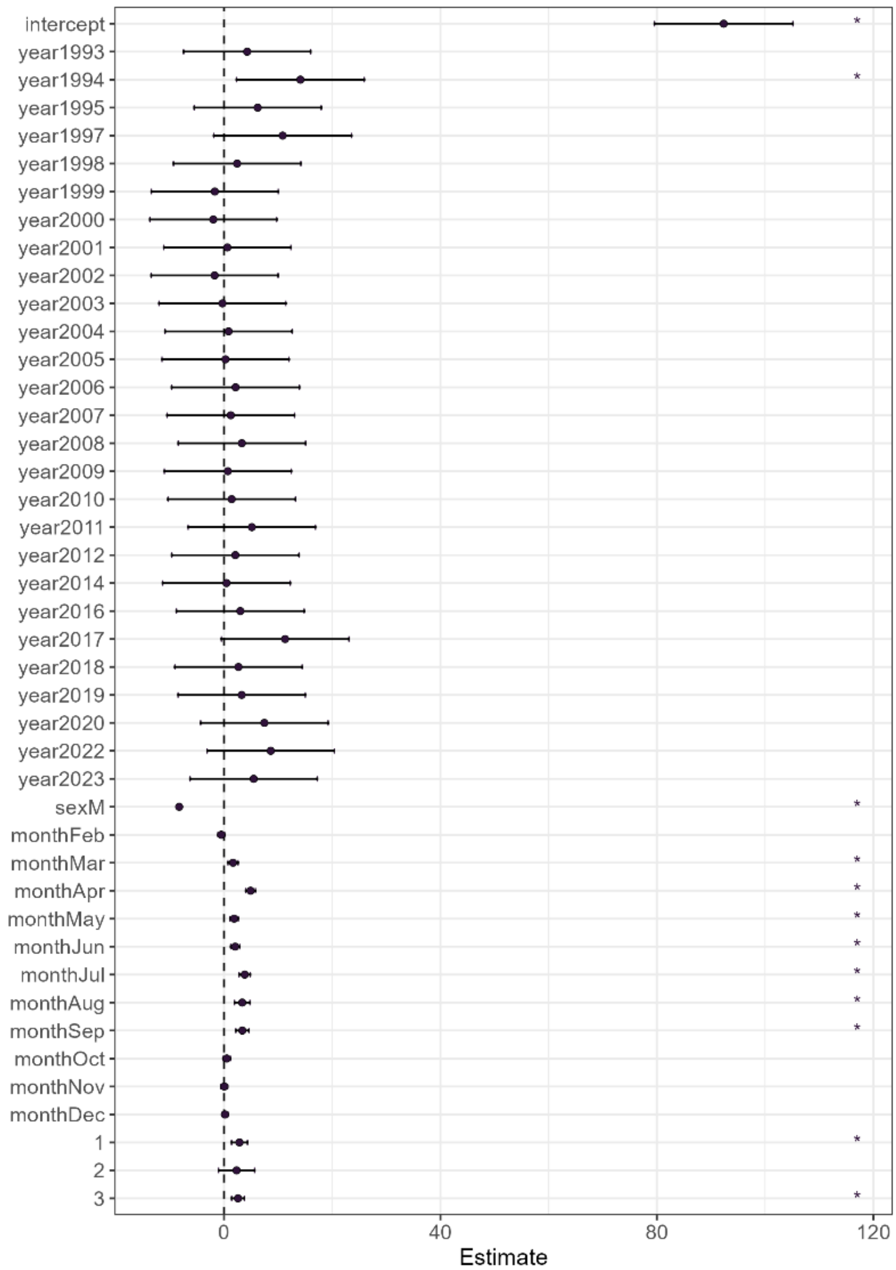


Figure B.9: The bottom longline fleet partial effects plots for the chosen model of Length ~ Intercept + Year + Sex + Month + s(Depth,3) + Space. * denotes a statistically significant parameter.

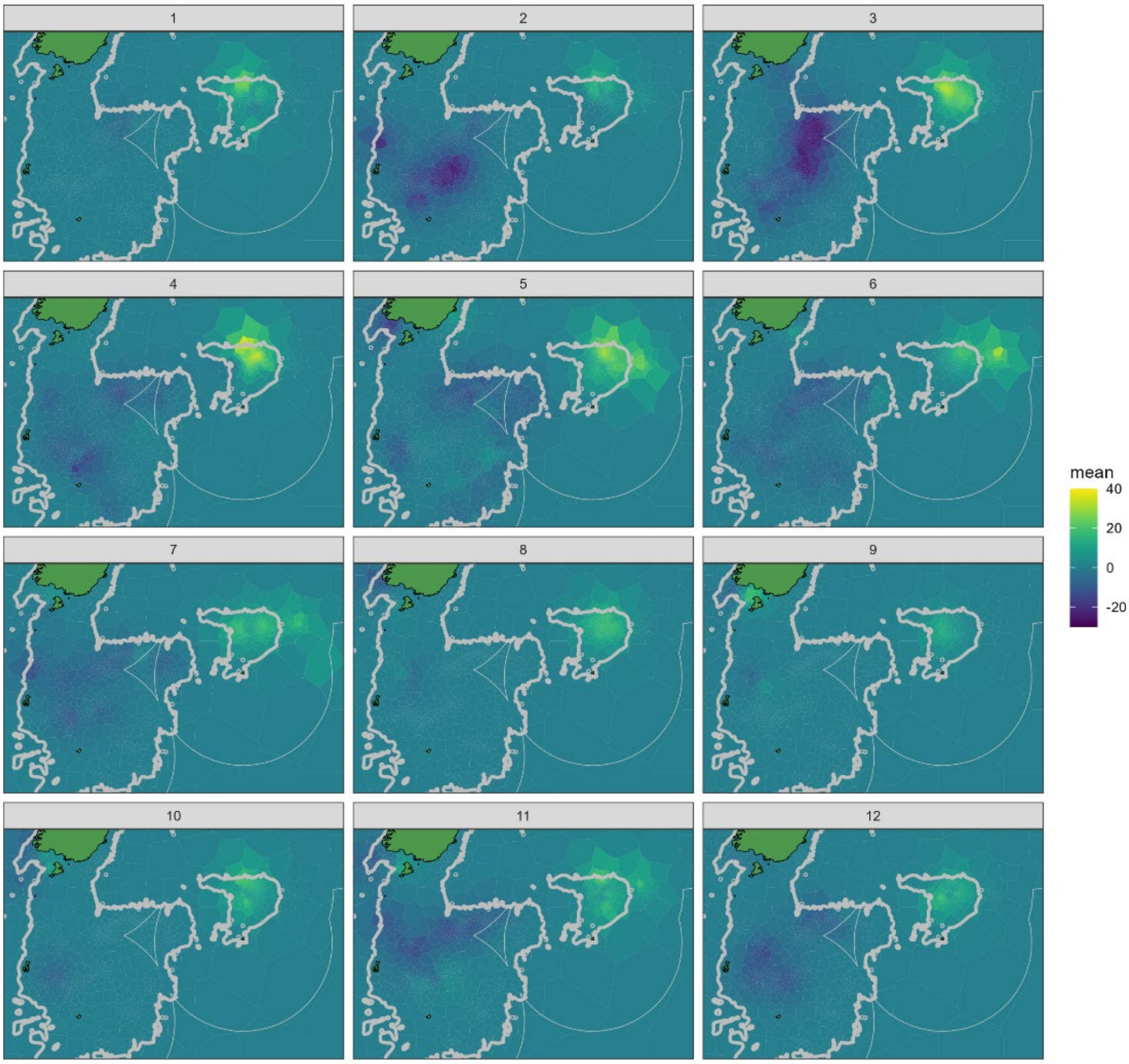


Figure B.10: The bottom longline fleet spatial effect for model of Length ~ Intercept + Year + Sex + s(Depth,3) + SPDE × Month, where 1 is January. 'mean' is the deviation from the mean length.

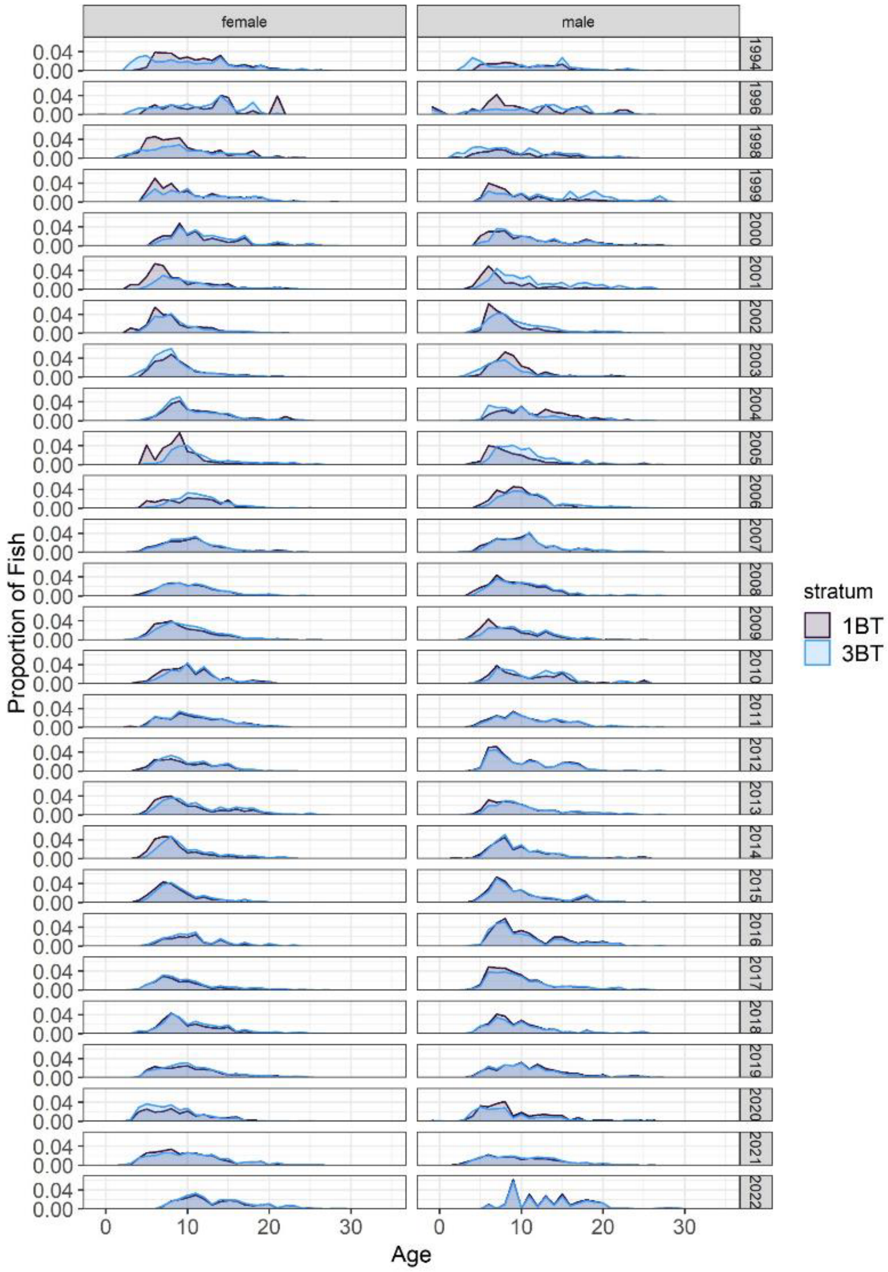


Figure B.11: Trend of scaled age frequency distributions of LIN 5&6 for bottom trawl in strata 1 (BT1) and 3 (BT3) (strata are defined in Figure B.8). Length and age data are limited to the October to May period, year is calendar year. All years when age frequency distributions could be calculated are plotted.

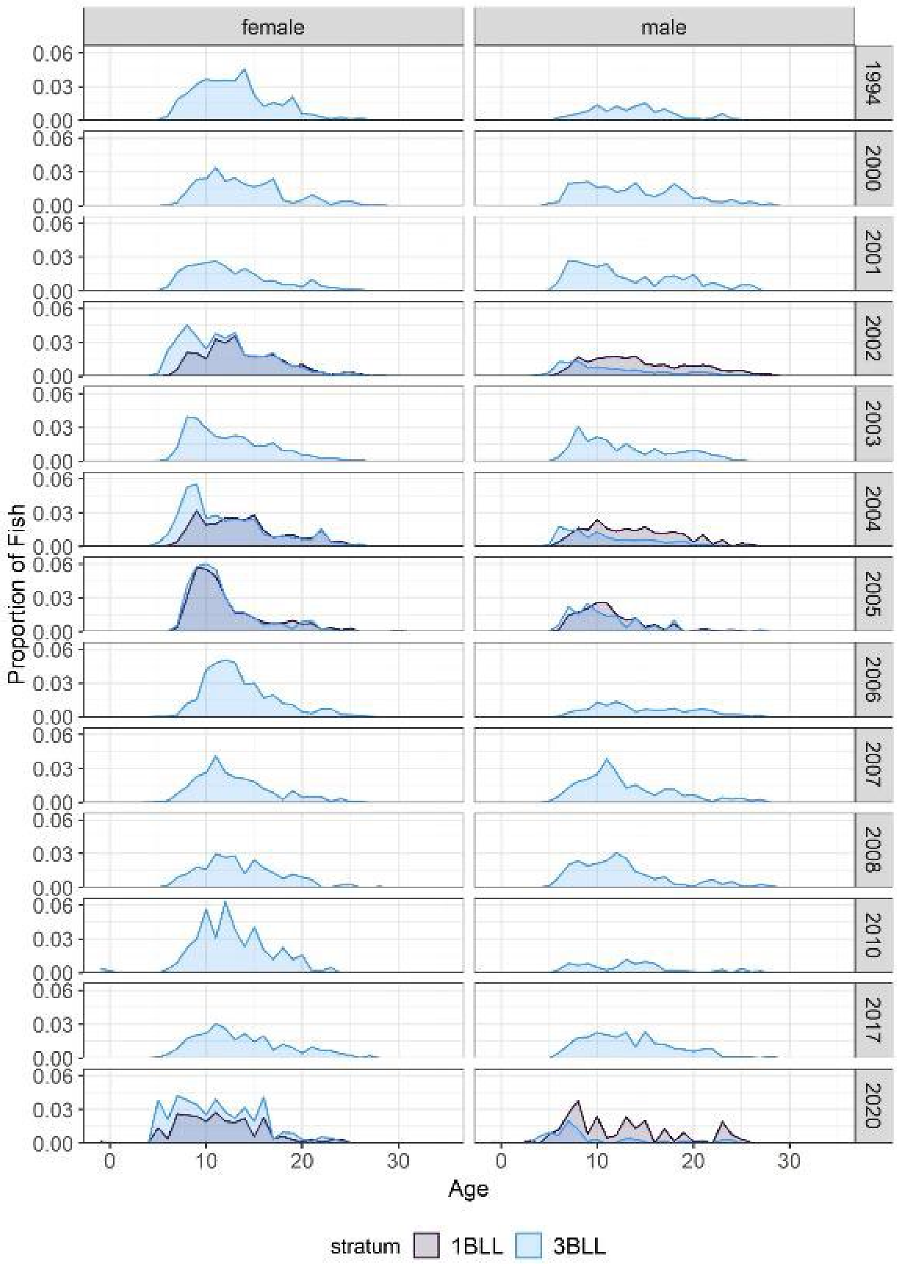


Figure B.12: Trend of scaled age frequency distributions of LIN 5&6 for bottom longline in strata 1 (BLL1) and 3 (BLL3) (strata are defined in Figure B.8). Length and age data are limited to the October-January period, year is calendar year. All years when age frequency distributions could be calculated are plotted.

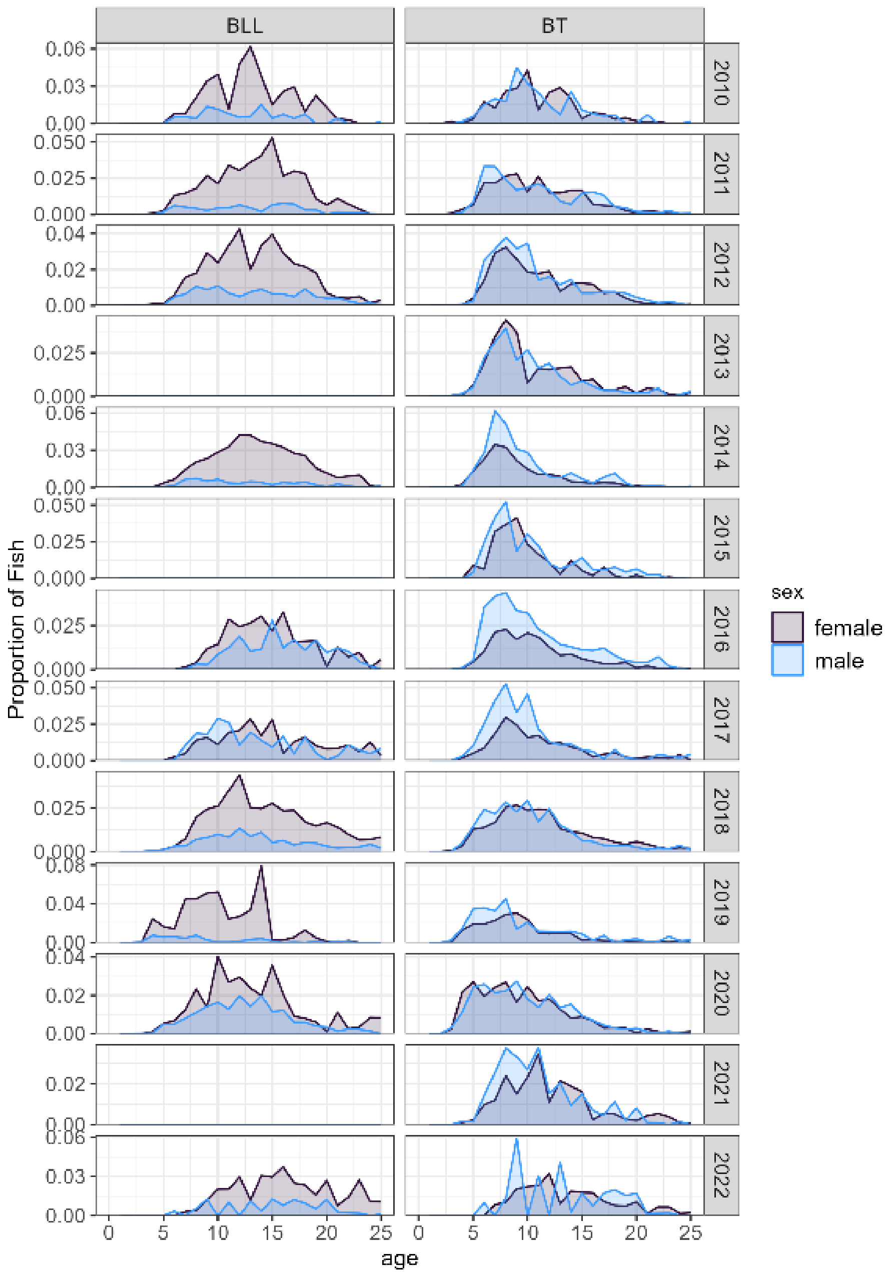


Figure B.13: Trend of scaled age frequency distributions of LIN 5&6 for bottom longline (BLL) and bottom trawl (BT) for the 2010–2022 calendar years when using all data and a single stratum per fishery as carried out in 2021 (Mormede et al. 2021a).

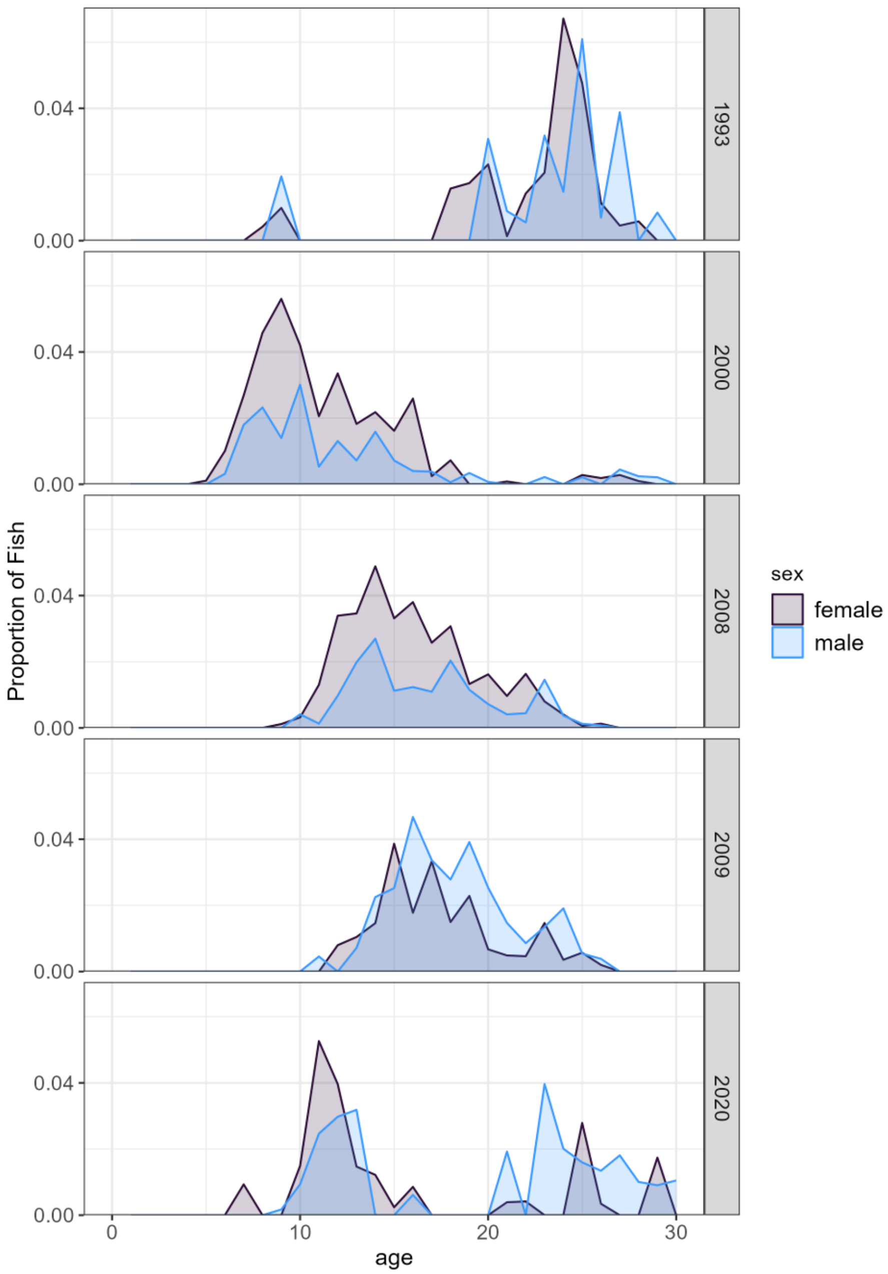


Figure B.14: Trend of scaled age frequency distributions of LIN 6B for bottom longline for all years where data were sufficient, using all data and a single stratum.

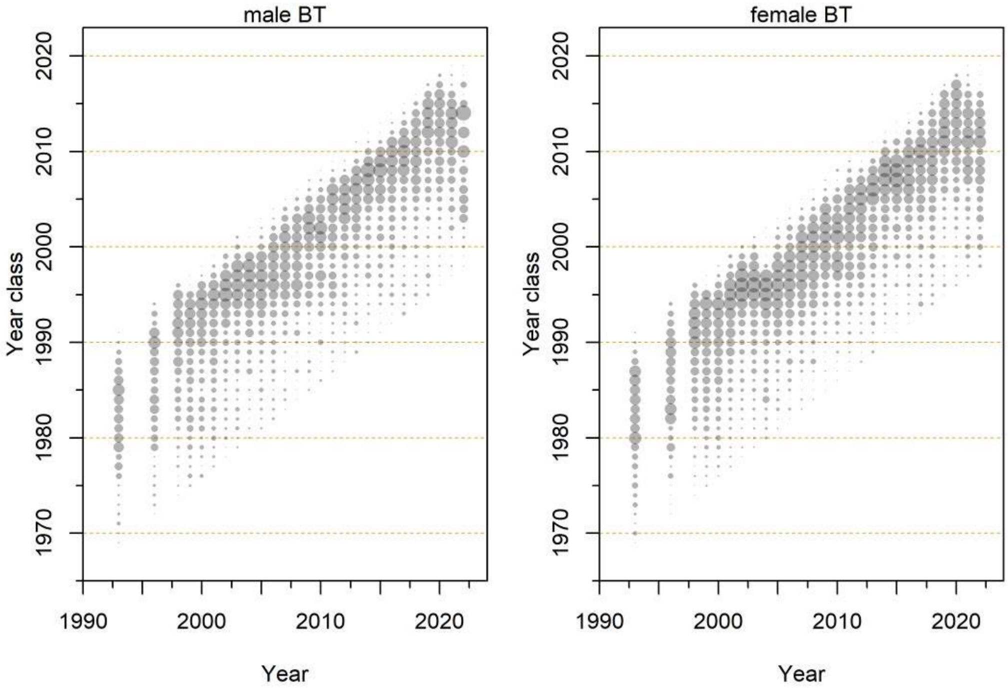


Figure B.15: LIN 5&6 progression of year classes in the bottom trawl (BT) fishery scaled age frequencies.

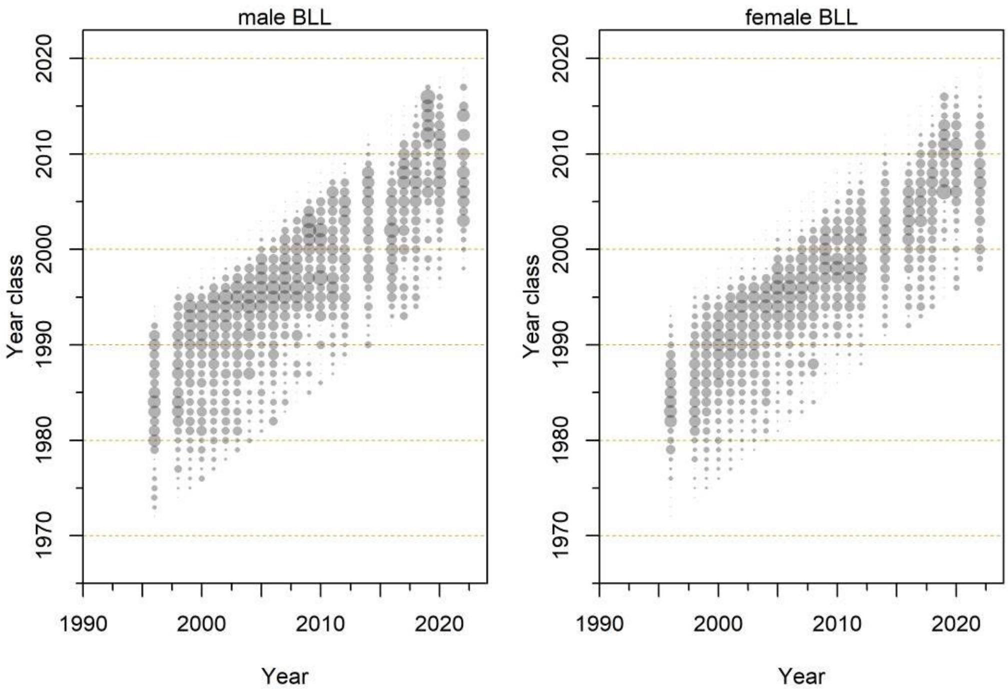


Figure B.16: Progression of year classes in the LIN 5&6 bottom longline fishery (BLL) scaled age frequency distributions.

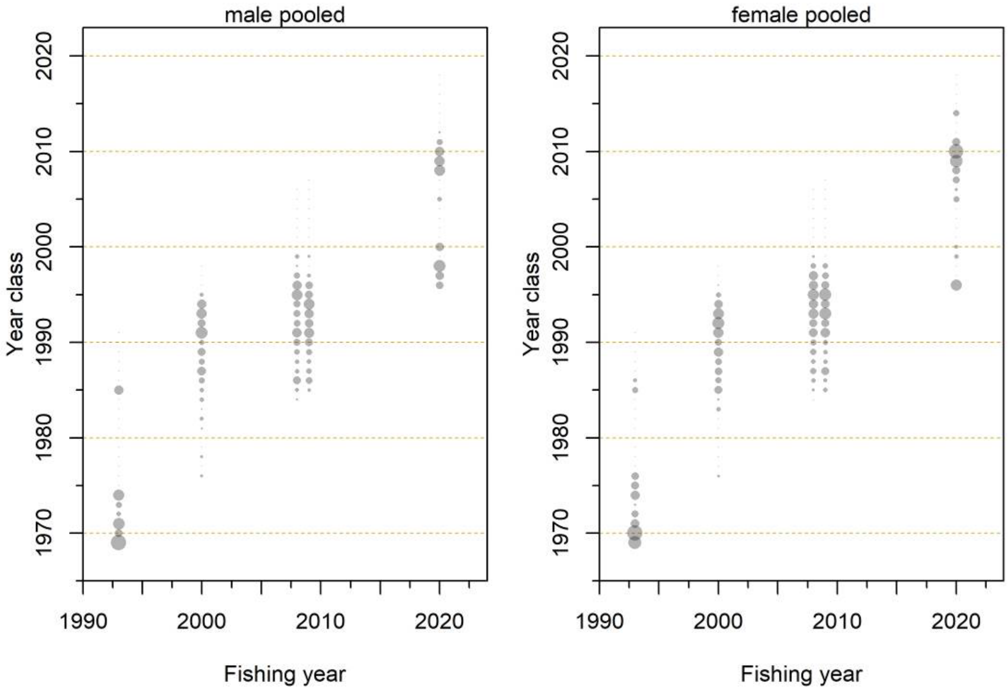


Figure B.17: Progression of year classes in the LIN 6B bottom longline fishery (BLL) scaled age frequency distributions.

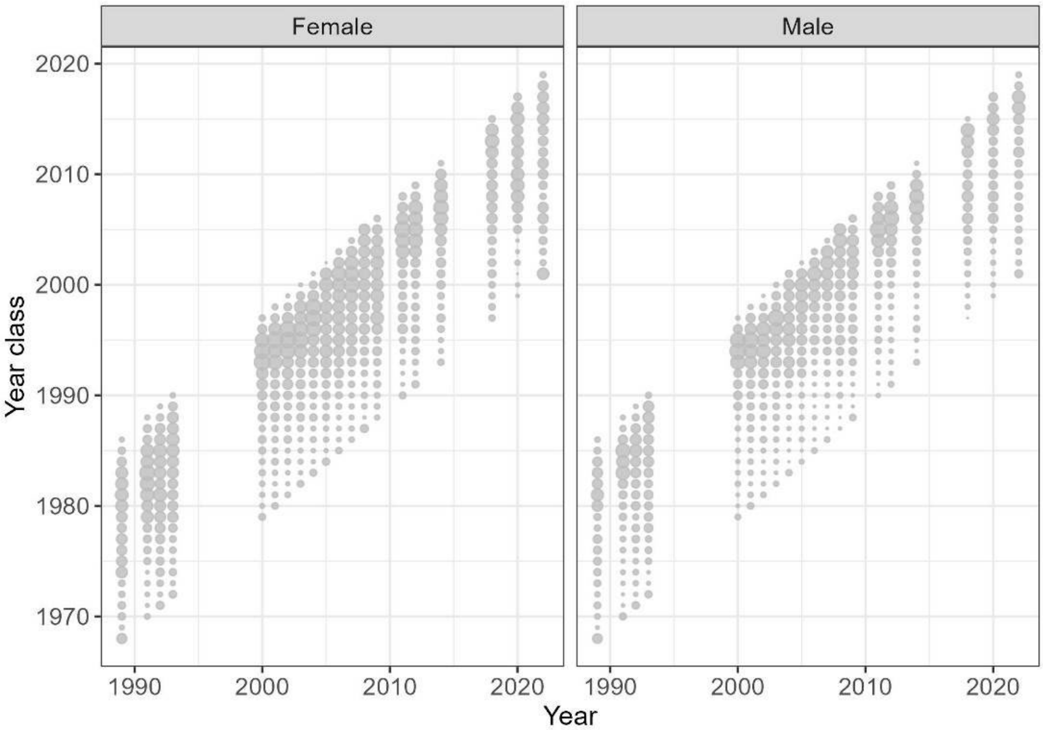


Figure B.18: Progression of year classes in the Sub-Antarctic trawl survey scaled age frequency distributions.

13. APPENDIX C – UPDATE OF BIOLOGICAL PARAMETERS

Table C.1: Length-weight parameters for ling in LIN 5&6 obtained in this analysis and compared with those reported by Horn (2005) and Mormede et al. (2021a).

Sex	Parameter	Horn (2005)	Mormede et al. (2021a)	This analysis
Male	*a*	2.08E-06	2.13E-06	2.105E-06
	b	3.190	3.179	3.181
Female	*a*	1.28E-06	1.32E-06	1.29E-06
	b	3.303	3.293	3.297

Table C.2: von Bertalanffy growth parameters for ling in LIN 5&6 obtained in this analysis and compared to those reported by Horn (2005, 2022) and Mormede et al. (2021a).

Sex	Parameter	Horn (2005)	Horn (2022)	Mormede et al. (2021a)	This analysis
M	L_{inf}	88.8	92.6	91.2	91.2
	k	0.295	0.215	0.14	0.19
	t_0	0.06	-0.1	-0.71	-1.16
	CV			0.07	0.07
F	L_{inf}	107.3	109.9	111.2	110.6
	k	0.220	0.163	0.14	0.13
	t_0	0.01	-0.1	-0.53	-1.53
	CV			0.08	0.08

Table C.3: von Bertalanffy growth parameters for ling in LIN 6B obtained in this analysis and compared to those reported by Horn (2005, 2022).

Sex	Parameter	Horn (2005)	Horn (2022)	This analysis
M	L_{inf}	120.5	121.9	120.3
	k	0.141	0.133	0.12
	t_0	0.02	-0.1	-2.29
	CV			0.07
F	L_{inf}	146.2	143.1	147.9
	k	0.101	0.107	0.09
	t_0	-0.53	-0.1	-2.31
	CV			0.07

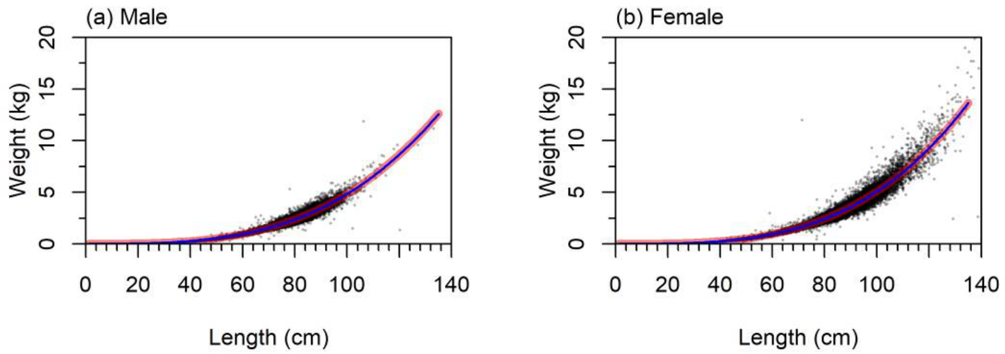


Figure C.1: Estimated length-weight relationships for ling in LIN 5&6: the red line represents the estimate by Mormede et al. (2021a) , the blue line is the estimated relationship from this analysis and dots are the data points used.

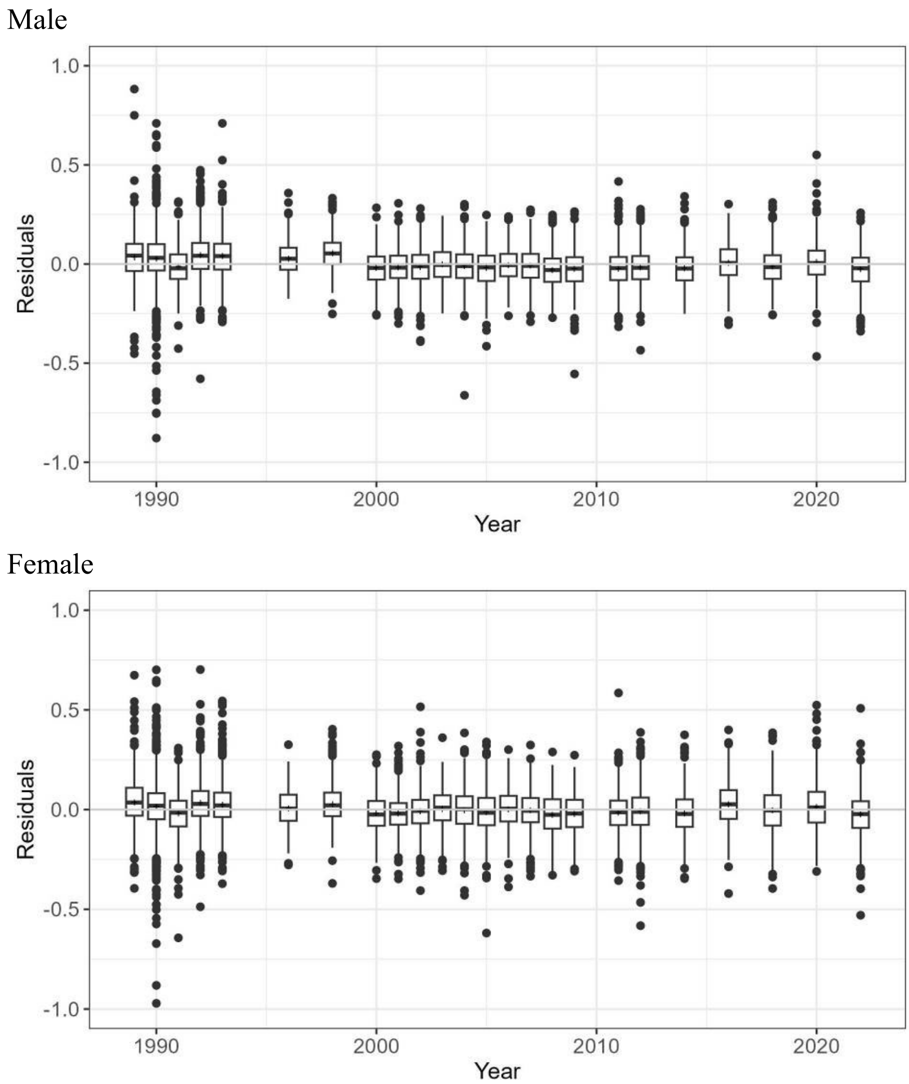
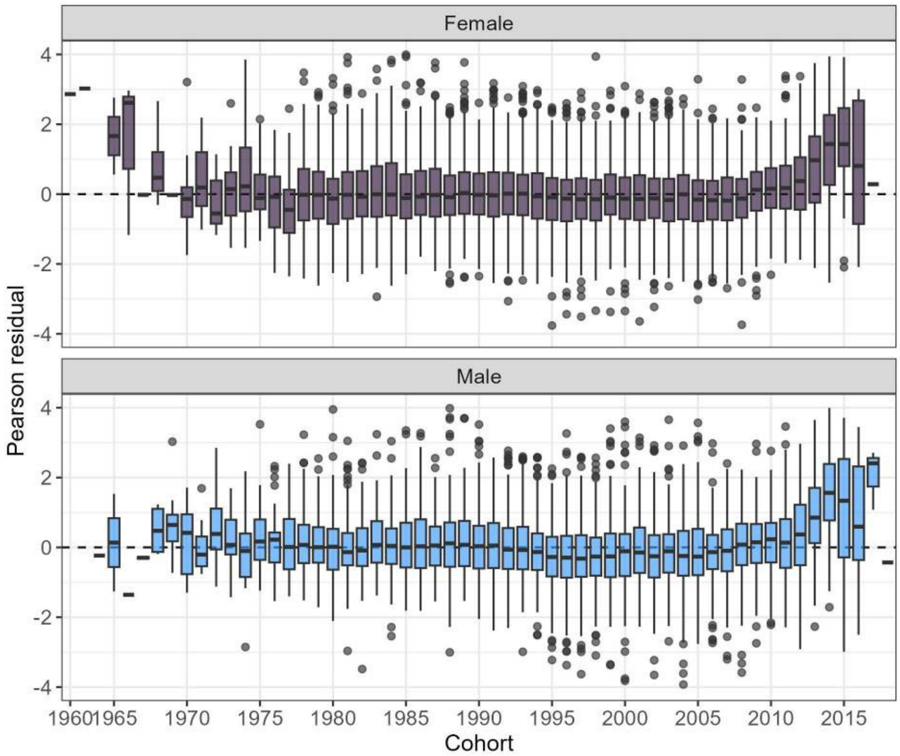


Figure C.2: LIN 5&6 standardised residuals by fishing year of the length-weight relationship for males (top) and females (bottom).



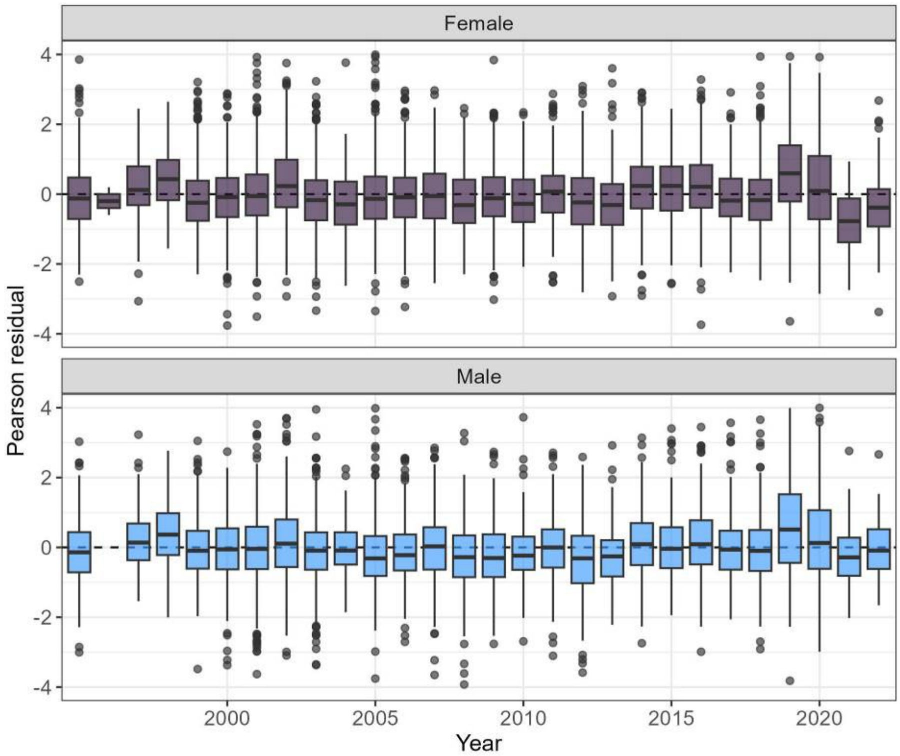
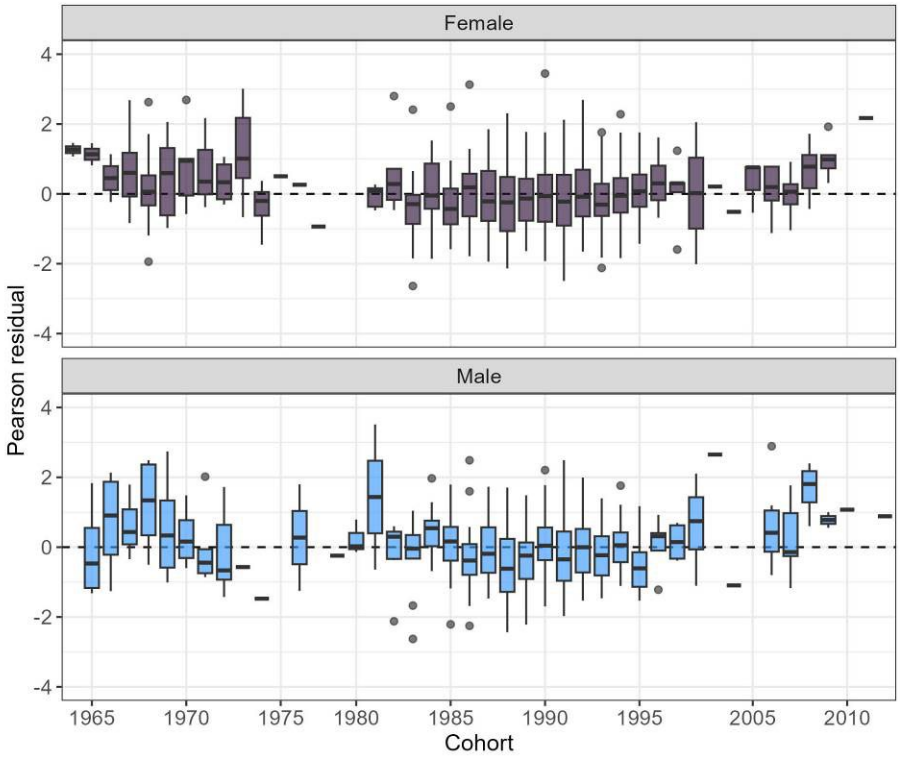


Figure C.3: LIN 5&6 standardised residuals of the maximum likelihood estimates for the von Bertalanffy models by cohort (top) or by calendar year (bottom).



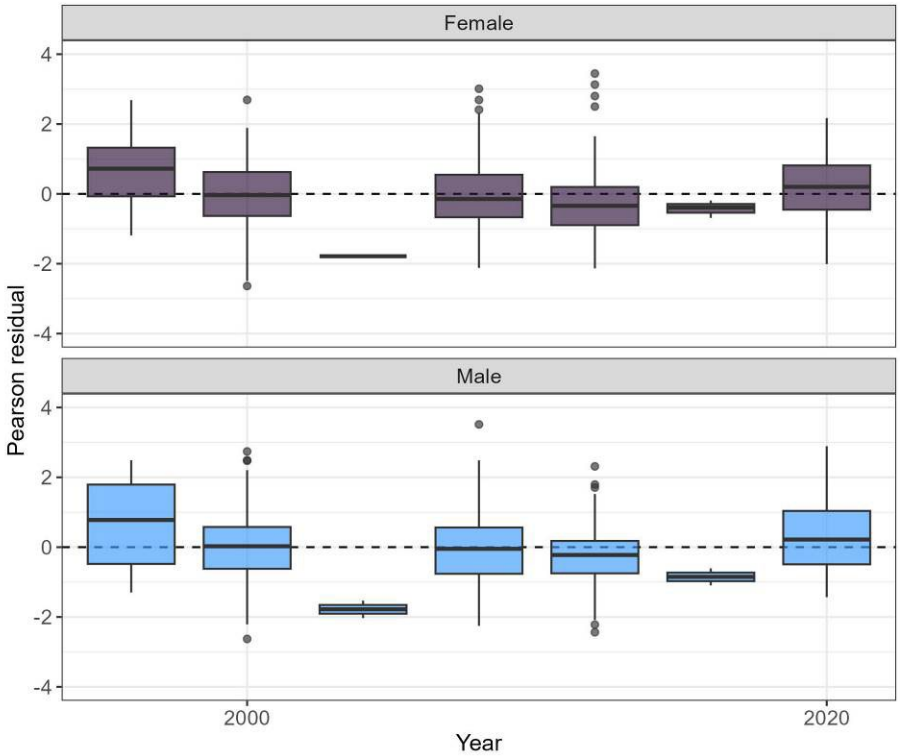


Figure C.4: LIN 6B Pearson residuals of the maximum likelihood estimates for the von Bertalanffy models by cohort (top) or by calendar year (bottom).

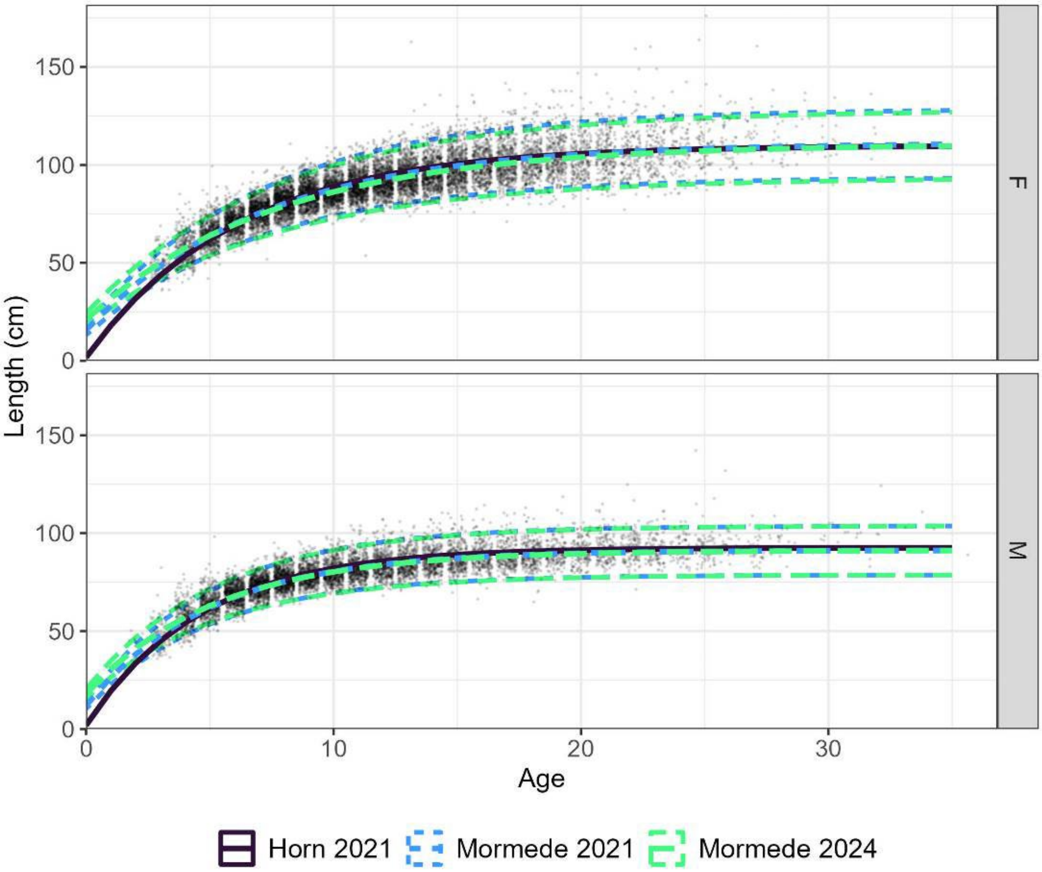


Figure C.5: LIN 5&6 comparison of the updated estimate for the von Bertalanffy models within this report (labelled Mormede 2024) with the 2021 estimate by Horn (2021, labelled Horn 2021) and the 2021 estimate of Mormede et al. (2021a, labelled Mormede 2021).

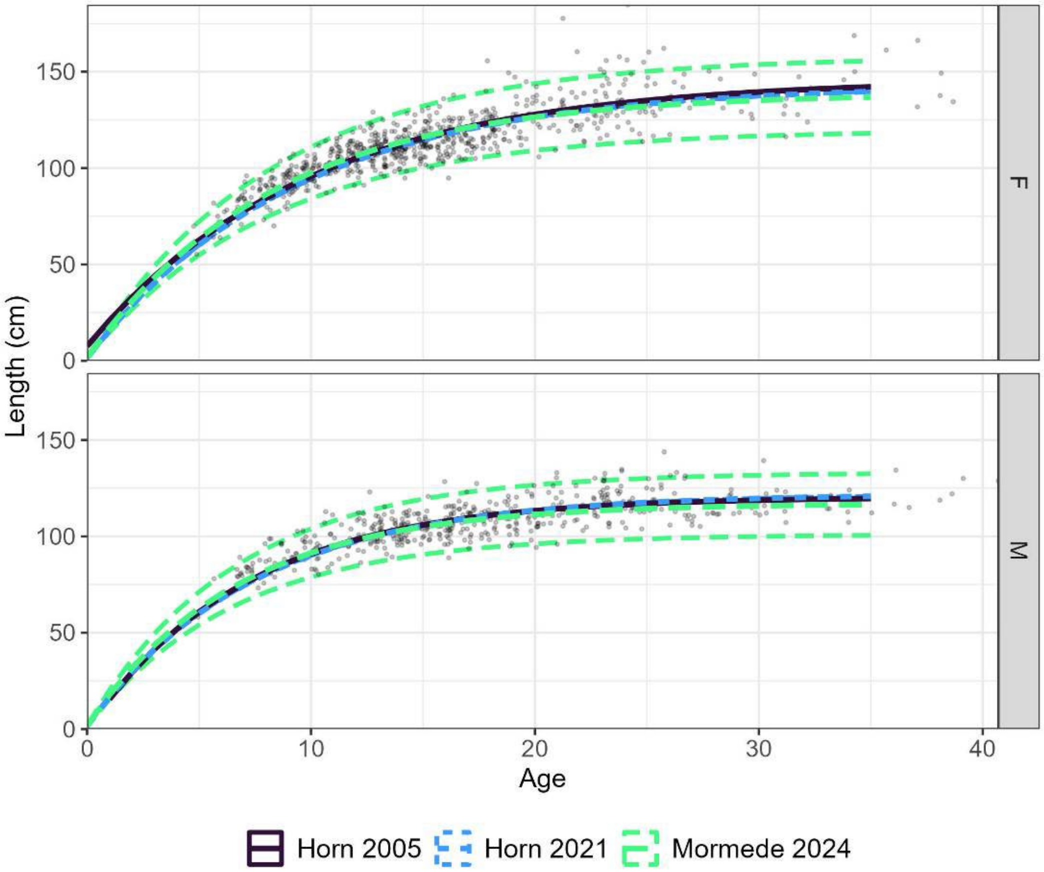


Figure C.6: LIN 6B comparison of the updated estimates for the von Bertalanffy models within this report (labelled Mormede 2024) with the 2007 estimate by Horn (2007, labelled Horn 2007), the 2021 estimate by Horn (2021, labelled Horn 2021) and the 2021 estimate of Mormede et al. (2021a, labelled Mormede 2021).

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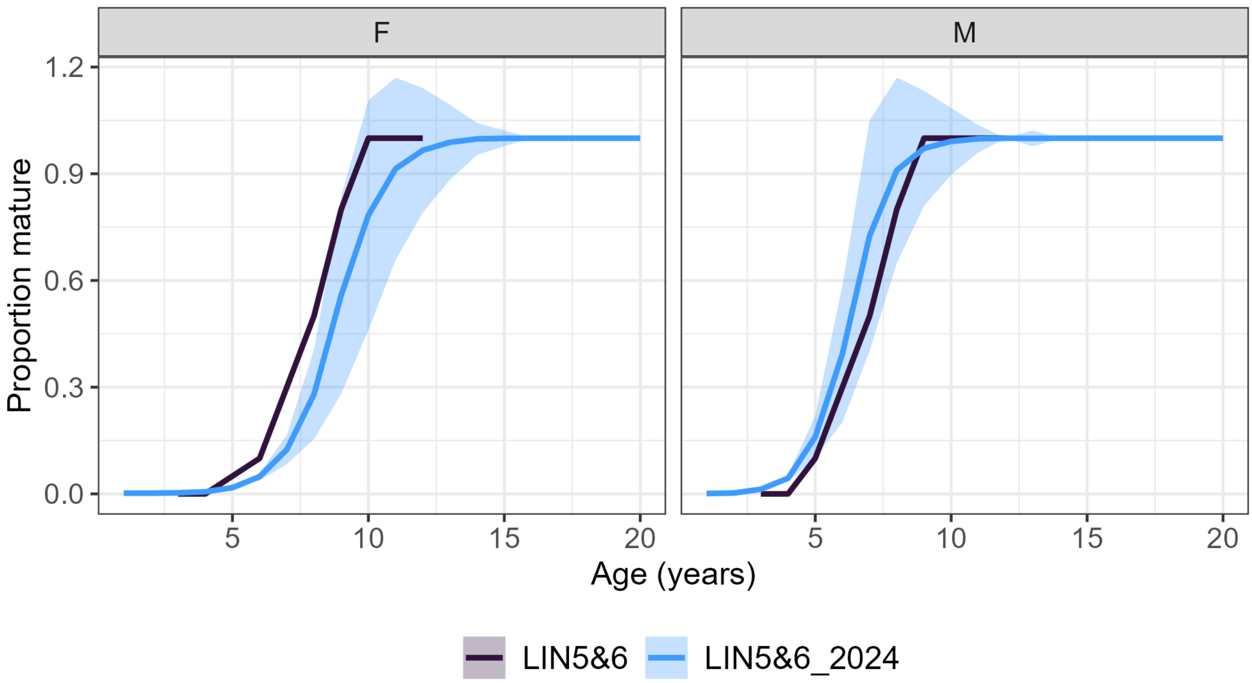


Figure C.7: LIN 5&6 maturity at age from Horn (2005, LIN5&6) and updated in this analysis (LIN5&6_2024) with the 95% credible interval of the posterior distribution in light blue.

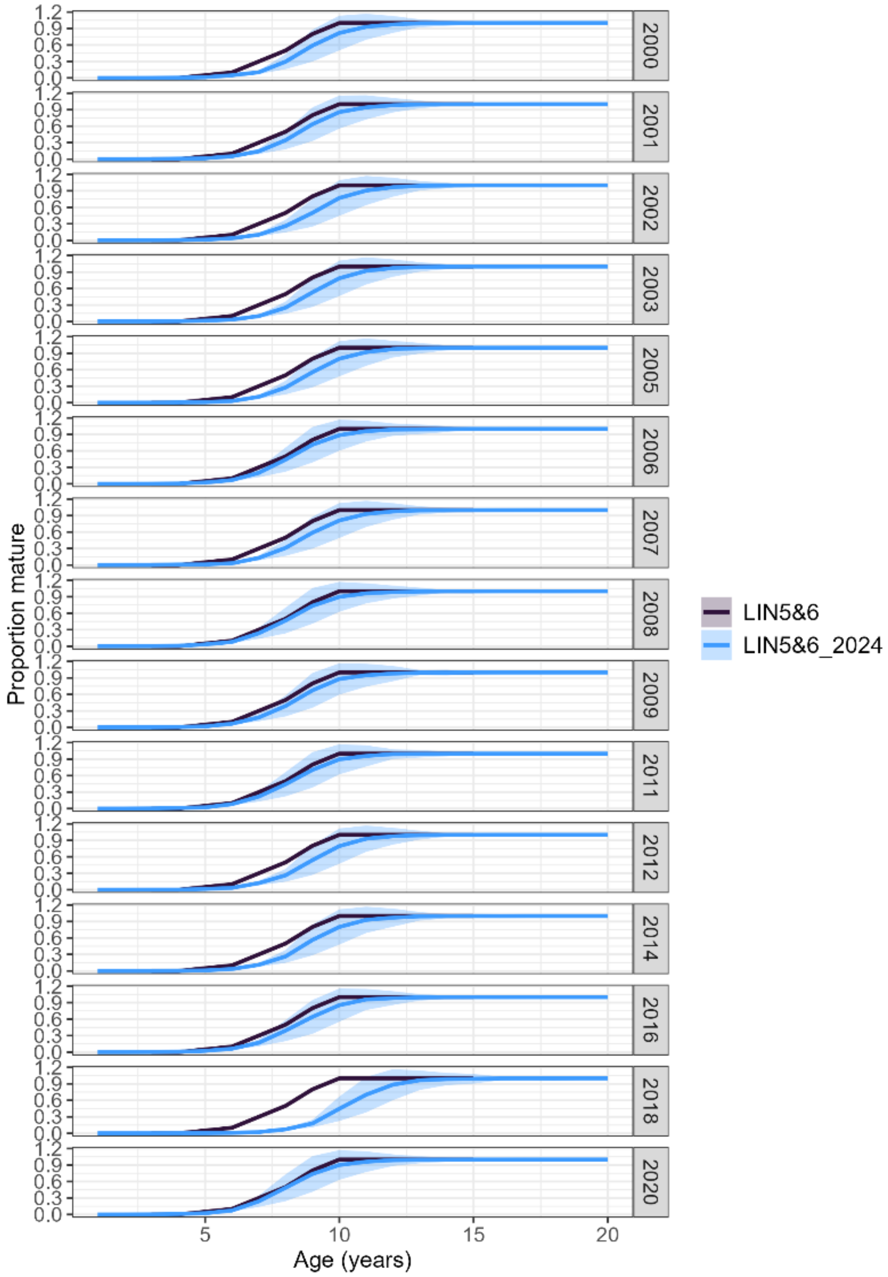


Figure C.8: LIN 5&6 maturity at age for female ling from Horn (2005, LIN5&6) and updated in this analysis with year as a random effect (LIN5&6_2024) with the 95% credible interval of the posterior distribution in light blue.

14. APPENDIX D – CPUE ANALYSES

Table D.1: Explanatory variables offered to the bottom longline rolled-up CPUE models.

Variable	Type	Description
Year	Categorical	Model year (calendar year)
Month	Categorical	Month of the year
Statistical area	Categorical	Statistical area
Vessel	Categorical	Unique vessel identifier
Day of year	3rd degree spline	Julian date, starting on 1 September
Total hooks	8th degree spline	Number of hooks set per day in a statistical area
Observed	Categorical	Whether an observer was onboard that day
Longline type	Categorical	Whether a longline is an autoline or handbait
Vessel experience	3rd degree spline	Years in the fishery
Spawning	Categorical	Whether in spawning months (October to December)

Table D.2: Data selection for the bottom longline rolled-up CPUE models of LIN 5&6 and LIN 6B separately.

Data source	CELR, LTCER, LCER, ERS – lining
Year range	1990–2023
Target species	Ling only
Rolling-up method	By vessel, day, and statistical area
Statistical Areas	50 rolled-up records minimum: Statistical Areas 026, 029–031, 602–605, 610–612, 618, 619, 625 for LIN 5&6 Statistical Areas 607 and 608 for LIN 6B
Catch per record	< 35 t
Gear type	Bottom longline only
Number of hooks per line	Between 50 and 44 000
Vessel experience	Over 80% of the catch: 5 years in the fishery for LIN 5&6 (~91% of ling catch) 3 years in the fishery for LIN 6B (~91% of ling catch)
Ling catch reporting position	Any record where ling is not recorded in the top 5 or top 5 QMS for ERS forms is given a ling catch of 0 (<0.01% of catch)
Year definition	Model year: January to December

Table D.3: Variables in order of decreasing explanatory value for the rolled-up longline CPUE for ling in 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
year			8 383	5 551	0.08	20 450
=+ns(hooks, df = 8)	8	2 486	8 375	3 065	0.49	15 467
=+statistical area	13	358	8 362	2 707	0.55	14 448
=+vessel	10	207	8 352	2 500	0.58	13 799
=+month	11	44	8 341	2 456	0.59	13 672
=+observed	1	13	8 340	2 444	0.59	13 630
=+ns(vessel experience, df = 3)	3	3	8 337	2 440	0.59	13 624
=+ns(day), df = 3)	1	1	8 336	2 440	0.59	13 624
=+line type	-	-	8 336	2 440	0.59	13 624
=+spawning	-	-	8 336	2 440	0.59	13 624

Table D.4: Variables in order of decreasing explanatory value for the rolled-up longline CPUE for ling in LIN 6B. The variables which each explain more than 1% of the deviance (r^2) are above the horizontal line and were retained in the model. Df = degrees of freedom.

Step	Df	Deviance	Residual Df	Residual Deviance	r^2	AIC
year			1 902	1 301	0.05	4 739
=+ns(hooks, df = 4)	4	382	1 898	919	0.33	4 080
=+month	11	67	1 887	852	0.38	3 956
=+vessel	8	49	1 879	803	0.42	3 858
=+vessel.experience	1	6	1 878	797	0.42	3 847
=+ns(day), df = 3)	3	3	1 875	794	0.42	3 846
=+observed	1	2	1 874	792	0.42	3 843
=+statarea	1	1	1 873	791	0.42	3 842

Table D.5: Variables in order of decreasing explanatory value for the spatial longline CPUE for ling. The variables which each explain more than 1% of the deviance (r^2) are above the horizontal line and were retained in the model. Tests for convergence are reported, dnf = did not finish.

Covariates	Deviance explained	Converges
Space	60.3	yes
Space + hooks	72.9	yes
Space + hooks + vessel	72.9	yes
Space + hooks + month	72.9	yes
Space + hooks +depth		dnf

Table D.6: CPUE standardised indices for the Sub-Antarctic ling (LIN 5&6 and LIN 6B separately or combined) rolled-up commercial bottom longline fishery and CVs using non-spatial standardisation (GLM) or spatial standardisation (VAST). Year is calendar year. '-' denotes no index due to the lack of data available.

	Non-spatial (GLM)				Spatial (VAST)					
Calendar year	LIN 5&6		LIN 6B		LIN 5&6		LIN 6B		LIN 5&6 and LIN 6B	
1991	6 310	0.07	19 960	0.06						
1992	9 030	0.04	11 380	0.06						
1993	8 610	0.04	9 440	0.07						
1994	7 620	0.05	6 300	0.11						
1995	8 870	0.04	2 510	0.42						
1996	7 150	0.05	6 190	0.1						
1997	7 950	0.04	5 660	0.11						
1998	6 970	0.04	6 950	0.08						
1999	5 330	0.04	6 830	0.08						
2000	6 380	0.04	7 340	0.07						
2001	7 320	0.04	5 420	0.09						
2002	7 160	0.04	4 880	0.1						
2003	5 030	0.07	5 400	0.09						
2004	4 710	0.07	4 810	0.13	12 879	0.07	2 143	0.19	15 022	0.07
2005	8 510	0.06	-	-	13 803	0.10	2 433	0.17	16 235	0.09
2006	5 810	0.06	-	-	14 962	0.10	3 410	0.19	18 372	0.09
2007	8 260	0.05	-	-	16 409	0.11	3 402	0.08	19 811	0.09
2008	6 310	0.06	-	-	12 340	0.11	3 692	0.05	16 032	0.09
2009	7 400	0.05	-	-	16 846	0.11	2 585	0.09	19 431	0.10
2010	5 840	0.05	-	-	16 495	0.06	1 991	0.29	18 485	0.07
2011	4 570	0.06	-	-	13 453	0.08	2 017	0.14	15 470	0.08
2012	5 570	0.04	-	-	17 986	0.08	1 944	0.25	19 930	0.08
2013	3 080	0.14	-	-	13 608	0.14	3 103	0.17	16 711	0.12
2014	4 940	0.06	-	-	16 045	0.07	2 568	0.12	18 613	0.07
2015	4 810	0.06	-	-	13 949	0.07	2 162	0.14	16 111	0.07
2016	3 880	0.08	-	-	16 102	0.08	3 348	0.11	19 449	0.07
2017	4 170	0.07	4 080	0.32	14 960	0.08	3 821	0.04	18 781	0.07
2018	5 920	0.05	-	-	17 450	0.08	2 729	0.09	20 179	0.07
2019	5 180	0.05	-	-	15 881	0.06	4 607	0.06	20 488	0.05
2020	5 520	0.04	-	-	15 523	0.05	4 780	0.10	20 304	0.05
2021	3 960	0.06	6 580	0.15	11 270	0.04	5 294	0.04	16 563	0.03
2022	4 140	0.06	4 410	0.23	10 182	0.04	3 228	0.06	13 410	0.04
2023	4 450	0.06	4 840	0.22	12 446	0.04	2 978	0.08	15 424	0.04

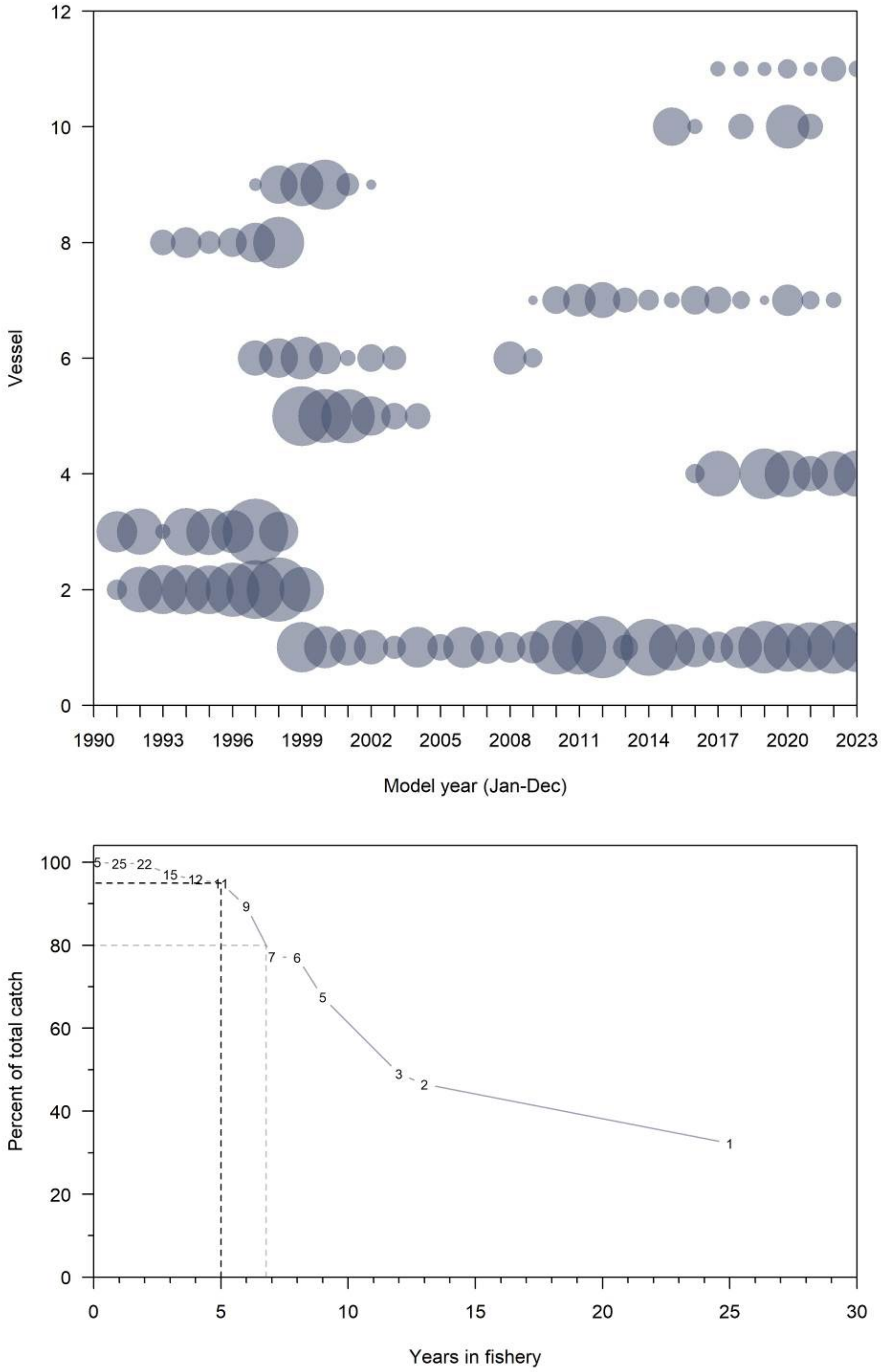
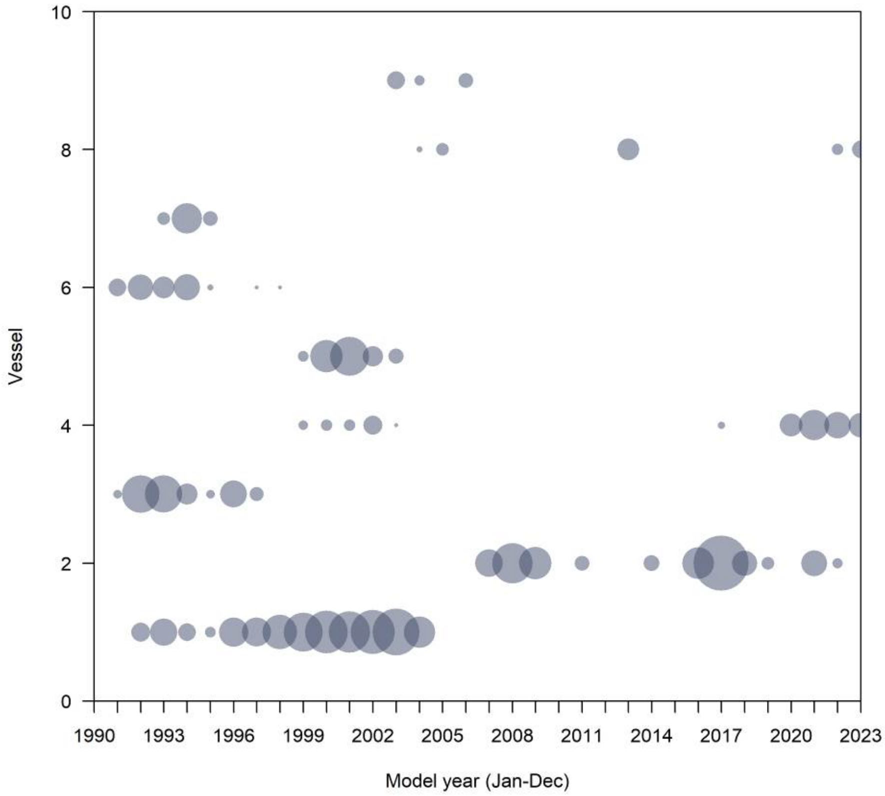


Figure D.1: LIN 5&6. Core vessel selection for the bottom longline CPUE model: annual catch by vessel over time (top) and proportion of total catch by vessel experience (bottom).



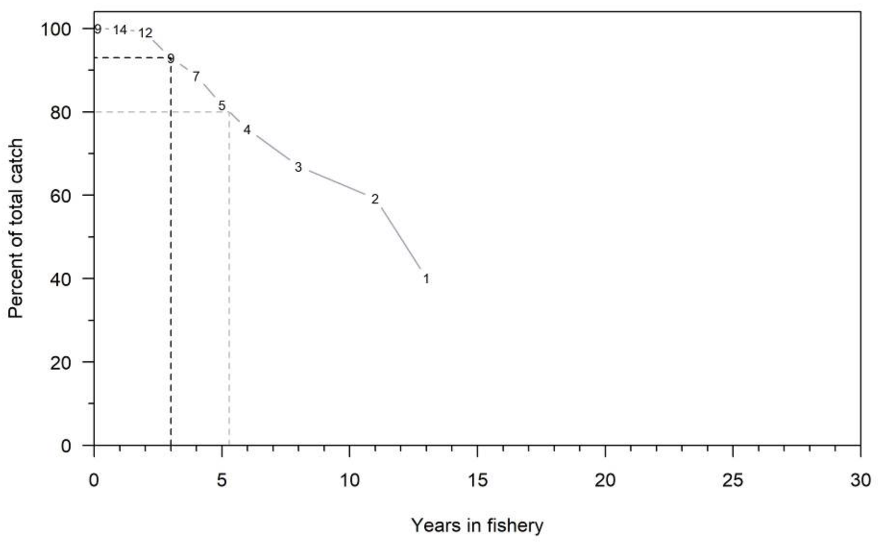


Figure D.2: LIN 6B. Core vessel selection for the bottom longline CPUE model: annual catch by vessel over time (top) and proportion of total catch by vessel experience (bottom).

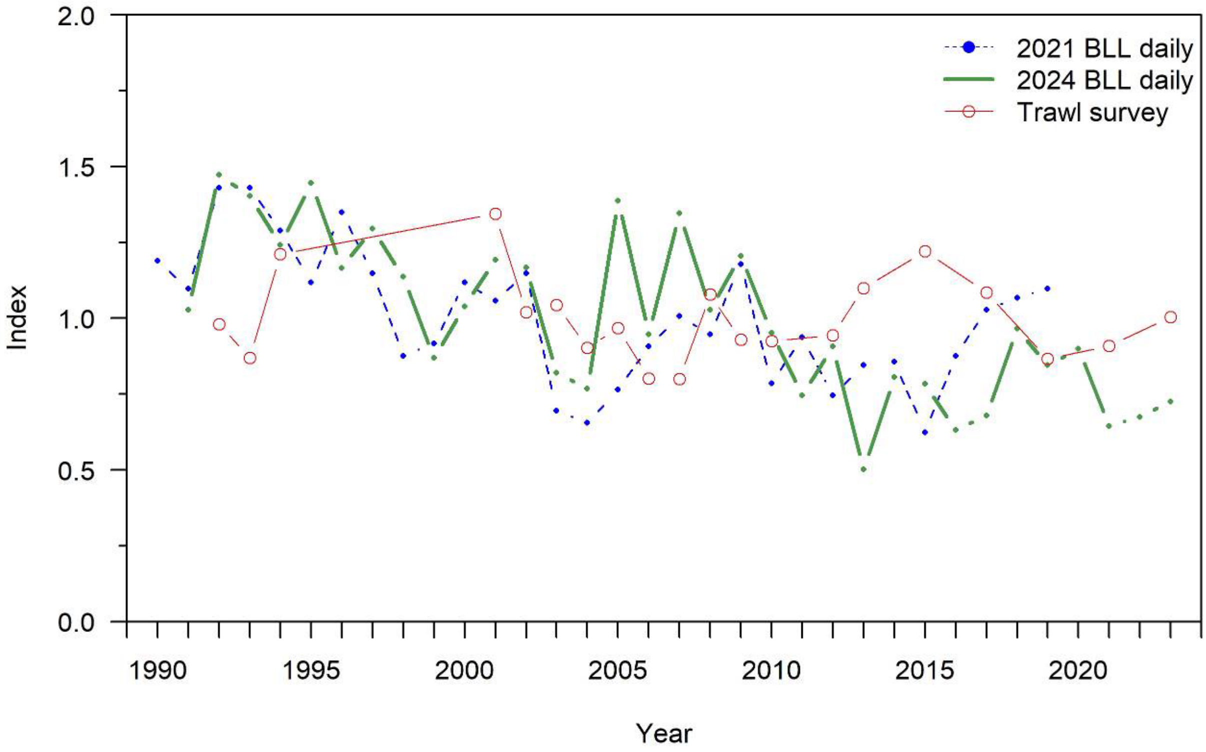


Figure D.3: LIN 5&6. Year index for the lognormal model for the rolled-up bottom longline. Also plotted is the bottom longline CPUE from the previous analysis (Mormede et al. 2021a) and the Sub-Antarctic trawl survey biomass series (Fisheries New Zealand 2024). Year was model year which was defined as the calendar year.

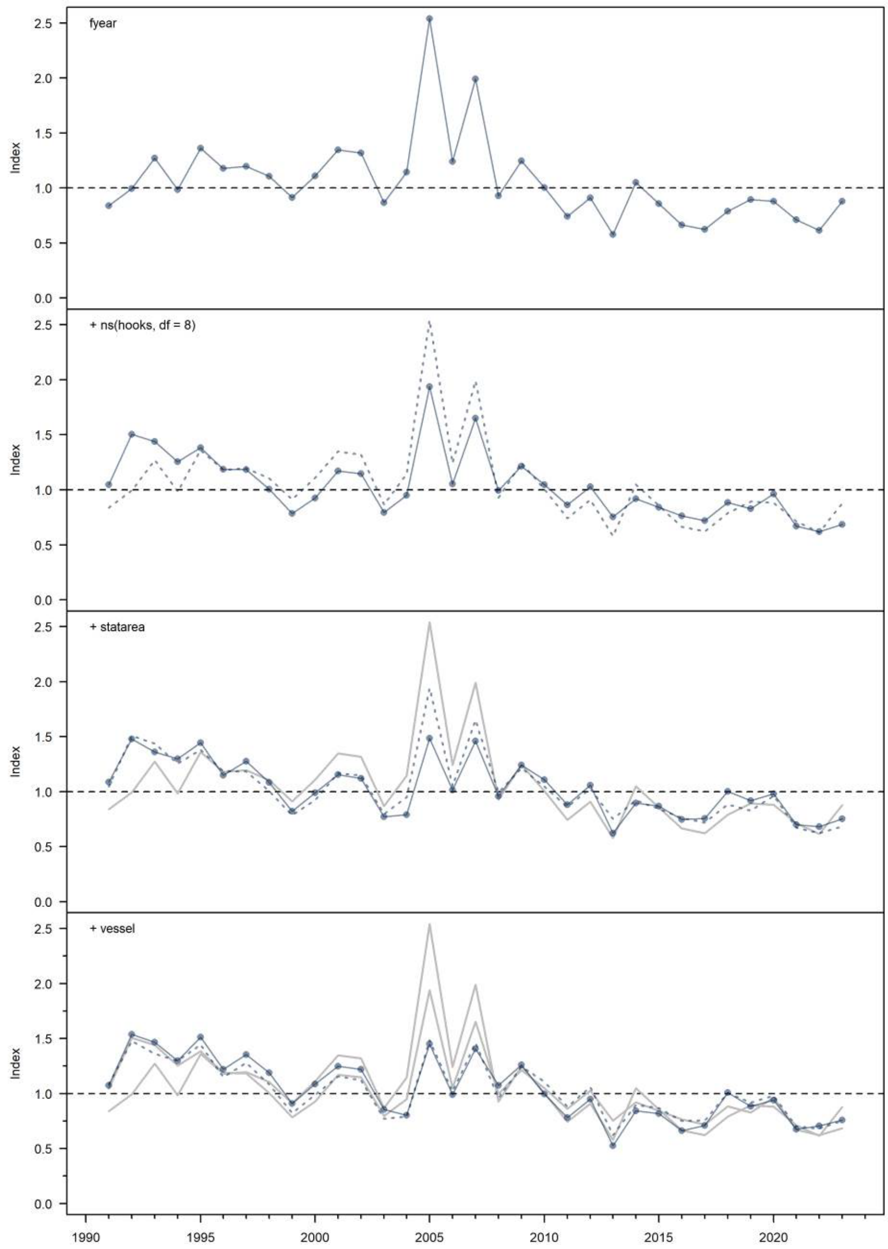


Figure D.4: LIN 5&6. Influence plots for the lognormal model of the rolled-up bottom longline CPUE for the parameters included in the final model (in order of inclusion in the model), assuming that all other parameters were constant at their median or modal value. Year was model year which was defined as the calendar year.

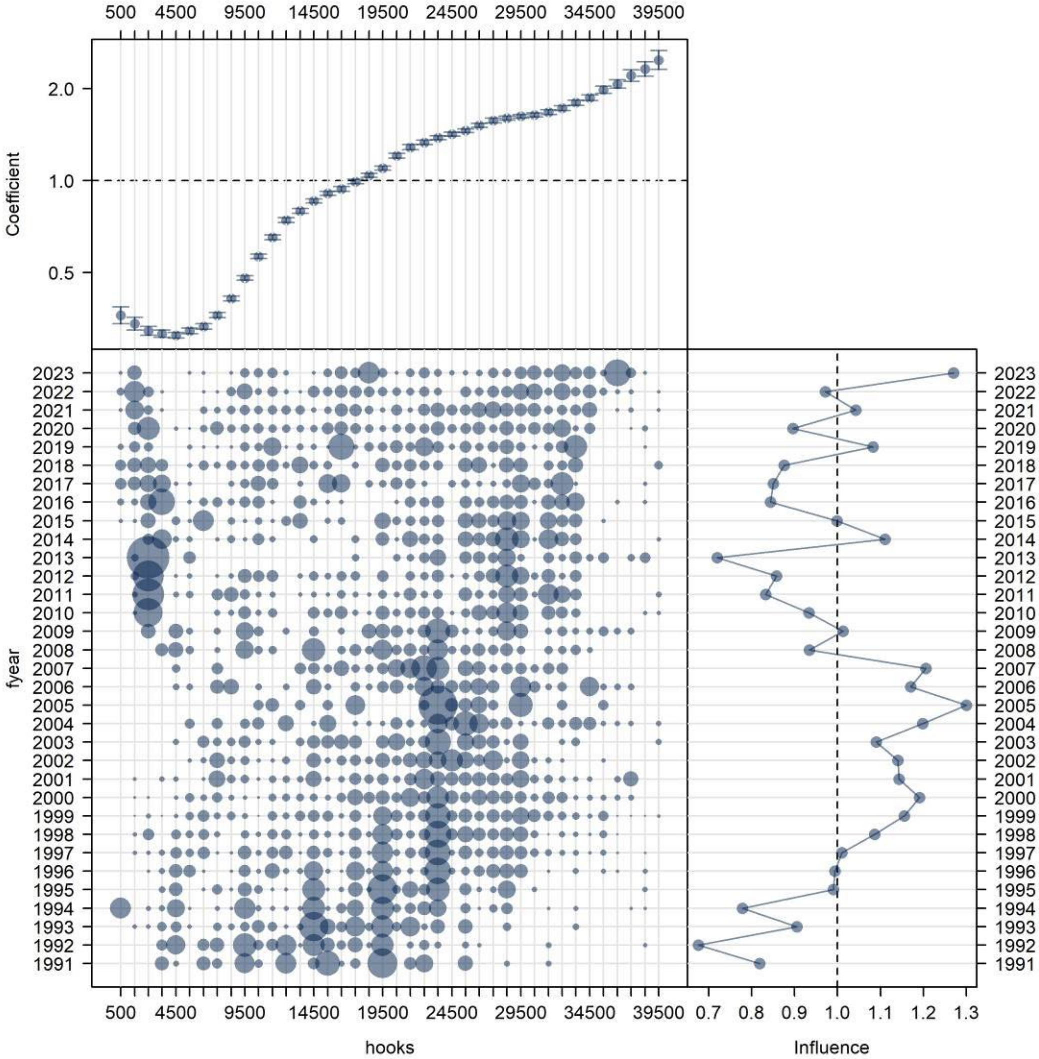


Figure D.5: LIN 5&6. Influence plots for the lognormal model of the rolled-up bottom longline CPUE for the number of hooks (per rolled up record) in relation to year, assuming that all other parameters were constant at their median or modal value. Year was model year which was defined as the calendar year.

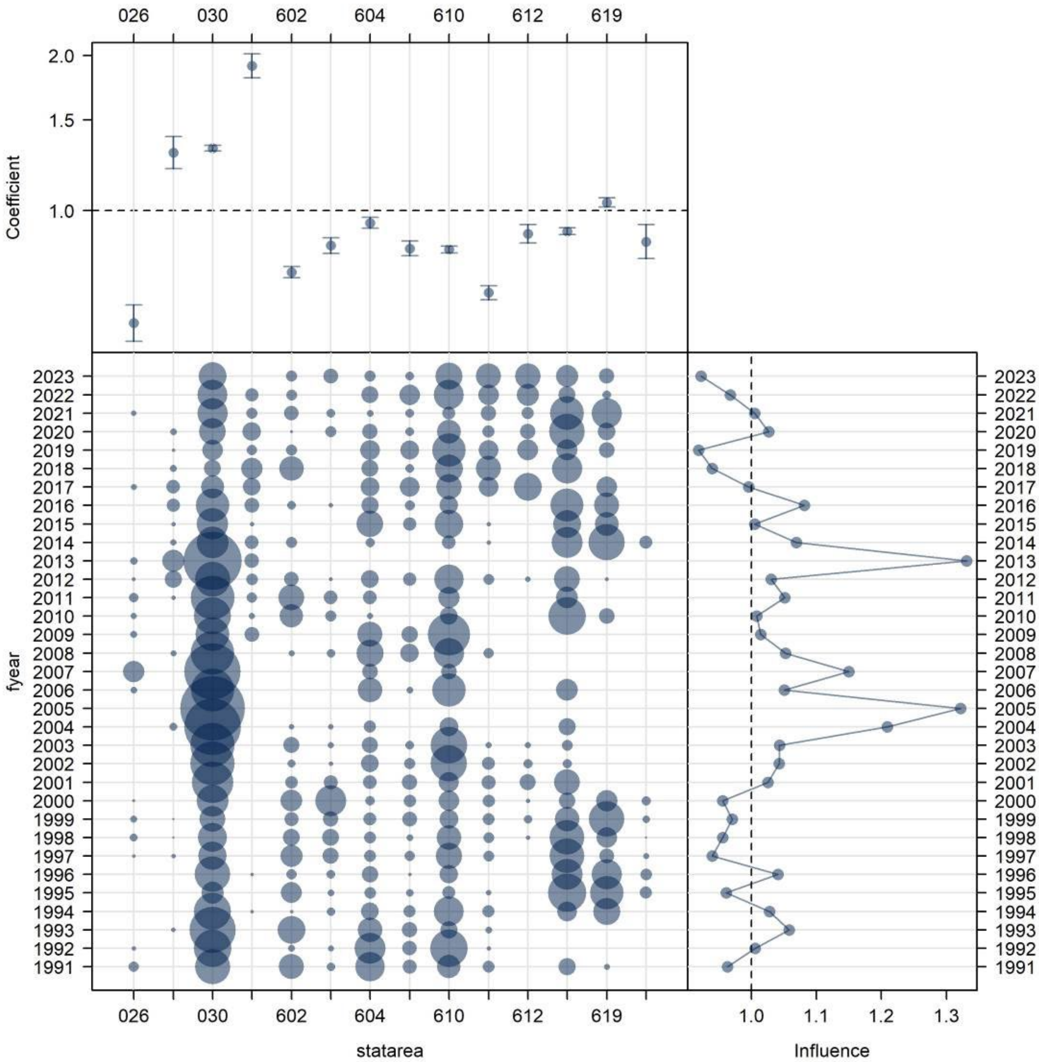


Figure D.6: LIN 5&6. Influence plots for the lognormal model of the rolled-up bottom longline CPUE for Statistical Area in relation to year, assuming that all other parameters were constant at their median or modal value. Year was model year which was defined as the calendar year.

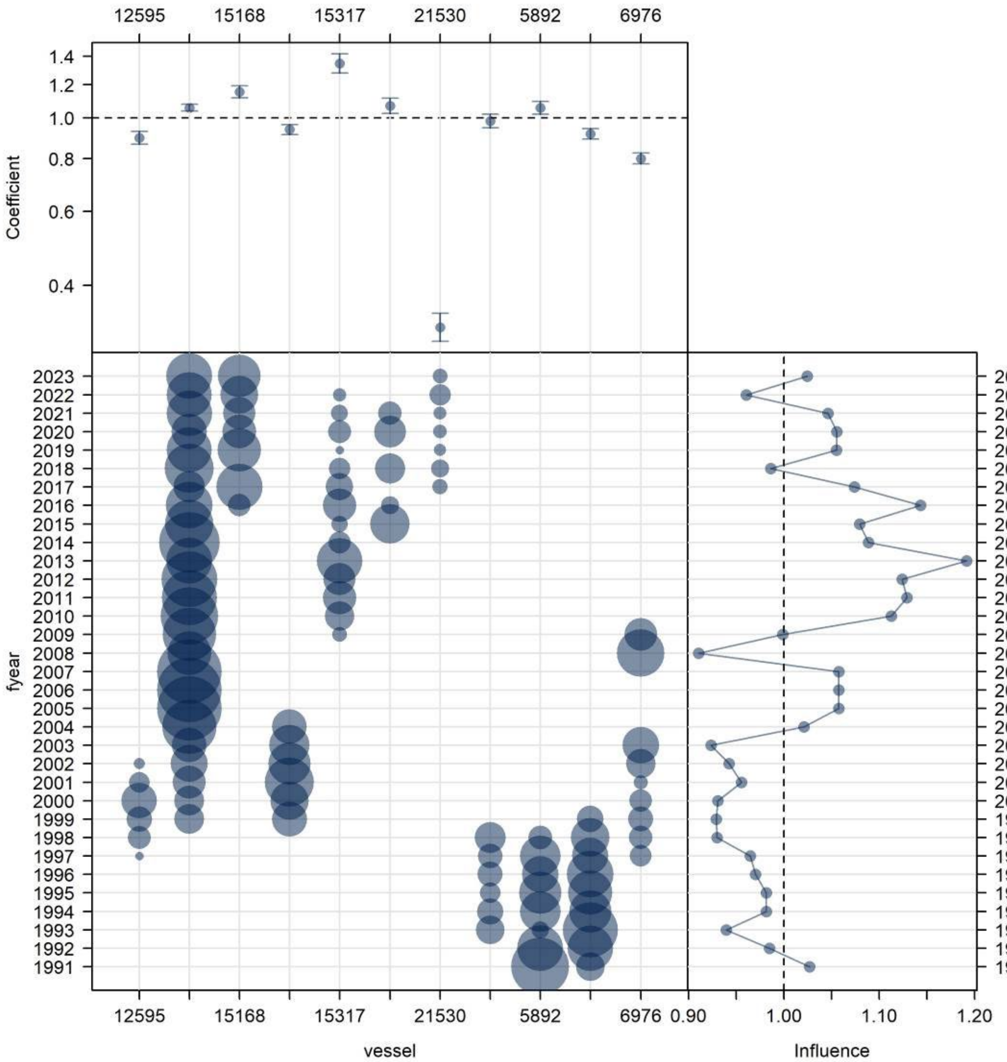


Figure D.7: LIN 5&6. Influence plots for the lognormal model of the rolled-up bottom longline CPUE for vessel identifier in relation to year, assuming that all other parameters are constant at their median or modal value. Year was model year which was defined as the calendar year.

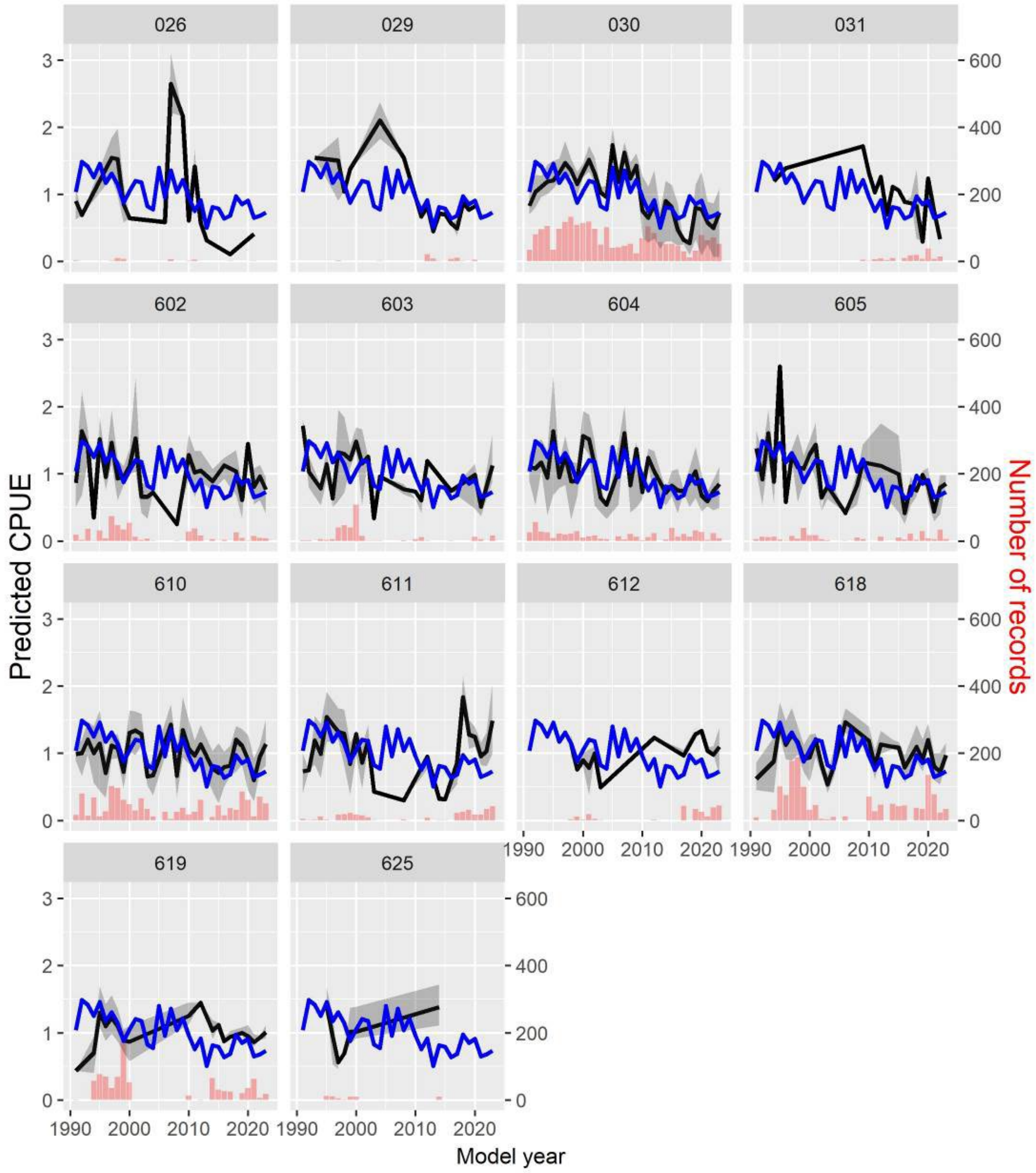


Figure D.8: LIN 5&6. Implied trends by statistical area for the lognormal model of the rolled-up bottom longline CPUE. The black trend and grey band represent the predicted mean standardised catch rate and interquartile range, and the blue trend the predicted year effect of the standardised CPUE. Year was model year which was defined as the calendar year. Only years where at least three vessels participated in any statistical area are depicted. The number of records is shown as the red bars using the right-hand axis.

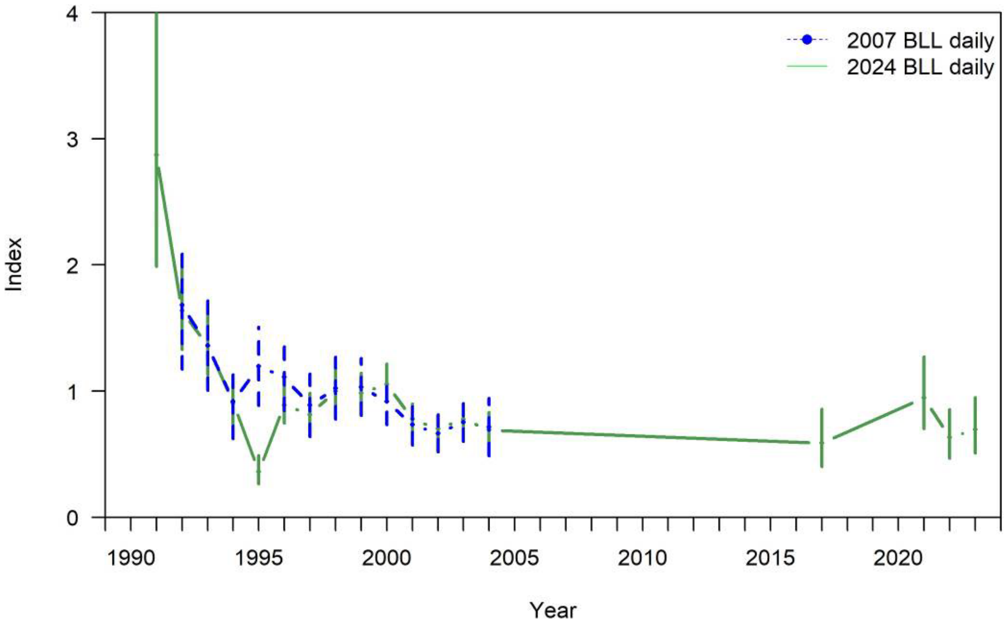


Figure D.9: LIN 6B. Year index for the lognormal model of the rolled-up bottom longline data. Also plotted is the bottom longline CPUE from the previous analysis in 2007 (Fisheries New Zealand 2024). Year was model year which was defined as the calendar year.

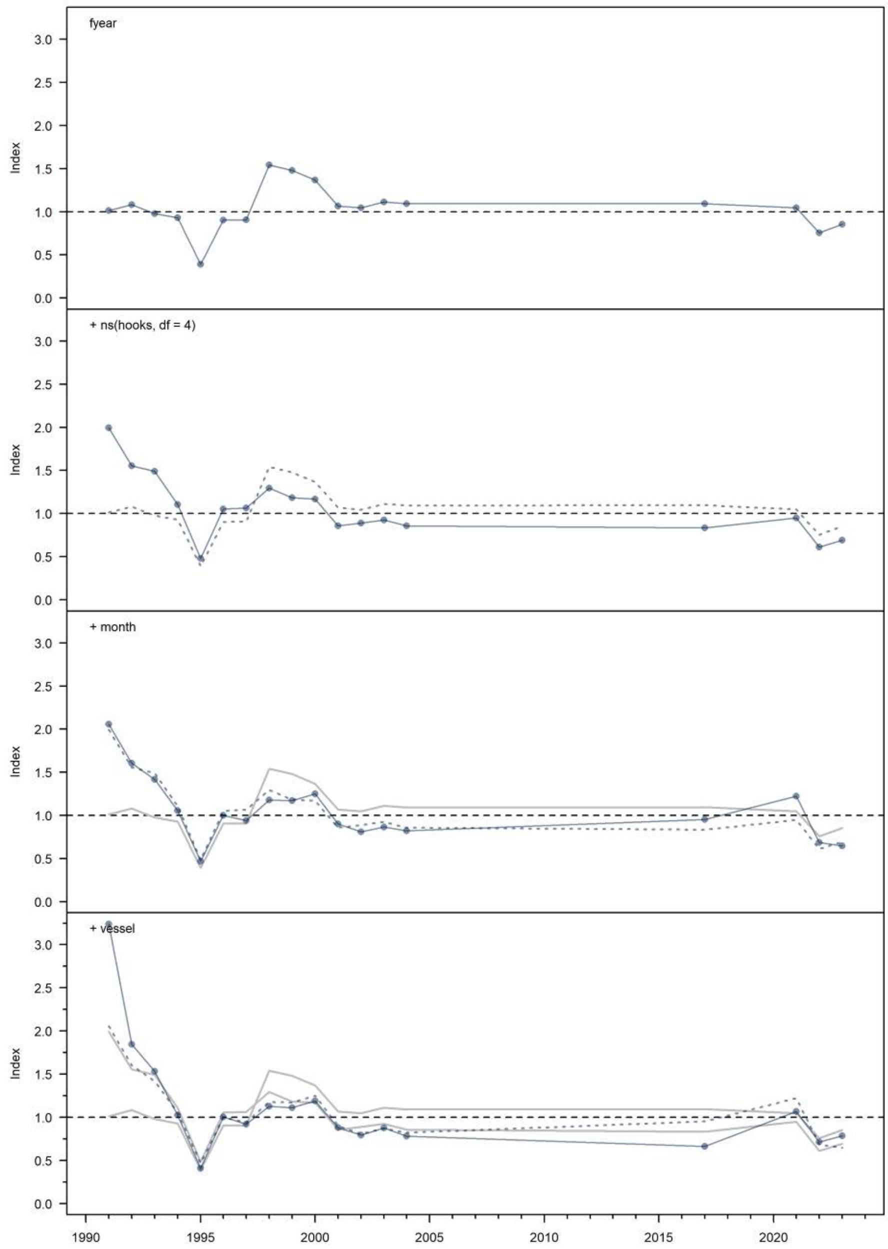


Figure D.10: LIN 6B. Influence plots for the lognormal model of the rolled-up bottom longline CPUE for the parameters included in the final model (in order of inclusion in the model), assuming that all other parameters were constant at their median or modal value. Year was model year which was defined as the calendar year.

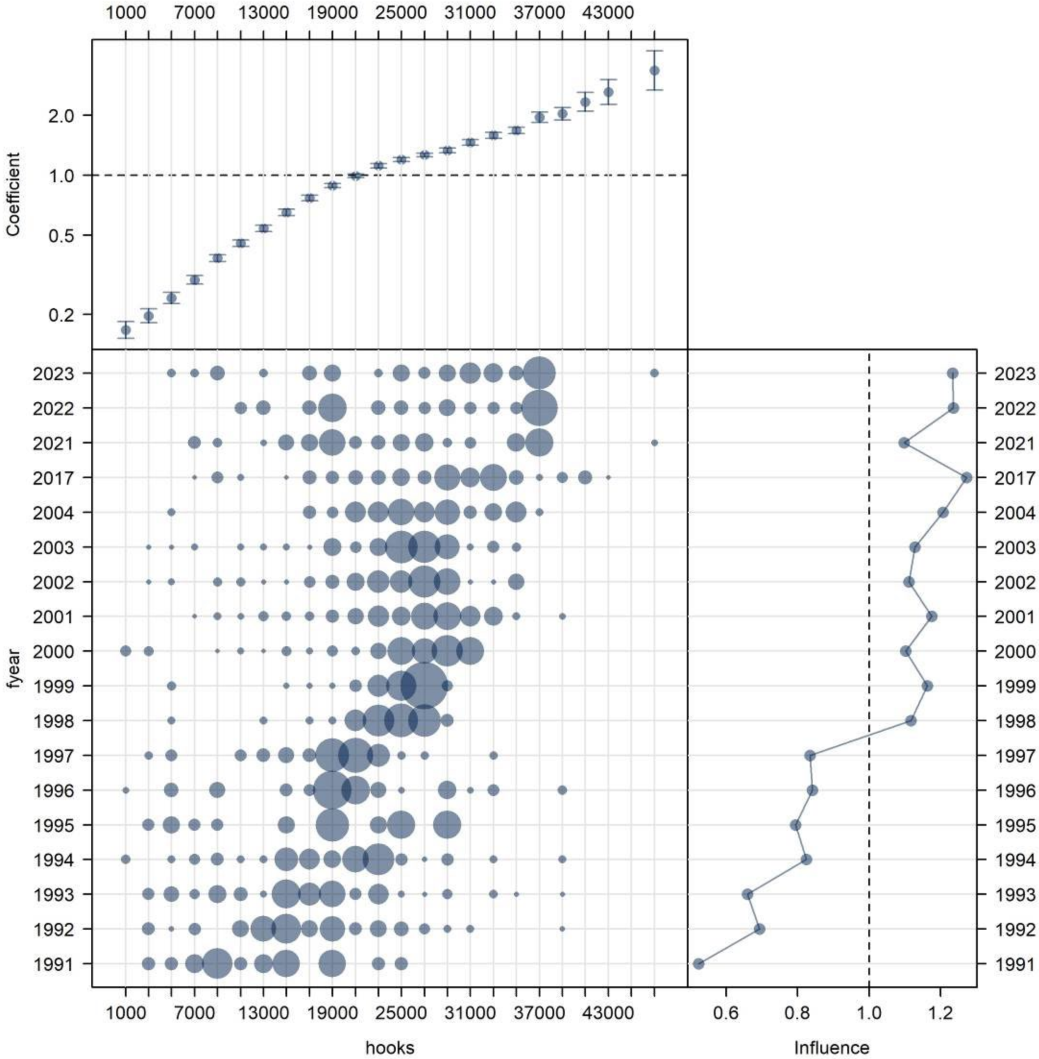


Figure D.11: LIN 6B. Influence plots for the lognormal model of the rolled-up bottom longline CPUE for the number of hooks (per rolled up record) in relation to year, assuming that all other parameters were constant at their median or modal value. Year was model year which was defined as the calendar year.

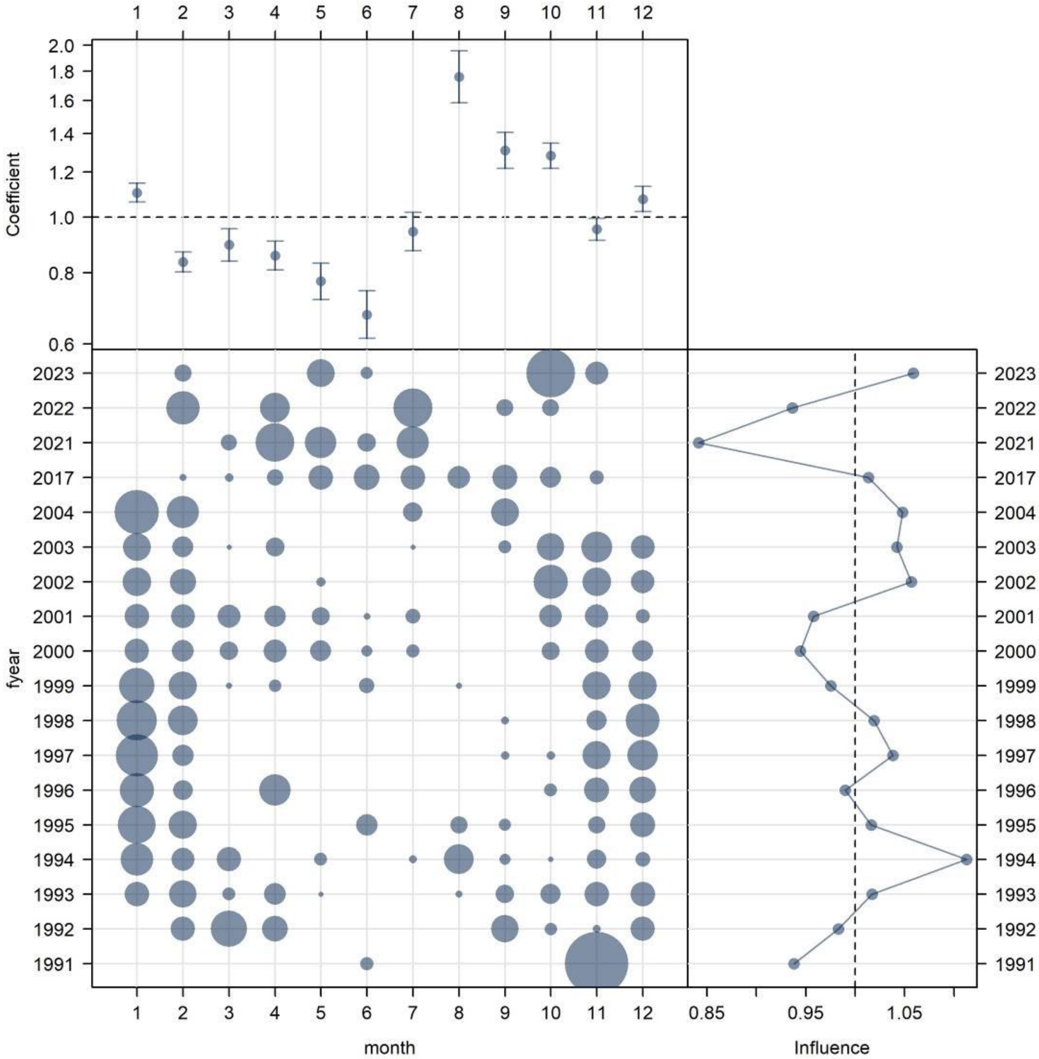


Figure D.12: LIN 6B. Influence plots for the lognormal model of the rolled-up bottom longline CPUE for month in relation to year, assuming that all other parameters were constant at their median or modal value. Year was model year which was defined as the calendar year, and month 1 is January.

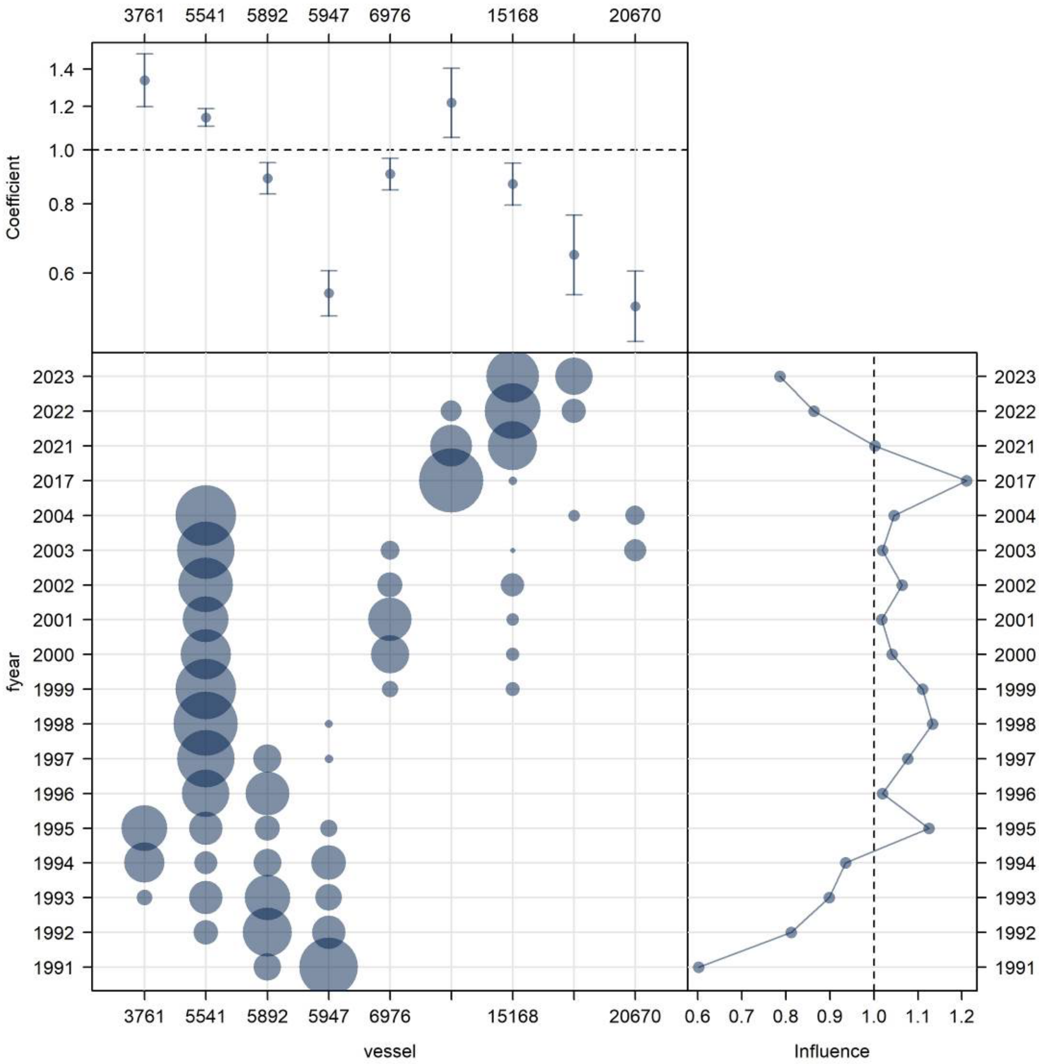


Figure D.13: LIN 6B. Influence plots for the lognormal model of the rolled-up bottom longline CPUE for vessel identifier in relation to year, assuming that all other parameters are constant at their median or modal value. Year was model year which was defined as the calendar year.

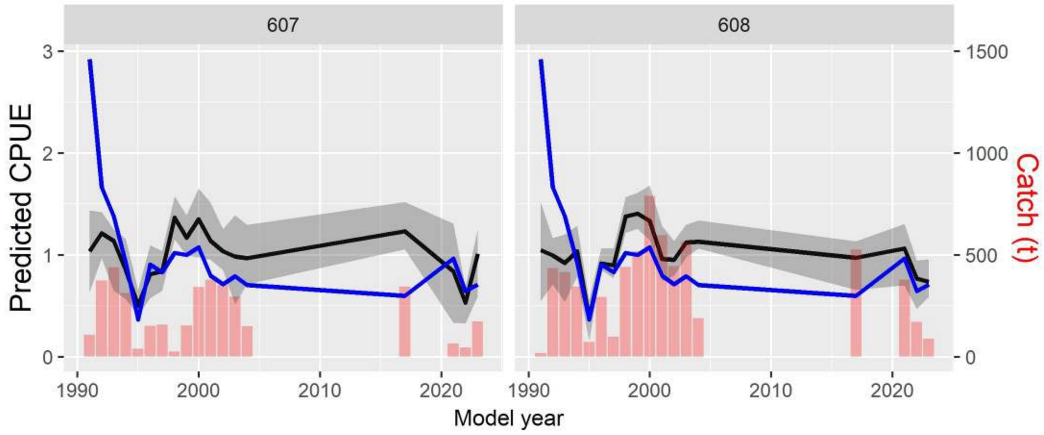


Figure D.14: LIN 6B. Implied trends by statistical area for the lognormal model for the rolled-up bottom longline CPUE. The black trend and grey band represent the predicted mean standardised catch rate and interquartile range, and the blue trend the predicted year effect of the standardised CPUE. Year was model year which was defined as the calendar year. Only years where at least three vessels participated in any statistical area are depicted. The number of records is shown as the red bars using the right-hand axis.

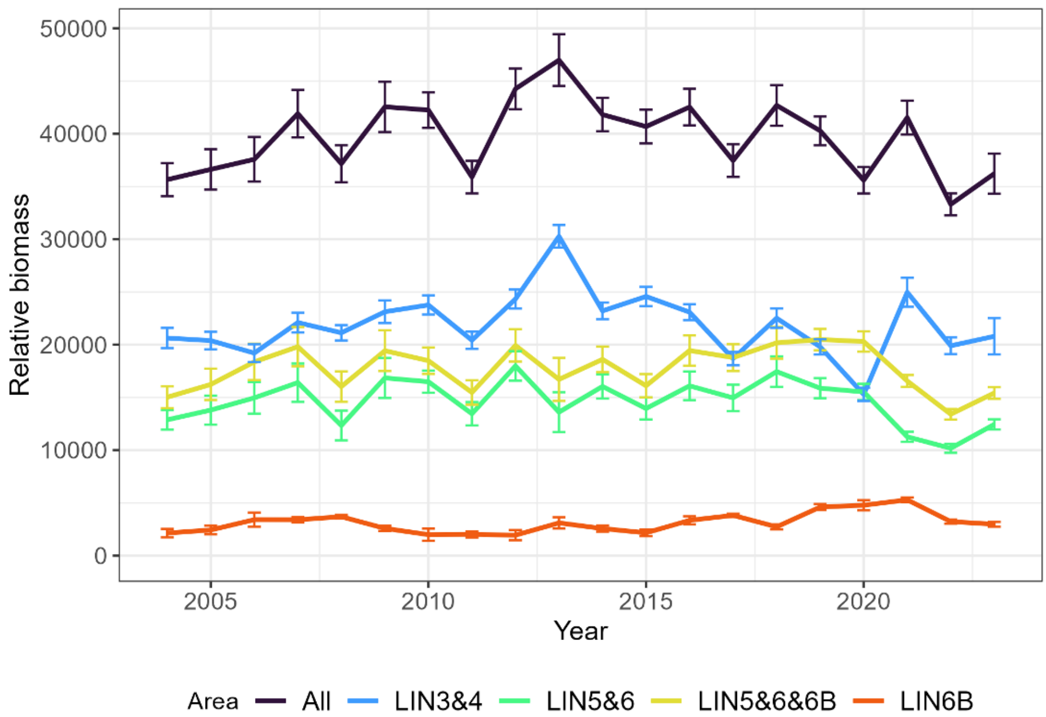


Figure D.15: Spatial bottom longline CPUE indices for LIN 3&4, LIN 5&6, LIN 5&6&6B, and LIN 6B as well as the entire area modelled (All).

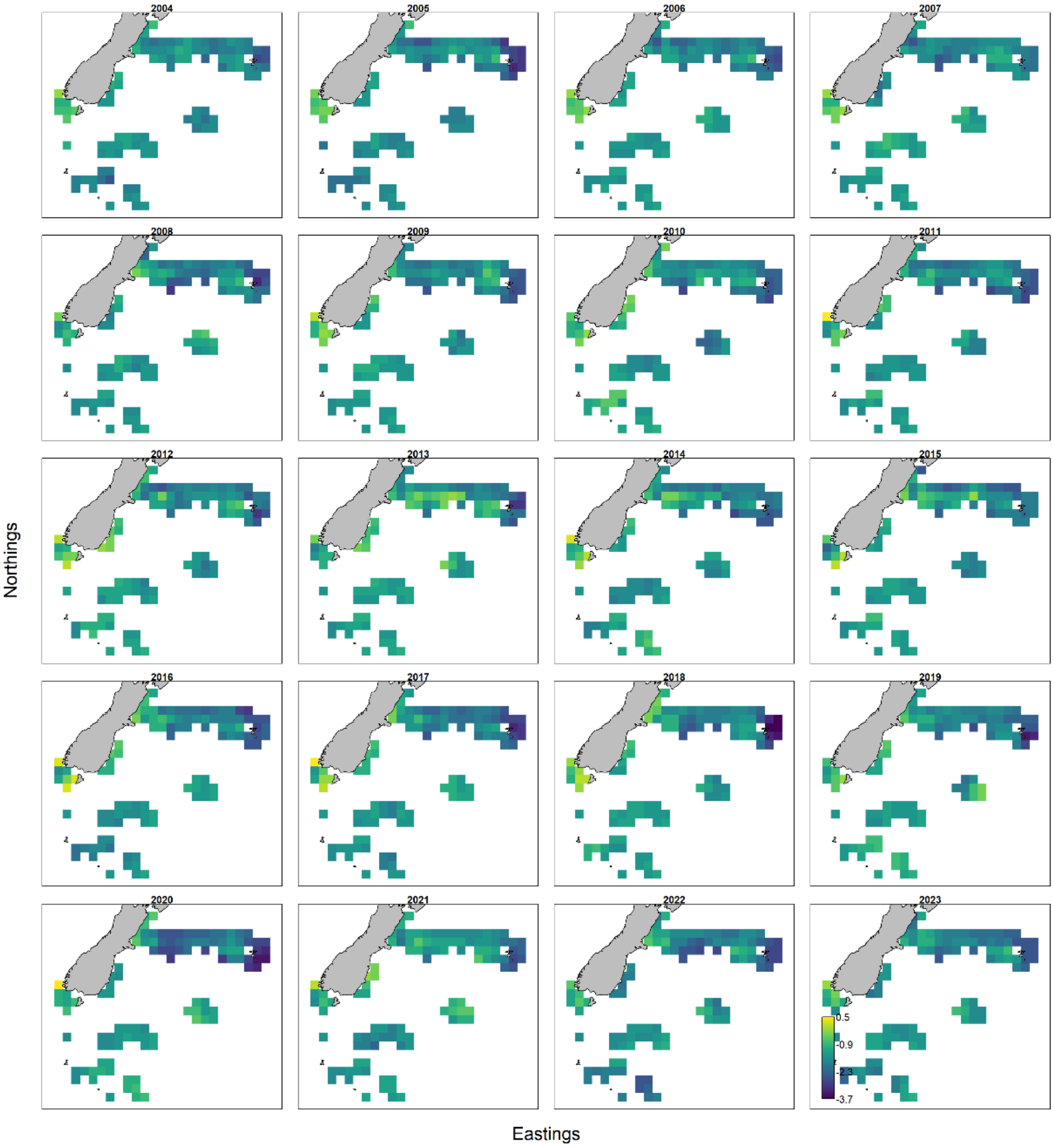


Figure D.16: Predicted biomass distribution (in log scale) in time and space for the spatial bottom longline CPUE model. Year was model year which was defined as the calendar year.

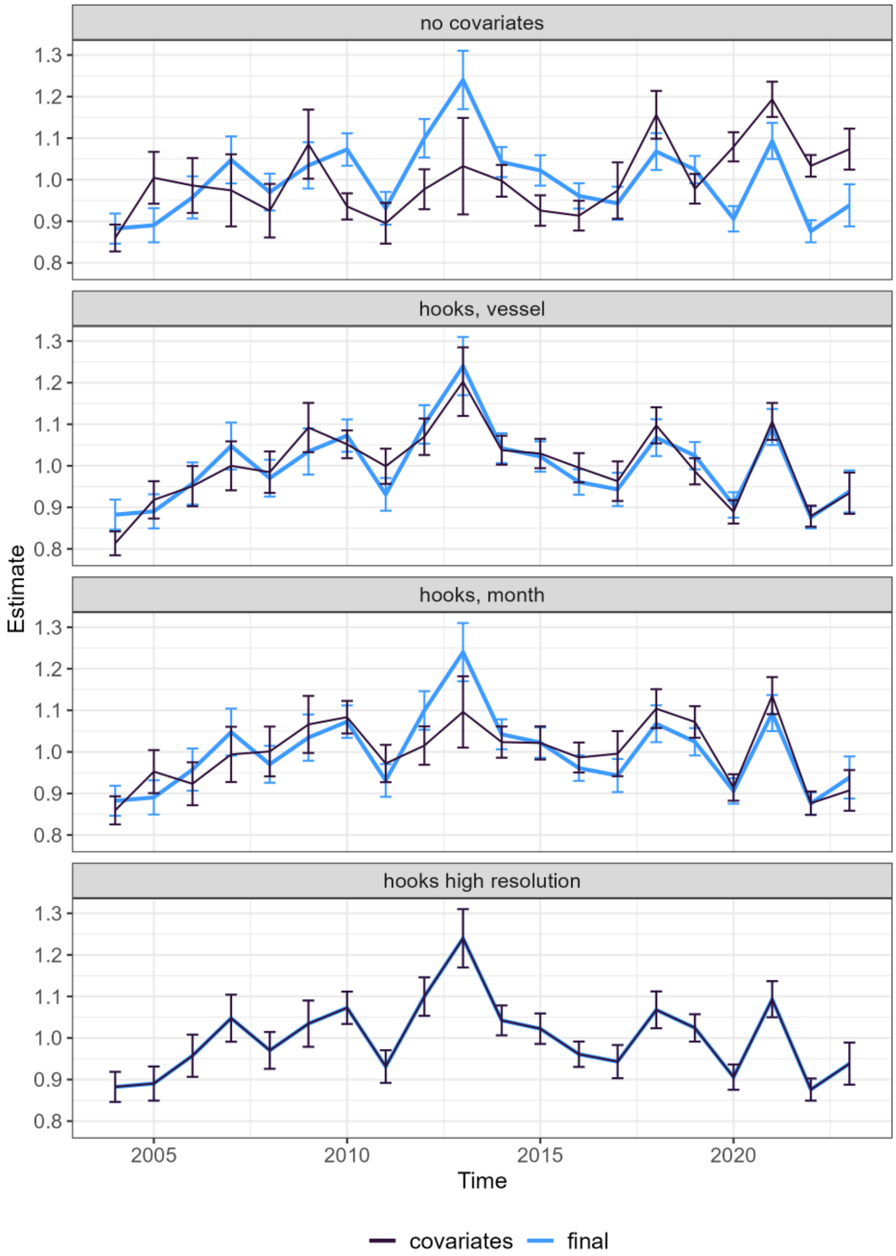


Figure D.17: Influence plots for the spatial bottom longline CPUE, assuming that all other parameters were constant at their median or modal value. The final model has hooks at high resolution (bottom panel and reproduced in light blue in all panels). Year was model year which was defined as the calendar year.

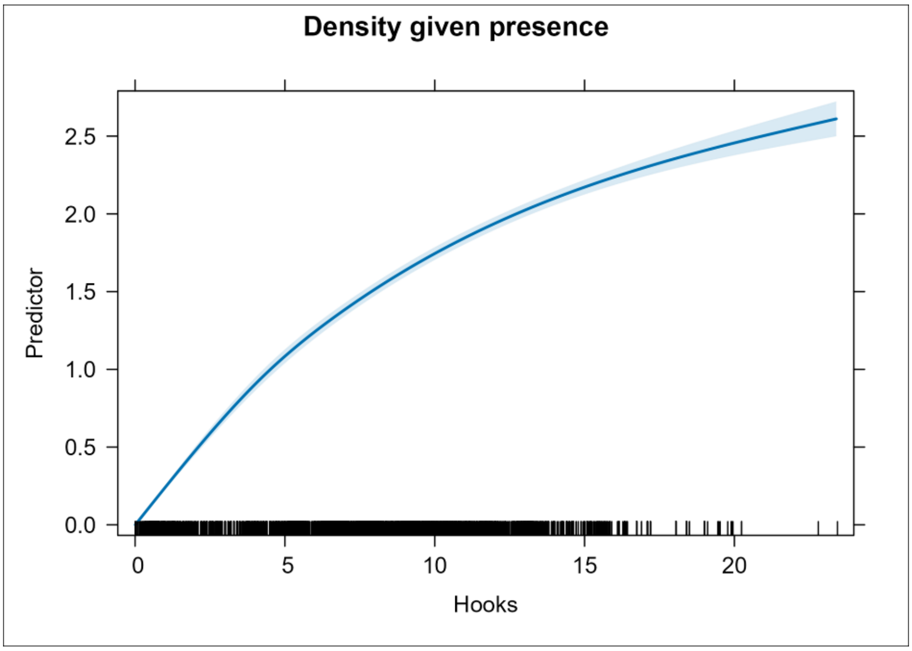


Figure D.18: Partial effect plot for the spatial bottom longline CPUE for number of hooks, assuming that all other parameters are constant at their median or modal value.

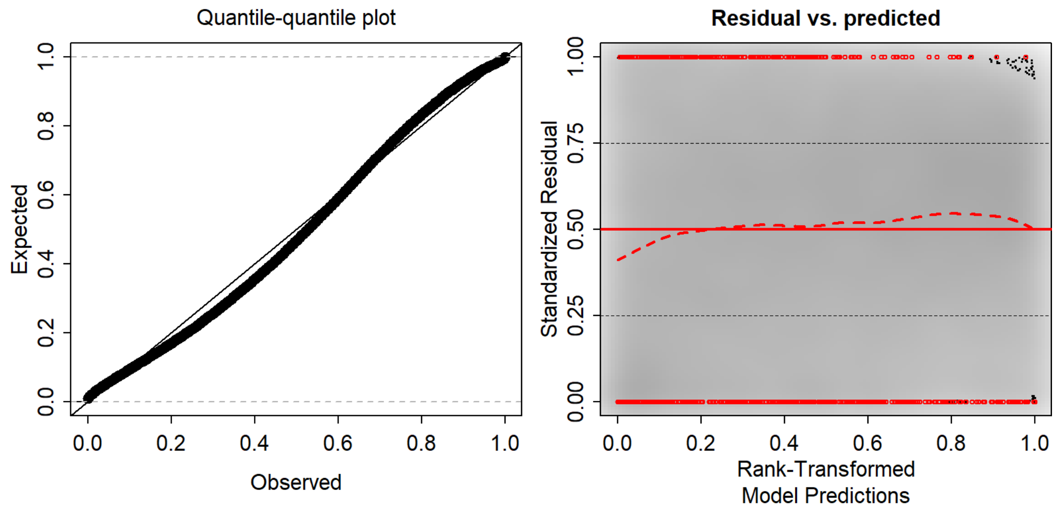


Figure D.19: Quantile-quantile plot and residual vs. predicted plot for the spatial bottom longline CPUE model.

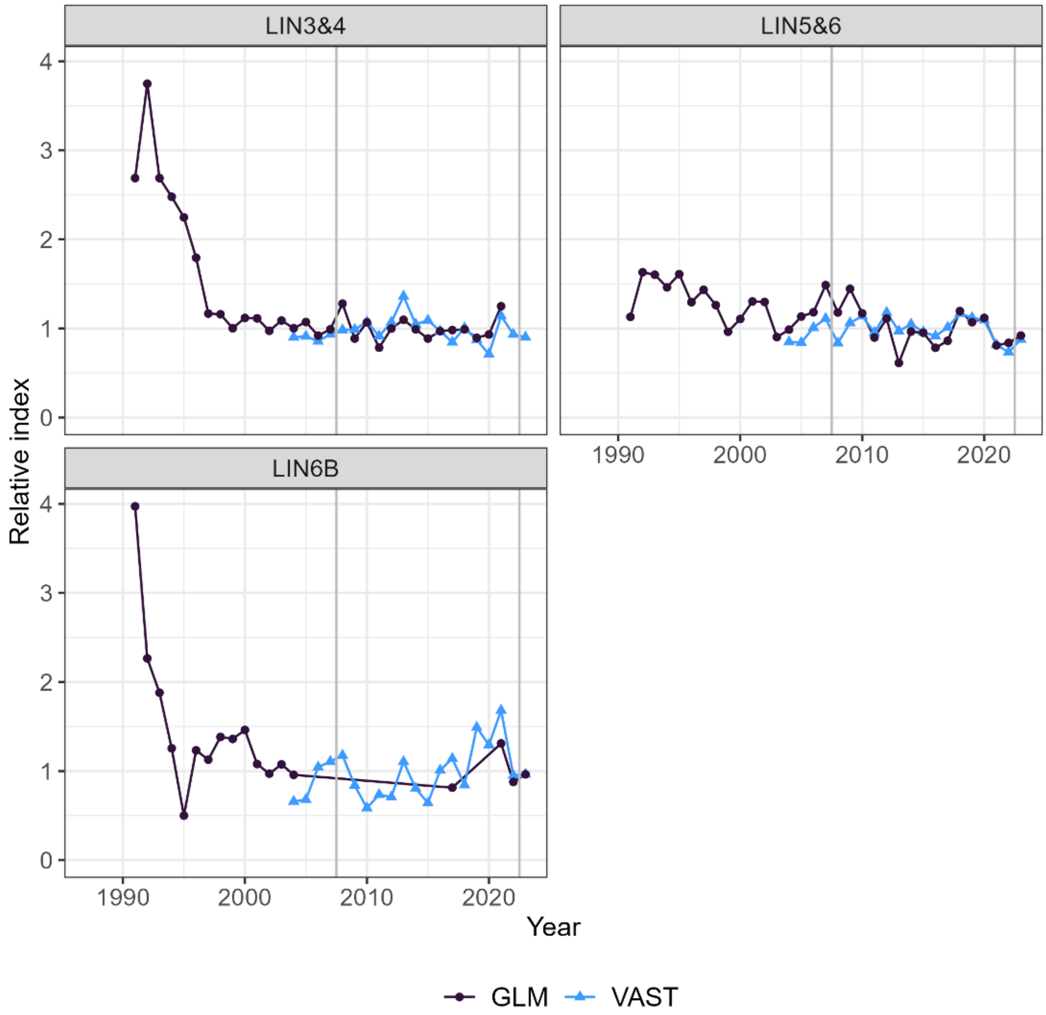


Figure D.20: Comparison of the annual bottom longline CPUE index standardised spatially (VAST) or not spatially (GLM) by ling stock. The LIN 3&4 GLM series is reproduced from Mormede et al. (2022a). Year was model year which was defined as the calendar year. The grey vertical bars correspond to the years the indices were standardised to.

15. APPENDIX E – INPUTS TO THE 2024 STOCK ASSESSMENT

Table E.1: Annual catch in tonnes per fishery used in the 2024 stock assessment (Mormede et al. 2024b). Year was model year which was defined as the calendar year. Bottom longline includes bottom longline and all potting methods, and bottom trawl includes all other catches.

Year	LIN 5&6		LIN 6B
	Bottom trawl	Bottom longline	Bottom longline
1972	0	0	0
1973	500	0	0
1974	1 120	0	0
1975	900	118	0
1976	3 402	190	0
1977	3 100	301	0
1978	1 945	494	10
1979	3 707	1 022	0
1980	5 200	0	0
1981	4 427	0	10
1982	2 402	0	0
1983	2 778	5	10
1984	3 203	2	6
1985	4 480	25	2
1986	3 182	2	0
1987	3 962	0	0
1988	2 065	6	0
1989	2 923	10	9
1990	5 004	0	14
1991	3 537	407	139
1992	7 663	1 026	1 244
1993	6 202	1 166	1 260
1994	6 782	1 423	652
1995	5 064	2 032	534
1996	6 872	2 101	614
1997	7 468	3 588	312
1998	5 771	3 267	493
1999	6 013	2 952	707
2000	7 506	2 328	1 175
2001	5 701	1 819	1 061
2002	7 720	1 264	859
2003	8 423	668	988
2004	8 016	1 509	422
2005	7 295	892	48
2006	7 118	781	110
2007	8 083	890	218
2008	5 345	659	446
2009	4 425	550	232
2010	4 391	1 064	2
2011	4 445	842	55
2012	6 608	1 168	4
2013	5 535	259	219
2014	6 075	925	75
2015	5 735	759	38
2016	4 482	618	214
2017	7 309	761	970
2018	7 355	768	149
2019	7 264	1 286	171
2020	6 168	2 033	255
2021	7 338	1 205	636
2022	7 198	1 378	249
2023	6 325	3 318	303

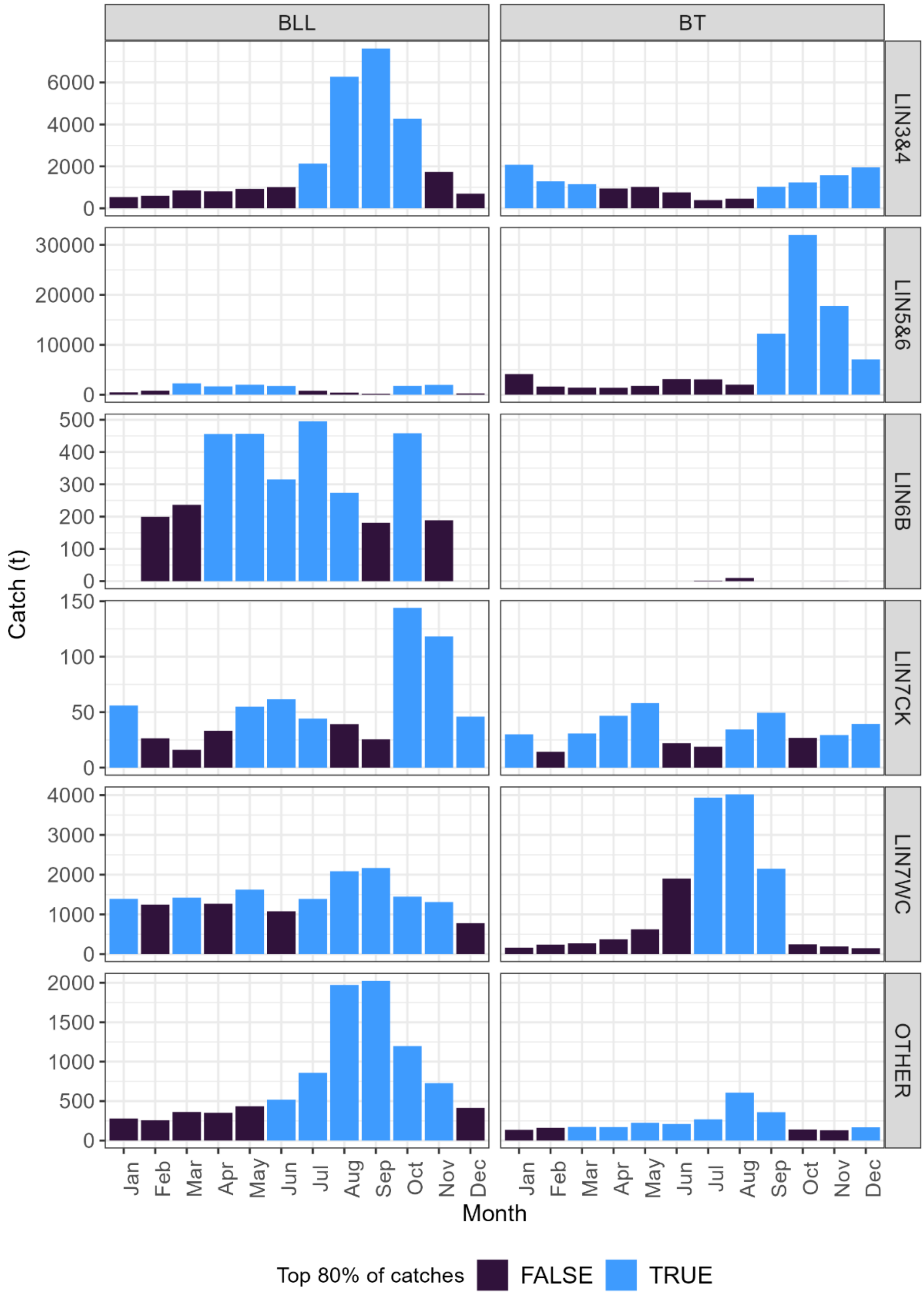


Figure E.1: Average monthly catches of ling by fishery (BT = bottom trawl and BLL = bottom longline), month and stock between 2019 and 2023. The bars in light blue represent the top 80% of catches.