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Characterisation and CPUE standardisation for school shark in New Zealand, 1989–90 to 2018–19

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School shark (*Galeorhinus galeus*) is a medium-sized coastal shark species that is common across the shelf and upper slope in New Zealand, and in temperate waters elsewhere. The New Zealand fisheries for school shark are complex because the species is caught by multiple fishing gears, both as a target species and as bycatch. The main fishing gears that catch school shark are set net and bottom longline (as target species), and bottom trawl (as bycatch). School shark individuals are highly mobile with frequent movements between quota management areas, and different life-stages use specific areas within their coastal distribution. This high mobility makes the interpretation of trends in fisheries catch-per-unit-effort (CPUE) data difficult. Previous analyses found conflicting trends in CPUE index series across regions, and sometimes between fishing gears in the same region.

This project summarised size-frequency information for school shark and updated previous fisheries characterisations. CPUE index series were standardised for five monitoring regions spanning New Zealand's Economic Exclusive Zone. In addition to the previously-used fishing methods of set net and bottom longline, standardised CPUE index series were also developed for bottom trawl as another fishing method. For the three fishing methods, candidate index series included at least two levels of effort resolution, for individual fishing events and for daily effort. For most fisheries, a third candidate index series was also developed at the effort resolution of individual fishing trips.

Size composition data for school shark catches in New Zealand were collated across three different sources: Fisheries New Zealand scientific observer programme, research trawl surveys, and voluntary logbook data forming part of a previous Adaptive Management Programme (AMP). The three size composition data sets showed variable patterns in the spatial distribution of sizes over time, but all data sets included a higher prevalence of large individuals in Southland or neighbouring areas. Mature individuals were also more common in commercial fishery samples from the observer programme and AMP samples than in the inshore trawl surveys for all regions where they co-occurred. This finding confirmed that large, mature school shark can be captured by commercial bottom trawl. Given that the AMP was discontinued in 2009, observer samples could provide valuable information on catch composition, gear vulnerability, and size distribution across a more representative sample of the population; however, there are currently few years with sufficient observations across all fishing gears to support a broad-scale analysis of these data.

This update of standardised CPUE series included the development of abundance indices at multiple effort resolutions across all series, resulting in a total of 36 index series. In general, the accepted index series were at the daily effort resolution for set-net and bottom longline fisheries, and at the trip effort resolution for bottom-trawl fisheries. The Inshore Fisheries Working Group (INSWG) accepted standardised CPUE series as indices of abundance for Far North & SCH 1E, Chatham Rise (SCH 4) and Lower SCH 3 & SCH 5, and an index of abundance from a research trawl survey for SCH 7, SCH 8 & lower SCH 1W. No index of abundance was accepted for SCH 2 & top of SCH 3, and this result was similar to the previous analysis. Based on the accepted indices, school shark abundance is increasing in Far North & SCH 1E, stable in Chatham Rise (SCH 4), declining in Lower SCH 3 & SCH 5, and stable in SCH 7, SCH 8 & lower SCH 1W, following a potential initial decline in the late 1990s.

Bottom-trawl CPUE index series were included in this analysis for all regions except Chatham Rise. These series were developed in part to elucidate conflicting trends in relative abundance from set-net and bottom longline CPUE index series. The bottom-trawl standardised index series was accepted by the

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INSWG as one of the three monitoring series for Far North & SCH 1E. The bottom-trawl index series for SCH 2 & top of SCH 3 did not resolve the ongoing conflict between the CPUE series developed from the set-net and bottom-longline fisheries in SCH 2 & top of SCH 3. Instead, this additional series matched the bottom-longline index series in the earlier part of the time series and the set-net index series in the latter part. Dedicated research for this CPUE monitoring unit that considers spatial overlap between fishing methods over time might help to resolve the uncertainty around this discrepancy. The spatial distribution of school shark across life stages in New Zealand also needs to be better characterised.

1. INTRODUCTION

School shark (*Galeorhinus galeus*) is a medium-sized coastal shark species that is common across the shelf and upper slope in New Zealand, and in temperate waters elsewhere (Blackwell & Francis 2010). The New Zealand and Australian populations of this species are considered to belong to a single stock based on tagging and genetic evidence (Hernández et al. 2015, Francis 2010). Maturity in school shark occurs between 125 and 135 cm for males, and between 135 and 140 cm for females (total length; Francis & Mulligan 1998). They feed on a diverse diet of teleosts, cephalopods and crustaceans throughout the water column, and move from inshore to deeper waters during winter (Dunn et al. 2010, Blackwell & Francis 2010).

School shark was introduced to the Quota Management System (QMS) in 1986 with a Total Allowable Commercial Catch (TACC) of 2513 t, which was increased to 3106 t the following year (Fisheries New Zealand 2021). The TACC has remained stable at 3416 t since 2004–05. Stock status is assessed relative to reference points derived from standardised catch-per-unit-effort (CPUE) indices for each of five regions spanning the seven Quota Management Areas (QMAs) for this species (SCH 1, SCH 2, SCH 3, SCH 4, SCH 5, SCH 7 and SCH 8) (Table 1 and Figure 1). The regions were initially defined in a New Zealand-wide review of stock and fishery boundaries (Starr & Kendrick 2016). When conducting the review, Starr & Kendrick (2016) observed that many of the existing QMA boundaries intersected with existing set-net and bottom-longline fisheries. For this reason, they delineated new fishery boundaries based on the spatial distribution of set-net and bottom-longline fishing effort catching school shark, resulting in five regions since used as spatial units for management.

Fisheries for school shark are complex because the species is caught by multiple gears in New Zealand waters, both as target species and as bycatch in other fisheries. Individuals move across QMAs, and different life-stages use specific areas within their coastal distribution (Francis 2010, see also Walker et al. 2008), making the interpretation of trends in fisheries catch-and-effort data difficult. Also, individuals are considered to show differential vulnerability to fishing gear based on their size (Blackwell & Francis 2010).

The main fishing gears that catch school shark are set net, bottom longline and bottom trawl. Previously, standardised indices were developed for set net and bottom longline only, because large-sized school shark were not considered to be vulnerable to bottom-trawl gear such that the resulting index would not be representative of population abundance. Nevertheless, Dunn & Bian (2018) found that large-sized individuals were captured by bottom trawl, and that their presence (or absence) in the catch composition data for trawl (by survey or observer) was associated in part with the area sampled.

The most recent CPUE analysis for school shark produced variable indices of abundance and no clear trend across all regions (Dunn & Bian 2018). The region comprising of eastern North Island and northeastern South Island (SCH 2 and top of SCH 3) was of particular concern as the set-net and bottom-longline indices were directly opposing, with steadily increasing trends for set net versus decreasing trends for bottom longline. At the same time, the latest assessment of the Australian sub-stock classified school shark as overfished; however, there is uncertainty as to whether overfishing is ongoing (Woodhams et al. 2020).

This report presents an updated characterisation of school shark fisheries in New Zealand waters for the period 1989–90 to 2018–19 (Fisheries New Zealand project SCH2019-01), following previous work by Starr & Kendrick (2016) and Dunn & Bian (2018). A review of size composition data was also completed, incorporating new and updated data sources, including research trawl surveys, Fisheries New Zealand observer programme data sets and logbook data from the Adaptive Management Programme (AMP). Standardised CPUE index series for this species were also expanded to include bottom-trawl indices for most regions.

Table 1: Spatial definition of catch-per-unit-effort monitoring units by region showing the main and additional statistical areas, when relevant, for specific gear within the region. Only the bottom-longline fishery in Chatham Rise (SCH 4) is used as a CPUE monitoring unit. (Adapted from table 14 of Starr & Kendrick 2016).

		Additional Statistical Areas		
Region	Core Statistical Areas	Set net	Bottom longline	Bottom trawl
Far North & SCH 1E	043-010	—	—	—
SCH 2 & top of SCH 3	011-015	018, 020	—	018, 020
Chatham Rise (SCH 4)	049-051, 401-412	N/A	019-021	N/A
Lower SCH 3 & SCH 5	022-033	—	—	—
SCH 7, SCH 8 & lower SCH 1W	034-042, 801	016, 017	016-018	016, 017

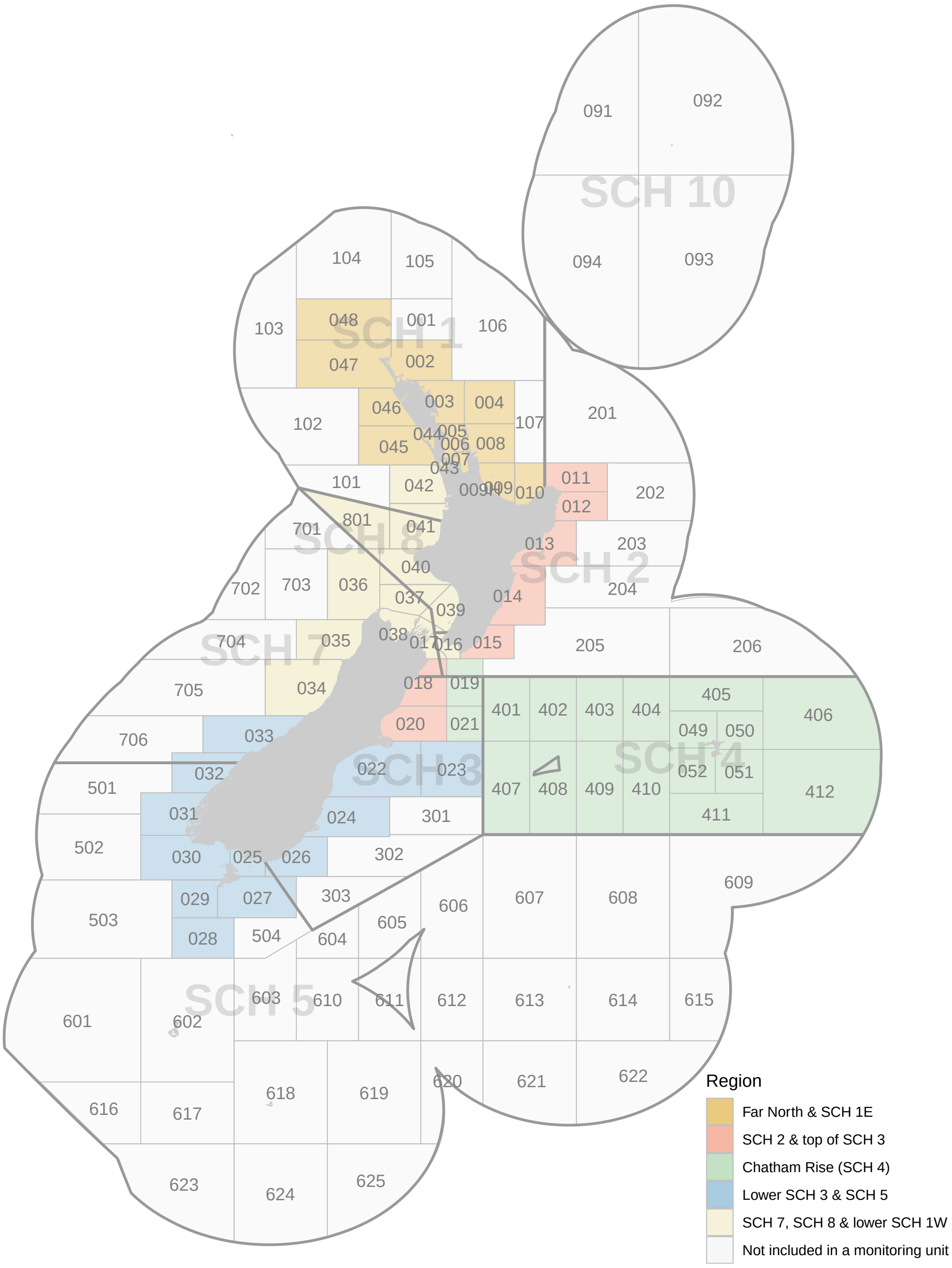

Figure 1: Overview of catch-per-unit-effort monitoring units and statistical areas for school shark in New Zealand. (Note that there can be some changes to the definition based on the fishing method.)

2. METHODS

2.1 Size composition and biomass indices

Length-composition data for school shark catches in New Zealand are available from fishery-independent trawl surveys (undertaken by the National Institute for Water and Atmospheric Research, NIWA, under contract to Fisheries New Zealand), observer records from the scientific observer programme managed by Fisheries New Zealand, and the Adaptive Management Programme (AMP). The AMP was a programme funded and managed by the fishing industry through the (then) New Zealand Seafood Industry Council. The programme ran from 1994–95 to 2008–09, and collected size composition data from a number of fisheries for school shark from 2004–05 to 2008–09, when it ended. The programme was designed based on the premise that fishers could be instructed to collect biological data from their fisheries. Most length samples for school shark were collected by set-net fisheries operating in Canterbury Bight, Otago, Foveaux Strait and off the west coast of South Island.

Time-series data of estimated survey biomass and population-scaled length-frequency distributions for school shark were obtained from Fisheries New Zealand for all research trawl surveys; these data were from the west coast of North Island (NIWA, unpublished data; see also Morrison & Parkinson 2001), east and west coasts of South Island (MacGibbon et al. 2019 and MacGibbon 2019), including Tasman and Golden bays, and Chatham Rise (Stevens et al. 2021). Note that the full set of results for the 2019 survey of the west coast of North Island (KAH1906) were unavailable at the time of writing, so only biomass estimates were included for this year of the survey.

The survey biomass and population-scaled length-frequency distributions were obtained from NIWA from observations of school shark by survey station using the area-swept method (see Francis 1989 for a description of the approach). The distributions were included here without further modifications, except for re-scaling the length-frequency distributions by survey to a unit of one to support comparisons with other surveys and data sets. The survey biomass and length-frequency distributions from the Tasman and Golden bays region were presented separately from the rest of the west coast South Island survey area.

Observer data for school shark were obtained from Fisheries New Zealand's Centralised Observer Database (COD) (replog 13410). All records of school shark measurements were requested, including information from the corresponding fishing event. The latter information included the fishing method, date, statistical area code, geographical coordinates, and total school shark catch (in green weight) associated with the fishing event. All events with fishing method codes "SN", "BLL" or "BT" were retained. Missing statistical area codes were imputed based on geographical coordinates, where possible. Some individuals were measured using fork length (FL) instead of total length (TL), especially in recent years ($\sim$80% of individuals). For these observations, fork length was converted to total length using a length-length relationship for school shark from Western Australia, wherein $TL = 1.140FL + 3.111$ (De Wysiecki & Braccini 2017). For annual size-frequency distributions, individual size records were grouped into 5-cm classes and aggregated by year, fishing method, and CPUE unit based on the statistical area code. The resulting distributions were scaled to a unit of one and otherwise not re-weighed because school shark catch (green weight in t) was missing for a high percentage of records (from 35.6% for bottom longline to 100% for bottom trawl). Mean length (in cm) by fishing year and 0.5-degree cell was also calculated by fishing method across all available years.

The AMP data sets collected by the Seafood Industry Council were obtained from Southern Inshore Fisheries Management Company Ltd. The data sets included a table describing the fishing events, the school shark catch data associated with the fishing events, and length measurements (in cm) of school shark individuals observed by fishing event. Only set net records were considered here because there were few length measurements of school shark from bottom longline and bottom trawl. Fishing events missing both statistical area and geographical coordinates were discarded, as were size records not matched to a catch event. Relative size distributions of school shark by year and spatial fishery unit (Figure 1) were obtained by re-weighing 5-cm size class samples by the total school shark catch in the set and re-scaling the size distribution to one. CPUE unit $\times$ fishing year $\times$ size class combinations were only retained if they had at least 10 observations. For spatial distributions, mean size by fishing year and 0.5-degree cell was calculated as the weighted mean of length, with individual length records weighted by the school shark catch in the set over all years available for each location.

Size-at-maturity for male and female school shark was obtained from Francis & Mulligan (1998). Three key life stages (the same for each sex) were defined based on total school shark length following Dunn & Bian (2018): juveniles measuring up to 100 cm, pre-adults measuring between 100 and 125 cm, and adults (or mature individuals) with lengths greater than 125 cm.

Key size composition statistics for all three data sources are summarised in Appendix A, and estimated survey biomass (and CV) for all research trawl surveys is listed in Appendix B.

2.2 Fisheries characterisation

Database extracts for landings, fishing events, and associated estimated catch from 1989–90 to 2018–19 were obtained from the Electronic Data Warehouse (EDW) (previously called the *warehou* database) hosted by Fisheries New Zealand (replogs 13159 and 13478). Quota Management Reports (QMRs) and Monthly Harvest Returns (MHRs) for school shark were also obtained for the same time period.

The "landings" table contains information about the school shark catch that was landed, including the type of form used to report the landing, the Quota Management System stock code, the weight of the processed catch (in kilograms), the state of the processed catch, the destination code, the conversion rate from processed to green weight given the state of the processed catch, and the green weight (in kilograms). Information about the fishing trip is also included, such as a vessel, the client number, the start and end date of the trip, a unique identifier for the trip, and, for electronic records, a source code (paper form or electronic).

The "fishing events" table (also referred to as "effort" table) contains information about individual fishing events, including the fishing trip identifier, fishing method, the date and time, the statistical area code of the area where the event(s) occurred; it also includes effort metrics relevant to the fishing method such as the hook number for bottom longline and net length for set net. For fishing events recorded on the Catch Effort Landing Return (CELR) forms (typically, from 1989–90 to 2006–07 or 2007–08, depending on the gear), all fishing events occurring on the same day are collated on the same form. For more recent fishing events, high-resolution, fishing-method specific forms are available, which allow recording at the individual fishing event level and the collection of additional spatial covariates, such as the geolocation of the fishing event and the bottom depth (in metres).

The "estimated catch" table contains estimates of catch by species by the vessel crew for each fishing event. For events using the (daily) CELR forms, only the top five species in the catch were reported. For events using the high-resolution forms, up to eight species can be recorded. There was no upper limit for the number of recorded species when electronic reporting was used, starting in 2017–18, but, at minimum, the top five QMS species and the top three non-QMS species must be included.

All landings records were extracted where "SCH" was used in the stock code, as well as all fishing events and estimated catch associated with the trips. These datasets were prepared separately to retain records relevant to the analysis and correct erroneous or improbable entries (see Appendix C).

The fishing year for school shark is defined from 1 October to 30 September the following year. Subsequent references to single fishing years correspond to the latter year in the time period.

The catches recorded in the landings table were considered to be the most accurate source of catch data by species, especially because species catch might not be recorded at the event level in the estimated catch table if it did not rank sufficiently high in the overall catch of an event. Also, because shark catches are usually processed at sea to avoid urea contamination, the estimated catches can be provided as processed weight instead of green weight (Starr & Kendrick 2016). School shark catches were allocated from the landings table to fishing events following the procedure outlined by Langley (2014):

- Total estimated school shark catch was calculated for each trip, only including estimated catch records where school shark ranked in the top five species caught in the fishing event. Estimated catches not within these top five positions were discarded to maintain continuity in the interpretation of the time series.
- The proportion of the total estimated school shark catch for each individual fishing event within a trip was calculated.
- School shark landings (green weight in kilogram) for a trip were apportioned amongst fishing events associated with the trip as the product of the green weight to the proportion of total estimated school shark catch in the fishing event.
- If there was no estimated catch of school shark with a rank of five or less for any of the fishing events associated with the trip, the trip landing was allocated instead by using the proportion of effort to the trip total in each fishing event. The effort metric used was total net length for set net, fishing duration for bottom trawl or midwater trawl, total hook number for bottom longline, and effort number for all other methods. When more than one primary method was declared for the trip, effort number was used as the effort metric for all fishing events (see Appendix C.4 for the proportion of landings that were allocated by fishing effort or estimated catch).

School shark catch was aggregated by target species and the mean catch rank was calculated for each. To preserve consistency in the time series, the mean rank was only calculated for fishing events where school shark ranked in the top five of species caught. Target species codes are defined in Appendix D.

Included in the characterisation were summaries of school shark catch and CPUE by bottom depth. Information of bottom depth has been recorded on high-resolution effort forms for bottom longline and bottom trawl: since 2003–04, bottom depth has been recorded on Lining Catch Effort Return (LCER) forms (for vessels exceeding 28 m length), and since 2007–08, on Trawl Catch Effort Return (TCER) and Lining Trip Catch Effort Return (LTCER) forms (for vessels between 6 and 28 m length). This information is not recorded on the high-resolution form collected for set net (Netting Catch Effort Landing Return, NCELR). Bottom-depth information is available from 1989–90 onwards on the Trawl Catch Effort Processing Return (TCEPR) forms used by large offshore trawlers (>28 m length). For consistency, all catch summaries including bottom depth information span the time period when high-resolution forms were used across fishing methods and most vessel types, i.e., from 2007–08 onwards. Bottom depth was assigned to 25-m classes for the catch summaries, and 50-m classes for the CPUE summaries.

2.3 CPUE standardisation

2.3.1 CPUE monitoring units

Standardised CPUE indices for school shark were developed at the level of the CPUE spatial monitoring unit (“CPUE unit” hereafter; see Table 1 and Figure 1). These CPUE units were initially defined by Starr & Kendrick 2016 and consist of a set of statistical areas and target species for each fishing gear catching school shark. These were defined for set net and bottom longline fishing methods, but not for bottom trawl. Also, the spatial definitions do not necessarily match QMA boundaries because they are meant to group aggregations of set-net and bottom-longline effort where school shark is captured and exclude non-productive areas where school shark is not captured. As such, the statistical areas included in the fishery definition sometimes differed between set-net and bottom-longline gears because the spatial extent was defined independently for each capture method and these gears sometimes caught school shark in different statistical areas within the same CPUE unit. The CPUE units usually spanned areas that were larger than single QMAs. For bottom-trawl indices, the spatial definition of the CPUE units was initially conservatively set to the larger set of statistical areas for each CPUE unit (i.e., often the equivalent area to the set-net fishery), and then further refined based on CPUE model diagnostics. Target species for bottom trawl fisheries were defined based on examination of prevalence of school shark in fishing events and also depth profiles (see Appendix E).

2.3.2 Preparation of datasets for CPUE standardisation

A separate extract of all fishing events for set net, bottom longline, and bottom trawl from 1989–90 to 2018–19 was obtained for CPUE standardisation (replogs 13159 and 13478). The fishing event dataset was expanded to include, for each CPUE unit, all fishing events with statistical areas and target species as specified in the definition of the CPUE unit (Table 1). Fishing events within trips with no associated school shark landings were assigned a school shark catch of zero; other fishing events were assigned school shark catch as determined by the catch allocation procedure described above.

Standardised indices for school shark were previously developed at the daily resolution, i.e., the resolution at which records were collected on the CELR forms (see Starr & Kendrick 2016, Dunn & Bian 2018). In the current assessment, indices were also developed at the event and trip resolution for most fisheries. Event-based indices use the high-resolution effort forms (starting in 2006–07 for set net, and 2007–08 for bottom longline and bottom trawl) in which additional spatial covariates are recorded (e.g., geographical coordinates of the event, bottom depth for trawl and bottom longline). Despite spanning a shorter timescale, the event-based indices serve as a diagnostic to ensure the inclusion of additional operational or spatial covariates (not available in the CELR form) do not change the overall trend of the long-term index.

Trip-based indices are most useful for fisheries where a high proportion of landings are allocated according to effort instead of estimated catch. For these trips, school shark was a minor component of the catch within the trip, so that it did not rank in the top five species for any fishing events. In this situation, landings were allocated by effort by spreading the catch proportionately over all fishing events within the trip. This spread can bias the binomial indices by inflating the positive occurrence of school shark in the catch (i.e., creating “false positives”). Langley (2019) found that CPUE standardisation models which included more than 20% of catches allocated by effort performed poorly as indices of abundance. In these instances trip-based indices are considered to be more appropriate despite the coarser resolution of the covariates, because the true occurrence of school shark in the catch within the CPUE unit is preserved.

Data sets were prepared for CPUE standardisation at the daily and trip scale by aggregating fields in the event-scale dataset at either the trip-vessel-day (“daily”) resolution or the trip-vessel resolution (“trip”). The event-scale data set was not changed. Following discussion with the Inshore Finfish Working Group (INSWG), for the trip-level resolution, trips were discarded if they included fishing events in statistical areas outside the CPUE unit definition. An additional diagnostic was added to CPUE indices at the trip resolution to show the annual landings that were omitted as part of this additional data preparation step.

When aggregating data at the daily and trip resolution, categorical fields (target species and statistical area code) were defined as the mode over the day or trip weighted by school shark catch; or, if no catch was allocated, by fishing effort (total net length for set net, total hook number for bottom longline, and fishing duration for bottom trawl). Ties were resolved alphabetically following Dunn & Bian (2018). Effort fields were summed and environmental variables (e.g., bottom depth) were averaged. Data summaries of the CPUE datasets across the effort resolutions are included for each CPUE unit in Appendix F.

For each CPUE unit, the core fleet was selected based on a minimum number of years of vessel activity, with years only considered if they met an annual trip threshold. The core fleet parameters followed parameters first defined by Starr & Kendrick (2016). For bottom trawl, core fleet was similarly defined to maximise catch coverage while minimising vessel number. The core fleet parameters used for each CPUE unit $\times$ fishing gear combination are defined in Appendix G. The same parameters were applied to all effort resolutions trialled within each CPUE unit.

2.3.3 Standardisation model

Candidate CPUE indices were developed for each CPUE unit based on relevant fishing gears within the region and appropriate resolution for each index following discussion with the Inshore Finfish Working

Group. Generalised linear models (GLMs) were developed for each series under a hurdle framework, with two models fitted separately for school shark occurrence in the catch (i.e., presence or absence) and, for positive events only, the size of the school shark catch in weight (kilogram).

The occurrence model was fitted under a logistic regression assuming a binomial error with a logit link. The abundance model was fitted under three alternative error distributions: log-normal, gamma, and Weibull. Assumptions about error distribution were verified by examining quantile residuals as implemented in the R package *statmod* (Dunn & Smyth 1996).

For all series, the log-normal error distribution resulted in normally distributed residuals which most respected model assumptions under all residual diagnostics, and so it was retained as the final error distribution for the abundance models. Key residual diagnostics considered were the overall distribution of residuals, a quantile-quantile plot of the residuals, and the distribution of residuals as a function of the response variable.

The selected model for each CPUE series was the model including the set of covariates that maximised explanatory power and minimised model complexity. A backward stepwise selection procedure was used to identify the 'best' model structure from a candidate pool of covariates (the covariates presented to the models are described in Table 2, and candidate model structures by fishing method and resolution are given in Table 3). This procedure used the Aikake Information Criteria (AIC) as a metric of model performance to select the best model relative to other candidates. Models were only considered if they resulted in an improvement in at least 1% of the deviance explained compared with the next competing model.

Upon examination of model diagnostics, some statistical areas were omitted from the original definition of the CPUE unit (outlined in Table 1), if they contributed few observations to the model. Similarly, the set of target species for each CPUE unit was modified in some instances based on model diagnostics and discussion with the INSWG. The final set of statistical areas and target species used for each index is listed in Appendix G.

Standardised indices of abundance were computed from the selected positive and occurrence models. For the positive model, 1000 draws were taken from a multivariate normal distribution as follows:

$X_{pos} \sim MVN([\beta_1, \beta_{2:N}], \Sigma)$,

with β_1 the model intercept (for the first year), $\beta_{2:N}$ the coefficients estimated for the remaining years in the model, N, the number of years in the index, and Σ, the positive model's variance-covariance matrix. The matrix for the positive index was then:

$POS[,1] = exp(X_{pos}[,1])$ for the first year, and

$POS[,2:N] = exp(X_{pos}[,1] + X_{pos}[,2:N])$ for all other years.

A similar approach was followed to create a binomial index matrix BIN from the binomial model, but β_1 is defined as the logit of the observed proportion of positive catch events in the first year.

To get the standardised binomial and lognormal indices, the geometric-mean was calculated for each draw (row) of the POS and BIN matrices, with the standardised index for each year, the mean of the geometric-mean-centred draws for each fishing year, and the 95% credible interval defined as the 2.5th and 97.5th quantiles of the geometric-mean-centred draws. The combined index was computed similarly, first calculating a combined matrix as the product of the binomial and positive index matrices, then geometric-mean-centring the combined draws across years and extracting the final combined index for each year as the mean of each column (year), with the 95% confidence interval defined as the 2.5th and 97.5th quantiles.

Table 2: Description of the covariates used as part of the model selection strategy for catch-per-unit-effort (CPUE) standardisation of school shark. When possible, the code matches the field name in the Electronic Data Warehouse. The assumed relationship is included for numerical variables under 'type'.

Name	Code	Description	Type
Fishing year	fyear	Fishing year when the fishing event or day occurred. For the trip resolution, the fishing year of the landing date was used.	Categorical
Month	month	Month of the fishing event, day, or landing date for trip-resolution indices.	Categorical
Vessel	vessel_key	Unique vessel identifier.	Categorical
Target species	target_species	Target species for the fishing event identified in effort return forms. Modal target species was used for daily- and trip-resolution indices.	Categorical
Statistical area	start_stat_area_code	Statistical area code for the fishing event identified in effort return forms. Modal statistical area code was used for daily- and trip-resolution indices.	Categorical
Effort number	effort_num	Number of fishing events recorded in the effort return form; summed for daily- and trip-resolution indices.	Linear
Fishing duration	fishing_duration	Fishing duration of fishing events recorded in the effort return form; summed for daily- and trip-resolution indices.	Natural cubic spline
Total net length	total_net_length	Total net length deployed in fishing events recorded in the effort return forms for set-net effort; summed for daily- and trip-resolution indices.	Natural cubic spline
Total hook number	total_hook_number	Total number of hooks used in fishing events recorded in the effort return forms for bottom-longline effort; summed for daily- and trip-resolution indices.	Natural cubic spline
Longitude	start_longitude	Longitude coordinate of fishing event; used in event-resolution indices only.	Natural cubic spline
Latitude	start_latitude	Latitude coordinate of fishing event; used in event-resolution indices only.	Natural cubic spline
Bottom depth	bottom_depth	Sea floor depth (in metres) at the location of the fishing event; used in bottom-longline and bottom trawl event-resolution indices only.	Natural cubic spline

Table 3: Model structure used as input to the backward model selection fitting procedure, by fishing method and effort resolution.

Daily effort stratum	
Set net	fishing year + month + vessel + target species + ns(log(total net length), 3) + statistical area
Bottom longline	fishing year + month + vessel + target species + ns(log(total hook number), 3) + poly(effort number, 1) + statistical area
Bottom trawl	fishing year + month + vessel + target species + ns(log(fishing duration), 3) + poly(effort number, 1) + statistical area
Event-based data	
Set net	fishing year + month + vessel + target species + ns(log(total net length), 3) + statistical area + month + ns(longitude, 3) + ns(latitude, 3)
Bottom longline	fishing year + month + vessel + target species + ns(log(total hook number), 3) + statistical area + month + ns(longitude, 3) + ns(latitude, 3) + ns(bottom depth, 3)
Bottom trawl	fishing year + month + vessel + target species + ns(log(fishing duration), 3) + statistical area + month + ns(longitude, 3) + ns(latitude, 3) + ns(bottom depth, 3)
Trip effort stratum	
Set net	fishing year + month + vessel + target species + ns(log(total net length), 3) + statistical area
Bottom longline	fishing year + month + vessel + target species + ns(log(total hook number), 3) + poly(effort number, 1) + statistical area
Bottom trawl	fishing year + month + vessel + target species + ns(log(fishing duration), 3) + poly(effort number, 1) + statistical area

Model diagnostics for key CPUE series considered by the INSWG are included in Appendix G, and all standardised CPUE series, compared across model resolution for each CPUE unit, are included in Appendix H. All selected indices were compared with the corresponding index, when available, from the previous CPUE standardisation for school shark spanning 1989–90 to 2015–16 (Dunn & Bian 2018). Please note that there was an error in the computation of the standardised combined indices published by Dunn & Bian (2018). Corrected indices are included in Appendix I and used in this report for all comparisons with updated indices.

Unless otherwise specified, descriptive statistics are at the daily resolution. Covariate "influence" is defined following Bentley et al. (2012) as a measure combining estimated model coefficients and variation in the distribution of the covariate through time. It quantifies whether the inclusion of the covariate has an effect on the standardised index. A positive influence means that the covariate inflates the nominal CPUE, so that the inclusion of the covariate in the standardisation model results in a lower value of the standardised index compared with the nominal. Conversely a negative influence means that the covariate reduces the nominal CPUE, and its inclusion in the standardisation model increases the standardised index.

Note that the results of the current analysis were also reported in the school shark chapter of the Fisheries New Zealand Plenary (Fisheries New Zealand 2021). Total catches by CPUE monitoring unit (used to compute the fishing intensity metric reported in the chapter) were scaled up based on landings from QMR/MHR reports, and also used an updated version of the statistical area code definition by CPUE monitoring unit. The procedure to generate total catches by CPUE monitoring unit is outlined in Appendix J.

3. RESULTS

3.1 Size composition and biomass indices

3.1.1 Inshore trawl surveys

Fisheries-independent trawl surveys have been conducted in key regions of New Zealand's Exclusive Economic Zone (EEZ) since the late 1980s or the early 1990s, depending on the area. Some regions were sampled every two years, whereas other regions were surveyed irregularly. Population-scaled length-frequency distributions of school shark based on the random-stratified design of these surveys document differences across years and regions (Figures 2 to 6; see Table A-1 for summary statistics).

For the North Island west coast, there were no apparent changes in size distribution over time, and most individuals caught were juveniles or pre-adults; some surveys caught no mature individuals (Figure 2). There was a considerable gap in the time series from 1999 to 2018.

Similarly, there were no mature school sharks caught in any of the 14 trawl surveys spanning Tasman and Golden bays from 1992 to 2019 (part of the west coast South Island survey; Figure 3). The central tendency of the size distribution appeared to be shifting towards larger individuals over time, from a median of around 55–60 cm in the early 1990s to a median of around 70 cm in more recent surveys (e.g., 2013, 2015, 2019).

The remainder of the areas covered by the South Island west coast survey (south of Tasman and Golden bays) sampled some mature school sharks every year over the 14-year survey period, but catches primarily consisted of juveniles and pre-adults (Figure 4). The size distribution of school shark sampled by this survey appeared to be getting smaller, with the median length for the early surveys around 80 cm (e.g., 1992, 1994, 1995), whereas the median lengths in the more recent surveys declined to around 50 cm to 60 cm (e.g., 2015, 2017, 2019).

The east coast South Island survey caught juveniles almost exclusively, with no trends in modal length through time (Figure 5). The mode was around 50 to 60 cm or 60 to 70 cm depending on the survey (note also that there is a gap in the time series between 1996 and 2007).

The Chatham Rise trawl surveys had the longest time series (25 years), but this survey sampled a considerably smaller number of school shark compared with the three inshore surveys (Figure 6). This trawl survey is a deepwater offshore survey which samples a core depth range between 200 and 800 m (e.g., Stevens et al. 2018), compared with depth ranges between 20 or 30 m to 400 m for the inshore surveys (e.g., MacGibbon 2019, MacGibbon et al. 2019). There were no clear temporal trends in the size distribution of school shark from this survey, although the small sample size precluded the identification of finer shifts in modal length. Individuals caught in Chatham Rise surveys tended to be mature, with median sizes between 130 and 145 cm, depending on the year.

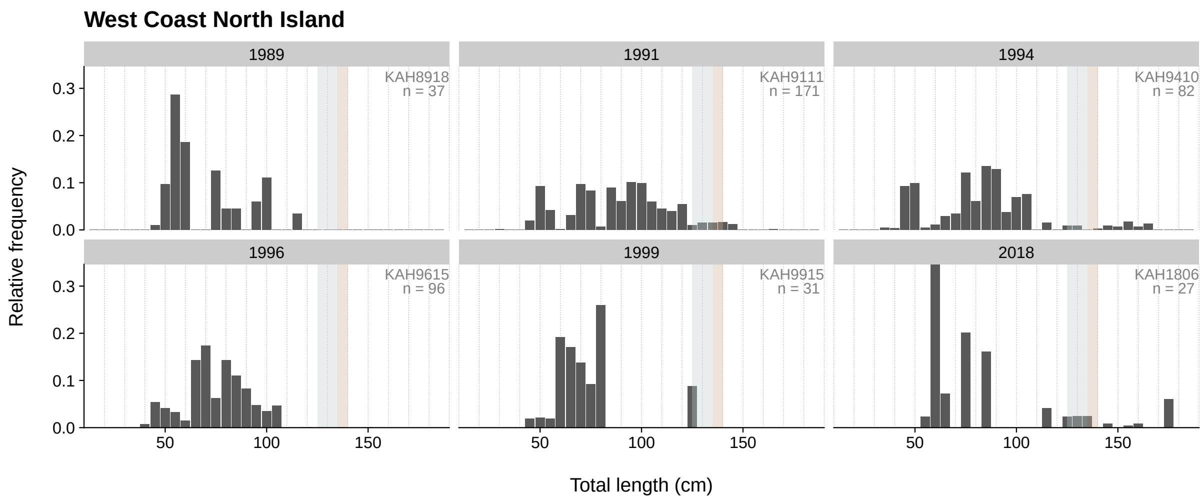

Figure 2: Relative scaled school shark size composition for inshore research trawl surveys off the North Island west coast between 1989 and 2019. Samples were aggregated into 5-cm size classes. Survey label and observed sample size by survey are shown in the top-right corner; vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively). See Table A-1 for survey data.

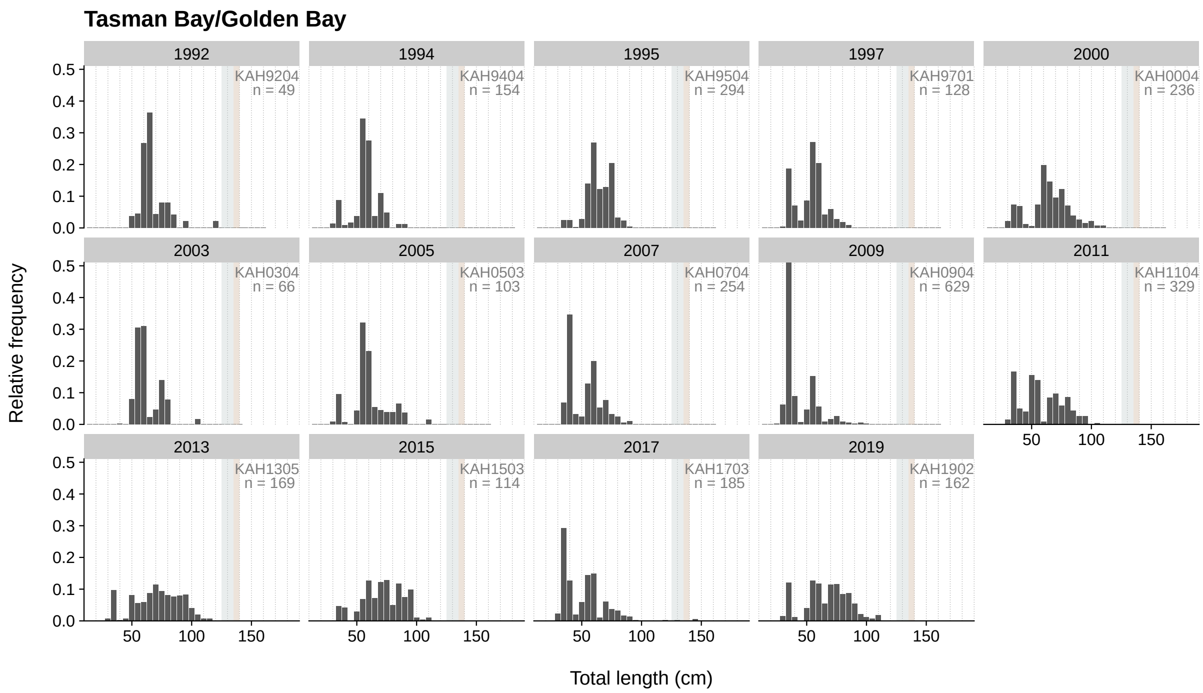

Figure 3: Relative scaled school shark size composition for inshore research trawl surveys in Tasman and Golden bays between 1992 and 2019. Samples were aggregated into 5-cm size classes. Survey label and observed sample size by survey are shown in the top-right corner; vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively). See Table A-1 for survey data.

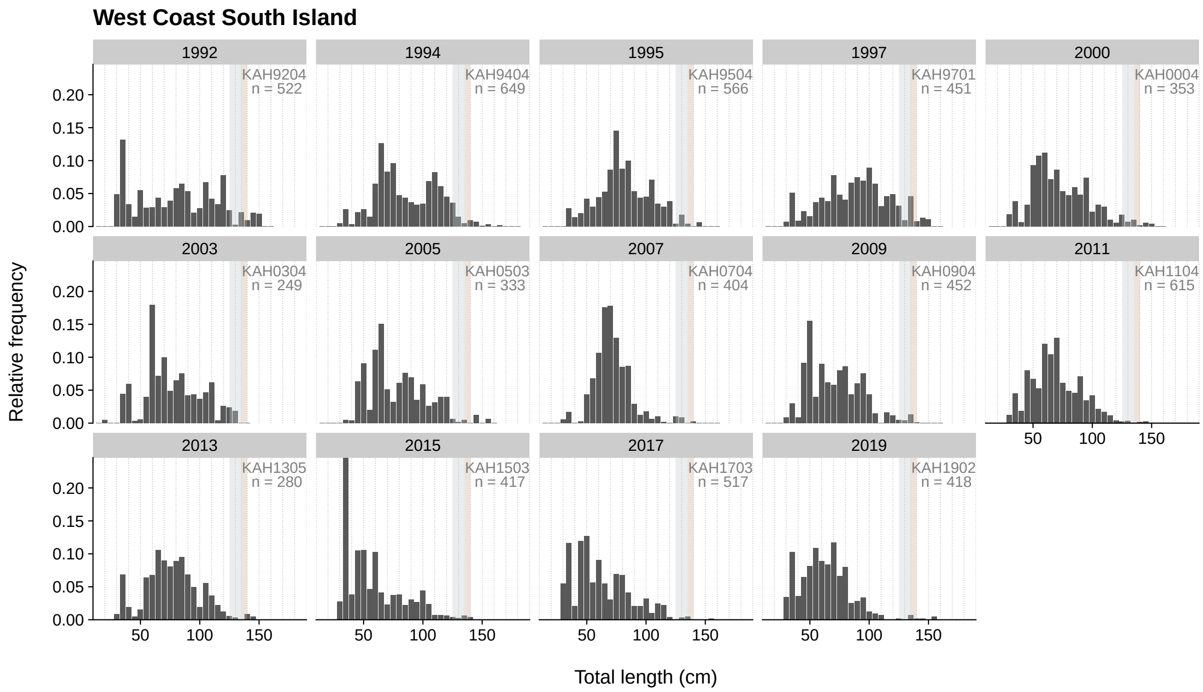

Figure 4: Relative scaled school shark size composition for inshore research trawl surveys off the South Island west coast between 1992 and 2019. Samples were aggregated into 5-cm size classes. Survey label and observed sample size by survey are shown in the top-right corner; vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively). See Table A-1 for survey data.

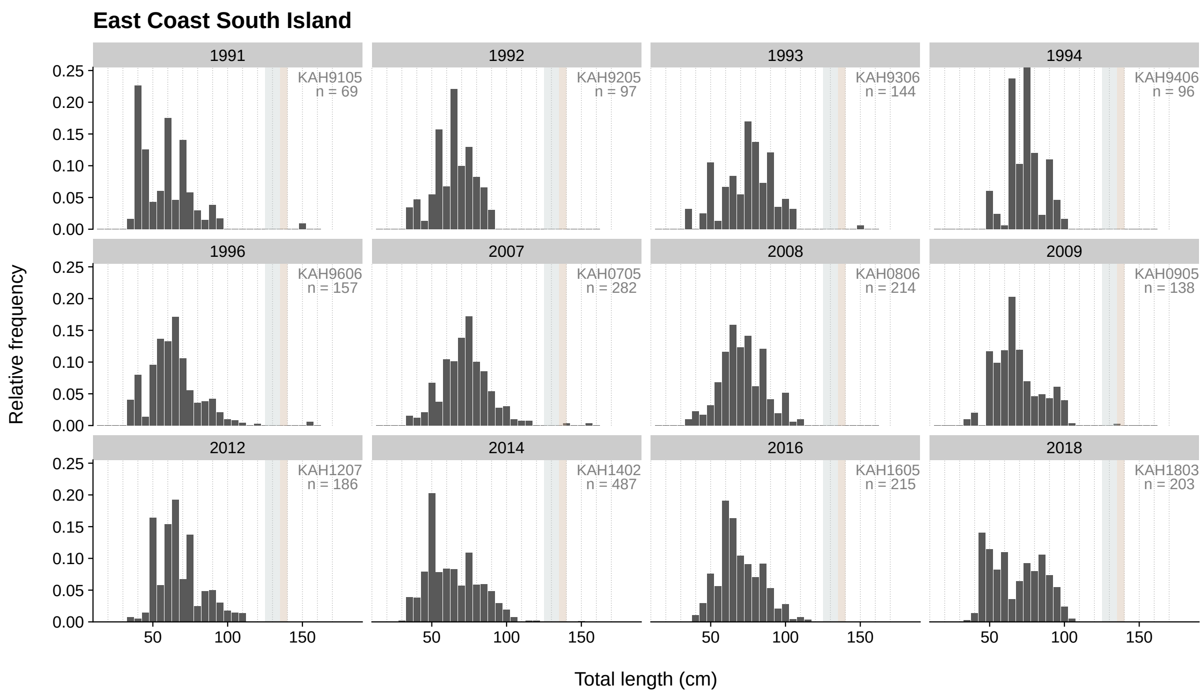

Figure 5: Relative scaled school shark size composition for inshore research trawl surveys off the South Island east coast between 1991 and 2018. Samples were aggregated into 5-cm size classes. Survey label and observed sample size by survey are shown in the top-right corner; vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively). See Table A-1 for survey data.

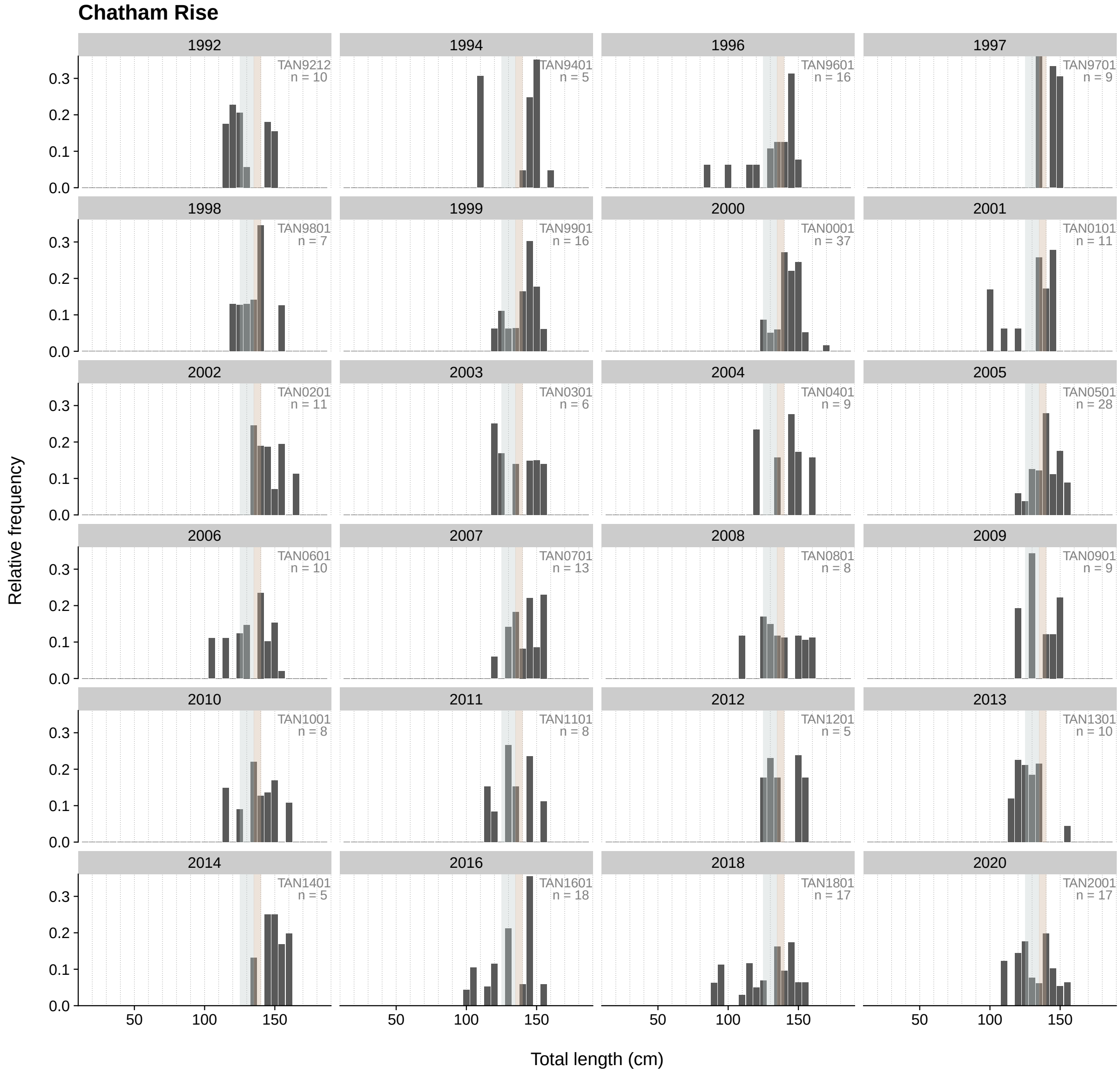

Figure 6: Relative scaled school shark size composition for deepwater research trawl surveys from core strata on Chatham Rise between 1992 and 2020. Samples were aggregated into 5-cm size classes. Survey label and observed sample size by survey are shown in the top-right corner; vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively). Only years when at least five individuals were sampled were included. See Table A-1 for survey data.

3.1.2 Fisheries New Zealand scientific observer programme

Size-composition data for school shark are also available from the scientific observer programme managed by Fisheries New Zealand. Samples are available for set net, bottom longline, and bottom trawl, depending on the area. The relative distribution of school shark sizes varied across gear, year, and CPUE region (Figures 7 to 11; see Table A-2 for summary statistics).

For Far North & SCH 1E, there was no clear temporal trend in the size distribution over time, with both bottom longline and bottom trawl catching juveniles, pre-adult, and mature individuals (Figure 7). There were no set-net samples available for this region. The median size for both bottom longline and bottom trawl was between 110 and 145 cm depending on the year, except for a few years with low sample size when mostly juveniles were caught (e.g., 2013–14 for bottom longline).

Individuals tended to be smaller for SCH 2 & top of SCH 3, but the time series of size composition data was sparse (Figure 8). Bottom-trawl samples were only available for a limited number of years, and the observed years often had low sample sizes (less than 20 individuals); there was only a single year of samples for set net, but with a high sample size, and three years for bottom longline (with low sample sizes). The median size for the single year of set net was 110 cm, and the distribution included observations with length exceeding the length-at-maturity for school shark. Catch size composition shifted for bottom trawl from earlier years with low sample sizes that included a high proportion of mature individuals (median length between 100 and 140 cm), to more recent years that mostly sampled juveniles (median length between 75 and 85 cm). For bottom longline, most observed captures were mature individuals, but the sample size was small (median size of 135 to 140 cm based on 10 to 22 annual observations).

By comparison, school shark caught in observed bottom-longline sets and bottom-trawl hauls on Chatham Rise (SCH 4) were larger in size, with a high proportion of mature individuals (Figure 9). Median sizes tended to be 135 cm or larger, with the exception of two years of bottom-trawl samples, when the distributions were dominated by juveniles between 50 and 105 cm length. For most years, there was no clear difference in the size distributions of individuals observed on bottom longlines compared with bottom trawls.

In Lower SCH 3 & SCH 5, school shark individuals were sampled by observers on set-net, bottom-longline, and bottom-trawl vessels (Figure 10). There was considerable variability in distributions between years, especially for bottom trawl. Set-net observations had the highest sample sizes overall, with over 1000 individuals sampled in a number of years (compared with less than 100 individuals per year for bottom trawl and bottom longline). Mature individuals were observed in most years for all gears, but were more prevalent in bottom trawl and set net. There was no clear temporal trend in size distributions, except for a recent decrease in median size from 130 to 105 cm for set-net observations (from 2014–15 to 2017–18); however, some years had few or no samples, and 2018–19 was not included because the sample size was small.

School shark observer samples for SCH 7, SCH 8 & lower SCH 1W were available for set net, bottom longline, and bottom trawl (Figure 11). Both bottom-trawl and set-net samples included mature individuals in most years, with some variability for bottom trawl because of the small sample sizes. The median size for set net was around 105 cm in most years. The median size in the bottom-trawl fishery declined over time from 120 cm in 2001–02 to 80 cm in 2014–15; however, samples sizes were small (between 30 and 50 individuals). Almost all individuals observed on bottom-longline sets were juveniles and pre-adults, with a median size of 85 cm for the single year of data available for this gear.

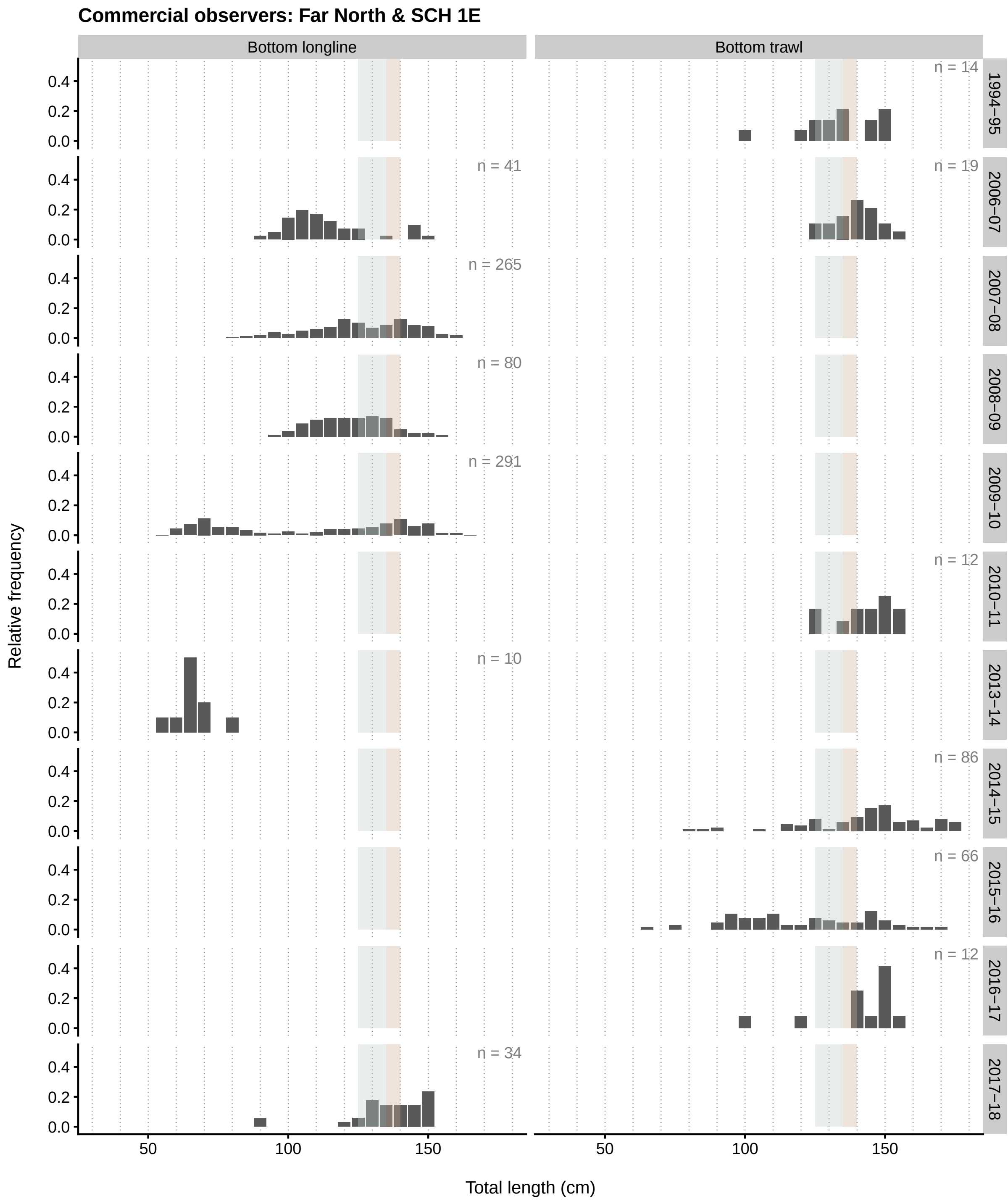

Figure 7: Relative size composition of school shark sampled by observers by gear (in columns) and fishing year (in rows) for Far North & SCH 1E. Samples were aggregated into 5-cm size classes. Observed sample size by year included in the top-right corner. Only years with at least 10 individuals sampled were included. Vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively).

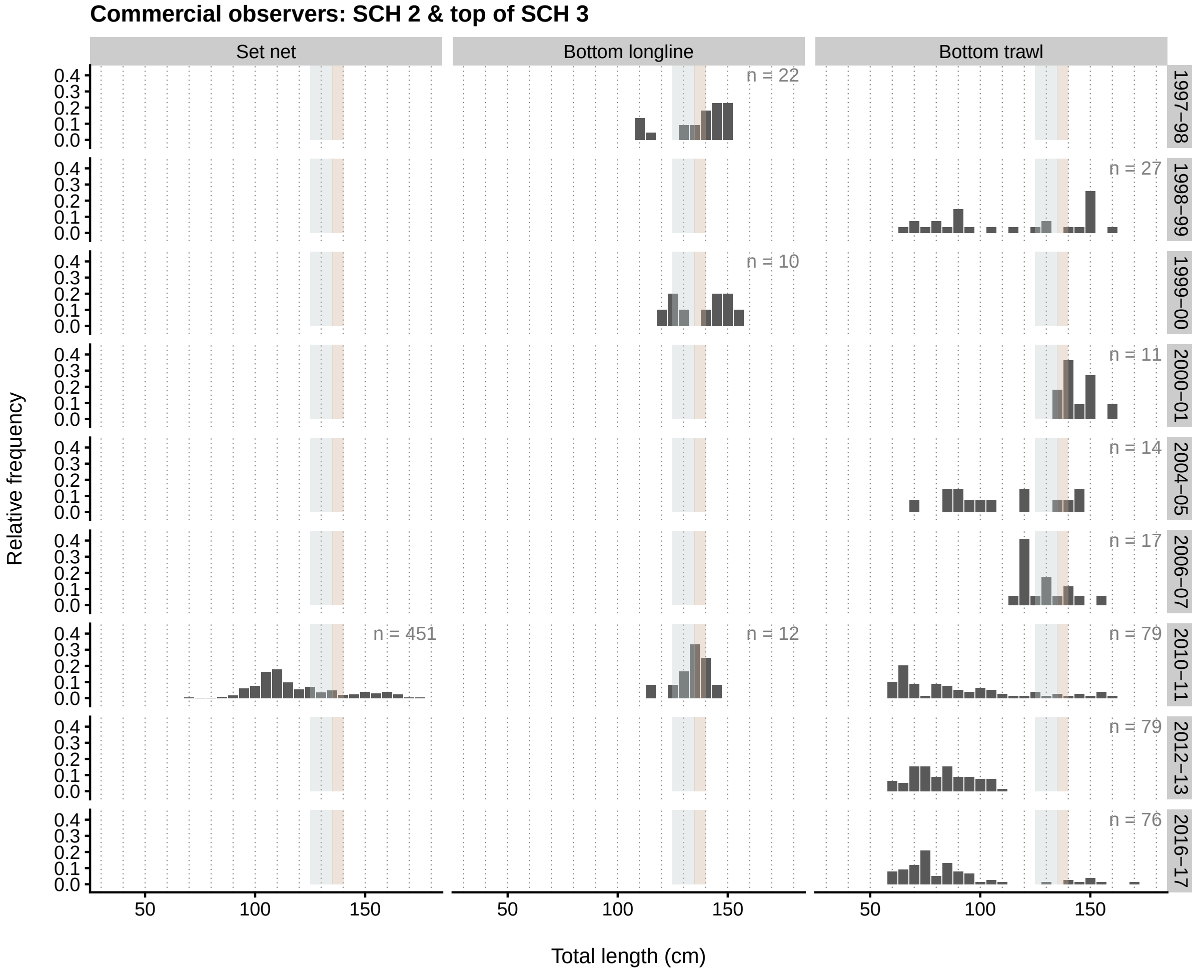

Figure 8: Relative size composition of school shark sampled by observers by gear (in columns) and fishing year (in rows) for SCH 2 & top of SCH 3. Samples were aggregated into 5-cm size classes. Observed sample size by year included in the top-right corner. Only years with at least 10 individuals sampled were included. Vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively).

Figure 9: Relative size composition of school shark sampled by observers by gear (in columns) and fishing year (in rows) for Chatham Rise (SCH 4). Samples were aggregated into 5-cm size classes. Observed sample size by year included in the top-right corner. Only years with at least 10 individuals sampled were included. Vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively).

Commercial observers: Lower SCH 3 & SCH 5

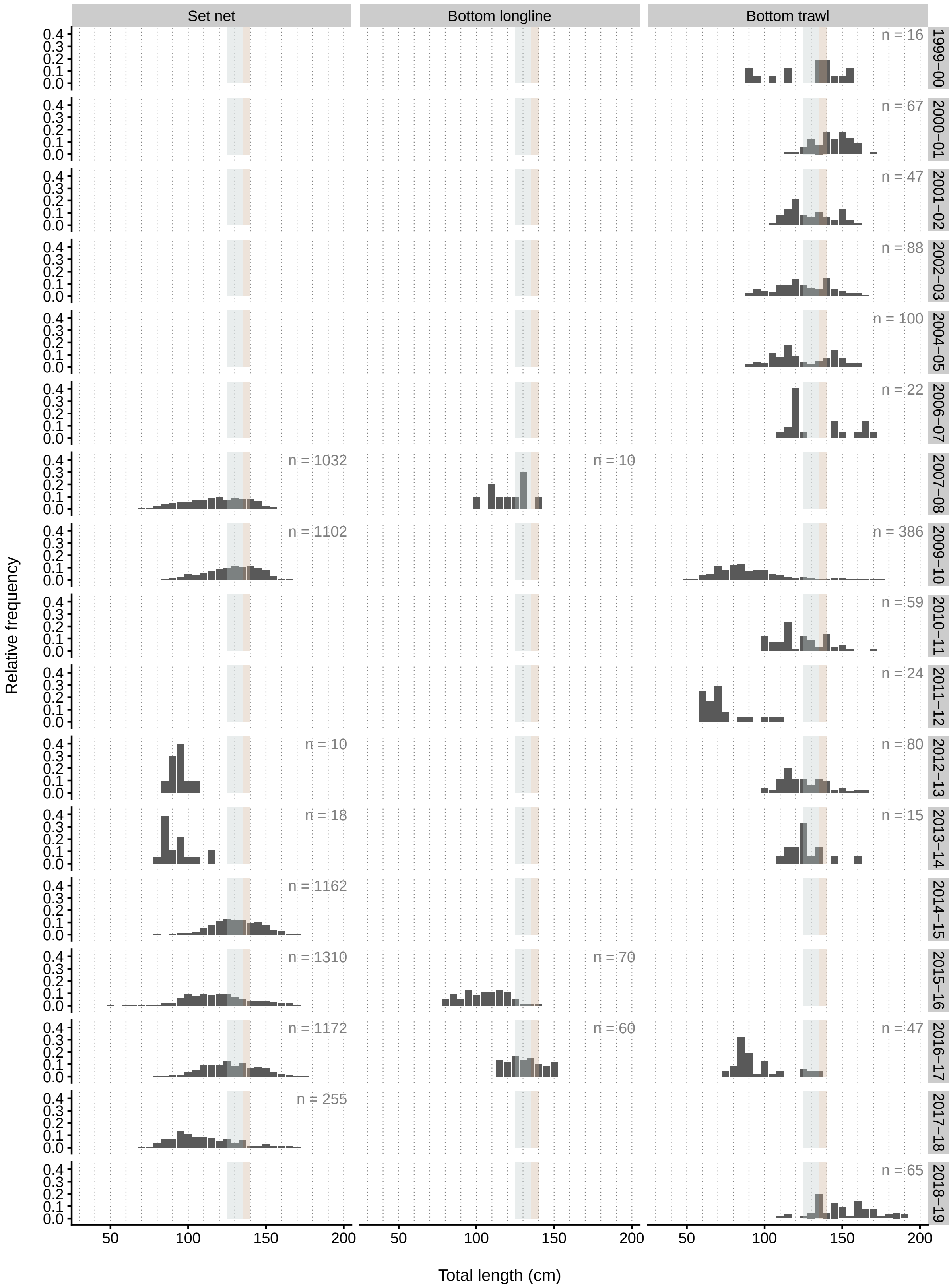

Figure 10: Relative size composition of school shark sampled by observers by gear (in columns) and fishing year (in rows) for Lower SCH 3 & SCH 5. Samples were aggregated into 5-cm size classes. Observed sample size by year included in the top-right corner. Only years with at least 10 individuals sampled were included. Vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively).

Figure 11: Relative size composition of school shark sampled by observers by gear (in columns) and fishing year (in rows) for SCH 7, SCH 8 & lower SCH 1W. Samples were aggregated into 5-cm size classes. Observed sample size by year included in the top-right corner. Only years with at least 10 individuals sampled were included. Vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively).

Observer records included geographical coordinates, allowing the mapping of the mean length of observer samples across New Zealand's EEZ (Figures 12 to 14). For both set net and bottom trawl, individuals caught in Southland were larger compared with individuals in other observed areas for most fishing years (Figures 12 and 14). There were few bottom-longline samples in Southland, but observed individuals were on average of pre-adult length (Figure 13).

For set net, the mean length of observed individuals tended to be smaller off the east coast of South Island (especially around Canterbury Bight). In comparison, there was more variability in mean length from North Island waters, although juveniles or pre-adults were prevalent in most locations (Figure 12). Mean length in Southland waters appeared to be smaller in 2017–18 than in other years, with observer records in 2017–18 also having a lower sample size compared with other years.

There was high variability in the spatial distribution of mean length for observed bottom-longline sets given the small sample size (Figure 13). There were two years with greater sample sizes (more than 300 individuals), showing contrasting spatial trends: in 2007–08, almost all observations in Northland (east side) were on average of mature size, whereas in 2009–10, there appeared to be a spatial gradient in mean size: locations close to the coast had a higher proportion of juveniles, and mean length increased with distance from the coast.

Similarly, there was variability in the spatial distribution of samples for bottom trawl, with southern locations (Southland and offshore Southland) consistently having large mature individuals, often with mean lengths exceeding 150 cm (Figure 14). Mature individuals also occurred at other locations throughout New Zealand's EEZ, including offshore areas of the west coast of South Island in some years, in Bay of Plenty, and off the east coast of Northland. Samples from around Canterbury Bight had smaller mean lengths corresponding with juvenile size for the three fishing years when samples were available. There was a single year of sampling for multiple locations off Hawke's Bay, and samples tended to consist of juveniles.

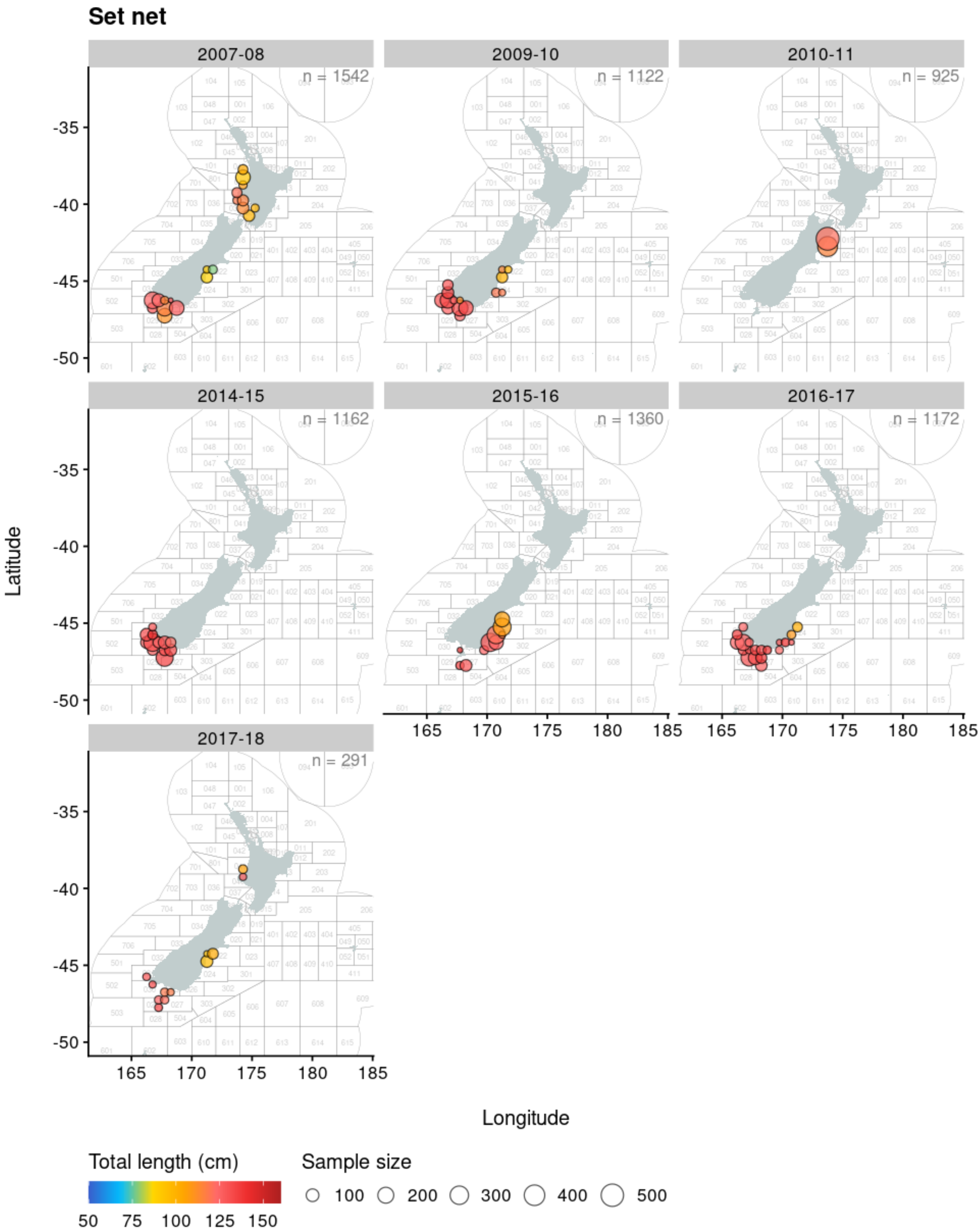

Figure 12: Mean length (in cm) of school shark individuals sampled by observers on set-net vessels, by fishing year. Only years with at least 50 observations were included. Circles are coloured by mean length from blue (small) to red (large), and the size of the circle scales with the observed sample size in each 0.5-degree cell.

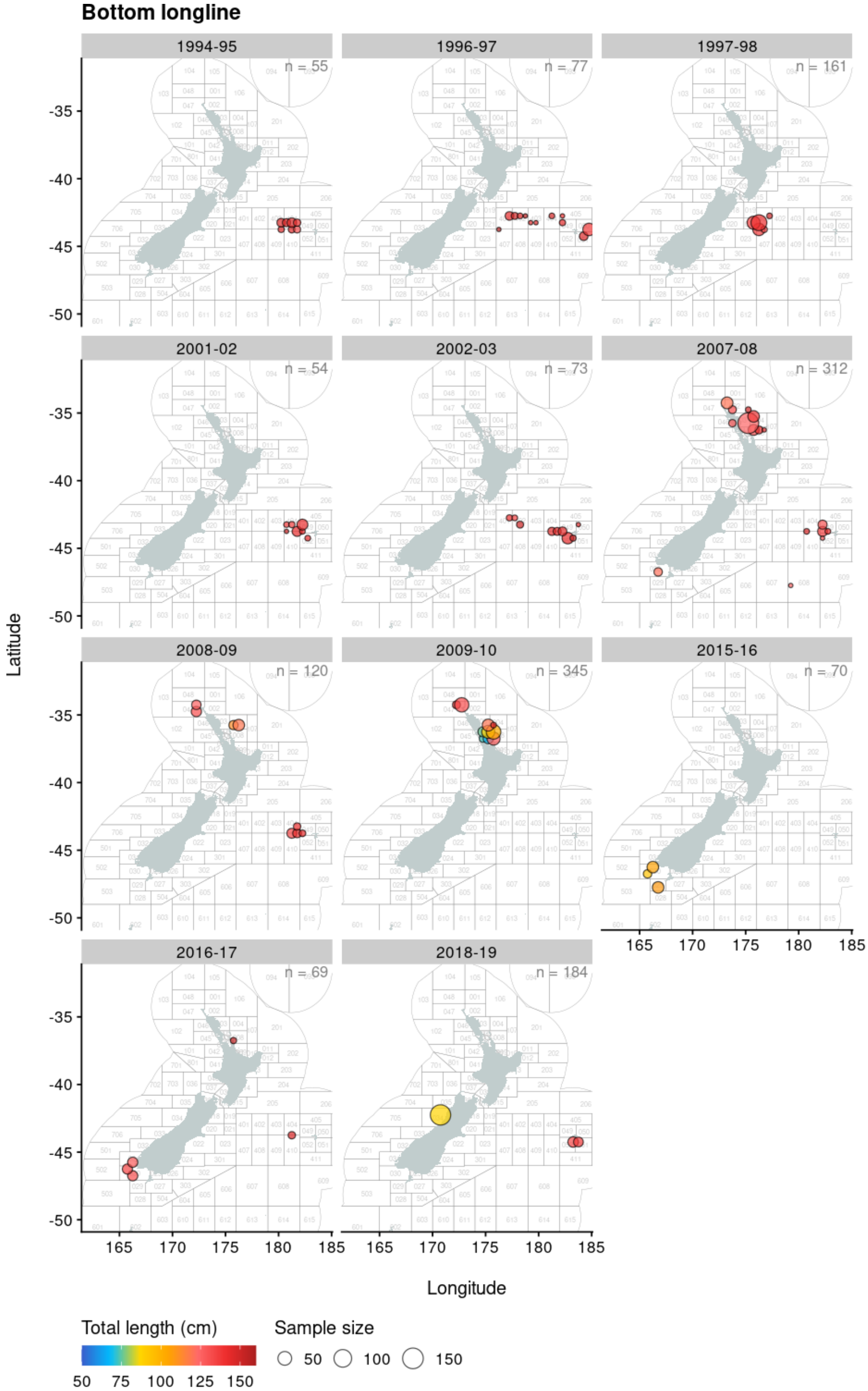

Figure 13: Mean length (in cm) of school shark individuals sampled by observers on bottom-longline vessels, by fishing year. Only years with at least 50 observations were included. Circles are coloured by mean length from blue (small) to red (large), and the size of the circle scales with the observed sample size in each 0.5-degree cell.

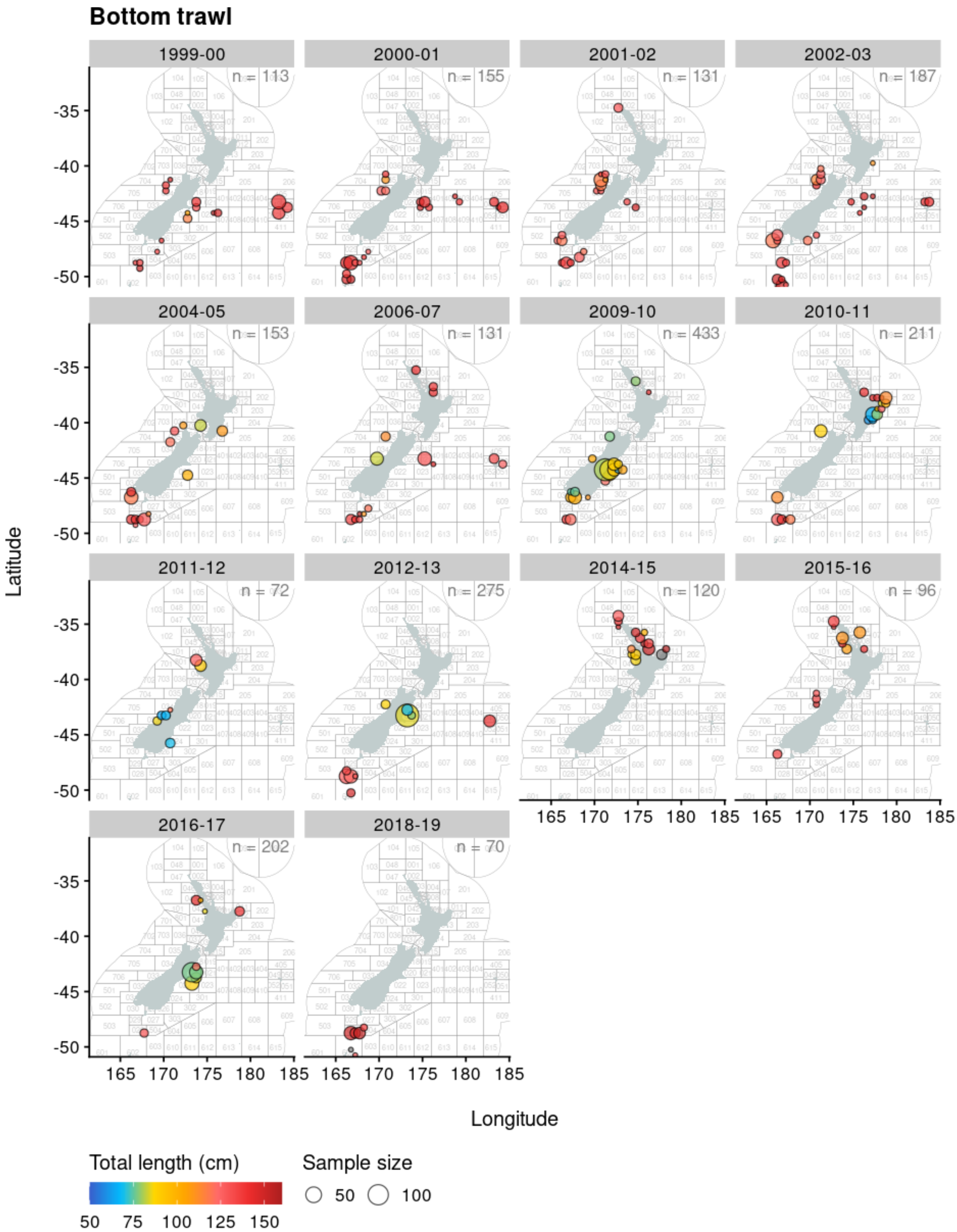

Figure 14: Mean length (in cm) of school shark individuals sampled by observers on bottom-trawl vessels, by fishing year. Only years with at least 50 observations were included. Circles are coloured by mean length from blue (small) to red (large), and the size of the circle scales with the observed sample size in each 0.5-degree cell.

3.1.3 Adaptive Management Programme

Length measurements of school shark were taken as part of the AMP from 1994–95 to 2009–2010. Most of the length records were for set net in SCH 2 & top of SCH 3, Lower SCH 3 & SCH 5, and SCH 7, SCH 8 & lower SCH 1W (Figures 15 to 17; see Table A-3 for summary statistics). Most of the individuals measured in SCH 2 & top of SCH 3 were juveniles or pre-adults, with no clear temporal trends in the size distribution across years (Figure 15). Mature individuals were observed in most years and formed a significant part of the distribution particularly in 1996–97 and 1999–2000, with median lengths of 130 cm for these two years, compared with 80 to 105 cm for other years.

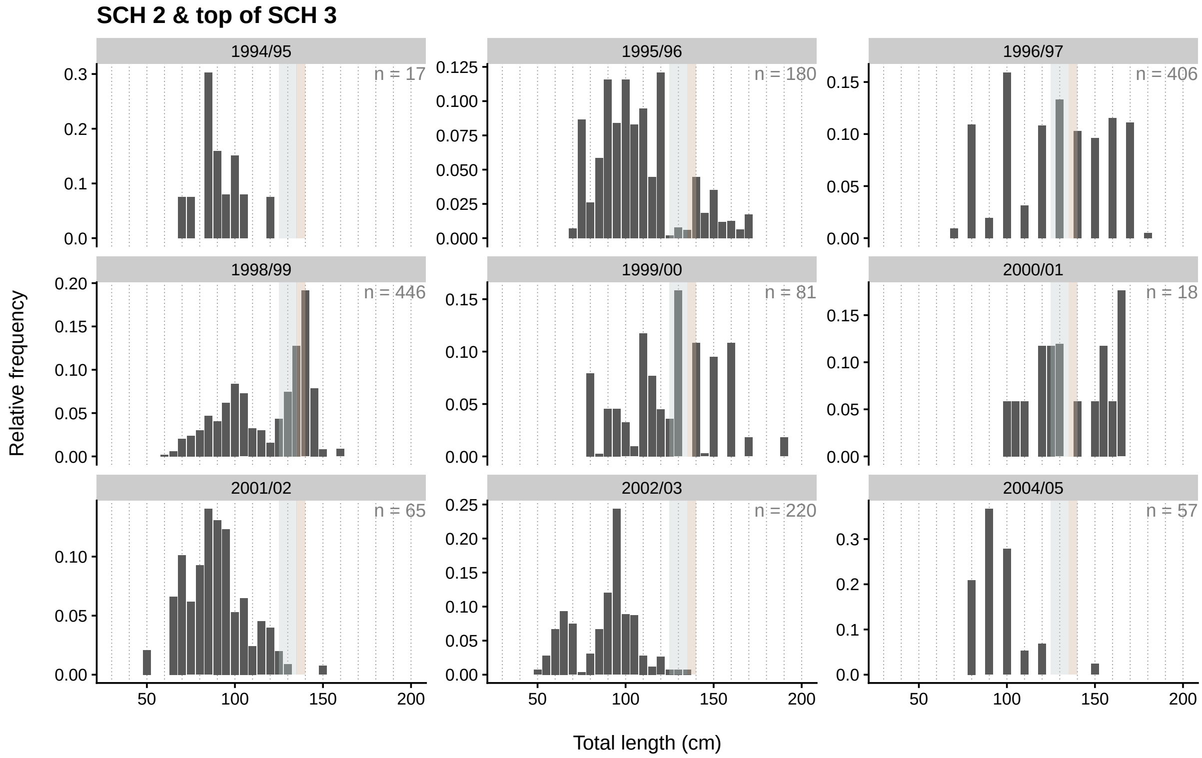

Figure 15: Relative size composition by fishing year (in panel) from school shark length measurements collected as part of the Adaptive Management Programme for set net in SCH 2 & top of SCH 3. Samples were aggregated into 5-cm size classes. Only years with at least 5 individuals sampled were included. Vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively).

The AMP sample sizes were greater for Lower SCH 3 & SCH 5, with most years having 500 or more school shark measurements (Figure 16). Size distributions included a high proportion of mature individuals, with median size frequently at 110 cm or bigger. There was no clear temporal trend in size distribution over time for this area.

There were fewer set-net length measurements collected by the AMP in SCH 7, SCH 8 & lower SCH 1W (Figure 17). The size distributions for the two available fishing years were bimodal with a first mode at the juvenile or pre-adult stage between 90 and 100 cm length, and a second mode for mature individuals around 135 cm length.

Length measurements taken through the AMP programme were geolocated and can be visualised in space (Figure 18). There was a clear spatial gradient in mean size by 0.5-degree cell across all years, whereby large, mature individuals were more frequent in sets occurring in Southland. Individuals measured from the east coast of South Island tended to be on average of juvenile length, especially around Canterbury Bight.

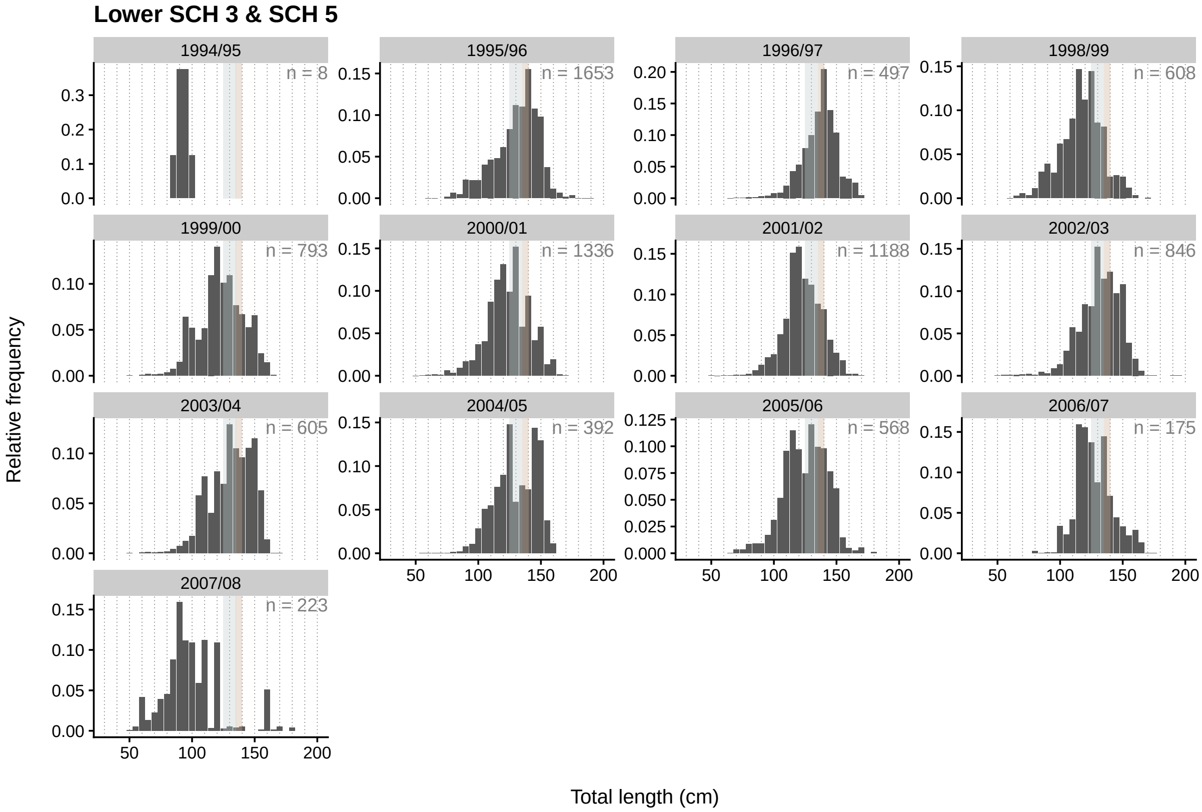

Figure 16: Relative size composition by fishing year (in panel) from school shark from length measurements collected as part of the Adaptive Management Programme for set net in Lower SCH 3 & SCH 5. Samples were aggregated into 5-cm size classes. Only years with at least 5 individuals sampled were included. Vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively).

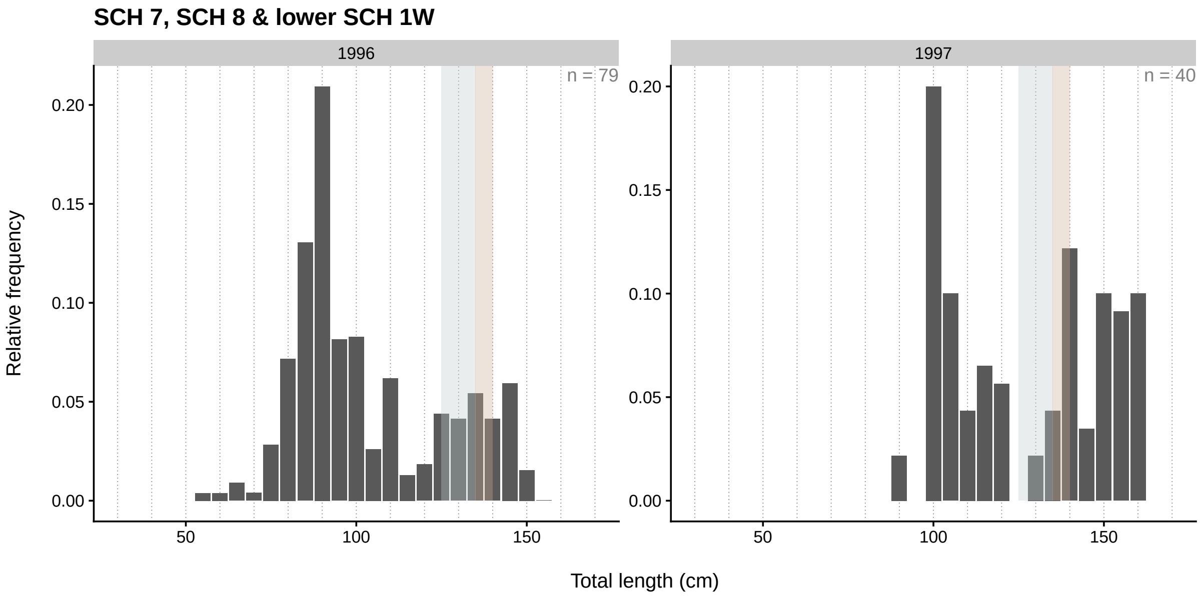

Figure 17: Relative size composition by fishing year (in panel) from school shark length measurements collected as part of the Adaptive Management Programme for set net in SCH 7, SCH 8 & lower SCH 1W. Samples were aggregated into 5-cm size classes. Only years with at least 5 individuals sampled were included. Vertical band indicates the range for size-at-maturity for males and females (grey and beige, respectively).

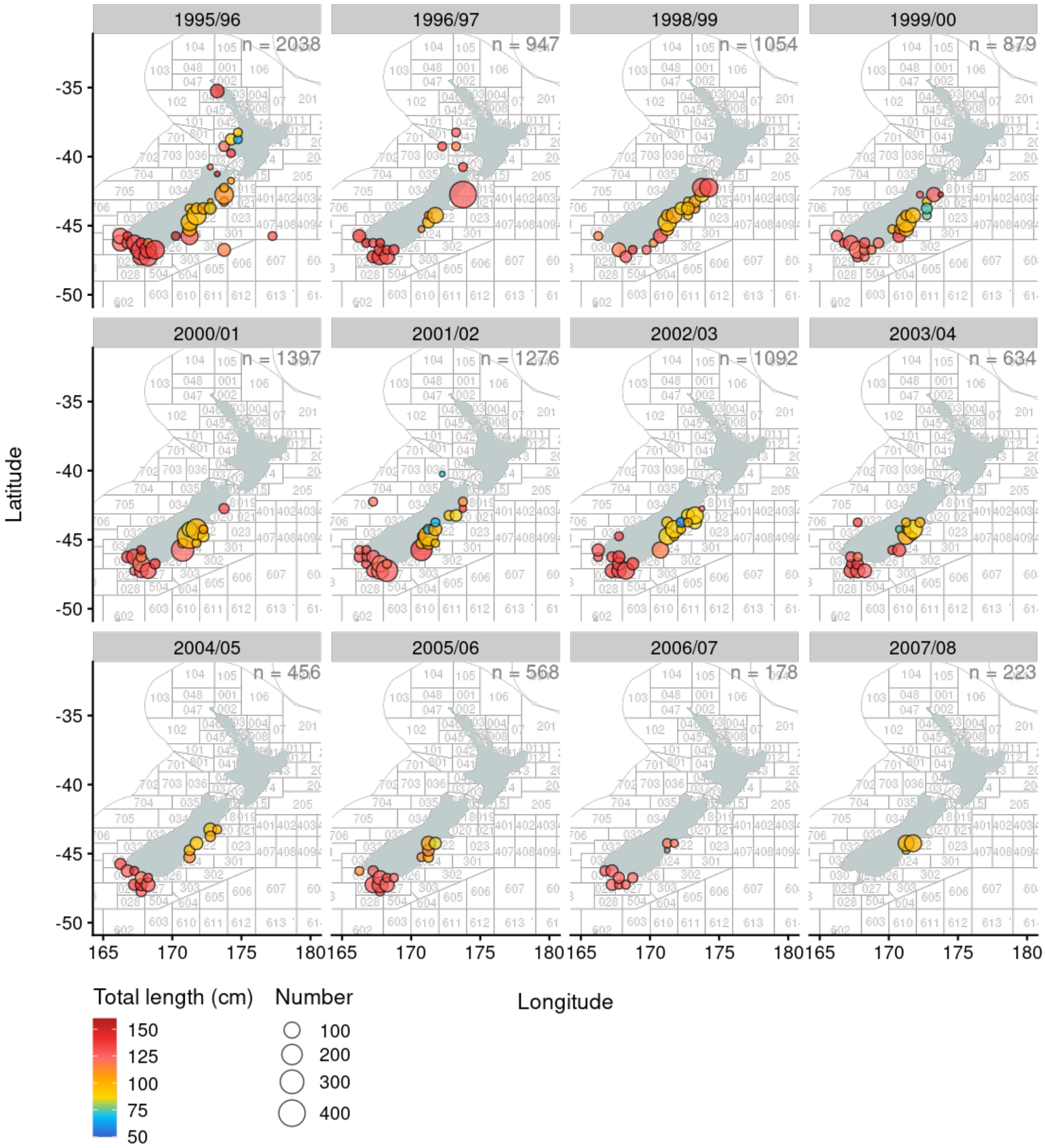

Figure 18: Mean length (in cm) of school shark individuals sampled as part of the Adaptive Management Programme in set-net fisheries, by fishing year. Samples were aggregated into 5-cm size classes. Only years with at least 50 observations were included. Circles are coloured by mean length from blue (small) to red (large), and the size of the circle scales with the observed sample size in each 0.5-degree cell

3.1.4 Scaled biomass estimates

Time series of biomass estimates based on the stratified research trawl surveys are included for school shark for the west coast of North Island, Tasman and Golden bays, the east and west coasts of South Island, and Chatham Rise (Figure 19 and Table B-1). These regions showed different temporal trends in estimated biomass: it was stable in Tasman and Golden bays, decreasing slightly in the west coast South Island from an initial high estimate in the 1990s, and increasing in the Chatham Rise region. The lack of a continuous time series for the west coast North Island and east coast South Island surveys hampered the detection of long-term trends. For the west coast North Island survey, recent biomass estimates were lower than earlier estimates. In contrast, for the east coast South Island survey, recent biomass estimates were higher than previous estimates.

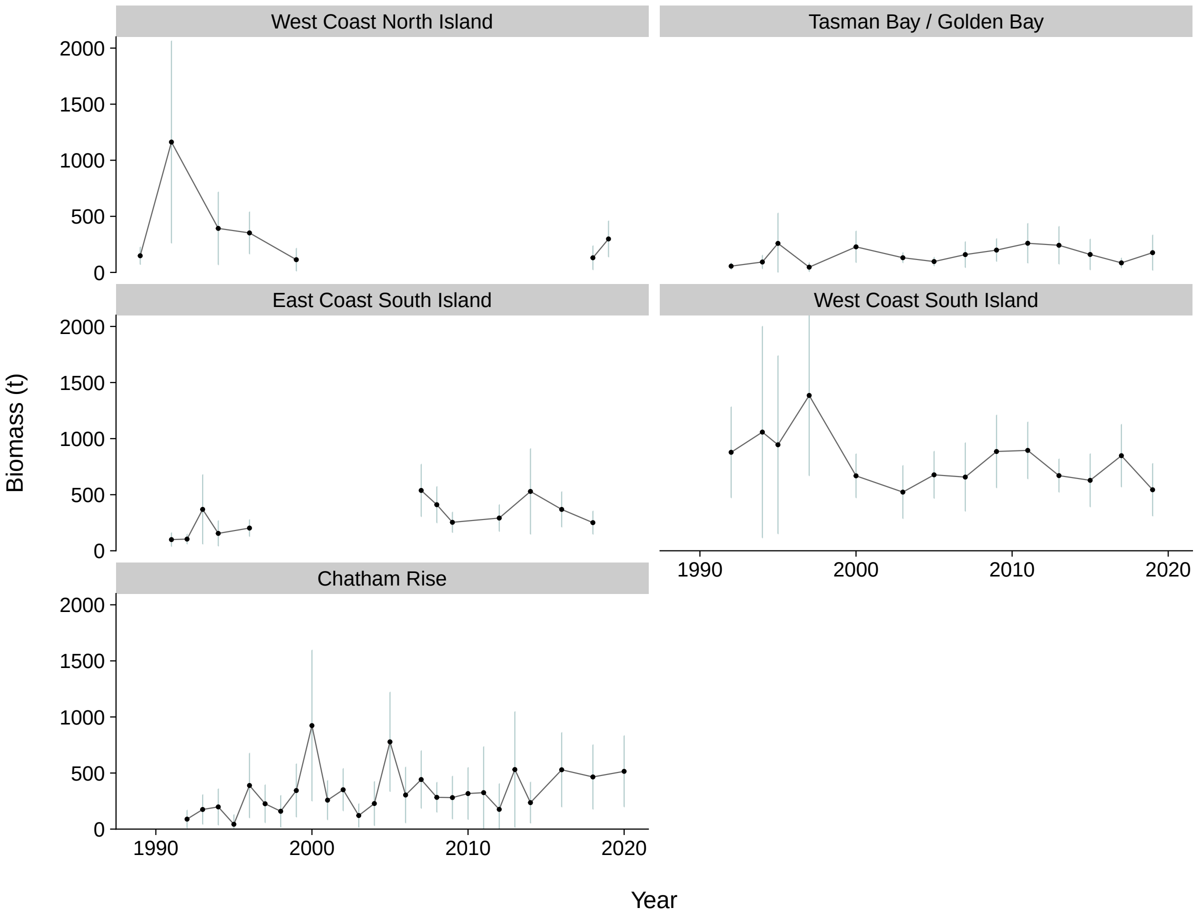

Figure 19: Time series of biomass estimates (in t) of school shark for key research trawl surveys. Estimates are for core survey strata only. Grey lines show the 95% confidence interval for each annual estimate. Surveys are connected by a solid line if they are separated by three years or less.

3.2 Fishery characterisation

3.2.1 Reporting of landings and effort

School shark landings were primarily recorded using the CELR form up to 2006–07, before use of the Catch Landing Return form (CLR) became more prevalent (Figure 20). The CELR form continued to be used for a small proportion of landings (between 10 and 15% in the last 12 years) in some QMAs (see SCH 2, SCH 3, SCH 7, and SCH 8), mostly due to vessels using drop line or Danish seine as fishing method; these fishing methods could only be reported on the CELR form before the introduction of electronic reporting. The NCELR form accounted for a high proportion of landings in QMAs that mostly caught school shark by set net, particularly SCH 3, SCH 5, and SCH 8, because this form was required by law for all vessels larger than 6 m in total length. Electronic forms started being used in 2017–18 and accounted for 17% to 36% of landings (in tonnes) in 2018–19 across all fisheries, depending on the QMA.

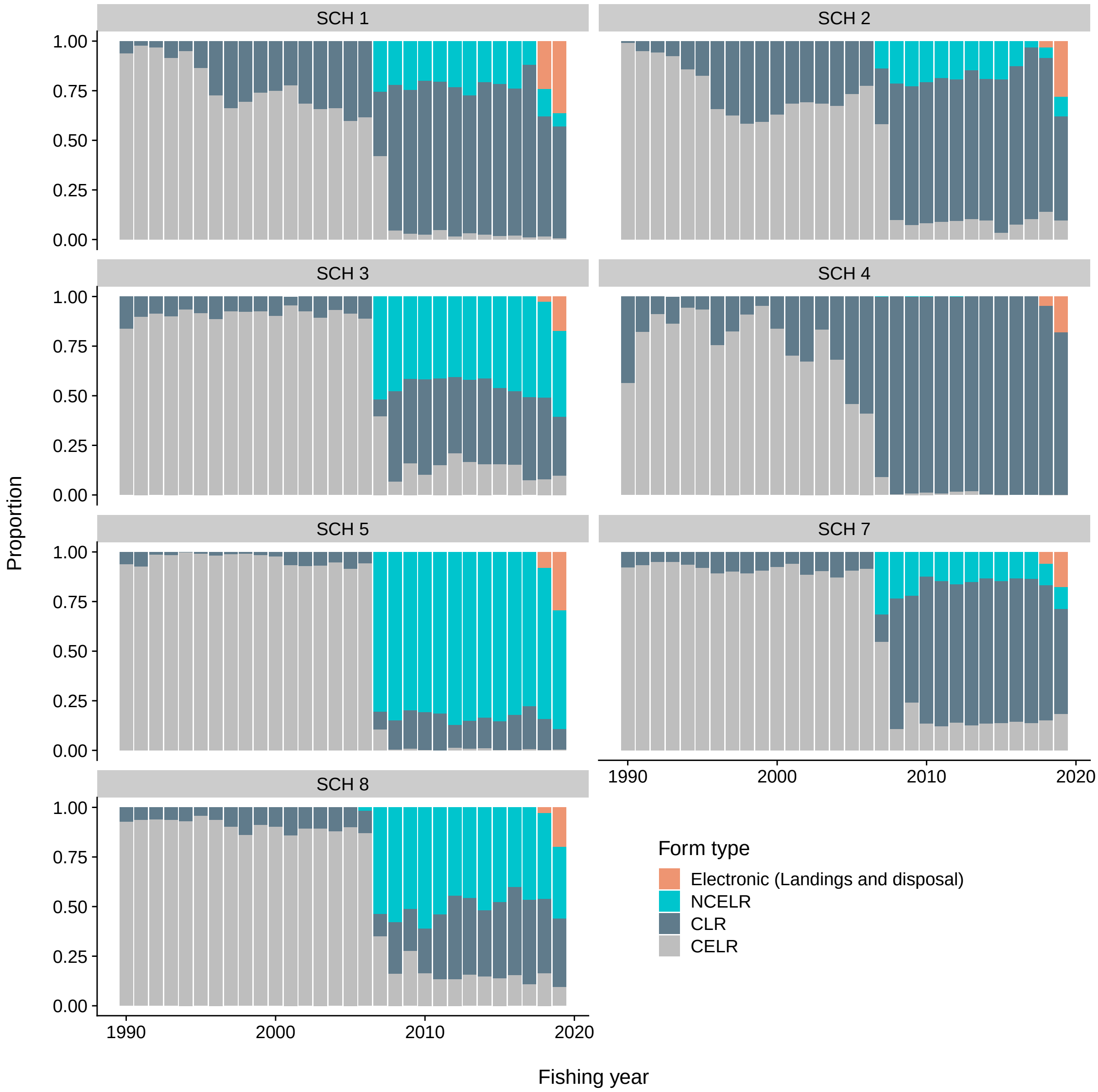

Figure 20: Proportion of school shark landings (green weight in t) reported on form type Catch, Effort and Landing Return (CELR), Catch Landing Return (CLR), Netting Catch, Effort and Landing Return (NCELR) or Electronic Landings and Disposal, by quota management area.

Similarly, fishing events (effort) were mostly recorded using the CELR form (all gears) and the TCEPR form (deepwater vessels) up to the mid-2000s (Figure 21). There was a transition in form usage from daily resolution CELR forms towards high-resolution forms in all QMAs, with specific trends regarding the usage of forms in each QMA corresponding to the primary fishing methods most commonly used. For set net, the CELR form was replaced by the NCELR form in 2006–07 (mandatory for vessels over 6 m length); for bottom longline, the CELR form was replaced by the LCER form (mandatory for vessels over 28 m length), starting in 2003–04, and the LTCER form, starting in 2007–08 (for vessels between 6 and 28 m length); for trawl, the CELR form was replaced by the TCER form, starting in 2007–08 (for vessels between 6 and 28 m length).

Usage of the CELR form has remained minimal in the 12 most recent years of the current study (2007–08 to 2018–19), because it is only used by small vessels less than 6 m in total length. As a result of the transition from the daily CELR form, the number of effort records has increased for all gear types, with fishing events being recorded individually and not aggregated at a daily scale. Electronic reporting using gear-specific Electronic Reporting System data entry platforms (ERS) began near the end of 2017–18, and increased in usage in 2018–19. Nevertheless, there was still substantial effort reported on paper forms in the final year of this study (2018–19). The TCEPR form was used throughout the study period by deepwater trawlers greater than 28 m in length, and also by some inshore trawlers. The larger vessels (over 28 m length) were the first fleet to implement electronic reporting, beginning in 2017–18.

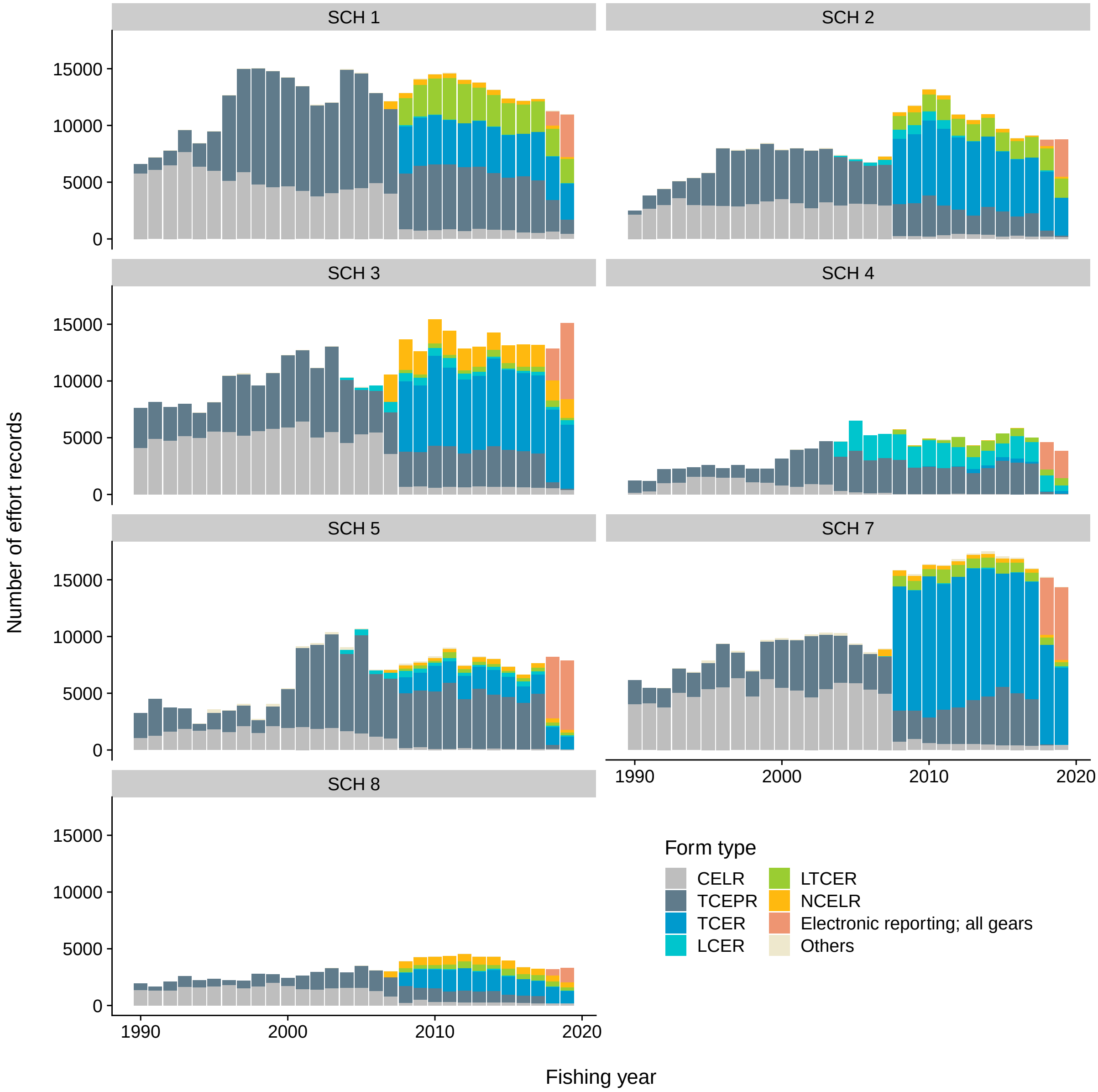

Figure 21: Number of fishing event records (ungroomed) by form type and quota management area. The main form types are Catch Effort Landing Return (CELR), Trawl Catch Effort Processing Return (TCEPR/TCP), Trawl Catch Effort Return (TCER), Lining Catch, Effort Return (LCER), Lining Trip Catch, Effort Return (LTC), Netting Catch, Effort and Landing Return (NCELR) and Electronic Reporting System (ERS) (category collated across fishing methods).

3.2.2 Catch characterisation

Commercial landings for school shark, based on the QMRs to 2000–01 and subsequently on MHRs, showed increased landings from the early 1990s onwards, from around 2500 t per year to around 3500 t in 2009 and 2011 (Figure 22). School shark landings peaked when most QMAs (except SCH 4) reached or slightly exceeded their respective TACC. Since then, landings have declined in almost every QMA, averaging 2866 t in the three most recent years of this study (2016–17 to 2018–19). Only SCH 2 and SCH 3 did not decline in these three years. In the eight years from 2012–13 to 2018–19, landings have been below the combined TACC of 3416 t (Figure 22).

Early and recreational catches for school shark are described by Fisheries New Zealand (2021).

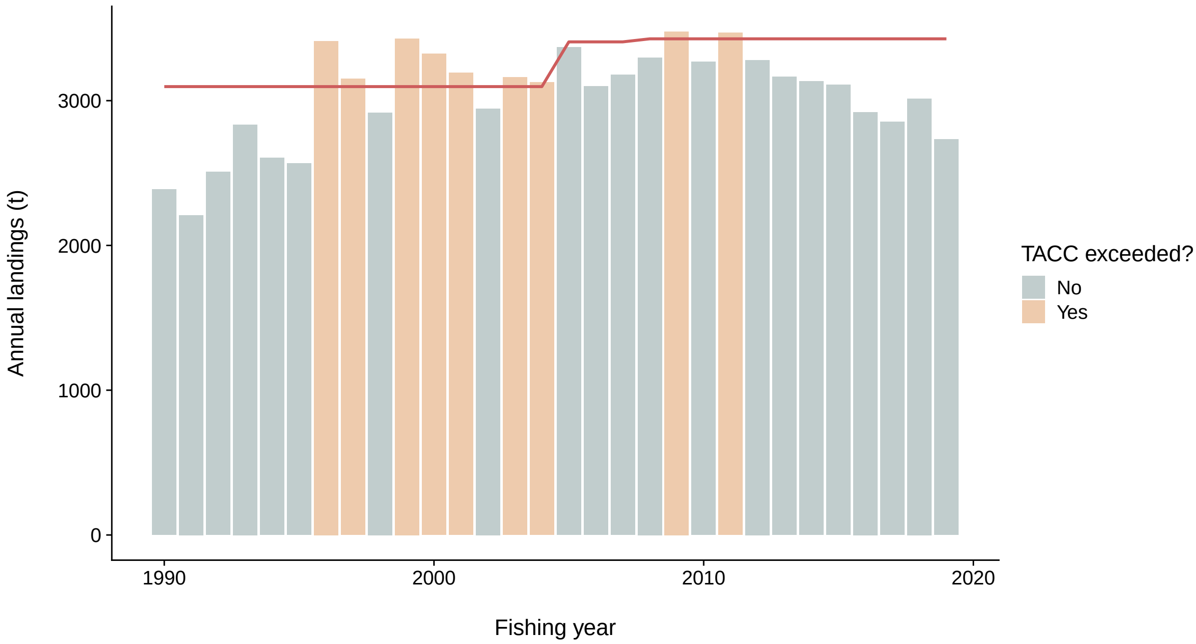

Figure 22: Annual school shark landings (t) from Quota Management Report (QMR) and Monthly Harvest Return (MHR) records for Quota Management Areas SCH 1, SCH 2, SCH 3, SCH 4, SCH 5, SCH 7, and SCH 8. Beige bars indicate when the Total Allowable Commercial Catch (TACC) was exceeded. The TACC for all stocks is shown as a red line.

Commercial landings were highest in SCH 1 and SCH 5, followed by SCH 7 and SCH 8 (Figure 23). The recent decline in landings was most pronounced in SCH 5 and SCH 8. The SCH 8 landings in 2018–19 were about half the TACC. Landings in SCH 1 have increased in the three most recent years (2016–17 to 2018–19), from low values in 2015–16. Average landings for these three most recent years in SCH 1 and SCH 5 were 573 t and 671 t, respectively, with an overall average for the combined school shark catch for all QMAs of 2867 t.

For the current study period, from 1989–90 to 2018–19, most school shark catches in New Zealand were by set net, followed by bottom trawl and bottom longline (Figure 24). Previous set-net catches were considerably larger than bottom-trawl and bottom-longline catches, but have declined by half since peaking in 2004–05. This decline is primarily due to the curtailment of the set-net fishery as a result of restrictions implemented for the conservation of Hector’s and Māui dolphins (see appendix D of Starr & Kendrick 2020). In contrast, catches by bottom trawl and bottom longline have been stable since the early 2000s, except for a 22% decline in bottom-longline catch beginning in 2016–17. School shark was also caught by other gears, particularly in SCH 1.

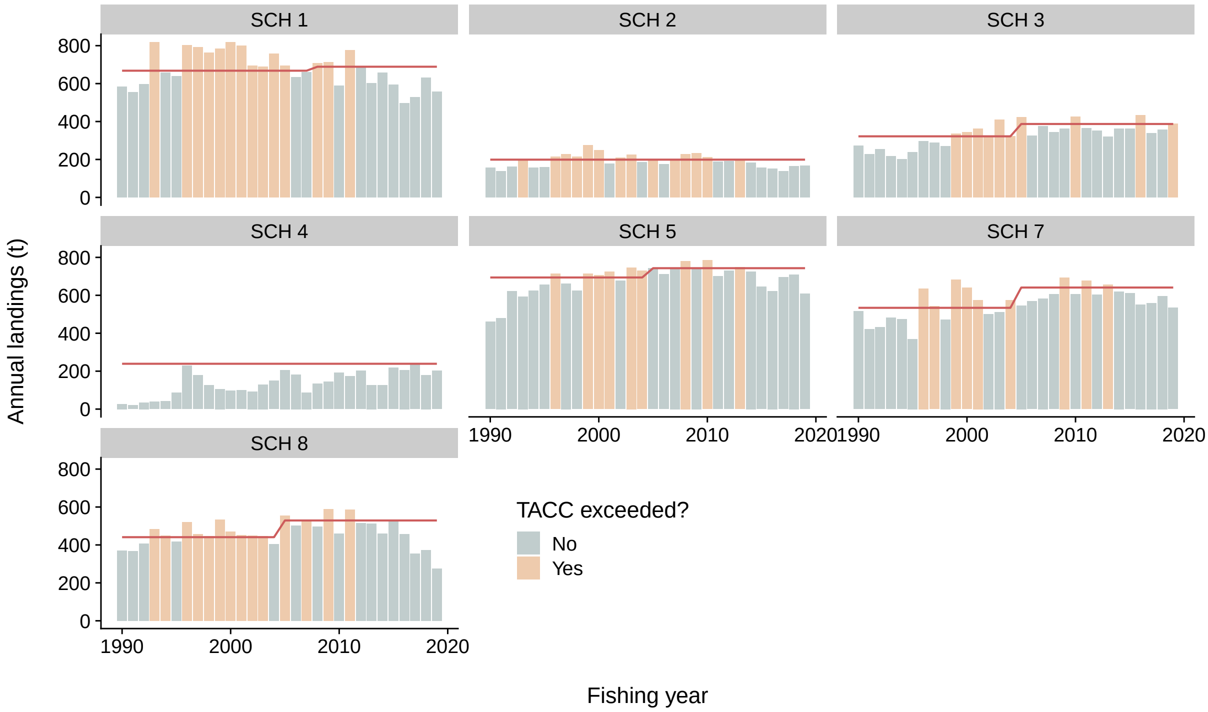

Figure 23: Annual landings (t) from Quota Management Reports (QMR) and Monthly Harvest Returns (MHR) records for school shark by Quota Management Area. Beige bars indicate when the Total Allowable Commercial Catch (TACC) was exceeded. The TACC for each QMA is shown as a red line.

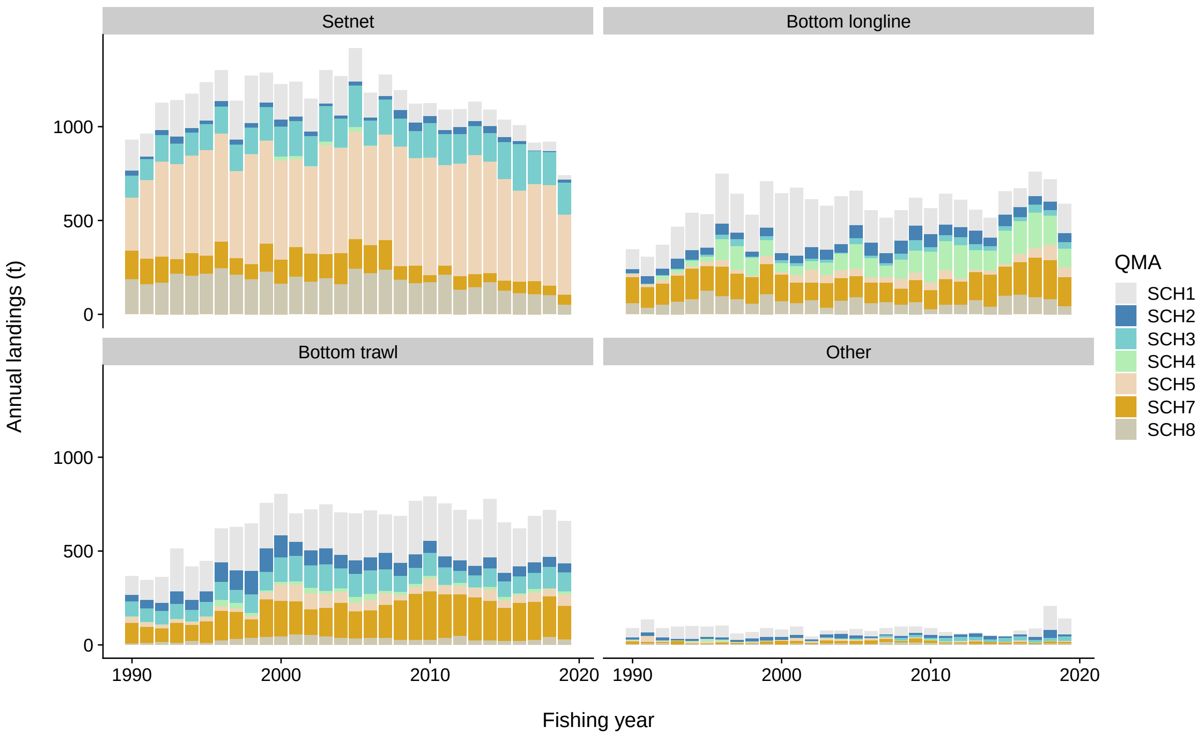

Figure 24: Annual school shark catches (allocated; t) by fishing method and Quota Management Area (QMA).

North Island catches of school shark by set net were concentrated around north and south Taranaki Bight (Figure 25). In the South Island, catches were particularly high in Southland waters, including Foveaux Strait and around Stewart Island, and in shallow waters in some areas off the east coast. Recent set-net catches (2016–17 to 2018–19) had a smaller spatial extent than earlier catches due to fishery restrictions put in place to protect Hector's and Māui dolphins. Spatial trends in CPUE were broadly similar to trends observed in catch, with higher CPUE off the North Island west coast, and also off the south of South Island. The Southland region overall had the highest school shark CPUE for set net, including in the recent time period.

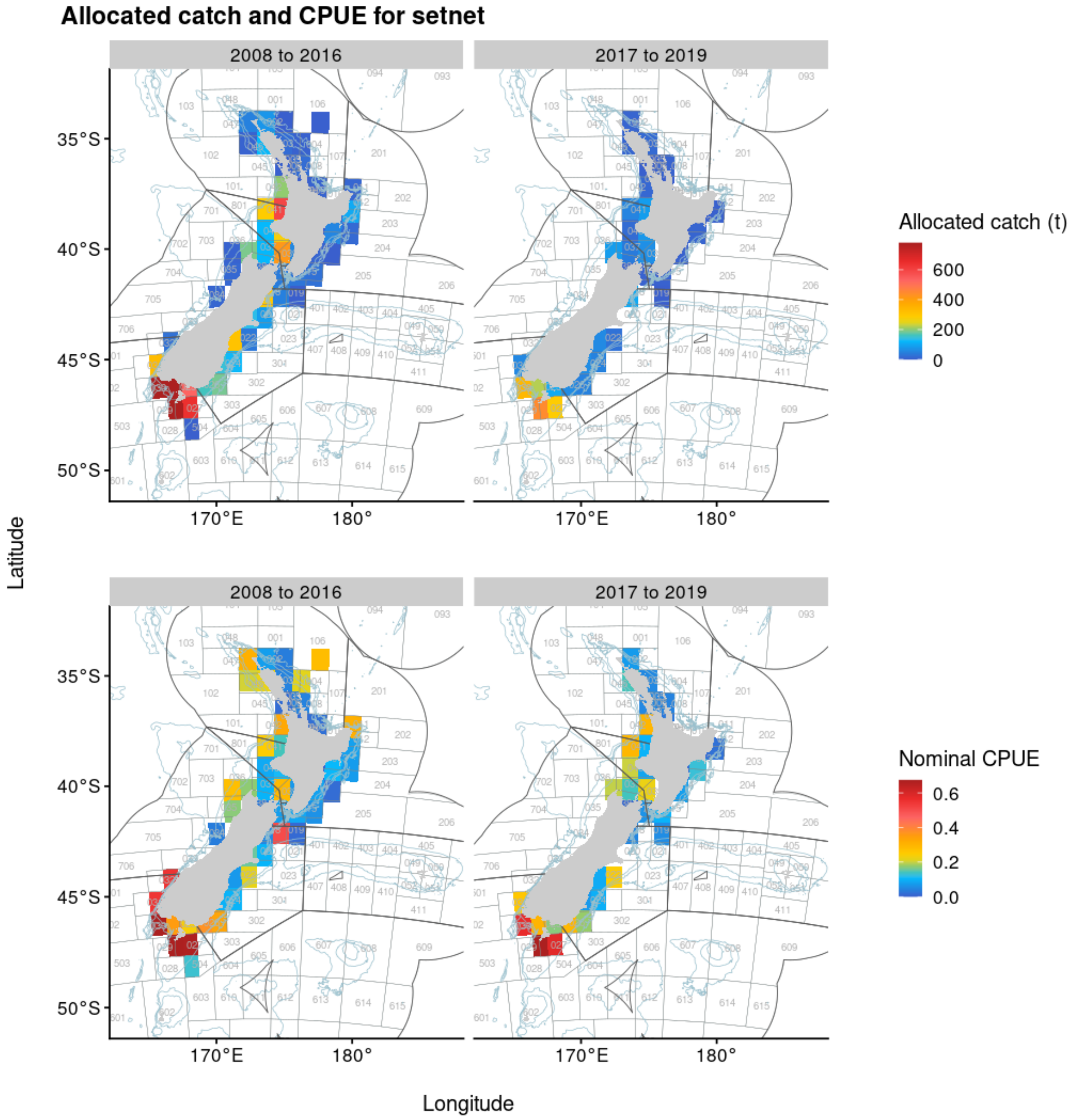

Figure 25: Total set-net catches (allocated catches in t; top) and catch-per-unit-effort (CPUE in t/km of net; bottom), by 1° cell. Catch and effort were summed over 2007–08 to 2015–16 (left column) and 2016–17 to 2018–19 (right column). Bathymetry contours for 200 m, 500 m, and 1000 m are outlined in light blue. Cells are only included if there were records from at least three clients and three vessels. The maximum value of the colour scale is set to the 97.5th quantile for each metric over the 2007–08 to 2018–19 period; cells with values exceeding this threshold are coloured in dark red.

Bottom-longline catches for school shark occurred throughout coastal areas around New Zealand, except for the South Island east coast, south of Banks Peninsula (Figure 26). Catches appeared to be concentrated along the continental slope, between 200 and 500 m water depth in most areas. Catches were high around Chatham Islands and Mernoo Bank. There were distinct CPUE "hotspots" for bottom longline, particularly off the west coast from Taranaki Bight to Cook Strait; off South Island north of Westland; and off the northern tip of Northland. Bottom-longline CPUE was moderately high around Chatham Islands and Mernoo Bank. Recent (2016–17 to 2018–19) spatial patterns in bottom-longline catches and CPUE followed earlier trends.

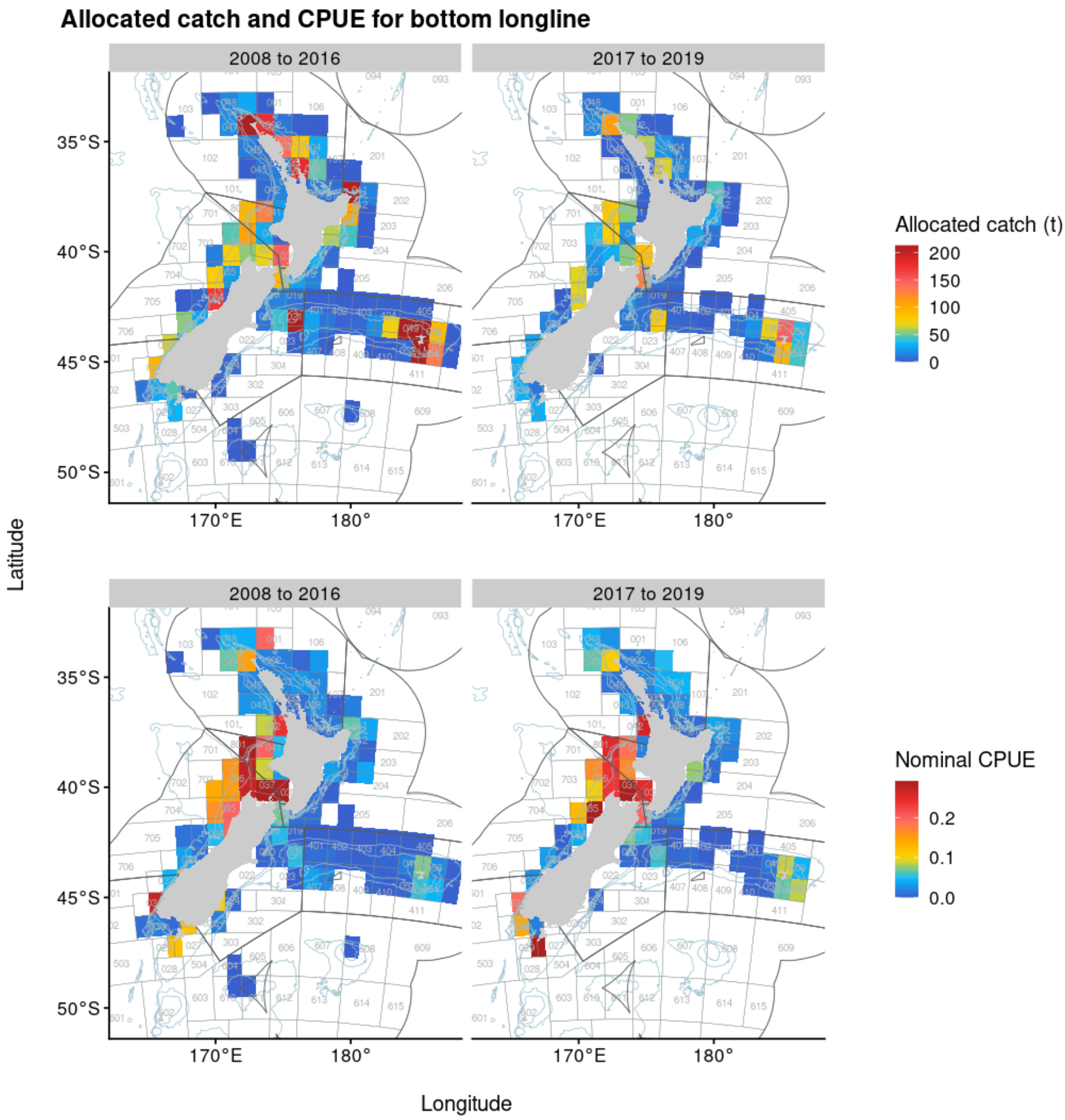

Figure 26: Total bottom longline catches (allocated catches in t; top) and catch-per-unit-effort (CPUE in t/thousand hooks; bottom), by 1° cell. Catch and effort were summed over 2007–08 to 2015–16 (left column) and 2016–17 to 2018–19 (right column). Bathymetry contours for 200 m, 500 m, and 1000 m are outlined in light blue. Cells are only shown if there were records from at least three clients and three vessels. The maximum value of the colour scale is set to the 97.5th quantile for each metric over the 2007–08 to 2018–19 period; cells with values exceeding this threshold are coloured in dark red.

Catches for school shark by bottom trawl were distributed throughout coastal waters in New Zealand, with most of the catches occurring in inshore areas (Figure 27). Off North Island, bottom-trawl catches were particularly high on the northern end of the west coast. Off South Island, west coast bottom-trawl catches were comparatively high at the northern end, from Westland to Tasman and Golden bays, and off the east coast around the Canterbury Bight. Spatial trends in CPUE followed the catch trends, except that CPUE was relatively low around Canterbury Bight. In most areas, there was also a depth pattern apparent in CPUE, with the CPUE for bottom trawl being lower closer to coasts. Bottom-trawl CPUE was also low along Chatham Rise (SCH 4), with slightly higher values around the Mernoo Bank and the Chatham Islands. Spatial trends in recent catches and CPUE (2016–17 to 2018–19) followed earlier patterns, except for recent catches off the northern tip of Northland, which were notably high.

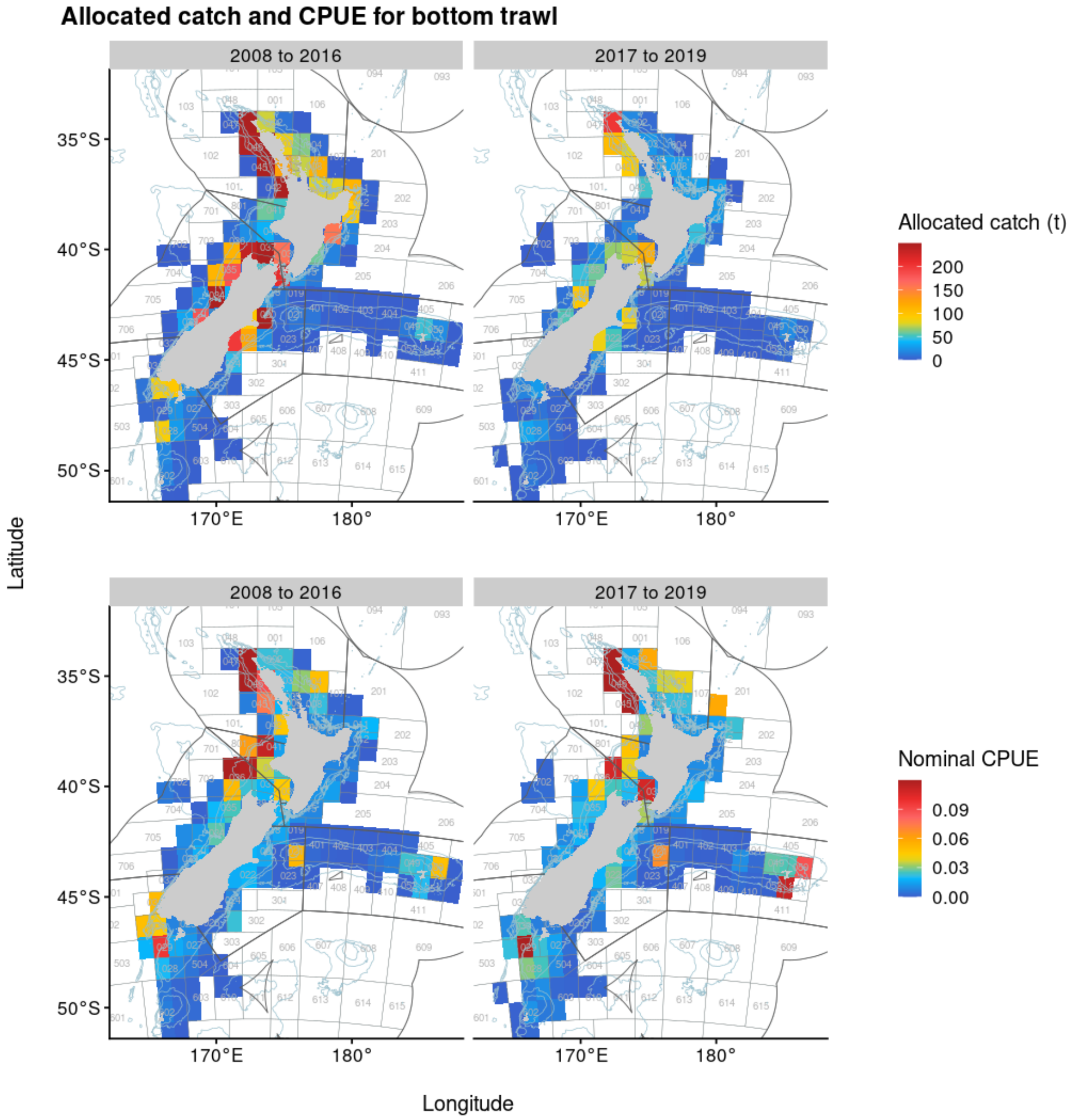

Figure 27: Total bottom trawl catches (allocated catches in t; top) and catch-per-unit-effort (CPUE in t/tow; bottom), by 1° cell. Catch and effort were summed over 2007–08 to 2015–16 (left column) and 2016–17 to 2018–19 (right column). Bathymetry contours for 200 m, 500 m, and 1000 m are outlined in light blue. Cells are only shown if there were records from at least three clients and three vessels. The maximum value of the colour scale is set to the 97.5th quantile for each metric over the 2007–08 to 2018–19 period; cells with values exceeding this threshold are coloured in dark red.

3.2.3 Description of the fisheries by QMA

SCH 1

School shark catches in SCH 1 were initially evenly split between set net, bottom longline, and bottom trawl (Figure 28, top panel). Over time, the contribution of set net diminished due to spatial management restrictions implemented to protect Māui and Hector’s dolphins (see Appendix D of Starr

& Kendrick 2020). The share of the total catch by bottom longline also diminished, but to a lesser extent. Other gears (including Precision Seafood Harvesting trawl) have increased in prevalence in recent years. From 2016–17 to 2018–2019, set net accounted for % of catches, bottom longline for 27.1%, and bottom trawl for 47.9%. Set-net catches tended to be higher during warmer months throughout the time series, although this trend was less clear in recent years, when there was a decline of set-net catches of school shark (Figure 29). For bottom longline, school shark catches tended to be high from September to November in the last 15 years (2004–05 to 2018–19), whereas bottom-trawl catches tended to be high from August to November.

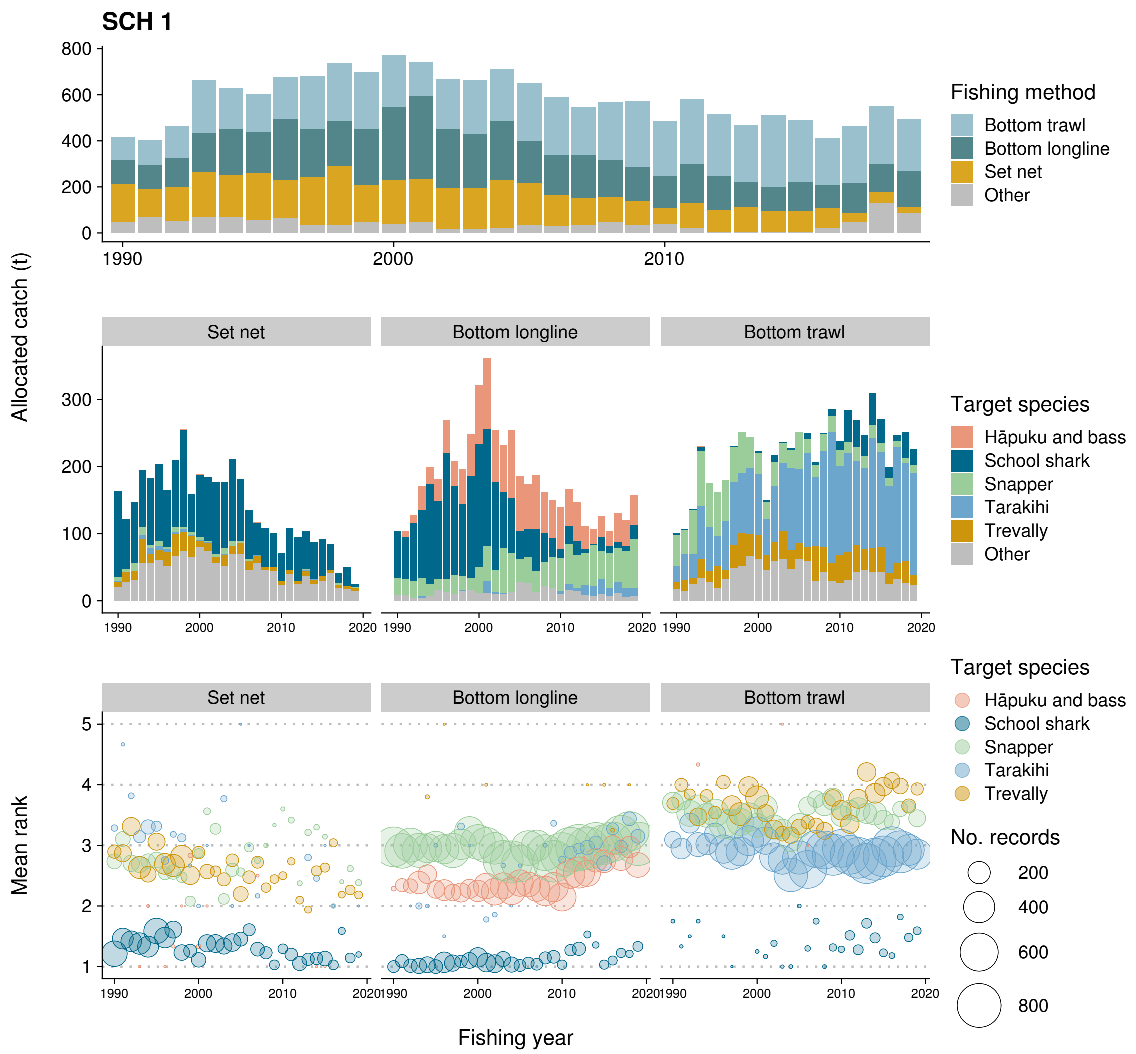

Figure 28: Allocated school shark catch (in t) for Quota Management Area SCH 1 over time, by fishing method (top), allocated catch by target species declared on the fishing event forms for each key fishing method (centre), and average school shark rank in the estimated catch forms by fishing method, aggregated by target species declared on the corresponding fishing event forms (bottom). Only the top 5 target species were included, calculated across fishing methods. The three most common "Other" target species were red gurnard, rig, and bluenose. The size of the circle of the average estimated rank scales with the number of records.

For landings in SCH 1, key target species for set net were school shark; for bottom longline, school shark, snapper, and hāpuku/bass; and for bottom trawl, tarakihi (Figure 28, centre panel). There was no clear trend in the recorded estimated school shark catch rank by target species for set net and bottom trawl, but the rank increased after 2009–10 for bottom-longline sets targeting snapper and hāpuku/bass, indicating a slight decline in the relative prevalence of school shark in the overall catch (Figure 28, bottom panel).

Bottom longline caught school shark at different depths depending on the target species, with relatively high catches in shallow waters (less than 150 m depth) for sets targeting snapper. In contrast, sets targeting hāpuku/bass caught school shark in waters deeper than 150 m (Figure 30). The CPUE for these target species was highest around 150 to 200 m depth. Bottom-longline sets targeting school shark also had high catches and CPUE at water depths of around 150 to 200 m. Bottom trawl targeting tarakihi had greater school shark catches at depths that exceeded 200 m, but there was no clear trend in CPUE by depth; school shark catches on tows targeting trevally, red gurnard, and snapper were also relatively high at depths exceeding 100 m. The CPUE for tows targeting school shark increased with depth, with a peak at around 200 m.

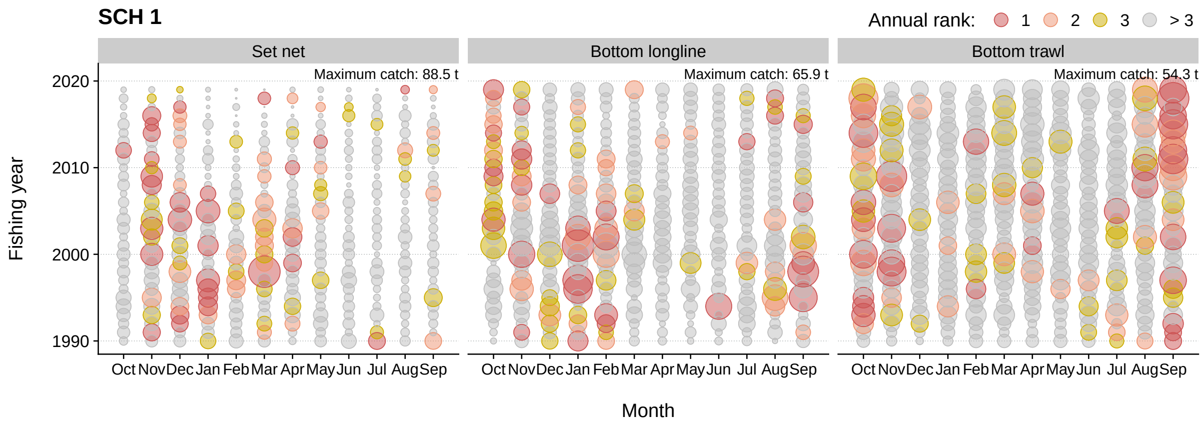

Figure 29: Seasonal distribution of school shark catch by month and fishing year, by fishing method for quota management area SCH 1, with the size of the circle scaling with the monthly allocated catch in t. The circle size was standardised within each fishing method; the monthly catch corresponding to the largest circle by method is noted in the top-right corner. For each fishing year, the three months with the larger catches during the year are highlighted in red, orange, and yellow, based on their rank.

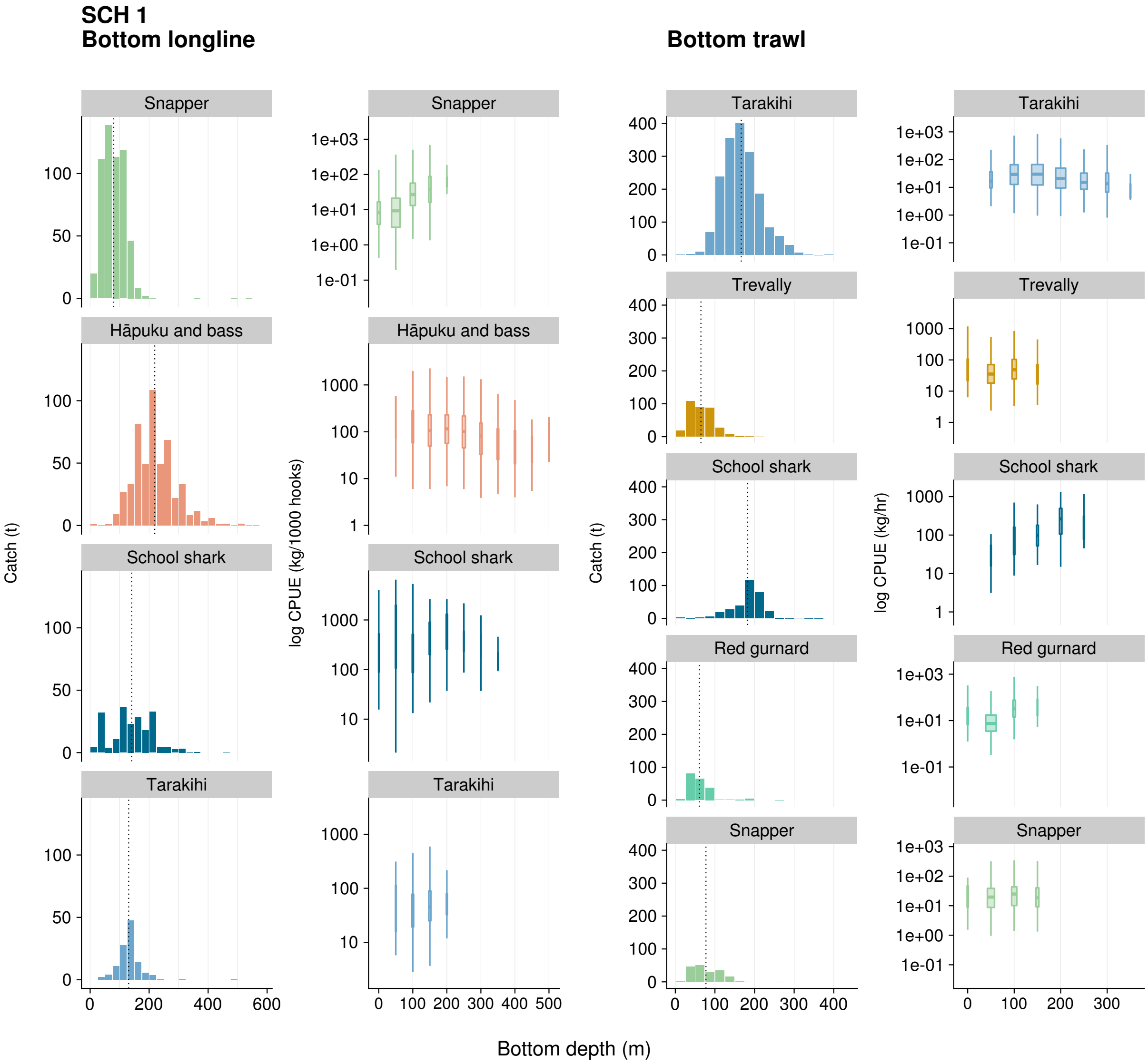

Figure 30: School shark catch and log catch-per-unit-effort (CPUE) by depth and fishing method for different target species in Quota Management Area SCH 1. Catch is in t and CPUE in kg per thousand hooks for bottom longline, and kg per hour for bottom trawl; records are aggregated over 50 m depth classes. Included records span 2007–08 to 2018–19. Target species were only included if they were among the top 5 contributors to school shark catch for the fishing method over the time period with at least 5% of the catch. Depth classes were only included in the boxplot panels if they included five records or more. Dotted vertical line on the catch panels denotes the mean depth of school shark catch for the target species. Boxplot hinges span the inter-quartile range (IQR), with lower and upper whiskers extending to the minimum and maximum observations within 1.5× the width of the IQR from the box. The relative width of the boxes within boxplot scales with the number of records included in the depth class.

SCH 2

In SCH 2, most of the school shark catch in recent years was by bottom longline and bottom trawl (Figure 31, top panel). Set-net catches markedly declined after 2016–17, and the contribution of bottom trawl also diminished steadily over time. From 2016–17 to 2018–19, set net accounted for % of catches (decreasing from an average of 18.5% from 2013–14 to 2015–16), bottom longline for 35.8%, and bottom trawl for 40.9%. Set-net catches for school shark tended to be comparatively low during winter months, whereas bottom-longline catches tended to be high from August to December, particularly after 2012–13 (Figure 32). There was no clear seasonal trend in bottom-trawl catches over the last ten years (from 2009–10 onwards).

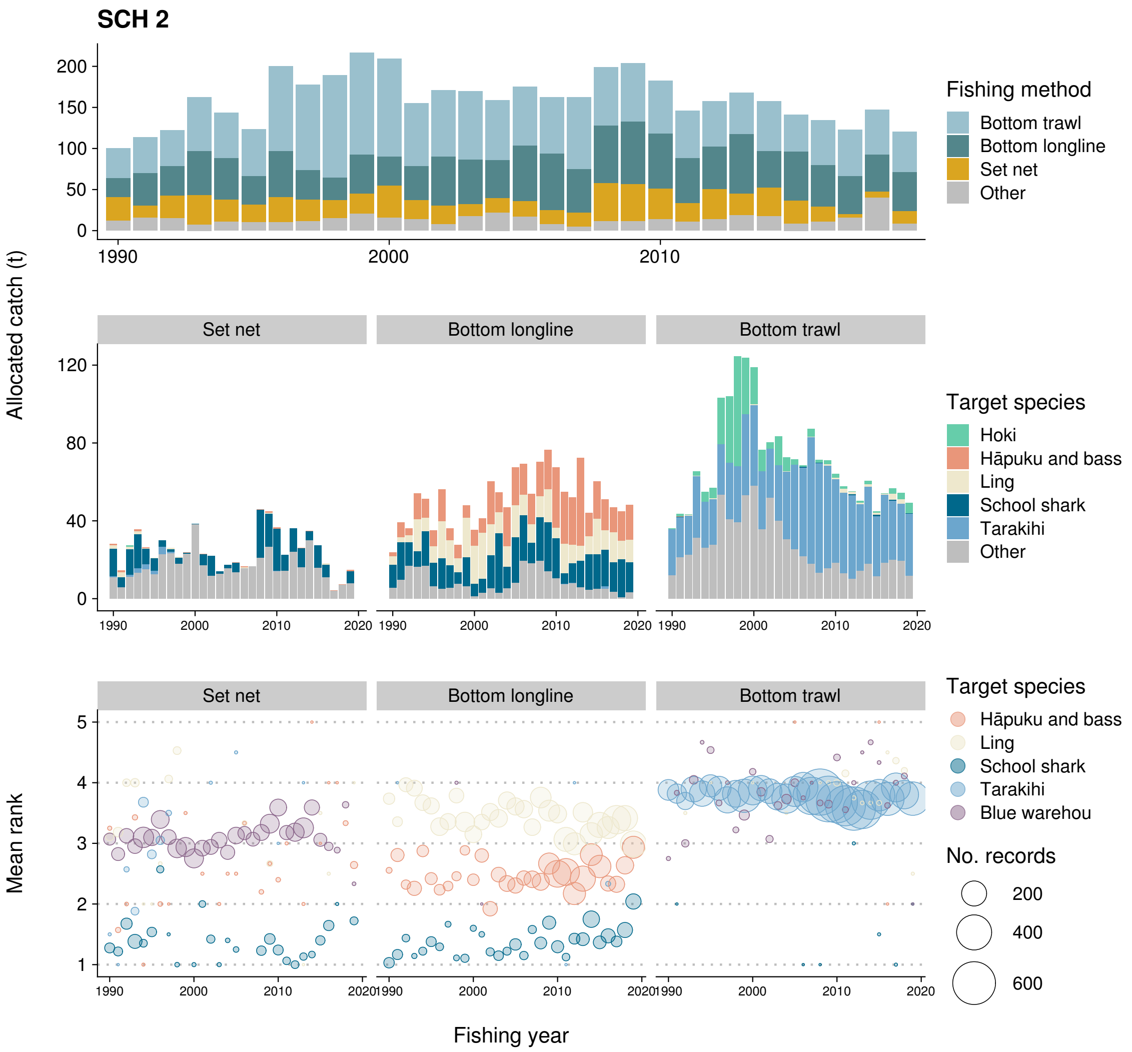

Figure 31: Allocated school shark catch (in t) for Quota Management Area SCH 2 over time, by fishing method (top), allocated catch by target species declared on the fishing event forms for each key fishing method (centre), and average school shark rank in the estimated catch forms by fishing method, aggregated by target species declared on the corresponding fishing event forms (bottom). Only the top 5 target species were included, calculated across fishing methods. The three most common "Other" target species were gemfish, blue warehou, and red gurnard. The size of the circle of the average estimated rank scales with the number of records.

Key species targeted when catching school shark in SCH 2 were school shark for set net, compared with school shark, ling, and hāpuku/bass for bottom longline, and tarakihi for bottom trawl (Figure 31, centre). Compared with SCH 1, there was greater diversity in target species across gears in SCH 2, with school shark also frequently caught by set-net effort targeting blue warehou and giant stargazer, by bottom-longline effort targeting bluenose, and by bottom-trawl effort targeting gemfish and red gurnard (Figure 31, centre). Bottom-longline sets targeting school shark showed a slight increase in the estimated school shark catch rank after the mid-2000s, indicating a higher prevalence of sets where school shark was not the most abundant species in the catch, even when targeted (Figure 31, bottom).

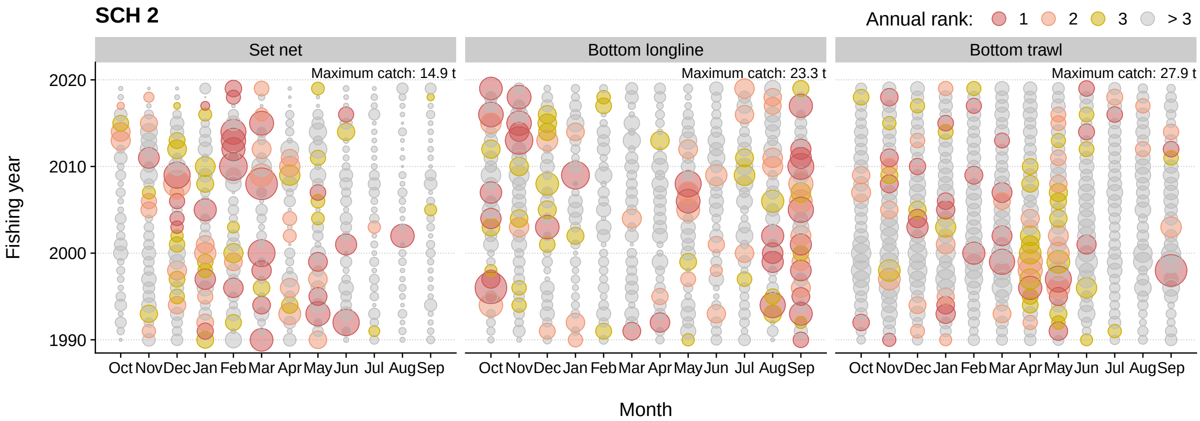

Figure 32: Seasonal distribution of school shark catch by month and fishing year, by fishing method for quota management area SCH 2, with the size of the circle scaling with the monthly allocated catch in t. The circle size was standardised within each fishing method; the monthly catch corresponding to the largest circle by method is noted in the top-right corner. For each fishing year, the three months with the larger catches during the year are highlighted in red, orange, and yellow, based on their rank.

Most bottom-longline effort targeting hāpuku/bass or school shark caught school shark at water depths between 100 and 300 m, with a higher CPUE at depths between 200 and 300 m (Figure 33). Although school shark catches in bottom-longline sets targeting ling and bluenose occurred in deeper waters (around 300 to 400 m), school shark CPUE for these deeper sets also declined with depth. For bottom-trawl effort, most school shark catches in tows targeting tarakihi were at depths not exceeding 200 m, but CPUE was highest between 200 and 300 m depth.

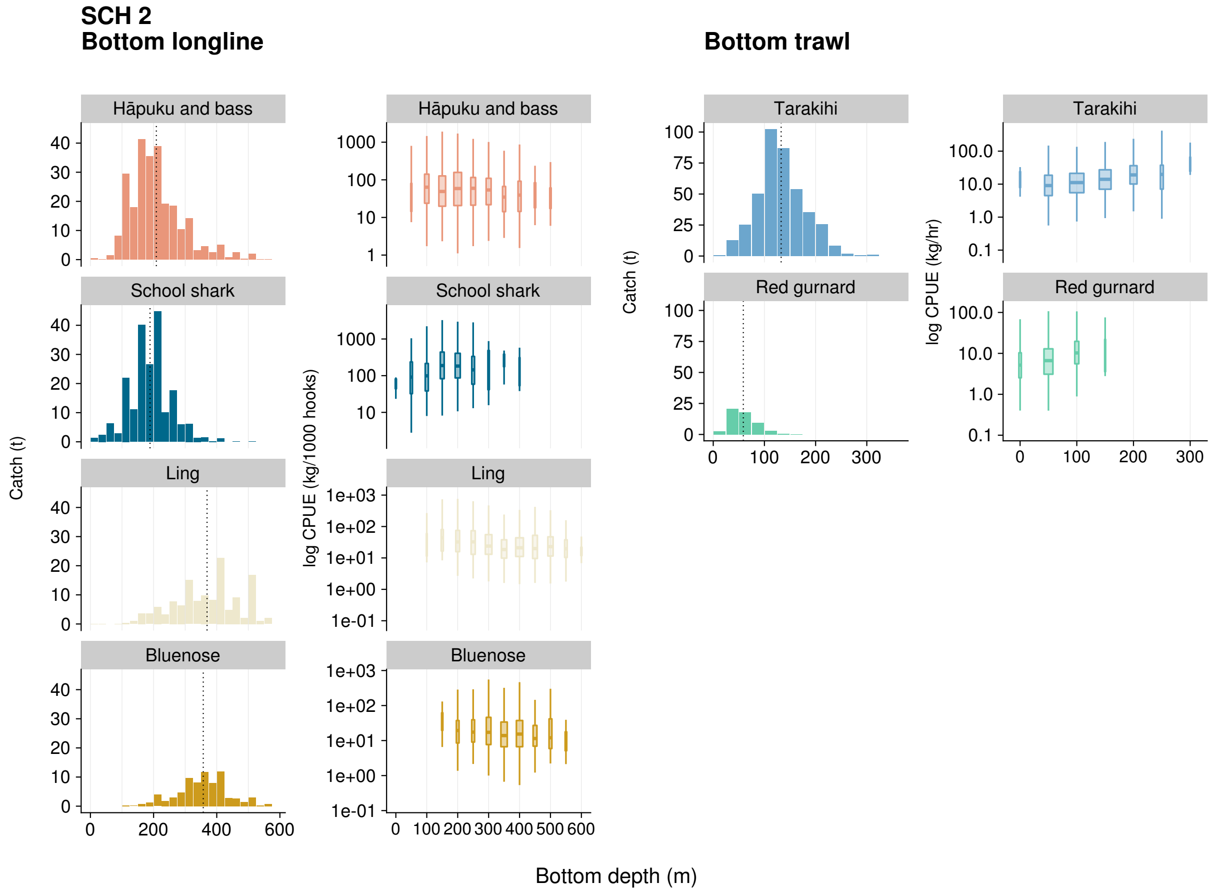

Figure 33: School shark catch and log catch-per-unit-effort (CPUE) by depth and fishing method for different target species in Quota Management Area SCH 2. Catch is in t and CPUE in kg per thousand hooks for bottom longline, and kg per hour for bottom trawl; records are aggregated over 50 m depth classes. Included records span 2007–08 to 2018–19. Target species were only included if they were among the top 5 contributors to school shark catch for the fishing method over the time period with at least 5% of the catch. Depth classes were only included in the boxplot panels if they included five records or more. Dotted vertical line on the catch panels denotes the mean depth of school shark catch for the target species. Boxplot hinges span the inter-quartile range (IQR), with lower and upper whiskers extending to the minimum and maximum observations within 1.5× the width of the IQR from the box. The relative width of the boxes within boxplot scales with the number of records included in the depth class.

SCH 3

In SCH 3, school shark catches were predominantly by set-net effort targeting school shark and rig (Figure 34, top and centre panels). Bottom-trawl effort targeting red cod and tarakihi contributed most of the remaining school shark catches, with smaller catches by bottom longline targeting hāpuku/bass. From 2016–17 to 2018–19, set net accounted for % of catches, bottom longline for 10.8%, and bottom trawl for 30.5%. Flatfish and barracouta were the other key target species for bottom trawl effort catching school shark. School shark catches by set-net effort targeting spiny dogfish were frequent up to the early 2000s, but were seldom recorded in recent years (Figure 34, centre). Earlier catches were due to regulations in the 1990s which required fishers to hold quota for target species, with spiny dogfish readily available. There were no apparent trends in the reported estimated school shark catch rank (Figure 34, bottom panel).

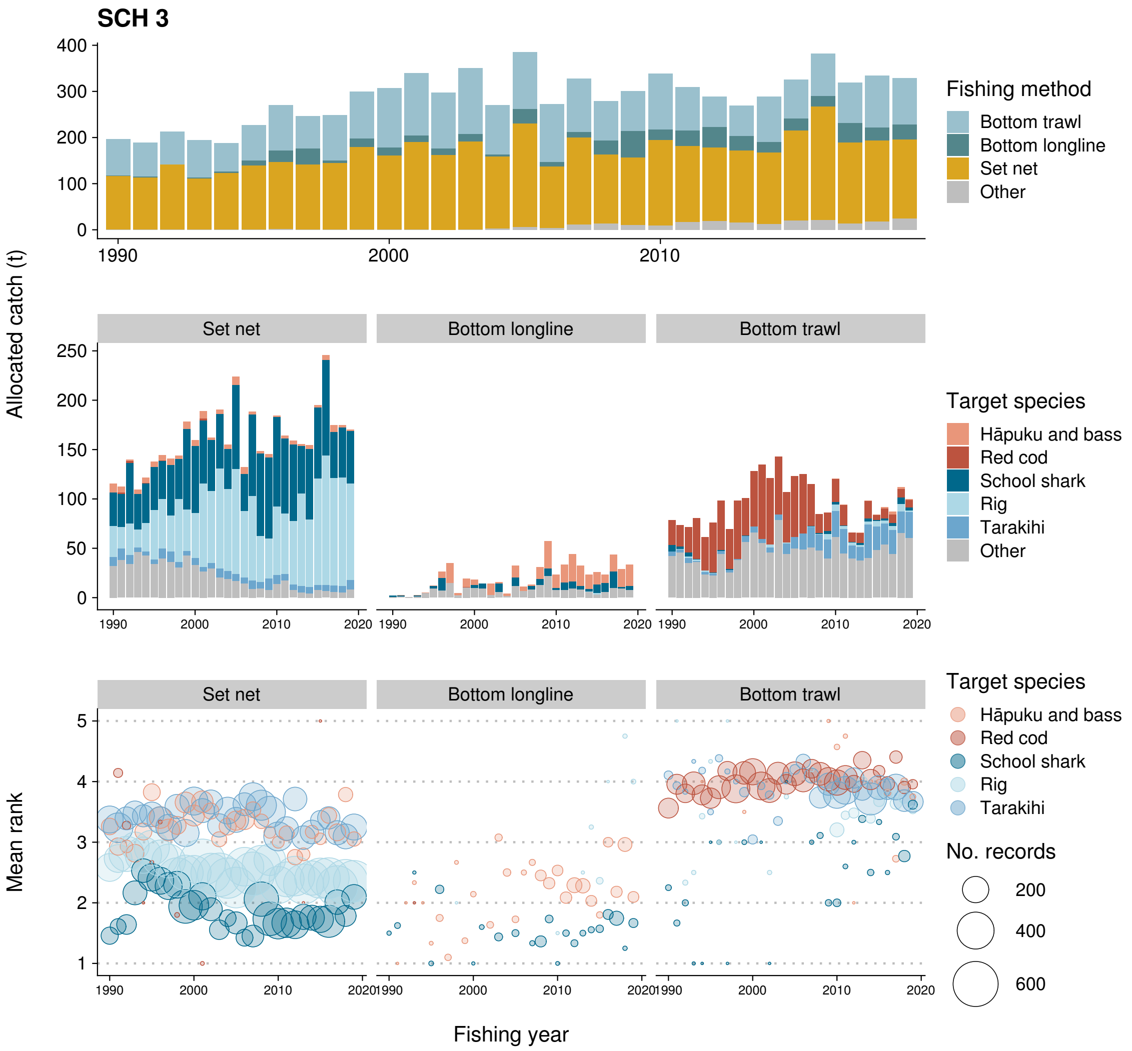

Figure 34: Allocated school shark catch (in t) for Quota Management Area SCH 3 over time, by fishing method (top), allocated catch by target species declared on the fishing event forms for each key fishing method (centre), and average school shark rank in the estimated catch forms by fishing method, aggregated by target species declared on the corresponding fishing event forms (bottom). Only the top 5 target species were included, calculated across fishing methods. The three most common "Other" target species were barracouta, flatfish, and elephantfish. The size of the circle of the average estimated rank scales with the number of records.

There was a pronounced seasonal trend in school shark catches for both set net and bottom trawl: catches were minimal during winter months, and higher between November to March for set net, and January to March for bottom trawl (Figure 35). Catches for bottom longline also tended to be lower during the colder months between May and August, but with more variability in the inter-annual distribution.

Bottom-longline sets targeting hāpuku/bass tended to catch school shark in waters down to 300 m depth, but CPUE was highest at depths between 100 and 200 m (Figure 36). Bottom-longline sets targeting ling caught school shark in deeper waters (around 400 m depth), but CPUE declined with depth. Bottom-longline sets targeting school shark had higher catches at depths between 100 to 200 m, but CPUE was higher in waters less than 100 m depth. Bottom trawlers in SCH 3 tended to catch school shark in waters shallower than 125 m, irrespective of target species, and there was no clear trend in CPUE.

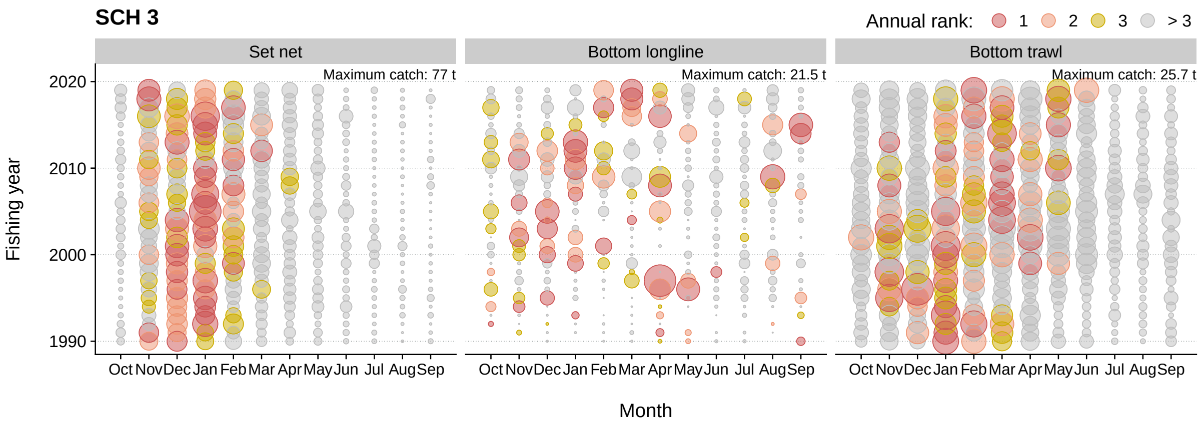

Figure 35: Seasonal distribution of school shark catch by month and fishing year, by fishing method for quota management area SCH 3, with the size of the circle scaling with the monthly allocated catch in t. The circle size was standardised within each fishing method; the monthly catch corresponding to the largest circle by method is noted in the top-right corner. For each fishing year, the three months with the larger catches during the year are highlighted in red, orange, and yellow, based on their rank.

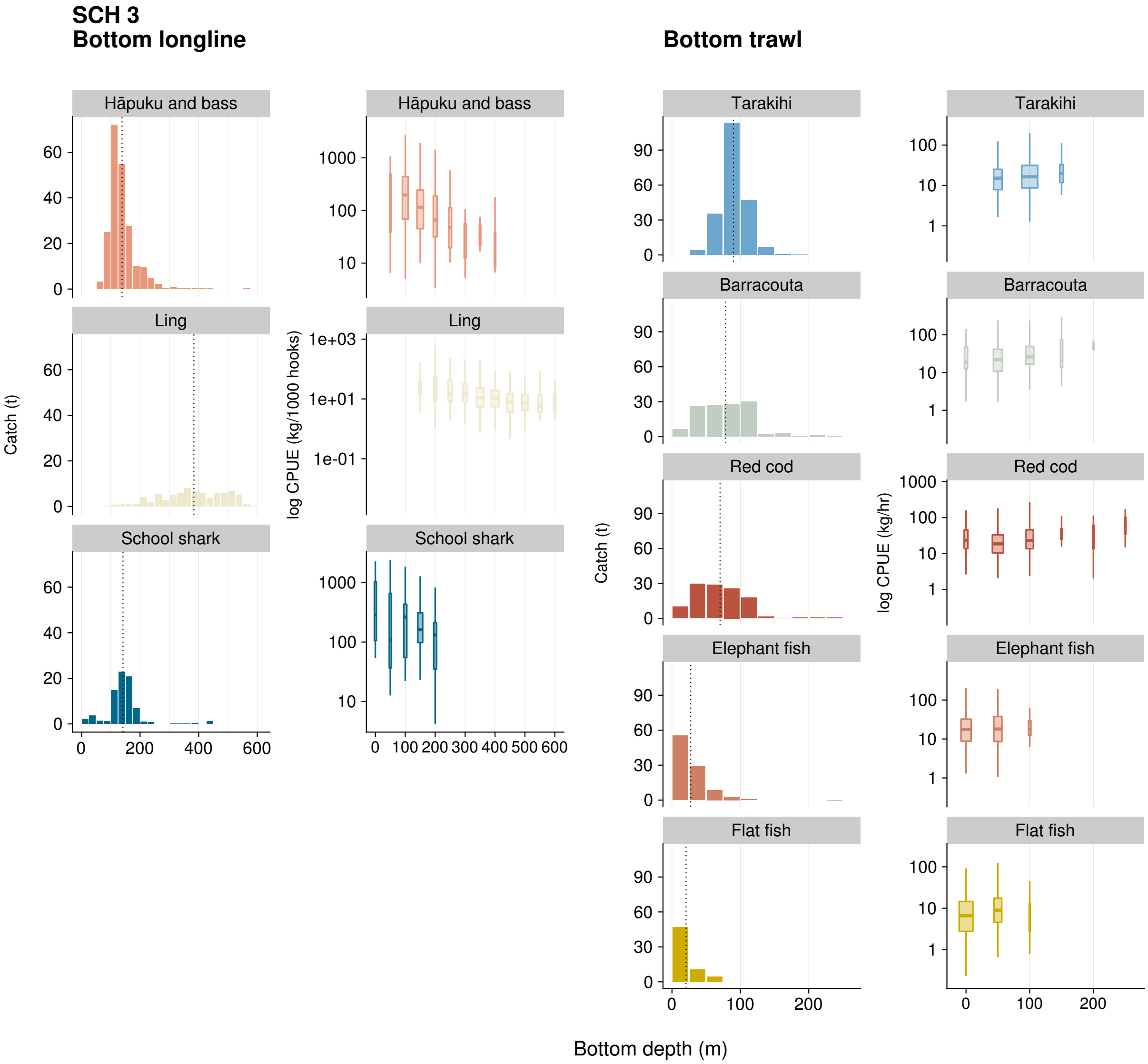

Figure 36: School shark catch and log catch-per-unit-effort (CPUE) by depth and fishing method for different target species in Quota Management Area SCH 3. Catch is in t and CPUE in kg per thousand hooks for bottom longline, and kg per hour for bottom trawl; records are aggregated over 50 m depth classes. Included records span 2007–08 to 2018–19. Target species were only included if they were among the top 5 contributors to school shark catch for the fishing method over the time period with at least 5% of the catch. Depth classes were only included in the boxplot panels if they included five records or more. Dotted vertical line on the catch panels denotes the mean depth of school shark catch for the target species. Boxplot hinges span the inter-quartile range (IQR), with lower and upper whiskers extending to the minimum and maximum observations within 1.5× the width of the IQR from the box. The relative width of the boxes within boxplot scales with the number of records included in the depth class.

SCH 4

School shark catches in SCH 4 were primarily by bottom-longline effort targeting school shark, ling, and hāpuku/bass, with a small contribution from bottom trawl targeting tarakihi (Figure 37, top and centre panels). From 2016–17 to 2018–19, bottom longline accounted for 91.7% of catches and bottom trawl for 7.8%. There was a small increasing trend in the reported estimated school catch rank for bottom-longline sets targeting ling, and a similar, more recent, increase for bottom-longline sets targeting hāpuku/bass (Figure 37, bottom panel).

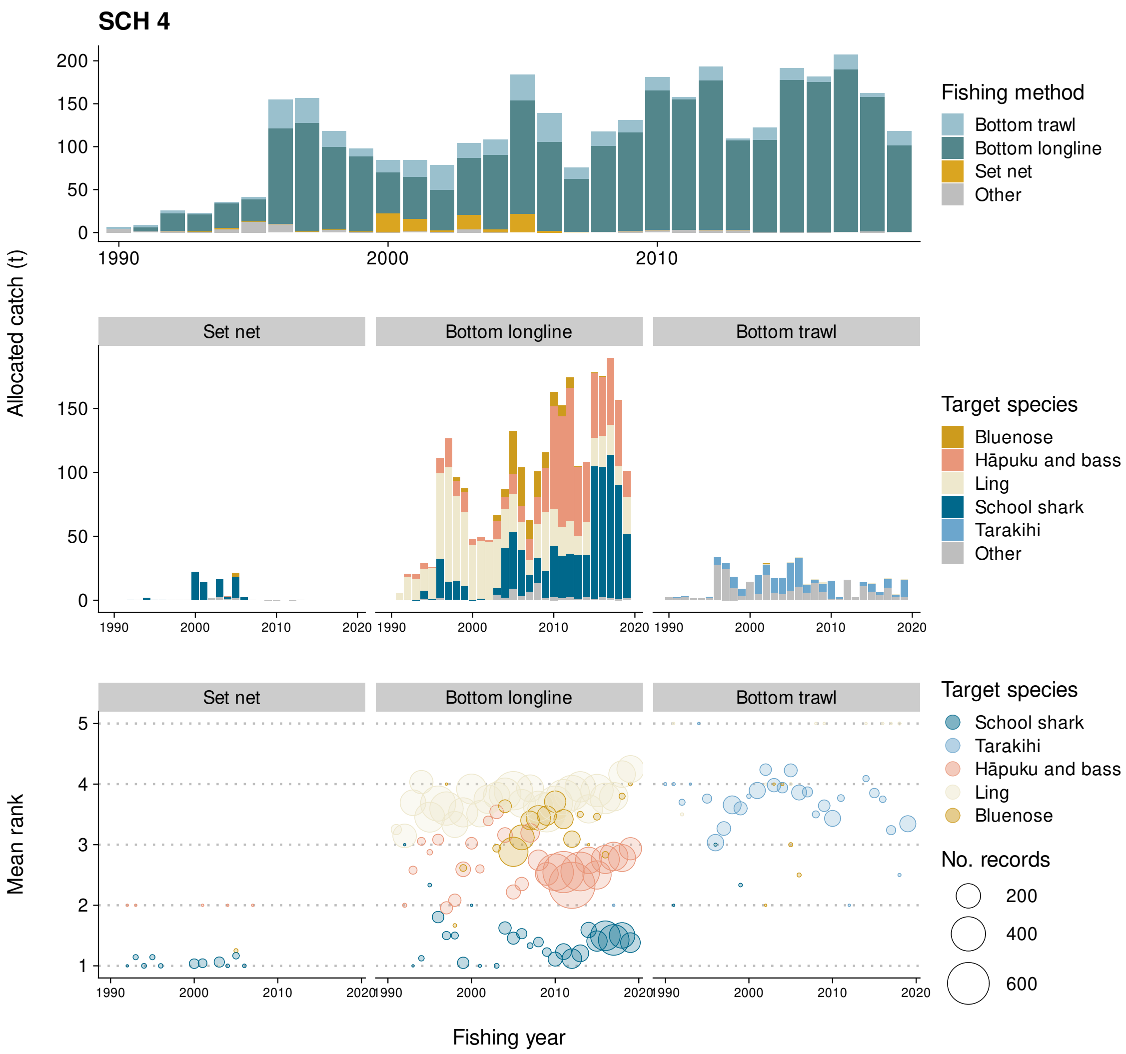

Figure 37: Allocated school shark catch (in t) for Quota Management Area SCH 4 over time, by fishing method (top), allocated catch by target species declared on the fishing event forms for each key fishing method (centre), and average school shark rank in the estimated catch forms by fishing method, aggregated by target species declared on the corresponding fishing event forms (bottom). Only the top 5 target species were included, calculated across fishing methods. The three most common "Other" target species were barracouta, giant stargazer, and trumpeter. The size of the circle of the average estimated rank scales with the number of records.

There was no pronounced seasonal trend in school shark catches in SCH 4 for bottom longline or bottom trawl, although catches tended to be lower during colder months from May to September (Figure 38).

Most bottom-longline sets targeting school shark or hāpuku/bass in SCH 4 tended to catch school shark in waters shallower than 200 m depth, although significant catches also occurred in deeper waters (Figure 39). There was a slight decline in CPUE with depth. School shark catches for sets targeting ling occurred mostly at depths between 300 and 500 m, with CPUE declining with depth. Bottom-trawl tows targeting tarakihi or barracouta caught school shark at water depths between 100 and 250 m, with no trend in CPUE across depths.

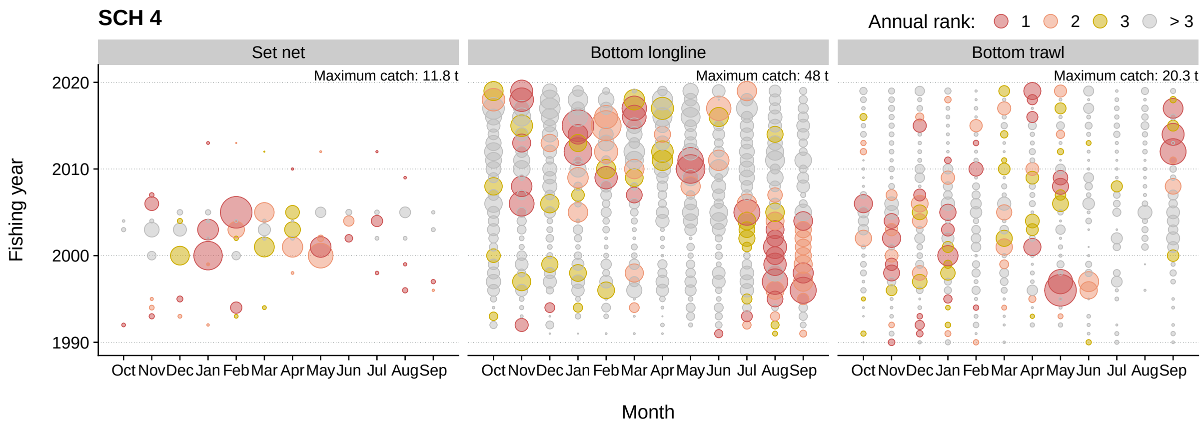

Figure 38: Seasonal distribution of school shark catch by month and fishing year, by fishing method for quota management area SCH 4, with the size of the circle scaling with the monthly allocated catch in t. The circle size was standardised within each fishing method; the monthly catch corresponding to the largest circle by method is noted in the top-right corner. For each fishing year, the three months with the larger catches during the year are highlighted in red, orange, and yellow, based on their rank.

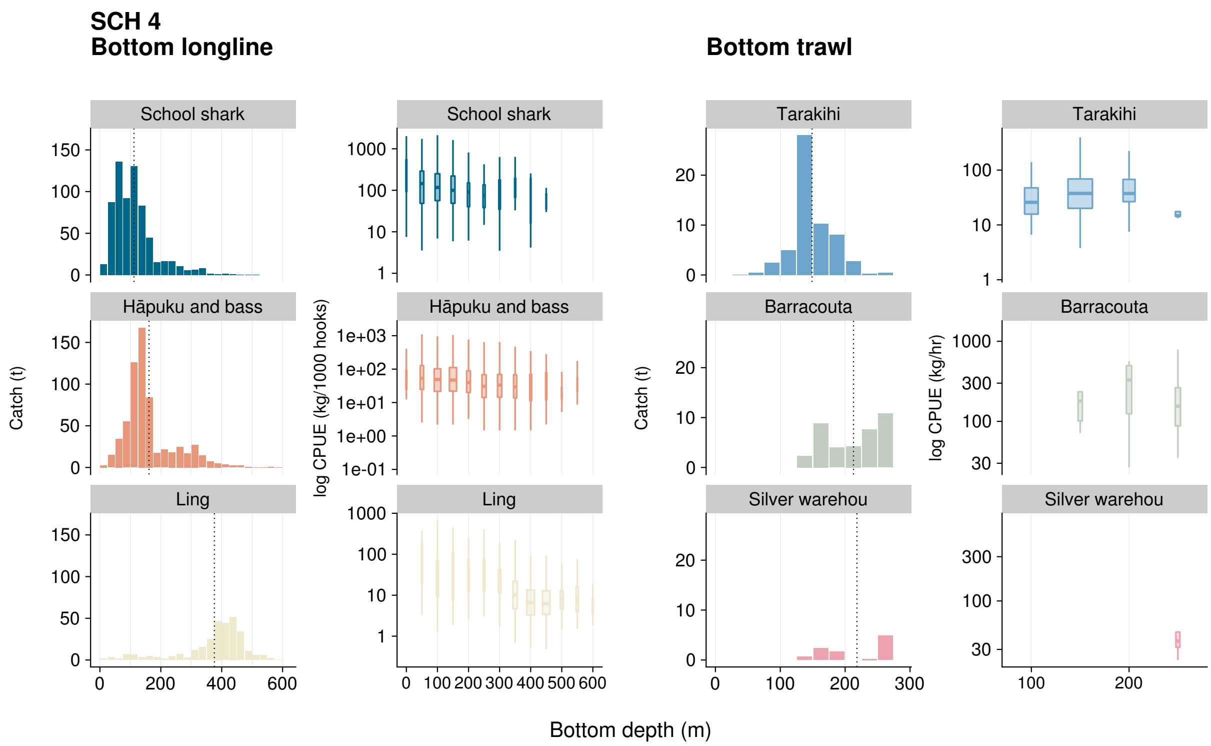

Figure 39: School shark catch and log catch-per-unit-effort (CPUE) by depth and fishing method for different target species in Quota Management Area SCH 4. Catch is in t and CPUE in kg per thousand hooks for bottom longline, and kg per hour for bottom trawl; records are aggregated over 50 m depth classes. Included records span 2007–08 to 2018–19. Target species were only included if they were among the top 5 contributors to school shark catch for the fishing method over the time period with at least 5% of the catch. Depth classes were only included in the boxplot panels if they included five records or more. Dotted vertical line on the catch panels denotes the mean depth of school shark catch for the target species. Boxplot hinges span the inter-quartile range (IQR), with lower and upper whiskers extending to the minimum and maximum observations within 1.5× the width of the IQR from the box. The relative width of the boxes within boxplot scales with the number of records included in the depth class.

SCH 5

In SCH 5, set-net effort targeting school shark made up most of the school shark catches with minimal contributions from bottom-longline and bottom-trawl effort (Figure 40, top panel). From 2016–17 to 2018–19, set-net effort accounted for % of catches, bottom longline for 10.0%, and bottom trawl for 8.2%. Key target species for bottom-longline effort were school shark and ling, and for bottom-trawl effort, stargazer, ling, and squid (Figure 40, centre panel). There was a gradual increasing trend in the reported estimated school shark rank for set net effort targeting rig. The rank of school shark in bottom-trawl tows targeting stargazer also increased from the early 2000s (Figure 40, bottom panel).

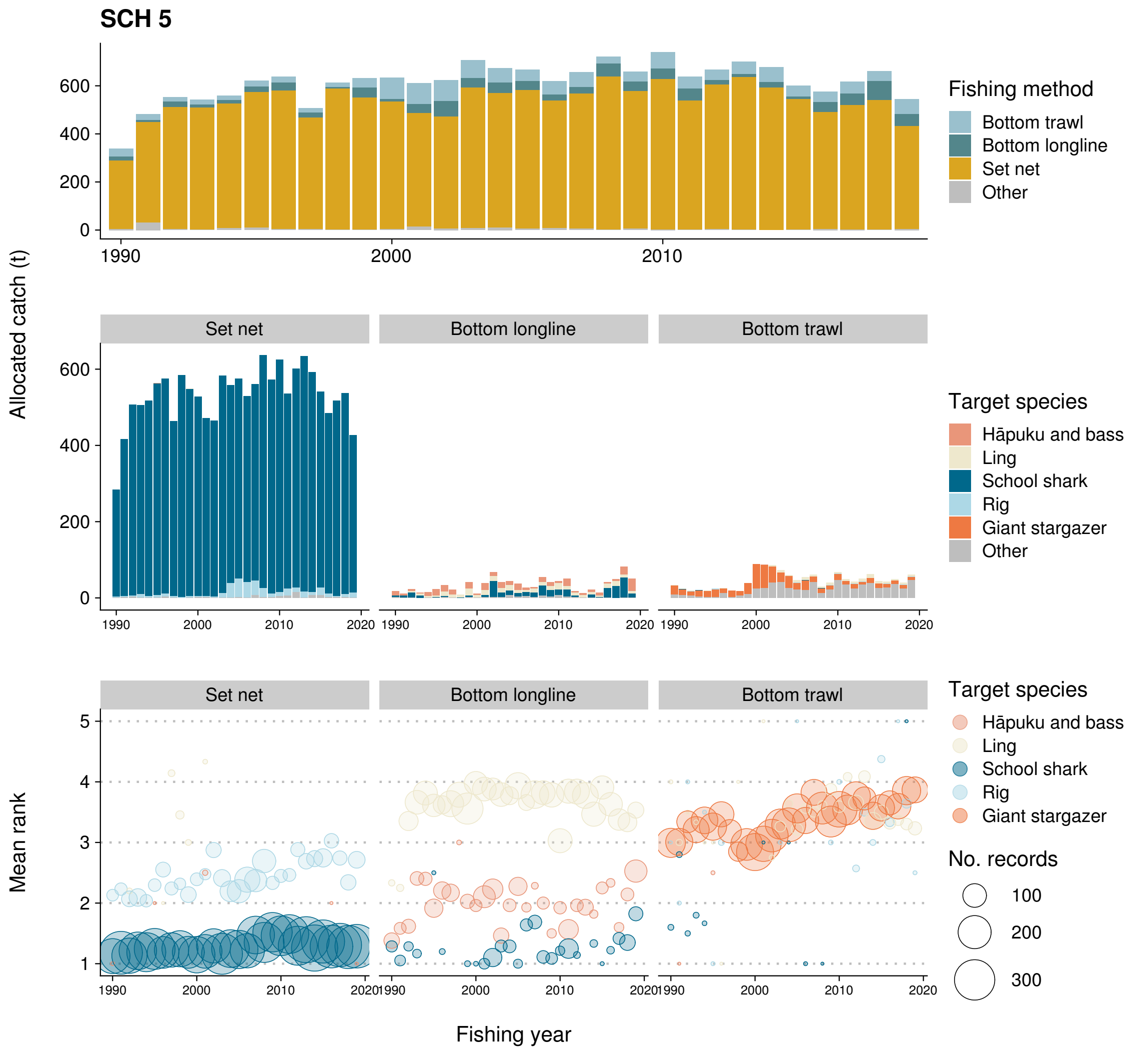

Figure 40: Allocated school shark catch (in t) for Quota Management Area SCH 5 over time, by fishing method (top), allocated catch by target species declared on the fishing event forms for each key fishing method (centre), and average school shark rank in the estimated catch forms by fishing method, aggregated by target species declared on the corresponding fishing event forms (bottom). Only the top 5 target species were included, calculated across fishing methods. The three most common "Other" target species were squid, flatfish, and bluenose. The size of the circle of the average estimated rank scales with the number of records.

There was a pronounced seasonal trend in SCH 5 school shark catches, particularly for set net: catches were almost consistently highest in the summer months of November or December to March (Figure 41). For bottom longline, school shark catches were also relatively high in the warmer months, from October to January, but with more inter-annual variability. Catches for bottom trawl tended to be low between June and September, then increased again in the next fishing year beginning in November and extending to April or May. This pattern was particularly pronounced in the last ten years (2009–10 to 2018–19).

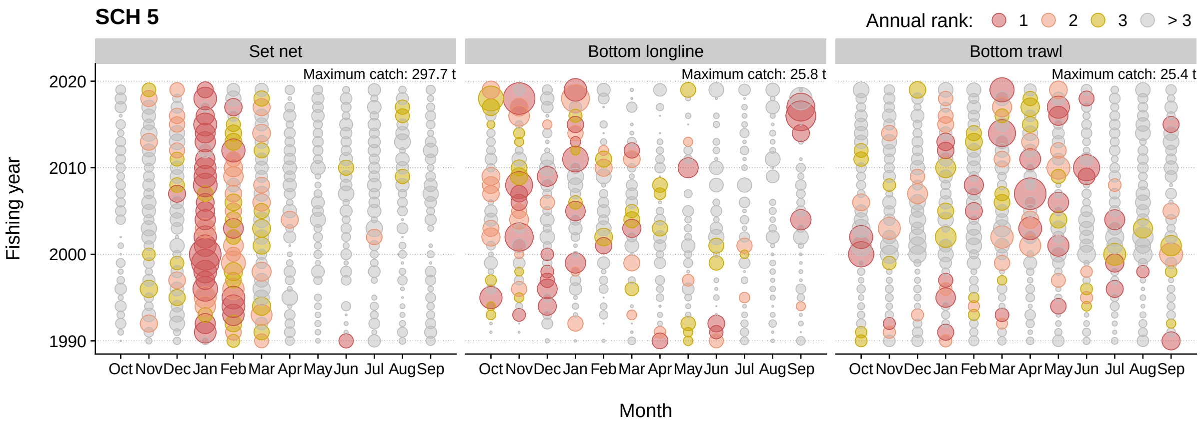

Figure 41: Seasonal distribution of school shark catch by month and fishing year, by fishing method for quota management area SCH 5, with the size of the circle scaling with the monthly allocated catch in t. The circle size was standardised within each fishing method; the monthly catch corresponding to the largest circle by method is noted in the top-right corner. For each fishing year, the three months with the larger catches during the year are highlighted in red, orange, and yellow, based on their rank.

Bottom-longline sets targeting school shark caught most school shark at depths to 200 m, with CPUE increasing with depth within that range (Figure 42). Bottom-longline sets targeting hāpuku/bass caught school shark at depths down to 350 m, with no clear trend in CPUE. At the same time, bottom-longline sets targeting ling caught most school shark at water depths down to 500 m, but with CPUE declining with depth. Bottom-trawl tows targeting squid caught school shark between 100 and 400 m, and tows targeting stargazer caught school shark in shallow waters down to 200 m depth. There was no clear trend of school shark CPUE with depth for any bottom-trawl target species, except for ling, where school shark was caught at depths between 300 and 500 m, and there was a slight decline in CPUE with depth.

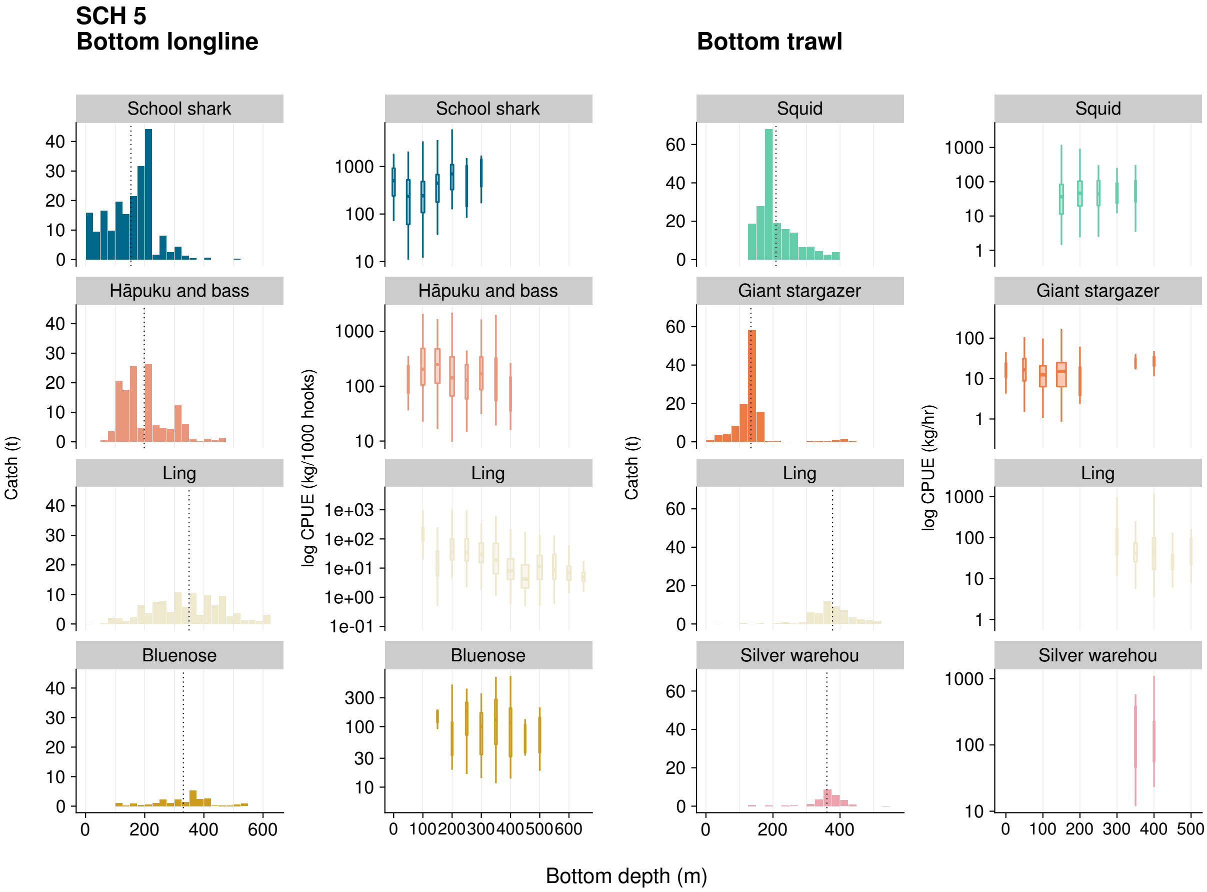

Figure 42: School shark catch and log catch-per-unit-effort (CPUE) by depth and fishing method for different target species in Quota Management Area SCH 5. Catch is in t and CPUE in kg per thousand hooks for bottom longline, and kg per hour for bottom trawl; records are aggregated over 50 m depth classes. Included records span 2007–08 to 2018–19. Target species were only included if they were among the top 5 contributors to school shark catch for the fishing method over the time period with at least 5% of the catch. Depth classes were only included in the boxplot panels if they included five records or more. Dotted vertical line on the catch panels denotes the mean depth of school shark catch for the target species. Boxplot hinges span the inter-quartile range (IQR), with lower and upper whiskers extending to the minimum and maximum observations within 1.5× the width of the IQR from the box. The relative width of the boxes within boxplot scales with the number of records included in the depth class.

SCH 7

School shark catches in SCH 7 were split between bottom trawl and bottom longline, with some contribution from set net (Figure 43, top panel). From 2016–17 to 2018–19, set net accounted for % of school shark catches, bottom longline for 41.8%, and bottom trawl for 43.7%. Set-net catches for school shark tended to be lower from June to October, followed by higher catches from November to April or May (Figure 44); this pattern was similar to the pattern observed for SCH 3 and SCH 5. School shark catches by bottom-longline effort also tended to be higher in warmer months from November to March, although in the last five years (from 2014–15 to 2018–19), there were also high catches in June and July. For bottom-trawl effort, catches tended to be lower between June and October, but there was otherwise no pronounced seasonal trend.

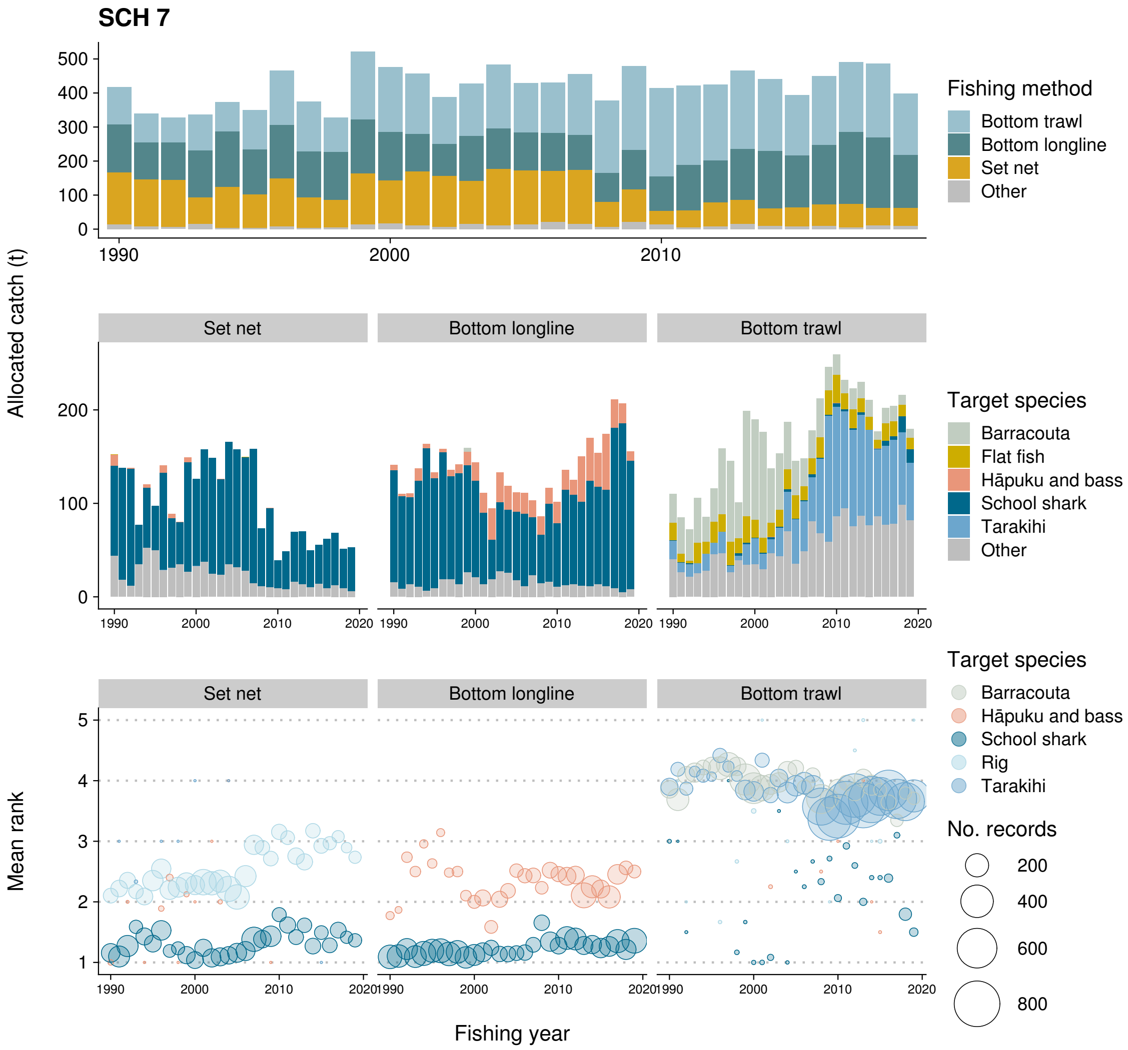

Figure 43: Allocated school shark catch (in t) for Quota Management Area SCH 7 over time, by fishing method (top), allocated catch by target species declared on the fishing event forms for each key fishing method (centre), and average school shark rank in the estimated catch forms by fishing method, aggregated by target species declared on the corresponding fishing event forms (bottom). Only the top 5 target species were included, calculated across fishing methods. The three most common "Other" target species were rig, ling, and hoki. The size of the circle of the average estimated rank scales with the number of records.

Key target species when capturing school shark were school shark for set net, school shark and hāpuku/bass for bottom longline, and tarakihi, barracouta, and flatfish for bottom trawl (Figure 43, centre panel). Other bottom-trawl target species where school shark was also captured included hoki and red cod. The estimated school shark catch rank for set net targeting both school shark and rig has increased since the mid-2000s because this fishery declined (Figure 43, bottom panel). In contrast, school shark has become more prevalent in bottom-trawl tows targeting tarakihi and barracouta.

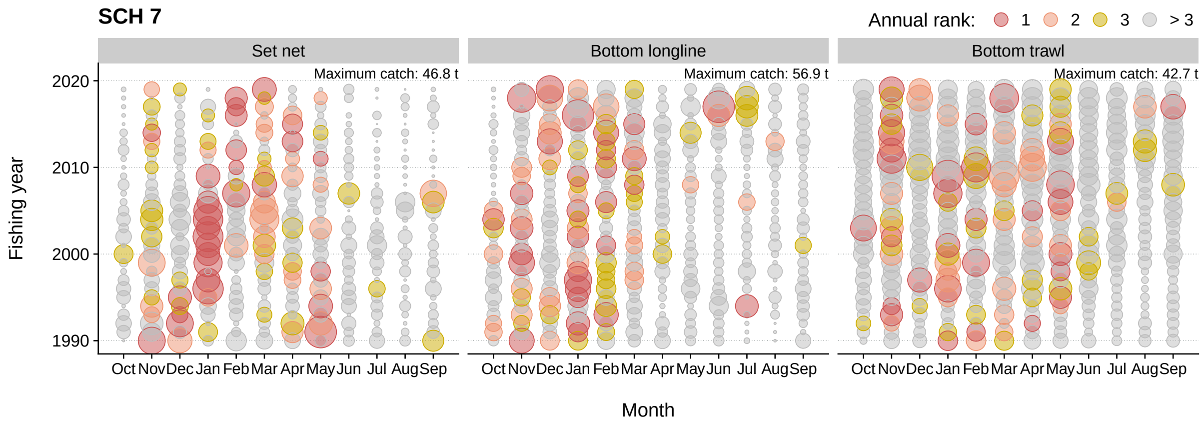

Figure 44: Seasonal distribution of school shark catch by month and fishing year, by fishing method for quota management area SCH 7, with the size of the circle scaling with the monthly allocated catch in t. The circle size was standardised within each fishing method; the monthly catch corresponding to the largest circle by method is noted in the top-right corner. For each fishing year, the three months with the larger catches during the year are highlighted in red, orange, and yellow, based on their rank.

In SCH 7, school shark catches by bottom-longline effort targeting school shark and hāpuku/bass occurred at a wide range of depths, between 25 and 300 m for school shark target and up to 400 m depth for hāpuku/bass target (Figure 45). For all key bottom-longline target species, there was a slight decline in school shark CPUE with depth, particularly for sets targeting hāpuku/bass. Bottom-trawl tows targeting tarakihi, barracouta, and stargazer caught most school shark at depths down to 200 m (sometimes to 300 m), with tows targeting gurnard and flatfish catching school sharks in waters shallower than 100 m depth. School shark CPUE increased with depth for all bottom-trawl target species.

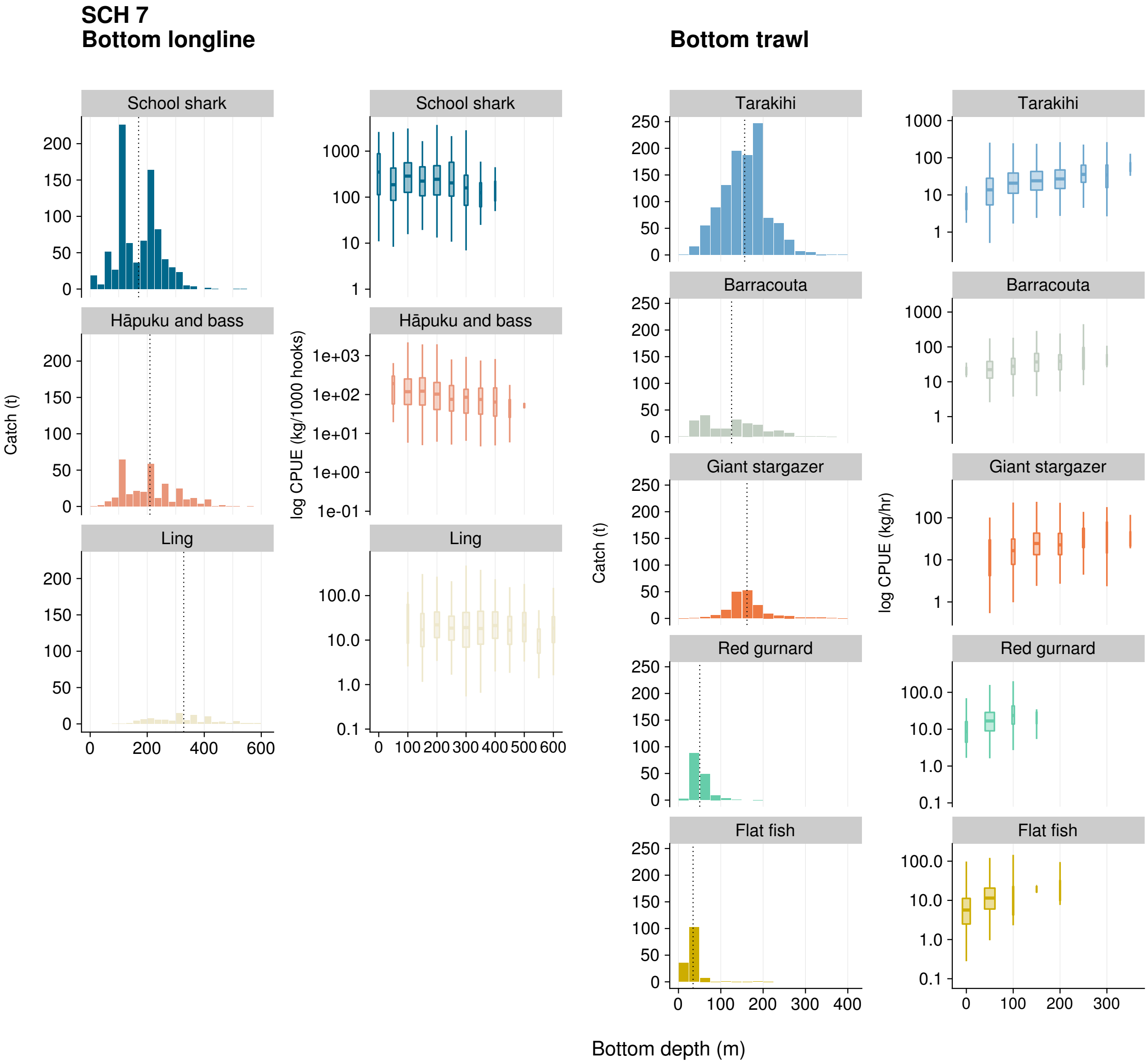

Figure 45: School shark catch and log catch-per-unit-effort (CPUE) by depth and fishing method for different target species in Quota Management Area SCH 7. Catch is in t and CPUE in kg per thousand hooks for bottom longline, and kg per hour for bottom trawl; records are aggregated over 50 m depth classes. Included records span 2007–08 to 2018–19. Target species were only included if they were among the top 5 contributors to school shark catch for the fishing method over the time period with at least 5% of the catch. Depth classes were only included in the boxplot panels if they included five records or more. Dotted vertical line on the catch panels denotes the mean depth of school shark catch for the target species. Boxplot hinges span the inter-quartile range (IQR), with lower and upper whiskers extending to the minimum and maximum observations within 1.5× the width of the IQR from the box. The relative width of the boxes within boxplot scales with the number of records included in the depth class.

SCH 8

In SCH 8, most school shark catches were previously by set net, but set-net catch levels declined over time due to fishery restrictions. For this reason, the relative contribution of bottom longline increased over time (Figure 46, top panel). From 2016–17 to 2018–19, set net effort accounted for % of school shark catches, bottom longline for 36.7%, and bottom trawl for 16.3%. Set-net catches for school shark in SCH 8 followed a similar pattern to those observed in SCH 3, SCH 5, and SCH 7, with generally high catches from November to late summer or early autumn, followed by low catches to the end of the fishing year (Figure 47). There was no clear seasonal trend for bottom longline in recent years, with catches ranking highest in February or March, and also June to September. Bottom-trawl catches were high from January to June up to the mid-2010s, but increased from October to December in the last five years (from 2014–15 to 2018–19).

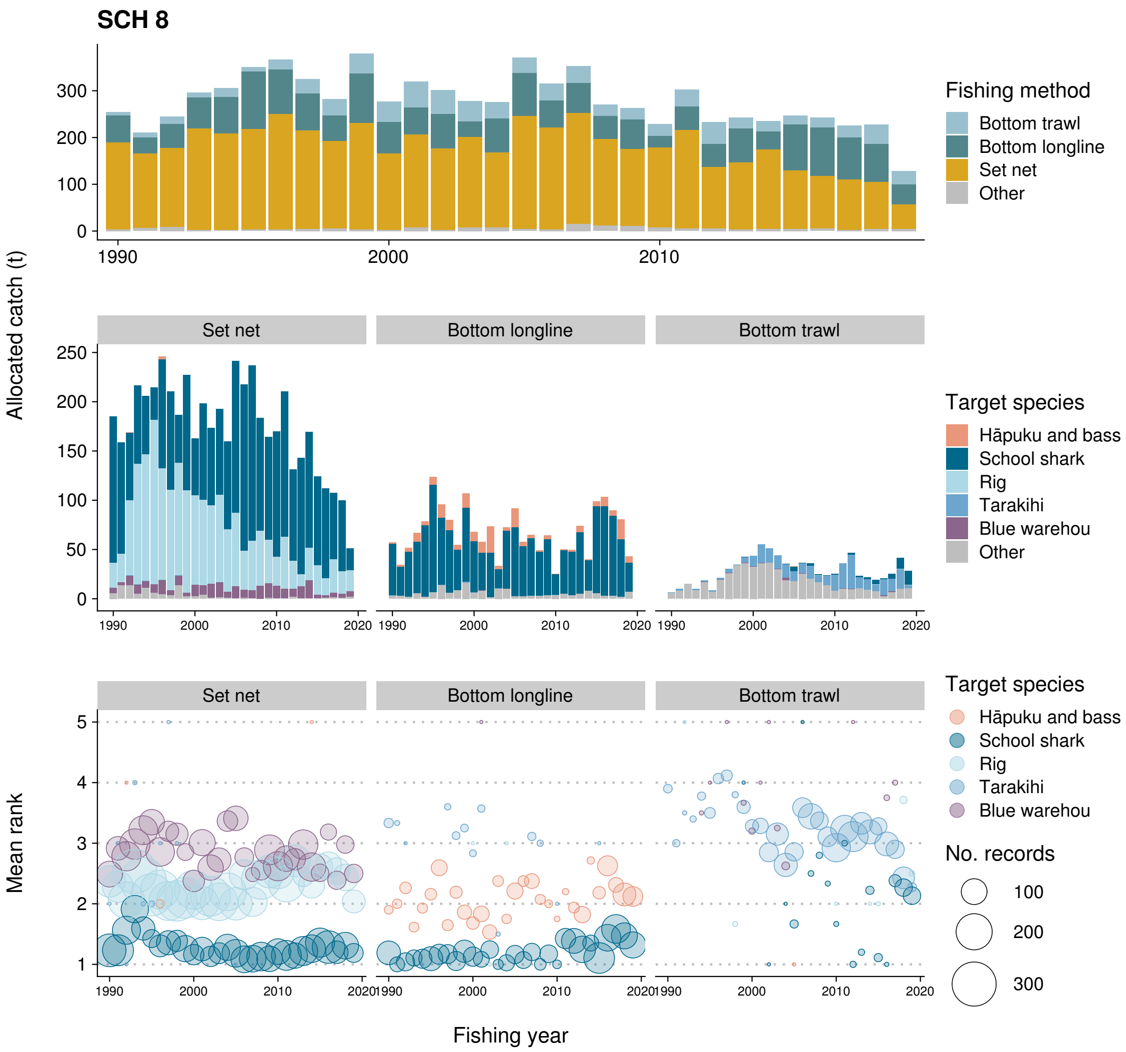

Figure 46: Allocated school shark catch (in t) for Quota Management Area SCH 8 over time, by fishing method (top), allocated catch by target species declared on the fishing event forms for each key fishing method (centre), and average school shark rank in the estimated catch forms by fishing method, aggregated by target species declared on the corresponding fishing event forms (bottom). Only the top 5 target species were included, calculated across fishing methods. The three most common "Other" target species were red gurnard, trevally, and bluenose. The size of the circle of the average estimated rank scales with the number of records.

Most of the school shark catches were on sets targeting school shark and rig for set nets, and on sets targeting school shark for bottom longlines (Figure 46, centre panel). School shark was mostly caught by bottom-trawl tows targeting tarahiki and, in the earlier part of the time series, red gurnard and trevally. There was a slight increase in estimated school shark rank for bottom longline targeting school shark. At the same time, there was a distinct decrease in rank in bottom-trawl tows targeting tarahiki, indicating that school shark became a more prevalent part of the catch (Figure 46, bottom panel).

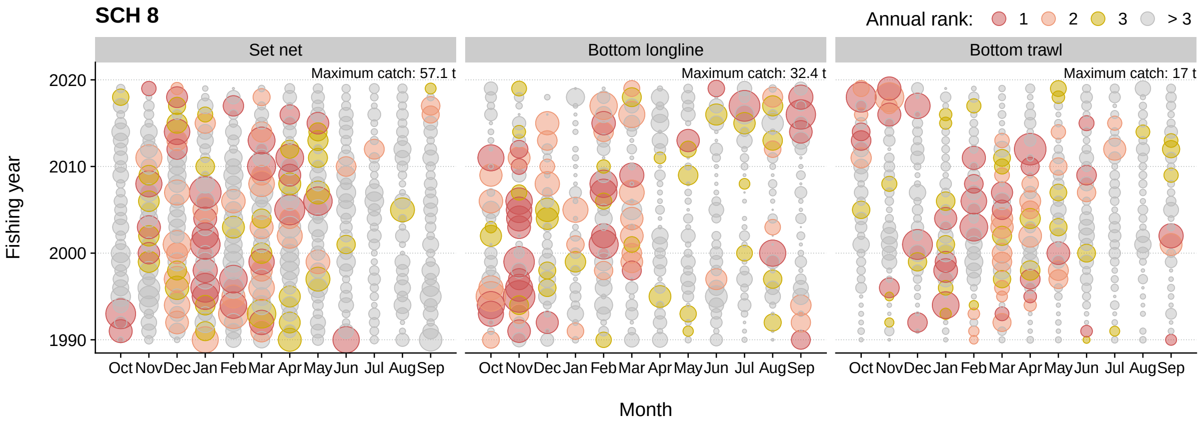

Figure 47: Seasonal distribution of school shark catch by month and fishing year, by fishing method for quota management area SCH 8, with the size of the circle scaling with the monthly allocated catch in t. The circle size was standardised within each fishing method; the monthly catch corresponding to the largest circle by method is noted in the top-right corner. For each fishing year, the three months with the larger catches during the year are highlighted in red, orange, and yellow, based on their rank.

Bottom-longline catches of school shark occurred mostly at depths to 250 m when school shark was targeted, with CPUE highest at 200 m depth (Figure 48). Catches by bottom-longline sets targeting hāpuku/bass occurred in deeper waters with no clear trend in CPUE. Bottom-trawl catches of school shark occurred in waters down to 200 m depth, with a slight increase in CPUE with depth for tows targeting school shark, red gurnard, and John dory.

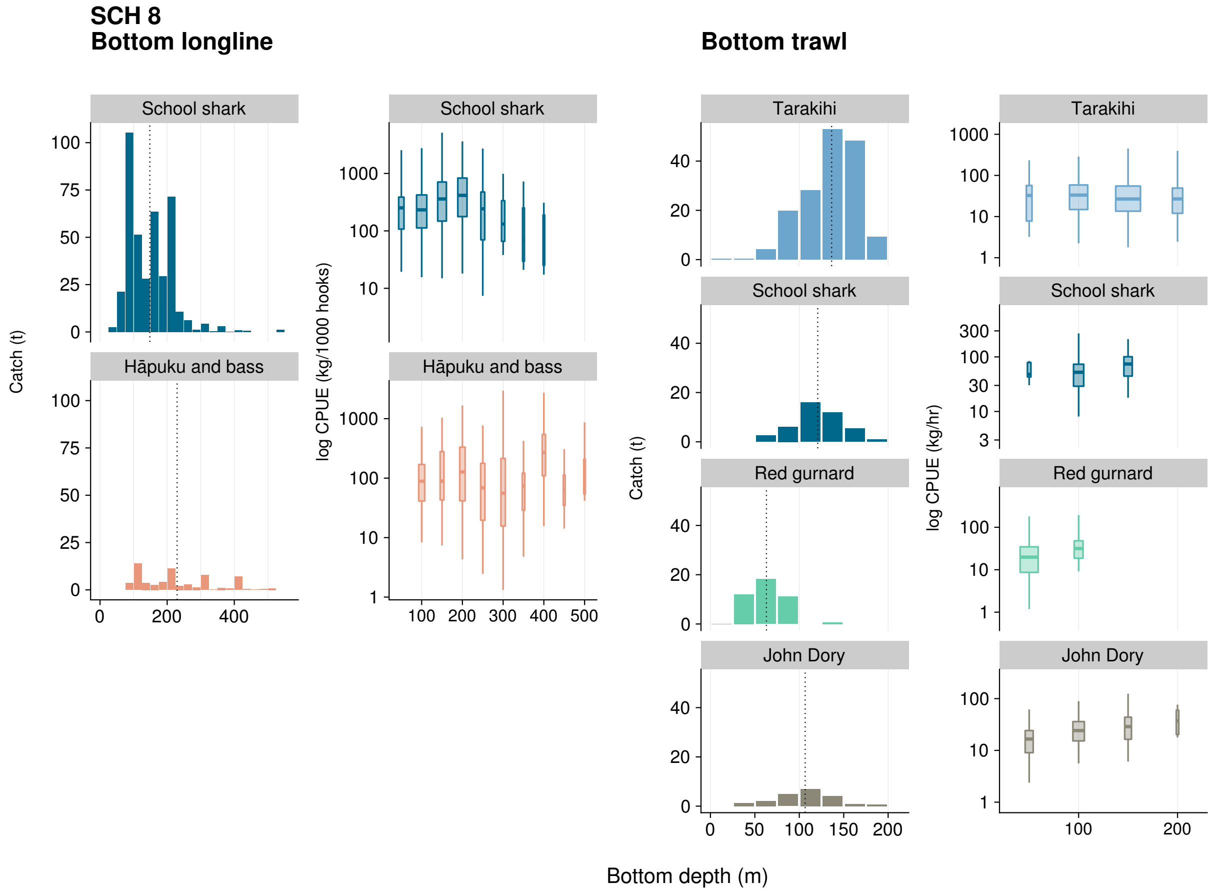

Figure 48: School shark catch and log catch-per-unit-effort (CPUE) by depth and fishing method for different target species in Quota Management Area SCH 8. Catch is in t and CPUE in kg per thousand hooks for bottom longline, and kg per hour for bottom trawl; records are aggregated over 50 m depth classes. Included records span 2007–08 to 2018–19. Target species were only included if they were among the top 5 contributors to school shark catch for the fishing method over the time period with at least 5% of the catch. Depth classes were only included in the boxplot panels if they included five records or more. Dotted vertical line on the catch panels denotes the mean depth of school shark catch for the target species. Boxplot hinges span the inter-quartile range (IQR), with lower and upper whiskers extending to the minimum and maximum observations within 1.5× the width of the IQR from the box. The relative width of the boxes within boxplot scales with the number of records included in the depth class.

3.3 CPUE standardisation

Standardised CPUE index series for school shark abundance were developed for set net, bottom longline, and bottom trawl for Far North & SCH 1E, SCH 2 & top of SCH 3, Lower SCH 3 & SCH 5, and SCH 7, SCH 8 & lower SCH 1W. For SCH 4, only bottom-longline series were developed. The set-net and bottom-longline series are updates of series previously presented to the INSWG (Dunn & Bian 2018), several of which had been accepted to represent school shark abundance in New Zealand. The four bottom-trawl series had not been previously presented to the INSWG. All new and updated series were presented to the INSWG at meetings held on 28 May and 20 October 2020. The series are described below for each fishery in the five CPUE units, with key conclusions accepted by the INSWG (see also Table 4 for a summary). All catch statistics refer to the main series considered by the working group, i.e., series at the daily resolution for set net and bottom longline, and series at the trip resolution for bottom trawl. Diagnostics for all series considered by the working group are included in Appendix G.

3.3.1 Far North & SCH 1E

Set net

Three series were developed for the set-net fishery in Far North & SCH 1E at three different effort resolutions: event, daily, and trip. The same core fleet definition was used for all effort resolutions, defined as vessels having participated in the fishery with at least five trips in five years. For the daily effort resolution, the core fleet consisted of 39 vessels which took 78.3% of the total catch. The allocated catches for the core fleet declined over time after being stable until the mid-2000s (Figure F-1). The proportion of positive catch events dropped in the recent time period (2008–09 to 2018–19) with some inter-annual variability; and positive catch events averaged 30.4% over time. The proportion of positive events was higher for effort recorded on NCELR forms compared with effort reported on CELR forms. The reason for this difference were a number of small vessels (less than 6 m length) operating in Kaipara and Manukau harbours, which were still permitted to report on CELR forms and which caught few school shark (Figure F-3, centre panel). This effect was also apparent in the nominal CPUE shown by form type (Figure F-3, bottom panel). The daily-resolution series was used for this CPUE unit given the low proportion of records allocated by effort (Figure G-3), and acceptable diagnostics of the selected model.

The selected binomial model for this fishery explained 22% of the deviance, and included vessel, target species, and month as covariates (Table G-3). The most influential covariate was vessel with a positive influence on the earlier part of the time series and a recent negative influence (Figure G-6).

The selected positive model explained 31.2% of the deviance, and included the covariates vessel, target species, and month (Table G-4). The most influential covariate was vessel with a positive influence between 1997–98 and 2005–06, and a negative influence between 2016–17 to 2018–19 (Figure G-7). Target species also had a negative influence between 2015–16 and 2018–19. The combined index reflected the increase in the binomial and positive indices in the recent time period, with a slow, increasing trend throughout the time series and a marked increase after 2013–14 (Figure 49).

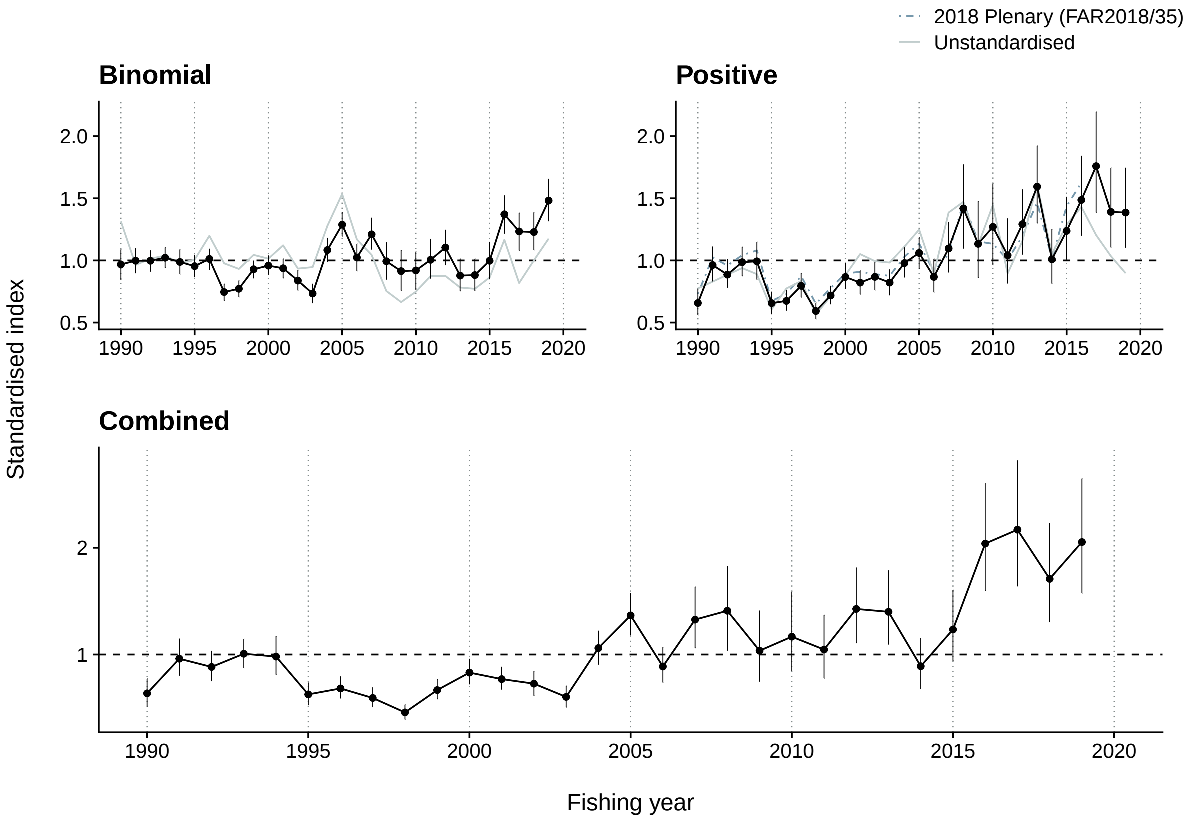

Figure 49: Standardised binomial, positive, and combined index for set net in Far North & SCH 1E. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference. FAR2018/35 is Dunn & Bian (2018).

Bottom longline

Three series were developed for the bottom-longline fishery in Far North & SCH 1E at the event, daily, and trip resolutions. The core fleet was defined as vessels participating in the fishery with at least five trips in five years. There were 79 vessels in the core fleet at the daily resolution, which took 76.2% of the total catch. Allocated catches for the bottom-longline core fleet increased up to the mid-2000s, and then decreased rapidly to a lower level between the mid-2000s and the early 2010s; there was another decline to a lower level from the early 2010s onwards (Figure F-4). The proportion of positive catch increased over time across all three effort resolutions (Figure F-4). Catches in 2018–19 increased considerably compared with 2017–18 catches. The average rate of positive catch events was 30.3% over the most recent three years (2016–17 to 2018–19). For this fishery, the daily resolution series was selected by the INSWG, based on the low proportion of allocated catch by effort (Figure G-15) and acceptable model diagnostics.

The selected binomial model for bottom longline in Far North & SCH 1E explained 17.8% of the deviance, and included vessel and target species as covariates (Table G-8). Vessel had a positive influence on the standardised index, inflating the nominal index from 2013–14 to 2017–18 (Figure G-18).

The selected positive model explained 42.9% of the deviance, and included vessel, target species, and statistical area (Table G-9). Vessel had a strong influence in the first part of the time series, cancelling an increase in the nominal index between 1989–90 and 2006–07 (Figure G-19). Target species had a negative influence in the latter part of the time series, also resulting in a less pronounced decline in the standardised trend. The combined daily index series was mostly stable up to 2001–02, after which it shifted to a higher level; it kept increasing from 2006–07 to a peak in 2011–12 followed by a decline to 2016–17. After 2016–17, the series increased markedly for two years to 2018–19 (Figure 50).

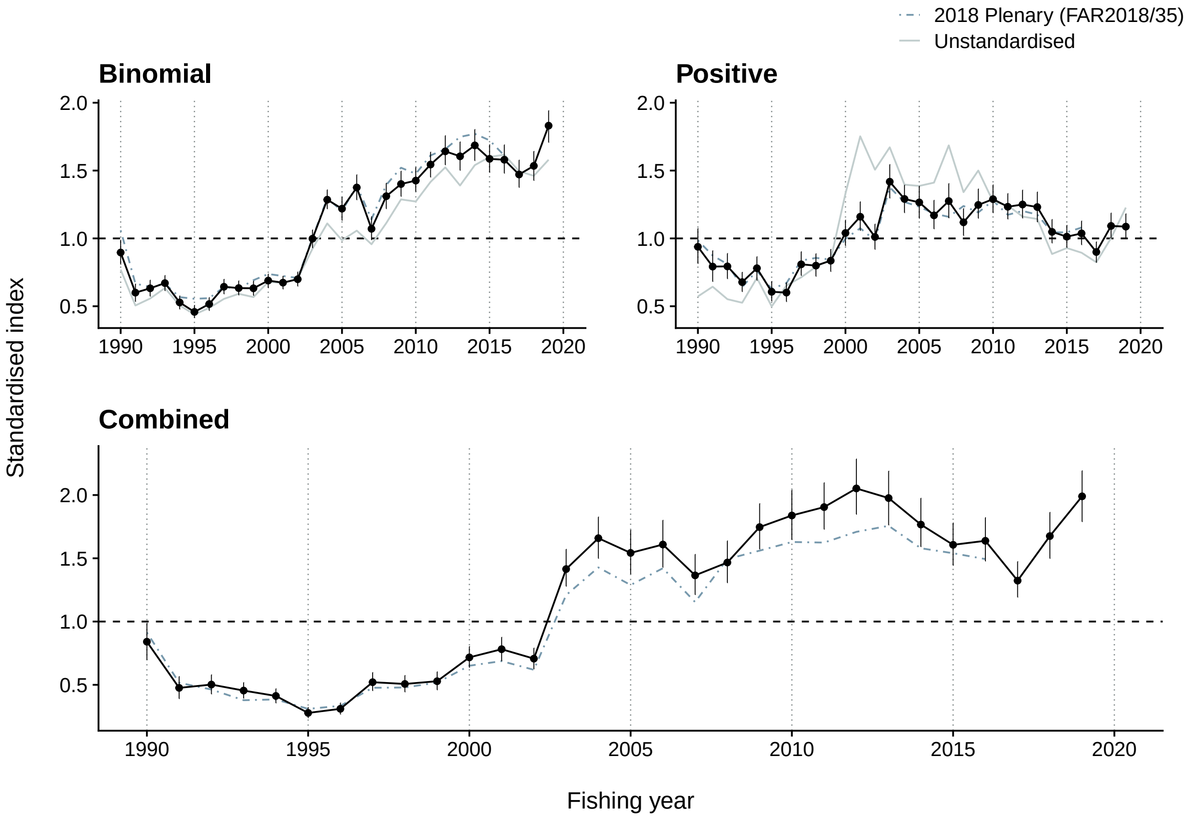

Figure 50: Standardised binomial, positive, and combined index for bottom longline in Far North & SCH 1E. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference. FAR2018/35 is Dunn & Bian (2018).

Bottom trawl

Standardised index series were developed for the bottom-trawl fishery in Far North & SCH 1E at the event, daily, and trip effort resolution. Data from fishing trips in multiple CPUE units were omitted from the full fleet dataset, corresponding to 28.8% of the catches and 16.7% of fishing trips (Figure G-28). There were 48 vessels meeting the selection criteria for the core fleet at the trip resolution, with 89.1% of the full fleet's total catch. Allocated catches for the core fleet generally increased over time, but were sensitive to data resolution (Figure F-7). There was also marked decline in allocated catches in 2017–18 and 2018–19 for all three effort-resolution levels (Figure F-7). The proportion of positive catch increased over time, but was also sensitive to the data resolution, with the rate of positive events highest at the trip resolution (average of 76.1% over 2016–17 to 2018–19; Figure F-7). The trip resolution series was selected by the INSWG to represent this fishery given the high proportion of catches allocated by effort and the consequent bias in the binomial series (Figure G-27).

The selected binomial model for the bottom trawl fishery in Far North & SCH 1E explained 28.5% of the deviance, and included statistical area, target species, and vessel as explanatory variables (Table G-13). Statistical area showed some positive influence on the nominal index from 2013–14 (Figure G-31).

The selected positive model explained 49.5% of the deviance and included statistical area, fishing duration, vessel key, and target species as explanatory variables (Table G-14). Statistical area had the highest impact on the standardised series, with a positive influence at the start of the time series and between 2014–115 and 2016–17; it had a negative influence in the middle part of the series (Figure G-32). Both the vessel and the fishing duration covariates had a positive influence on the nominal index from the mid-2000s to 2014–15. The combined index showed two relatively stable periods, with one period extending from 1989–90 to 2002–03. The other period was at a higher level, extending to 2016–17, after which there was a notable increase to 2018–19 (Figure 51).

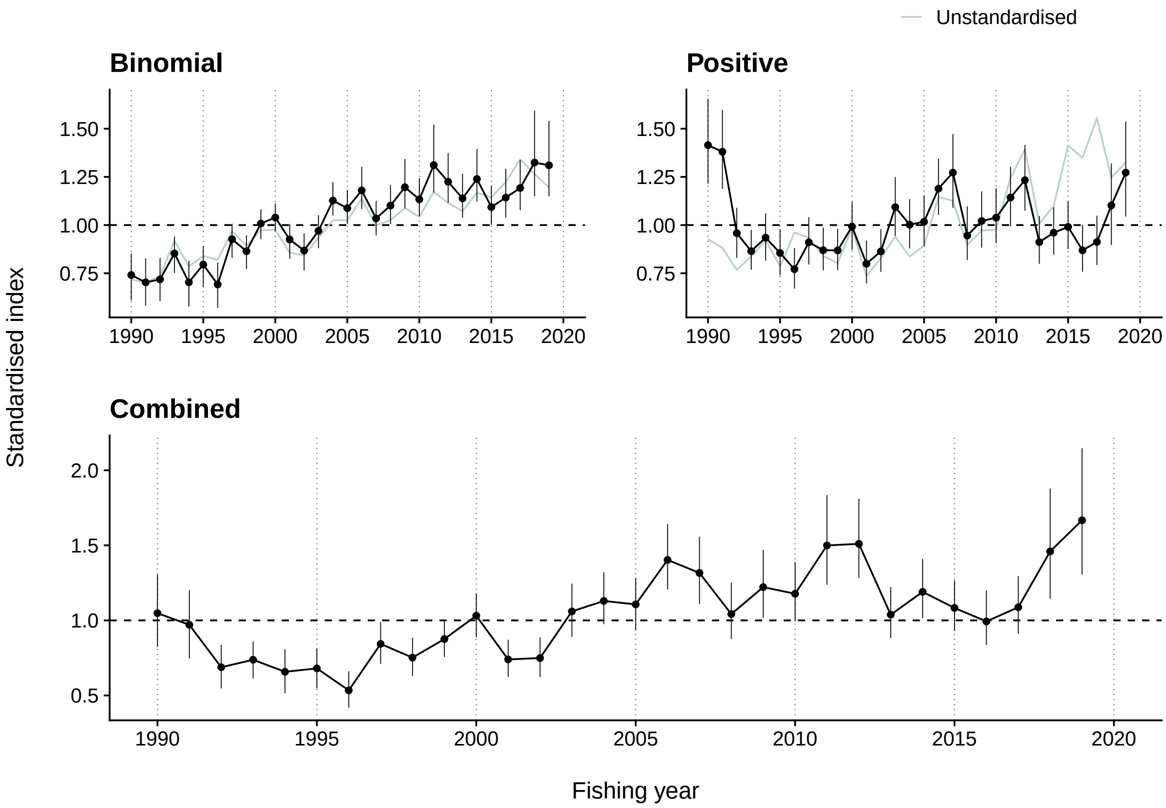

Figure 51: Standardised binomial, positive, and combined index for bottom trawl in Far North & SCH 1E. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference.

Summary

The INSWG accepted all three combined CPUE series as indices of abundance for the Far North & SCH 1E CPUE unit: set net at the daily effort resolution, bottom longline at the daily effort resolution, and bottom trawl at the trip effort resolution (Figure 52). All three series showed a similar relative trend with a stable biomass at the start of the time series to 2001–02 and a steady increase afterwards. The INSWG defined the region-wide series as the average of all three series (Figure 52).

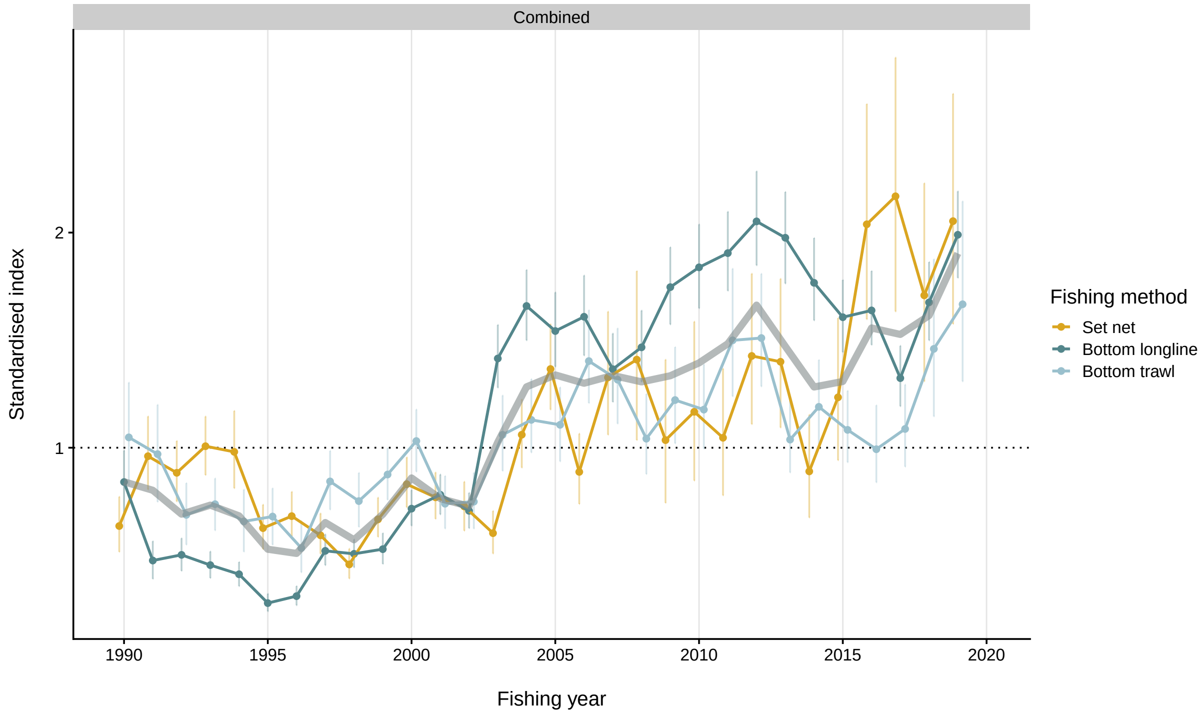

Figure 52: Comparison of key standardised catch-per-unit-effort indices across fishing methods for Far North & SCH 1E. All series are combined binomial-lognormal indices. Points show the point estimates for each year, vertical lines the 95% confidence intervals for each series. The series are slightly offset to improve clarity; the level of no change (index value of 1) is shown with a dotted line for reference. Bold line shows the arithmetic mean of the set-net, bottom-longline and bottom-trawl point estimates.

3.3.2 SCH 2 and top of SCH 3

Set net

Three series were developed for the set-net fishery in SCH 2 & top of SCH 3 at the event, daily, and trip effort resolution. The core fleet was defined as vessels having participating in the fishery with at least five trips in four years. There were 40 vessels in the core fleet at the daily resolution, which caught 86.1% of the total set-net catch in the dataset. Allocated catches for the core fleet showed a steady increase from 1990–91, stabilised at a relatively high plateau from the late 1990s to the early 2000s, before declining by half to the late 2000s (Figure F-10). Catches increased again to a peak in 2014–15, then decreased markedly to 2018–19. The proportion of positive catch events increased steadily to the late 2000s, stabilising near 75% in the recent ten-year period (2008–09 to 2018–19). The primary series considered for this fishery was the daily effort series given the low proportion of catches allocated by effort (Figure G-40). A trip effort series was developed as a diagnostic series given there was some divergence between the daily effort and event-based series.

The selected binomial model at the daily resolution for this fishery explained 30.5% of the deviance and retained vessel and month as covariates (Table G-18). Vessel was particularly influential throughout the time series, stabilising the increasing trend in positive catch events through time, except in the two most recent years (2017–18 and 2018–19) (Figure G-43).

The selected positive catch model explained 42% of the deviance with vessel, target species, month, and net length as covariates (Table G-19). The main standardisation effect was between 2011–12 and 2015–16, when a marked increase in nominal CPUE was accounted for by the target species effect (Figure G-44). Some variability in the nominal CPUE was also accounted for by the vessel effect. The resulting combined index increased steadily throughout the time series (Figure 53).

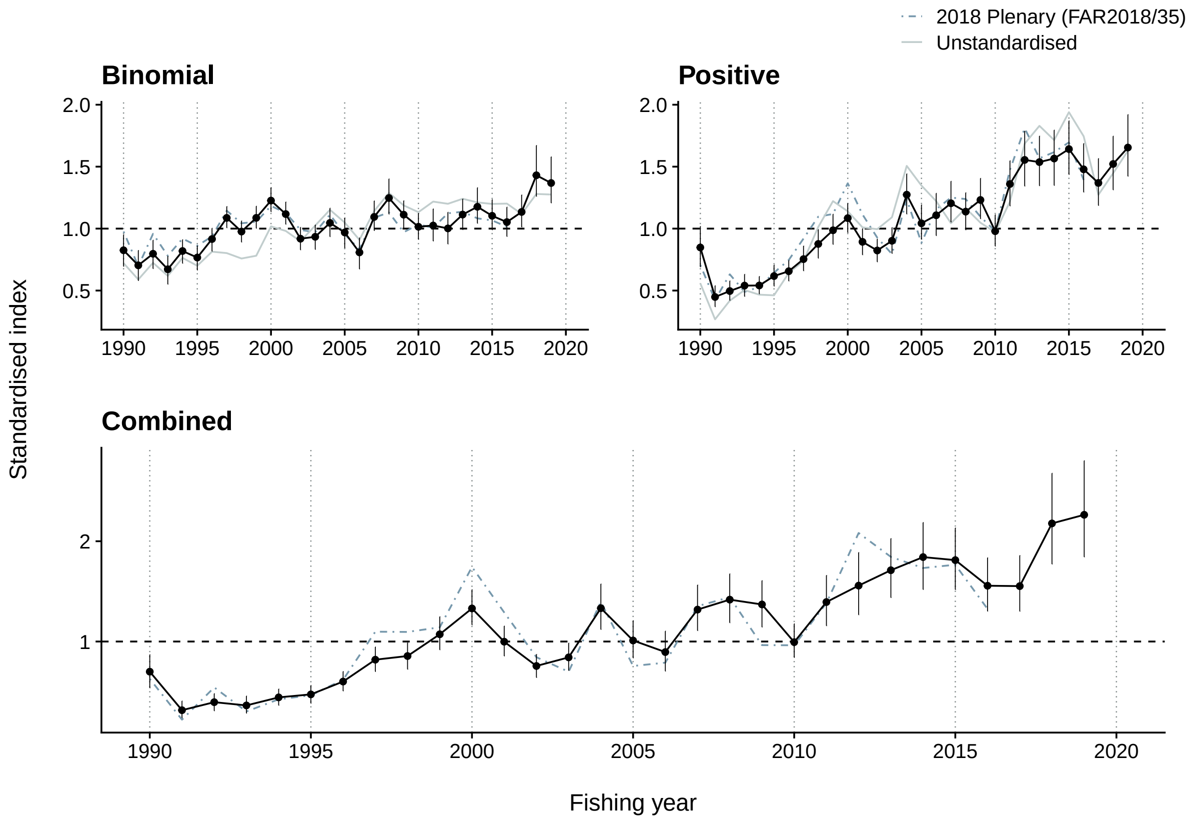

Figure 53: Standardised binomial, positive, and combined index for set net in SCH 2 & top of SCH 3. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference. FAR2018/35 is Dunn & Bian (2018).

Bottom longline

Index series for the bottom-longline fishery in SCH 2 & top of SCH 3 were developed at three levels of effort resolution: event, daily, and trip. The spatial definition for the bottom-longline series was slightly narrower than for the set-net series, only including the northern component of the CPUE unit definition (i.e., only statistical areas off the east coast of North Island) (Starr & Kendrick 2016). The same core fleet definition was used for all three series, with vessels participating in the fishery for at least three trips in four years. The core fleet at the daily resolution consisted of 40 vessels, taking 84.1% of the total catch in the dataset. The allocated catches for the core fleet increased steadily up to 2013–14, and declined subsequently (Figure F-13).

The proportion of positive catch events differed depending on the effort resolution. At the trip effort resolution, positive school shark occurrence increased steadily over time with a recent average of 77.1% between 2009–10 and 2018–19. The daily effort resolution dataset had an equivalent positive occurrence average of 40.8%, with no trend over time (Figure F-13). At the event effort resolution, the positive catch trajectory was similar to the daily trajectory, except that it was offset to a lower proportion of positive records. There were a number of multiple fishing events per day in this fishery, with a considerable increase in the number of sets in a day to more than three sets in 2018–19 (Figure F-14). The mean number of days per trips increased in the late 2000s to over four days per trip. The main index series considered for this fishery was the daily effort series, given the low proportion of catches allocated according to effort (Figure G-52) and acceptable model diagnostics.

The selected model for the binomial index at the daily resolution in this fishery explained 11.9% of the deviance, with target species, vessel, and statistical area retained as model covariates (Table G-23).

Amongst the covariates, vessel had the highest impact with a negative influence on the nominal index at the start of the time series, which resulted in a declining trend in the standardised series (Figure G-55).

The selected model for the positive catch index explained 30.9% of the deviance and included target species, vessel, statistical area, and hook number as explanatory variables (Table G-24). Target species and vessel had the greatest influence, with the addition of target species resulting in a somewhat steeper decline in the CPUE series; the addition of a vessel covariate further steepened the decline in the earlier part of the series (Figure G-56). The resulting combined index decreased from 1989–90 to 2000–01, and then continued to decline at a slower rate (Figure 54).

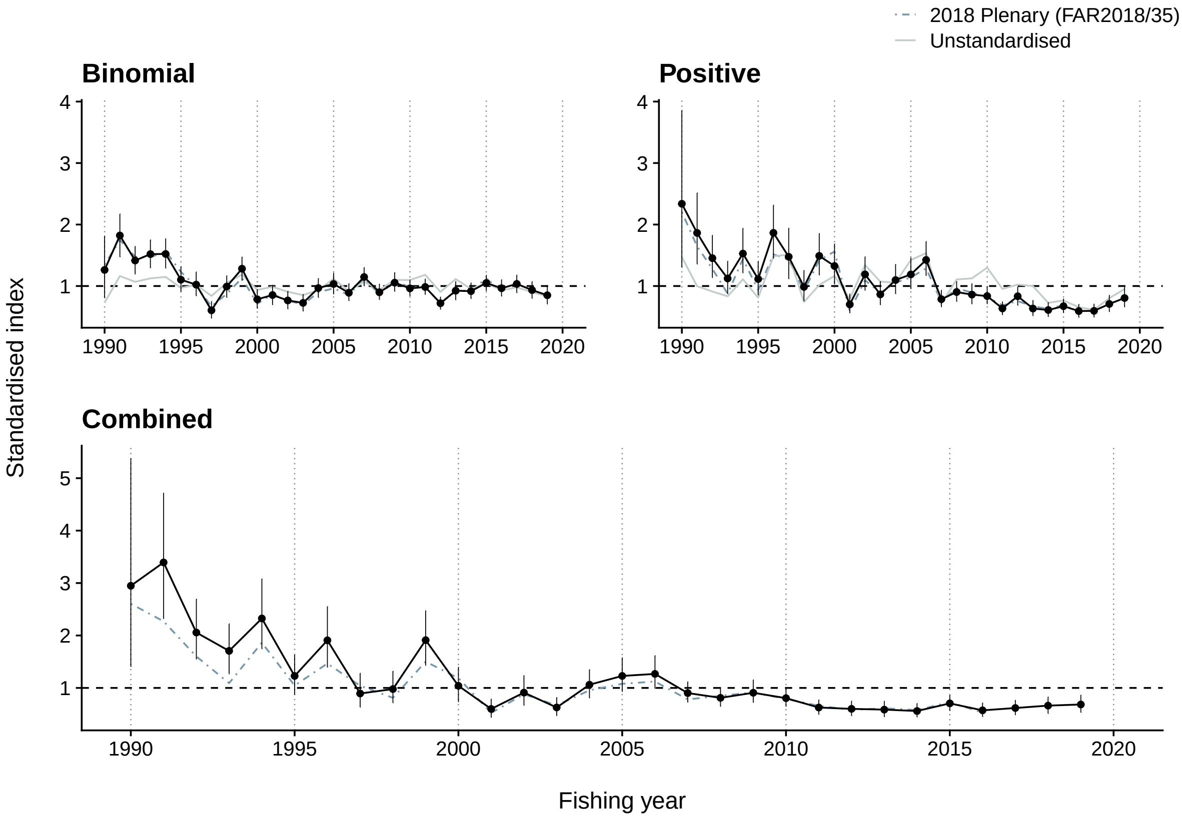

Figure 54: Standardised binomial, positive, and combined index for bottom longline in SCH 2 & top of SCH 3. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference. FAR2018/35 is Dunn & Bian (2018).

Bottom trawl

Bottom-trawl index series for SCH 2 & top of SCH 3 were developed at the event, daily, and trip effort resolution. Trips fishing in multiple CPUE units were omitted from the full fleet dataset, corresponding to 25.2% of the catches and 18.8% of trips (Figure G-65). The core fleet was defined as vessels having participated in the fishery with at least five trips in five years. The core fleet at the trip effort resolution for this fishery consisted of 72 vessels, which caught 83.9% of the full fleet catch. Allocated catches for the core fleet increased between 1991–92 and 2006–07, but subsequently declined, with some variability (Figure F-16). The proportion of positive catch events increased over time and stabilised at 60.1% over the last ten years (2009–10 to 2018–19); trip resolution had the highest average positive rate at nearly 60% (Figure F-16).

Positive occurrence rate is sensitive to the effort resolution in the later part of the time series, increasing from event to daily to trip resolution. The length of trips increased over time, approaching three days in the final three years of the dataset (2016–17 to 2018–19) (Figure F-17). The trip-level index series was the series preferred by the INSWG for this fishery, given the high proportion of catch allocated by effort (Figure G-64) and acceptable model diagnostics.

The selected binomial model for the trip-level index explained 29.9% of the deviance, with vessel, fishing duration, and month retained as covariates (Table G-28). Vessel had the greatest effect on the standardised series, with a negative influence between 1998–99 and 2003–04, and a positive influence from 2016–17 to 2018–19 (Figure G-68). The standardised series increased from the start of the series to 1999–00, remained at a high level until the early 2000s, and then declined to an intermediate plateau, where it remained up to 2018–19 (Figure 55, top left).

The selected positive catch model explained 39.8% of the variance, with vessel, fishing duration, month, and target species as covariates (Table G-29). Vessel and fishing duration had the greatest effect on the standardised series, with the inclusion of vessel flattening the slight increase in nominal CPUE and fishing duration having a negative influence throughout the time series, resulting in a standardised index declining over time (Figure G-69). The combined index series showed high variability with an increase at the start of the time series up to 1999–2000, and a declining trend beginning in 2002–03 (Figure 55).

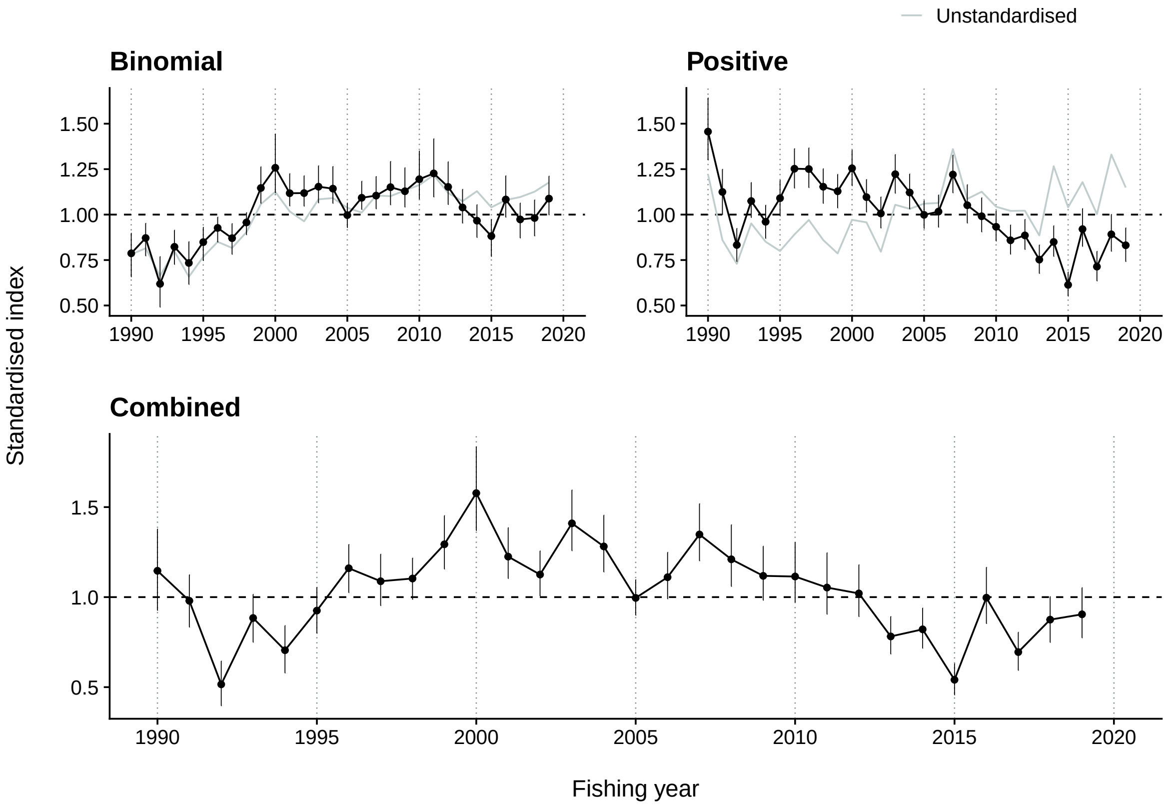

Figure 55: Standardised binomial, positive, and combined index for bottom trawl in SCH 2 & top of SCH 3. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference.

Summary

Owing to the conflicting trends in the set-net, bottom-longline, and bottom-trawl index series, none of these series were accepted by the INSWG as indicative of the abundance in SCH 2 & top of SCH 3 (Figure 56). The bottom-trawl series was developed to provide additional information on possible abundance trends in this region, given the conflicting trends previously observed between the set-net and bottom-longline series (Dunn & Bian 2018). Because the combined bottom-trawl series matched the combined set-net series up to 2009–10 and the combined bottom-longline series in subsequent years, the addition of the bottom-trawl series did not resolve the conflict among the three series available (Figure 56). Furthermore, the east coast South Island trawl survey was not considered as a suitable index of school shark abundance because it almost exclusively sampled juveniles. Also, the survey's spatial coverage only included a small area at the southern end of SCH 2 & top of SCH 3, not including the east coast of North Island.

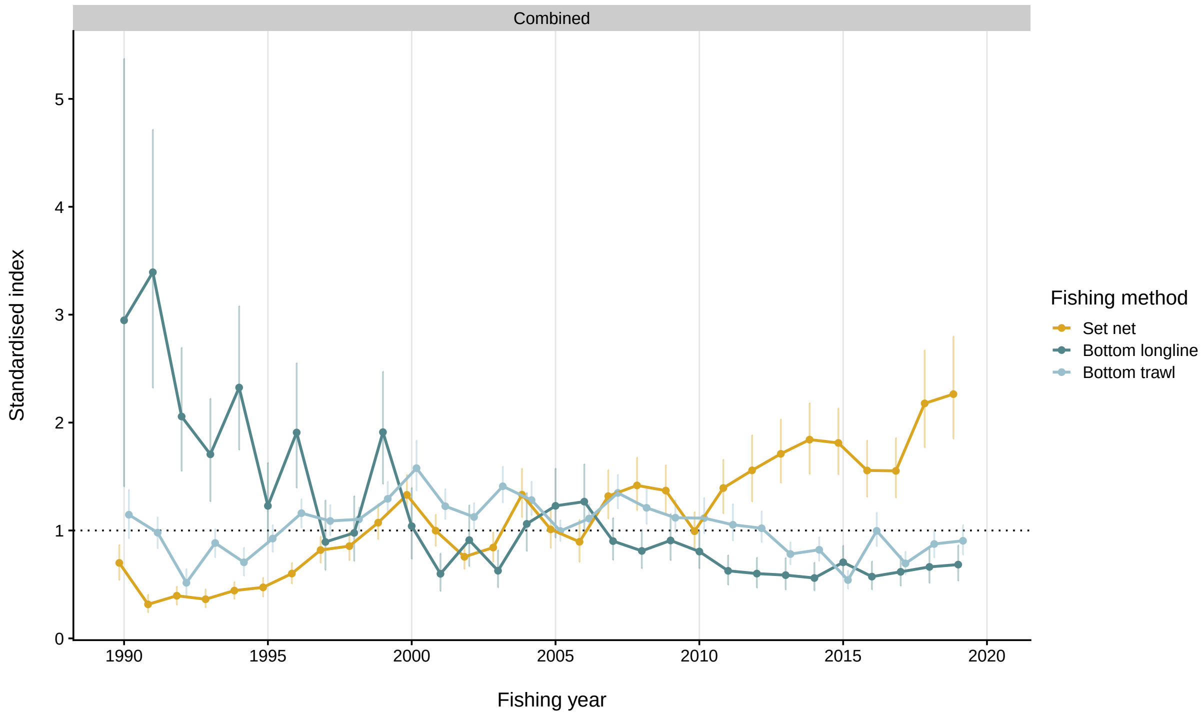

Figure 56: Comparison of key standardised CPUE indices across fishing methods for SCH 2 & top of SCH 3. All series are combined binomial-lognormal indices. Points show the point estimates for each year, vertical lines the 95% confidence intervals for each series. The series are slightly offset to improve clarity; the level of no change (index value of 1) is shown with a dotted line for reference. Bold line shows the arithmetic mean of the set-net, bottom-longline and bottom-trawl point estimates.

3.3.3 Chatham Rise (SCH 4)

Bottom longline

Bottom longline was the only Chatham Rise (SCH 4) fishery that had sufficient data to be developed into an index series. Index series for the bottom-longline fishery were developed using daily and event effort resolution. These series started later (2003–04) than other school shark series because of insufficient data in the preceding years. The core fleet for these series was defined as vessels having participated in the fishery with at least three trips in three years. There were 17 vessels in the core fleet at the daily resolution for this fishery, taking 88.2% of the total catch. Core fleet catches increased from 2003–04 to 2011–12, and have been variable since then, including a marked decline in catch in 2017–18 and 2018–19 (Figure F-19). At the daily resolution, the proportion of positive school shark catch declined slightly over time, with an average of 58.3%. Trips in SCH 4 were longer than in other areas, approaching ten days per trip in the most recent year (2018–19), with multiple sets per day (Figure F-20). The main index series considered for this fishery was the daily effort resolution series given the low proportion of catches allocated according to fishing effort (Figure G-77) and acceptable model diagnostics.

The selected binomial model for school shark in Chatham Rise (SCH 4) explained 20.3% of the deviance, with target species, vessel, month, and effort number selected as covariates (Table G-33). There was a standardisation effect of target species at the start and end of the time series, which increased the rate of decline in the standardised index (Figure G-80). Vessel also had a positive influence on the nominal index from 2006–07 to 2011–12. The final index series showed a slight decline overall with some variability throughout the time series (Figure 57, top left).

The selected positive catch model explained 47.7% of the deviance, and included target species, hook number, vessel, and statistical area as covariates (Table G-34). Target species had the greatest impact on the standardised index, with a negative influence at the start, and a positive influence towards the end of the time series, as the prevalence of sets targeting school shark increased in the dataset (Figure G-81 and Figure G-82). The final positive index series did not show a discernible trend, although there was considerable inter-annual variability and a potentially increasing trend at the end of the series. The combined index series showed no trend, but was highly variable in the earlier part of the time series (Figure 57).

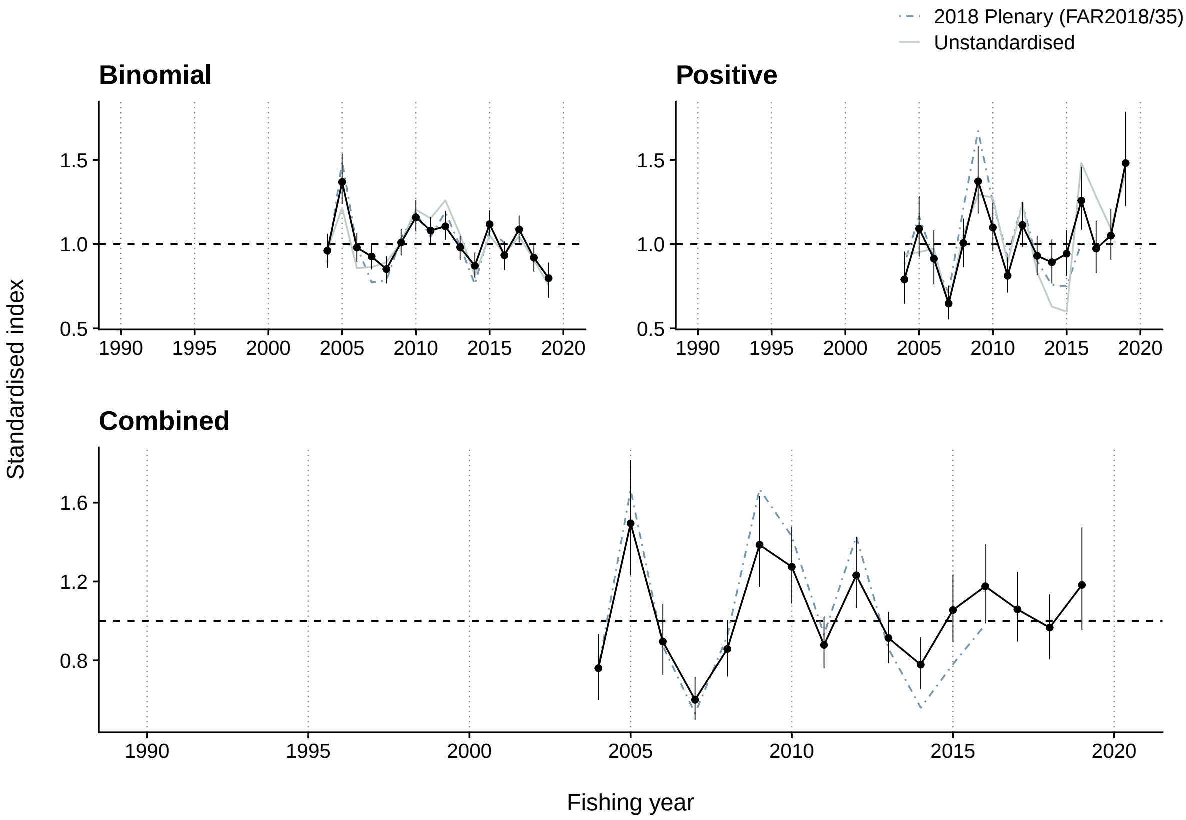

Figure 57: Standardised binomial, positive, and combined index for bottom longline in Chatham Rise (SCH 4). Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference. FAR2018/35 is Dunn & Bian (2018).

Summary

The bottom-longline standardised combined index at the daily resolution was accepted by the INSWG as an index of abundance for school shark in Chatham Rise (SCH 4) (Figure 57). Biomass estimates from the Chatham Rise trawl survey were not accepted, because the survey's depth range, beginning at 300 m, did not include a key part of the preferred depth range of school shark, and only large individuals were sampled during the survey.

3.3.4 Lower SCH 3 and SCH 5

Set net

Three index series were developed for set net in Lower SCH 3 & SCH 5 at the event, daily, and trip effort resolution. The core fleet was defined as vessels having participated in the fishery with at least three trips in four years. The core fleet for this fishery at the daily resolution consisted of 60 vessels, which took 96.8% of the total set-net catch. Allocated catches for the core fleet increased over time up to 2009–10, and have since then declined, with a notable drop in the last year of the time series (2018–19) (Figure F-22). This drop was greater at the daily and event resolution. The proportion of occurrence of school shark in the catch was high and increased into the mid-2000s, stabilising at 86.9% from 2009–10 to 2018–19. Most trips lasted one day, although average trip length increased slightly since 2000–01 (Figure F-23). The main index series considered for this area was at the daily effort resolution given the low proportion of records allocated by effort (Figure G-89) and acceptable model diagnostics.

The selected binomial model for Lower SCH 3 & SCH 5 explained 24.1% of the deviance, and included vessel, month, target species, and statistical area (Table G-38). Vessel had the most impact on the standardised index, with a negative influence in the earlier part of the time series, which raised the standardised index. In the latter part, this covariate had a positive influence, which decreased the standardised index (Figure G-92). The most likely explanation for this trend was that less efficient vessels had left the fishery (Figure G-96). The overall standardised rate of occurrence was stable but variable (Figure 58, top left).

The selected positive catch model explained 60.8% of the deviance, and retained vessel, target species, statistical area, and month as covariates. Vessel and target species had the greatest impact on the standardised series (Table G-39). Similar to the binomial model, the vessel covariate increased the rate of decline of the standardised index compared with the nominal index (Table G-39). Target species increased the variability in the index from 1999–2000 to 2005–06 due to a decline in sets targeting school shark during this period. The positive standardised series declined steadily over time, resulting in a combined index series that was also declining, with both series showing considerable inter-annual variability (Figure 58).

Bottom longline

Standardised index series for the bottom-longline fishery in Lower SCH 3 & SCH 5 were developed at the daily and event effort resolution level. The bottom-longline fishery in Lower SCH 3 & SCH 5 mostly operated off the west coast of South Island off Fiordland, but the definition of the CPUE unit also included statistical areas on the east coast (Starr & Kendrick 2016). The core fleet was defined as vessels having participated in the fishery with at least three trips in three years. There were 29 vessels in the core fleet at the daily resolution, which made up 73.5% of the total school shark catch in the dataset.

Core fleet catches for this fishery increased over time, with smaller catches between 2011–12 and 2014–15, and a notable increase in catches in 2017–18 (Figure F-25). At the daily resolution, the proportion of school shark occurrence in the catch increased slowly throughout the time series, with an average of 48.7% overall; the rate of increase at the trip effort resolution was greater (Figure F-25). The average number of sets per day was constant over time (between 1.25 and 1.50 sets per day; Figure F-25). The main series considered for this fishery was the daily effort resolution series given the low proportion of catches allocated by effort (Figure G-102) and acceptable model diagnostics.

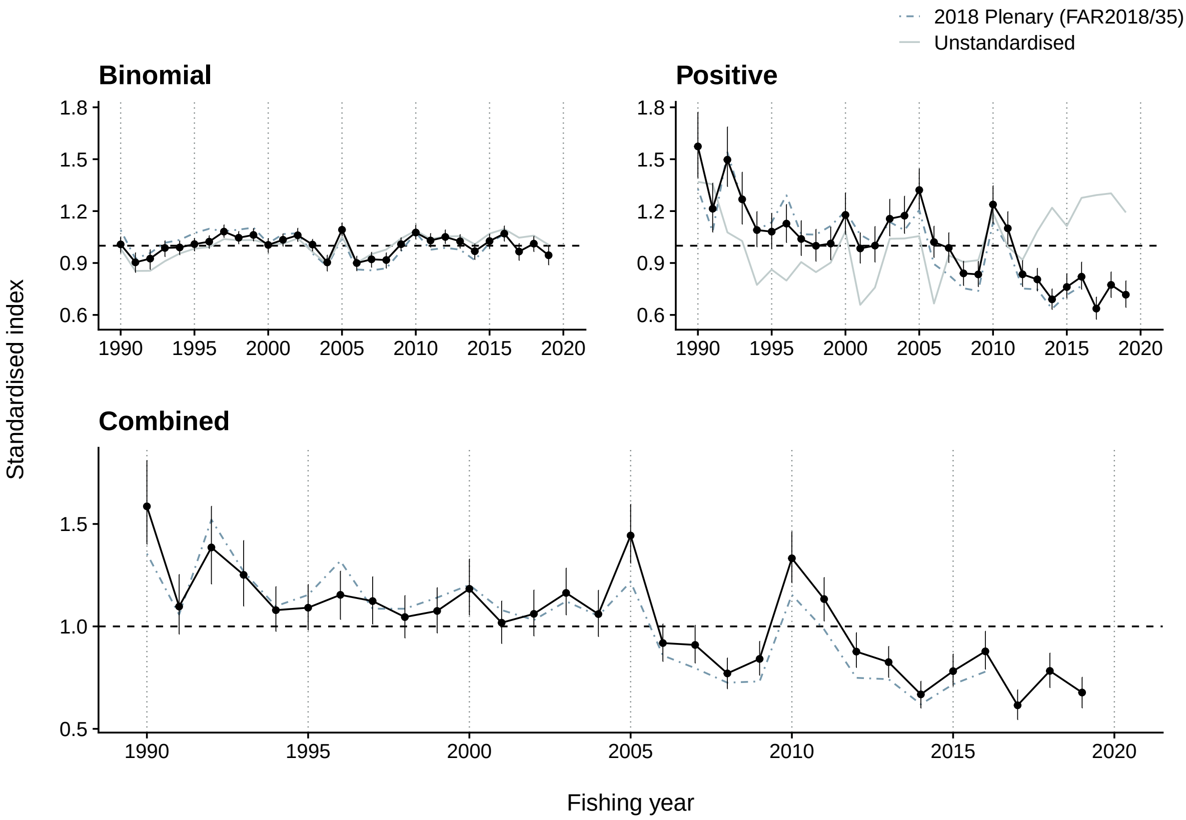

Figure 58: Standardised binomial, positive, and combined index for bottom longline in Lower SCH 3 & SCH 5. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference. FAR2018/35 is Dunn & Bian (2018).

The selected binomial model for bottom longline in Lower SCH 3 & SCH 5 explained 13.3% of the deviance and retained target species, vessel, and month as covariates (Table G-43). There was little standardisation effect, except for vessel and target species in the first year (i.e., intercept), which resulted in a pronounced increase in the value of the standardised index compared with the nominal index for that year (Figure G-105). Because of this effect, the overall trend showed a marked decrease from the first year, and a slow increase throughout the remainder of the time series (Figure 59, top left). The marked decline in the first year is unlikely to be representative of occurrence, but reflects the poor data availability in this fishing year.

The selected positive model explained 45.4% of the deviance, with target species, statistical area, month, and vessel as covariates (Table G-44). Target species and statistical area had the greatest impact on the standardised index (Figure G-106). Target species had a negative influence on the nominal index at the start of the time series (up to 1998–99), and a positive influence between 2000–01 and 2006–07. Statistical area was influential throughout the time series, depending on the spatial distribution of effort; in particular, Statistical Area 030 was associated with a high model coefficient, but had variable fishing effort throughout the time series (Figure G-108). The final positive series showed a slight increasing trend, but was mostly constant with high inter-annual variability (Figure 59, top right). The combined series showed a considerable decline in 1990–91 (reflecting the likely biased binomial index for that year), and a slowly increasing trend over time with some inter-annual variability (Figure 59).

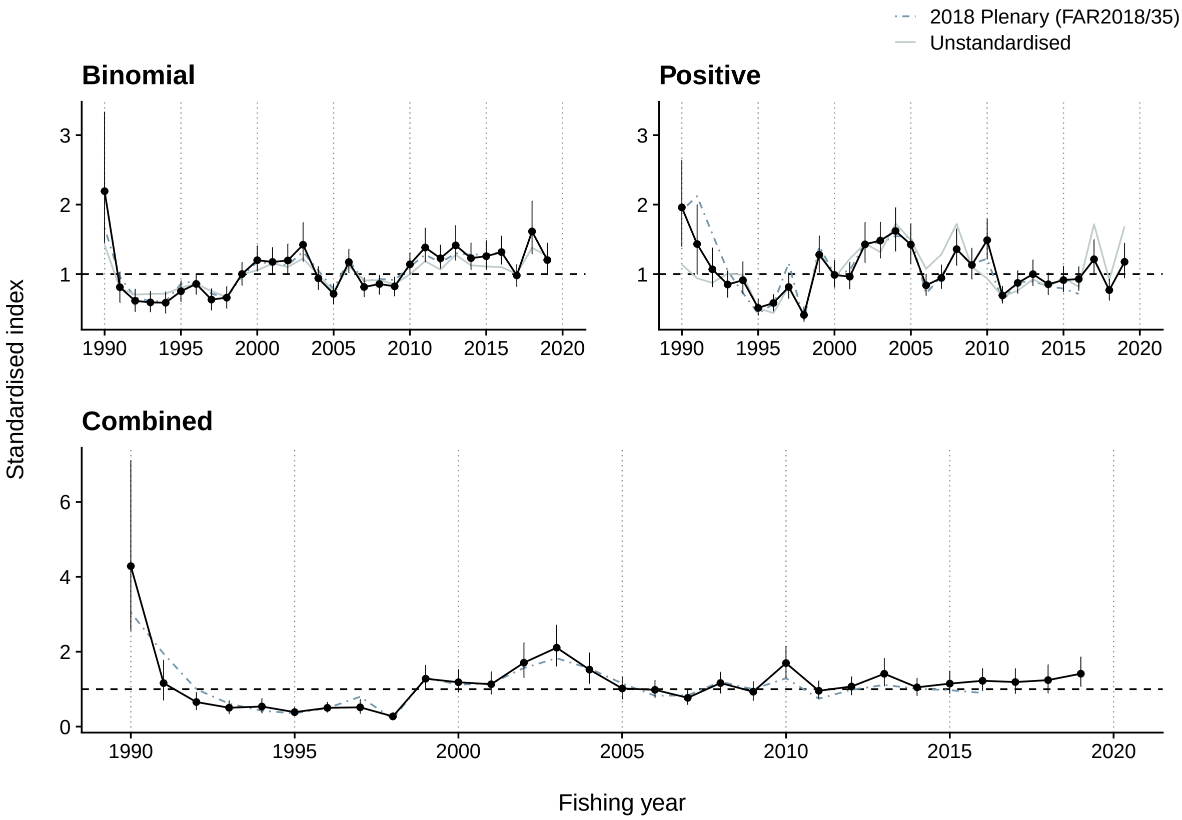

Figure 59: Standardised binomial, positive, and combined index for bottom longline in Lower SCH 3 & SCH 5. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference. FAR2018/35 is Dunn & Bian (2018).

Bottom trawl

Standardised index series for the bottom-trawl fishery in Lower SCH 3 & SCH 5 were developed at the event, daily, and trip effort resolution. Trips fishing in multiple CPUE units were omitted from the full fleet dataset, corresponding to 21.1% of the catches and 11.1% of trips (Figure G-116). The reduction in data due to ambiguous trips was lower in this CPUE unit than for bottom-trawl fisheries in other CPUE units. The core fleet was defined as vessels having participated in the fishery for at least five trips in five years. There were 92 vessels in the core fleet for this fishery at the trip resolution, which took 91.6% of the total catch.

School shark catches for the core fleet were variable over time, with a peak in 1999–2000 followed by a decline, before stabilising between 2007–2008 and 2018–19 (Figure F-28). Trends in the proportion of positive catch events were similar across the three effort resolutions (Figure F-28). The rate of positive catches increased slightly, with an average of 35.2%. The main index considered for this fishery used the trip effort resolution, given the high proportion of catches allocated according to effort (Figure G-115) and acceptable model diagnostics.

The selected binomial model for bottom trawl in Lower SCH 3 & SCH 5 at the trip resolution explained 26.8% of the deviance, and retained vessel, month, fishing duration, and statistical area as covariates (Table G-48). There was little standardisation effect, although vessel had the most influence amongst the covariates, tending to increase the inter-annual variability (Figure G-119). The final binomial index series increased up to 1999–2000 and was then stable, but variable (Figure 60, top left).

The selected model of positive catch explained 35.2% of the deviance and included vessel, fishing duration, and month as covariates (Table G-49). Vessel and particularly fishing duration had an impact on the standardised series, with the vessel covariate increasing the rate of decline from 2003–04 to 2010–11. Fishing duration had both negative and positive influences at different segments in the series (Figure G-120). The final positive index declined steeply at the start of the time series, and showed a lower rate of decline in subsequent years, with some variability (Figure 60, top right). The combined index series was variable over time with no clear trend in relative abundance (Figure 60).

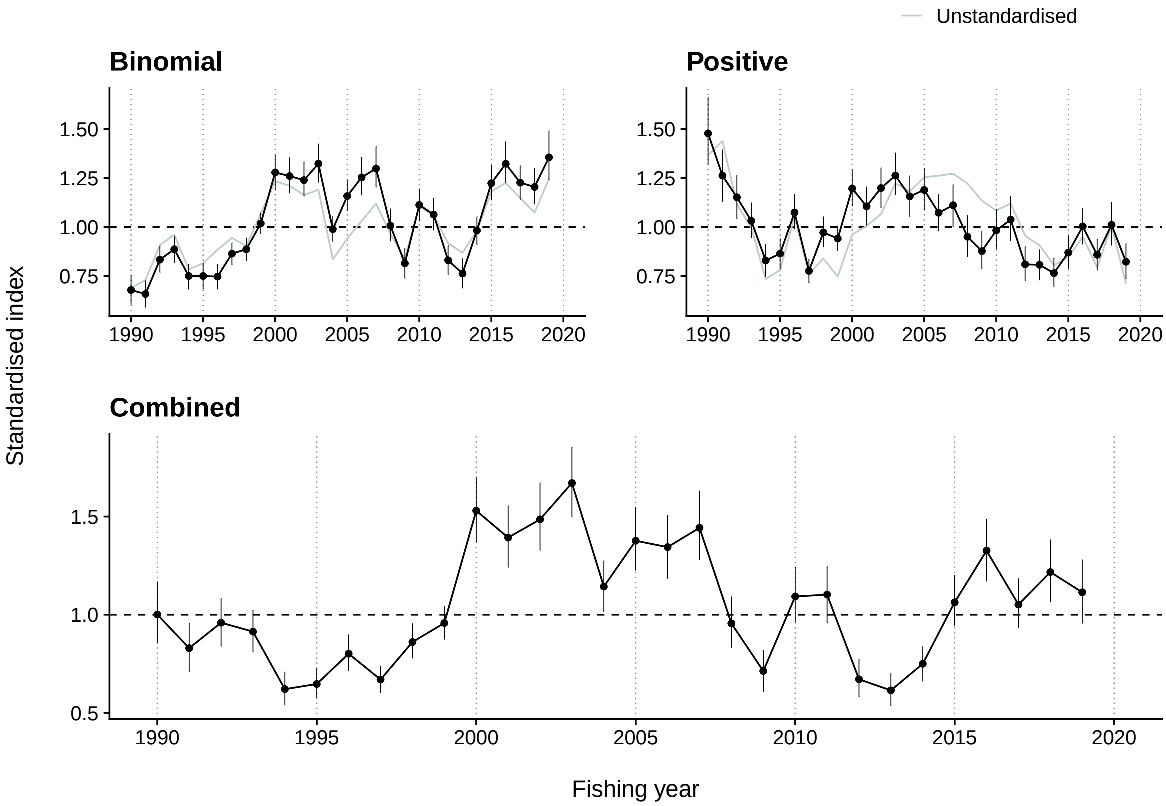

Figure 60: Standardised binomial, positive, and combined index for bottom longline in Lower SCH 3 & SCH 5. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference.

Summary

The INSWG accepted the set-net combined index series at the daily resolution as an index of abundance for school shark in Lower SCH 3 & SCH 5. This series showed a steady decline in relative abundance over time (Figure 58) and was chosen because it had the broadest spatial coverage. The bottom-longline index only covered areas off the lower South Island west coast, and the bottom trawl index was based on effort in shallow waters off the east coast south of Banks Peninsula and around Foveaux Strait. These two index series were also in conflict with the declining trend estimated by the set-net index series, but the latter was considered more reliable by the INSWG (Figure 61). The east coast South Island research trawl survey was not considered an adequate index of abundance for school shark in Lower SCH 3 & SCH 5 given its narrow spatial coverage compared with the area definition (i.e., omitting the important area for school shark of Foveaux Strait), low number of school shark observations, and scarcity of large individuals in the observations.

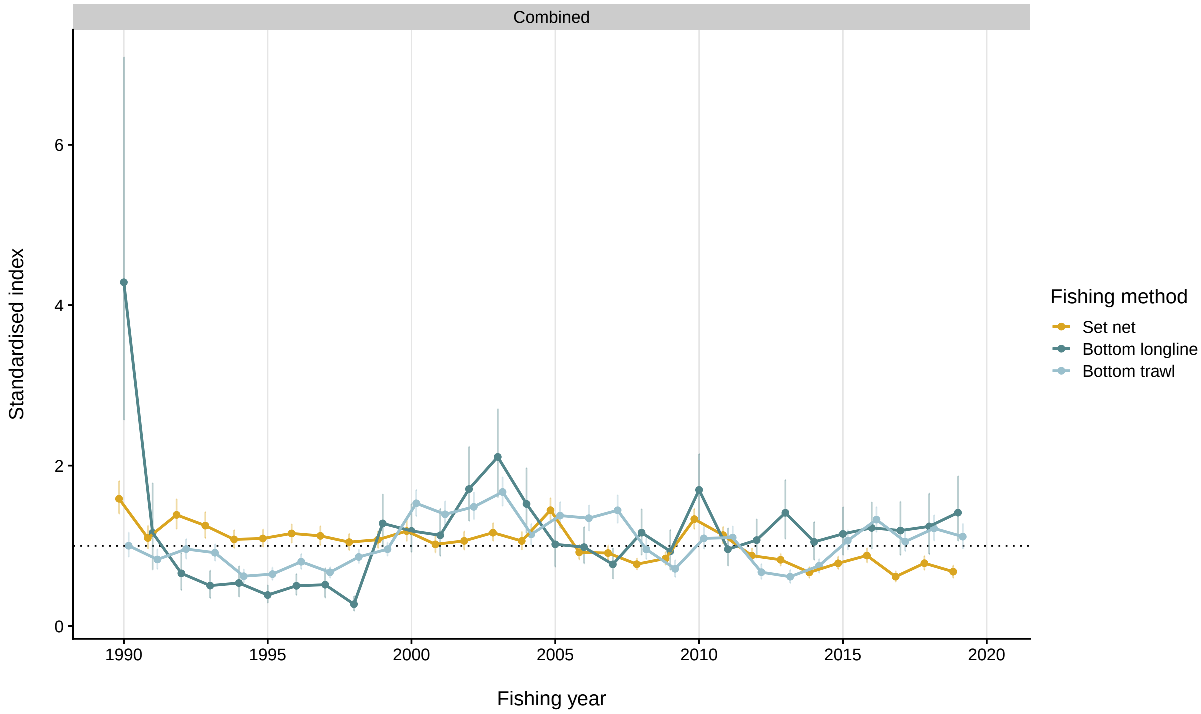

Figure 61: Comparison of key standardised CPUE indices across fishing methods for Lower SCH 3 & SCH 5. All series are combined binomial-lognormal indices. Points show the point estimates for each year, vertical lines the 95% confidence intervals for each series. The series are slightly offset to improve clarity; the level of no change (index value of 1) is shown with a dotted line for reference.

3.3.5 SCH 7, SCH 8 & lower SCH 1W

Set net

Standardised index series for the set-net fishery in SCH 7, SCH 8 & lower SCH 1W were developed at the event, daily, and trip effort resolution. The core fleet was defined as vessels having participated in the fishery with at least five trips in five years. There were 45 vessels in the core fleet at the daily resolution, which took 92.5% of the total catch in the dataset. The core fleet catch showed considerable inter-annual variability; it generally remained high until the mid-2000s, and then declined steadily to a level of less than one third of peak catches (Figure F-31). The proportion of positive catch events steadily increased after 1994–95, stabilising around 77.6% since 2006–07 (Figure F-31). Trip length first increased over time for this fishery but has stabilised at between 2.5 and 3.0 days per trip between 2006–07 and 2018–19 (Figure F-32). The daily index series was the series considered for this fishery, given the low proportion of catch allocated by effort (Figure G-127) and acceptable model diagnostics.

The selected binomial model for the set-net fishery in SCH 7, SCH 8 & lower SCH 1W explained 27.5% of the deviance, with target species, vessel, month, and statistical area retained as covariates (Table G-53). Target species was particularly influential as a covariate, with a negative influence at the start and a positive influence at the end of the time series, resulting in a flattening of the standardised series. Vessel was also an influential covariate by increasing the inter-annual variability at the end of the time series (Figure G-130). The final binomial index series showed a steady increase over time beginning in the mid-1990s, and stabilised in the last 12 years of the time series from 2007–08 to 2018–19 (Figure 62, top left).

The selected model of positive catch explained 46.7% of the deviance, and included target species, vessel, statistical area, and month as covariates (Table G-54). Target species had the highest impact on the standardised index series, with a negative influence at the start and a positive influence at the end of the time series, which resulted in a stabilisation of the standardised series over time (Figure G-131). Vessel was particularly influential at the start of the time series, resulting in a steeper rate of decline in the standardised index series over the first ten years. The final positive index series declined from the start of the time series to the early 2000s, and then stabilised (Figure 62, top right). Given the slight upward trend in the binomial index, the positive index series determined most of the variation in the combined index series. This series declined from the start of the time series to the early 2000s, and then stabilised near the mean of the long-term series (with some inter-annual variability) after 2000–01 (Figure 62).

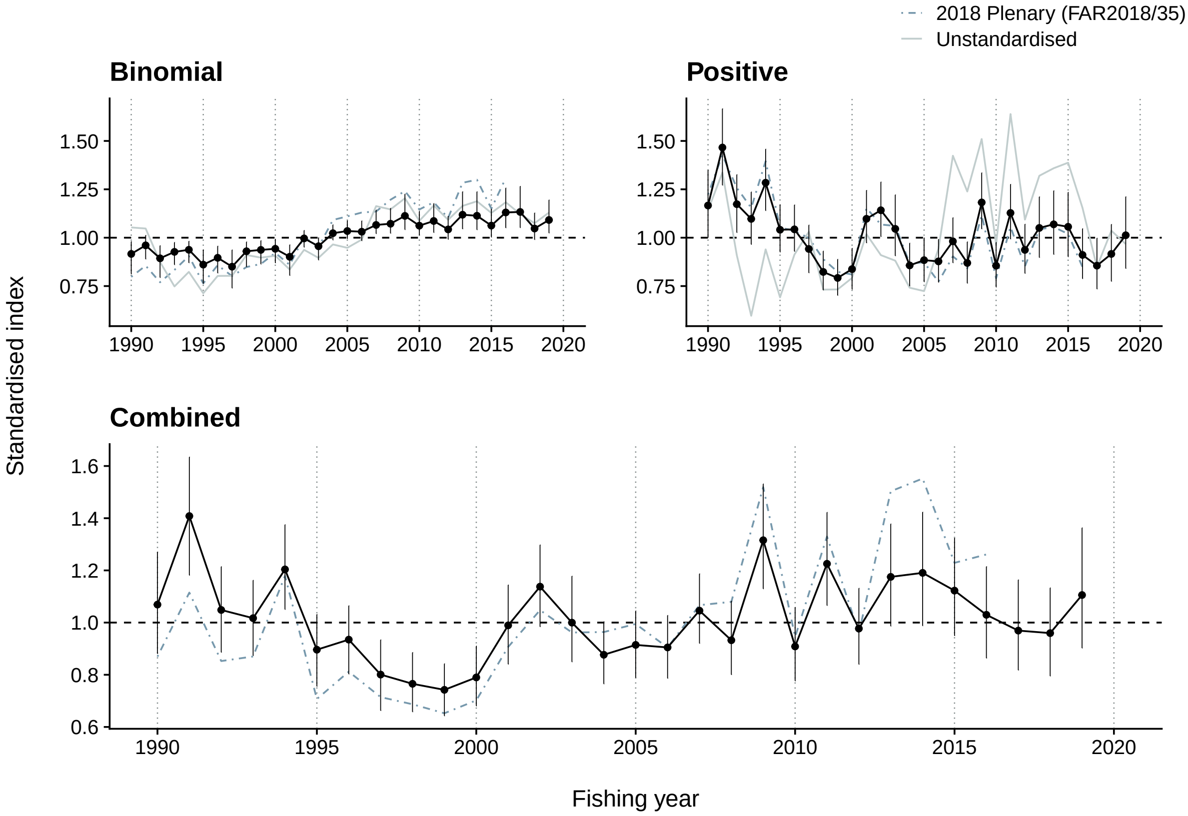

Figure 62: Standardised binomial, positive, and combined index for set net in SCH 7, SCH 8 & lower SCH 1W. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference. FAR2018/35 is Dunn & Bian (2018).

Bottom longline

Standardised indices for the bottom-longline fishery in SCH 7, SCH 8 & lower SCH 1W were developed at the event and daily effort resolution. The core fleet was defined as vessels having participated in the fishery with at least five trips in four years. The core fleet for this fishery consisted of 40 vessels at the daily resolution, which caught 73.3% of the total school shark catch in the dataset. Allocated catches for the core fleet were variable over time with a recent peak from 2014–15 to 2017–18, and a discernible decline by nearly one-half in 2018–19 (Figure F-34). The percentage of events with positive catch was stable over 60% up to the late 2000s, then increased to a higher plateau near 75% to 2017–18, before decreasing again in 2018–19 (Figure F-34). The main index series considered for this fishery was at the daily effort resolution, given the low proportion of catches allocated by effort (Figure G-140) and acceptable model diagnostics.

The selected binomial model of catch occurrence for bottom longline in SCH 7, SCH 8 & lower SCH 1W explained 27.8% of the deviance; target species and vessel were retained as model covariates (Table G-58). The inclusion of target species smoothed out the transition to the higher positive catch rate plateau from 2007–08 to 2008–09, and vessel had a positive influence, particularly in the latter part of the time series, resulting in a decline in the standardised series from 2008–09. The final binomial index series was low up to the mid-1990s, increased to the long-term series average until 2008–09, and then increased to another plateau, where it remained for subsequent years (Figure 63, top left).

The selected positive catch model explained 60.6% of the deviance, and retained target species, vessel, month, statistical area, and hook number as covariates (Table G-59). There was a strong standardisation effect with the inclusion of target species, vessel, and hook number, resulting in a peak in the standardised index in 2001–02 (Figure G-144). Target species also had a positive influence at the start of the time series. The final positive index series included a pronounced peak from 2001–01 to 2003–04, with a period of low indices before the peak, and variable indices subsequently (Figure 63, top right). The combined index series closely resembled the positive series, which also showed a decline from 2014–15 to 2018–19 (Figure 63).

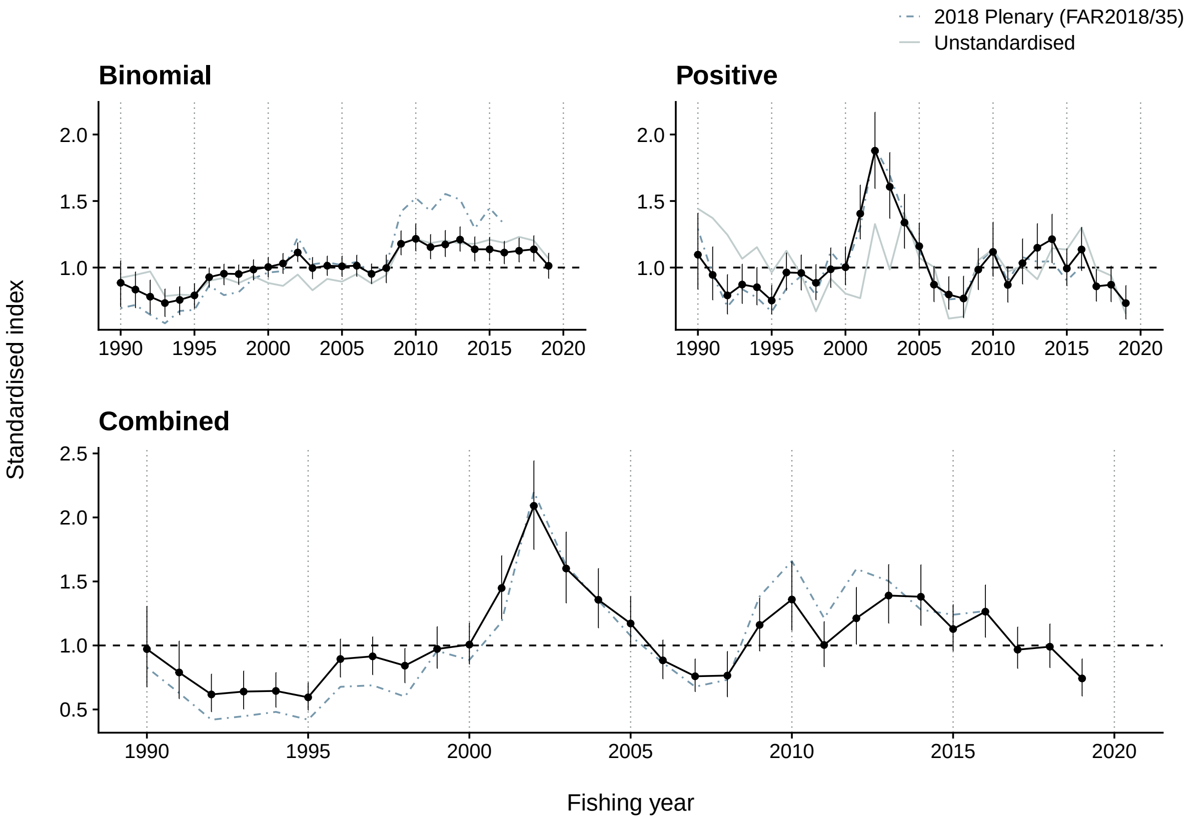

Figure 63: Standardised binomial, positive, and combined index for bottom longline in SCH 7, SCH 8 & lower SCH 1W. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference. FAR2018/35 is Dunn & Bian (2018).

Bottom trawl

Standardised index series for the bottom-trawl fishery in SCH 7, SCH 8 & lower SCH 1W were developed at the event, daily, and trip effort resolution. Trips fishing in multiple CPUE units were omitted from the full fleet dataset, corresponding to 30.3% of the catches and 15% of trips (Figure G-154). The core fleet was defined as vessels having participated in the fishery with at least five trips in five years. There were 112 vessels in the core fleet at the trip resolution, which took 83.4% of the total school shark catch. Catches for the core fleet increased over time up to 1998–99, then decreased and increased again to a peak in 2009–10, then declined in subsequent years (Figure F-37). The rate of positive catch events at the daily resolution increased up to 1999–2000, and stabilised in subsequent years. The proportion of positive catches was higher for trip resolution data compared with daily and event effort resolution; it increased over time with a recent average of 70.4% between 2016–17 to 2018–19. The main series considered for this fishery was the trip effort resolution given the high proportion of catches that were allocated according to effort at the daily resolution (Figure G-153) and acceptable model diagnostics.

The selected binomial model for bottom trawl at the trip resolution in SCH 7, SCH 8 & lower SCH 1W explained 20.4% of the deviance, and included vessel, fishing duration, month, and target species as model covariates (Table G-63). There was little standardisation effect, but the inclusion of the vessel covariate had a positive influence at the end of the time series by reducing an increase in the nominal index series from 2008–09 onwards (Figure G-157). The final binomial index series increased steadily from the early 1990s (Figure 64, top left).

The selected positive catch model explained 44% of the deviance, and retained vessel, fishing duration, target species, and month as covariates (Table G-64). Vessel and fishing duration had a strong influence in the earlier part of the time series, resulting in a steep decline in the standardised index series over the first three years (Figure G-158). The final positive index series was stable over time from 1992–93 onwards (Figure 64, top right). The combined index series increased from the early to the late 1990s, then varied around the long-term series average, determined by the binomial index series, with some added inter-annual variability from the positive index series (Figure 64).

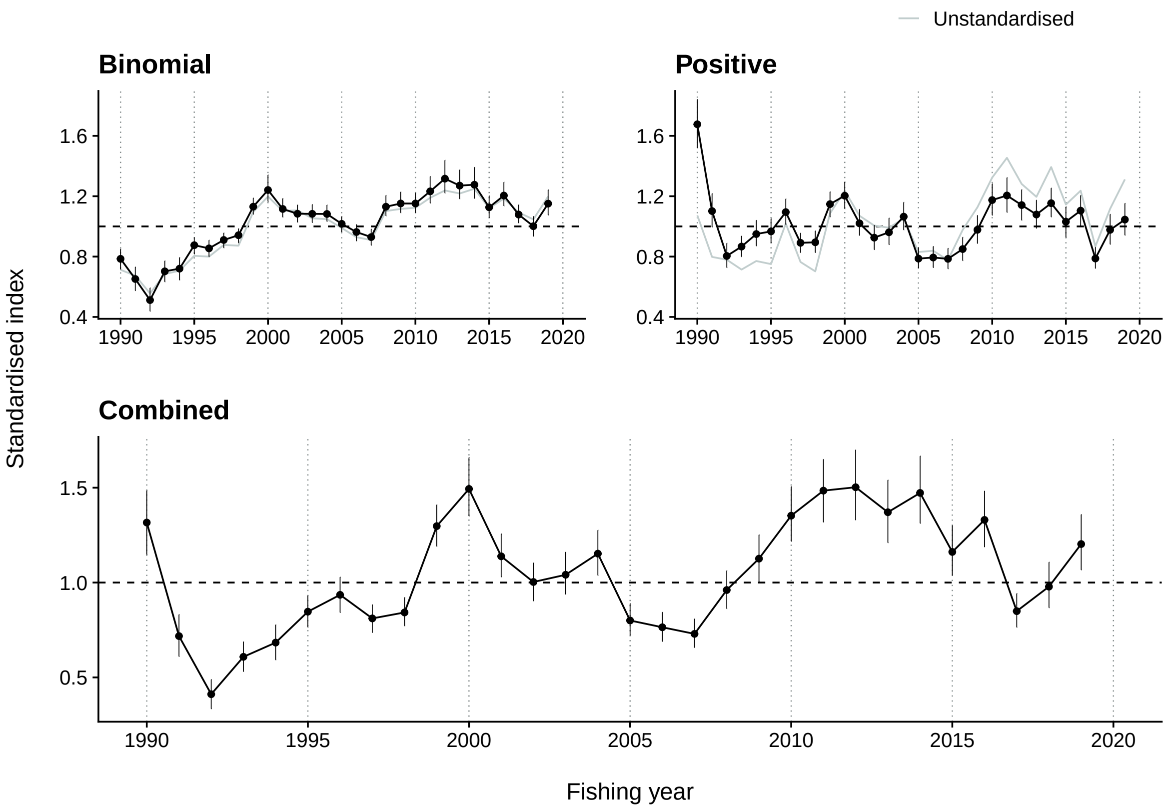

Figure 64: Standardised binomial, positive, and combined index for bottom trawl in SCH 7, SCH 8 & lower SCH 1W. Grey line shows the unstandardised index, dotted blue line the previously-developed index. Vertical black lines show the 95% confidence intervals for each fishing year. The level of no change (index value of 1) is shown with a dashed line for reference.

Summary

The west coast South Island (WCSI) research trawl survey, excluding the Tasman and Golden bays strata, was accepted by the INSWG as the main index of abundance in SCH 7, SCH 8 & lower SCH 1W, with a stable population abundance since 2000 following an earlier decline (Figure 19; MacGibbon 2019). The survey was selected because recent school shark catches had high sample sizes with acceptable CVs for population estimates, along with a wide range of individual sizes observed. The set-net CPUE index series at the daily resolution was impacted by spatial management measures (implemented for the conservation of Māui and Hector's dolphins) and some interactions across statistical areas in model diagnostics. The INSWG noted that the set-net series could be considered to be an auxiliary series to the WCSI survey. Combined series from bottom longline and bottom trawl were rejected as indices of abundance; the bottom-longline index series showed high inter-annual variability, unlikely to be representative of abundance. At the same time, the spatial scope of the bottom-trawl fishery matched that of the WCSI survey, providing limited new information. There was little agreement between the three standardised series across the time period covered (Figure 65).

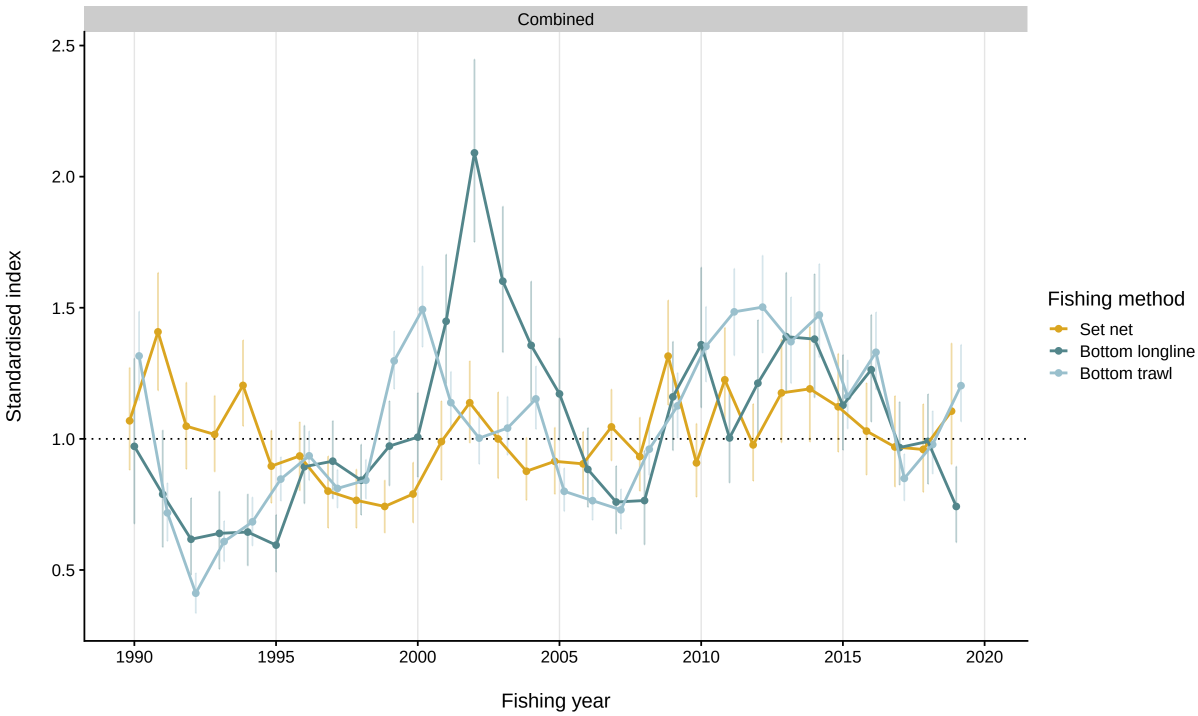

Figure 65: Comparison of key standardised catch-per-unit-effort indices across fishing methods for SCH 7, SCH 8 & lower SCH 1W. All series are combined binomial-lognormal indices. Points show the point estimates for each year, vertical lines the 95% confidence intervals for each series. The series are slightly offset to improve clarity; the level of no change (index value of 1) is shown with a dotted line for reference.

Table 4: Standardised catch-per-unit-effort index series for school shark considered by the Inshore Finfish Working Group. Series are for different areas and fisheries, status refers to working group discussions, with a summary of key discussion points (explanation) informing acceptance of a series as an index of abundance. Fishing methods were set net (SN), bottom longline (BLL), and bottom trawl (BT); effort resolution was daily, event, and trip. Main series considered by the working group for each fishery are indicated by ∗. The compromised allocation procedure refers to instances where a high proportion of catch was allocated according to fishing effort (see Methods).

Fishery	Index	Status	Explanation
Far North & SCH 1E	SN1 trip	Rejected	Used to confirm trend in daily index given difference between event and daily indices; standardised trend similar to the trend of the daily index.
	SN1 daily (∗)	Accepted	Low proportion of catches allocated by effort; trend supported by trip index.
	SN1 event	Rejected	Restricted temporal scope; standardised trend different to the trend of the daily index.
	BLL1 trip	Rejected	Coarse resolution; trend similar to that in the daily index.
	BLL1 daily (∗)	Accepted	Low proportion of catches allocated by effort; trend supported by trip and event indices.
	BLL1 event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.
	BT1 trip (∗)	Accepted	High proportion of catches allocated by effort; trend supported by daily and event indices.
	BT1 daily	Rejected	Compromised catch allocation procedure.
	BT1 event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.
SCH 2 & top of SCH 3	SN 2/3 trip	Rejected	Coarse resolution; trend similar to the trend of the daily index.
	SN 2/3 daily (∗)	Rejected	Low proportion of catches allocated by effort; trend supported by trip and event indices, but conflicting trends across fishing methods in the region.
	SN 2/3 event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.
	BLL 2/3 trip	Rejected	Coarse resolution; trend similar to the trend of the daily index.
	BLL 2/3 daily (∗)	Rejected	Low proportion of catches allocated by effort; trend supported by trip and event indices, but conflicting trends across fishing methods in the region.
	BLL 2/3 event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.
	BT 2/3 trip (∗)	Rejected	High proportion of catches allocated by effort; trend supported by trip and event indices, but conflicting trends across fishing methods in the region.
	BT 2/3 daily	Rejected	Compromised catch allocation procedure; trend matches trip index.
	BT 2/3 event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.
Chatham Rise (SCH 4)	BLL 4 daily (∗)	Accepted	Low proportion of catches allocated by effort; trend supported by event index.
	BLL 4 event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.
Lower SCH 3 & SCH 5	SN 3/5 trip	Rejected	Coarse resolution; trend similar to the trend of the daily index.
	SN 3/5 daily (∗)	Accepted	Low proportion of catches allocated by effort; trend supported by trip and event indices; index covers broad spatial area.
	SN 3/5 event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.

Continued on next page

Table 4 – *Continued from previous page*

Fishery	Index	Status	Explanation
	BLL 3/5 daily (∗)	Rejected	Low proportion of catches allocated by effort; trend supported by event index, but limited spatial coverage.
	BLL 3/5 event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.
	BT 3/5 trip (∗)	Rejected	High proportion of catches allocated by effort; trend supported by daily and event indices, but limited spatial coverage.
	BT 3/5 daily	Rejected	Compromised catch allocation procedure; trend matches trip index.
	BT 3/5 event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.
SCH 7, SCH 8 & lower SCH 1W	SN 7/8/1W trip	Rejected	Coarse resolution; trend similar to the trend of the daily index.
	SN 7/8/1W daily (∗)	Rejected	Low proportion of catches allocated by effort; trend supported by trip and event indices; impacted by spatial management measures and some interactions across statistical areas in model diagnostics.
	SN 7/8/1W event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.
	BLL 7/8/1W daily (∗)	Rejected	Low proportion of catches allocated by effort; trend supported by event index, but high variability unlikely to be representative of abundance.
	BLL 7/8/1W event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.
	BT 7/8/1W trip (∗)	Rejected	High proportion of catches allocated by effort; some difference with trip and event indices, but limited value compared with West Coast South Island research trawl survey based on overlap in spatial coverage.
	BT 7/8/1W daily	Rejected	Compromised catch allocation procedure.
	BT 7/8/1W event	Rejected	Restricted temporal scope; used as diagnostic for the influence of spatial covariates.

4. DISCUSSION

This analysis summarised available size-frequency information for school shark, and updated the previous fisheries characterisation by Dunn & Bian (2018). A five-region spatial structure was used to group school shark data for characterisation and biomass trend analysis, following Starr & Kendrick (2016). New standardised CPUE index series were developed for bottom trawl, in addition to the previously-used set-net and bottom-longline series. Index series were developed at two levels of effort resolution, daily and individual fishing event, for all fishing methods analysed in all five regions. All set-net and bottom-trawl index series were also analysed at the level of the fishing trip, as well as the two North Island bottom-longline index series.

The INSWG accepted standardised CPUE series as being representative of abundance for Far North & SCH 1E, Chatham Rise (SCH 4), and Lower SCH 3 & SCH 5, and an index of abundance from a research trawl survey for SCH 7, SCH 8 & lower SCH 1W. No index of abundance was accepted for SCH 2 & top of SCH 3, similar to the two previous analyses (Starr & Kendrick 2016, Dunn & Bian 2018). Based on the accepted indices, school shark abundance is increasing in Far North & SCH 1E, stable on Chatham Rise (SCH 4), declining in Lower SCH 3 & SCH 5, and stable in SCH 7, SCH 8 & lower SCH 1W, following a possible initial decline in the late 1990s.

Conflicting patterns in CPUE index series across regions were found in this analysis, as well as previous ones (see Starr & Kendrick 2016, Dunn & Bian 2018). These are difficult to understand: school shark is a mobile species consisting of what is believed to be a single population within New Zealand, and under this assumption relative biomass trends across regions should be consistent (Francis 2010, Fisheries New

Zealand 2021). However, school shark is also caught by diverse fishing gears with different vulnerability, and known to have size-specific spatial distribution patterns (Blackwell & Francis 2010). Studies of school shark populations elsewhere have reported different movement patterns across areas, sex, and size classes, including partial migrations of mature female in both the north-east Atlantic Ocean and off Australia (Walker et al. 2008, McMillan et al. 2019, Thorburn et al. 2019). These studies suggest that the spatial ecology of school shark in New Zealand waters is likely to be complex. All of these factors are likely to complicate the interpretation of biomass indices.

The relative vulnerability of school shark to different fishing gears across size class and spatial location remains a key uncertainty. This knowledge is required to interpret fisheries-dependent CPUE series as potential indices of abundance, and would assist in resolving conflicts between CPUE series across gears and regions. As a step towards this, size composition for school shark catches in New Zealand were collated across three different data sources: observer samples from commercial vessels, research trawl surveys, and voluntary fisher logbooks from the AMP. The inclusion of the AMP logbook data was a research recommendation from the previous analysis (Dunn & Bian 2018). Although these datasets provided information on the size distribution of school shark in different regions and across gears, they need to be interpreted with caution, given differences in data collection and processing in the datasets. Other factors to consider are uncertainty in the representativeness of the coverage of the commercial samples, multi-year gaps in the samples, and lack of coverage in some key area-fishery combinations.

The three size composition datasets showed variability in the spatial distribution of sizes over time, but some patterns were apparent. The two commercial fishery datasets included a higher prevalence of large individuals in Southland or neighbouring areas; a similar pattern was also observed in a now-defunct research trawl survey in Southland (Hurst & Bagley 1994). Comparatively large individuals were also sampled by the observer programme in the Far North & SCH 1E and Chatham Rise (SCH 4) fisheries. Mature individuals were more common in the commercial observer programme and AMP samples than in the inshore trawl surveys, suggesting that the inshore trawl surveys predominantly sample the juvenile component of the school shark population. However, there remain significant gaps in the understanding of habitat use by school shark, and it is unclear how the observed spatial patterns in size composition datasets reflect habitat use or gear vulnerability. Given that the AMP was discontinued in 2009, commercial observer samples could provide valuable information to clarify these patterns for a representative sample of the population, particularly if the level of coverage was increased and targeted at school shark. Currently, there are few years with sufficient observations for all fishing gears to support a broad-scale analysis of these data (e.g., there are no observer records for set-net samples for Far North & SCH 1E). However, a model of observer samples based on selected years and regions using individual size as a response variable might help differentiate operational from spatial factors for some size-composition patterns in New Zealand.

This analysis implemented a significant update from previous analyses by developing CPUE index series at multiple effort resolutions, resulting in a total of 36 index series. In general, the accepted index series remained at the daily-effort resolution for set-net and bottom-longline fisheries, and at the trip-effort resolution for bottom trawl. The main criterion used by the INSWG to select the appropriate resolution was the proportion of landings that were allocated to events or daily strata by effort, following the recommendations by Langley (2019). Event-based series were primarily developed as a diagnostic tool to identify discrepancies that may arise in the daily-effort series from the inclusion of additional covariates. Ultimately, the event-based series were not considered because of their shorter time-span. In general, there was a close match between event and daily index series for most fisheries except in the Far North & SCH 1E, where a subset of the fleet used the low-resolution CELR forms; these small vessels had different school shark catch rates, because they operate in harbours where the school shark population likely differs from that in other parts of the region.

An ongoing consideration for school shark is the possibility of using bottom-trawl CPUE as a potential index of abundance. There has been concern that bottom-trawl CPUE only indexes a restricted portion of the population, because large individuals are rarely caught in the inshore research trawl surveys (although this aspect varies to some extent between survey areas). Dunn & Bian (2018) reported the presence of large individuals in observer samples from commercial bottom-trawl fisheries, and in the discontinued research survey in Southland (Hurst & Bagley 1994). This observation was supported in the current analysis given large individuals in observer samples from bottom trawl in all CPUE units; AMP samples also highlighted a higher presence of large individuals in Southland compared with other regions.

For this reason, bottom-trawl indices of school shark relative abundance were included in this analysis for all regions (except for Chatham Rise). These indices were in part developed to elucidate conflicting trends in CPUE series from set-net and bottom-longline index series. The bottom-trawl standardised index series was accepted as one of three monitoring series by the INSWG for Far North & SCH 1E. The bottom-trawl index series for SCH 2 & top of SCH 3 did not resolve the ongoing discrepancy between the CPUE series developed from the set-net and bottom-longline fisheries in SCH 2 & top of SCH 3. Instead, this additional series matched the bottom-longline series in the earlier part of the time series, and the set-net series in the latter part. Dedicated research that considers spatial overlap between fishing methods over time in this CPUE monitoring unit might help to resolve the uncertainty around this conflict. For this region, it would be worth considering approaches to generate fishery-independent indices, but they might be challenging in the short term.

One consideration for school shark bottom-trawl indices is that they need to be examined at the trip resolution, based on the high proportion of school shark catches allocated according to effort. The high-effort allocation results from school shark not being a target species in bottom-trawl fisheries, so that this species is often not included in the estimated catch logbook (because only the top 5 or 8 species in the catch are recorded, depending on form type). This aspect resulted in a reasonably large proportion of landings having to be removed from the analysis (between 21.1% and 30.3% of total landings, in tonnes, depending on the fishery), because trips had to be discarded when they spanned multiple CPUE units. This aspect is especially relevant for trip-resolution indices for species monitored using non-QMA areas, because trip landings are reported at the QMA level. For school shark, it might curtail some of the advantages of using trip-resolution indices to preserve the integrity of landings if the excluded trips have different trends in CPUE compared with the retained trips. Additional analyses examining the spatial distribution of the retained trips are recommended to ensure that no spatial bias in the CPUE unit is introduced by the removal of trips spanning multiple monitoring units.

A key feature across regions was a decrease in the final analysis year (2018–19) of total school shark catches in most individual QMAs. In part, this decline coincided with the onset of electronic reporting, prompting concern that school shark catches might be reported differently under the ERS. Nevertheless, a number of fisheries that are not using ERS also showed a decrease in school shark catches, and the ERS CPUE was comparable with the CPUE for other form types for fisheries where ERS use was common. Instead, the recent decline in school shark catches appeared to result from the long-term decline in set-net fishing effort, following the implementation of set-net regulations for the conservation of Hector's and Māui dolphins (described by Starr & Kendrick 2020). In addition, a recent decline in bottom-longline catches, particularly for SCH 4, SCH 7 and SCH 8, appeared to partly correspond with declining effort in recent years in these fisheries.

The factor 'vessel' was consistently an influential covariate in the CPUE standardisation analyses. Most vessels are active for at least four to five years (typically more). For this reason, the vessel effect is unlikely to be confounded by the year effect, which is used to index abundance; however, vessel effect remains a coarse proxy of increased fleet efficiency and other fishery practices (e.g., spatial use, net deployment practices, etc.). Another model covariate frequently retained was target species, but this covariate was not as influential as the vessel covariate on standardised indices, except for the bottom-longline fishery of SCH 7, SCH 8 & lower SCH 1W. Key trends in school shark catch rates across regions by target species (other than school shark) were comparatively high catch rates for set-net fishing targeting rig, bottom longline targeting hāpuku/bass, and bottom-trawl fishing targeting barracouta and red cod, with some variability across regions. Bottom-longline fishing targeting ling had particularly low catch rates for school shark.

The CPUE indices from all three fishing methods were accepted for Far North & SCH 1E, with the region index accepted by the INSWG defined as the average of all three metrics (without including uncertainty estimates). The INSWG suggested generating a weighted combined index including uncertainty using a bootstrap approach; it was noted that approaches to combine indices across fisheries and regions need to be considered carefully for a highly mobile species like school shark with catches spread across fishing methods. The development of a single index of abundance for school shark has been recommended in previous analyses and plenary reports for school shark (Starr & Kendrick 2016, Dunn & Bian 2018, Fisheries New Zealand 2020). However, based on the differing trends across (and sometimes within) regions, and the concern that different fisheries might be indexing different components of the population, combining fishery-dependent indices using a weighting approach, e.g., using landings as weight, is unlikely to yield a single index that is representative of school shark abundance. At the same time, the continued development of multiple standardised CPUE series that are lacking the required biological context for the interpretation of relative abundance trends may be of limited use to generate metrics that support the fishery management of this species.

An important consideration when interpreting catch composition data is the size-at-maturity of individuals; however, there are no published estimates of this metric for school shark in New Zealand (unpublished estimates are cited by Francis & Mulligan 1998). At the same time, there is currently no key available for converting length measurements from fork length to total length based on information of school shark individuals collected in New Zealand. With a high proportion of recent observer records providing fork length measurements (e.g., about 80% in the three most recent years of this assessment), compared with earlier observer records and trawl surveys mostly providing total length measurements, this conversion key is important to ensure that catch composition samples retain a consistent interpretation across sources and through time.

Although there are anecdotal reports of size-specific distributions of school shark, e.g., the location of nursery grounds (Paul & Bradford 2000, Blackwell & Francis 2010), existing published accounts of school shark distributions in New Zealand are likely more representative of juveniles given the sampling methodology (e.g., see Hurst et al. 2000, Stephenson et al. 2020). However, the ongoing challenges in interpreting trends in abundance throughout New Zealand waters warrant a dedicated study that characterises the spatial distribution of school shark life stages in New Zealand waters; this study would expand previous research by Blackwell & Francis (2010) and Francis (2010) and follow the suggestion by Fisheries New Zealand (2021) to conduct further work on stock structure and movements among stocks.

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APPENDIX A: Summary statistics for size-composition data

A.1 Research trawl surveys

Table A-1: Summary statistics for the size composition of school shark for each fishing year when research trawl surveys were conducted. For each survey, statistics were aggregated by fishing year, and include the number of school shark individuals measured (N), the number of fishing events with observations, and the median, mean, and maximum total length observed (all in cm). Surveys with less than five individuals observed were not included. The most recent recent published reports are referred to under each survey series.

Survey	Trip	Year	N	Events	Median	Mean	Max. length
West Coast North Island	1989	KAH8918	37	25	58.0	66.4	119
e.g., Morrison; Parkinson (2001)	1991	KAH9111	171	56	75.0	82.0	165
	1994	KAH9410	82	36	66.5	76.0	168
	1996	KAH9615	96	63	68.0	68.8	150
	1999	KAH9915	31	29	67.0	68.8	126
	2018	KAH1806	27	39	78.0	98.0	179
Tasman Bay/Golden Bay	1992	KAH9204	49	12	66.0	69.2	121
e.g., MacGibbon (2019)	1994	KAH9404	154	11	59.0	55.1	92
	1995	KAH9504	294	15	63.0	63.5	91
	1997	KAH9701	128	17	57.0	54.4	87
	2000	KAH0004	236	13	64.0	64.3	111
	2003	KAH0304	66	7	61.5	64.3	107
	2005	KAH0503	103	15	59.0	61.0	111
	2007	KAH0704	254	12	43.5	50.9	93
	2009	KAH0904	629	15	39.0	45.6	102
	2011	KAH1104	329	12	56.0	60.1	107
	2013	KAH1305	169	11	64.0	64.1	115
	2015	KAH1503	114	11	75.5	74.0	111
	2017	KAH1703	185	25	52.0	53.9	145
	2019	KAH1902	162	15	66.5	66.9	113
West Coast South Island	1992	KAH9204	522	71	73.0	73.7	152
e.g., MacGibbon (2019)	1994	KAH9404	649	80	74.0	78.6	165
	1995	KAH9504	566	74	76.0	77.4	149
	1997	KAH9701	451	57	78.0	79.8	154
	2000	KAH0004	353	60	68.0	72.7	152
	2003	KAH0304	249	48	73.0	76.5	134
	2005	KAH0503	333	54	68.0	75.8	157
	2007	KAH0704	404	39	72.0	72.9	141
	2009	KAH0904	452	49	61.0	66.0	144
	2011	KAH1104	615	50	66.0	67.8	148
	2013	KAH1305	280	49	75.0	75.8	147
	2015	KAH1503	417	34	51.0	59.0	144
	2017	KAH1703	517	40	56.0	61.0	155
	2019	KAH1902	418	42	60.0	63.1	157
East Coast South Island	1991	KAH9105	69	23	60.0	61.4	150
e.g., MacGibbon et al. (2019)	1992	KAH9205	97	33	69.0	68.2	94
	1993	KAH9306	144	29	80.0	80.9	154
	1994	KAH9406	96	24	77.0	76.9	101
	1996	KAH9606	157	49	67.0	70.1	157
	2007	KAH0705	282	48	73.5	74.2	157
	2008	KAH0806	214	45	70.0	71.4	112
	2009	KAH0905	138	36	67.0	71.1	137
	2012	KAH1207	186	59	65.0	68.2	110
	2014	KAH1402	487	77	68.0	68.9	150
	2016	KAH1605	215	51	72.0	73.8	118
	2018	KAH1803	203	52	78.0	76.0	107
Chatham Rise	1992	TAN9212	10	12	131.0	135.0	200
e.g., Stevens et al. (2021)	1994	TAN9401	5	1	145.0	143.0	200

(Continued on next page)

Table A-1: (*continued*)

Survey	Year	Trip	N	Events	Median	Mean	Max. length
	1996	TAN9601	16	7	140.0	133.5	200
	1997	TAN9701	9	6	147.0	145.8	200
	1998	TAN9801	7	5	135.0	137.4	200
	1999	TAN9901	16	10	146.5	142.6	200
	2000	TAN0001	37	18	146.0	143.2	200
	2001	TAN0101	11	11	141.0	134.8	200
	2002	TAN0201	11	13	153.0	150.4	200
	2003	TAN0301	6	7	141.0	140.2	200
	2004	TAN0401	9	7	148.0	143.7	200
	2005	TAN0501	28	15	143.0	142.1	200
	2006	TAN0601	10	8	142.0	138.3	200
	2007	TAN0701	13	9	146.0	143.2	200
	2008	TAN0801	8	6	140.0	140.0	200
	2009	TAN0901	9	9	132.0	136.7	200
	2010	TAN1001	8	7	140.5	141.0	200
	2011	TAN1101	8	4	136.5	137.1	200
	2012	TAN1201	5	3	135.0	140.6	200
	2013	TAN1301	10	7	128.0	130.7	200
	2014	TAN1401	5	6	153.0	150.4	200
	2016	TAN1601	18	11	133.5	132.9	200
	2018	TAN1801	17	11	135.0	128.9	200
	2020	TAN2001	17	9	133.0	134.3	200

A.2 Fisheries New Zealand scientific observer programme

Table A-2: Summary statistics for the size composition of school shark for each fishing year when samples were collected by the Fisheries New Zealand scientific observer programme. For each fishing method, statistics were aggregated by catch-per-unit-effort monitoring unit and fishing year, and include the number of school shark individuals measured (N), the number of fishing events with observations, and the median, mean, and maximum total length observed (all in cm).

Fishing method	Unit	Fishing year	N	Events	Median	Mean	Max. length
Bottom longline	Far North & SCH 1E	2006-07	41	3	112.0	115.7	152
		2007-08	265	26	129.0	128.8	164
		2008-09	80	7	124.5	124.5	158
		2009-10	291	51	119.4	111.2	166
		2013-14	10	7	68.5	68.8	83
		2016-17	3	2	155.0	154.0	157
		2017-18	34	8	142.2	138.9	155
	SCH 2 & top of SCH 3	1997-98	22	3	143.0	139.0	154
		1999-00	10	1	143.5	140.6	155
		2000-01	5	2	149.0	149.2	160
		2010-11	12	3	137.5	135.5	147
	Lower SCH 3 & SCH 5	2003-04	5	4	144.0	145.0	153
		2007-08	10	1	124.0	122.9	142
		2015-16	70	7	107.5	107.0	141
		2016-17	60	3	133.1	133.6	154
	Chatham Rise (SCH 4)	1994-95	55	20	147.0	145.8	161
		1996-97	77	17	146.0	143.7	162
		1997-98	139	22	144.0	141.3	159
		1999-00	13	2	145.0	141.6	155
		2000-01	4	1	148.0	149.0	160
		2001-02	51	12	146.0	144.7	159
		2002-03	73	26	147.0	145.3	160
		2003-04	5	2	147.0	143.2	153
		2007-08	36	13	138.5	136.7	158
		2008-09	40	15	143.5	140.1	155
		2016-17	6	1	148.5	148.5	154

(Continued on next page)

Table A-2: (*continued*)

Fishing method	Unit	Fishing year	N	Events	Median	Mean	Max. length
		2018-19	39	2	136.5	137.7	159
	SCH 7, SCH 8 & lower SCH 1W	2018-19	145	3	86.3	90.3	154
		1998-99	21	3	122.0	121.8	130
		2001-02	3	1	139.0	143.0	152
		2007-08	1	1	125.0	125.0	125
		2009-10	54	5	72.5	86.4	150
Bottom trawl	Far North & SCH 1E	1994-95	14	5	137.5	136.1	152
		1995-96	3	1	136.0	138.7	151
		2001-02	8	2	139.0	131.8	149
		2006-07	19	10	141.0	141.5	158
		2009-10	9	5	80.6	88.0	147
		2010-11	12	4	145.3	144.8	157
		2014-15	86	21	148.5	145.8	179
		2015-16	66	16	120.0	122.5	172
		2016-17	12	2	149.0	142.5	159
	SCH 2 & top of SCH 3	1995-96	7	7	140.0	135.1	151
		1998-99	27	7	119.0	116.4	163
		1999-00	5	4	141.0	137.4	162
		2000-01	11	4	144.0	146.5	163
		2001-02	2	2	141.0	141.0	147
		2002-03	2	2	127.0	127.0	143
		2004-05	14	1	106.0	111.3	147
		2005-06	2	1	145.0	145.0	153
		2006-07	17	1	127.0	130.5	157
		2010-11	79	40	85.0	92.3	160
		2012-13	79	11	82.9	84.9	110
		2014-15	3	1	166.1	163.5	180
		2016-17	76	8	80.1	89.0	171
	Lower SCH 3 & SCH 5	1992-93	1	1	116.0	116.0	116
		1994-95	7	4	149.0	141.4	156
		1996-97	1	1	145.0	145.0	145
		1998-99	4	4	150.0	152.5	165
		1999-00	16	10	137.5	129.5	159
		2000-01	67	25	146.0	145.4	170
		2001-02	47	24	127.0	131.6	164
		2002-03	88	37	126.0	127.2	166
		2003-04	4	3	126.0	126.0	138
		2004-05	100	21	121.5	126.8	162
		2005-06	7	5	152.0	150.4	158
		2006-07	22	7	124.0	136.8	172
		2007-08	2	1	104.0	104.0	106
		2009-10	386	80	88.0	93.2	175
		2010-11	59	8	123.0	125.4	172
		2011-12	24	6	71.5	75.2	111
		2012-13	80	7	125.7	128.3	167
		2013-14	15	1	127.4	130.4	160
		2015-16	8	1	143.9	139.2	158
		2016-17	47	3	92.0	97.5	138
		2018-19	65	14	151.3	153.9	193
	Chatham Rise (SCH 4)	1995-96	4	4	148.0	140.0	151
		1998-99	7	4	152.0	151.4	154
		1999-00	84	11	144.0	141.8	162
		2000-01	39	10	147.0	144.6	163
		2001-02	2	2	141.0	141.0	147
		2002-03	20	11	146.0	145.2	155
		2003-04	1	1	138.0	138.0	138
		2005-06	2	1	145.0	145.0	153
		2006-07	34	4	129.5	131.6	157
		2007-08	8	1	137.5	130.9	141

(Continued on next page)

Table A-2: (*continued*)

Fishing method	Unit	Fishing year	N	Events	Median	Mean	Max. length
		2012-13	101	12	89.8	98.3	158
		2016-17	66	5	78.4	80.9	143
	SCH 7, SCH 8 & lower SCH 1W	1993-94	9	1	102.0	102.6	138
		1994-95	15	3	108.0	114.6	156
		1996-97	17	2	107.0	113.2	154
		1998-99	7	1	152.0	151.9	175
		1999-00	6	4	140.0	140.2	156
		2000-01	18	10	119.5	123.6	164
		2001-02	60	16	120.0	121.2	162
		2002-03	34	11	126.0	124.3	154
		2003-04	8	4	129.0	131.0	143
		2004-05	37	8	103.0	102.7	157
		2005-06	18	6	121.0	119.8	157
		2006-07	38	2	85.0	92.2	145
		2007-08	2	1	134.0	134.0	139
		2009-10	10	1	69.0	78.6	119
		2010-11	26	1	93.2	91.4	108
		2011-12	48	5	102.9	104.8	149
		2012-13	8	1	88.0	90.1	103
		2014-15	31	15	84.0	93.9	169
		2015-16	19	9	119.4	123.4	186
		2016-17	1	1	89.8	89.8	90
		2017-18	3	1	141.1	139.5	147
		1994-95	1	1	133.0	133.0	133
		1999-00	2	2	154.5	154.5	161
		2000-01	20	8	149.0	146.9	160
		2001-02	12	6	128.5	129.1	150
		2002-03	43	15	150.0	146.4	171
		2004-05	2	2	121.5	121.5	125
		2005-06	2	2	150.5	150.5	154
		2006-07	1	1	114.0	114.0	114
		2007-08	1	1	149.0	149.0	149
		2009-10	28	6	101.6	105.4	174
		2010-11	35	8	65.0	86.1	155
		2012-13	7	2	145.6	138.8	171
		2013-14	1	1	126.0	126.0	126
		2015-16	3	1	150.0	146.0	155
		2018-19	5	4	141.1	145.6	180
Set net	SCH 2 & top of SCH 3	2010-11	451	114	114.8	121.3	179
	Lower SCH 3 & SCH 5	2007-08	1032	36	121.0	119.3	173
		2009-10	1102	64	133.0	130.5	173
		2012-13	10	1	95.0	96.4	107
		2013-14	18	4	91.0	95.0	119
		2014-15	1162	33	133.0	133.5	170
		2015-16	1310	55	120.0	121.7	174
		2016-17	1172	70	129.7	130.1	178
		2017-18	255	25	109.1	112.8	172
	SCH 7, SCH 8 & lower SCH 1W	2007-08	510	40	104.0	106.9	157
		2010-11	451	114	114.8	121.3	179
		2017-18	36	13	109.7	115.1	167
		2018-19	9	2	114.8	114.5	154
		2009-10	20	1	126.5	129.1	166
		2010-11	23	4	111.4	115.1	157
		2015-16	50	1	100.5	100.1	172

A.3 Adaptive Management Programme

Table A-3: Summary statistics for the size composition of school shark for each fishing year when samples were collected by the Adaptive Management Programme. For each fishing method, statistics were aggregated by catch-per-unit-effort monitoring unit and fishing year, and include the number of school shark individuals measured, the number of fishing events with observations, and the median, mean, and maximum total length observed (all in cm).

Fishing method	Unit	Fishing year	N	Events	Median	Mean	Max. length
Set net	Far North & SCH 1E	1995-96	60	6	146.0	147.8	163
	SCH 2 & top of SCH 3	1994-95	17	3	93.0	94.1	120
		1995-96	180	42	105.0	113.1	170
		1996-97	406	87	130.0	125.0	180
		1998-99	446	76	130.0	121.1	163
		1999-00	81	10	115.0	119.1	190
		2000-01	18	11	130.0	136.5	165
		2001-02	65	21	92.0	96.3	154
		2002-03	220	30	81.5	82.6	135
		2004-05	57	6	90.0	95.3	150
	Lower SCH 3 & SCH 5	1994-95	8	1	94.5	94.4	101
		1995-96	1653	192	127.0	124.0	192
		1996-97	497	54	135.0	128.2	170
		1998-99	608	77	100.0	106.9	170
		1999-00	793	98	111.0	114.4	169
		2000-01	1336	190	112.0	114.1	170
		2001-02	1188	162	120.0	118.8	170
		2002-03	846	108	123.0	116.2	195
		2003-04	605	97	115.0	116.3	170
		2004-05	392	44	124.0	122.4	160
		2005-06	568	72	120.5	121.5	181
		2006-07	175	22	127.0	129.1	179
		2007-08	223	42	100.0	102.3	181
	SCH 7, SCH 8 & lower SCH 1W	1995-96	79	10	98.0	103.5	155
		1996-97	40	4	132.5	129.1	163
		2001-02	1	1	70.0	70.0	70

APPENDIX B: Biomass estimates from research trawl surveys

Table B-1: Relative total biomass indices (t) and coefficients of variation (CV) for school shark from research trawl surveys in different New Zealand regions. Estimates are shown for the core strata only, as defined within each survey design.

Survey	Year	Trip	Biomass	CV	Year	Trip	Biomass	CV
West Coast North Island	1989	KAH8918	149	26	1999	KAH9915	114	44
e.g., Morrison; Parkinson (2001)	1991	KAH9111	1162	39	2018	KAH1806	131	41
	1994	KAH9410	392	41	2019	KAH1906	299	27
	1996	KAH9615	352	26				
Tasman Bay/Golden Bay	1992	KAH9204	56	26	2007	KAH0704	159	36
e.g., MacGibbon (2019)	1994	KAH9404	93	32	2009	KAH0904	199	25
	1995	KAH9504	259	52	2011	KAH1104	260	34
	1997	KAH9701	47	41	2013	KAH1305	242	34
	2000	KAH0004	228	31	2015	KAH1503	160	43
	2003	KAH0304	131	17	2017	KAH1703	85	25
	2005	KAH0503	97	19	2019	KAH1902	176	44
West Coast South Island	1992	KAH9204	878	23	2007	KAH0704	657	23
e.g., MacGibbon (2019)	1994	KAH9404	1058	44	2009	KAH0904	885	18
	1995	KAH9504	945	42	2011	KAH1104	895	14
	1997	KAH9701	1385	26	2013	KAH1305	670	11
	2000	KAH0004	668	15	2015	KAH1503	628	19
	2003	KAH0304	523	22	2017	KAH1703	848	16
	2005	KAH0503	677	15	2019	KAH1902	544	21
East Coast South Island	1991	KAH9105	100	30	2008	KAH0806	411	20
e.g., MacGibbon et al. (2019)	1992	KAH9205	104	21	2009	KAH0905	254	18
	1993	KAH9306	369	42	2012	KAH1207	292	20
	1994	KAH9406	155	36	2014	KAH1402	529	36
	1996	KAH9606	202	18	2016	KAH1605	369	21
	2007	KAH0705	538	22	2018	KAH1803	251	20
Chatham Rise	1992	TAN9106	89	44	2005	TAN0501	778	28
e.g., Stevens et al. (2021)	1993	TAN9212	175	37	2006	TAN0601	304	41
	1994	TAN9401	198	41	2007	TAN0701	442	29
	1995	TAN9501	43	100	2008	TAN0801	283	23
	1996	TAN9601	389	37	2009	TAN0901	281	34
	1997	TAN9701	226	37	2010	TAN1001	317	36
	1998	TAN9801	159	44	2011	TAN1101	325	63
	1999	TAN9901	344	34	2012	TAN1201	176	65
	2000	TAN0001	923	36	2013	TAN1301	531	48
	2001	TAN0101	258	34	2014	TAN1401	236	39
	2002	TAN0201	351	27	2016	TAN1601	529	31
	2003	TAN0301	121	43	2018	TAN1801	465	31
	2004	TAN0401	228	43	2020	TAN2001	515	31

APPENDIX C: Preparation of catch and effort data

C.1 General preparation of the landings dataset

School shark landing records were prepared for the fisheries characterisation and catch-per-unit-effort (CPUE) standardisation. Landings were filtered to only retain records for fish stocks SCH 1, SCH 2, SCH 3, SCH 4, SCH 5, SCH 7, and SCH 8. Following Starr & Kendrick (2016), destination codes “B”, “D”, “P”, “Q”, “R”, “T”, “J”, “P” and “NULL” were omitted, because they represented intermediate holding states that could result in double-counting of catches or invalidate other components of the analysis (e.g., the landed catch allocation). These omissions amounted to 3267.4 t (or 3.6% of the landings assigned to destination code “L”, Landed to Licensed Fish Receiver).

Starr & Kendrick (2016) noted that intermediate destination codes “R”, “T”, and particularly “Q” could invalidate catch allocation approaches, which assume that the landed catch was taken on the current trip. For school shark, the ratio of “R/T/Q” catches to “L” catches remained below 10% in recent years (2008–09 to 2018–19) across most quota management areas (QMAs) (Figure C-1). There was a slight increase in the ratio in SCH 2 and SCH 3, but levels overall remained low. Previously, SCH 4 had the highest ratio of R/T/Q landings to “L” landings, but there was a discernible decrease in this ratio in the fishing years between 2017–18 and 2018–19. Of the destination codes that were retained in the analysis, “L” accounted for most (>99.5%) of the retained landings (Table C-1).

Table C-1: School shark landings (green weight, GW, in t) by destination code, including whether the destination code was included in the analysis (Status). The landings for all destination codes are shown unprocessed from the original dataset extract; prepared landings data for the retained destination codes are also included (groomed).

Destination code	Description	Status	GW (t)	GW, groomed (t)
L	Landed in NZ (to Licensed Fish Receiver, LFR)	Keep	91 470.55	88 717.89
C	Disposed to Crown	Keep	112.79	109.25
O	Conveyed outside NZ	Keep	63.51	63.18
X	Returned to water (Schedule 6)	Keep	58.54	58.54
A	Accidental loss	Keep	52.73	52.61
NP	Not provided	Keep	40.22	40.17
E	Eaten	Keep	30.17	30.15
U	Bait used on board	Keep	17.56	2.05
F	Landed under “approval” from Fisheries NZ	Keep	9.43	9.30
W	Sold at wharf	Keep	6.53	6.20
EOY	Landed under regulation 4(2)(b)	Keep	3.74	3.74
QL	Transferred from holding to LFR	Keep	2.57	2.52
LR	Landed to a LFR but previously recorded as retained on board	Keep	1.84	1.84
S	Seized by Crown	Keep	0.26	0.26
H	Loss from holding pot	Keep	0.13	0.13
M	Spiny dogfish returned to water	Keep	0.10	0.10
R	Retained on board	Omit	1 388.05	
T	Transferred to another vessel	Omit	1 020.64	
Q	Holding receptacle on land	Omit	748.34	
J	Observer-authorised discard	Omit	82.82	
D	Discarded	Omit	24.11	
B	Bait stored for later use	Omit	3.37	
P	Holding receptacle in water	Omit	0.03	

Duplicate landings were identified as records with identical vessel key, client number, trip number, destination type, fish stock code, state code, landing date, unit type, green weight, and processed weight. All duplicate records were removed from the dataset.

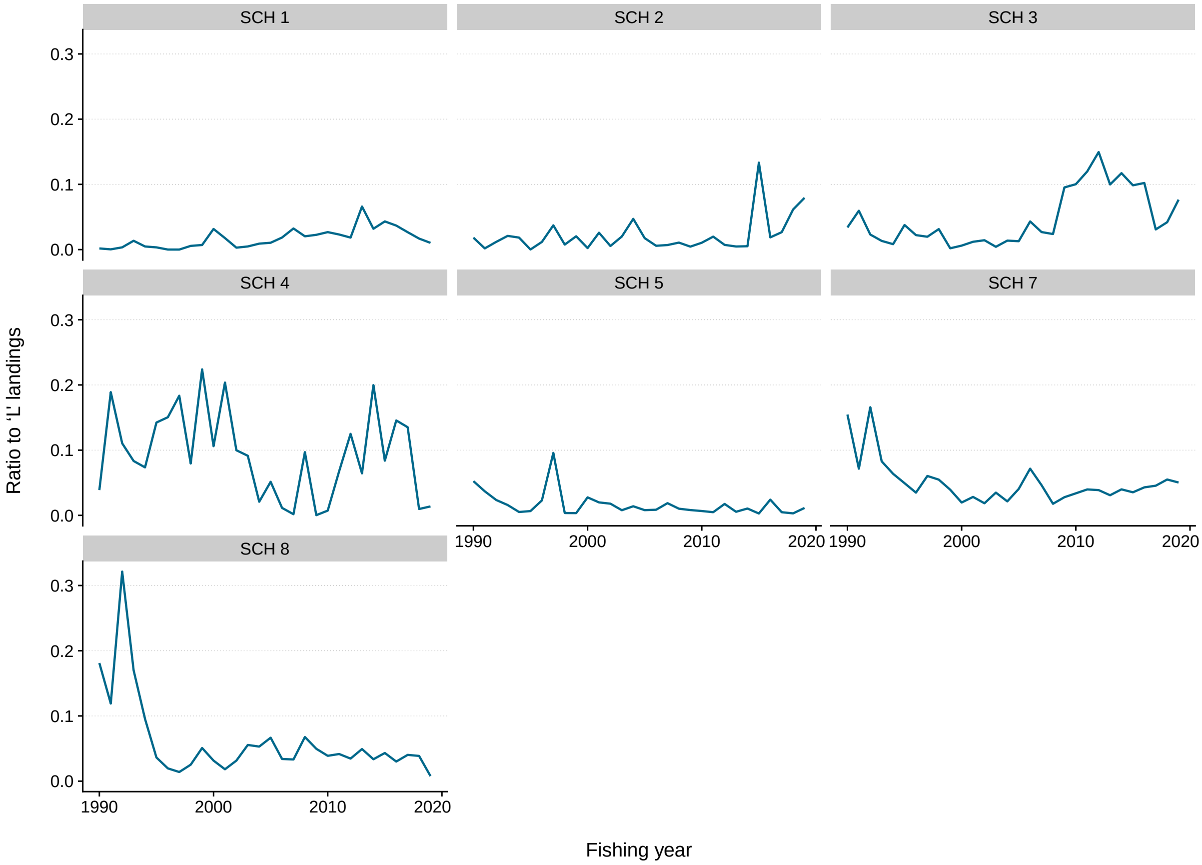

Figure C-1: Ratio of school shark landings (green weight in t) assigned to intermediate destination codes "R", "T", or "Q" for each quota management area, compared with landings recorded as landed to Licensed Fish Receiver, "L". The landings recorded as "R", "T", or "Q" were not groomed as part of the data preparation.

Records with state codes BEA, SHU, WIN, and SCT were removed as they are irrelevant to school shark, and were likely entered erroneously. To avoid double counting of the same record, landings of shark fins or specific shark parts (state codes SHF, FIN, FLP, and ROE) were removed from the analysis when another state code was also reported for the same trip. The proportion of landings assigned to a shark fin code (SHF or FIN) increased from the the mid-1990s onwards, and subsequently stayed relatively constant (13.7% over the last 12 years; Figure C-2, top panel). School shark catches were otherwise primarily landed as "Dressed" (DRE), followed by "Headed and Gutted" (HGU) (Figure C-2, bottom panel). The prevalence of dressed landings increased from the early 1990s to the mid-2000s but has stayed constant at 90.7% on average over the most recent 15 years. Conversely, headed and gutted landings formed about 6.8% of annual landings over the last 12 years of this study.

Missing conversion factors for the conversion between processed and green weight were imputed by replacing missing entries by the median conversion factor for that state code in the year. Records with no available conversion factor for the state code and year combination were discarded. In general, there was little variability in the reported conversion factors, with conversion factors used for all main state codes staying constant since 1993–94 (Figure C-3). Early conversion factors for DRE and HGU were adjusted for consistency from 2 to 1.95 and 2 to 1.85, respectively (see Starr & Kendrick 2016); the green weight for those state codes for 1989–90 to 1992–93 was recalculated with the updated conversion factor.

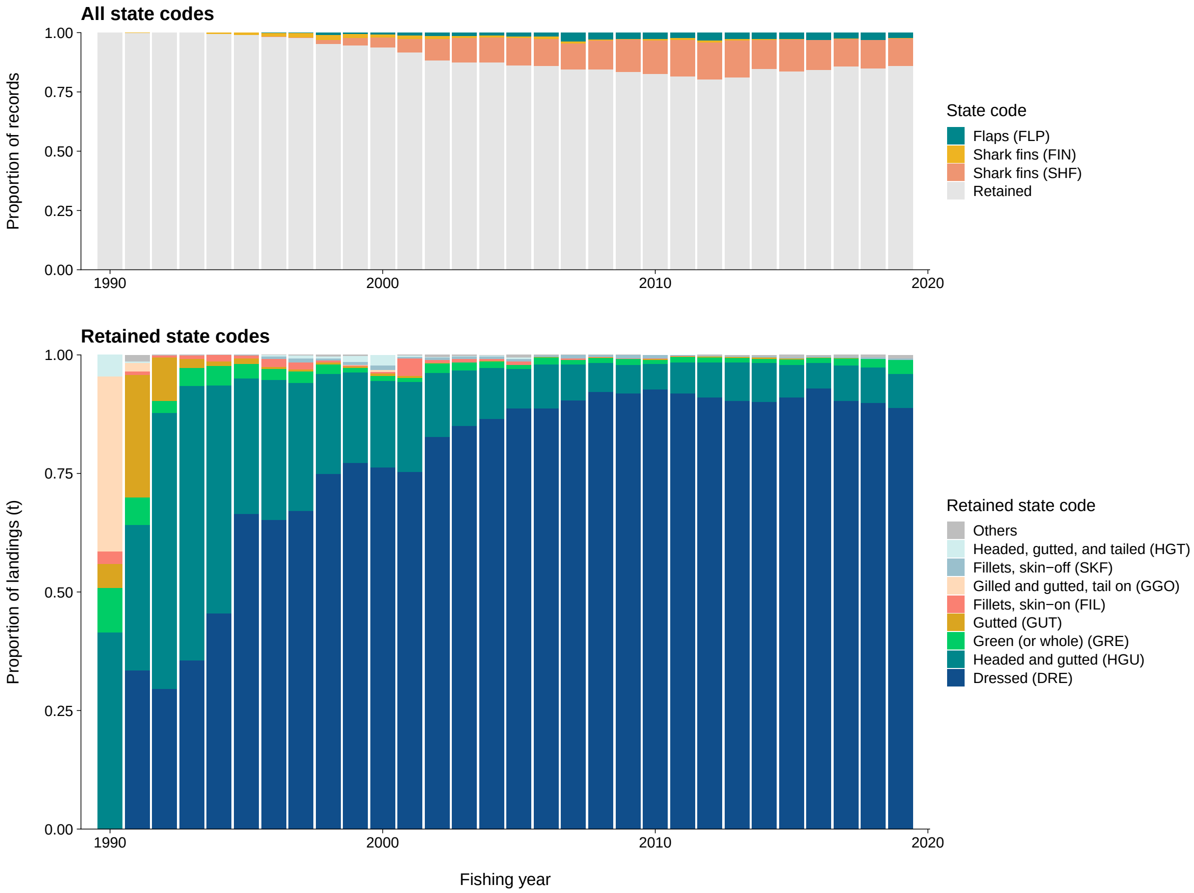

Figure C-2: Proportion of landing records removed from the analysis for including a "Flaps" or "Shark Fins" state code together with another state code in the same trip (top). Bars are colour-coded by the Flaps or Sharks Fins state code reported; records in grey were retained. Proportion of landings (in t) by state code category for records with retained state codes (bottom). Bars are colour-coded by the retained state code.

Records with missing green weight and also missing the unit number (*unit_num*) and unit weight were discarded. Green weight was recalculated for all records as the product of the unit number, the unit weight and the conversion factor for the state code. The recalculated green weight was used to impute missing green weight entries. It was also used in the out-of-range procedure (see below). Green weight could not be recalculated for records with state code "MEA" (meal), because a different reporting procedure was used for the unit number field. The meal reporting procedure was revised and described in a letter to fishers, Ref 22/9/0, from Russell Burnard, Manager Regulatory and Information, Ministry of Fisheries, and active from September 2008 (David Foster, Fisheries New Zealand, pers. comm.). Implausible entries for the unit number field with state code MEA were found throughout the time series prior to 2008, so that the original green weight for MEA records was used throughout.

Straddling statistical areas are statistical areas that overlap with multiple fish stocks boundaries (e.g., the boundaries for 037 overlap with SCH 7 and SCH 8). Trips with landings to multiple school shark QMAs that also included fishing events in straddling statistical areas were discarded, because the school shark landing could not be attributed to a stock.

C.2 Out-of-range landings

Out-of-range landings were identified and removed from the fisheries characterisation and CPUE analyses following the grid approach described in Starr & Kendrick (2016). Under this approach, the ratio of declared green weight to recalculated green weight is used as a metric of trip landing reliability:

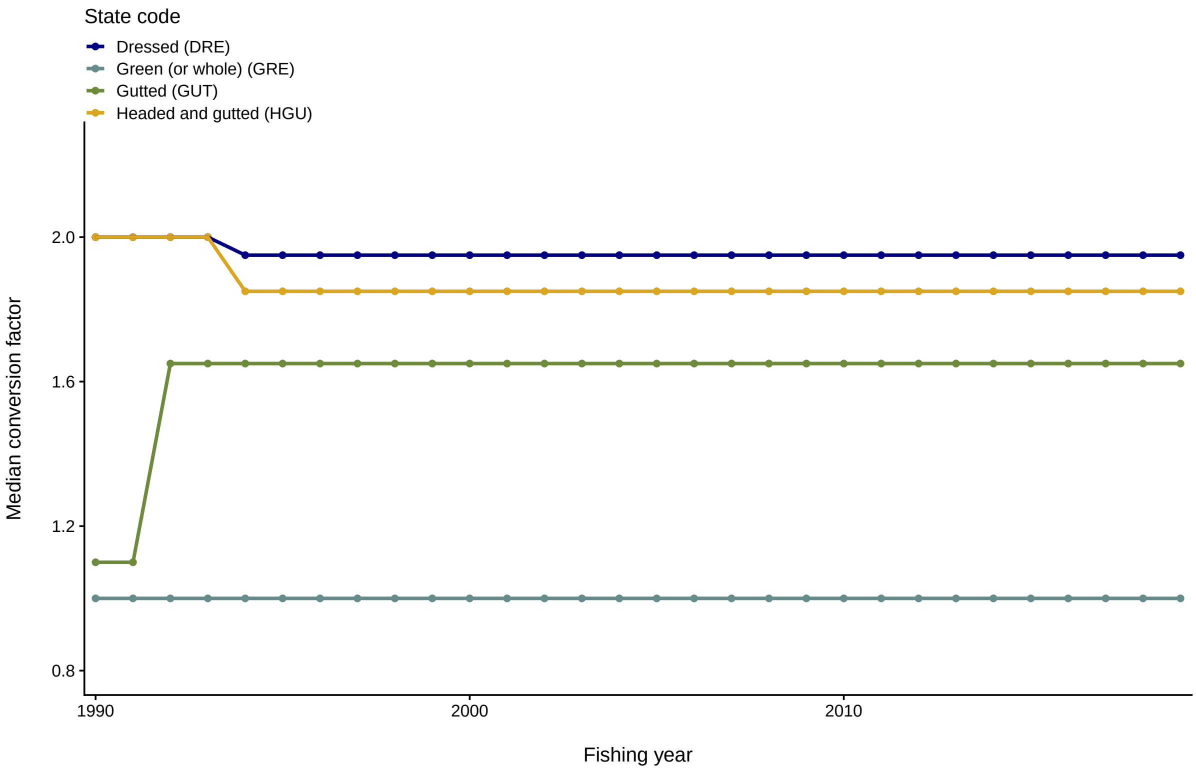

Figure C-3: Median conversion factor used to convert from processed to green weight over time for the four most-used state codes for school shark landings.

a record is considered more reliable if the declared green weight matches or approaches the green weight recalculated from the product of the conversion factor, the unit weight and the unit number. Individual landings that are in a high-quantile position compared with other landings in the QMA are also considered less reliable. For each QMA, a threshold ratio of declared to recalculated green weight and a maximum landings quantile are defined. When a record exceeds the threshold ratio for both metrics, the landing is considered out-of-range and discarded. Optimal thresholds are selected by trialling combinations of candidate thresholds and comparing the resulting groomed annual landings with the corresponding annual QMR/MHR records using the sum-of-square (SS^2). Optimal thresholds are thresholds that minimise the SS^2 of the fit to the QMR/MHR data. The final selection of out-of-range trips is based on those optimal thresholds.

For each QMA, the SS^2 between the groomed landings and the QMR records was calculated for all combinations of green weight-to-recalculated threshold ratios of 2, 4, 6, 8 and 10, and for maximum landing quantiles of 0.90, 0.92, 0.94, 0.96, 0.97, 0.98, 0.99 and 0.999 (the resulting quantile and ratio thresholds by QMA are shown in Figure C-4). Following this procedure, a total of 39 trips were removed, including a substantial landing of 808.1 t in SCH 8. The quantile threshold that maximised the fit to QMR landings was 99 or higher, except for SCH 4, where the quantile threshold was 98. There was more variability in the optimal ratio threshold, with a value of 2 or 4 selected for five out of seven QMAs. There were no trips that exceeded both thresholds in SCH 4 or SCH 5, so no trips were omitted for these QMAs.

Annual landings by QMA following the data preparation are shown in Table C-2.

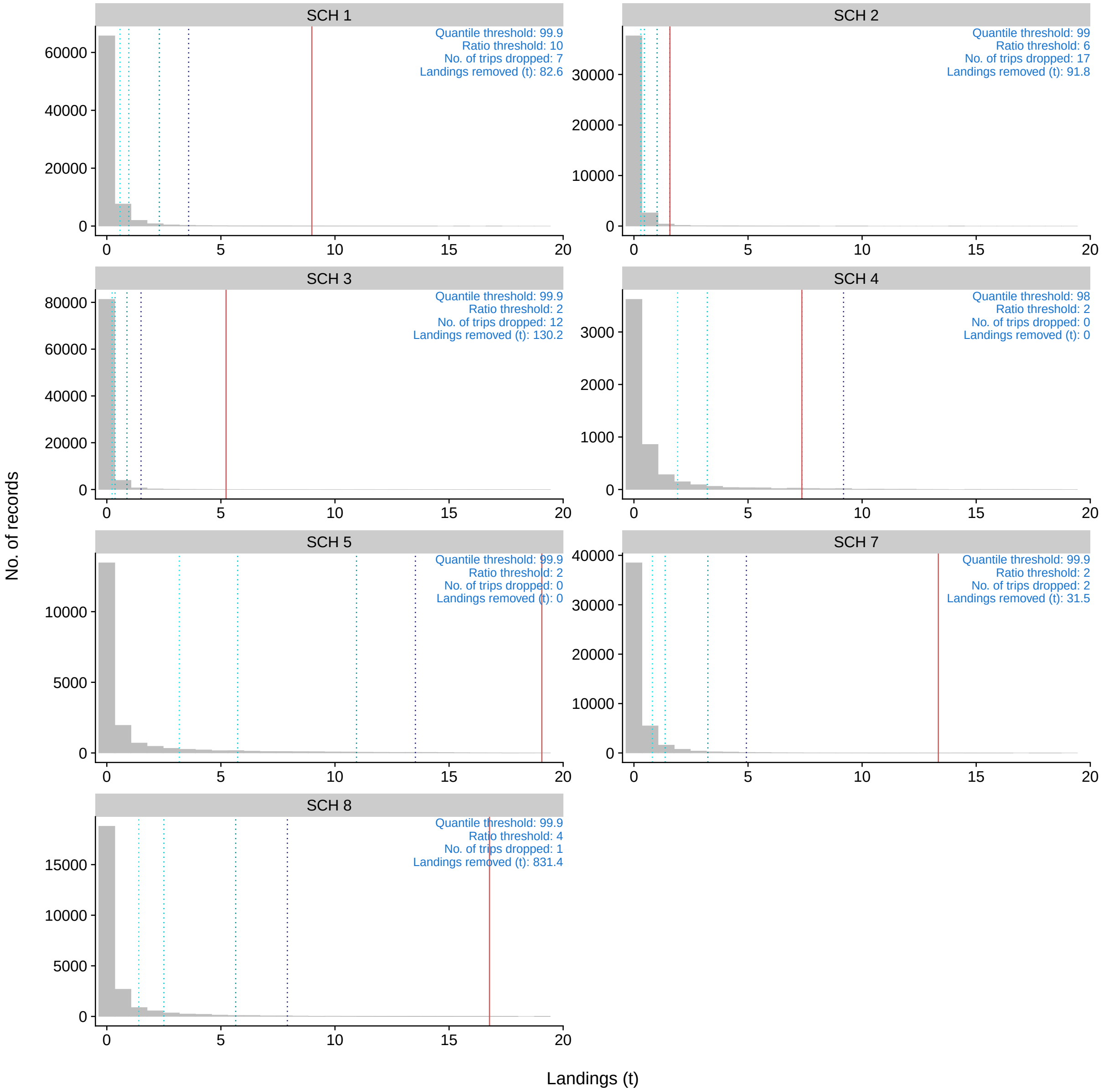

Figure C-4: Distribution of school shark landings by trip for each quota management area (QMA), with the dotted line showing the 90th, 94th, 98th and 99th quantiles from light to dark shades of blue, and the quantile threshold selected by the grid method shown in red. For each QMA, the value of the selected quantile and ratio thresholds, the number of trips omitted and the omitted landings associated with the trips are noted in the top-right corner of the panel.

Table C-2: School shark landings (in t) by fishing year for each quota management area (QMA), following the data preparation.

Fishing year	SCH 1	SCH 2	SCH 3	SCH 4	SCH 5	SCH 7	SCH 8	Total
1989–90	422.39	121.05	221.08	13	369.35	475.52	340.63	1963.02
1990–91	499.59	121.41	202.45	18.17	495.09	392.64	310.38	2039.73
1991–92	518.1	130.66	231.46	31.26	585.2	389.63	327.22	2213.53
1992–93	699.34	176.17	199.42	31.87	562.22	459.85	438.03	2566.9
1993–94	645.75	159.76	212.78	41.06	579.66	453.8	410.85	2503.66
1994–95	613.5	154.27	253.17	78.84	639.11	404.93	415.88	2559.7
1995–96	746.94	232.21	302.76	190.65	706	647.01	522.43	3348
1996–97	748.61	219.83	269.67	200.1	630.51	548.24	441.14	3058.1
1997–98	784.15	204.88	272.58	129.05	640.92	461	421.92	2914.5
1998–99	763.28	262.05	336.6	108.96	661.2	665.6	524.2	3321.89
1999–00	799.59	248.82	332.83	95.87	672.4	637.99	454.08	3241.58
2000–01	783.56	173.72	371.38	100.67	684.01	590.35	433.03	3136.72
2001–02	713.89	200.65	326.33	88.86	658.28	495.29	458.72	2942.02
2002–03	696.46	207.9	398.36	122.28	758.51	514.18	437.55	3135.24
2003–04	752.18	180.99	333.24	143.9	694.54	567.63	389.38	3061.86
2004–05	703.77	193.02	417.69	224.42	736.61	547.75	540.7	3363.96
2005–06	631.06	181.8	305.35	176.41	645.88	567.53	514.23	3022.26
2006–07	664.52	190.82	375.38	92.76	705.53	598.17	517.18	3144.36
2007–08	684.6	227.17	333.41	125.26	766.41	617.92	492.01	3246.78
2008–09	711.02	227.5	383.15	146.82	731.06	693.37	588.21	3481.13
2009–10	586.33	207.58	418.33	201.53	786.22	603.41	459.15	3262.55
2010–11	779.21	195.12	359.75	165.76	692.08	685.96	578.6	3456.48
2011–12	693.34	194.88	333.9	191.52	716.59	613.29	505.86	3249.38
2012–13	599.99	205.32	319.34	135.53	747.21	649.83	513.81	3171.03
2013–14	654.69	178.04	363.24	127.58	721.52	622.25	462.7	3130.02
2014–15	591.01	166.86	365.03	207.38	638.31	595.54	518.61	3082.74
2015–16	493.89	153.08	448.75	200.41	597.21	555.08	463.5	2911.92
2016–17	530.66	139.15	361.28	229.23	669.23	548.25	354.14	2831.94
2017–18	636.23	167.22	354.76	182.61	706.2	603.46	364.7	3015.18
2018–19	568.58	163.16	380.87	202.46	590.21	535.39	281.16	2721.83
Total	19716.23	5585.09	9784.34	4004.22	19787.27	16740.86	13480	89098.01

C.3 Preparation of the fishing event (effort) dataset

Trips likely to include double-reporting of effort were discarded by identifying records where more than a single effort return form type was used across fishing events in the trip. Records listing rock lobster pots (RLP), cod pots (CP) and fyke nets (FN) as a primary method were excluded from the form type count, as these fishing methods are unlikely to catch school shark.

Missing entries for fishing method, statistical area, and target species were corrected when possible by assuming that if a unique value for these variables was used in other fishing events belonging to the trip, the missing entries could be imputed to this unique value. Trips with missing fishing event fields that listed more than one unique value for the field in other fishing events were discarded. Trips where all entries for fishing method, statistical area, or target species were missing were discarded (see Figure C-5 for the impact of successive data preparation steps on the remaining landings associated with the fishing records, once trips were discarded following the preparation of effort data). The data preparation step with the biggest impact on the remaining landings data was the removal of trips listing multiple effort return forms; this impact was particularly apparent from 2007–08 onwards, when the transition towards high-resolution forms was completed.

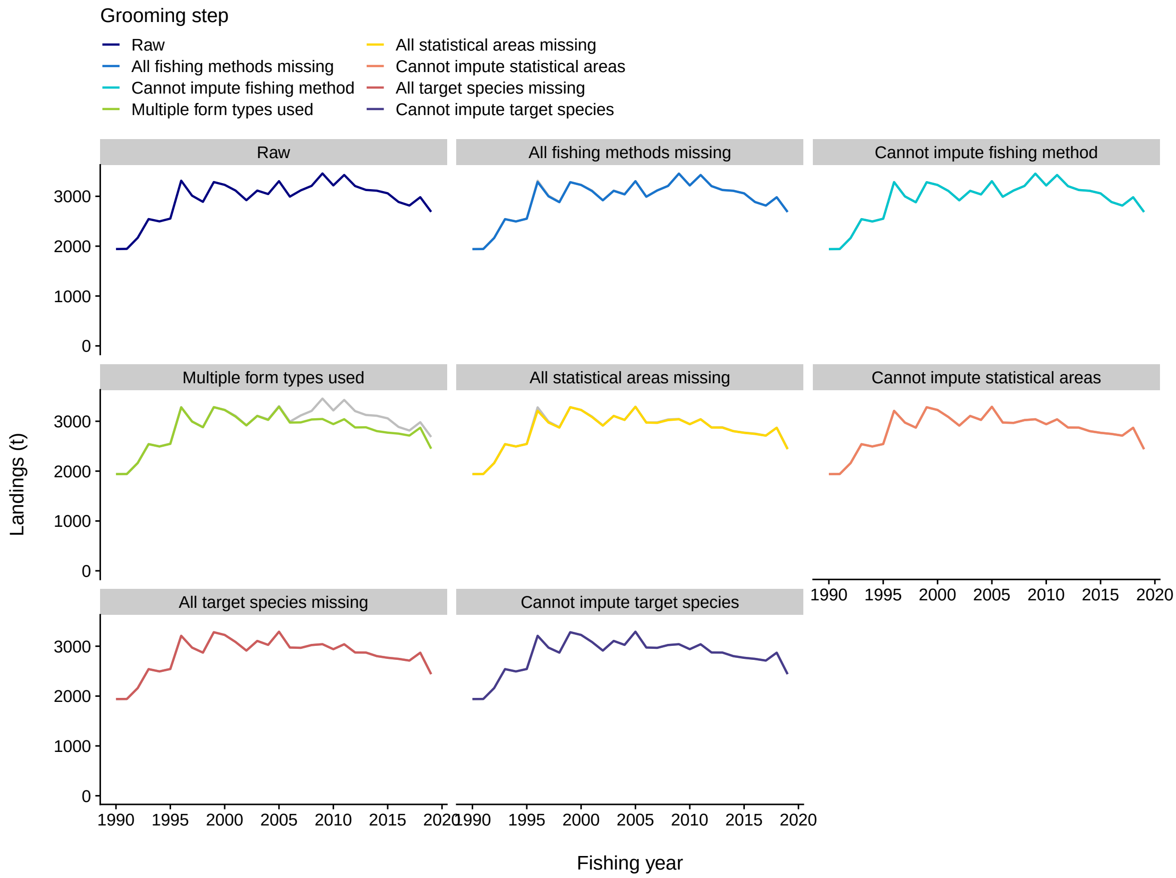

Figure C-5: Annual school shark landings (in t) remaining once trips were removed following each data preparation step applied to the fishing event data. Steps were applied sequentially from left to right columns, and top to bottom rows.

For each CPUE unit, data in the key effort fields were prepared for set net, bottom longline and bottom trawl to identify entries that were considered to be outside of plausible effort bounds (Figures C-6 to Figure C-8). The amended effort fields for set net were fishing duration and total net length; for bottom-longline, they were effort number (number of sets) and total hook number; and for bottom-trawl, they were effort number (number of tows) and fishing duration. For each of these fields, plausible bounds for effort values were defined based on examination of the distribution by gear and CPUE unit (see marginal histograms in Figures C-6 to C-8). Bounds were either set as a fixed value or as a multiple of the 90th quantile. When the effort value for a given field was outside of the specified limits, it was corrected to the vessel median for that field × CPUE unit × gear combination. If the vessel median was also outside of the specified limits, the effort value was set to the overall median for that field × CPUE unit × gear combination. All imputed effort records were retained for the characterisation but only effort records originally within the likely effort bounds were retained for the CPUE standardisation.

Considering the key quantiles for the distribution of the amended effort by CPUE unit showed that for set net, the duration of most events was a day or shorter, except for SCH 2 & top of SCH 3, where some events extended to two days or more (Table C-3). Net length was generally between 300 and 3000 m, except in SCH 7, SCH 8 & lower SCH 1W where net length tended to be longer (95th quantile: 4000 m). For bottom longline, sets generally had less than 5000 hooks in Far North & SCH 1E, SCH 2 & top of SCH 3, and SCH 7, SCH 8 & lower SCH 1W, but the number of hooks increased to 9000 to 10 000 hooks in Lower SCH 3 & SCH 5 and Chatham Rise (SCH 4) (95th quantile). For Chatham Rise (SCH 4), the median number of hooks (4000) was two to four times larger than the number of hooks in other CPUE units. For bottom trawl, fishing duration was usually three to four hours, extending to up to 10 to 12 hours.

Table C-3: Summary of key metrics of effort (5th, 50th and 95th quantile) by gear for each catch-per-unit-effort monitoring unit.

Gear	Metric	Qtl	Far North & SCH 1E	SCH 2 & top of SCH 3	Lower SCH 3 & SCH 5	SCH 7, SCH 8 & lower SCH 1W	Chatham Rise (SCH 4)
Bottom trawl	Fishing duration	5	1.1	1.3	1.7	1.5	
		50	3.2	4.0	4.0	4.0	
		95	10.0	12.5	12.0	12.0	
Bottom longline	No. of hooks	5	450.0	600.0	500.0	300.0	1000.0
		50	1620.0	1500.0	2000.0	1000.0	4000.0
		95	4500.0	4200.0	8750.0	4500.0	10000.0
Set net	Fishing duration	5	5.0	7.0	4.0	5.5	
		50	12.0	24.0	12.0	13.5	
		95	18.0	48.0	22.0	24.0	
	Total net length	5	500.0	300.0	700.0	500.0	
		50	1500.0	1000.0	1900.0	2000.0	
		95	3000.0	2800.0	3000.0	4000.0	

C.4 Catch allocation

The allocation of school shark landings to effort records (described in subsection 2.2) resulted in annual catch values that matched the trends in the overall landings and in the QMR/MHR records for school shark (Figure C-9). There was a slightly higher discrepancy in the later part of the time series due to the removal of trips listing multiple form types (see Figure C-5). Overall, most catches were allocated according to the estimated catch, but there were gear-specific trends in the proportion of catches allocated as a function of effort (Figure C-10). More specifically, bottom-trawl records had a higher proportion of catches allocated according to effort in all QMAs, sometimes exceeding 50% in the earlier part of the time series. For all gears, the proportion of catches allocated according to effort was lower in the later part of the time -series when fishing event-specific forms were in use.

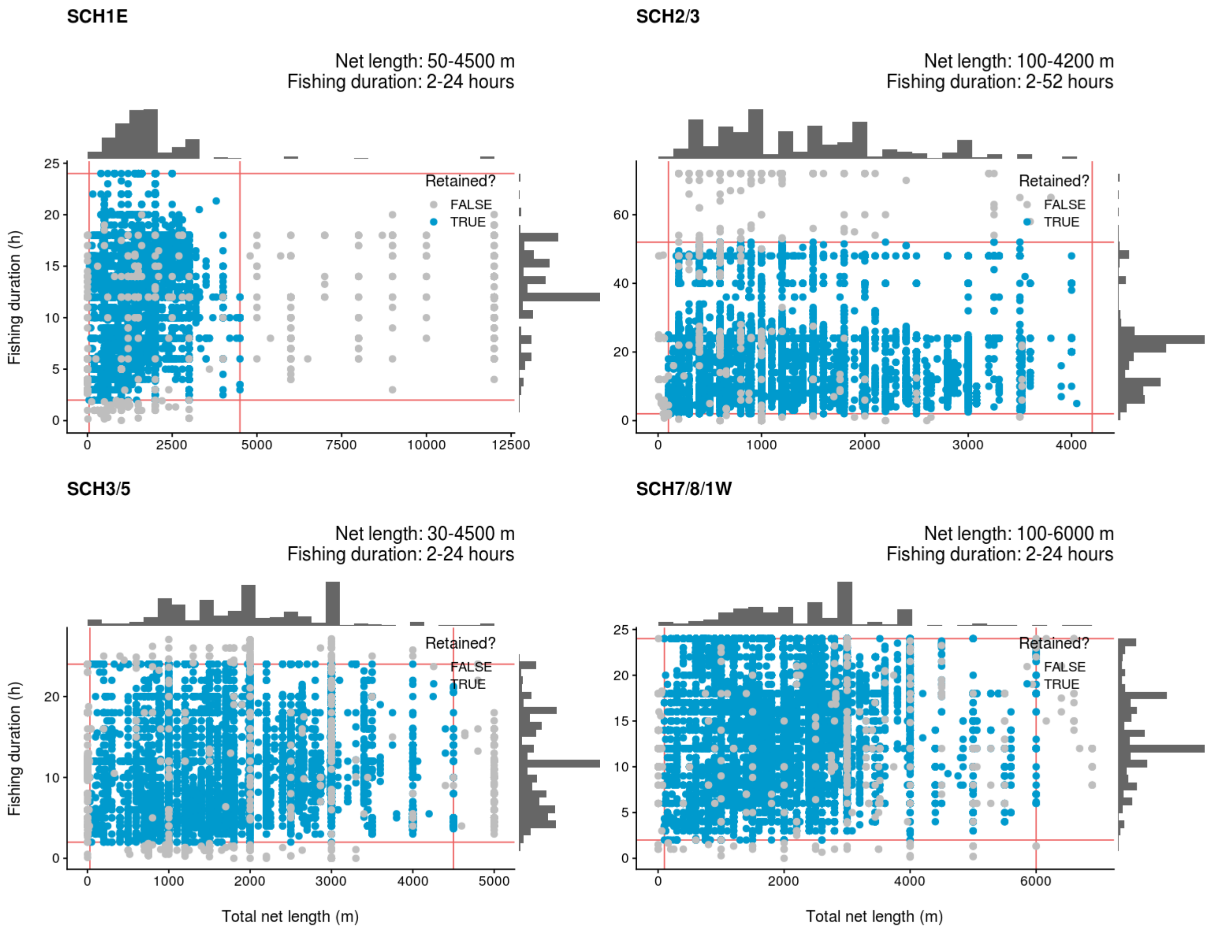

Figure C-6: Relationship between net length and fishing duration recorded on effort return forms for set net by catch-per-unit-effort unit. Marginal distributions for each variable are shown in the top and right margins of each panel. Records that were retained in the analysis are shown in blue. Threshold ranges used to delineate plausible effort values by vessel are noted in the right-hand corner of each panel, and indicated by red lines.

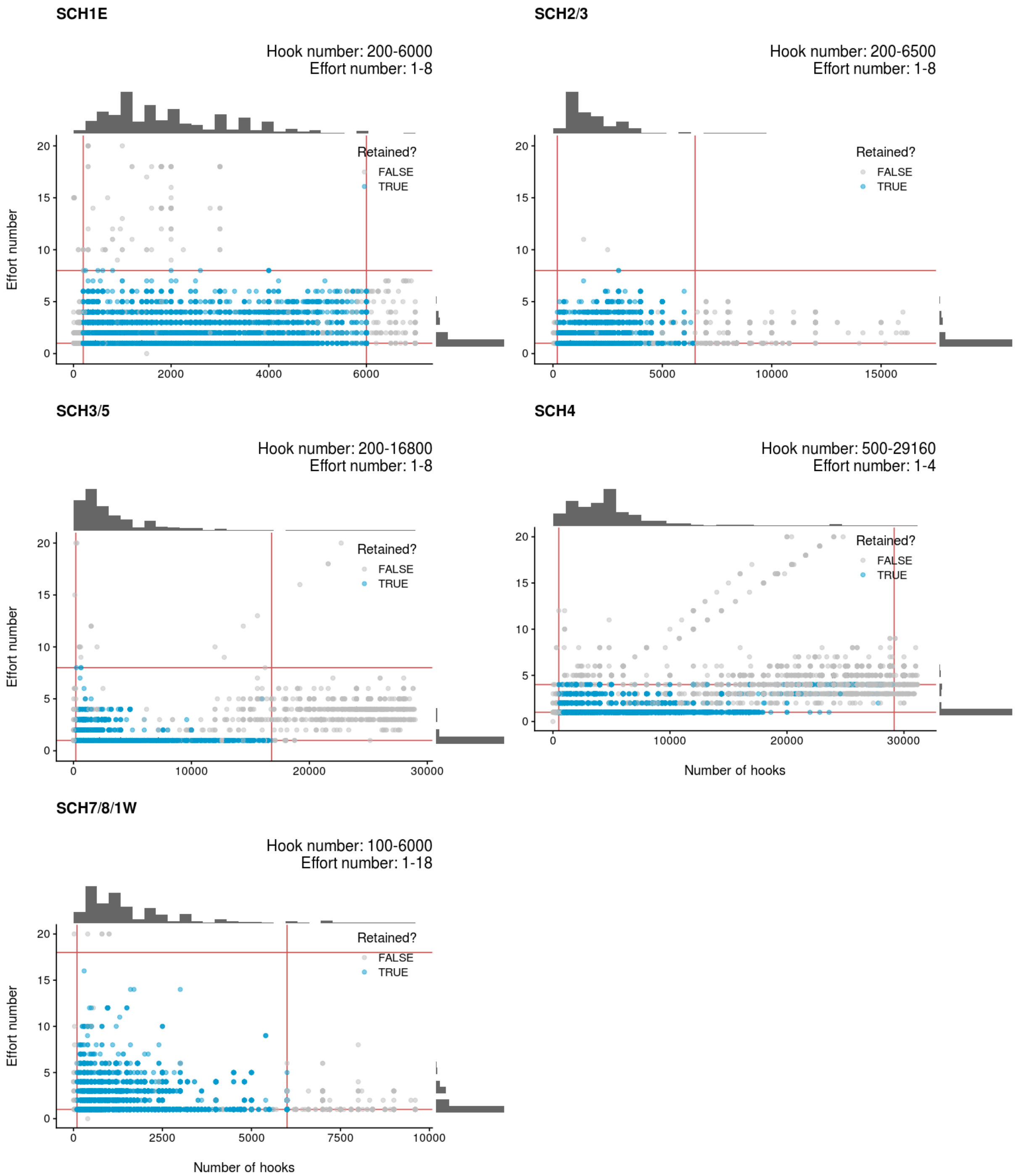

Figure C-7: Relationship between hook and effort number recorded on effort return forms for bottom longline by catch-per-unit-effort unit. Marginal distributions for each variable are shown in the top and right margins of each panel. Records that were retained in the analysis are shown in blue. Threshold ranges used to delineate plausible effort values by vessel are noted in the right-hand corner of each panel, and indicated by red lines.

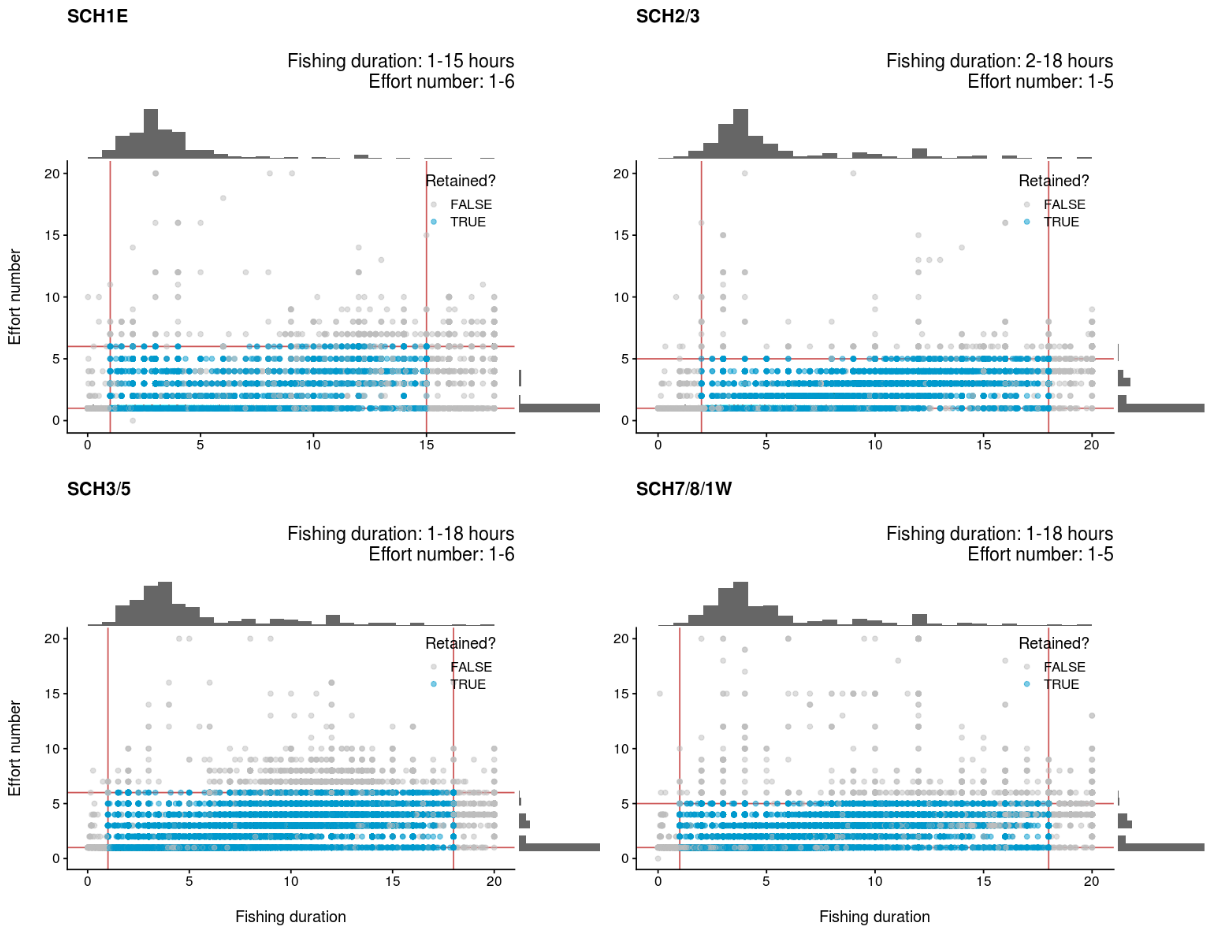

Figure C-8: Relationship between fishing duration and effort number recorded on effort return forms for bottom trawl by catch-per-unit-effort unit. Marginal distributions for each variable are shown in the top and right margins of each panel. Records that were retained in the analysis are shown in blue. Threshold ranges used to delineate plausible effort values by vessel are noted in the right-hand corner of each panel, and indicated by red lines.

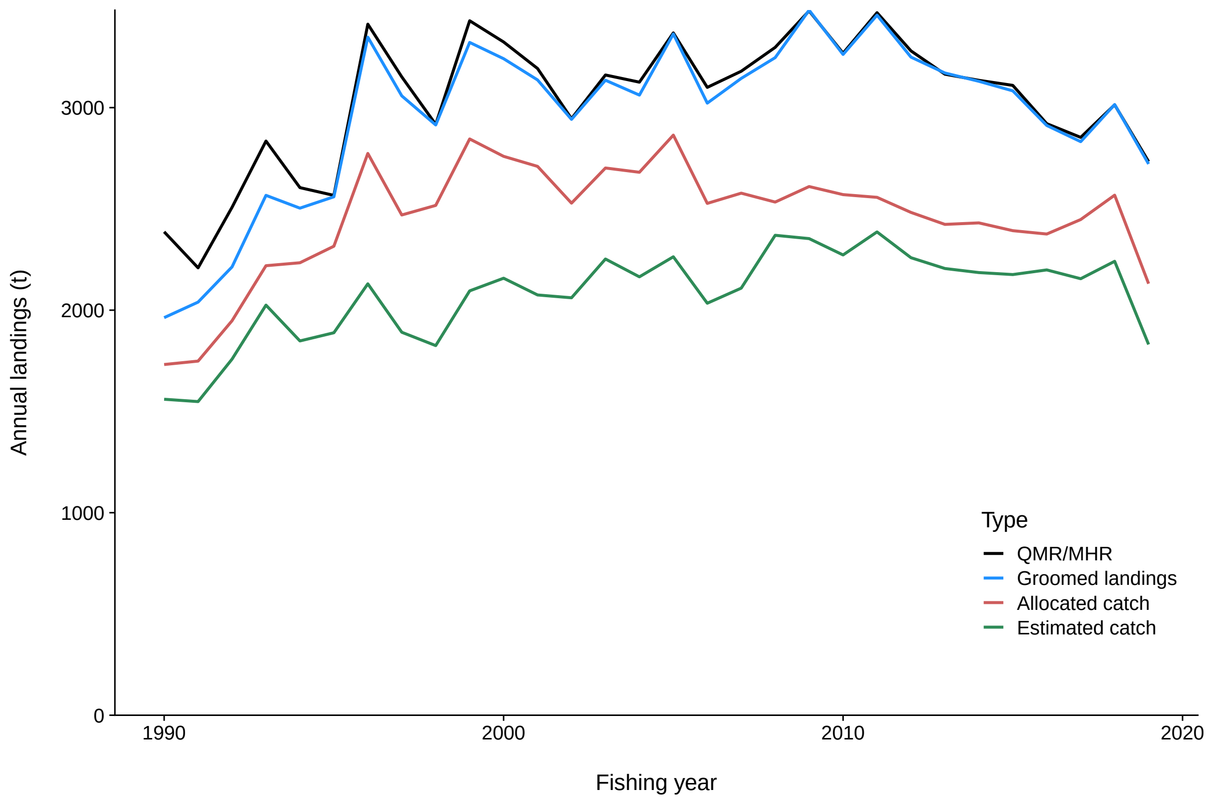

Figure C-9: Annual school shark landings (in t) across the different sources of catch data used in this analysis. The allocated catch dataset is the version used for the characterisation, excluding additional steps of data preparation for the catch-per-unit-effort standardisation. QMR, Quota Management Report; MHR, Monthly Harvest Return.

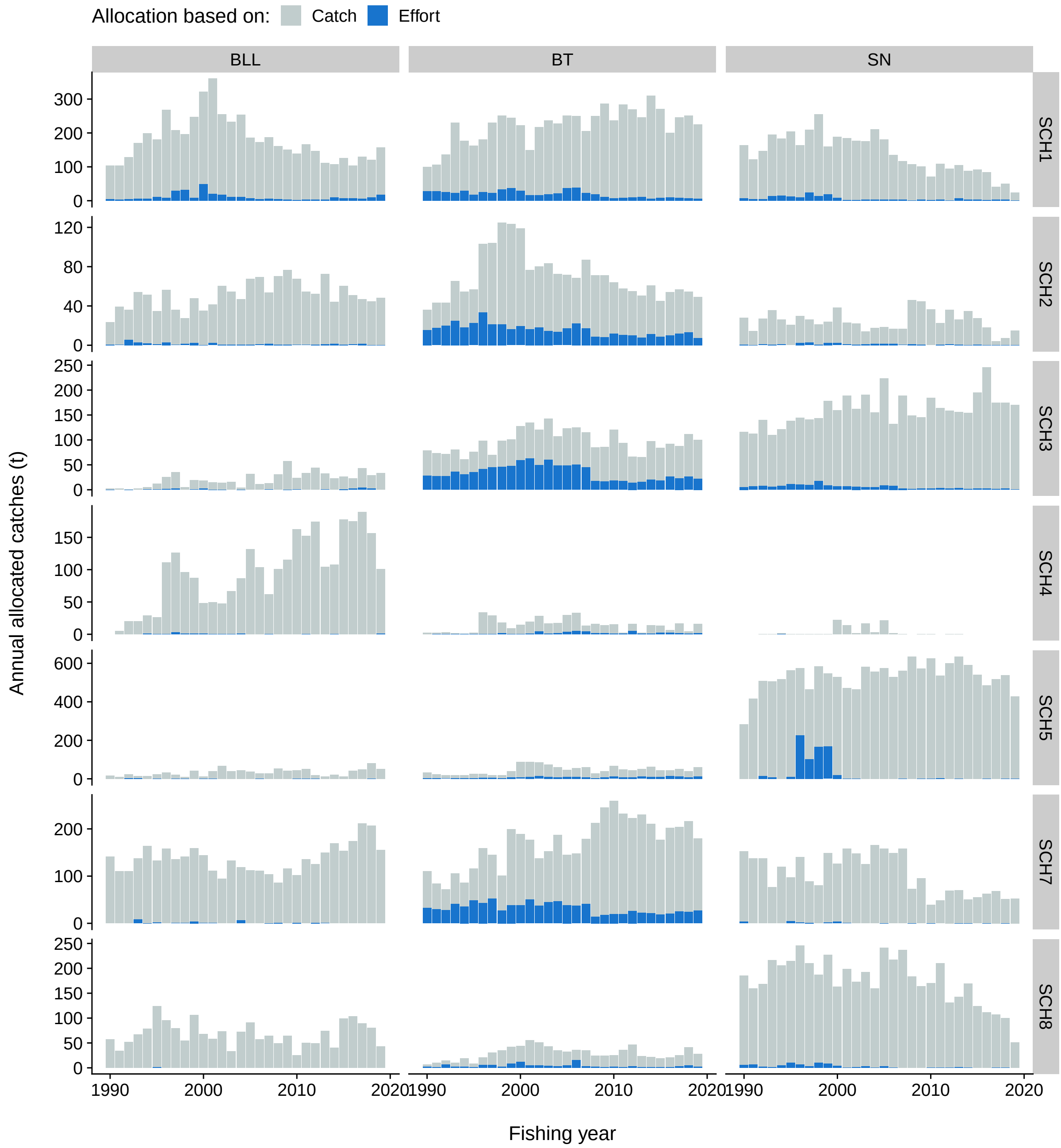

Figure C-10: Annual allocated school shark catches (in t) for each fishing method by quota management area. Colour of the bar indicates the allocation of trip landings to a fishing event according to estimated catch (light blue) or fishing effort (dark blue).

APPENDIX D: Target species codes

Table D-1: Definition of codes for target species.

Code	Common name	Scientific name
BAR	Barracouta	*Thyrsites atun*
BNS	Bluenose	*Hyperoglyphe antarctica*
ELE	Elephantfish	*Callorhinchus milii*
FLA	Flatfish	Multiple species
GUR	Red gurnard	*Chelidonichthys kumu*
HOK	Hoki	*Macruronus novaezelandiae*
HPB	Hāpuku and bass	*Polyprion oxygeneios* and *P. americanus*
JDO	John dory	*Zeus faber*
LIN	Ling	*Genypterus blacodes*
MOK	Blue moki	*Latridopsis ciliaris*
RCO	Red cod	*Pseudophycis bachus*
SCH	School shark	*Galeorhinus galeus*
SKI	Gemfish	*Rexea solandri*
SNA	Snapper	*Chrysophrys auratus*
SPO	Rig	*Mustelus lenticulatus*
SQU	Squid	*Nototodarus gouldi, N. sloanii*
STA	Giant stargazer	*Kathetostoma* spp.
SWA	Silver warehou	*Seriolella punctata*
TAR	Tarakihi	*Nemadactylus macropterus*
TRE	Trevally	*Pseudocaranx dentex*
WAR	Blue warehou	*Seriolella brama*

APPENDIX E: Distribution of school shark catches by target species for bottom trawl

E.1 Far North & SCH 1E bottom trawl

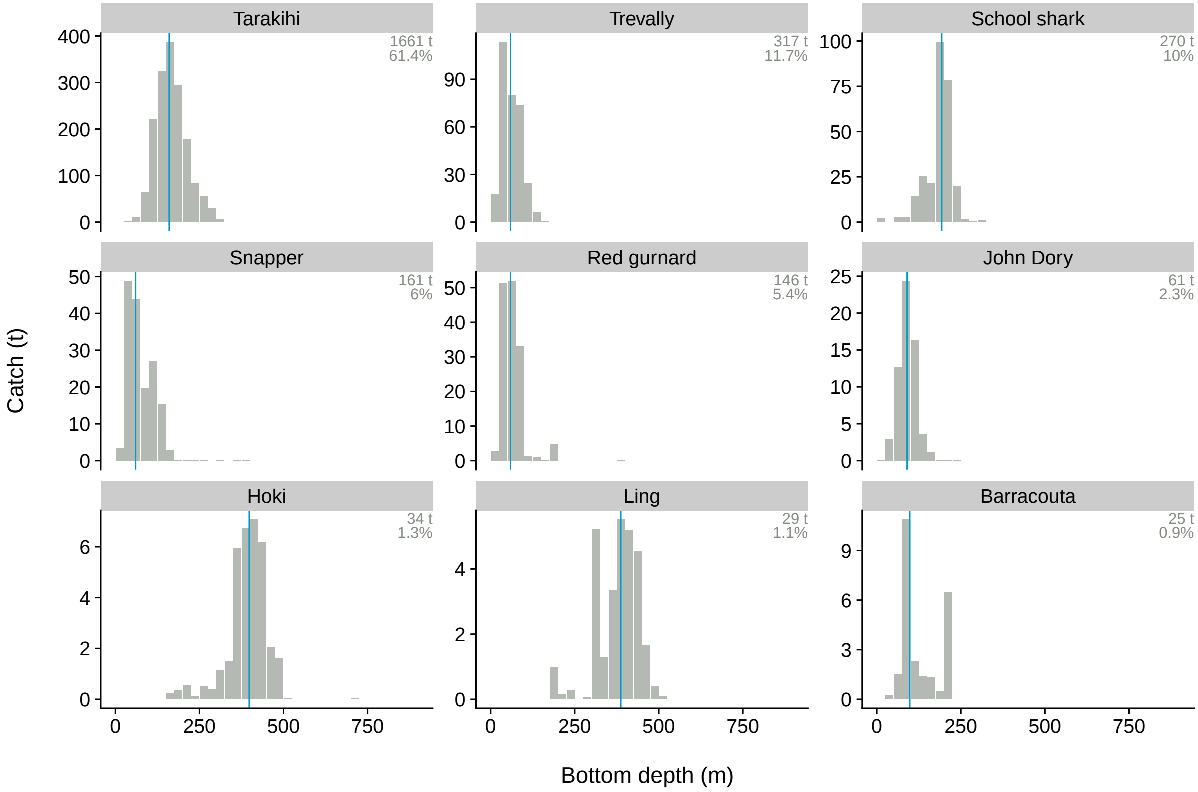

Figure E-1: Distribution of school shark catch (in t) by depth as a function of the target species recorded on the effort return form for Far North & SCH 1E bottom trawl from 2007–08 to 2018–19. Panels are ordered by the scale of catches from left to right and top to bottom. Blue line shows the median depth at which school shark was caught; school shark catch for the target species and its proportion of the total catch are noted in the top-right corner.

E.2 SCH 2 & top of SCH 3 bottom trawl

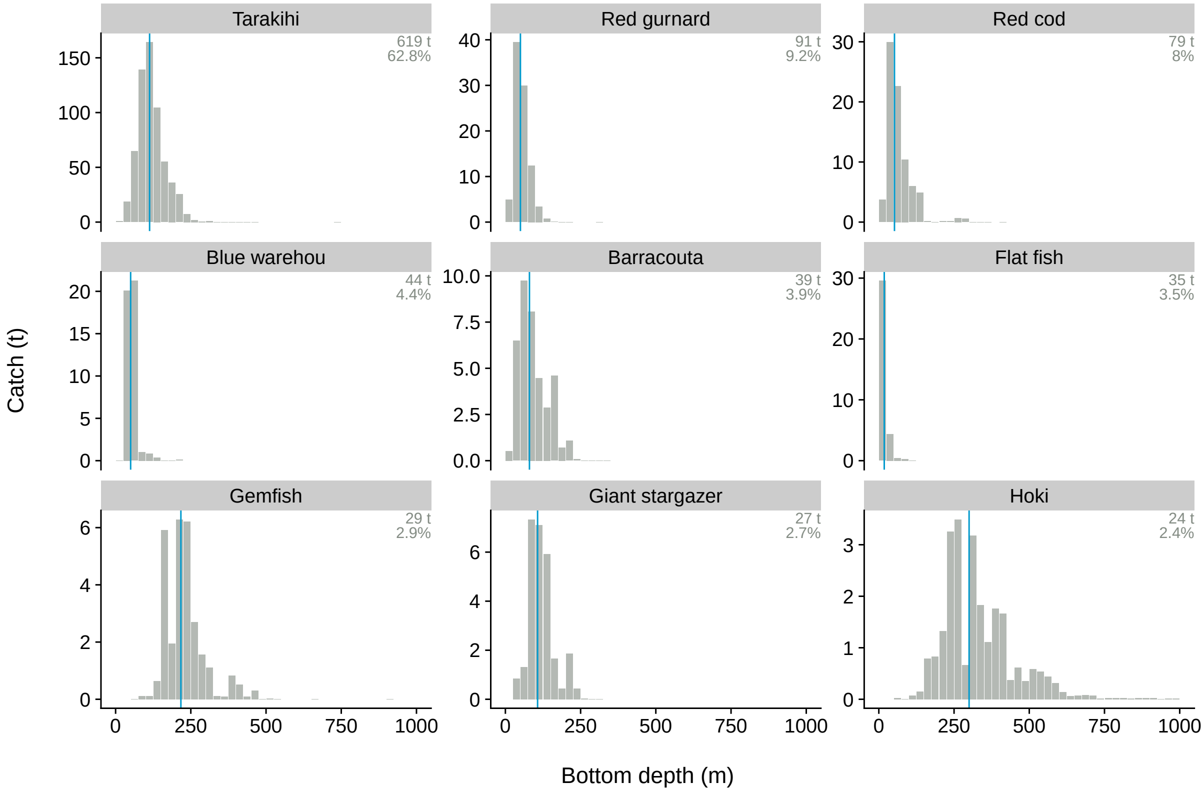

Figure E-2: Distribution of school shark catch (in t) by depth as a function of the target species recorded on the effort return form for SCH 2 & top of SCH 3 bottom trawl from 2007–08 to 2018–19. Panels are ordered by the scale of catches from left to right and top to bottom. Blue line shows the median depth at which school shark was caught; school shark catch for the target species and its proportion of the total catch are noted in the top-right corner.

E.3 Lower SCH 3 & SCH 5 bottom trawl

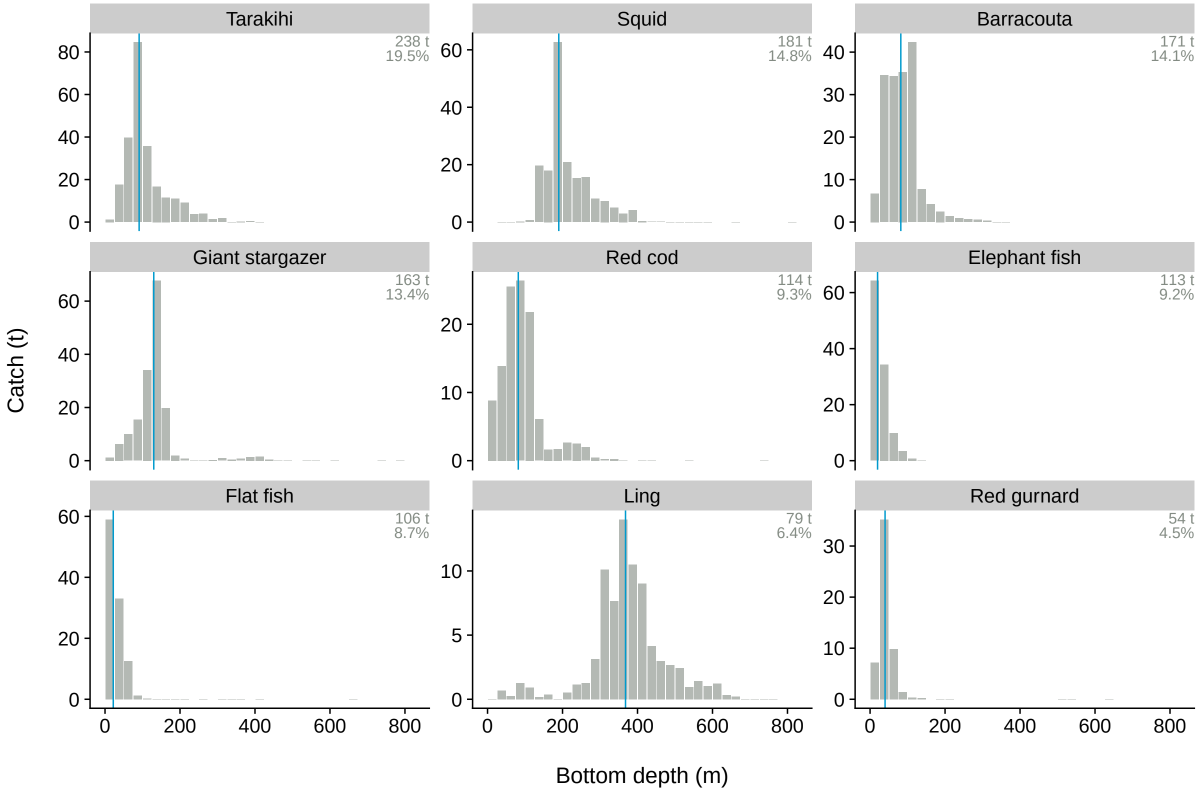

Figure E-3: Distribution of school shark catch (in t) by depth as a function of the target species recorded on the effort return form for Lower SCH 3 & SCH 5 bottom trawl from 2007–08 to 2018–19. Panels are ordered by the scale of catches from left to right and top to bottom. Blue line shows the median depth at which school shark was caught; school shark catch for the target species and its proportion of the total catch are noted in the top-right corner.

E.4 SCH 7, SCH 8 & lower SCH 1W bottom trawl

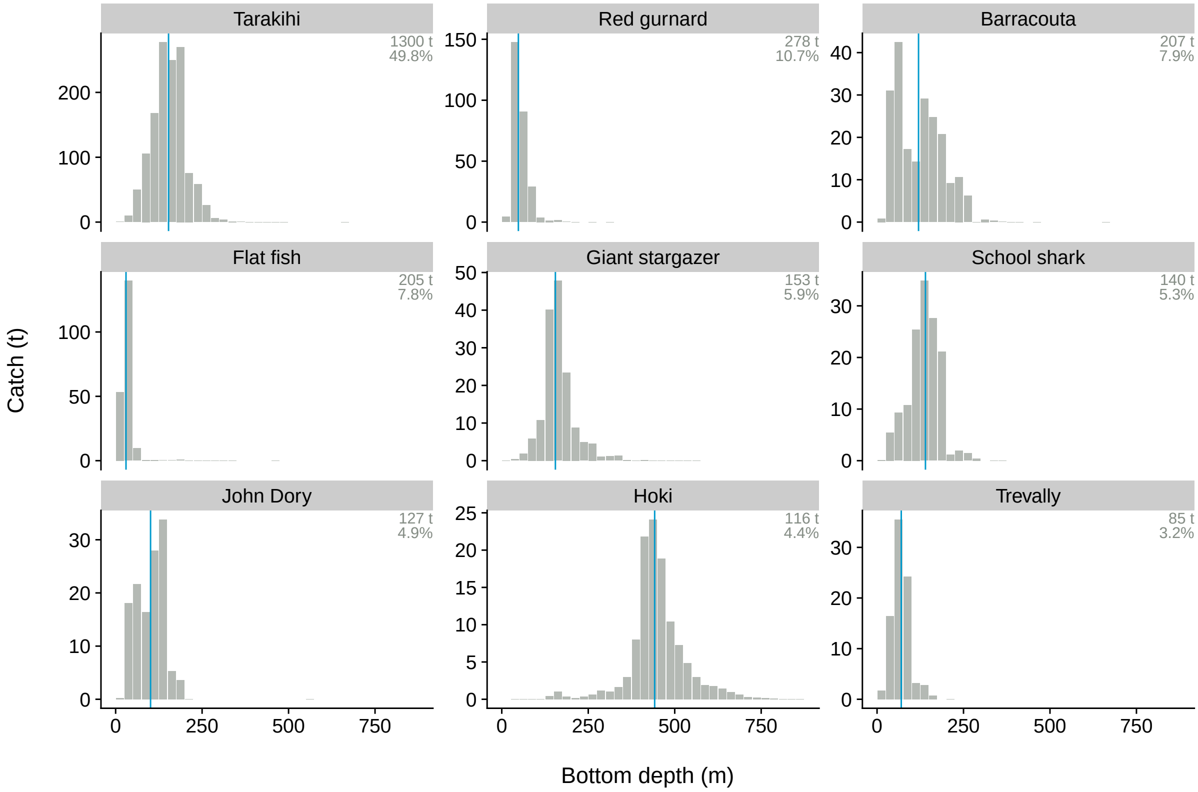

Figure E-4: Distribution of school shark catch (in t) by depth as a function of the target species recorded on the effort return form for SCH 7, SCH 8 & lower SCH 1W bottom trawl from 2007–08 to 2018–19. Panels are ordered by the scale of catches from left to right and top to bottom. Blue line shows the median depth at which school shark was caught; school shark catch for the target species and its proportion of the total catch are noted in the top-right corner.

APPENDIX F: Summary of CPUE data by fishery across effort resolutions

F.1 Far North & SCH 1E set net

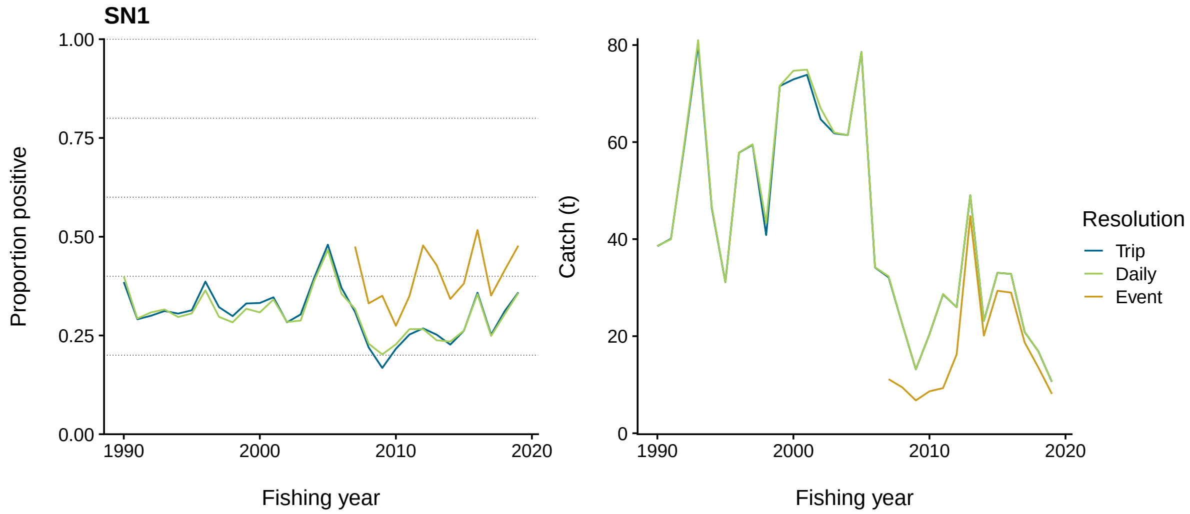

Figure F-1: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

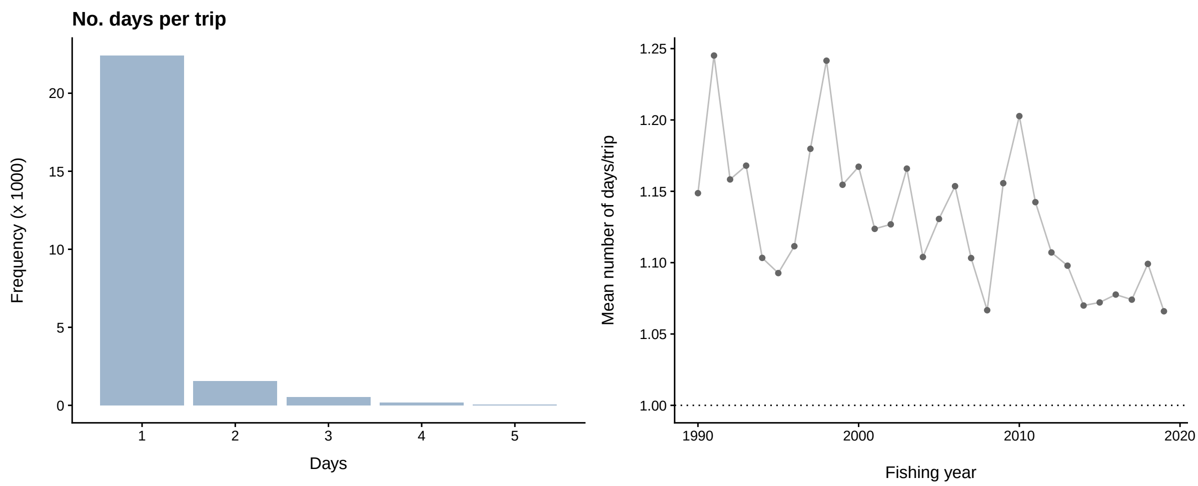

Figure F-2: Distribution of trip length (in days) and change in mean trip length over time from 1989–90 to 2018–19. The number of sets was not recorded continuously during this time period, so no set count summary and time series are included for this fishery. Records included are for the core fleet only.

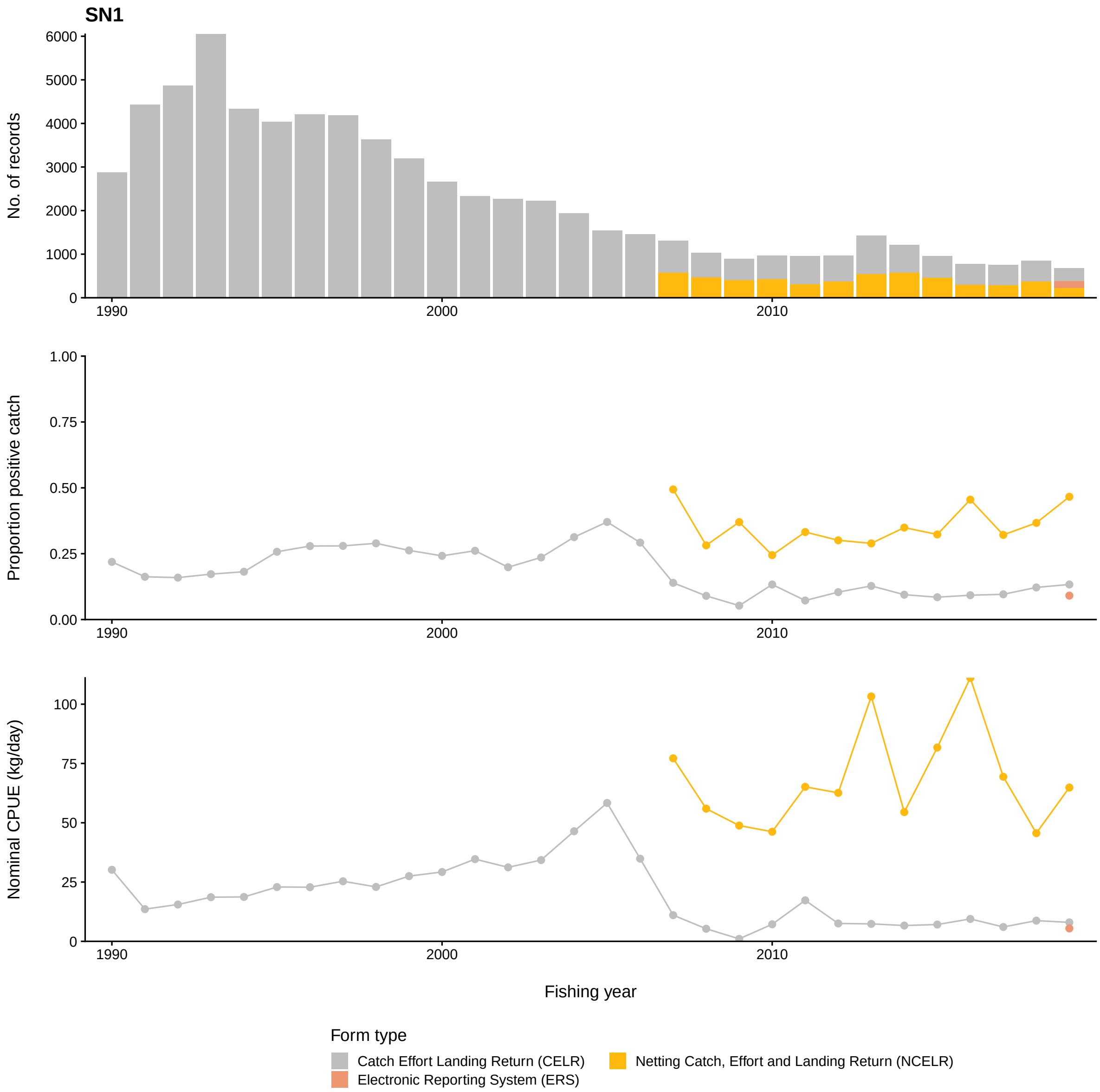

Figure F-3: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.2 Far North & SCH 1E bottom longline

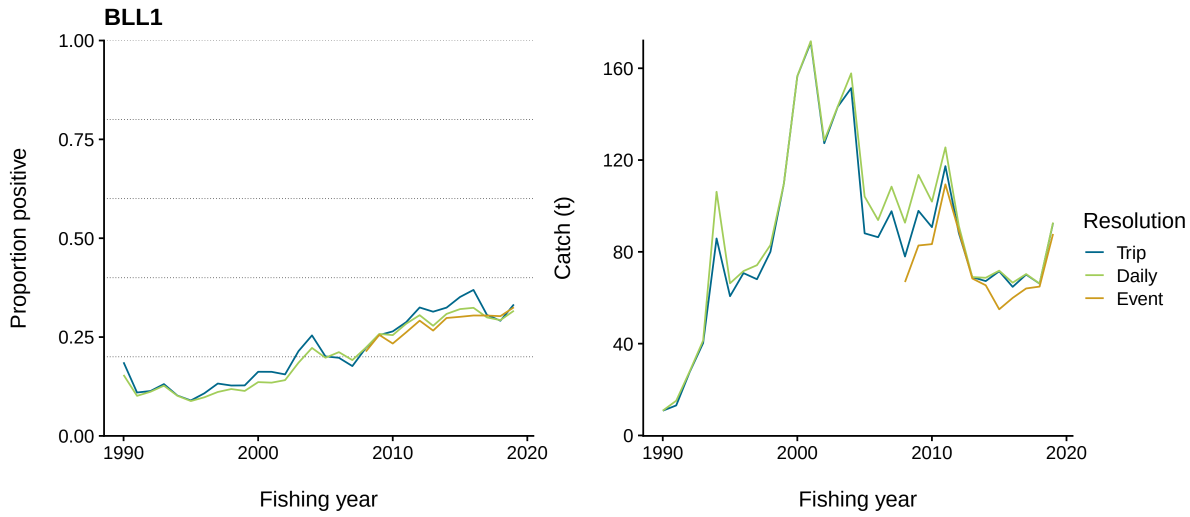

Figure F-4: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

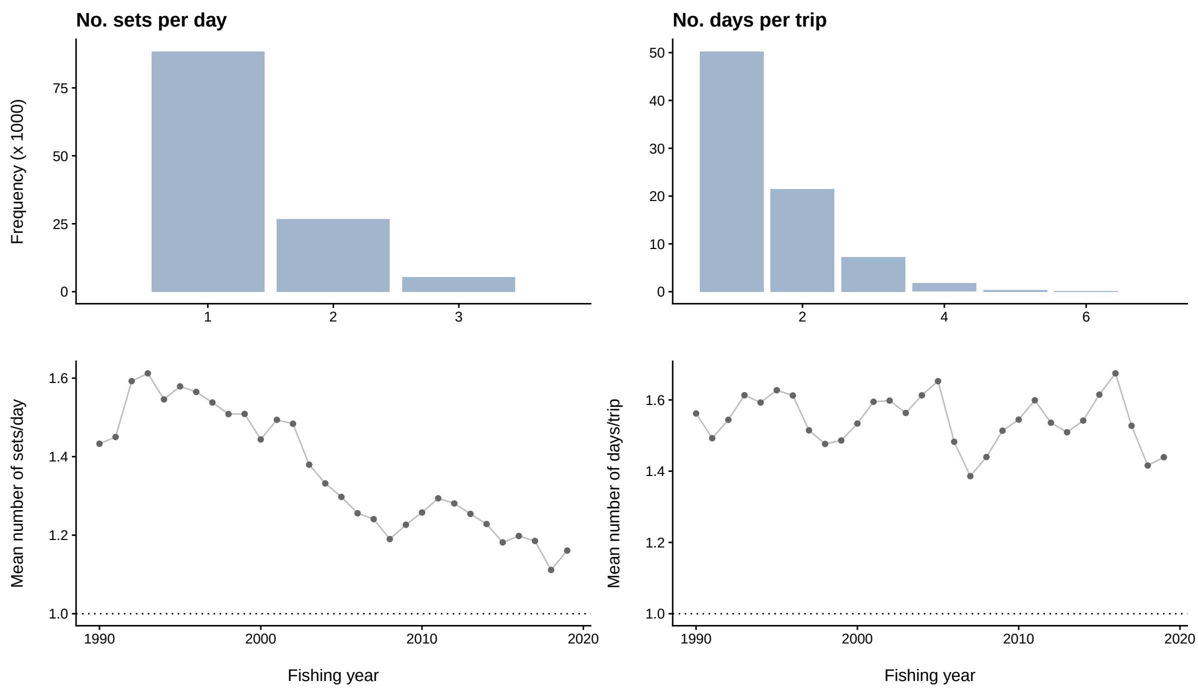

Figure F-5: Distribution of the number of sets and change in mean number of sets over time from 1989–90 to 2018–19 (left column); distribution of trip length (in days) and change in mean trip length over time (right column). Records included are for the core fleet only.

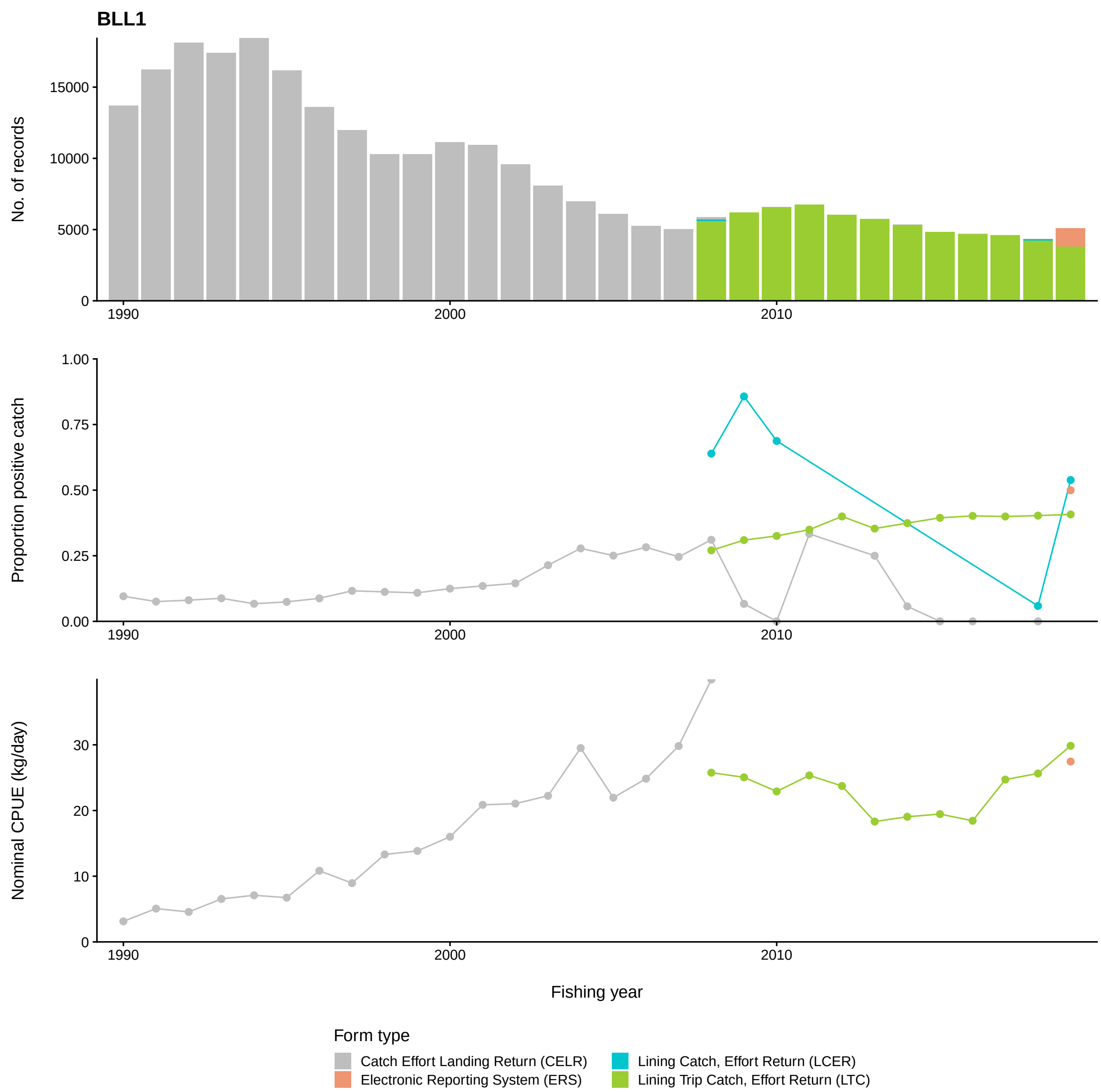

Figure F-6: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.3 Far North & SCH 1E bottom trawl

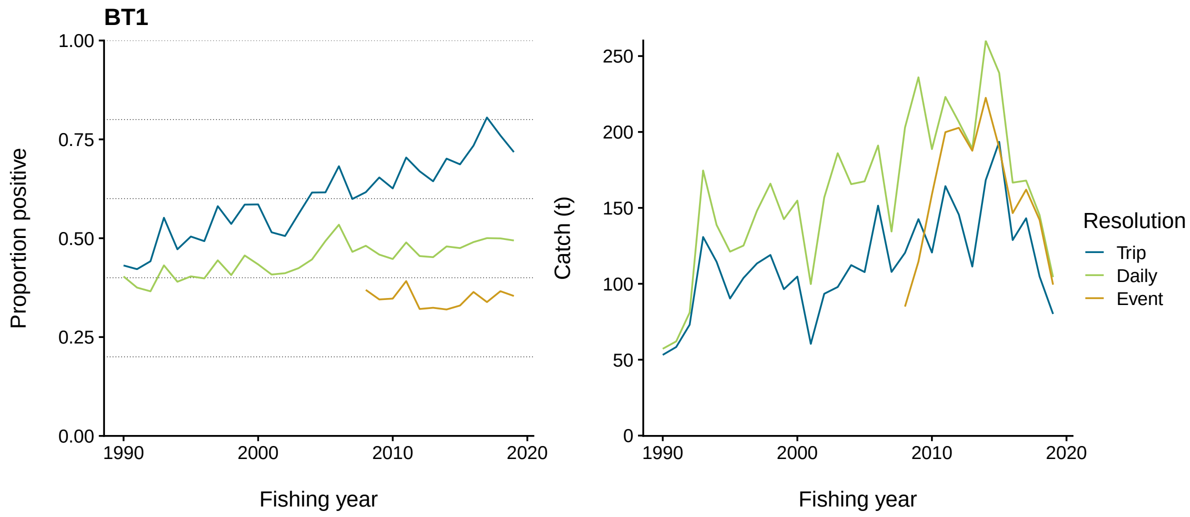

Figure F-7: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

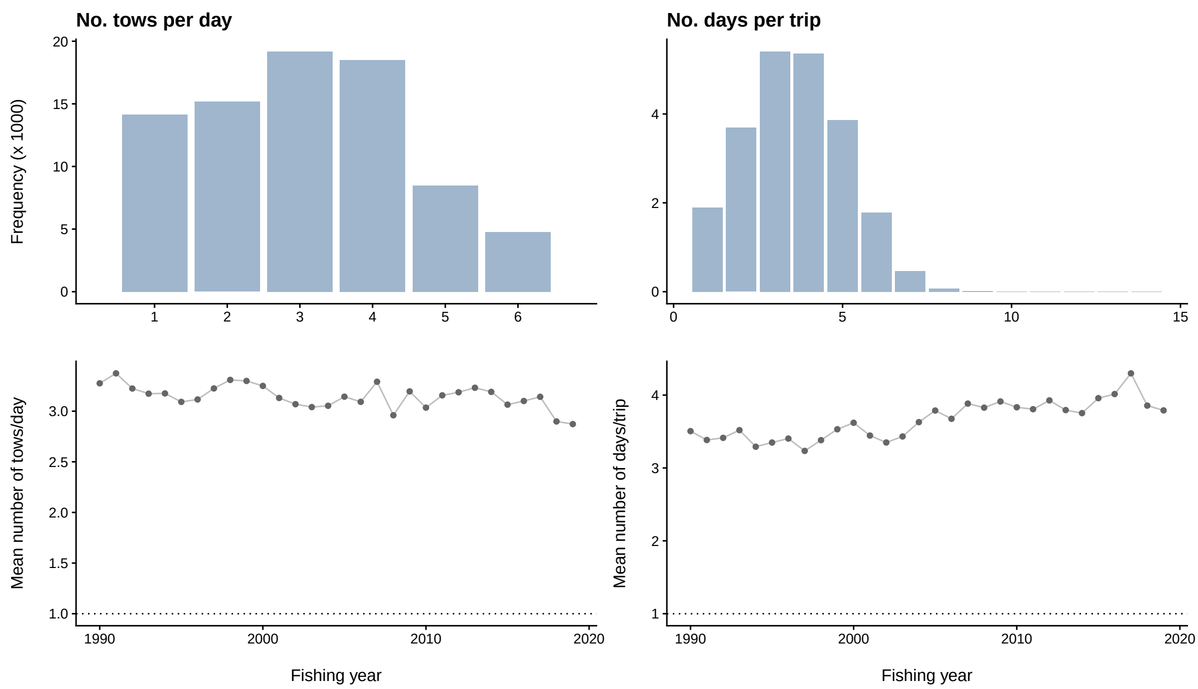

Figure F-8: Distribution of the number of tows and change in mean number of tows over time from 1989–90 to 2018–19 (left column); distribution of trip length (in days) and change in mean trip length over time (right column). Records included are for the core fleet only.

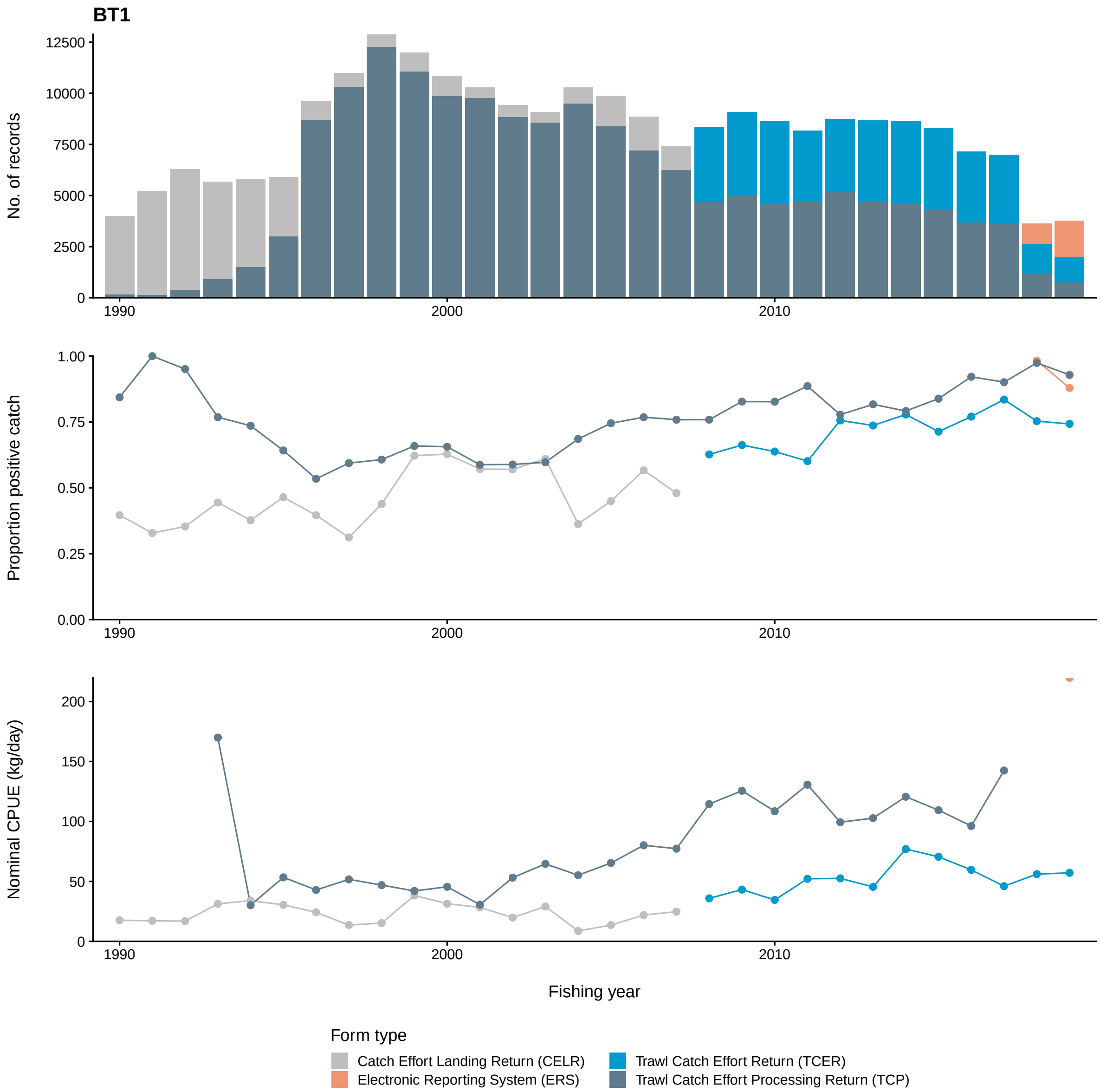

Figure F-9: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.4 SCH 2 & top of SCH 3 set net

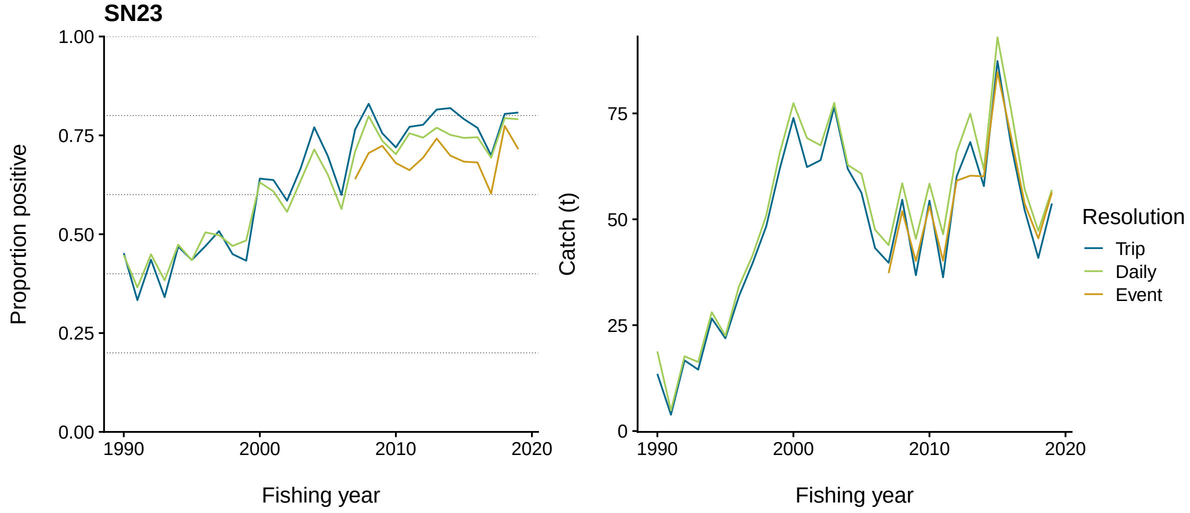

Figure F-10: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

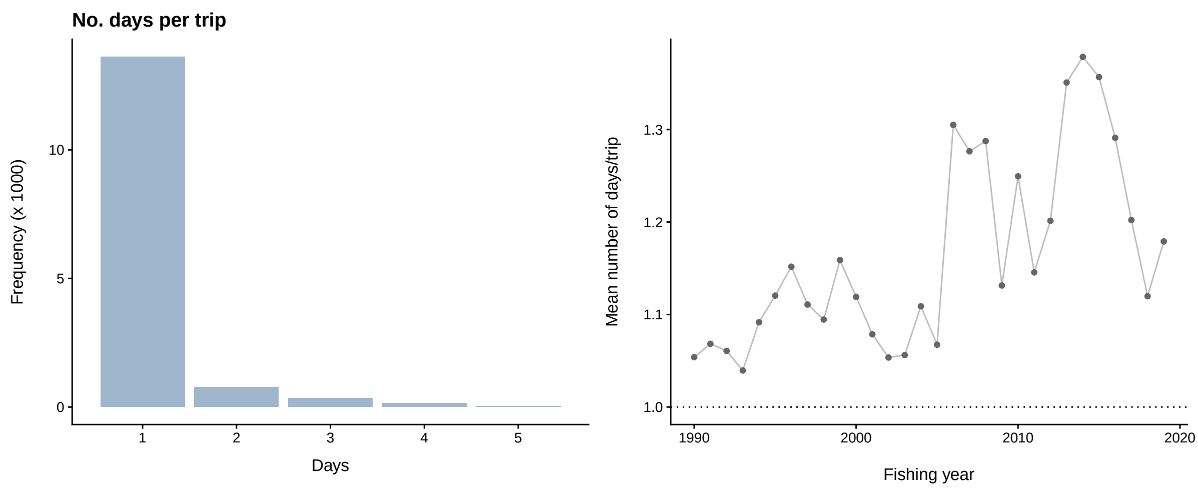

Figure F-11: Distribution of trip length (in days) and change in mean trip length over time from 1989–90 to 2018–19. The number of sets was not recorded continuously during this time period, so no set count summary and time series are included for this fishery. Records included are for the core fleet only.

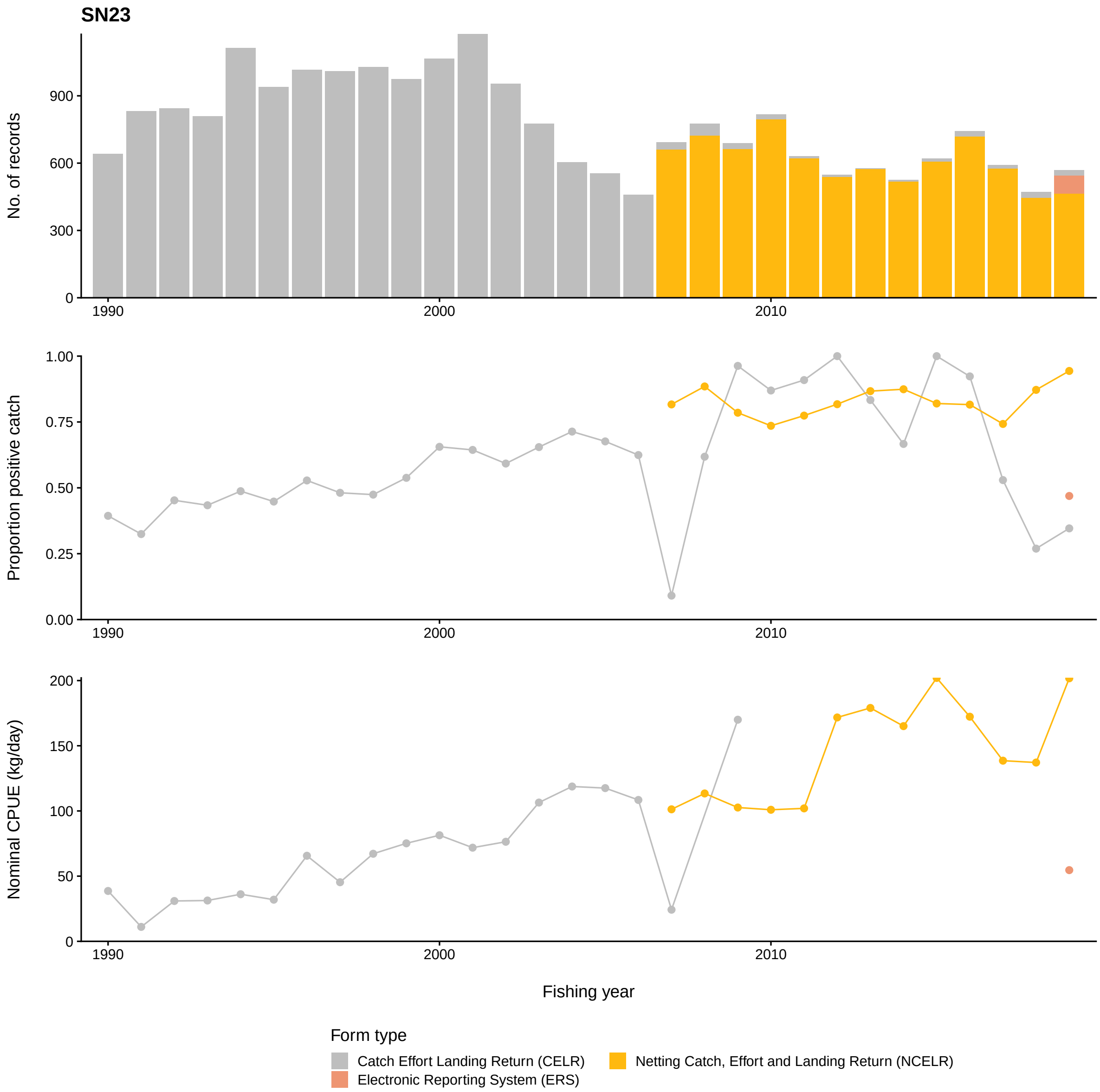

Figure F-12: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.5 SCH 2 & top of SCH 3 bottom longline

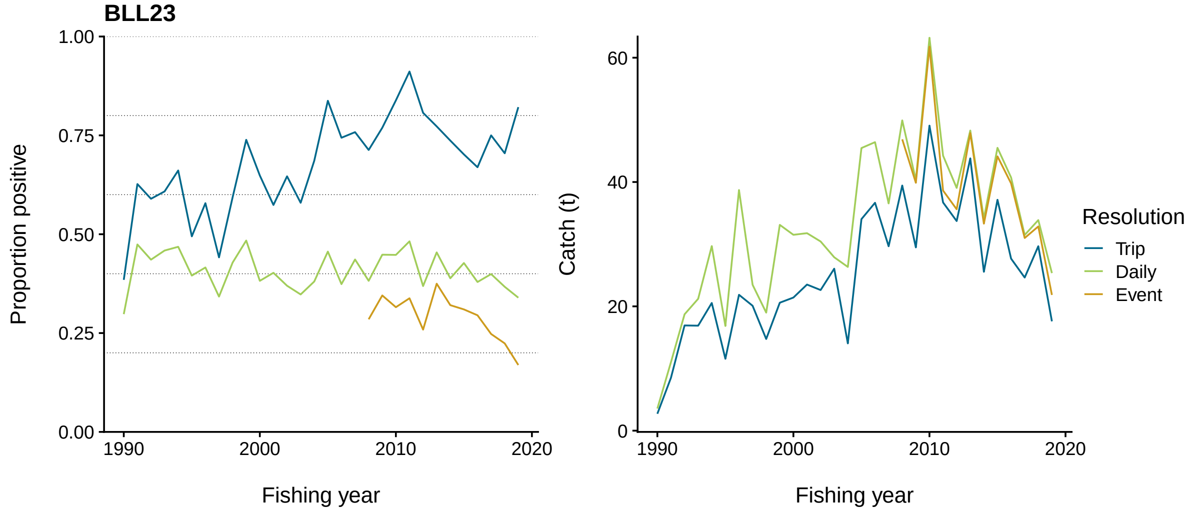

Figure F-13: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

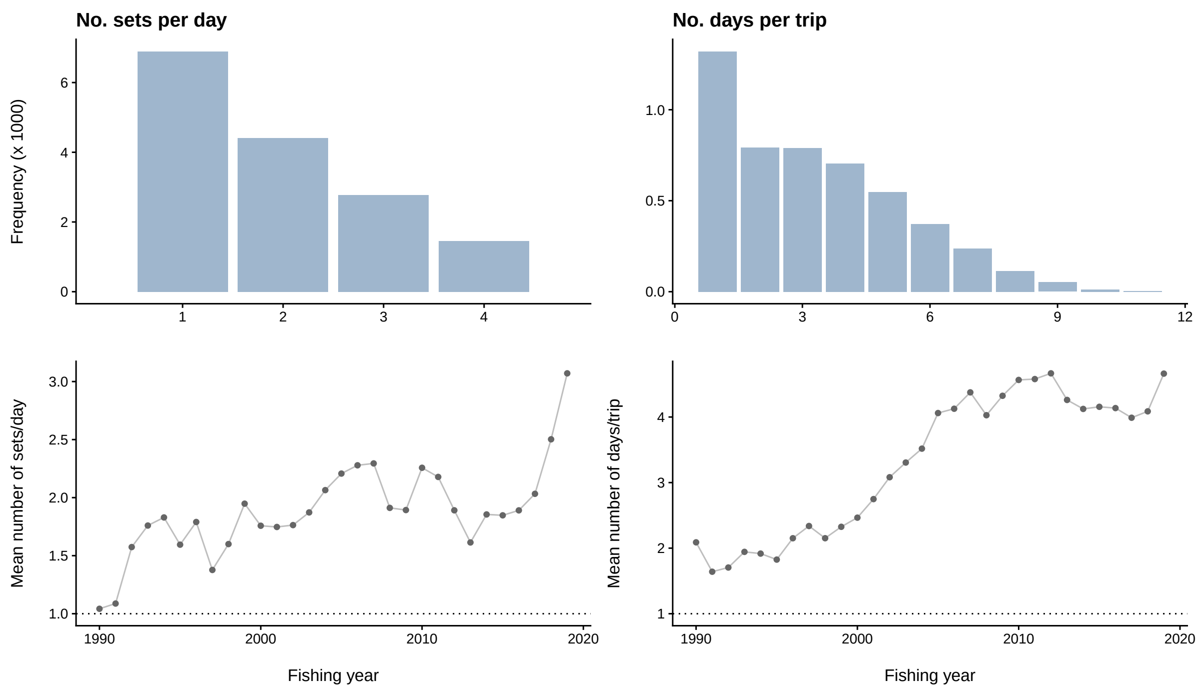

Figure F-14: Distribution of the number of sets and change in mean number of sets over time from 1989–90 to 2018–19 (left column); distribution of trip length (in days) and change in mean trip length over time (right column). Records included are for the core fleet only.

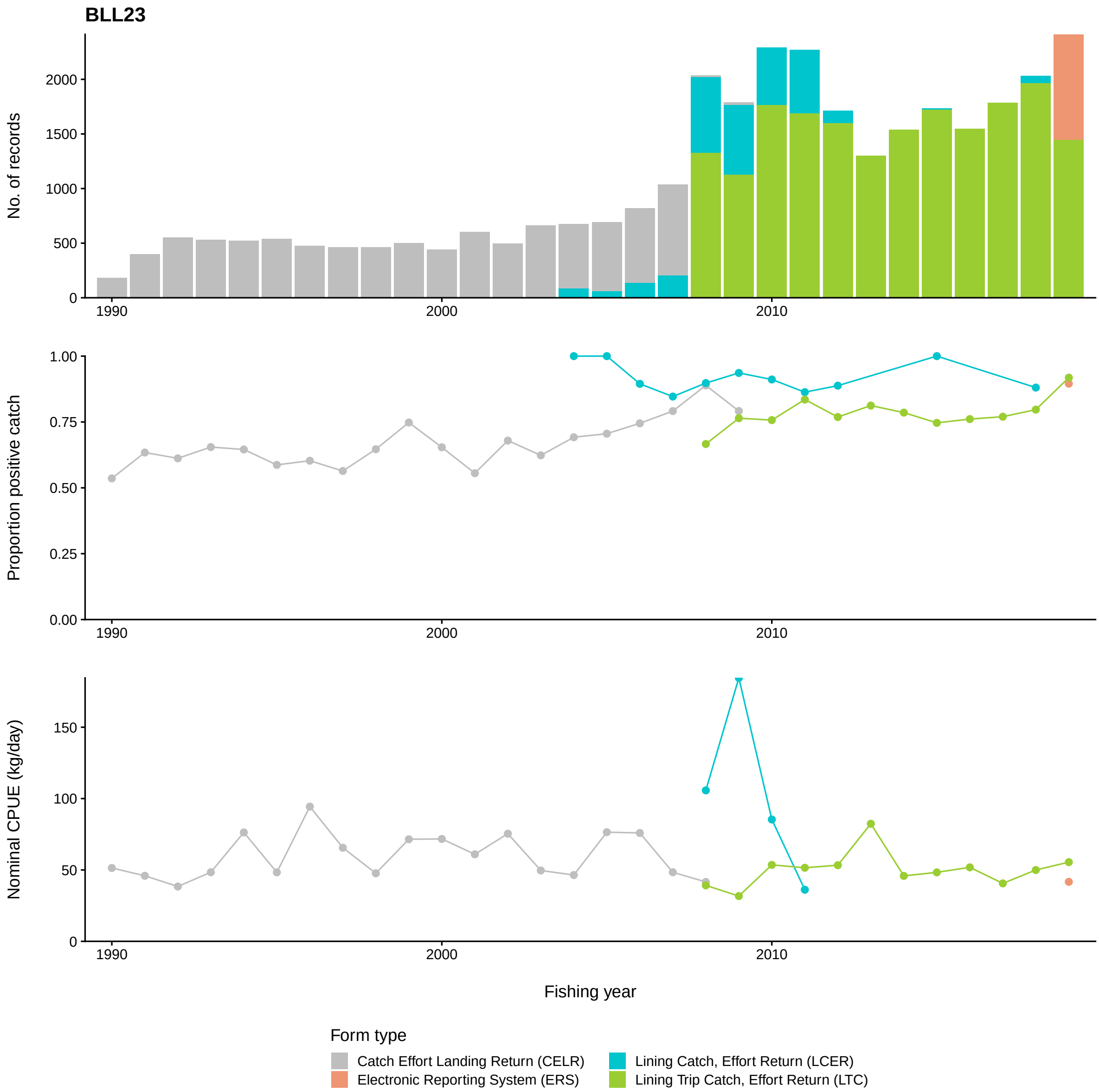

Figure F-15: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.6 SCH 2 & top of SCH 3 bottom trawl

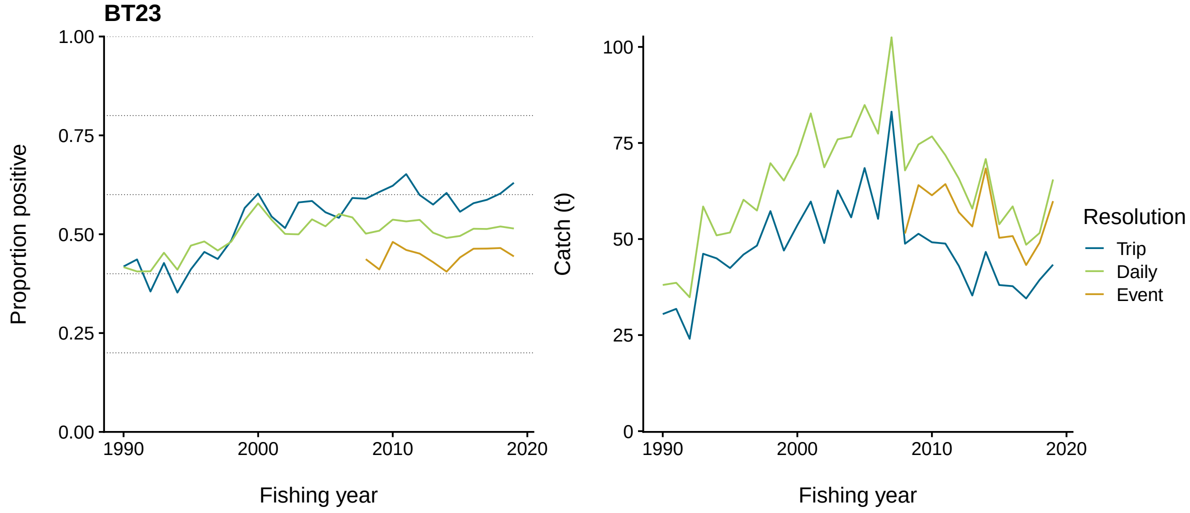

Figure F-16: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

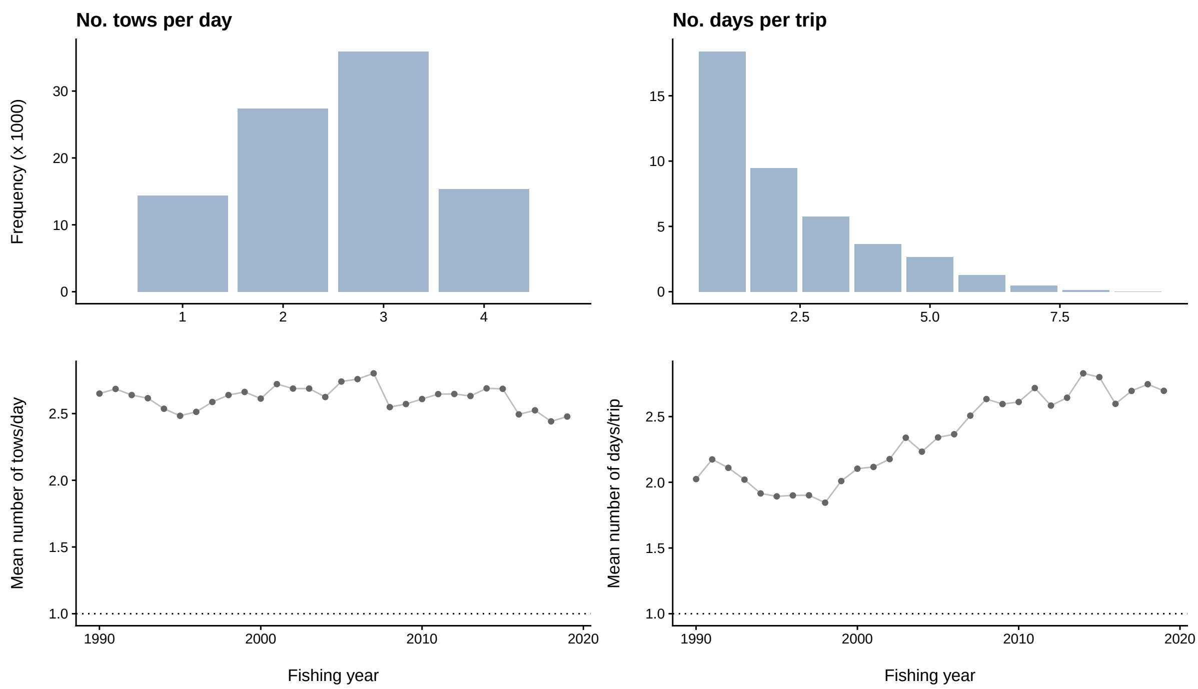

Figure F-17: Distribution of the number of tows and change in mean number of tows over time from 1989–90 to 2018–19 (left column); distribution of trip length (in days) and change in mean trip length over time (right column). Records included are for the core fleet only.

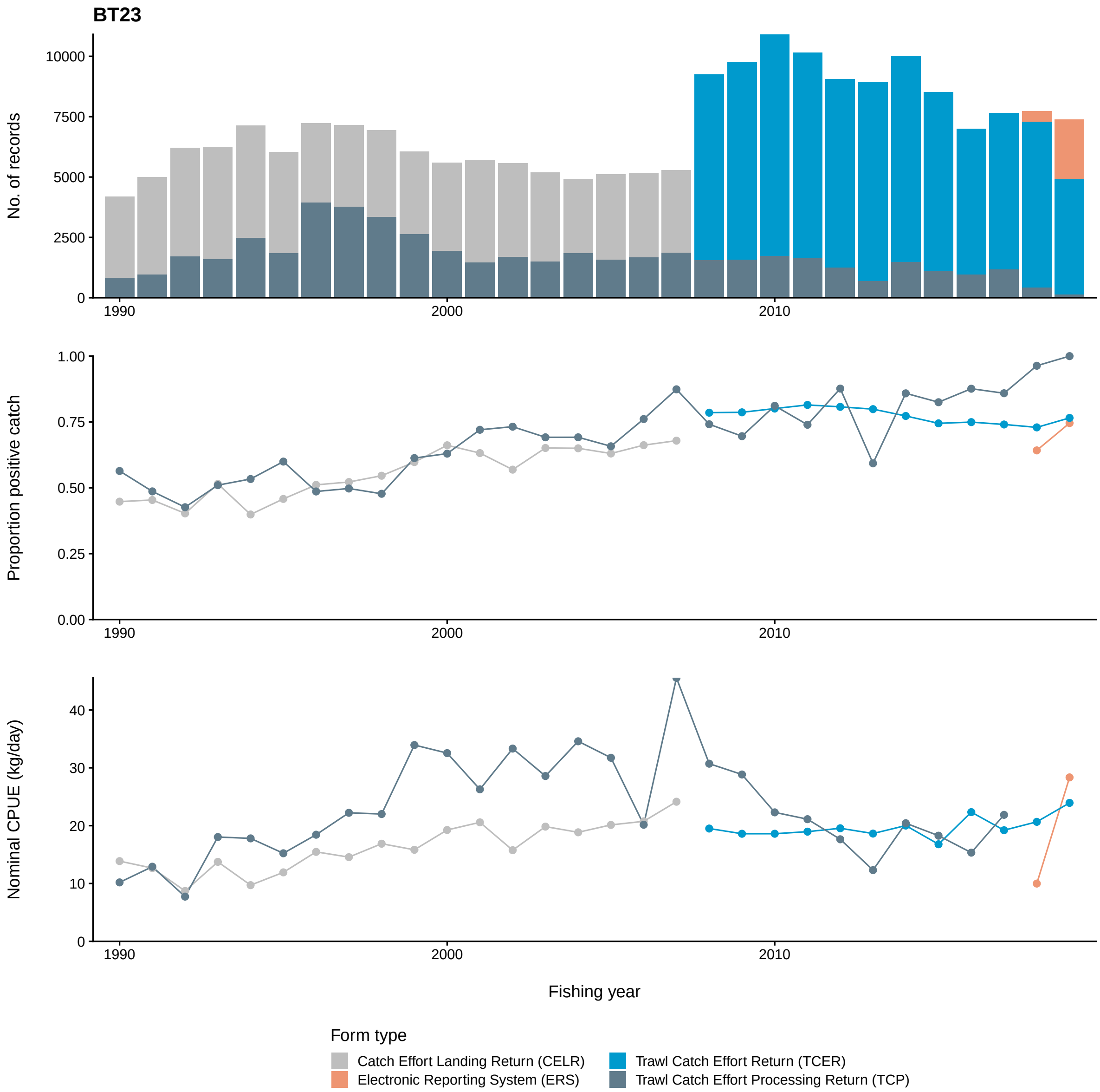

Figure F-18: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.7 Chatham Rise (SCH 4) bottom longline

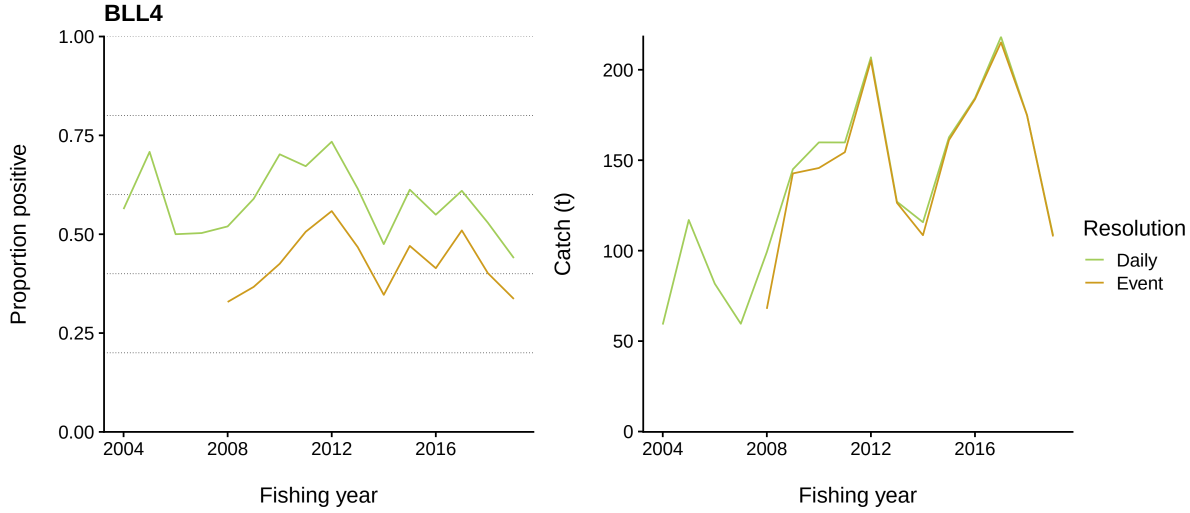

Figure F-19: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

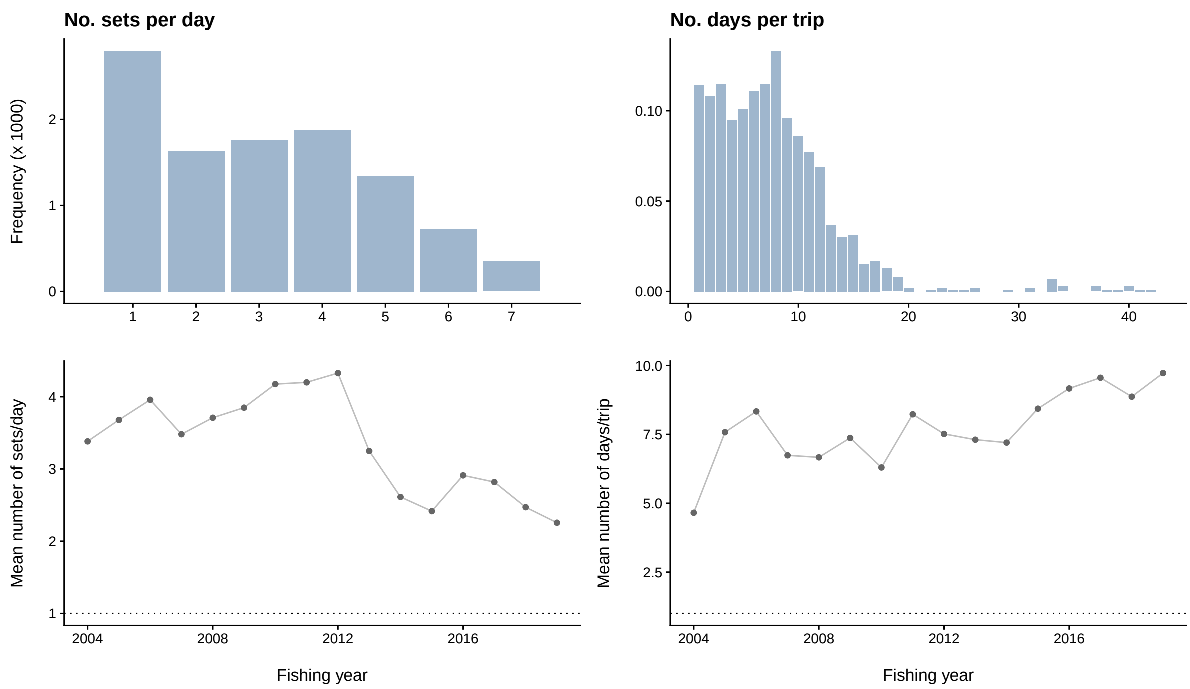

Figure F-20: Distribution of the number of sets and change in mean number of sets over time from 2003–04 to 2018–19 (left column); distribution of trip length (in days) and change in mean trip length over time (right column). Records included are for the core fleet only.

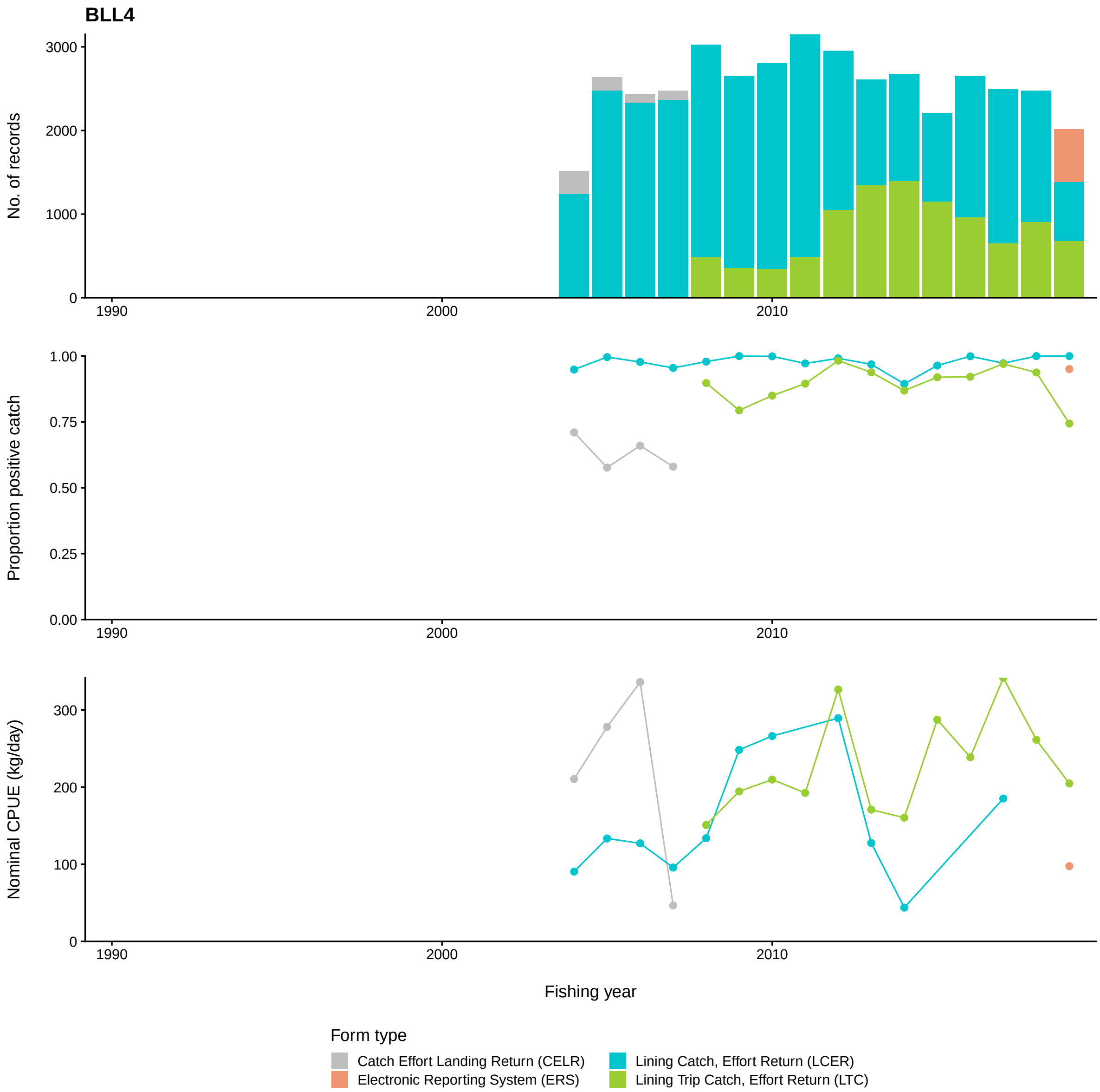

Figure F-21: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.8 Lower SCH 3 & SCH 5 set net

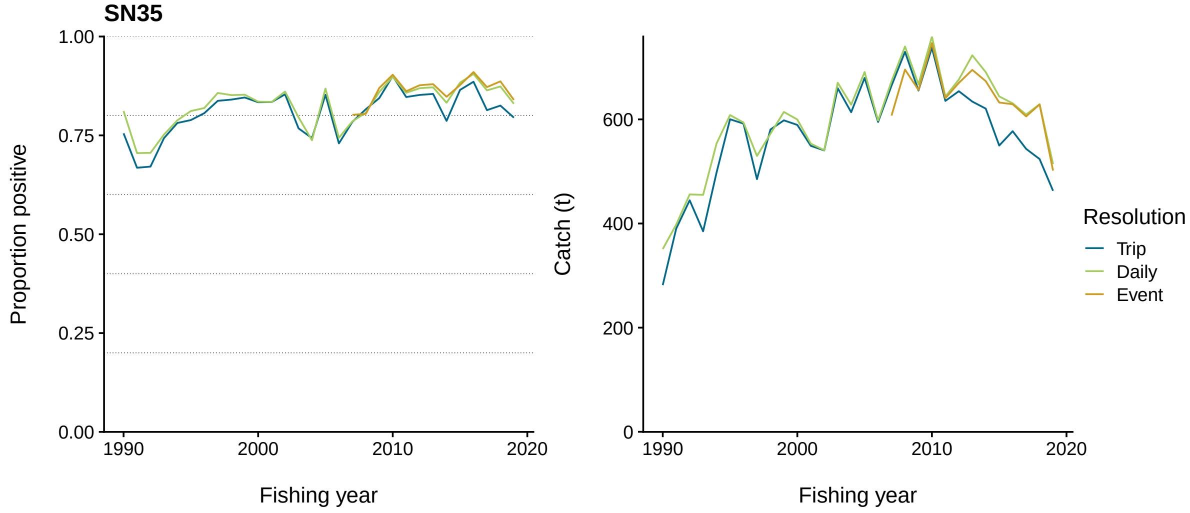

Figure F-22: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

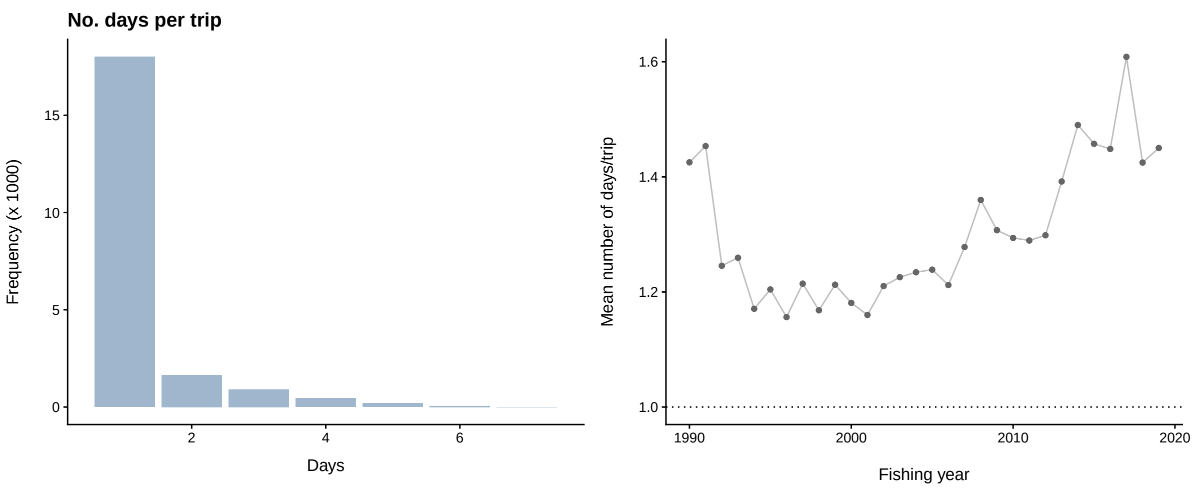

Figure F-23: Distribution of trip length (in days) and change in mean trip length over time from 1989–90 to 2018–19. The number of sets was not recorded continuously during this time period, so no set count summary and time series are included for this fishery. Records included are for the core fleet only.

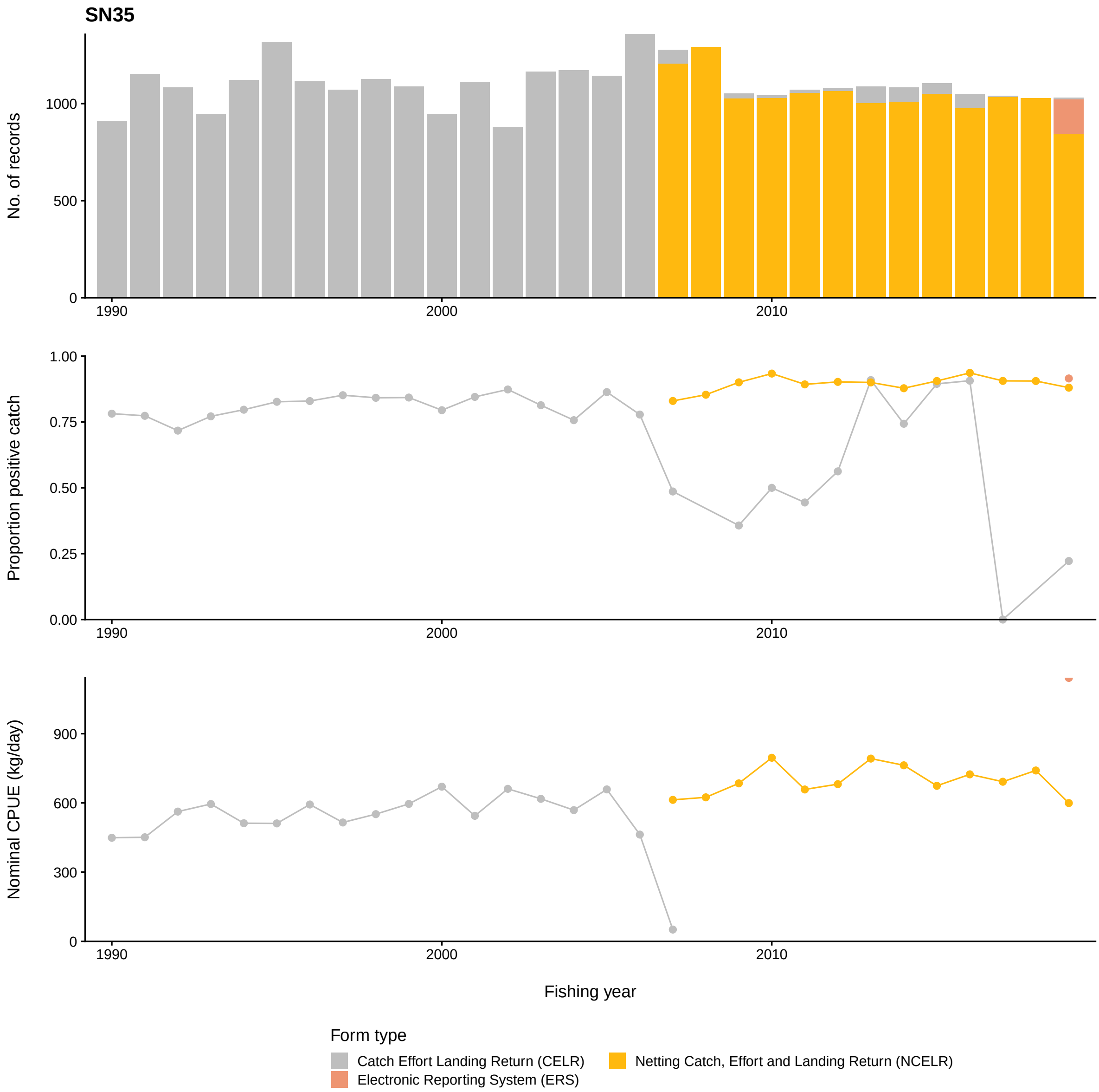

Figure F-24: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.9 Lower SCH 3 & SCH 5 bottom longline

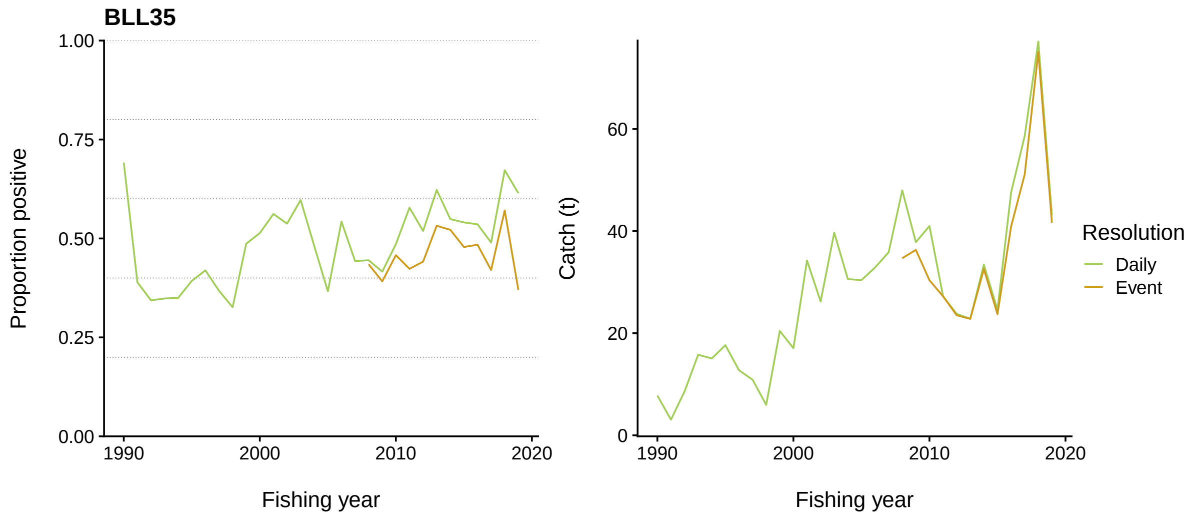

Figure F-25: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

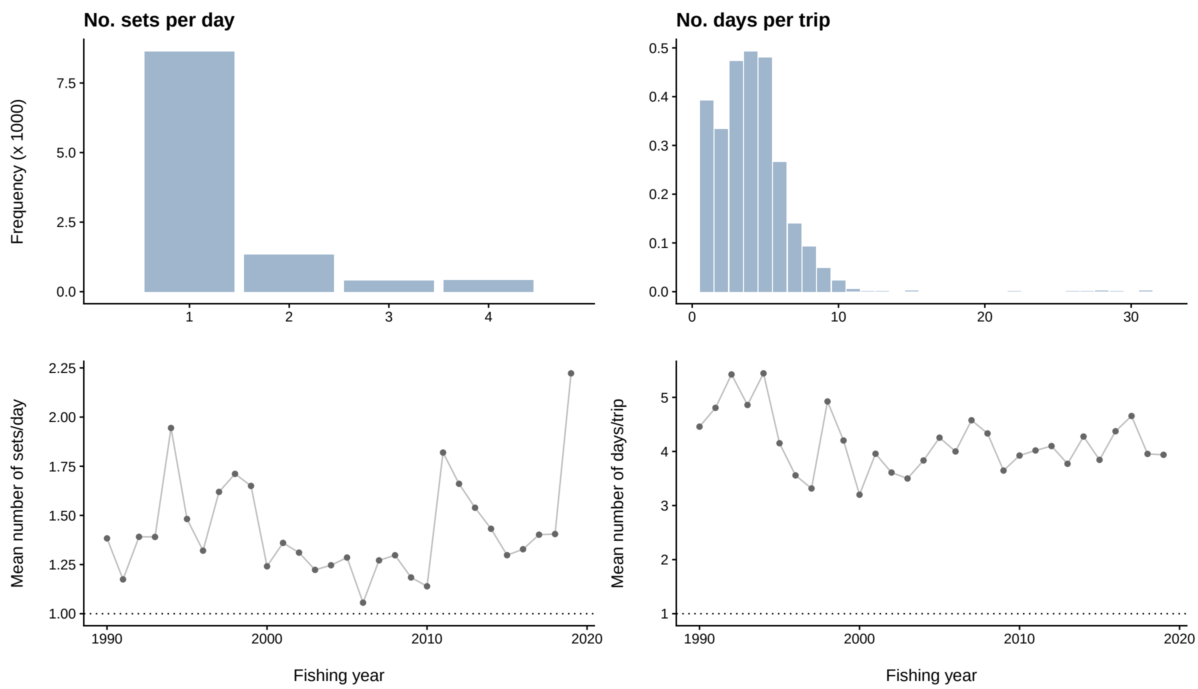

Figure F-26: Distribution of the number of sets and change in mean number of sets over time from 1989–90 to 2018–19 (left column); distribution of trip length (in days) and change in mean trip length over time (right column). Records included are for the core fleet only.

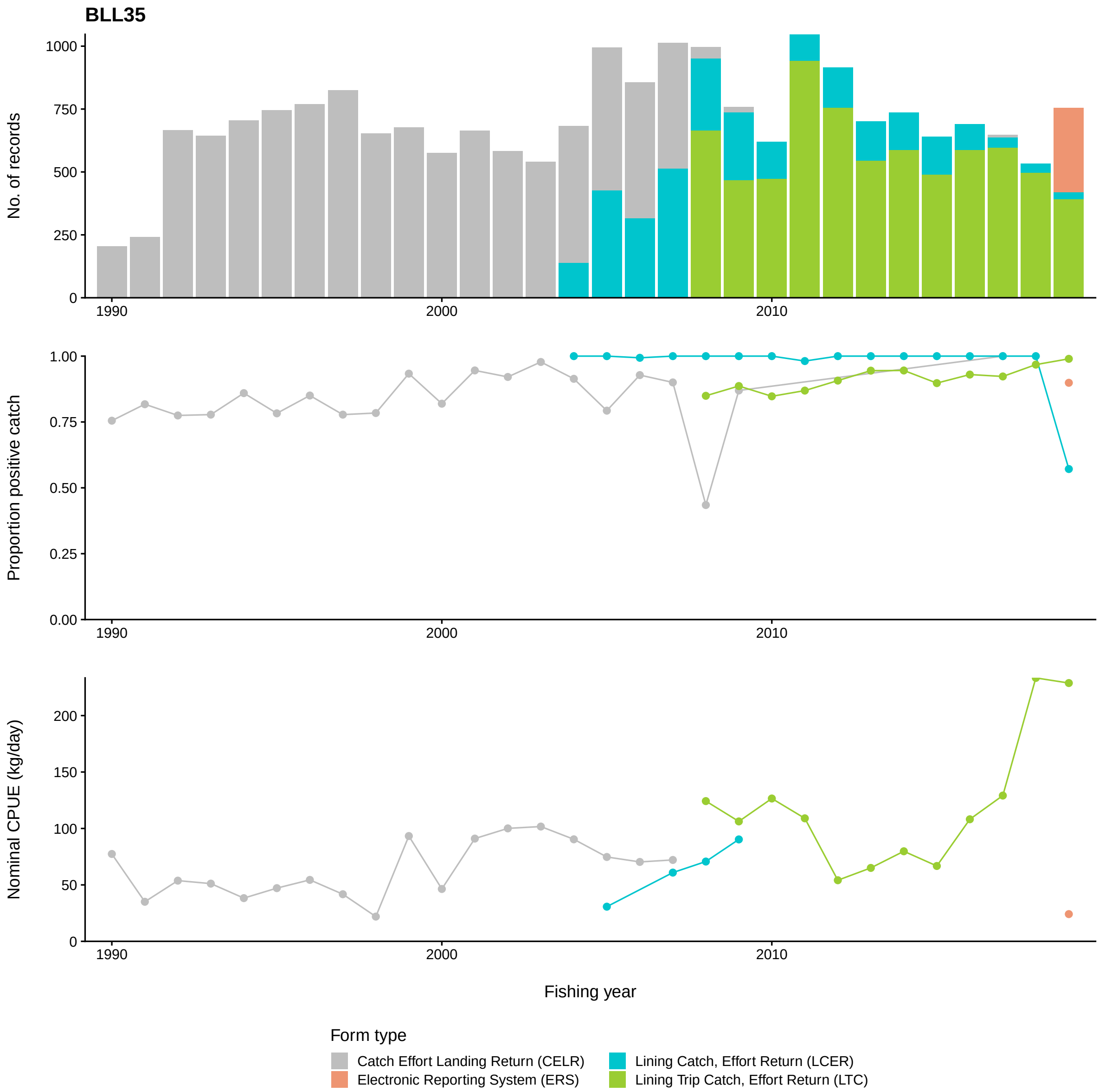

Figure F-27: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.10 Lower SCH 3 & SCH 5 bottom trawl

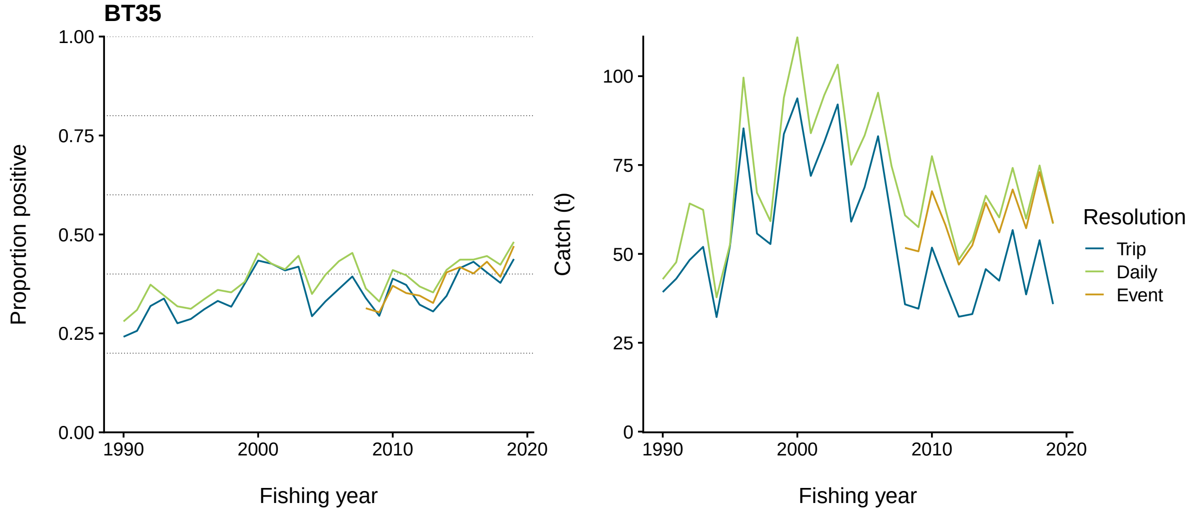

Figure F-28: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

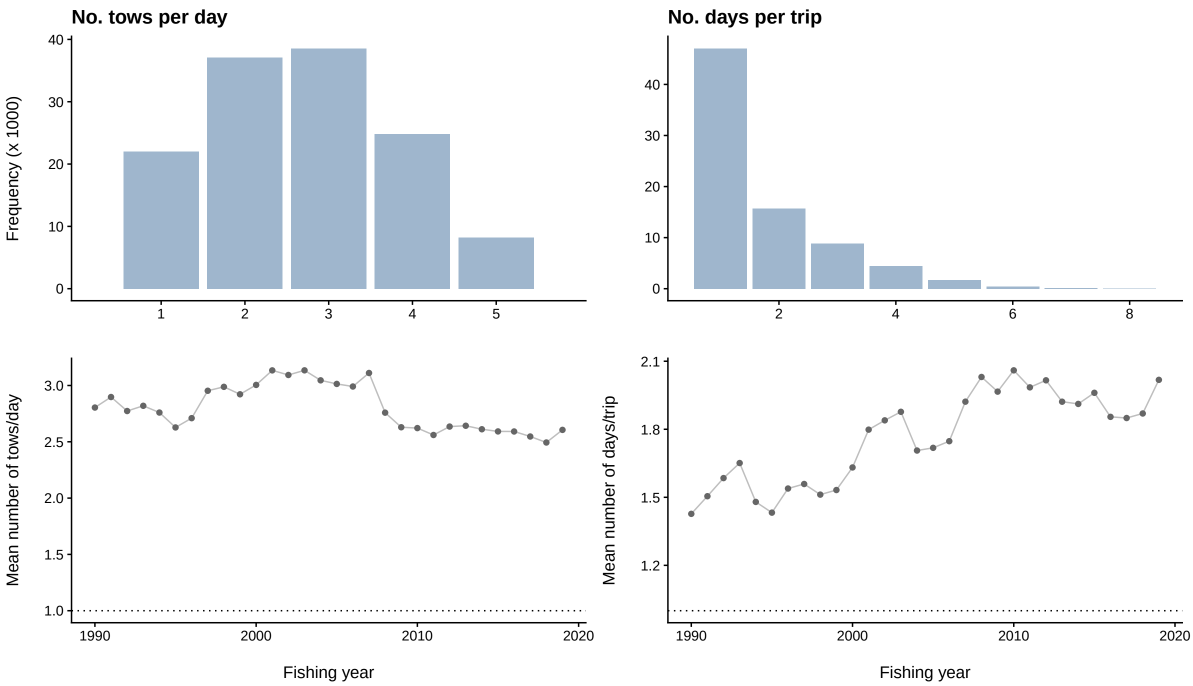

Figure F-29: Distribution of the number of tows and change in mean number of tows over time from 1989–90 to 2018–19 (left column); distribution of trip length (in days) and change in mean trip length over time (right column). Records included are for the core fleet only.

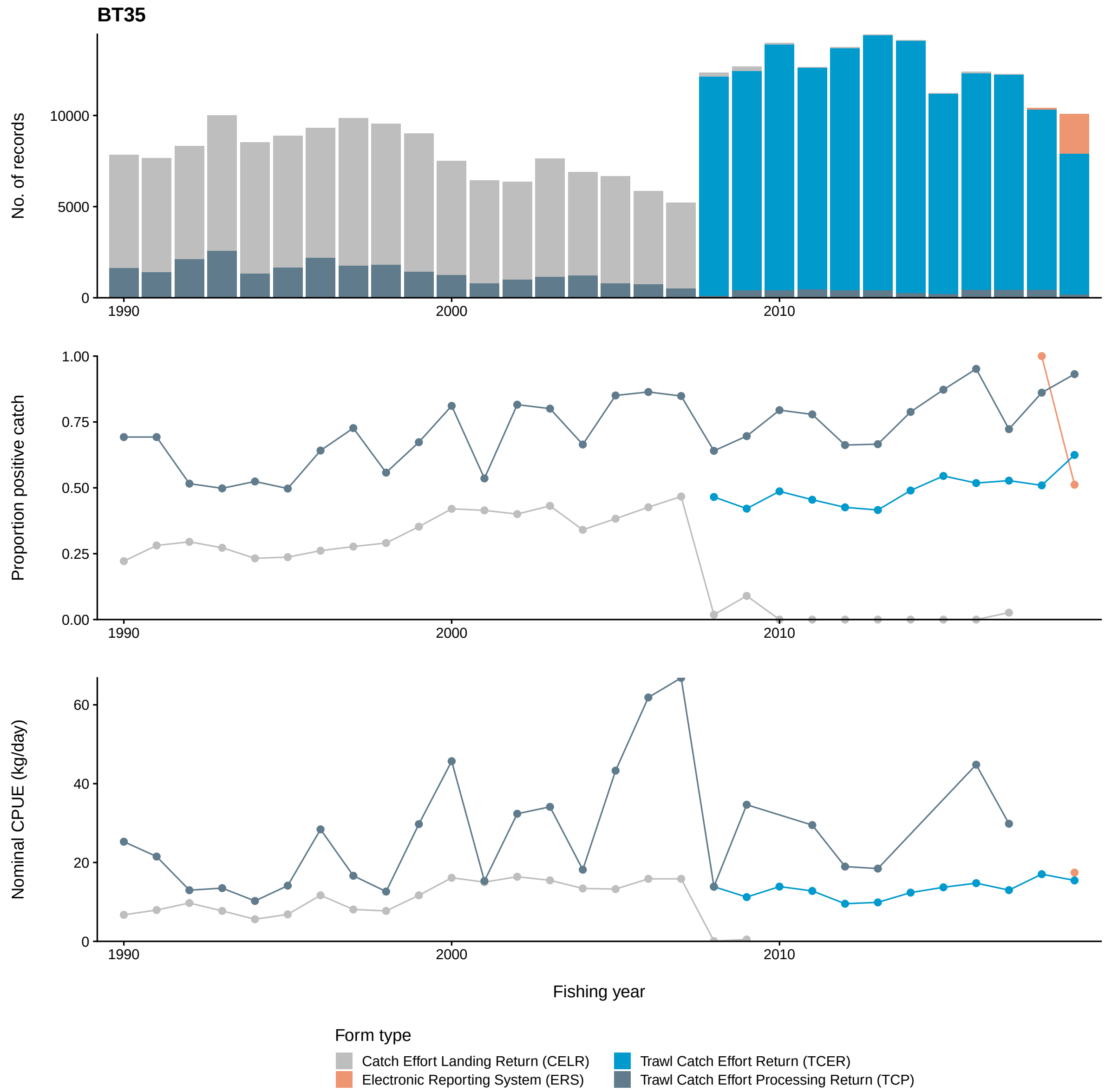

Figure F-30: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.11 SCH 7, SCH 8 & lower SCH 1W set net

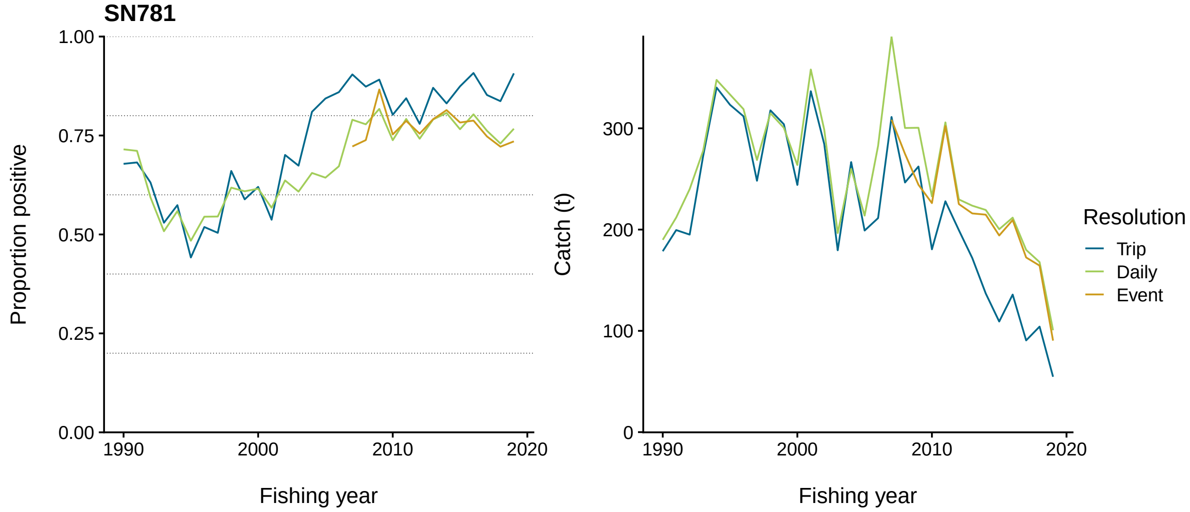

Figure F-31: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

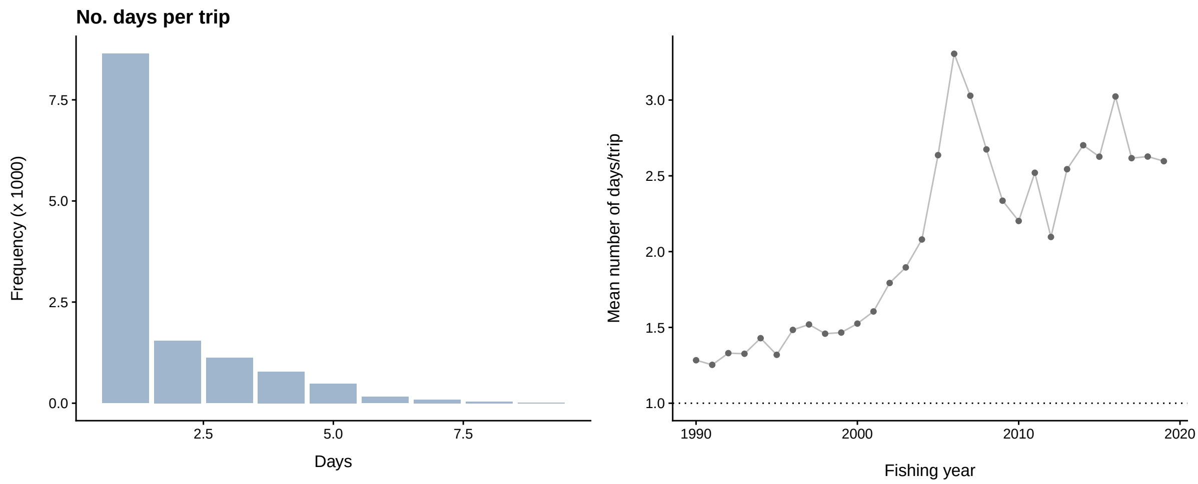

Figure F-32: Distribution of trip length (in days) and change in mean trip length over time from 1989–90 to 2018–19. The number of sets was not recorded continuously during this time period, so no set count summary and time series are included for this fishery. Records included are for the core fleet only.

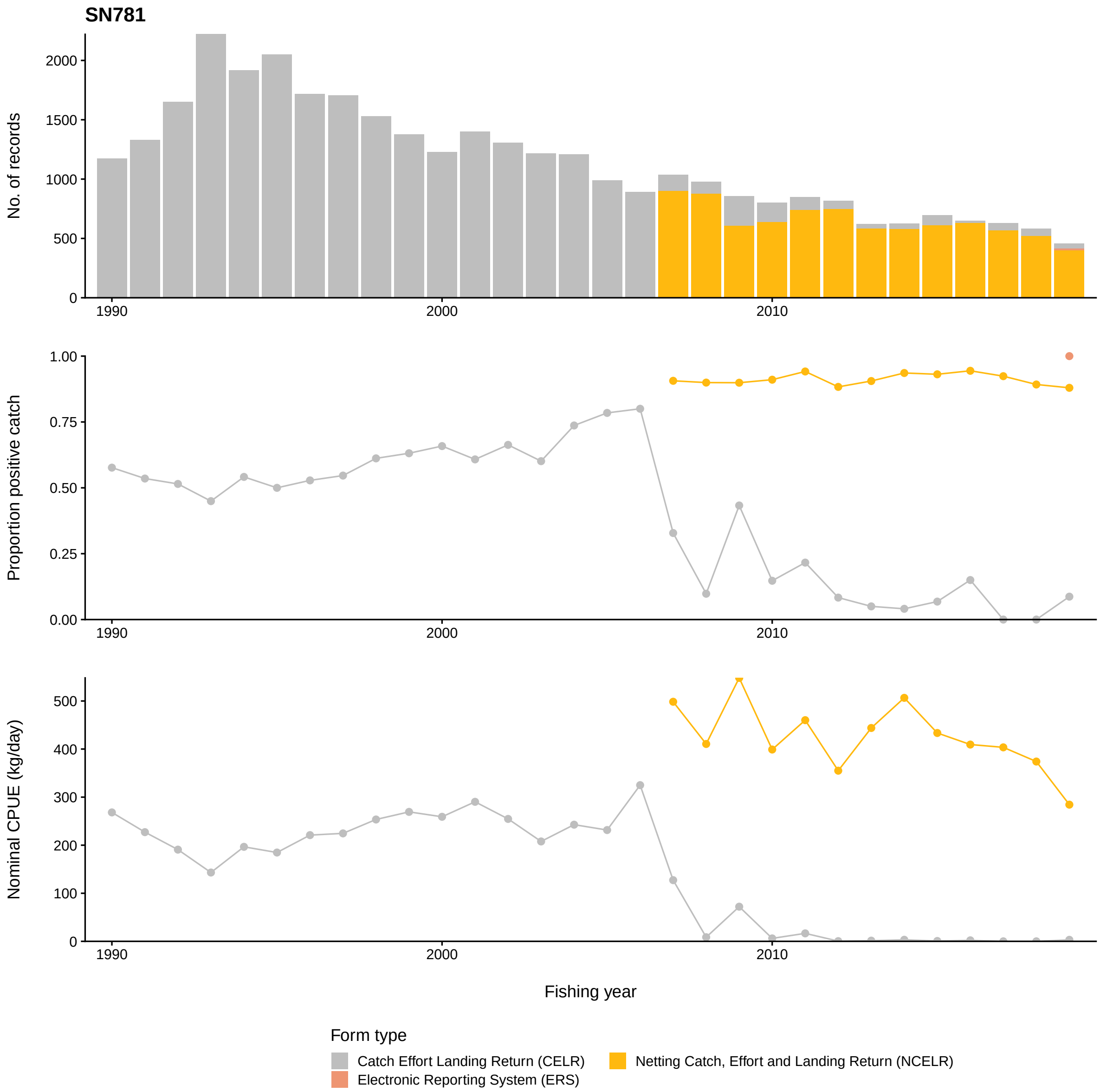

Figure F-33: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.12 SCH 7, SCH 8 & lower SCH 1W bottom longline

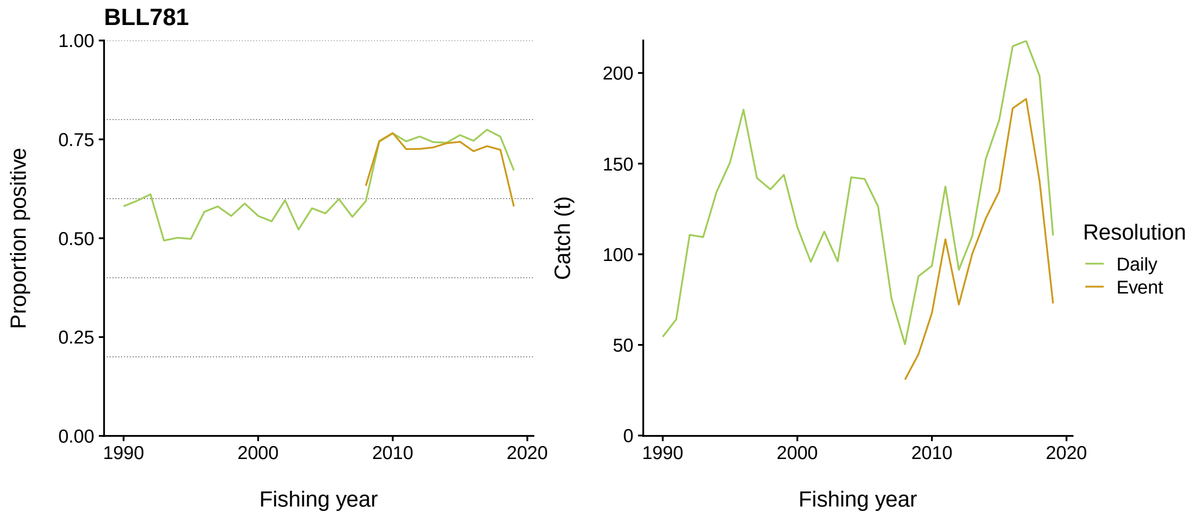

Figure F-34: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

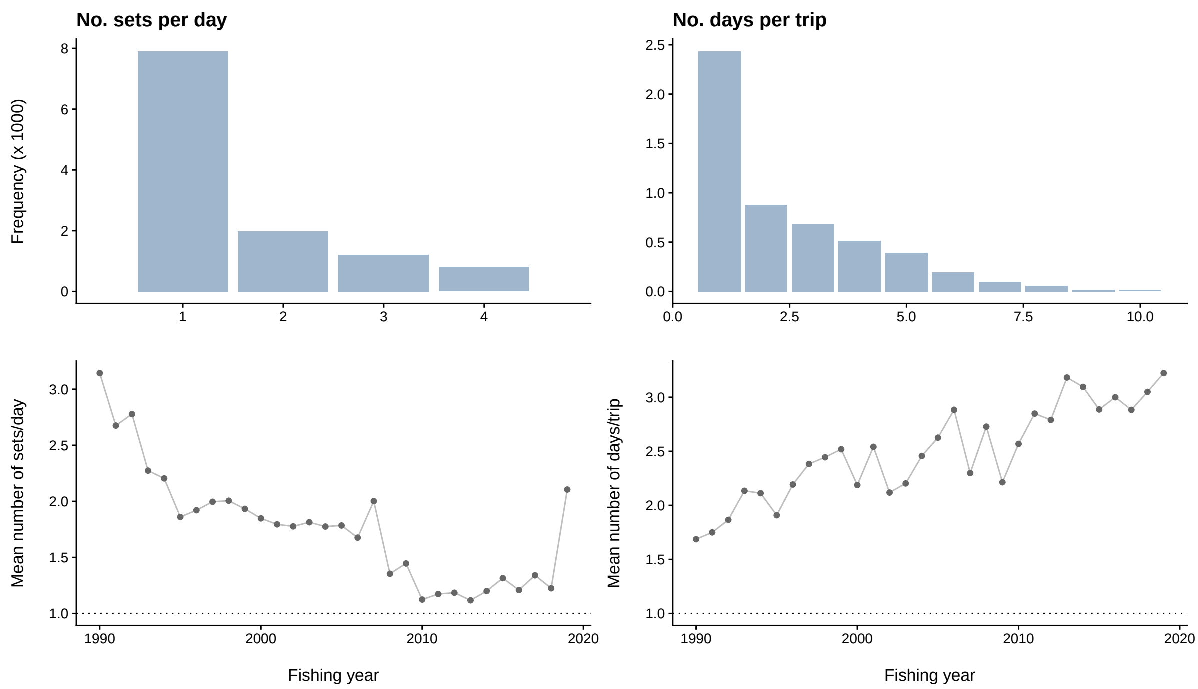

Figure F-35: Distribution of the number of sets and change in mean number of sets over time from 1989–90 to 2018–19 (left column); distribution of trip length (in days) and change in mean trip length over time (right column). Records included are for the core fleet only.

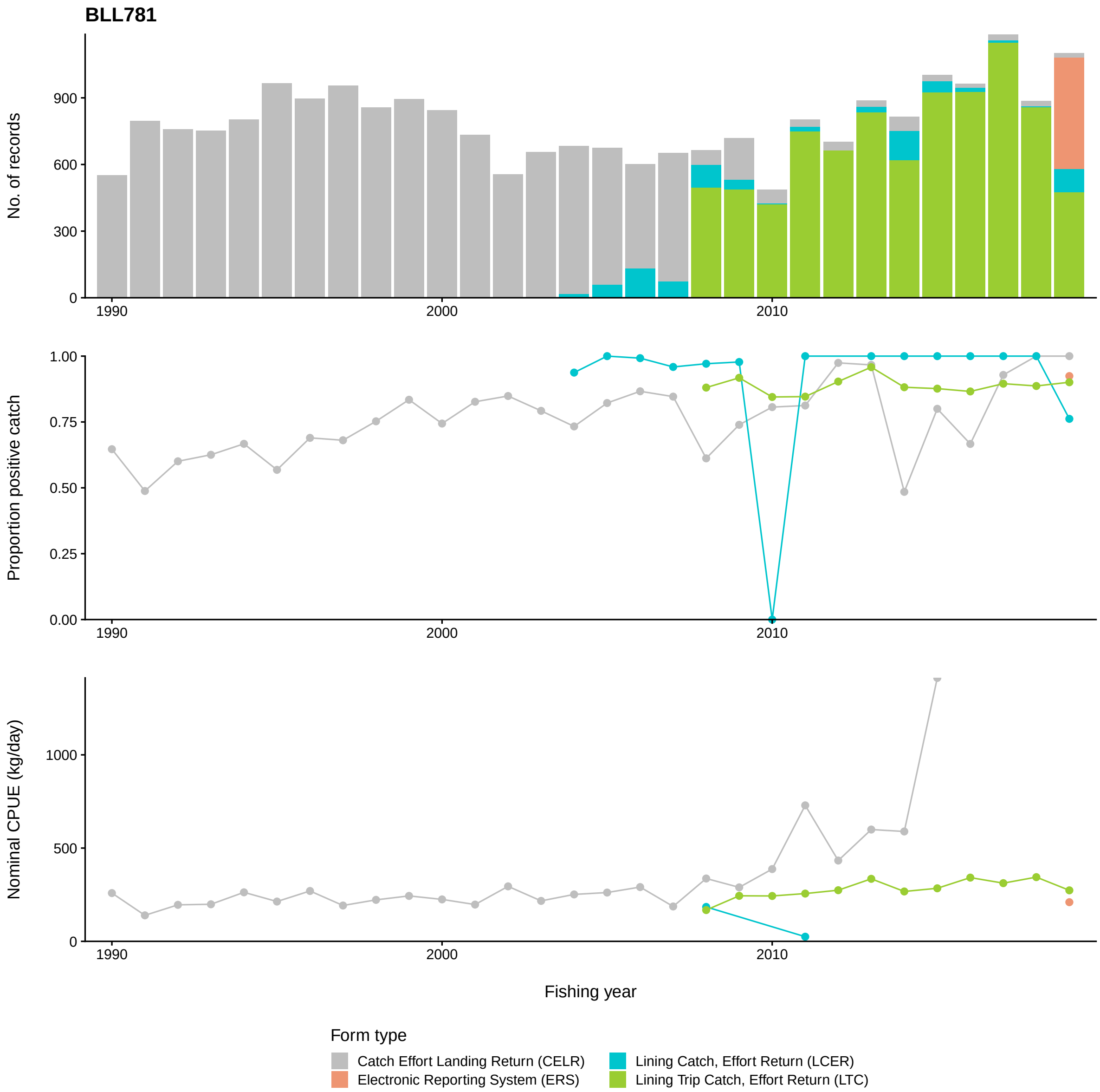

Figure F-36: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

F.13 SCH 7, SCH 8 & lower SCH 1W bottom trawl

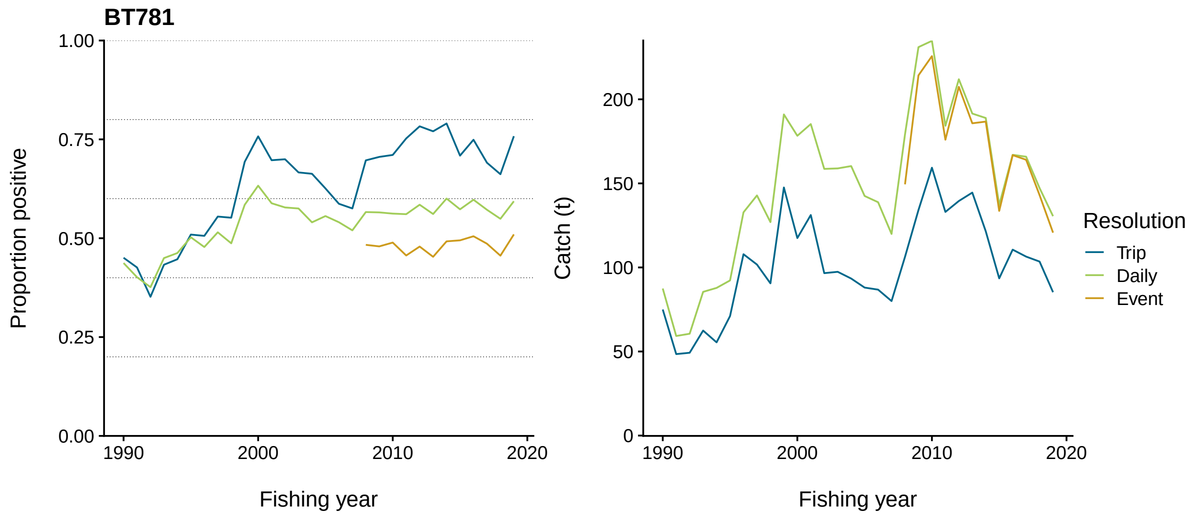

Figure F-37: Proportion of positive catch (left) and annual school shark catch (t; right) by levels of effort resolution for the catch-per-unit-effort index series. Records included are for the core fleet only.

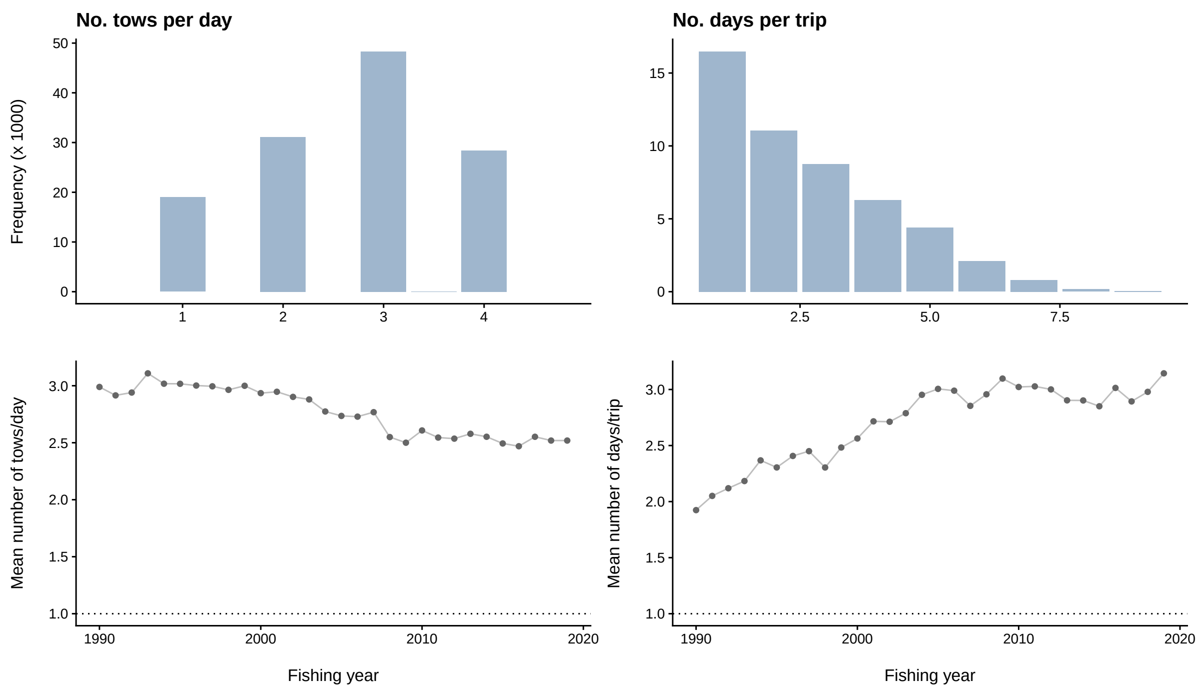

Figure F-38: Distribution of the number of tows and change in mean number of tows over time from 1989–90 to 2018–19 (left column); distribution of trip length (in days) and change in mean trip length over time (right column). Records included are for the core fleet only.

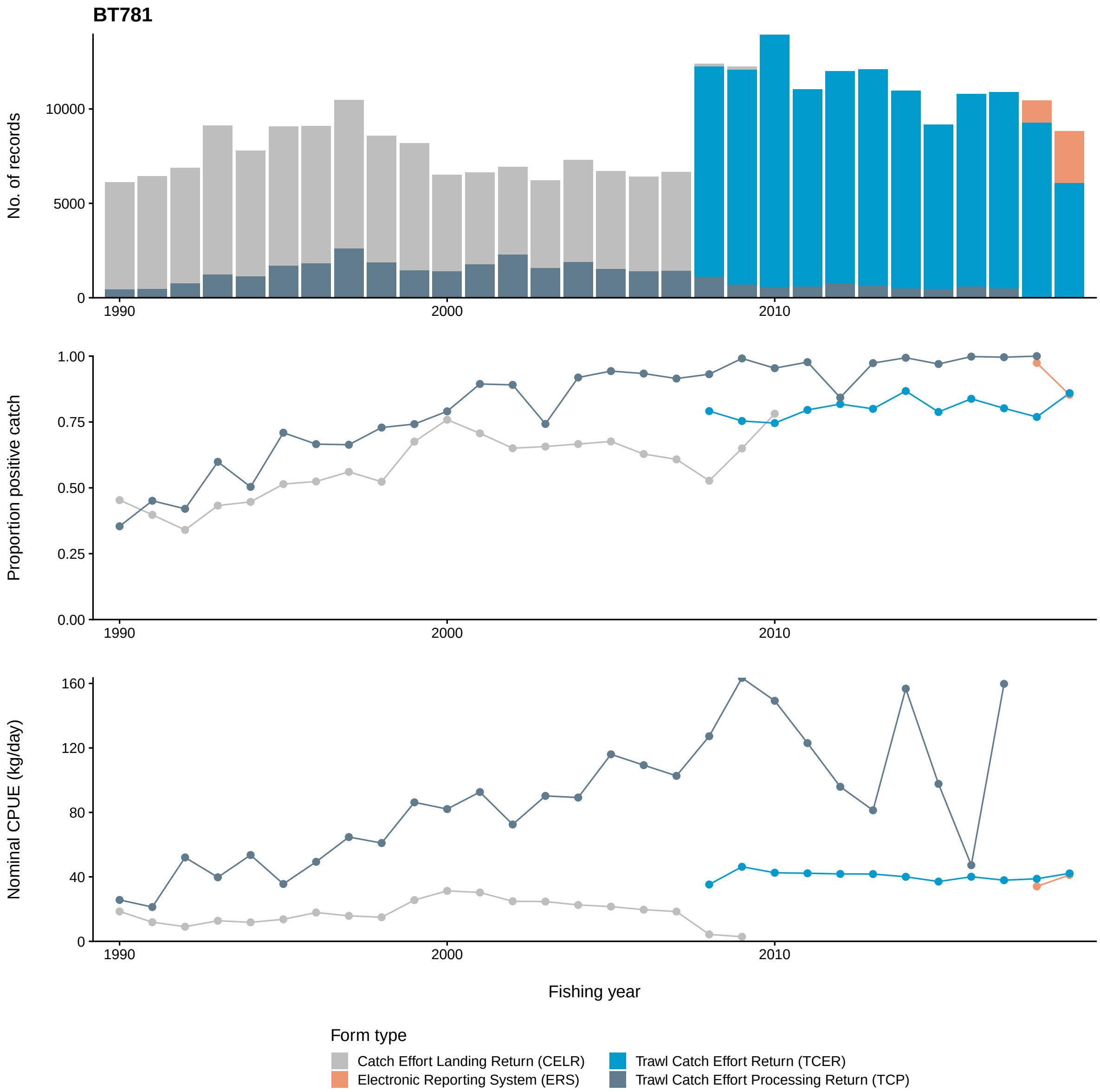

Figure F-39: Key metrics by form type and fishing year: the number of records by category (top), proportion of positive catch (centre) and the nominal catch-per-unit-effort (CPUE; kg/day) (bottom). Records for all vessels are included; annual summaries for a given year are only shown for form types with at least five records.

APPENDIX G: Diagnostics for the standardised CPUE index series

G.1 Far North & SCH 1E set net (daily effort)

Table G-1: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 1E SN daily.

Variable	Value
Label	SN1_daily
Forms	CEL, NCE, ERS - Netting
Period	1989-10-01 to 2019-09-30
Resolution	Daily
Core fleet (min years)	5
Core fleet (min trips)	5
Target species	SNA, TRE, SPO, SCH, GUR
Statistical areas	046, 047, 002, 003, 007, 008, 009, 010

Table G-2: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 1E SN daily. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (net length [km])	Catch (t)	Positive rate
1990	13	612	703	1 195.5	38.61	39.97
1991	16	877	1 092	1 894.9	39.95	29.30
1992	22	1 257	1 456	2 500.8	60.02	30.84
1993	24	1 399	1 634	2 839.7	81.00	31.58
1994	23	987	1 089	1 984.6	46.76	29.66
1995	23	1 122	1 226	2 059.9	31.12	30.59
1996	29	1 336	1 485	2 660.4	57.83	36.43
1997	28	1 524	1 798	3 029.2	59.56	29.70
1998	26	1 507	1 871	3 220.6	43.33	28.33
1999	23	1 669	1 927	3 386.1	71.59	31.76
2000	22	1 453	1 696	3 165.1	74.70	30.84
2001	21	1 326	1 490	2 753.6	74.92	34.09
2002	22	1 159	1 306	2 332.9	66.99	28.41
2003	23	1 109	1 293	2 413.2	61.95	28.77
2004	21	914	1 009	1 885.3	61.43	38.85
2005	23	819	926	1 812.6	78.57	46.65
2006	17	651	751	1 451.7	34.22	35.55
2007	15	494	545	994.2	32.33	31.74
2008	13	405	432	770.0	22.50	22.92
2009	11	334	386	633.8	13.15	20.21
2010	11	296	356	637.6	20.41	22.75
2011	13	316	361	549.0	28.70	26.59
2012	14	448	496	780.8	25.97	26.61
2013	13	521	572	908.1	49.07	23.78
2014	13	486	520	723.6	23.17	23.46
2015	11	416	446	655.0	33.06	26.23
2016	11	322	347	532.5	32.83	35.45
2017	10	378	406	662.5	20.87	24.88
2018	10	353	388	647.7	16.90	30.41
2019	10	273	291	468.1	10.58	35.74

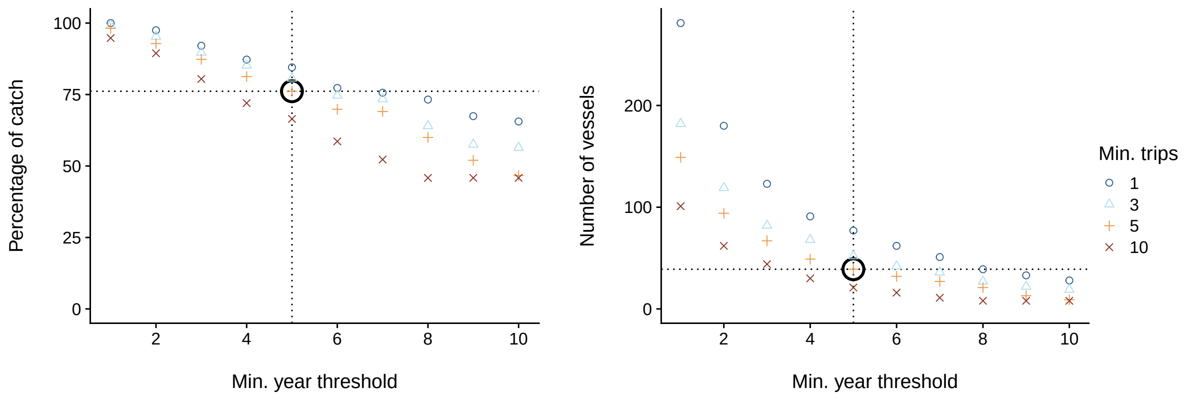

Figure G-1: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 1E SN daily. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

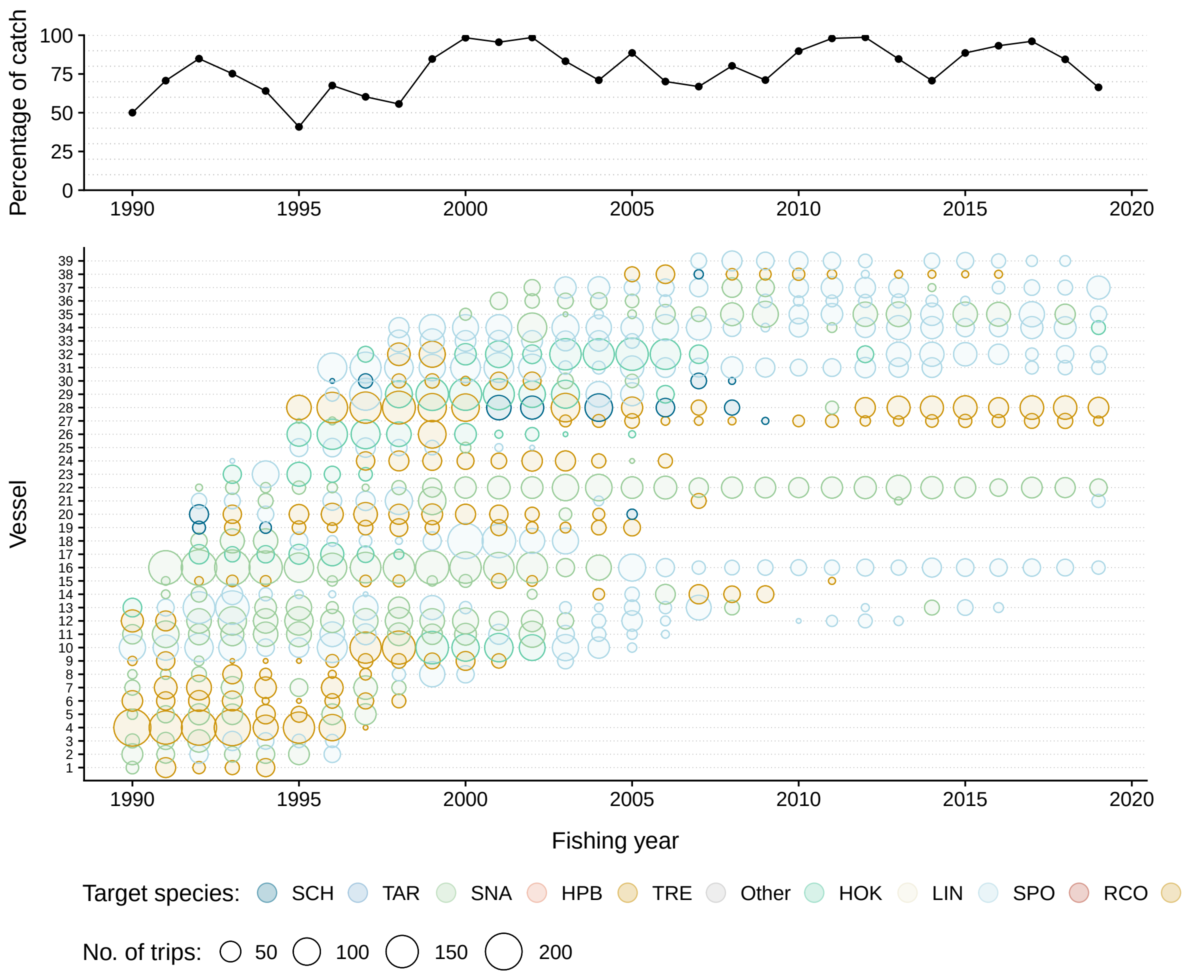

Figure G-2: Proportion of school shark catch retained by the core fleet in SCH 1E SN daily (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

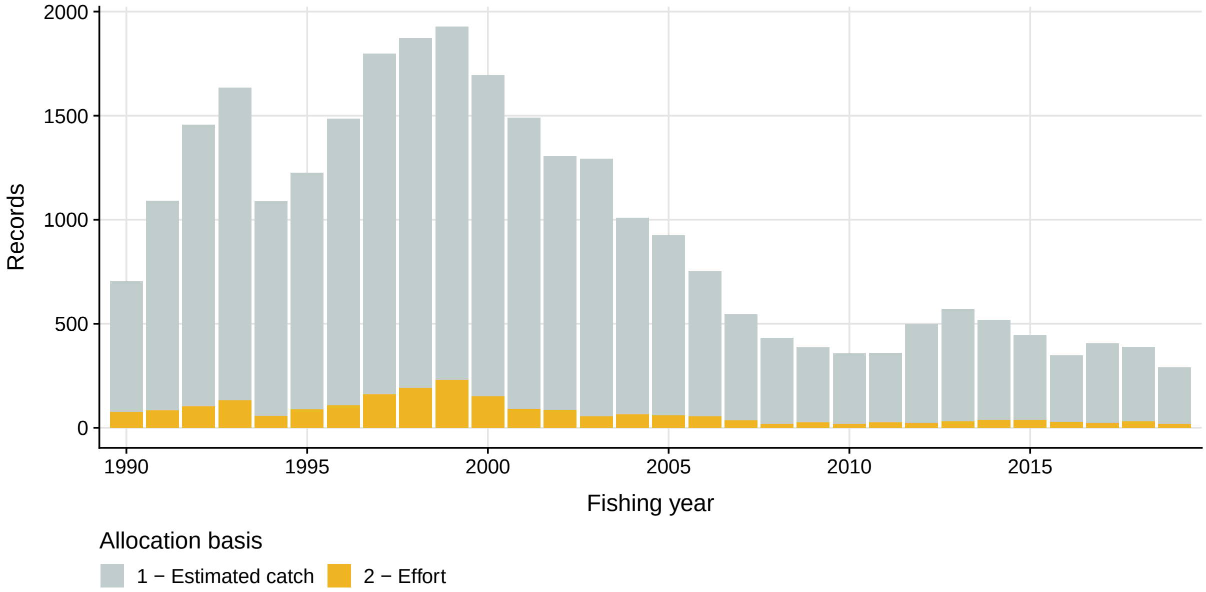

Figure G-3: Number of records by fishing year for the core fleet in SCH 1E SN daily. Records with landings allocated based on estimated catch are highlighted in yellow.

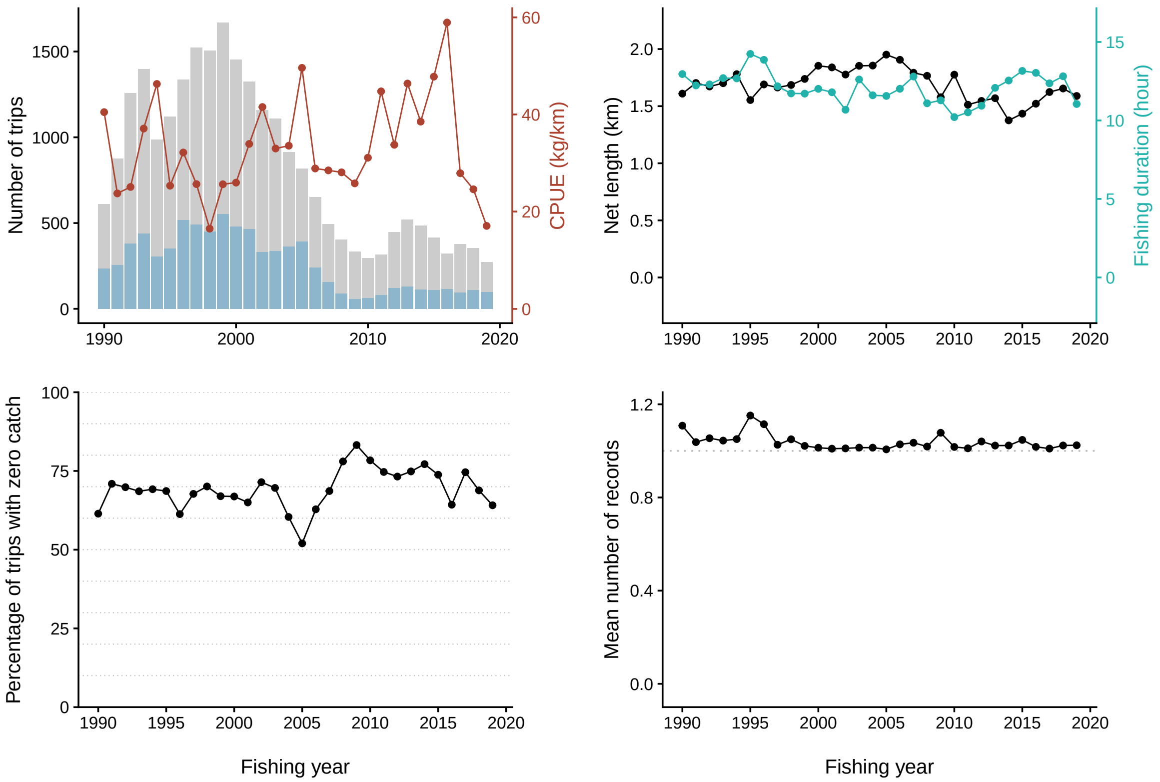

Figure G-4: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 1E SN daily, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all daily records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the daily resolution over time.

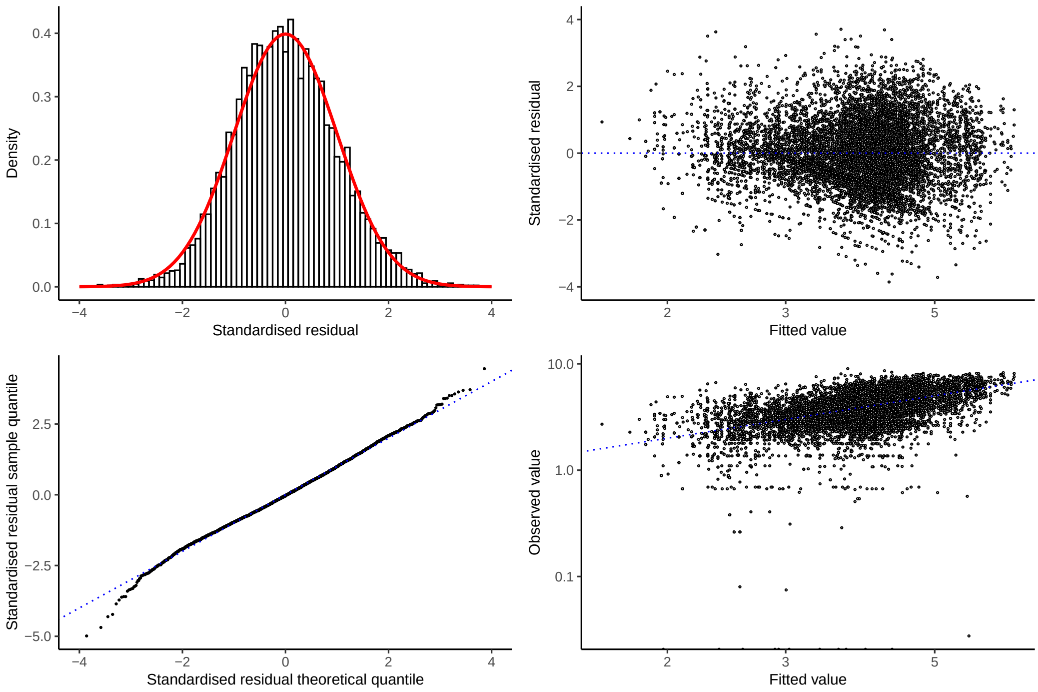

Figure G-5: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 1E SN daily: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-3: Summary of stepwise selection for binomial occurrence model for SCH 1E SN daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	34876	0.90	0.90	*
+ vessel_key	38.00	30192	14.40	13.60	*
+ month	11.00	28781	18.50	4.10	*
+ target_species	4.00	27578	22.00	3.40	*
+ stat_area	7.00	27457	22.30	0.40	
+ ns(log(total_net_length), 3)	3.00	27360	22.60	0.30	

Table G-4: Summary of stepwise selection for positive catch model for SCH 1E SN daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	31268	2.70	2.70	*
+ vessel_key	38.00	29281	23.00	20.30	*
+ target_species	4.00	28498	29.60	6.60	*
+ month	11.00	28316	31.20	1.60	*
+ stat_area	7.00	28278	31.60	0.40	
+ ns(log(total_net_length), 3)	3.00	28256	31.90	0.20	

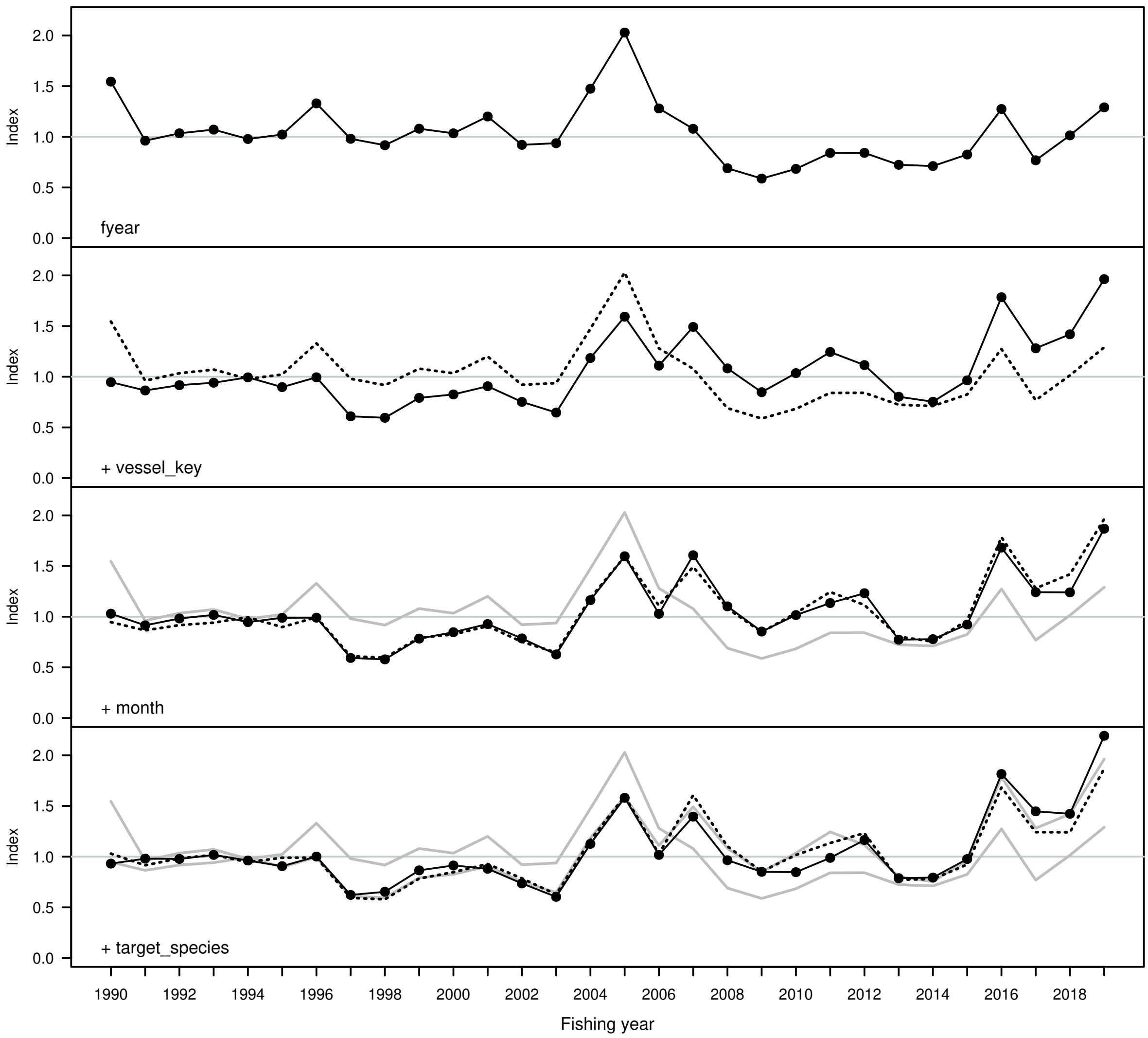

Figure G-6: Stepwise plot for the binomial occurrence model for SCH 1E SN daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

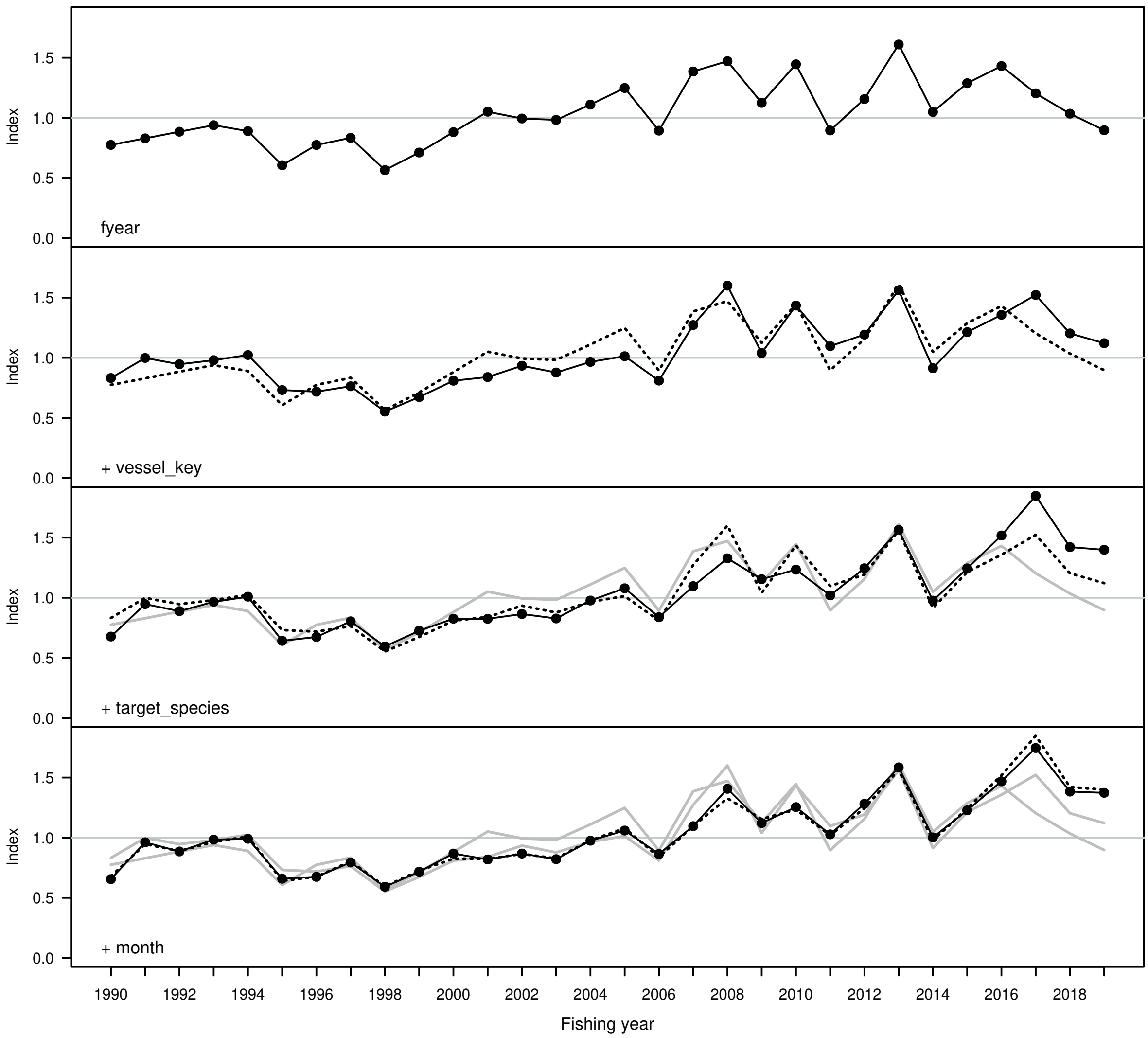

Figure G-7: Stepwise plot for the positive lognormal model for SCH 1E SN daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

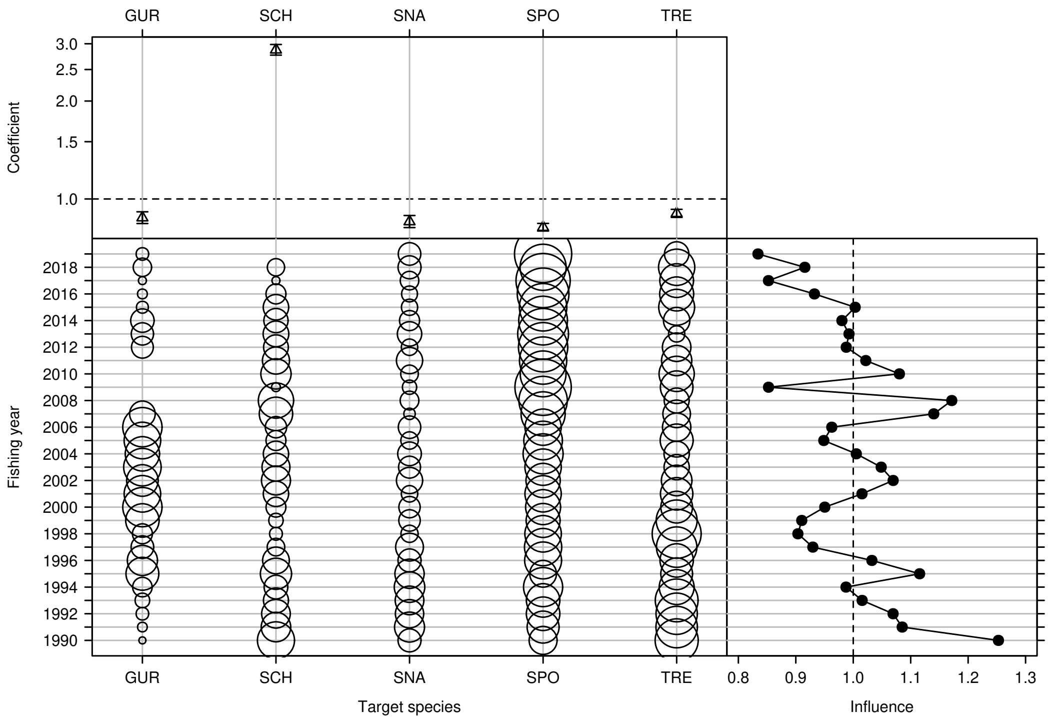

Figure G-8: Influence plot for target species for the lognormal model of school shark in SCH 1E SN daily, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

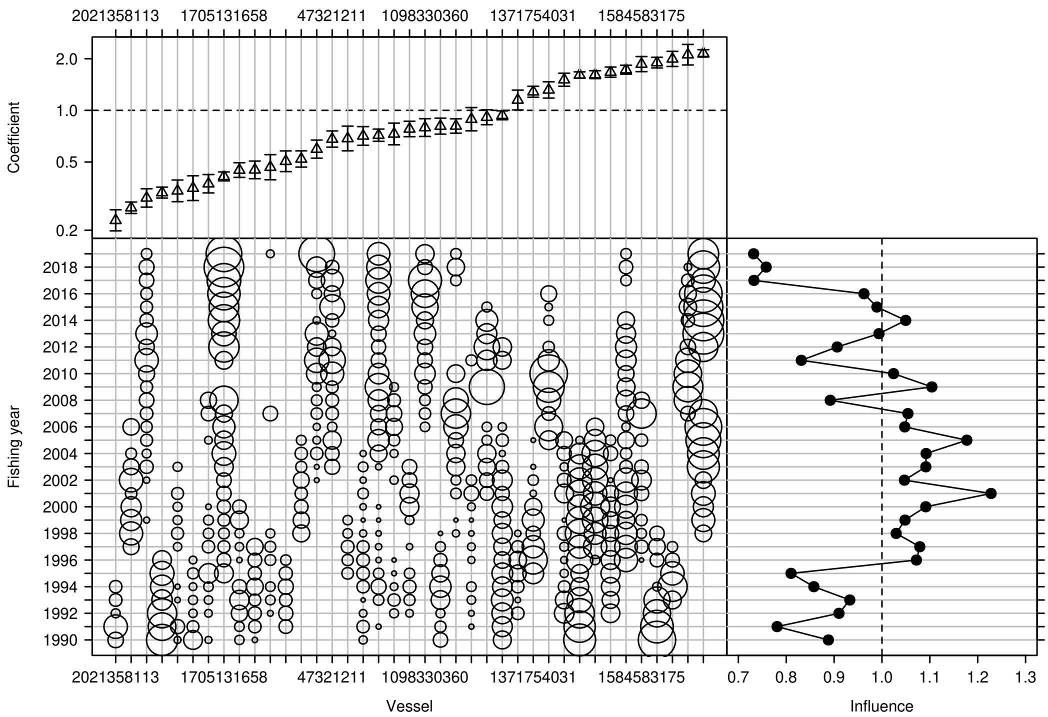

Figure G-9: Influence plot for vessel for the lognormal model of school shark in SCH 1E SN daily, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

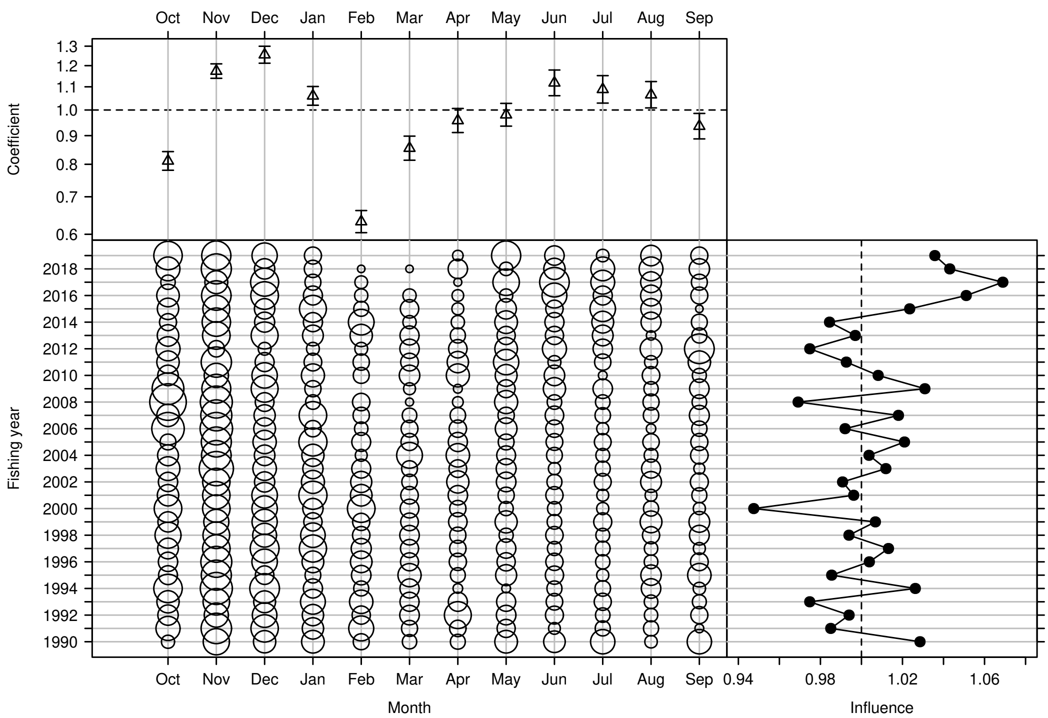

Figure G-10: Influence plot for month for the lognormal model of school shark in SCH 1E SN daily, showing model coefficients for each month (top panel), the distribution of observations over time across each month (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

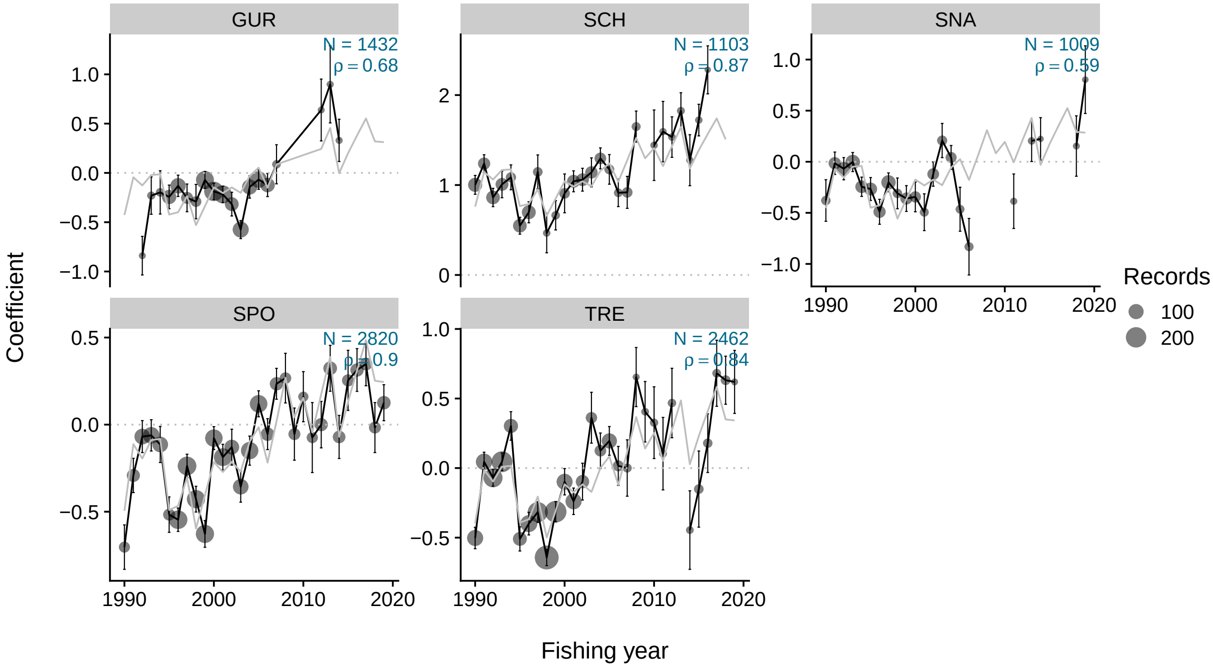

Figure G-11: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 1E SN daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

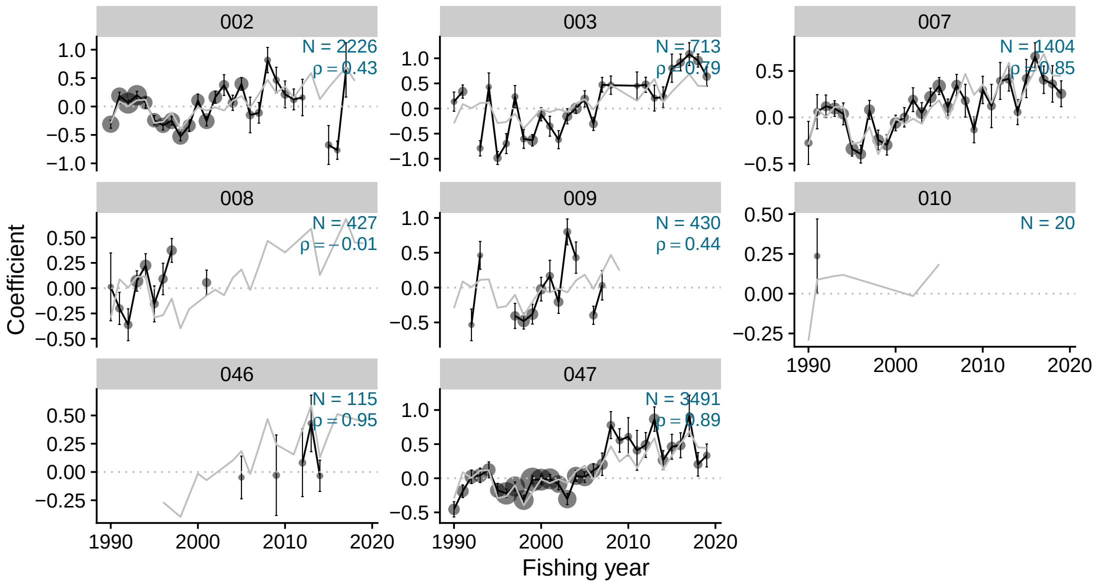

Figure G-12: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 1E SN daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-5: Standardised binomial, positive (lognormal) and combined indices for SCH 1E SN daily, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5^{th}	97.5^{th}
1990	0.968	0.657	0.636	0.516	0.772
1991	0.998	0.963	0.961	0.804	1.146
1992	0.997	0.886	0.883	0.753	1.032
1993	1.022	0.986	1.007	0.873	1.146
1994	0.988	0.993	0.981	0.812	1.171
1995	0.954	0.656	0.626	0.528	0.734
1996	1.012	0.674	0.682	0.590	0.795
1997	0.745	0.795	0.593	0.506	0.693
1998	0.772	0.593	0.458	0.392	0.530
1999	0.929	0.718	0.667	0.584	0.769
2000	0.958	0.867	0.831	0.723	0.957
2001	0.937	0.821	0.770	0.671	0.885
2002	0.838	0.868	0.727	0.614	0.843
2003	0.734	0.822	0.603	0.507	0.705
2004	1.083	0.979	1.060	0.906	1.220
2005	1.288	1.060	1.366	1.179	1.574
2006	1.024	0.867	0.888	0.738	1.068
2007	1.210	1.096	1.327	1.062	1.633
2008	0.993	1.419	1.410	1.039	1.827
2009	0.914	1.134	1.036	0.746	1.411
2010	0.919	1.270	1.167	0.846	1.588
2011	1.005	1.041	1.046	0.778	1.369
2012	1.104	1.292	1.427	1.109	1.811
2013	0.878	1.594	1.400	1.094	1.788
2014	0.882	1.009	0.890	0.677	1.154
2015	0.997	1.238	1.234	0.942	1.603
2016	1.371	1.487	2.039	1.599	2.599
2017	1.233	1.759	2.169	1.641	2.817
2018	1.228	1.391	1.708	1.305	2.230
2019	1.482	1.385	2.053	1.574	2.647

G.2 Far North & SCH 1E bottom longline (daily effort)

Table G-6: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 1E BLL daily.

Variable	Value
Label	BLL1_daily
Forms	CEL, LCE, ERS - Lining, LTC
Period	1989-10-01 to 2019-09-30
Resolution	Daily
Core fleet (min years)	5
Core fleet (min trips)	5
Target species	SNA, HPB, SCH
Statistical areas	046, 047, 048, 002, 003, 004, 005, 006, 007, 008, 009, 010

Table G-7: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 1E BLL daily. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (1000 hooks)	Catch (t)	Positive rate
1990	29	1 498	2 340	3 619.4	10.80	15.43
1991	36	2 083	3 109	5 028.9	15.12	10.13
1992	44	2 668	4 120	7 122.6	27.91	11.17
1993	49	2 937	4 738	8 562.7	41.35	12.71
1994	48	3 064	4 880	8 562.5	106.18	10.14
1995	49	3 222	5 243	9 284.3	66.30	8.81
1996	46	3 156	5 089	8 880.4	71.62	9.77
1997	48	3 311	5 015	8 391.1	74.19	11.11
1998	49	3 417	5 045	8 504.1	82.97	11.85
1999	48	3 603	5 355	9 117.4	109.72	11.37
2000	52	3 762	5 770	10 078.4	156.56	13.60
2001	55	3 752	5 984	11 120.6	171.88	13.47
2002	51	3 456	5 523	10 321.5	128.50	14.10
2003	49	3 246	5 075	9 657.5	143.36	18.52
2004	51	2 976	4 800	9 268.8	157.78	22.25
2005	44	2 519	4 163	7 771.0	104.10	19.77
2006	43	2 394	3 549	6 764.2	93.84	21.19
2007	41	2 577	3 572	6 808.8	108.42	19.18
2008	41	2 476	3 565	6 505.3	92.71	22.30
2009	42	2 548	3 857	7 382.8	113.52	25.80
2010	41	2 720	4 202	8 961.0	101.88	25.49
2011	39	2 651	4 239	9 467.1	125.52	28.38
2012	33	2 388	3 668	8 831.7	91.32	30.53
2013	30	2 205	3 328	8 100.8	69.02	27.85
2014	31	2 129	3 283	8 579.5	68.71	30.86
2015	34	2 062	3 330	9 003.8	71.81	32.07
2016	29	1 915	3 207	8 877.4	66.57	32.40
2017	28	2 080	3 177	8 494.8	70.32	29.97
2018	28	2 243	3 176	8 207.9	66.19	29.28
2019	26	2 388	3 437	8 161.5	92.78	31.66

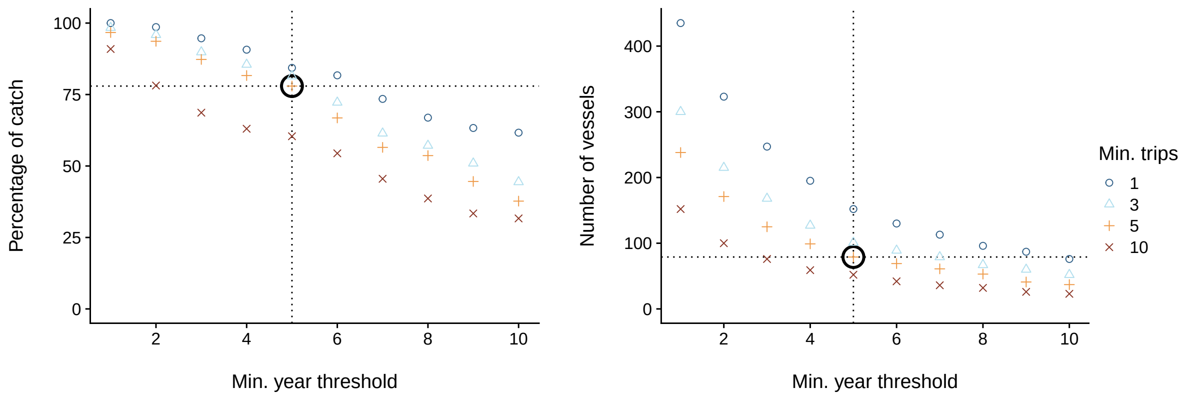

Figure G-13: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 1E BLL daily. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

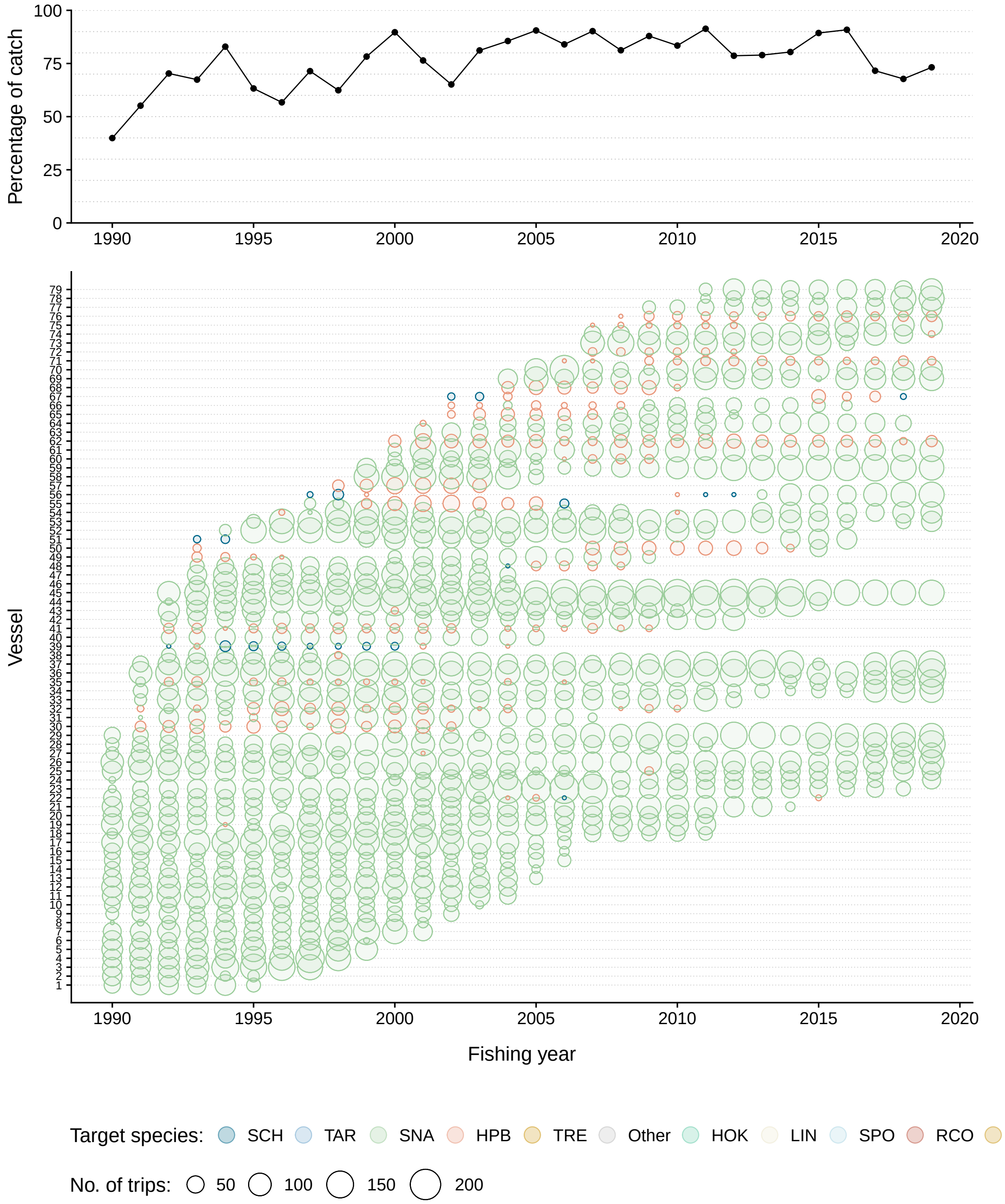

Figure G-14: Proportion of school shark catch retained by the core fleet in SCH 1E BLL daily (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

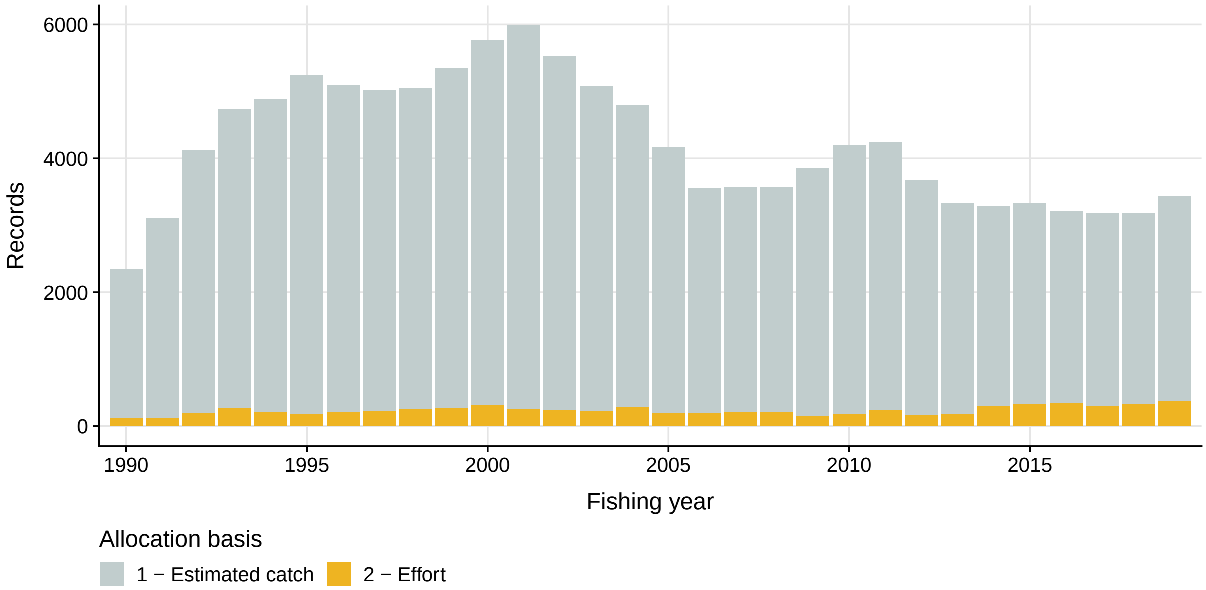

Figure G-15: Number of records by fishing year for the core fleet in SCH 1E BLL daily. Records with landings allocated based on estimated catch are highlighted in yellow.

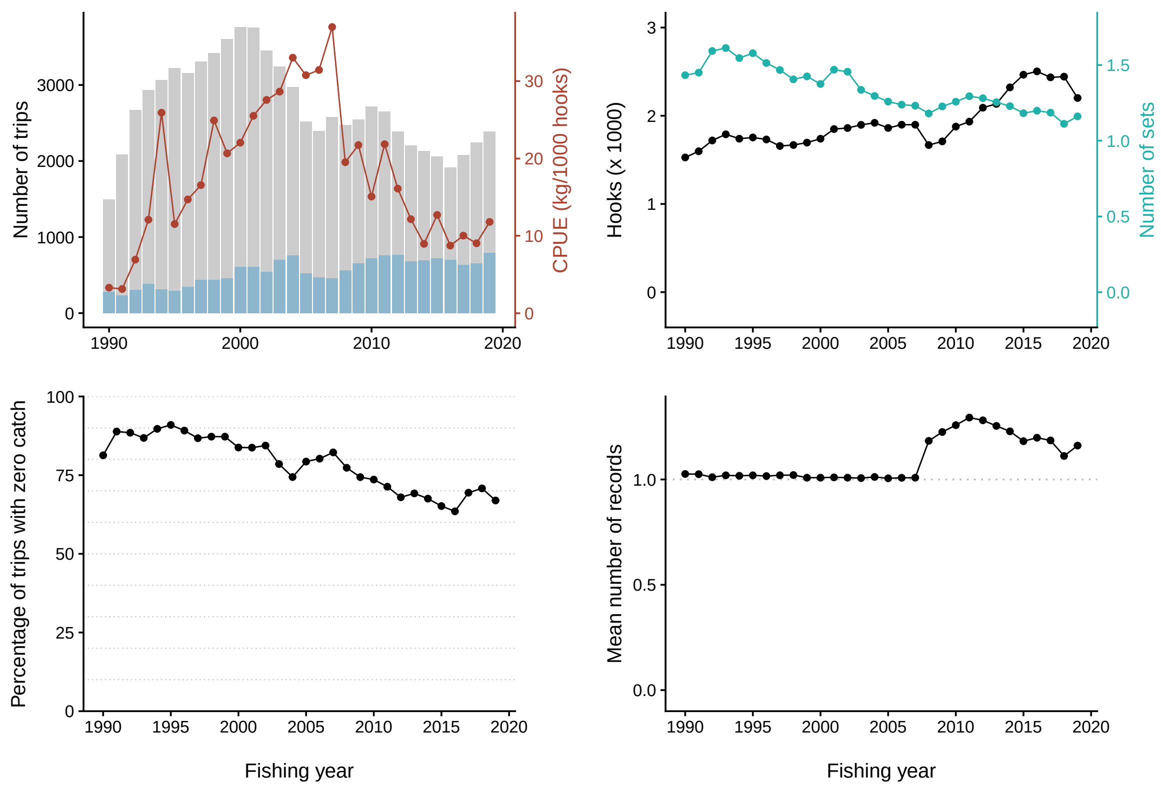

Figure G-16: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 1E BLL daily, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all daily records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the daily resolution over time.

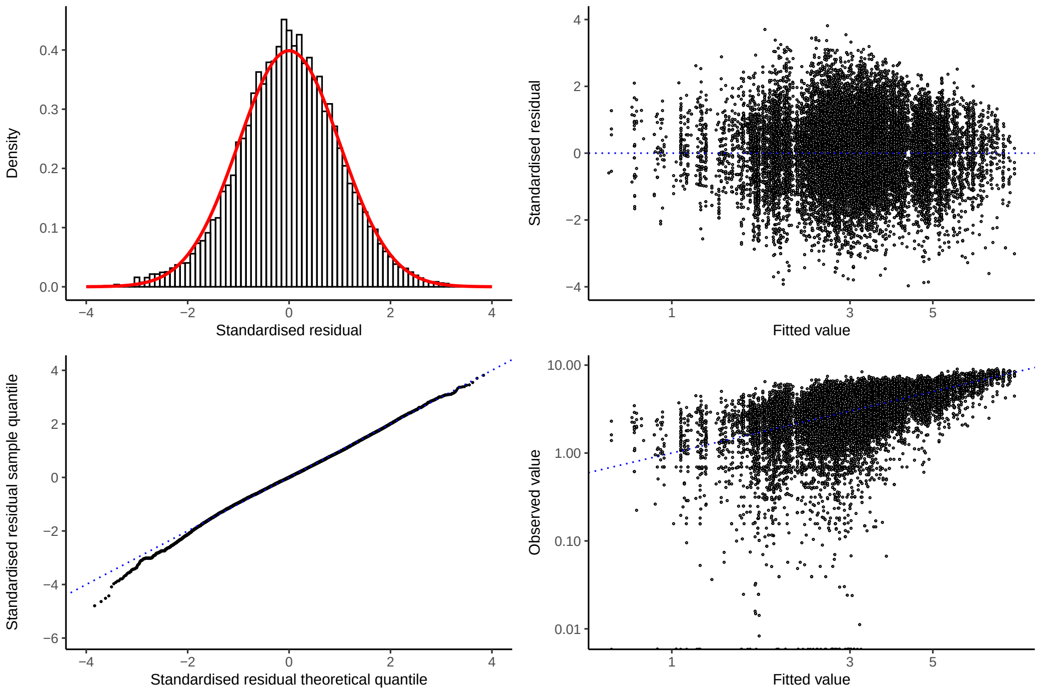

Figure G-17: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 1E BLL daily: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-8: Summary of stepwise selection for binomial occurrence model for SCH 1E BLL daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	116972	4.20	4.20	*
+ vessel_key	78.00	102234	16.40	12.20	*
+ target_species	2.00	100559	17.80	1.40	*
+ stat_area	11.00	99605	18.60	0.80	
+ ns(log(total_hook_num), 3)	3.00	99171	18.90	0.40	
+ month	11.00	99021	19.10	0.10	
+ effort_num	1.00	99021	19.10	0.00	

Table G-9: Summary of stepwise selection for positive catch model for SCH 1E BLL daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	91439	3.90	3.90	*
+ vessel_key	78.00	82407	34.70	30.80	*
+ target_species	2.00	80294	40.20	5.60	*
+ stat_area	11.00	79251	42.90	2.60	*
+ month	11.00	79124	43.20	0.40	
+ effort_num	1.00	79079	43.30	0.10	
+ ns(log(total_hook_num), 3)	3.00	79063	43.40	0.10	

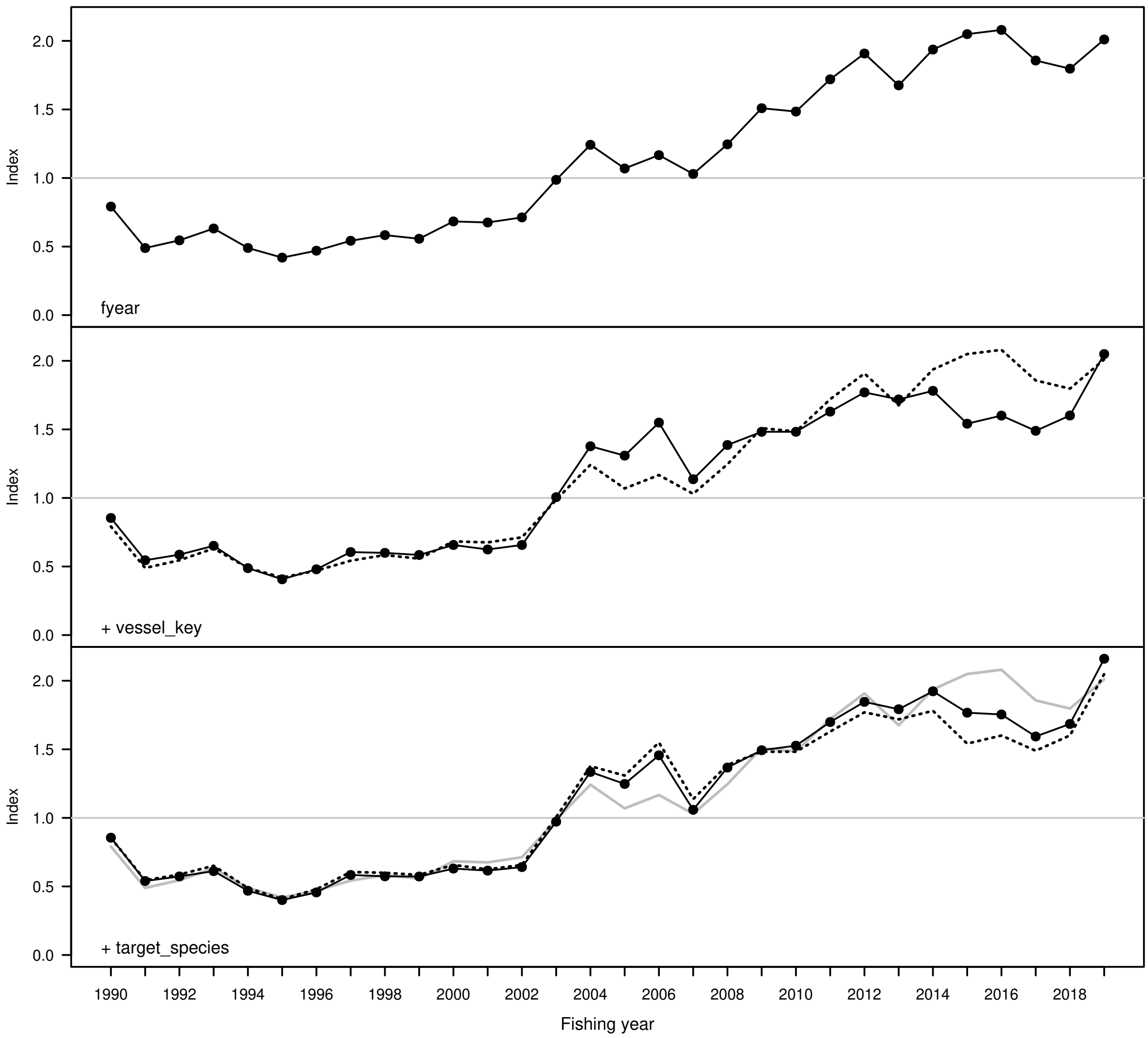

Figure G-18: Stepwise plot for the binomial occurrence model for SCH 1E BLL daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

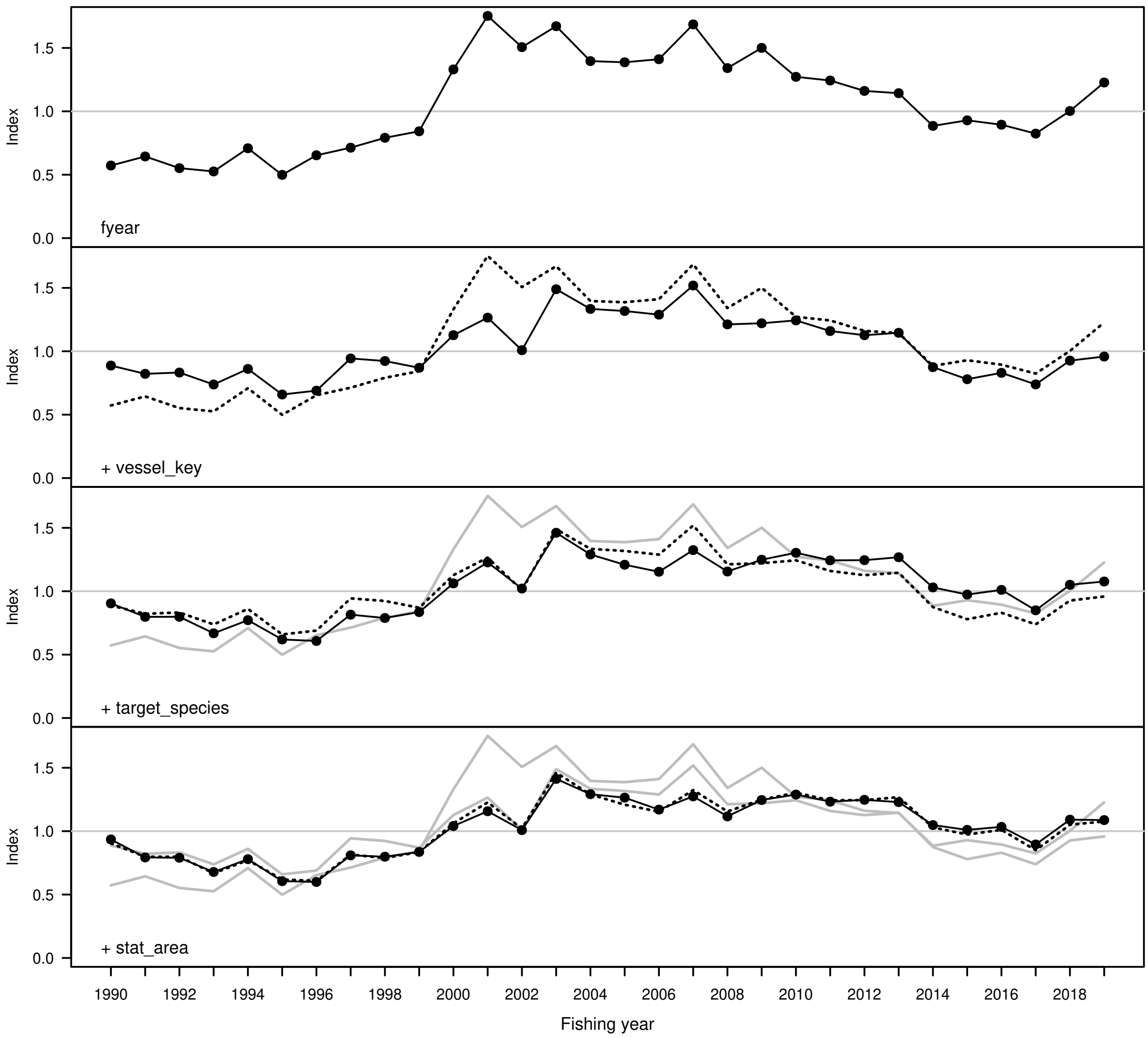

Figure G-19: Stepwise plot for the positive lognormal model for SCH 1E BLL daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

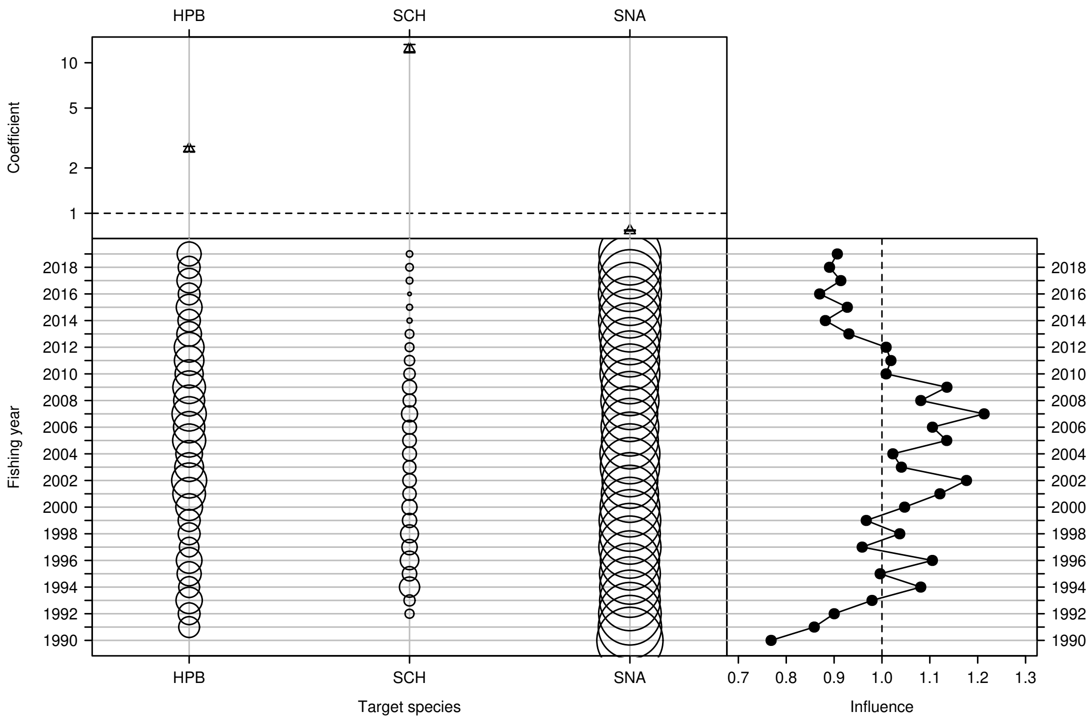

Figure G-20: Influence plot for target species for the lognormal model of school shark in SCH 1E BLL daily, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

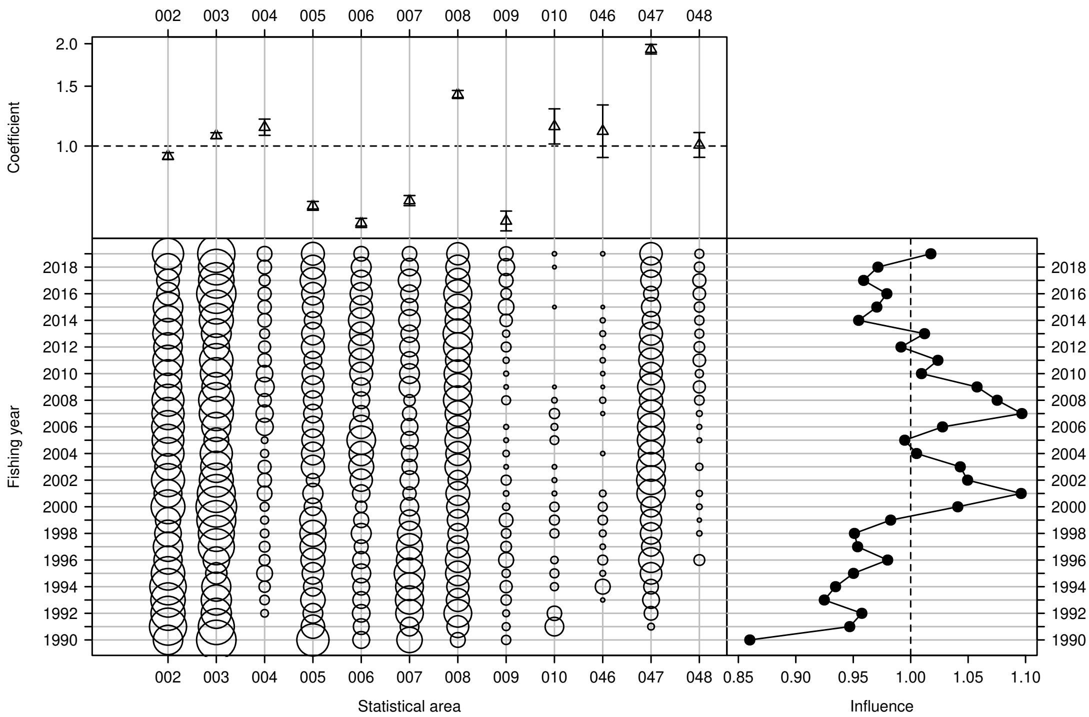

Figure G-21: Influence plot for statistical area for the lognormal model of school shark in SCH 1E BLL daily, showing model coefficients for each statistical area (top panel), the distribution of observations over time across each statistical area (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

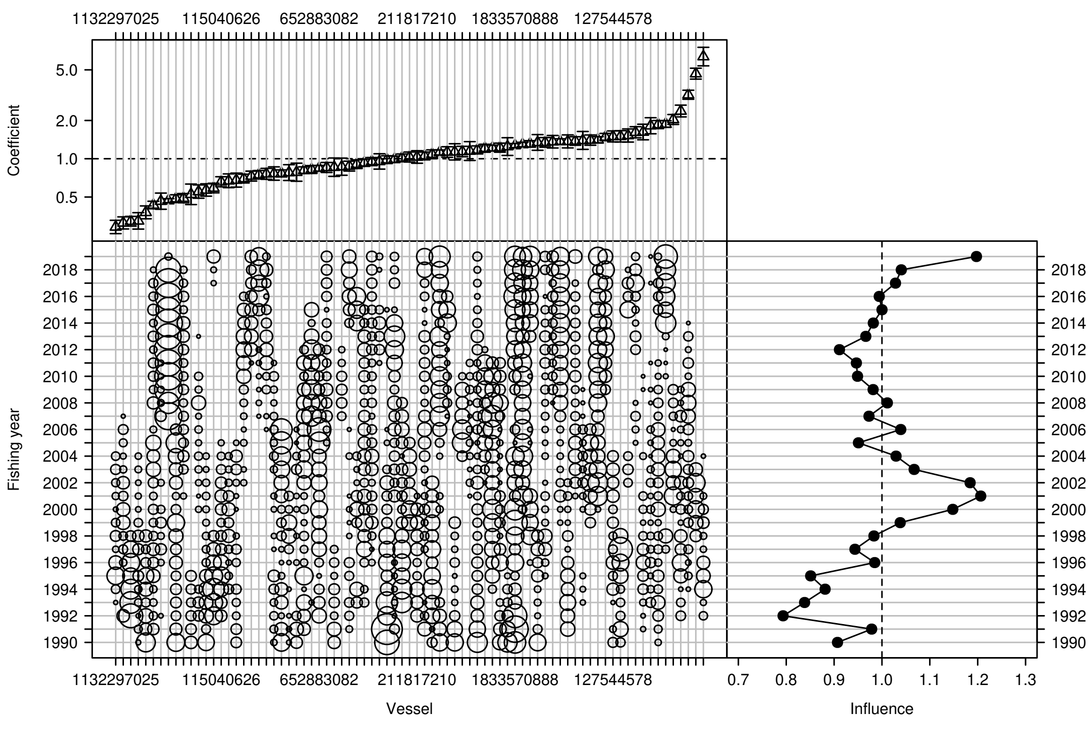

Figure G-22: Influence plot for vessel for the lognormal model of school shark in SCH 1E BLL daily, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

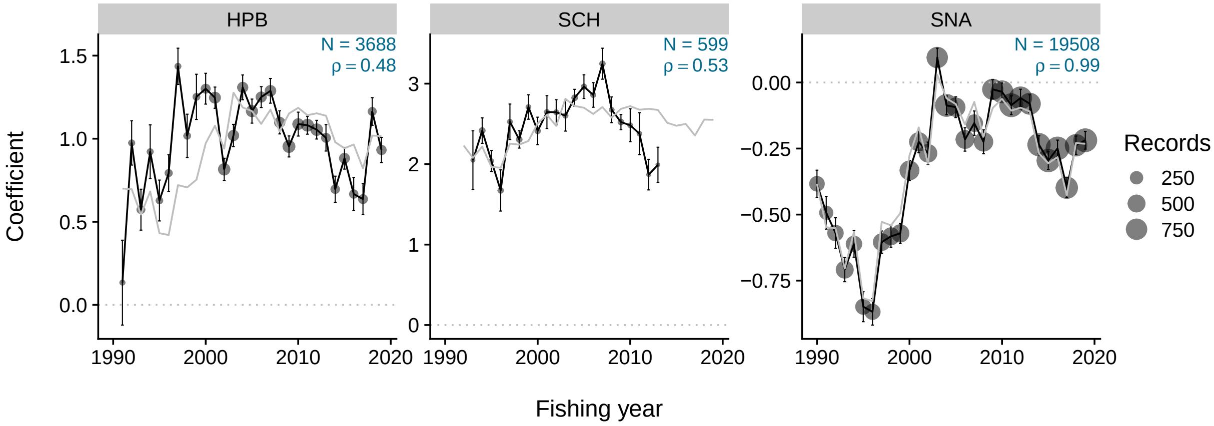

Figure G-23: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 1E BLL daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

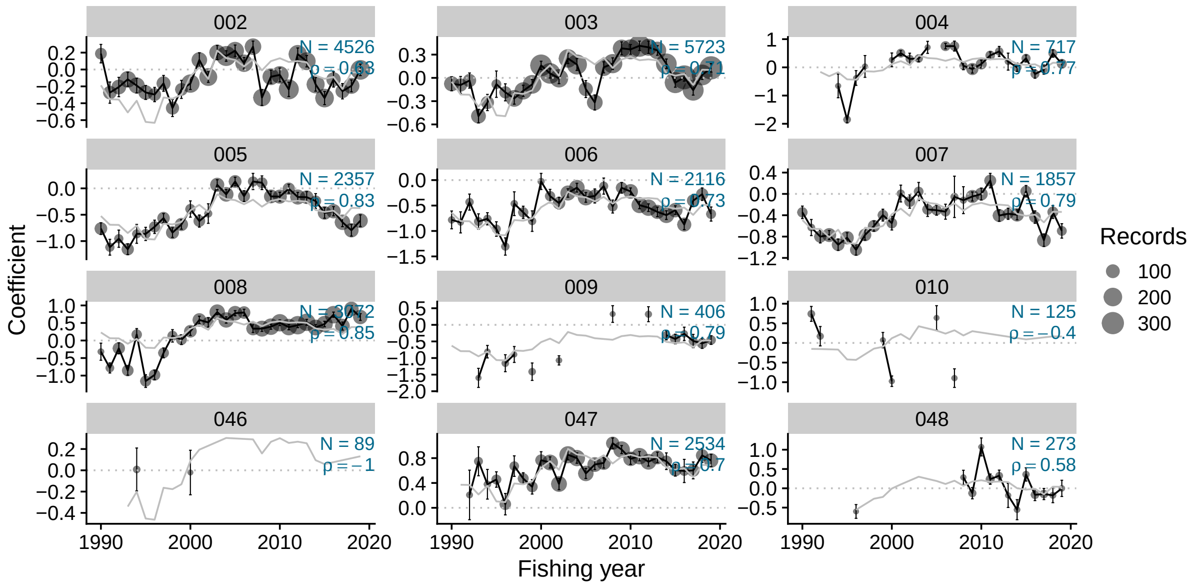

Figure G-24: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 1E BLL daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-10: Standardised binomial, positive (lognormal) and combined indices for SCH 1E BLL daily, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5th	97.5th
1990	0.896	0.938	0.841	0.699	0.987
1991	0.600	0.792	0.476	0.391	0.566
1992	0.632	0.794	0.502	0.428	0.579
1993	0.671	0.678	0.454	0.394	0.518
1994	0.528	0.780	0.412	0.356	0.469
1995	0.458	0.606	0.278	0.240	0.321
1996	0.516	0.601	0.310	0.268	0.357
1997	0.644	0.809	0.521	0.454	0.597
1998	0.634	0.799	0.507	0.444	0.574
1999	0.632	0.836	0.529	0.460	0.603
2000	0.689	1.040	0.717	0.638	0.803
2001	0.674	1.160	0.782	0.690	0.876
2002	0.699	1.011	0.707	0.626	0.790
2003	0.998	1.418	1.415	1.279	1.571
2004	1.285	1.291	1.659	1.499	1.827
2005	1.219	1.265	1.543	1.377	1.722
2006	1.375	1.170	1.609	1.429	1.801
2007	1.071	1.275	1.365	1.213	1.531
2008	1.311	1.119	1.467	1.307	1.638
2009	1.401	1.247	1.746	1.573	1.932
2010	1.426	1.289	1.839	1.648	2.038
2011	1.544	1.233	1.905	1.730	2.097
2012	1.642	1.250	2.052	1.848	2.285
2013	1.605	1.231	1.976	1.763	2.189
2014	1.686	1.048	1.767	1.592	1.975
2015	1.586	1.013	1.607	1.444	1.780
2016	1.580	1.037	1.638	1.478	1.822
2017	1.471	0.900	1.324	1.193	1.474
2018	1.535	1.092	1.676	1.499	1.863
2019	1.831	1.087	1.990	1.790	2.192

G.3 Far North & SCH 1E bottom trawl (trip effort)

Table G-11: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 1E BT trip.

Variable	Value
Label	BT1_trip
Forms	CEL, TCP, TCE, ERS - Trawl
Period	1989-10-01 to 2019-09-30
Resolution	Trip
Core fleet (min years)	5
Core fleet (min trips)	5
Target species	TAR, TRE, SNA, SCH, GUR, BAR, JDO
Statistical areas	045, 046, 047, 002, 003, 004, 005, 006, 008, 009, 010, 105

Table G-12: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 1E BT trip. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (tows)	Catch (t)	Positive rate
1990	27	624	624	7 367	53.17	43.11
1991	26	690	690	8 062	58.36	42.17
1992	31	858	858	9 774	73.07	44.17
1993	35	792	792	9 021	130.82	55.18
1994	33	820	820	8 973	114.50	47.20
1995	33	706	706	7 647	90.31	50.42
1996	33	674	674	7 559	103.84	49.26
1997	33	716	716	8 093	113.39	58.10
1998	36	802	802	9 659	118.98	53.62
1999	33	771	771	9 385	96.44	58.50
2000	32	772	772	9 392	104.75	58.55
2001	33	670	670	7 786	60.44	51.49
2002	32	714	714	7 710	93.43	50.56
2003	30	613	613	7 049	97.88	56.12
2004	28	632	632	7 563	112.30	61.55
2005	28	664	664	8 431	107.71	61.60
2006	27	648	648	7 926	151.47	68.21
2007	22	529	529	7 188	107.81	59.92
2008	21	524	524	6 262	120.38	61.64
2009	22	511	511	6 903	142.59	65.36
2010	19	532	532	6 690	120.58	62.59
2011	21	490	490	6 461	164.31	70.41
2012	18	499	499	6 792	145.57	66.93
2013	18	500	500	6 662	111.36	64.40
2014	20	549	549	6 857	168.33	70.13
2015	21	562	562	7 127	193.52	68.68
2016	19	474	474	6 150	128.81	73.42
2017	15	416	416	5 943	143.16	80.53
2018	13	229	229	2 604	104.78	75.98
2019	12	241	241	2 722	80.14	71.78

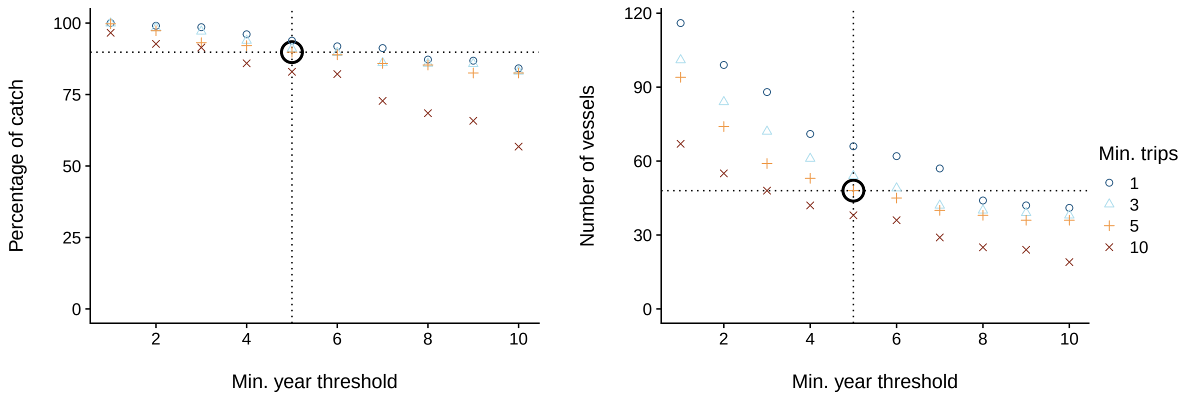

Figure G-25: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 1E BT trip. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

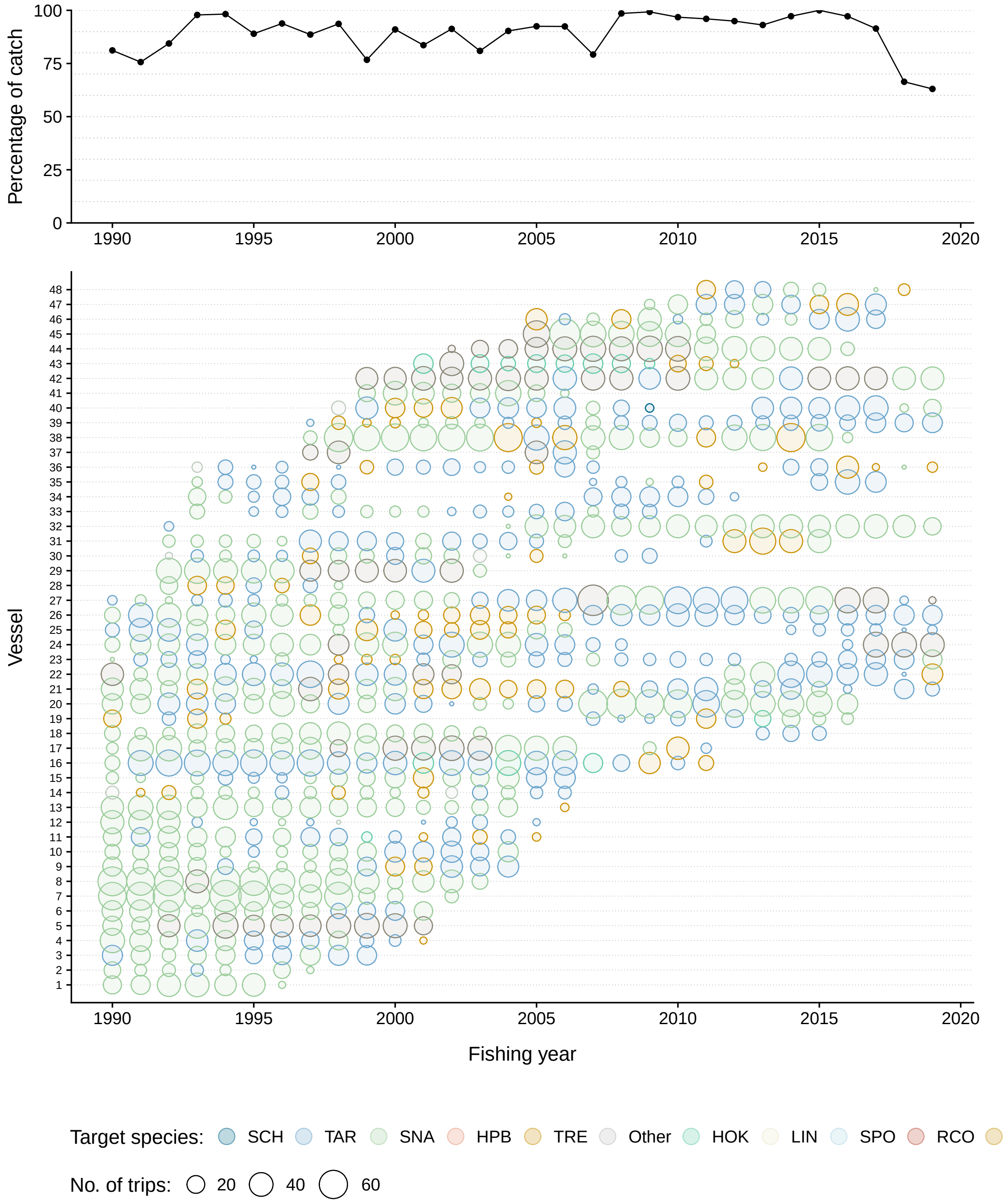

Figure G-26: Proportion of school shark catch retained by the core fleet in SCH 1E BT trip (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

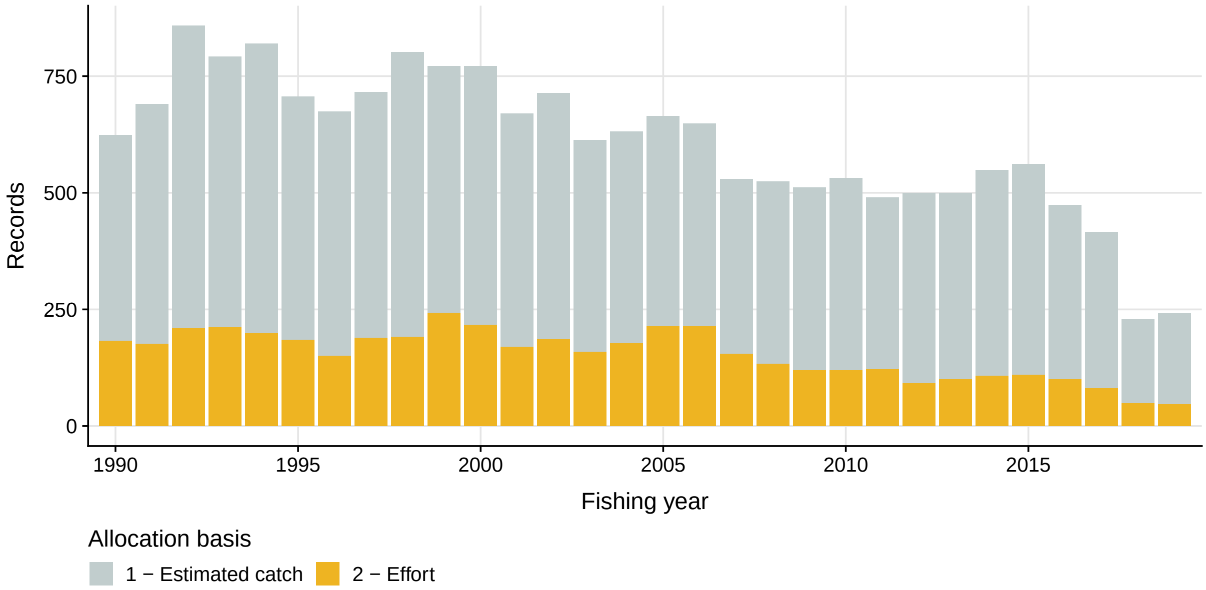

Figure G-27: Number of records by fishing year for the core fleet in SCH 1E BT trip. Records with landings allocated based on estimated catch are highlighted in yellow.

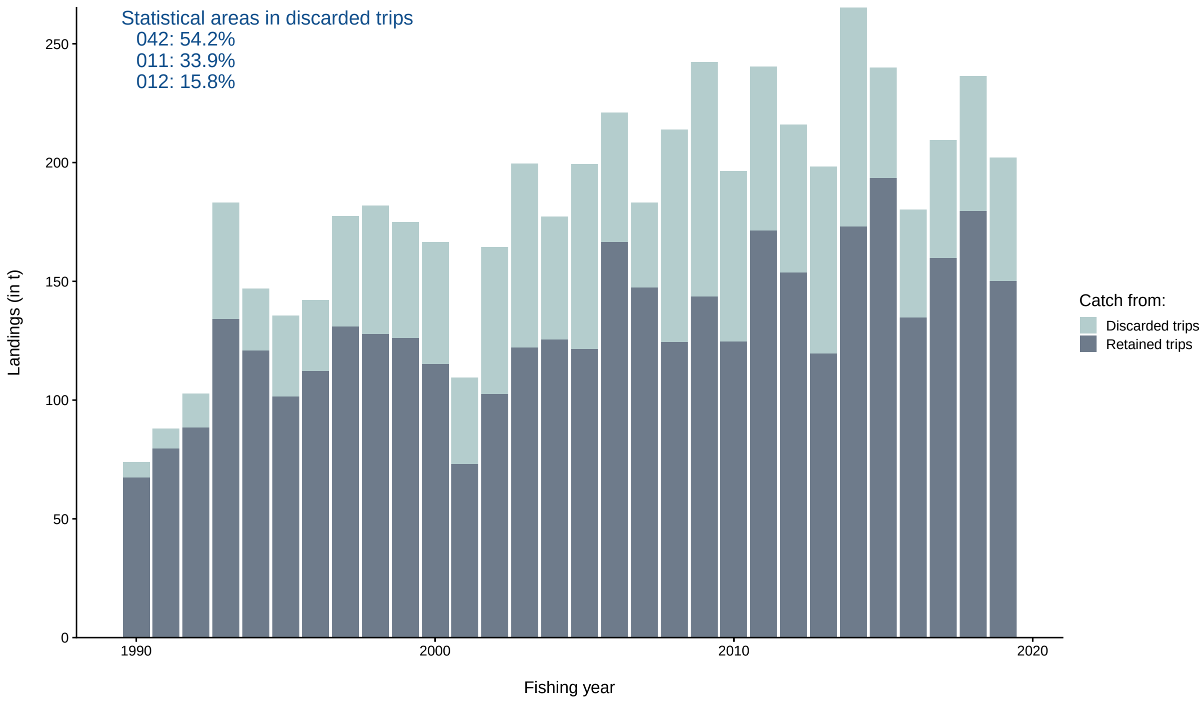

Figure G-28: Total landings and landings retained in the analysis for SCH 1E BT trip for the full fleet following data preparation to remove trips spanning multiple catch-per-unit-effort (CPUE) units. The top three statistical areas most often present in the omitted trips are noted in the top-left corner, including the corresponding proportion of discarded trips.

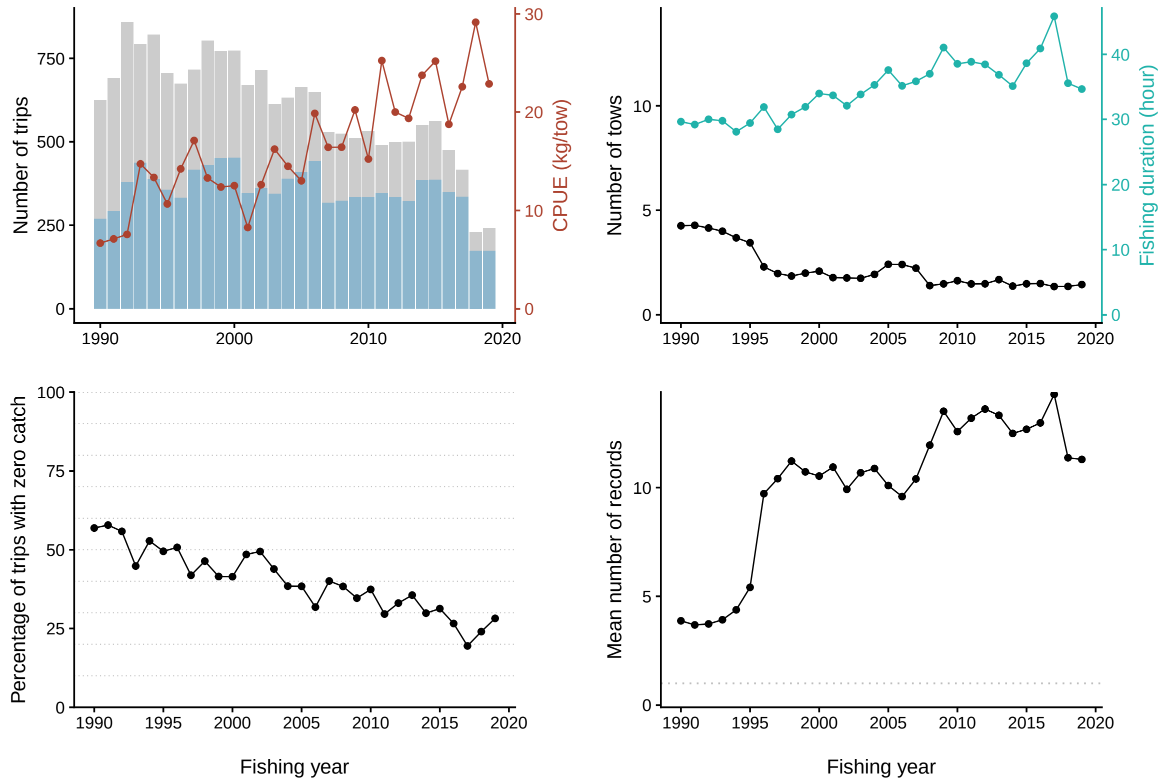

Figure G-29: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 1E BT trip, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all trip records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the trip resolution over time.

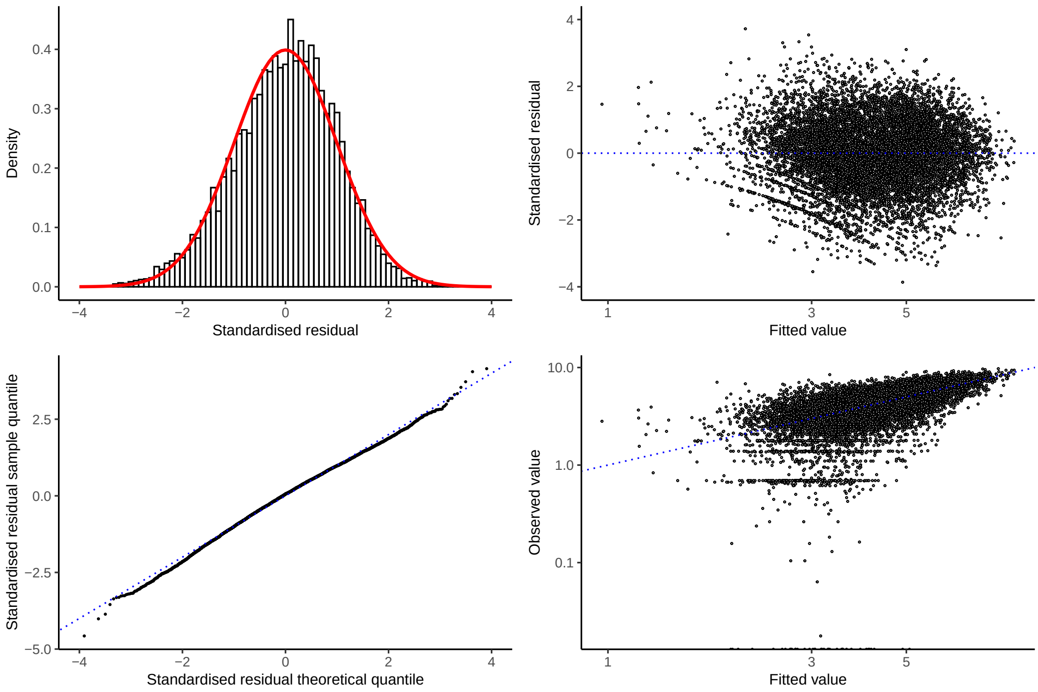

Figure G-30: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 1E BT trip: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-13: Summary of stepwise selection for binomial occurrence model for SCH 1E BT trip. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	24157	2.70	2.70	*
+ stat_area	10.00	20791	16.40	13.70	*
+ vessel_key	47.00	19308	22.80	6.40	*
+ target_species	6.00	18514	26.00	3.30	*
+ ns(log(fishing_duration), 3)	3.00	17895	28.50	2.50	*
+ month	11.00	17709	29.40	0.80	
+ effort_num	1.00	17672	29.50	0.20	

Table G-14: Summary of stepwise selection for positive catch model for SCH 1E BT trip. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	42297	1.20	1.20	*
+ stat_area	10.00	37845	35.20	34.00	*
+ ns(log(fishing_duration), 3)	3.00	36746	41.60	6.40	*
+ vessel_key	47.00	35968	46.20	4.60	*
+ target_species	6.00	35312	49.50	3.30	*
+ month	11.00	35148	50.40	0.90	

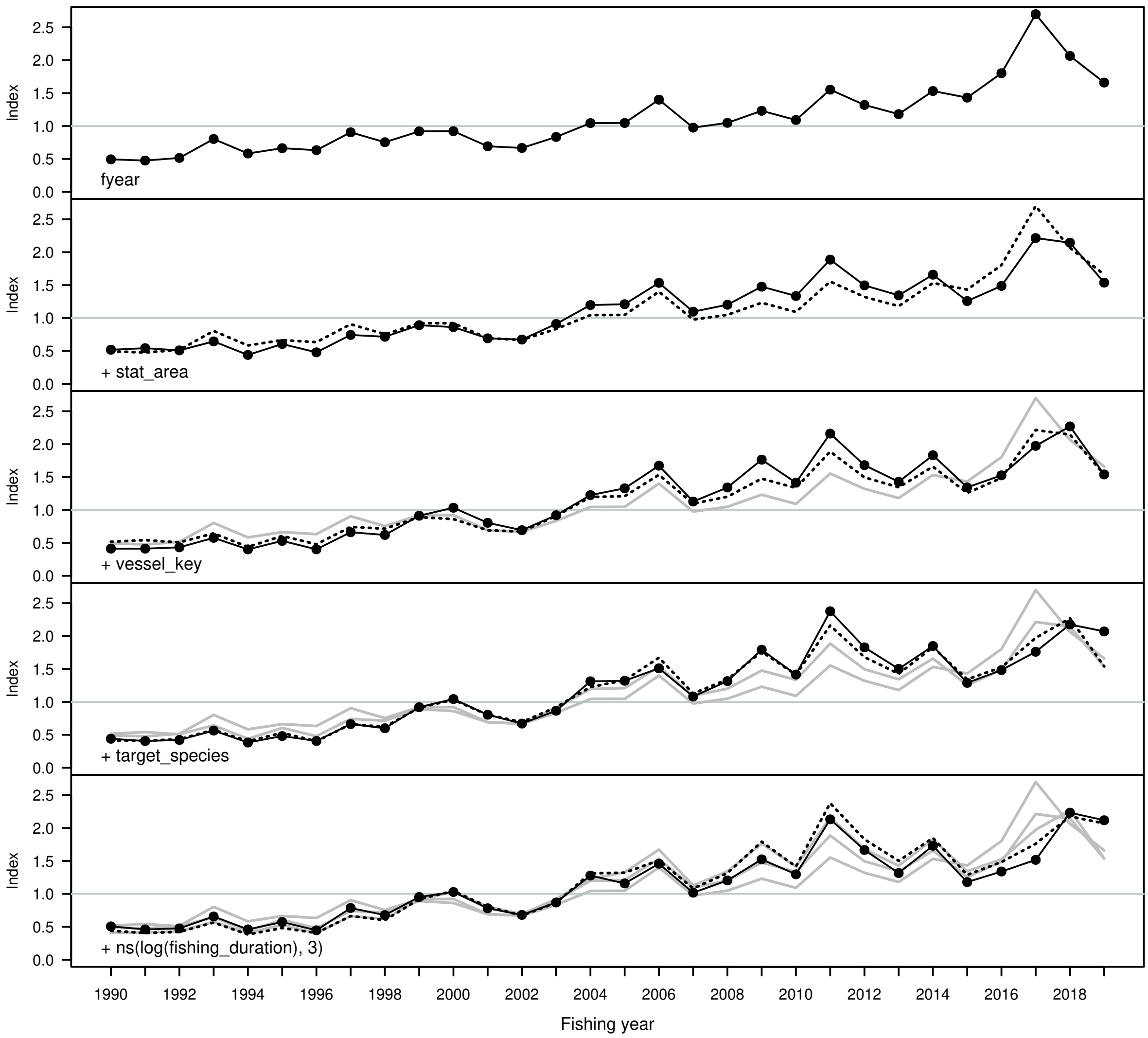

Figure G-31: Stepwise plot for the binomial occurrence model for SCH 1E BT trip showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

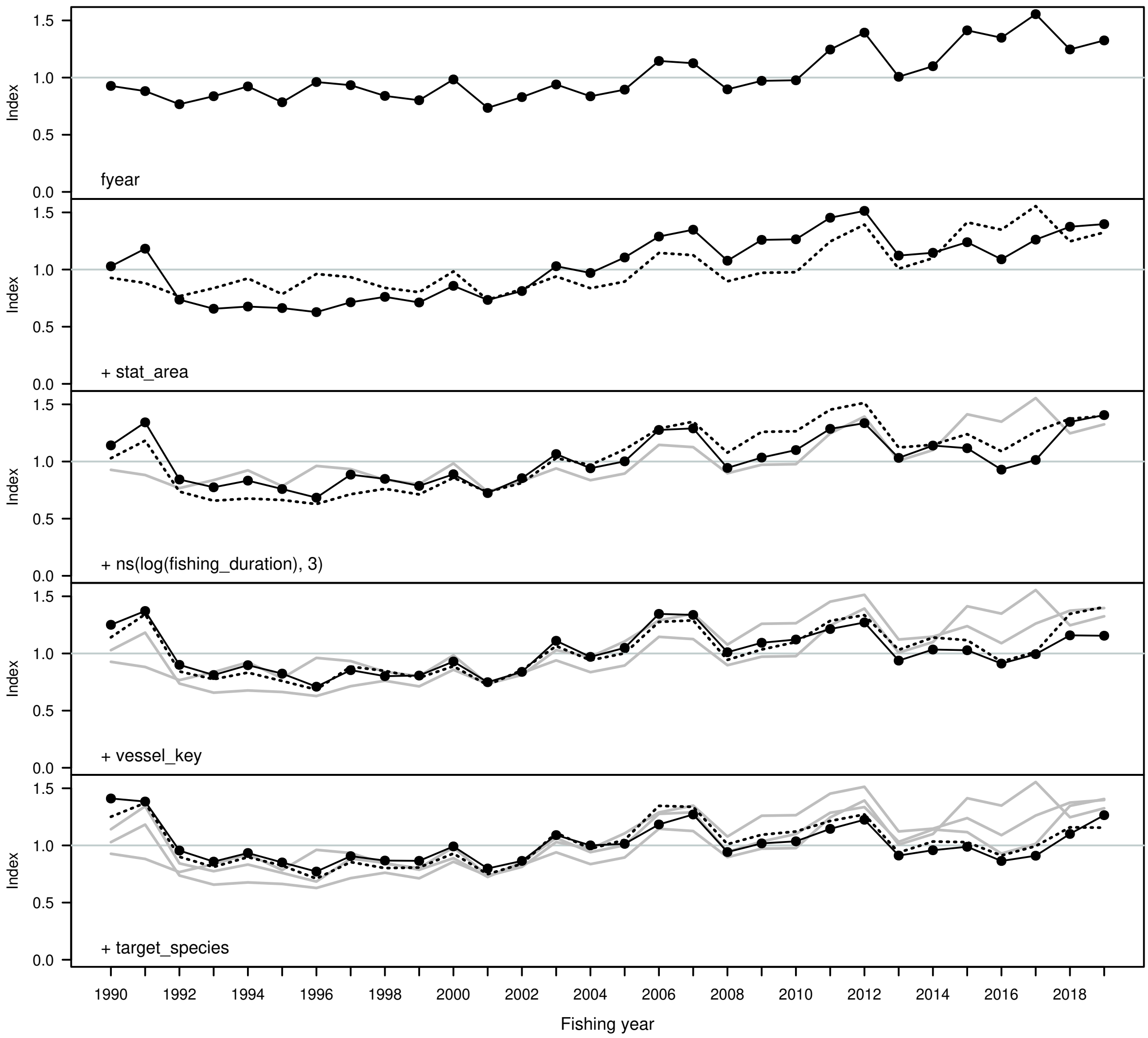

Figure G-32: Stepwise plot for the positive lognormal model for SCH 1E BT trip showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

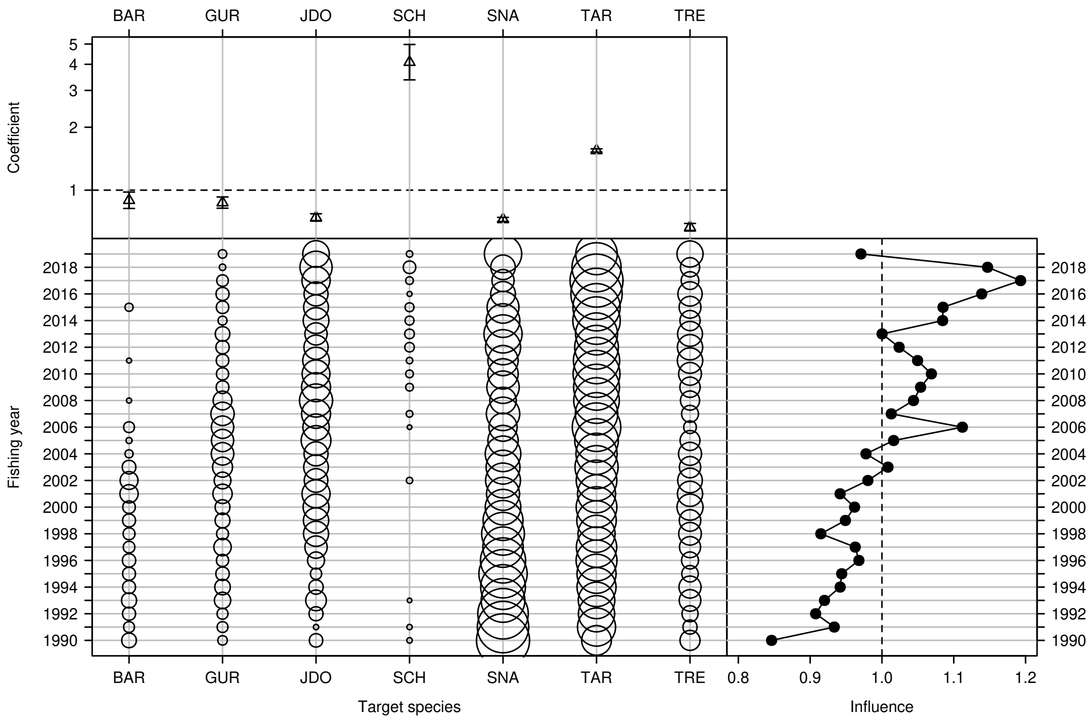

Figure G-33: Influence plot for target species for the lognormal model of school shark in SCH 1E BT trip, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

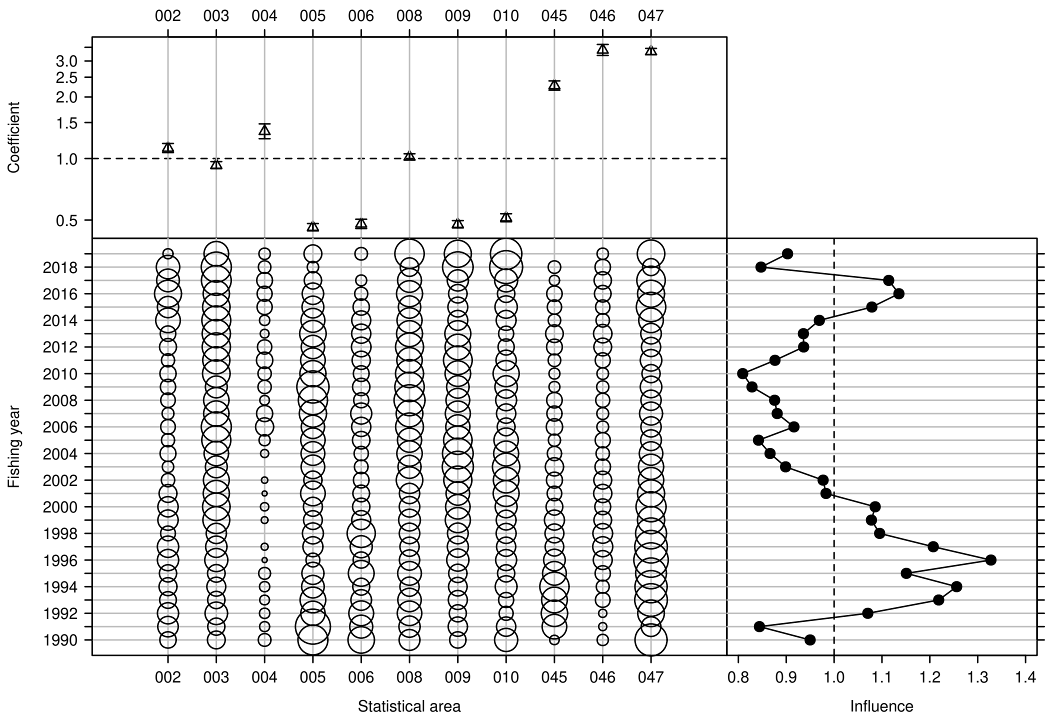

Figure G-34: Influence plot for statistical area for the lognormal model of school shark in SCH 1E BT trip, showing model coefficients for each statistical area (top panel), the distribution of observations over time across each statistical area (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

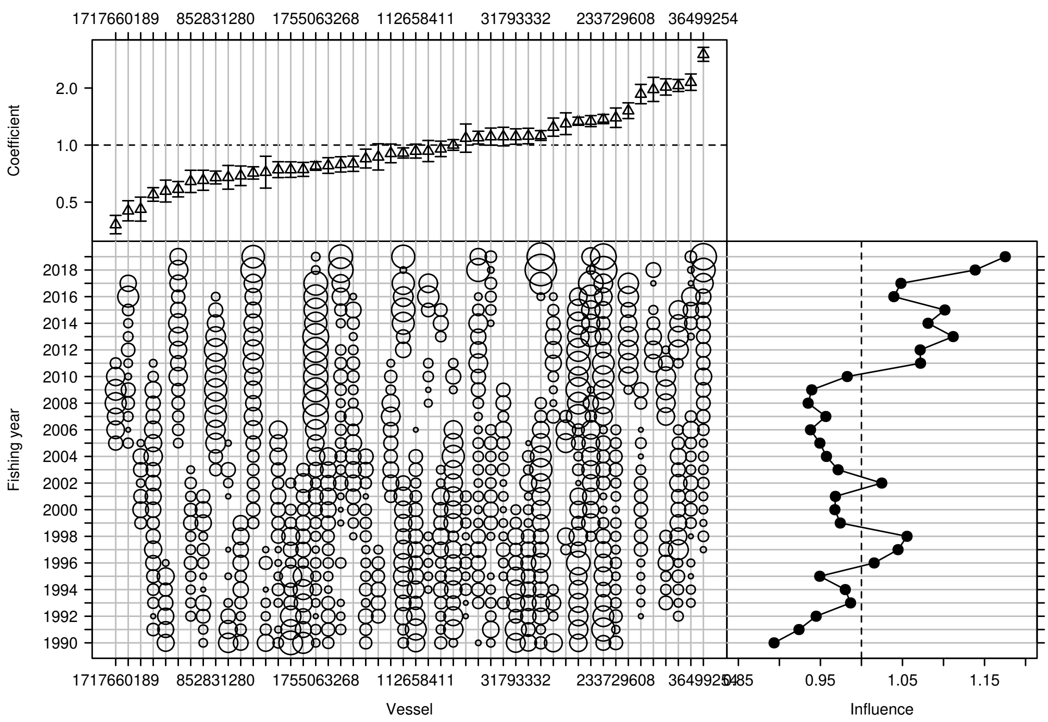

Figure G-35: Influence plot for vessel for the lognormal model of school shark in SCH 1E BT trip, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

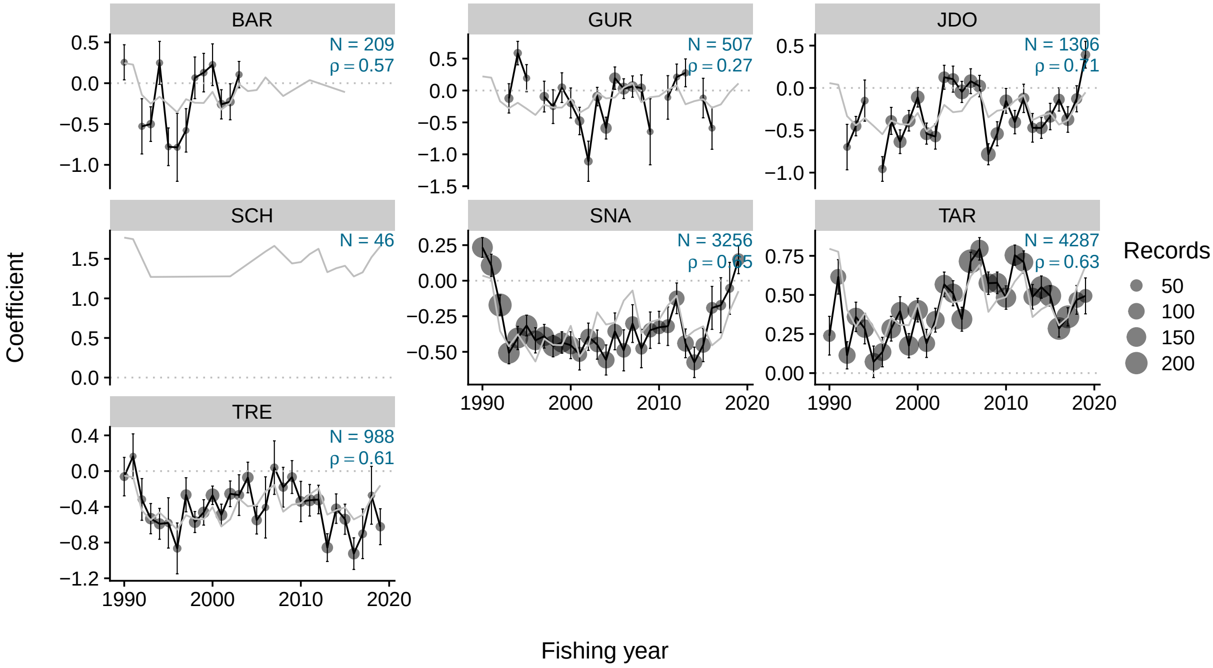

Figure G-36: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 1E BT trip, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

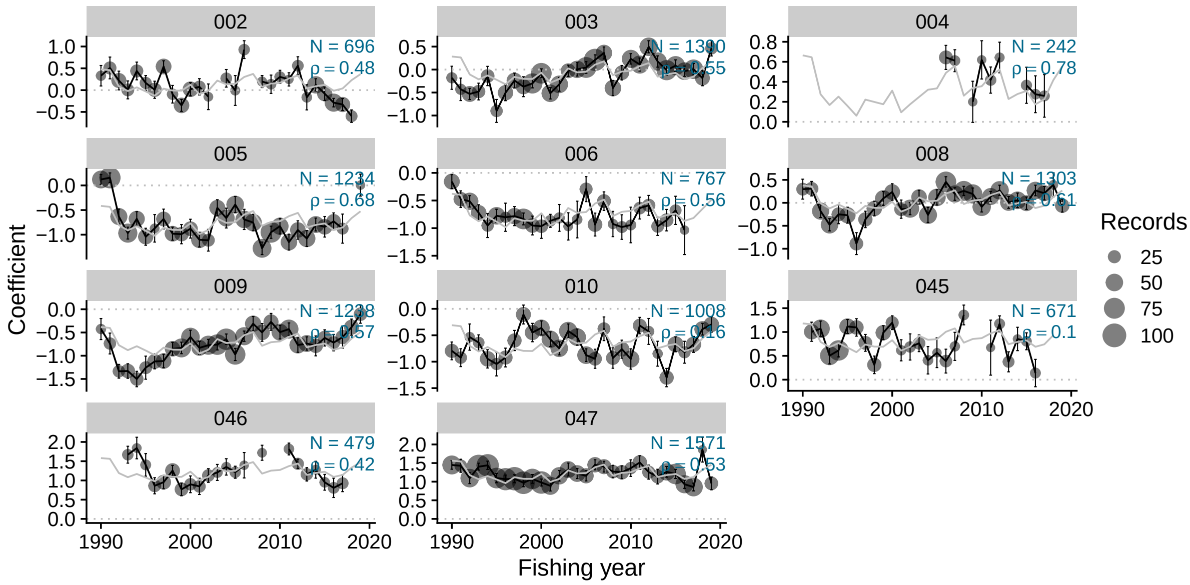

Figure G-37: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 1E BT trip, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-15: Standardised binomial, positive (lognormal) and combined indices for SCH 1E BT trip, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5th	97.5th
1990	0.741	1.415	1.048	0.825	1.303
1991	0.703	1.380	0.970	0.748	1.200
1992	0.718	0.958	0.688	0.549	0.836
1993	0.853	0.865	0.738	0.616	0.858
1994	0.703	0.935	0.657	0.517	0.805
1995	0.795	0.855	0.680	0.549	0.811
1996	0.692	0.771	0.534	0.421	0.659
1997	0.926	0.910	0.843	0.712	0.985
1998	0.864	0.870	0.752	0.632	0.883
1999	1.008	0.869	0.876	0.758	0.998
2000	1.039	0.992	1.031	0.889	1.178
2001	0.925	0.800	0.740	0.624	0.869
2002	0.868	0.863	0.749	0.624	0.884
2003	0.970	1.093	1.060	0.892	1.243
2004	1.127	1.002	1.129	0.978	1.319
2005	1.088	1.017	1.107	0.936	1.280
2006	1.180	1.189	1.403	1.208	1.639
2007	1.035	1.272	1.316	1.112	1.555
2008	1.101	0.946	1.042	0.877	1.250
2009	1.196	1.021	1.222	1.020	1.468
2010	1.133	1.039	1.177	0.996	1.387
2011	1.311	1.143	1.499	1.239	1.832
2012	1.225	1.233	1.510	1.285	1.809
2013	1.139	0.911	1.038	0.885	1.221
2014	1.239	0.960	1.190	1.016	1.408
2015	1.093	0.990	1.083	0.932	1.265
2016	1.143	0.869	0.993	0.839	1.197
2017	1.192	0.912	1.087	0.912	1.293
2018	1.325	1.102	1.460	1.145	1.876
2019	1.310	1.272	1.667	1.308	2.145

G.4 SCH 2 & top of SCH 3 set net (daily effort)

Table G-16: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 2/3 SN daily.

Variable	Value
Label	SN23_daily
Forms	CEL, NCE, ERS - Netting
Period	1989-10-01 to 2019-09-30
Resolution	Daily
Core fleet (min years)	4
Core fleet (min trips)	5
Target species	SCH, SPO, WAR, MOK
Statistical areas	012, 013, 014, 015, 018, 020

Table G-17: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 2/3 SN daily. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (net length [km])	Catch (t)	Positive rate
1990	11	297	313	333.5	18.80	44.73
1991	11	351	375	401.0	4.86	36.53
1992	12	445	472	562.9	17.65	44.92
1993	12	557	579	723.4	16.31	38.34
1994	17	764	834	1 089.4	28.06	47.36
1995	17	664	744	979.7	22.48	43.41
1996	16	659	759	1 076.2	34.20	50.46
1997	19	713	792	1 074.8	41.48	49.75
1998	18	740	810	1 056.5	50.87	47.04
1999	17	743	861	1 101.0	65.69	48.43
2000	18	831	930	1 376.1	77.41	63.12
2001	18	928	1 001	1 493.7	69.17	60.84
2002	22	822	866	1 216.4	67.46	55.66
2003	22	605	639	931.5	77.48	63.54
2004	18	404	448	592.9	62.80	71.43
2005	17	445	475	769.7	60.75	65.05
2006	14	318	415	628.0	47.54	56.39
2007	12	387	494	749.7	43.90	70.85
2008	13	386	497	663.5	58.50	79.88
2009	12	449	508	632.8	45.37	73.62
2010	13	449	561	682.6	58.42	70.23
2011	11	371	425	554.3	46.46	75.53
2012	13	293	352	509.5	65.84	74.43
2013	13	305	412	715.2	74.95	76.94
2014	14	280	386	609.3	61.76	75.13
2015	14	342	464	761.3	92.95	74.35
2016	13	371	479	795.5	75.82	74.53
2017	13	361	434	735.8	57.06	69.35
2018	13	359	402	666.6	47.28	79.35
2019	10	296	349	576.8	56.94	79.08

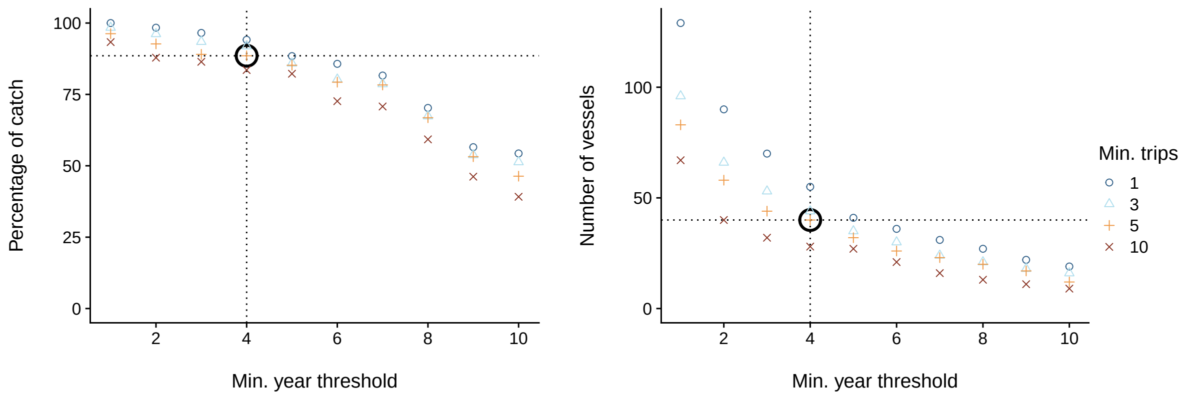

Figure G-38: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 2/3 SN daily. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

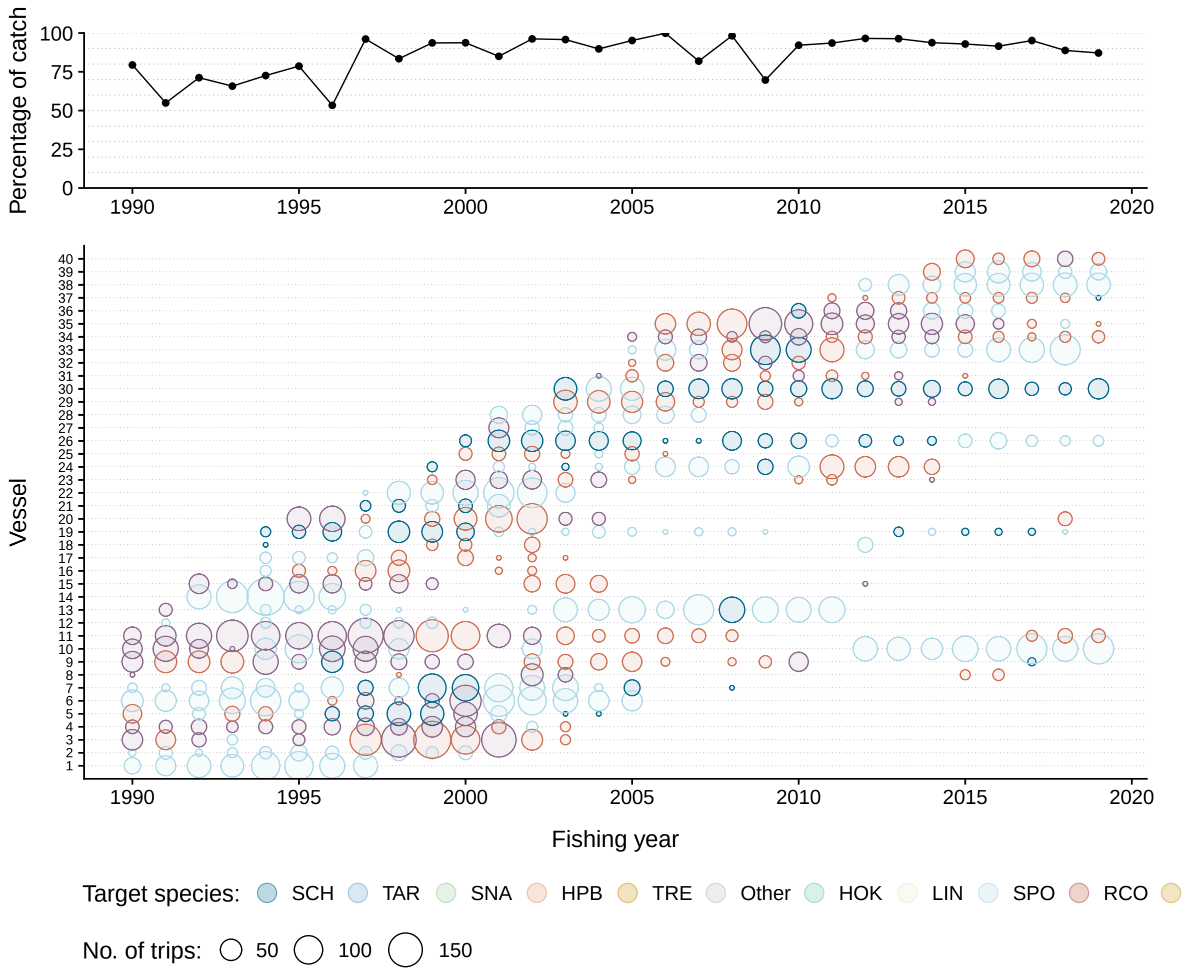

Figure G-39: Proportion of school shark catch retained by the core fleet in SCH 2/3 SN daily (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

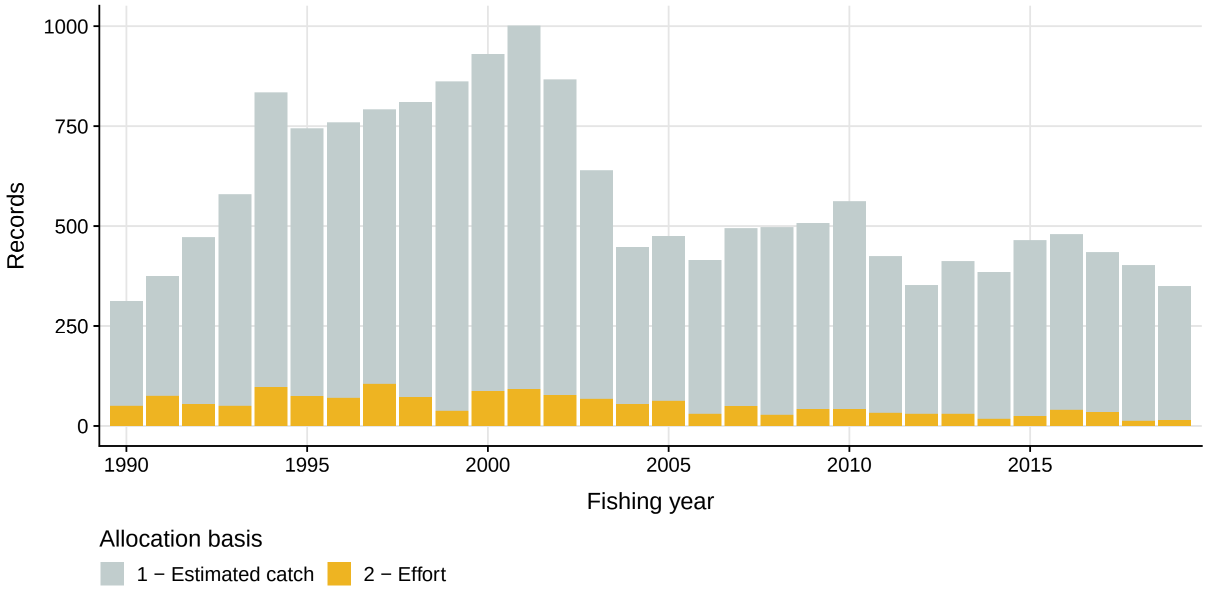

Figure G-40: Number of records by fishing year for the core fleet in SCH 2/3 SN daily. Records with landings allocated based on estimated catch are highlighted in yellow.

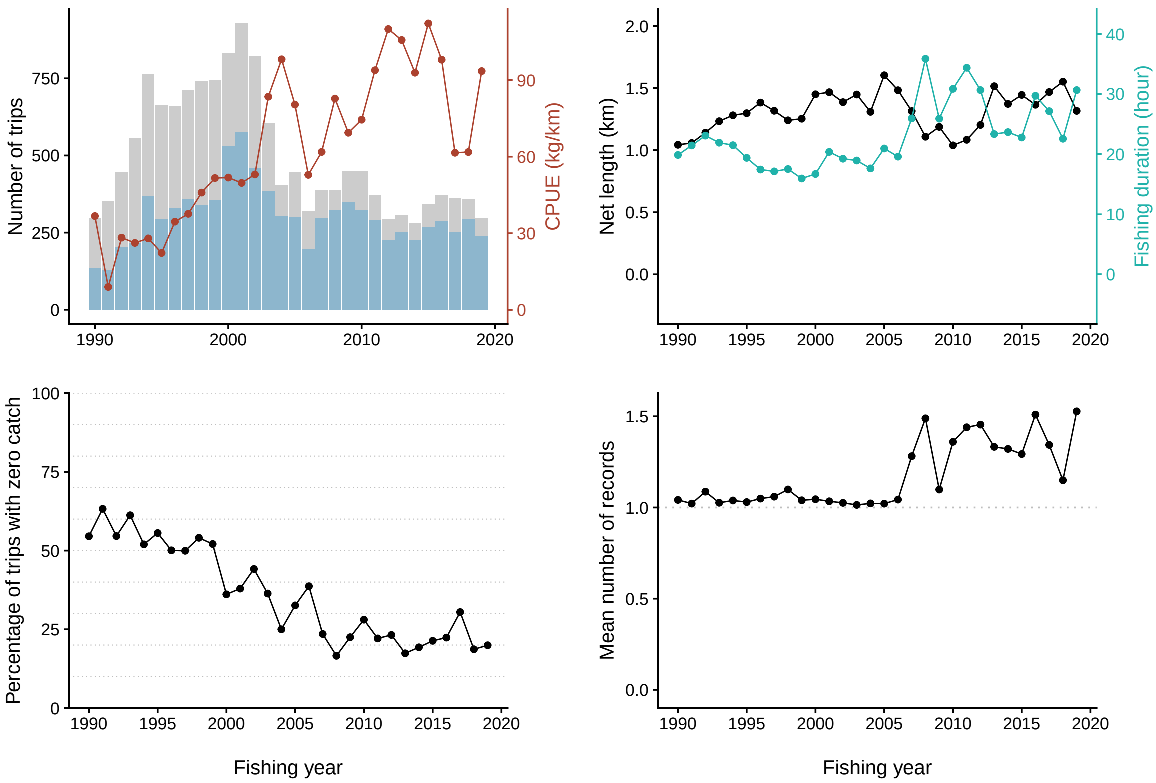

Figure G-41: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 2/3 SN daily, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all daily records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the daily resolution over time.

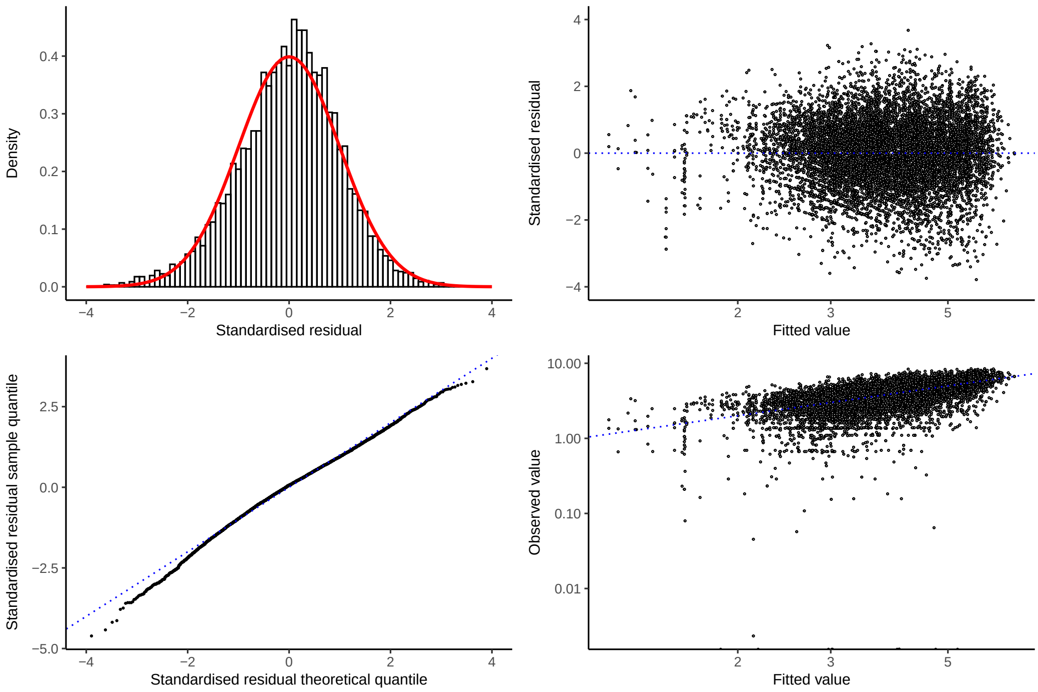

Figure G-42: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 2/3 SN daily: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-18: Summary of stepwise selection for binomial occurrence model for SCH 2/3 SN daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	21840	5.20	5.20	*
+ vessel_key	39.00	17546	24.20	19.00	*
+ month	11.00	16127	30.50	6.30	*
+ target_species	3.00	15930	31.40	0.90	
+ ns(log(total_net_length), 3)	3.00	15782	32.10	0.70	
+ stat_area	5.00	15688	32.50	0.50	

Table G-19: Summary of stepwise selection for positive catch model for SCH 2/3 SN daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	36399	8.30	8.30	*
+ vessel_key	39.00	33508	31.30	23.10	*
+ month	11.00	32859	35.70	4.30	*
+ ns(log(total_net_length), 3)	3.00	32319	39.00	3.30	*
+ target_species	3.00	31812	42.00	3.00	*
+ stat_area	5.00	31696	42.70	0.70	

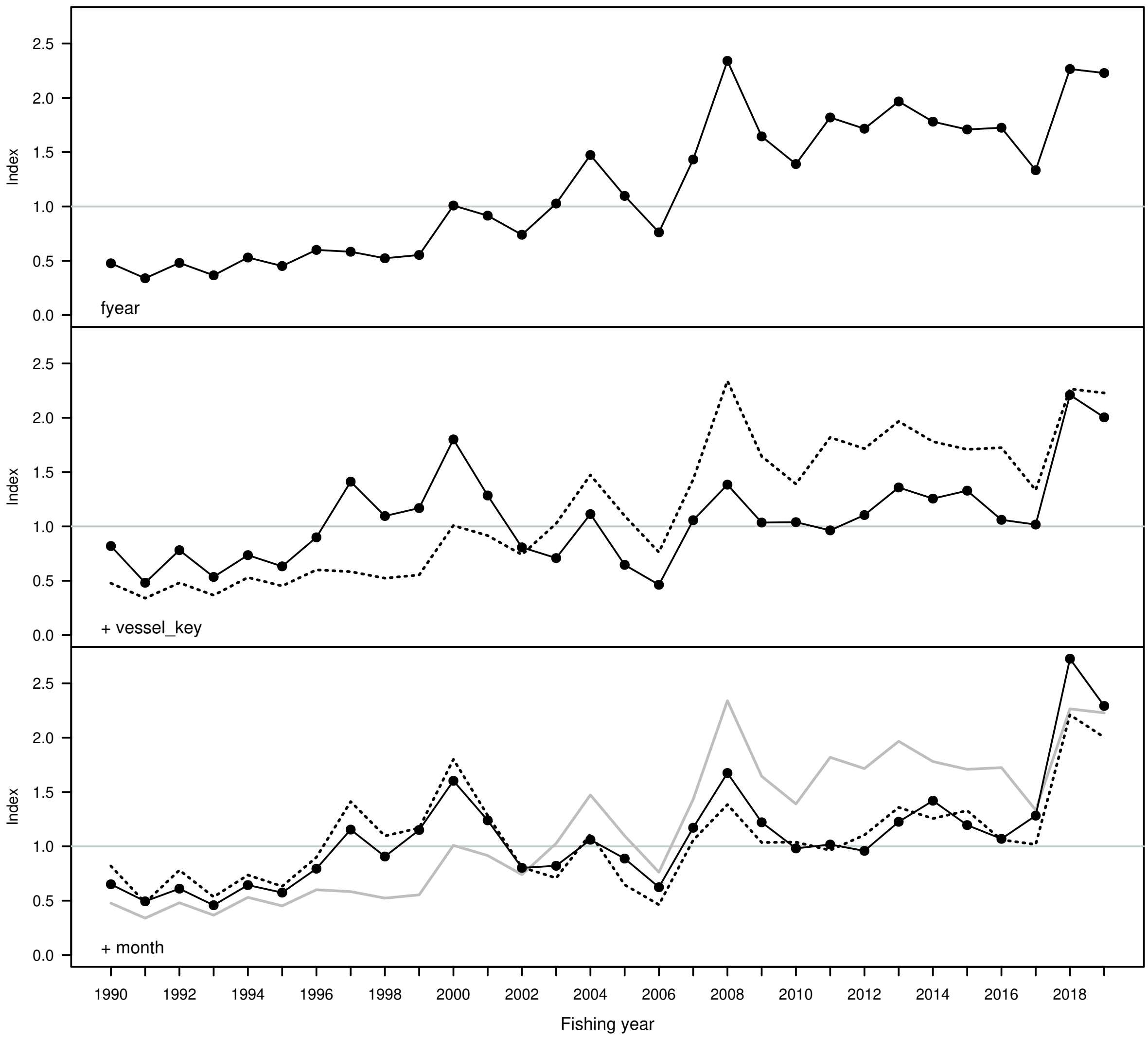

Figure G-43: Stepwise plot for the binomial occurrence model for SCH 2/3 SN daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

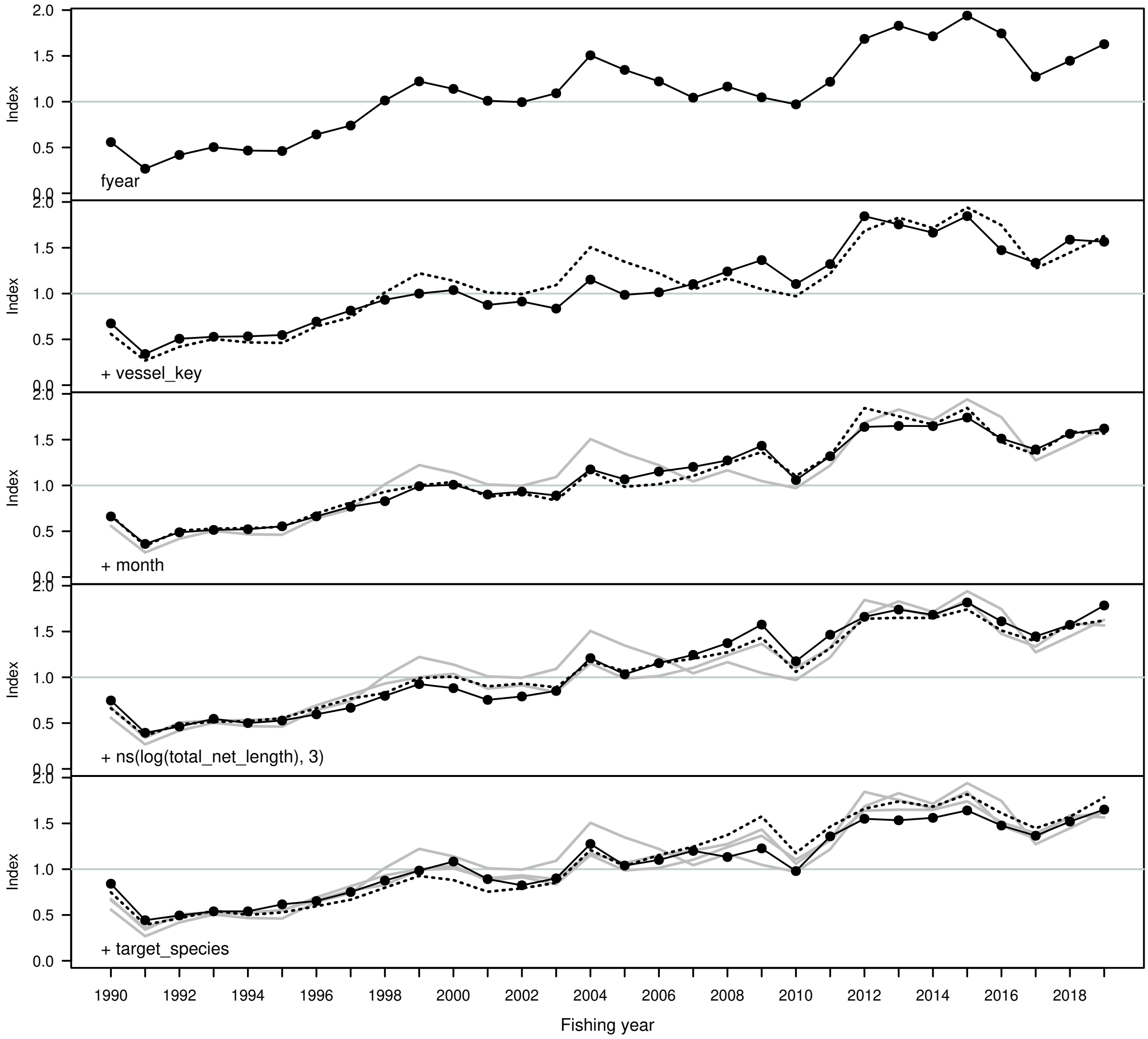

Figure G-44: Stepwise plot for the positive lognormal model for SCH 2/3 SN daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

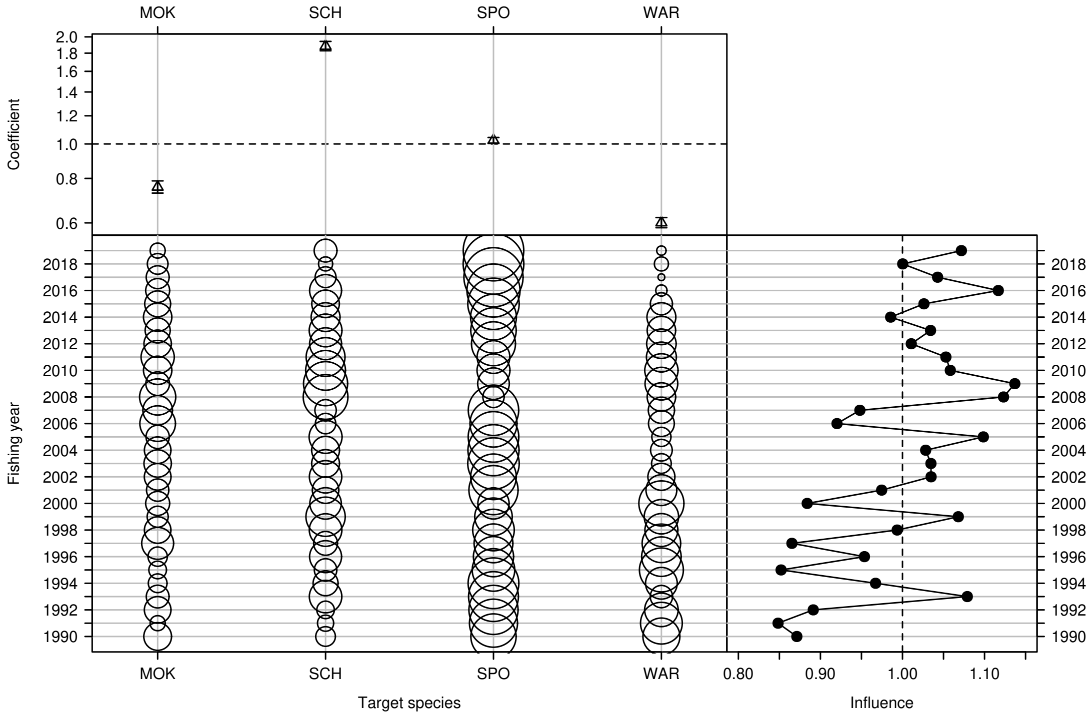

Figure G-45: Influence plot for target species for the lognormal model of school shark in SCH 2/3 SN daily, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

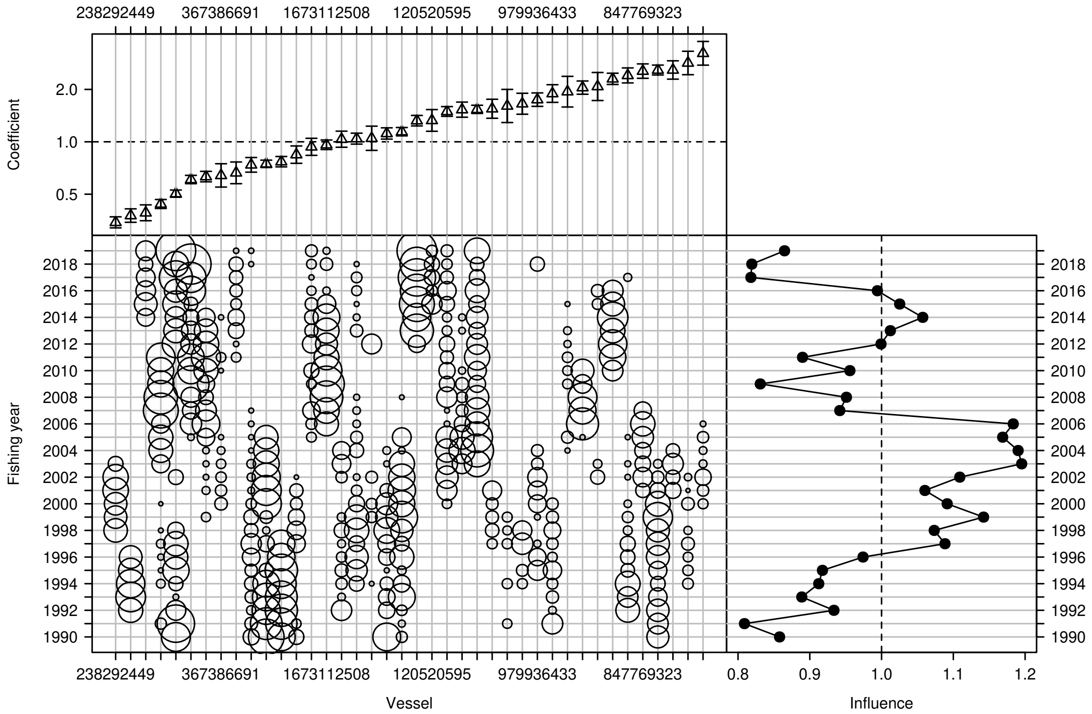

Figure G-46: Influence plot for vessel for the lognormal model of school shark in SCH 2/3 SN daily, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

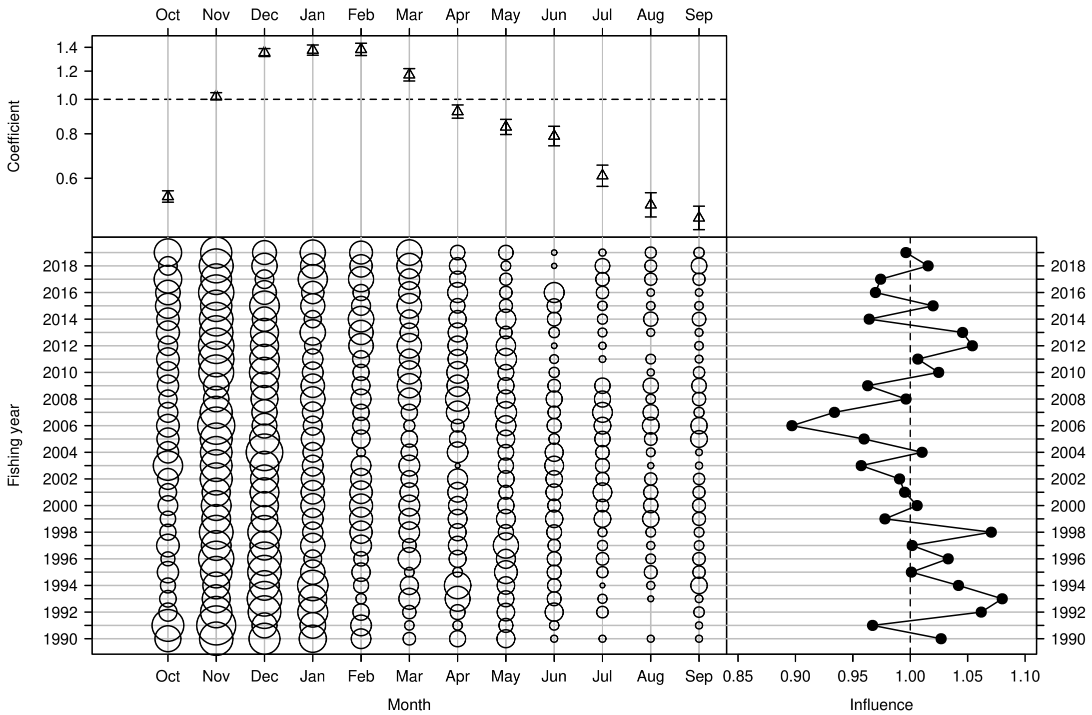

Figure G-47: Influence plot for month for the lognormal model of school shark in SCH 2/3 SN daily, showing model coefficients for each month (top panel), the distribution of observations over time across each month (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

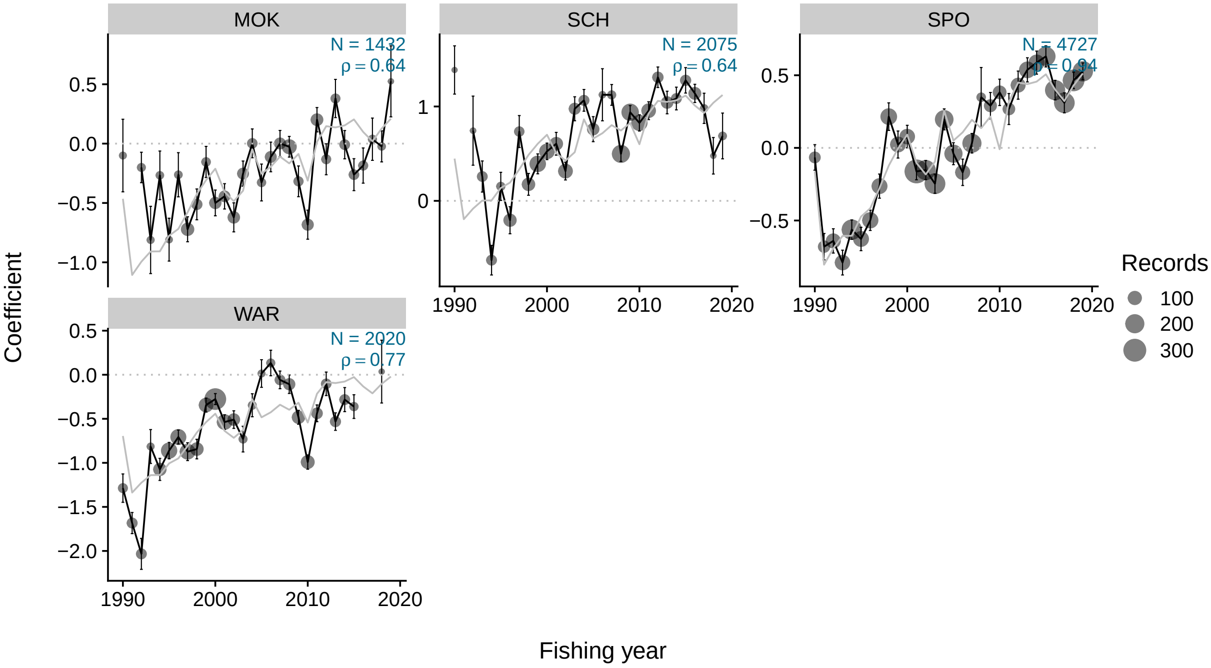

Figure G-48: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 2/3 SN daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

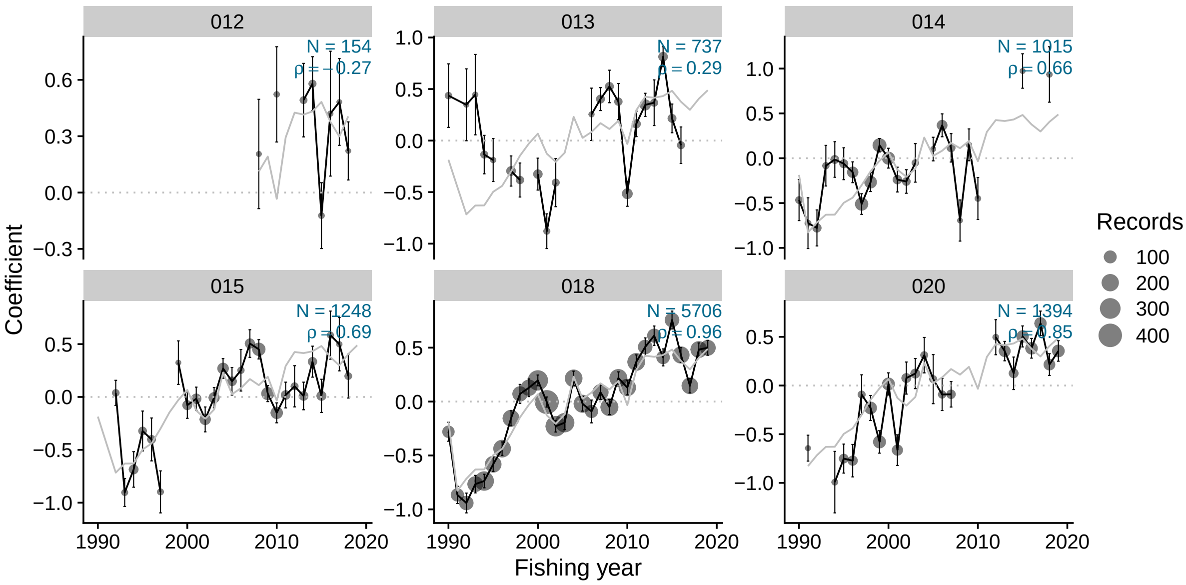

Figure G-49: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 2/3 SN daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-20: Standardised binomial, positive (lognormal) and combined indices for SCH 2/3 SN daily, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5^{th}	97.5^{th}
1990	0.825	0.848	0.699	0.538	0.869
1991	0.704	0.448	0.315	0.241	0.407
1992	0.797	0.496	0.395	0.309	0.480
1993	0.672	0.540	0.363	0.285	0.457
1994	0.819	0.541	0.443	0.364	0.527
1995	0.766	0.617	0.473	0.384	0.562
1996	0.916	0.656	0.601	0.507	0.701
1997	1.087	0.754	0.819	0.701	0.946
1998	0.976	0.876	0.855	0.723	0.988
1999	1.087	0.987	1.072	0.918	1.247
2000	1.226	1.085	1.330	1.166	1.517
2001	1.117	0.893	0.998	0.856	1.154
2002	0.918	0.823	0.756	0.641	0.872
2003	0.934	0.902	0.842	0.711	0.984
2004	1.046	1.274	1.332	1.120	1.574
2005	0.969	1.043	1.010	0.836	1.208
2006	0.808	1.108	0.895	0.704	1.104
2007	1.094	1.205	1.318	1.109	1.564
2008	1.247	1.137	1.418	1.187	1.675
2009	1.113	1.231	1.370	1.144	1.607
2010	1.015	0.979	0.994	0.841	1.177
2011	1.025	1.360	1.394	1.157	1.659
2012	1.002	1.555	1.558	1.267	1.888
2013	1.113	1.537	1.711	1.438	2.027
2014	1.176	1.566	1.842	1.519	2.187
2015	1.103	1.642	1.812	1.518	2.132
2016	1.053	1.479	1.556	1.303	1.835
2017	1.134	1.369	1.552	1.302	1.858
2018	1.431	1.522	2.178	1.772	2.678
2019	1.368	1.654	2.264	1.843	2.803

G.5 SCH 2 & top of SCH 3 bottom longline (daily effort)

Table G-21: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 2/3 BLL daily.

Variable	Value
Label	BLL23_daily
Forms	CEL, LCE, ERS - Lining, LTC
Period	1989-10-01 to 2019-09-30
Resolution	Daily
Core fleet (min years)	4
Core fleet (min trips)	3
Target species	LIN, BNS, SCH, HPB
Statistical areas	011, 012, 013, 014, 015

Table G-22: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 2/3 BLL daily. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (1000 hooks)	Catch (t)	Positive rate
1990	5	45	94	96.8	3.56	29.79
1991	7	153	251	273.4	11.01	47.41
1992	11	237	404	535.6	18.72	43.56
1993	11	212	412	722.5	21.21	45.87
1994	11	205	393	794.9	29.70	46.82
1995	15	212	387	706.5	16.84	39.53
1996	14	152	327	692.7	38.71	41.59
1997	12	145	339	655.4	23.47	34.22
1998	12	178	383	729.2	18.99	42.82
1999	12	175	407	687.0	33.11	48.40
2000	14	172	424	993.5	31.51	38.21
2001	12	151	415	973.2	31.77	40.24
2002	14	122	376	791.9	30.44	36.97
2003	13	134	443	932.8	27.89	34.76
2004	14	139	489	1 160.7	26.34	38.04
2005	12	115	467	1 138.1	45.46	45.61
2006	16	142	586	1 667.3	46.42	37.37
2007	13	186	814	2 790.4	36.56	43.61
2008	14	180	725	3 088.8	49.92	38.21
2009	12	145	627	2 678.0	40.30	44.82
2010	16	182	831	3 409.5	63.21	44.77
2011	16	164	751	2 899.0	44.25	48.20
2012	18	165	770	2 630.9	39.05	36.88
2013	16	138	588	1 551.2	48.28	45.41
2014	19	186	767	1 888.3	34.13	38.85
2015	20	218	906	2 327.3	45.50	42.72
2016	18	183	757	2 133.1	40.73	37.91
2017	17	189	754	1 889.0	31.48	39.92
2018	16	184	752	1 937.1	33.88	36.70
2019	17	151	704	2 033.4	25.35	33.95

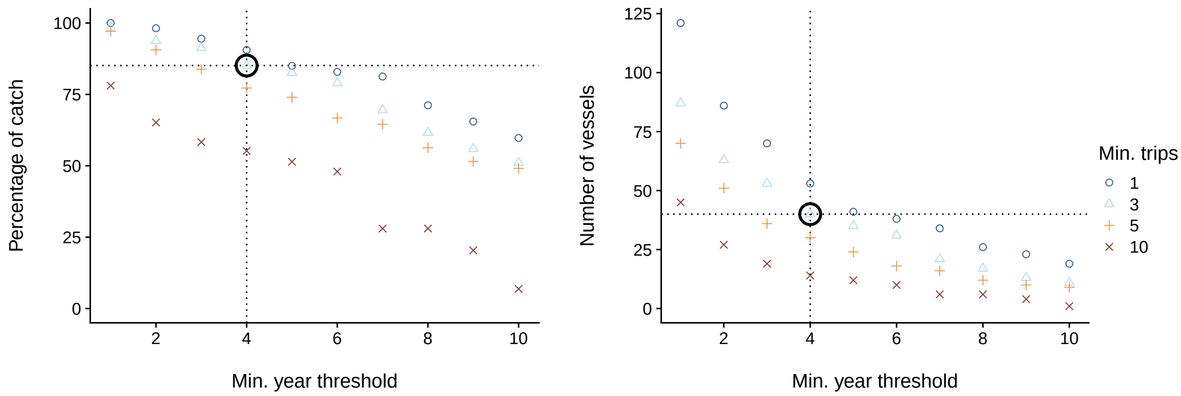

Figure G-50: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 2/3 BLL daily. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

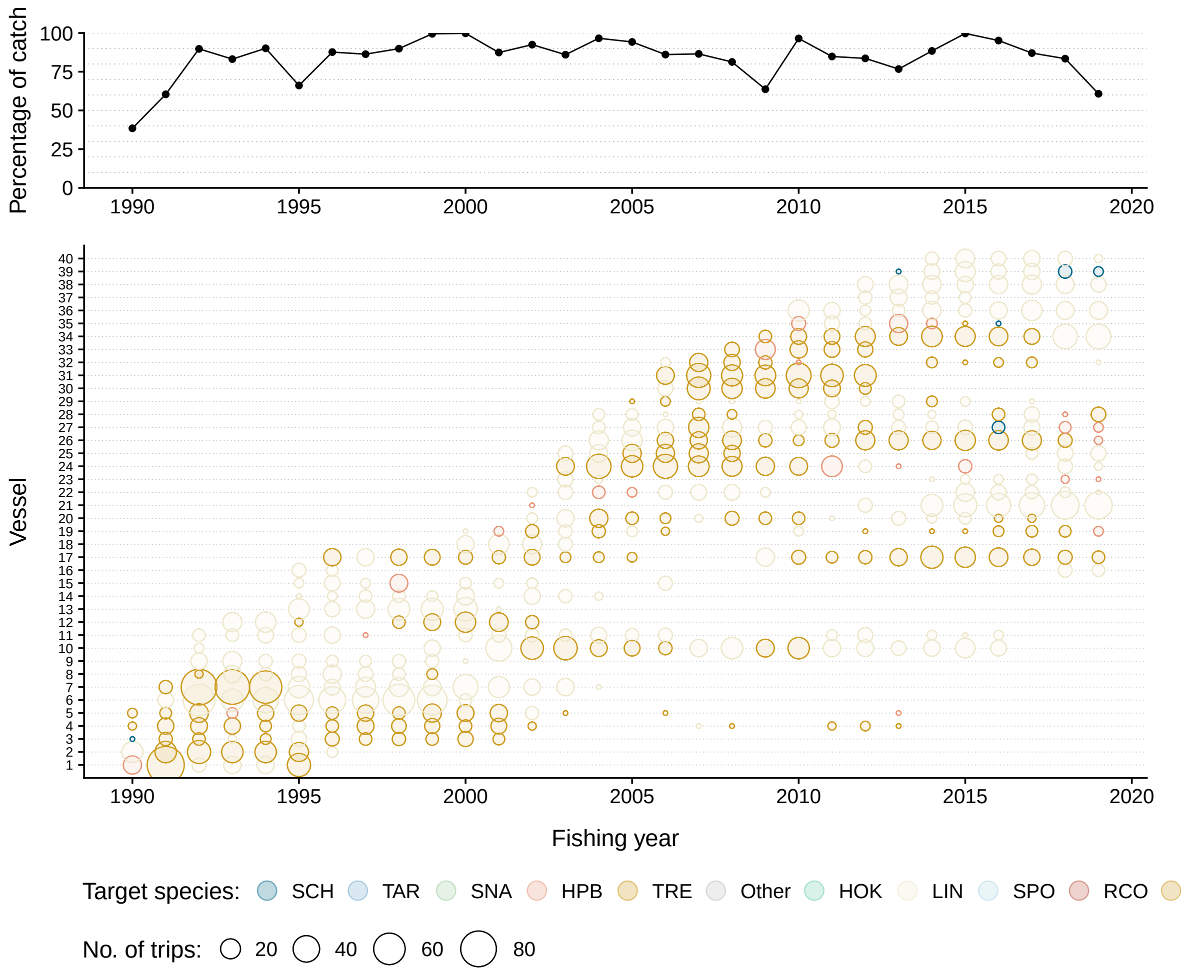

Figure G-51: Proportion of school shark catch retained by the core fleet in SCH 2/3 BLL daily (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

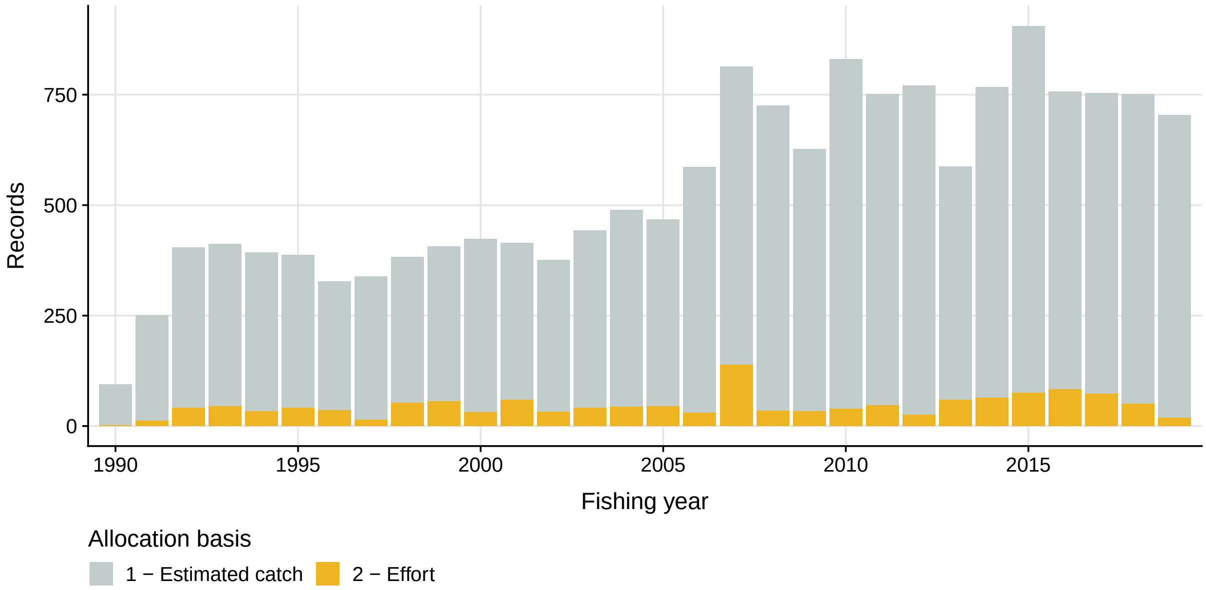

Figure G-52: Number of records by fishing year for the core fleet in SCH 2/3 BLL daily. Records with landings allocated based on estimated catch are highlighted in yellow.

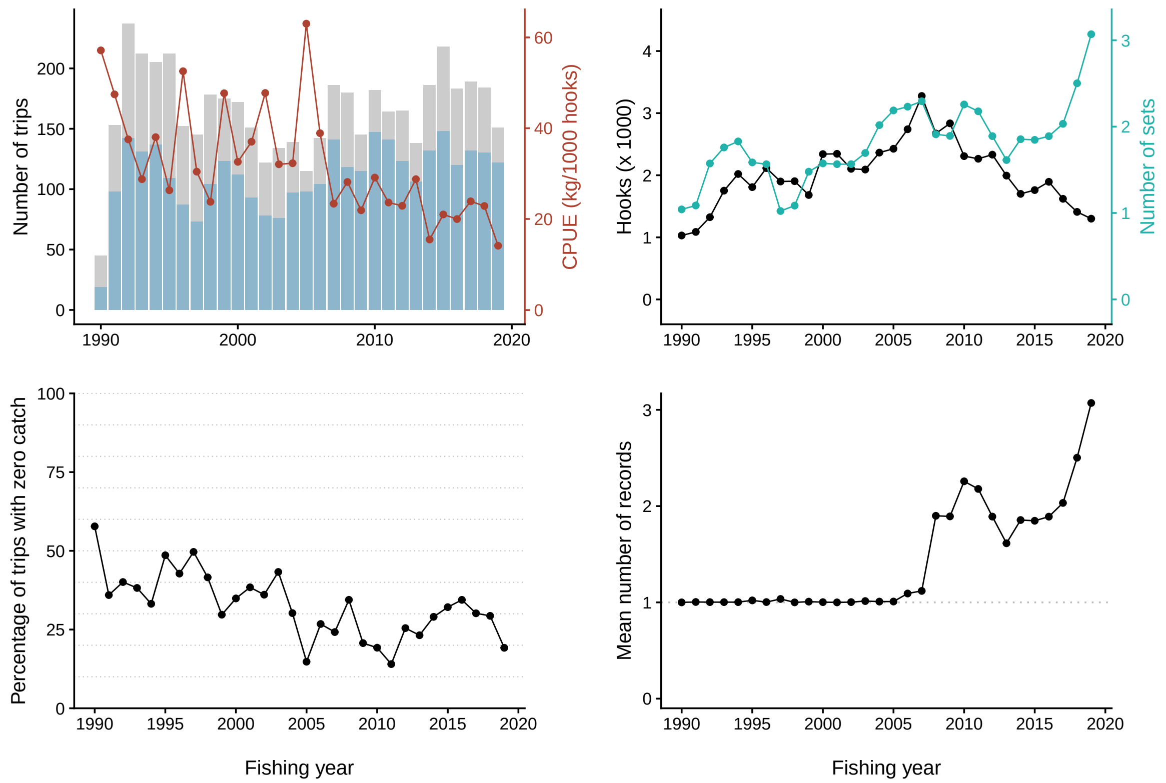

Figure G-53: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 2/3 BLL daily, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all daily records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the daily resolution over time.

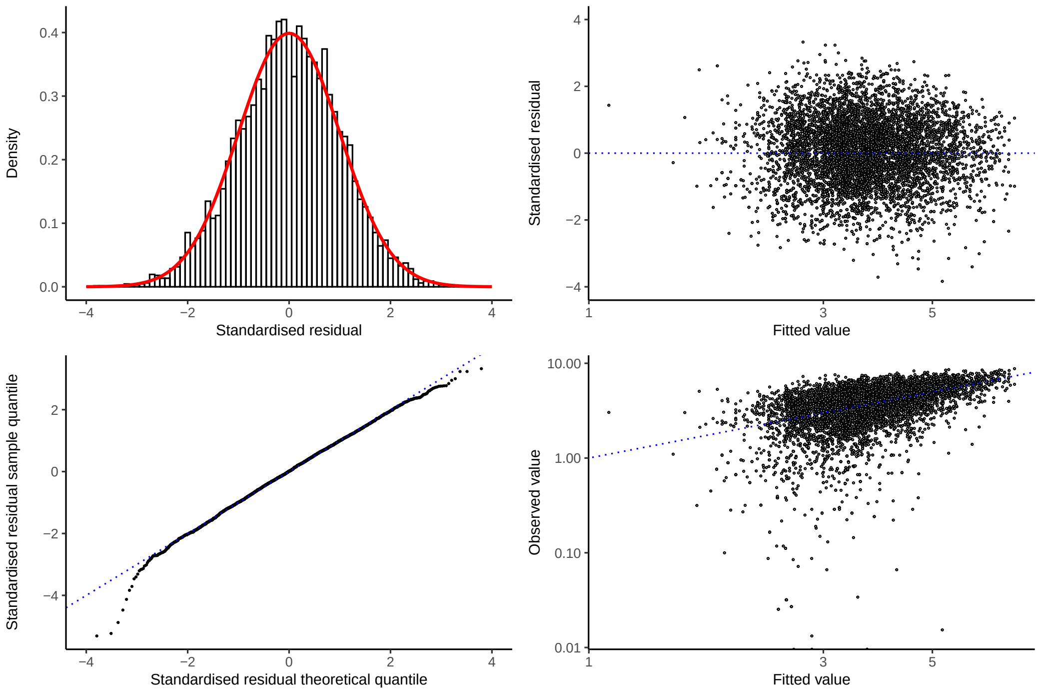

Figure G-54: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 2/3 BLL daily: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-23: Summary of stepwise selection for binomial occurrence model for SCH 2/3 BLL daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	22052	0.60	0.60	*
+ target_species	3.00	20312	8.40	7.90	*
+ vessel_key	39.00	19874	10.80	2.30	*
+ stat_area	4.00	19643	11.90	1.10	*
+ effort_num	1.00	19555	12.30	0.40	
+ month	11.00	19474	12.70	0.50	
+ ns(log(total_hook_num), 3)	3.00	19470	12.80	0.00	

Table G-24: Summary of stepwise selection for positive catch model for SCH 2/3 BLL daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	25471	2.40	2.40	*
+ target_species	3.00	23893	23.00	20.60	*
+ vessel_key	39.00	23630	26.80	3.80	*
+ stat_area	4.00	23354	29.80	3.10	*
+ ns(log(total_hook_num), 3)	3.00	23262	30.90	1.00	*
+ month	11.00	23203	31.70	0.80	

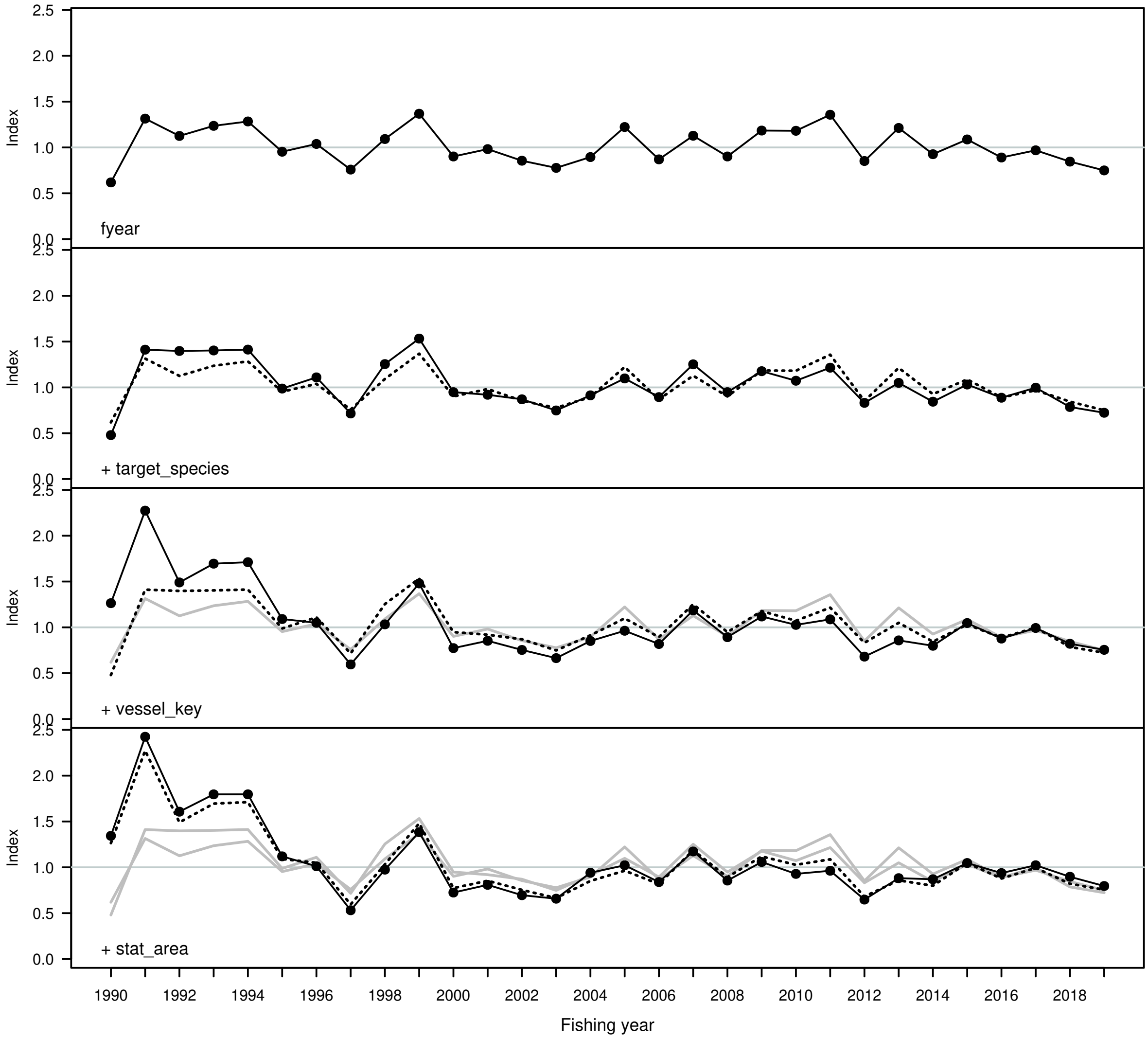

Figure G-55: Stepwise plot for the binomial occurrence model for SCH 2/3 BLL daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

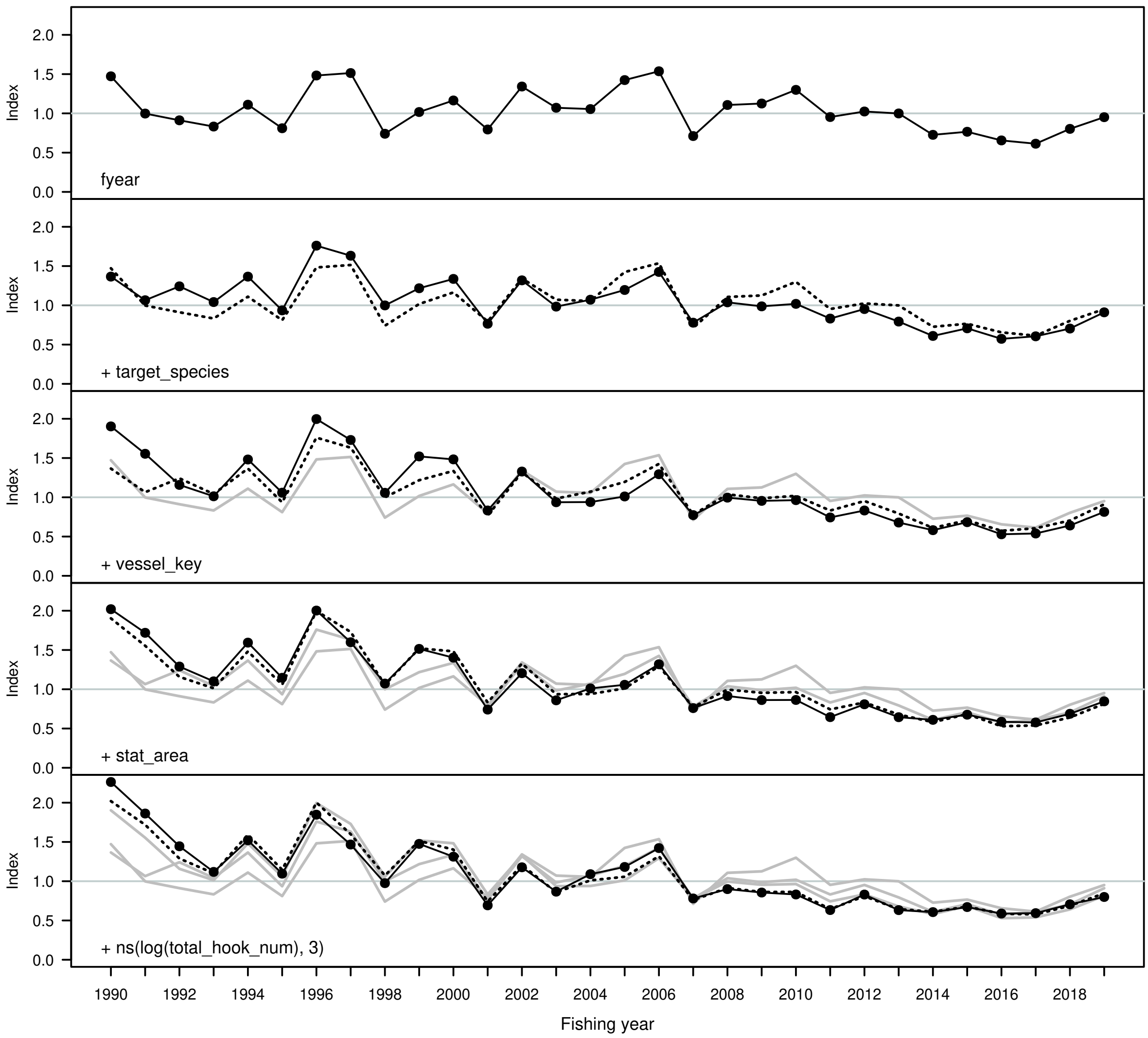

Figure G-56: Stepwise plot for the positive lognormal model for SCH 2/3 BLL daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

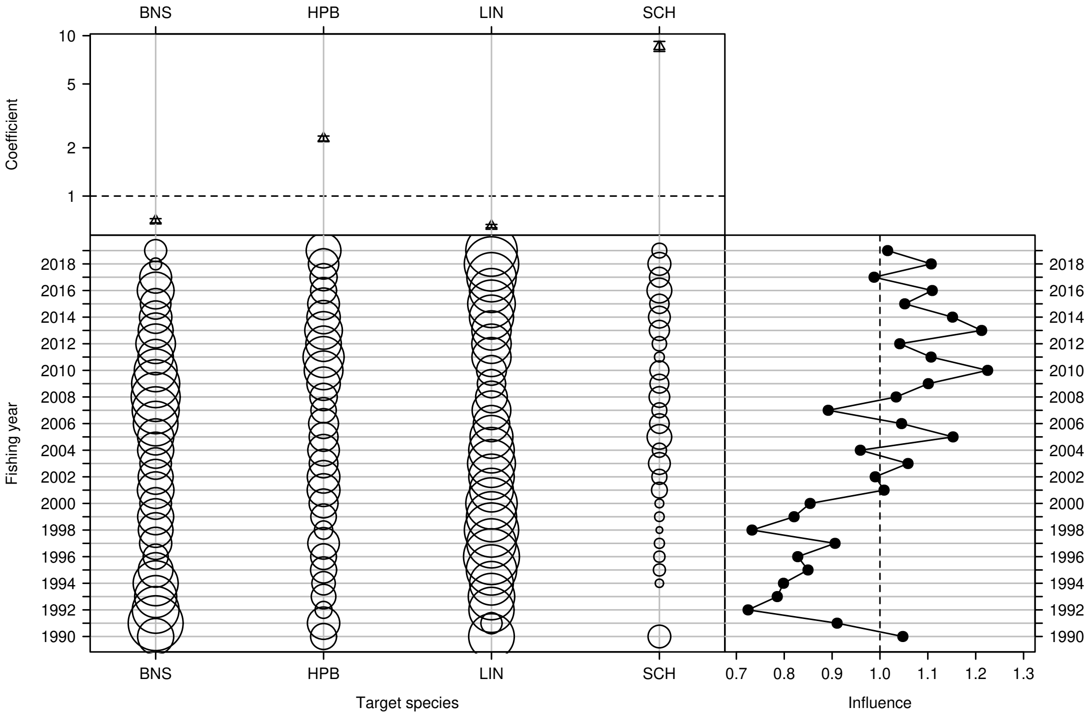

Figure G-57: Influence plot for target species for the lognormal model of school shark in SCH 2/3 BLL daily, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

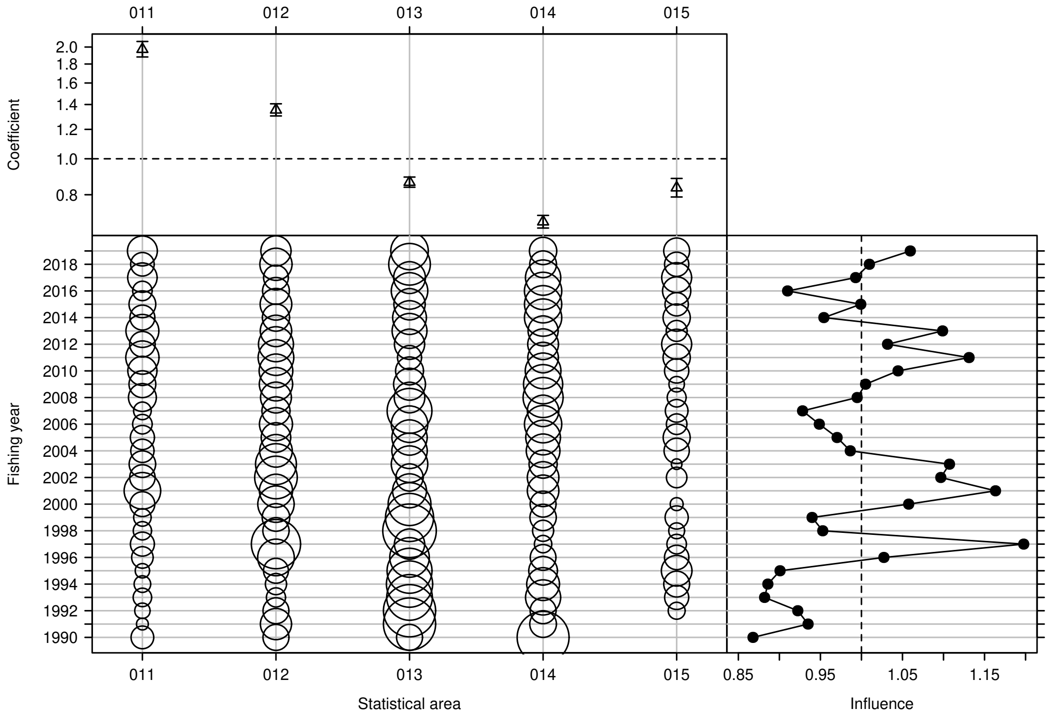

Figure G-58: Influence plot for statistical area for the lognormal model of school shark in SCH 2/3 BLL daily, showing model coefficients for each statistical area (top panel), the distribution of observations over time across each statistical area (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

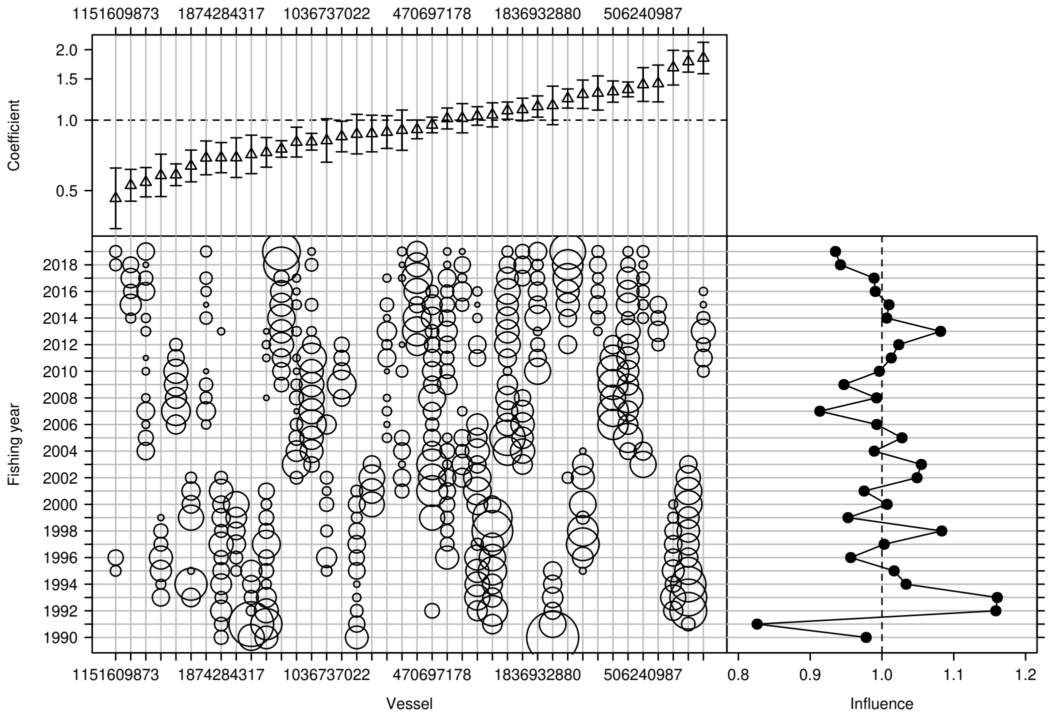

Figure G-59: Influence plot for vessel for the lognormal model of school shark in SCH 2/3 BLL daily, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

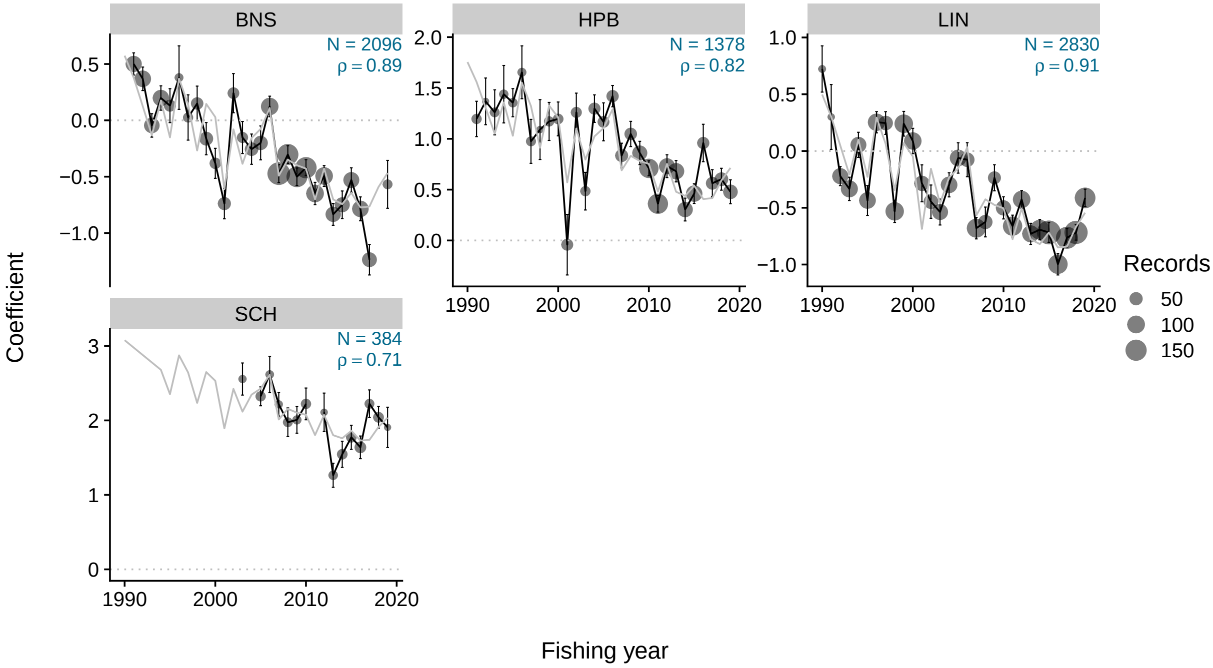

Figure G-60: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 2/3 BLL daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

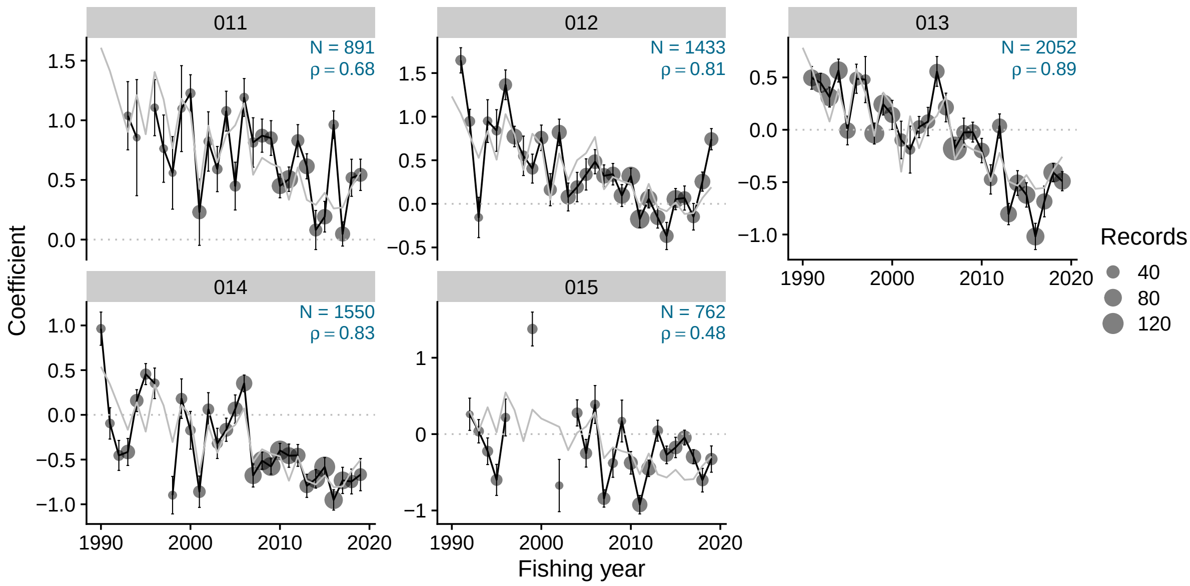

Figure G-61: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 2/3 BLL daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-25: Standardised binomial, positive (lognormal) and combined indices for SCH 2/3 BLL daily, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5th	97.5th
1990	1.262	2.338	2.948	1.406	5.373
1991	1.822	1.864	3.393	2.321	4.716
1992	1.415	1.453	2.056	1.550	2.695
1993	1.519	1.123	1.706	1.267	2.223
1994	1.522	1.528	2.325	1.746	3.080
1995	1.103	1.114	1.228	0.875	1.628
1996	1.023	1.865	1.908	1.394	2.553
1997	0.605	1.476	0.894	0.632	1.280
1998	0.991	0.986	0.978	0.716	1.320
1999	1.282	1.490	1.911	1.430	2.473
2000	0.784	1.326	1.040	0.736	1.396
2001	0.854	0.701	0.599	0.437	0.788
2002	0.765	1.190	0.911	0.667	1.235
2003	0.726	0.864	0.627	0.472	0.817
2004	0.967	1.098	1.061	0.808	1.349
2005	1.033	1.189	1.228	0.932	1.575
2006	0.890	1.424	1.267	0.990	1.616
2007	1.147	0.786	0.902	0.726	1.117
2008	0.898	0.903	0.811	0.648	1.009
2009	1.055	0.861	0.908	0.723	1.155
2010	0.962	0.837	0.805	0.648	0.999
2011	0.985	0.636	0.626	0.495	0.772
2012	0.720	0.834	0.601	0.469	0.749
2013	0.924	0.634	0.586	0.450	0.746
2014	0.917	0.610	0.560	0.443	0.703
2015	1.049	0.672	0.705	0.566	0.860
2016	0.965	0.593	0.572	0.452	0.715
2017	1.035	0.596	0.617	0.486	0.765
2018	0.934	0.709	0.662	0.512	0.828
2019	0.850	0.805	0.684	0.533	0.863

G.6 SCH 2 & top of SCH 3 bottom trawl (trip effort)

Table G-26: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 2/3 BT trip.

Variable	Value
Label	BT23_trip
Forms	CEL, TCP, TCE, ERS - Trawl
Period	1989-10-01 to 2019-09-30
Resolution	Trip
Core fleet (min years)	5
Core fleet (min trips)	5
Target species	TAR, GUR, BAR, RCO, HOK, SKI
Statistical areas	011, 012, 013, 014, 015, 018, 020

Table G-27: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 2/3 BT trip. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (tows)	Catch (t)	Positive rate
1990	30	913	913	4 877	30.46	41.84
1991	32	1 089	1 089	6 438	31.82	43.62
1992	39	1 366	1 366	7 552	24.03	35.51
1993	40	1 629	1 629	8 409	46.17	42.73
1994	41	1 771	1 771	8 547	44.97	35.23
1995	44	1 778	1 778	8 177	42.45	41.11
1996	41	1 518	1 518	6 987	45.96	45.52
1997	41	1 530	1 530	7 342	48.29	43.73
1998	41	1 705	1 705	8 300	57.27	48.39
1999	39	1 333	1 333	7 335	47.00	56.64
2000	35	1 296	1 296	7 207	53.60	60.26
2001	40	1 452	1 452	8 215	59.76	54.48
2002	37	1 348	1 348	7 716	48.95	51.56
2003	33	1 268	1 268	7 972	62.64	58.04
2004	33	1 166	1 166	6 776	55.64	58.40
2005	33	1 298	1 298	8 434	68.49	55.55
2006	35	1 219	1 219	7 878	55.24	54.14
2007	31	1 195	1 195	8 194	83.15	59.16
2008	31	875	875	6 278	48.78	58.97
2009	32	941	941	6 855	51.37	60.68
2010	32	1 073	1 073	7 833	49.15	62.26
2011	28	928	928	7 296	48.82	65.19
2012	28	913	913	6 565	43.01	59.91
2013	24	800	800	6 165	35.30	57.50
2014	27	819	819	6 737	46.65	60.44
2015	27	801	801	6 267	38.03	55.68
2016	24	714	714	4 793	37.73	57.84
2017	21	695	695	5 036	34.53	58.71
2018	21	680	680	4 858	39.37	60.29
2019	22	692	692	4 828	43.32	63.01

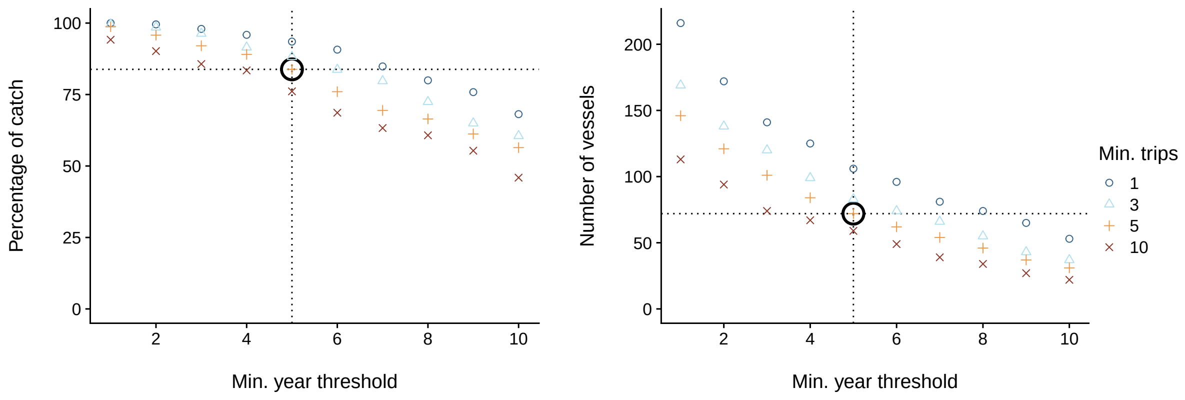

Figure G-62: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 2/3 BT trip. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

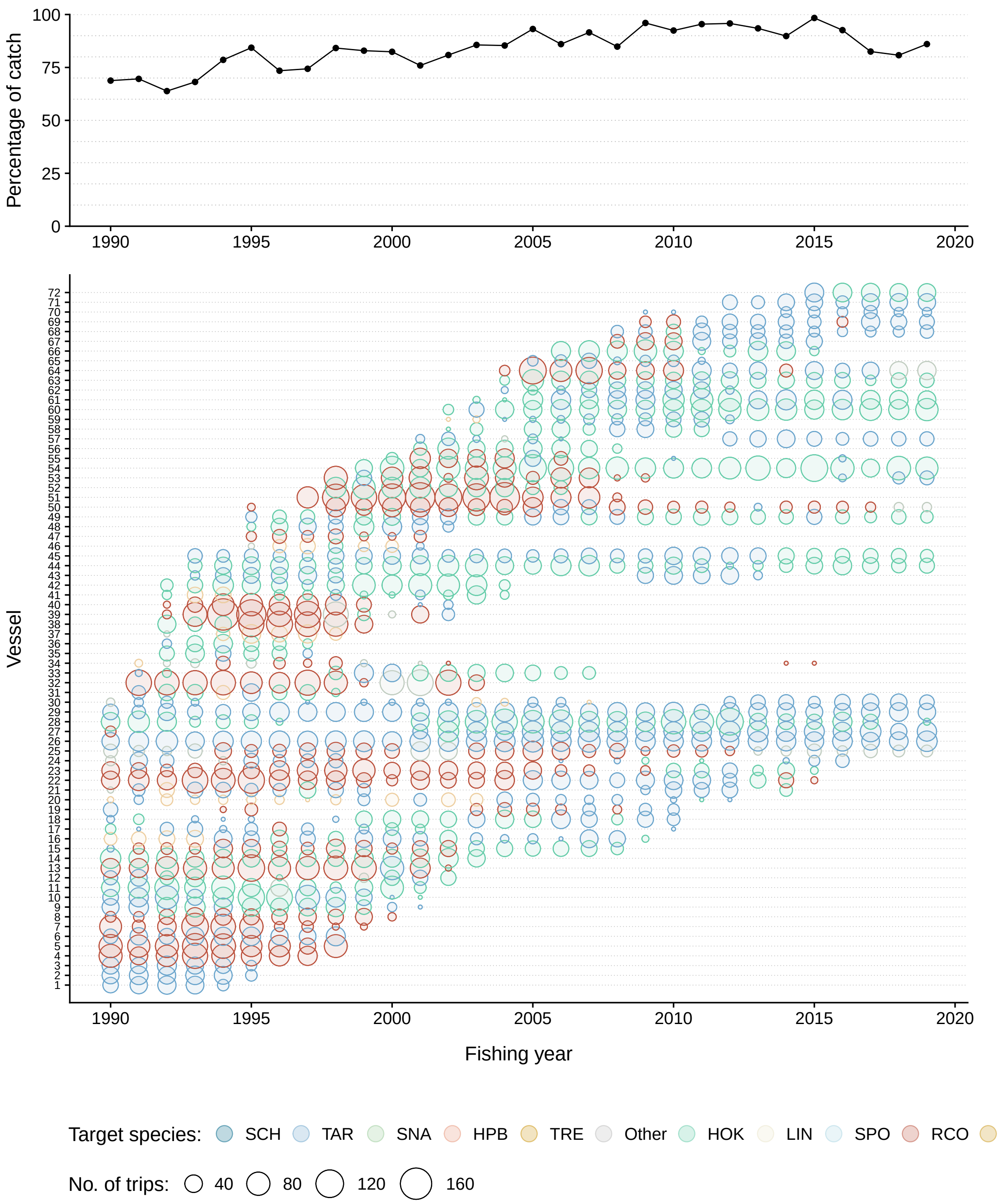

Figure G-63: Proportion of school shark catch retained by the core fleet in SCH 2/3 BT trip (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

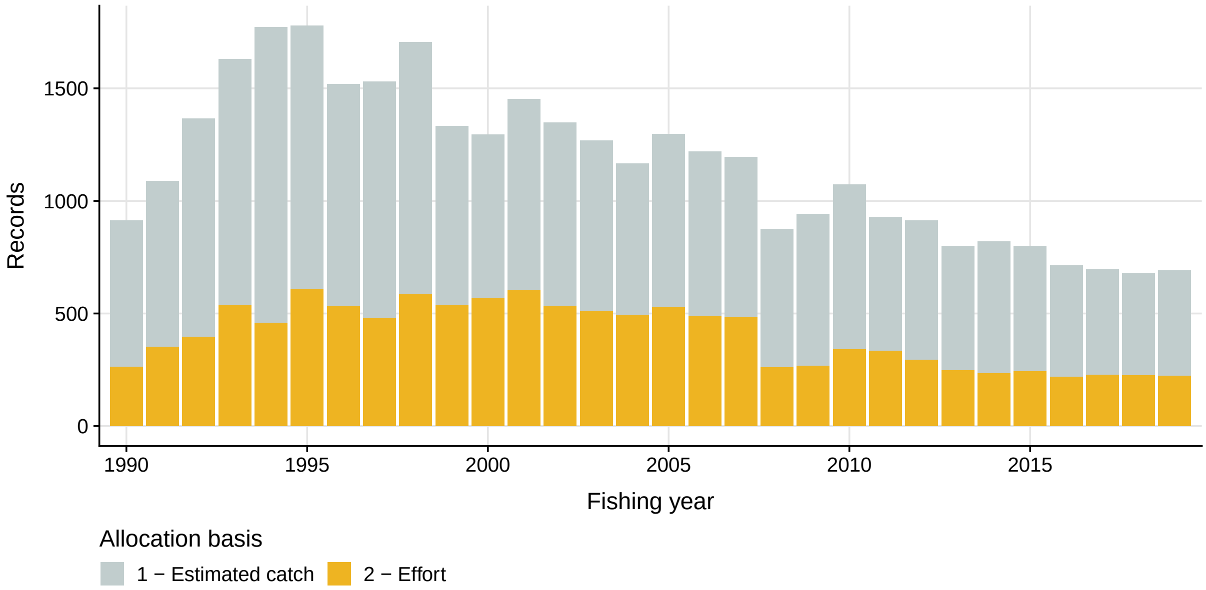

Figure G-64: Number of records by fishing year for the core fleet in SCH 2/3 BT trip. Records with landings allocated based on estimated catch are highlighted in yellow.

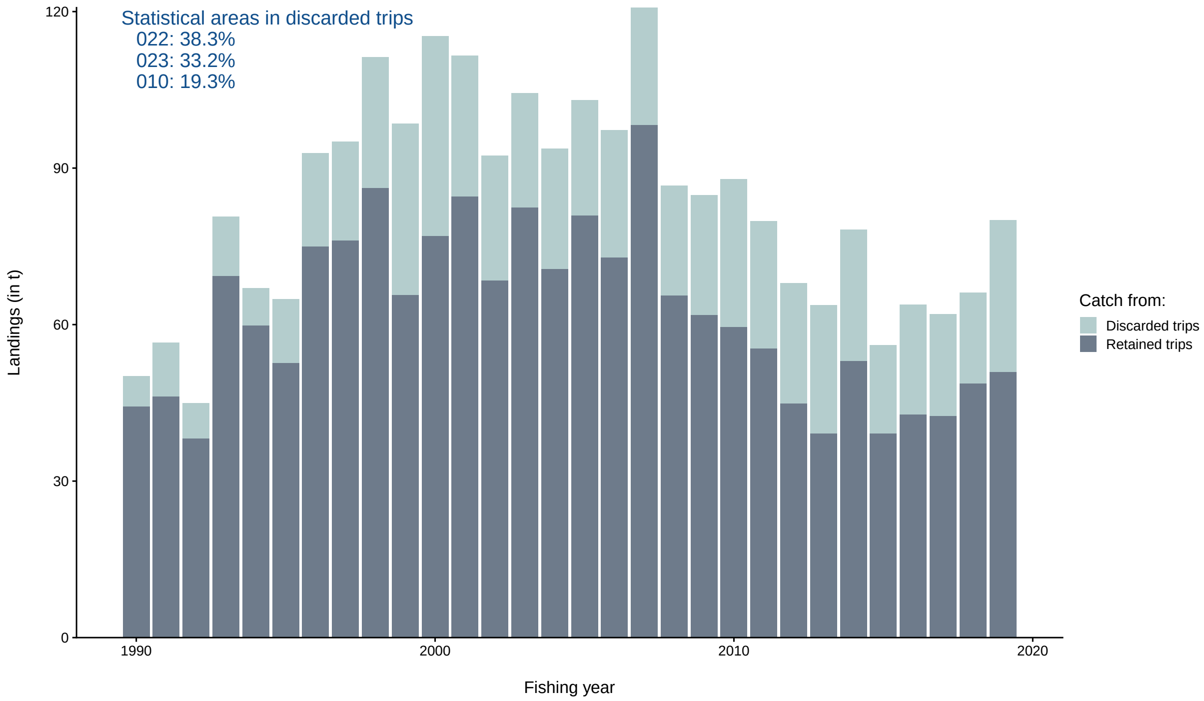

Figure G-65: Total landings and landings retained in the analysis for SCH 2/3 BT trip for the full fleet following data preparation to remove trips spanning multiple catch-per-unit-effort (CPUE) units. The top three statistical areas most often present in the omitted trips are noted in the top-left corner, including the corresponding proportion of discarded trips.

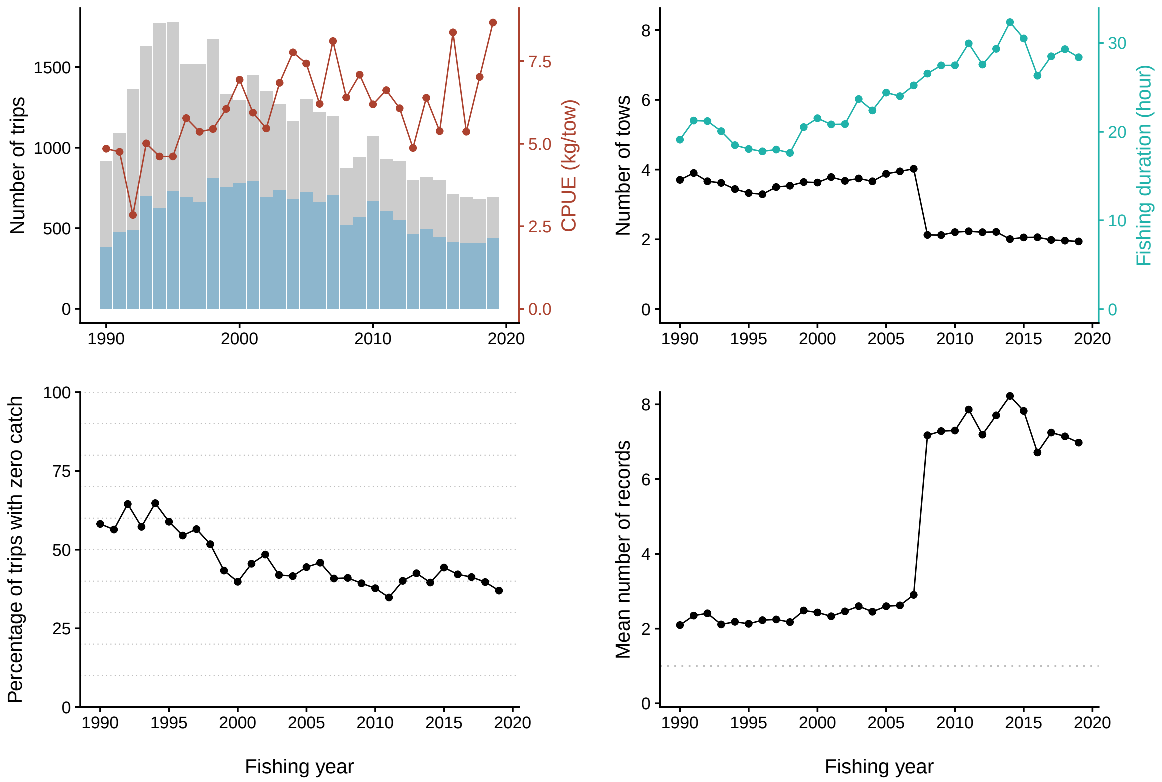

Figure G-66: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 2/3 BT trip, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all trip records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the trip resolution over time.

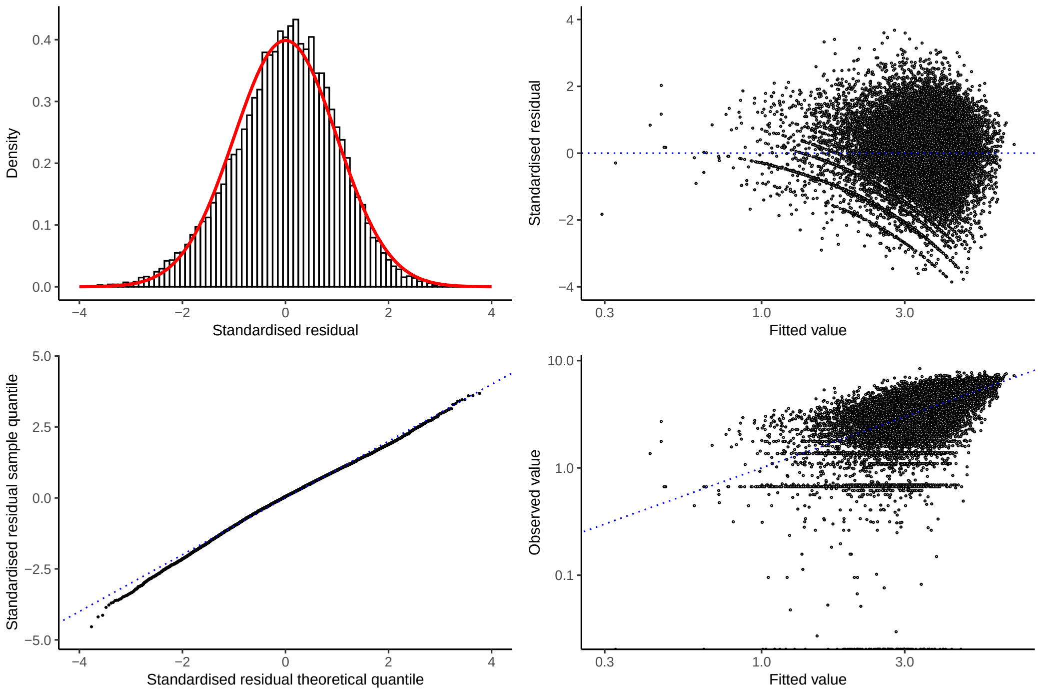

Figure G-67: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 2/3 BT trip: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-28: Summary of stepwise selection for binomial occurrence model for SCH 2/3 BT trip. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	47203	2.20	2.20	*
+ vessel_key	71.00	37515	22.60	20.40	*
+ ns(log(fishing_duration), 3)	3.00	34942	27.90	5.40	*
+ month	11.00	34017	29.90	2.00	*
+ target_species	5.00	33625	30.70	0.80	
+ stat_area	6.00	33399	31.20	0.50	
+ effort_num	1.00	33389	31.30	0.00	

Table G-29: Summary of stepwise selection for positive catch model for SCH 2/3 BT trip. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	64307	1.10	1.10	*
+ vessel_key	71.00	59571	24.50	23.40	*
+ ns(log(fishing_duration), 3)	3.00	56915	34.80	10.30	*
+ month	11.00	55844	38.70	3.80	*
+ target_species	5.00	55502	39.80	1.20	*
+ stat_area	6.00	55321	40.50	0.60	

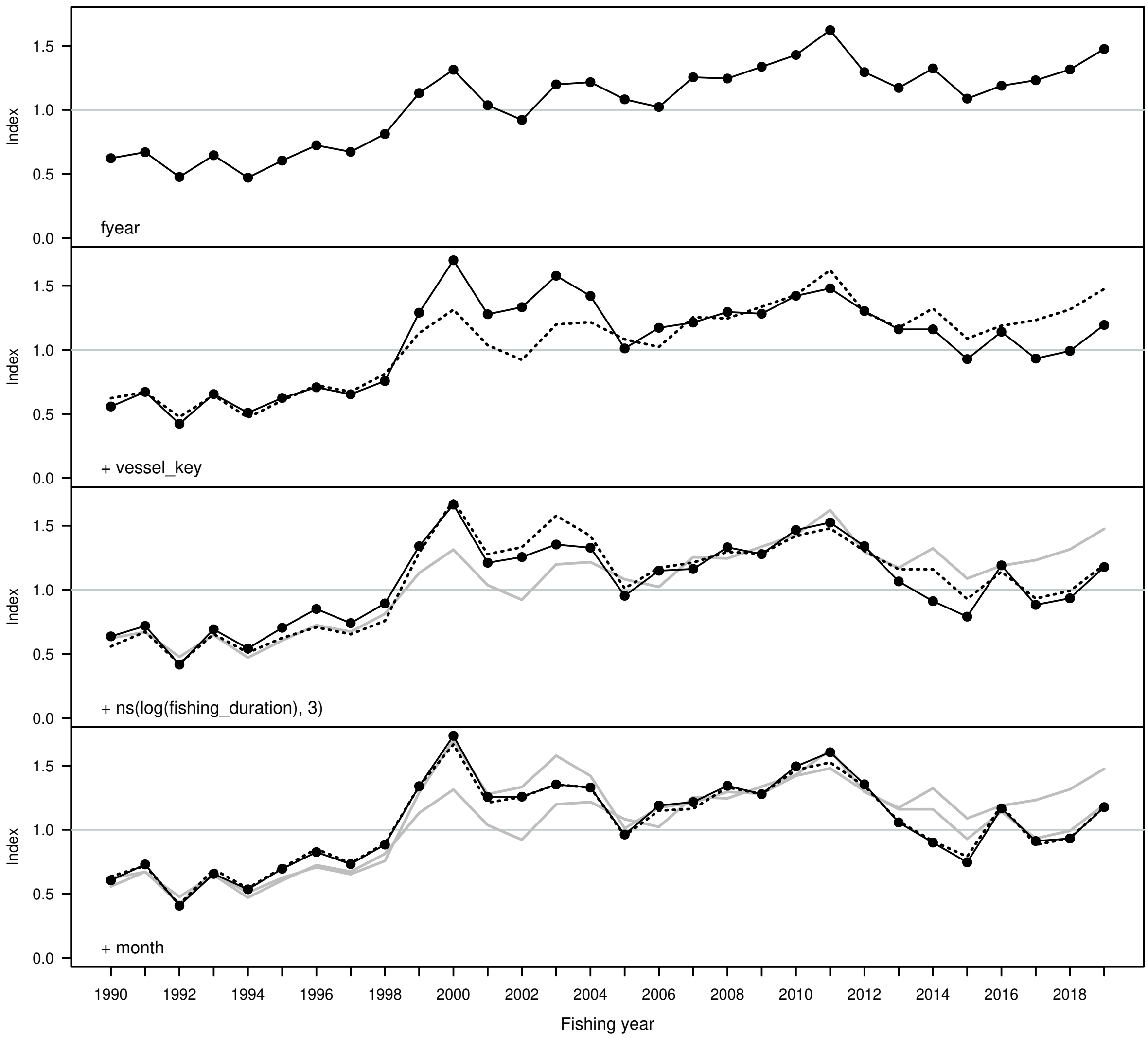

Figure G-68: Stepwise plot for the binomial occurrence model for SCH 2/3 BT trip showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

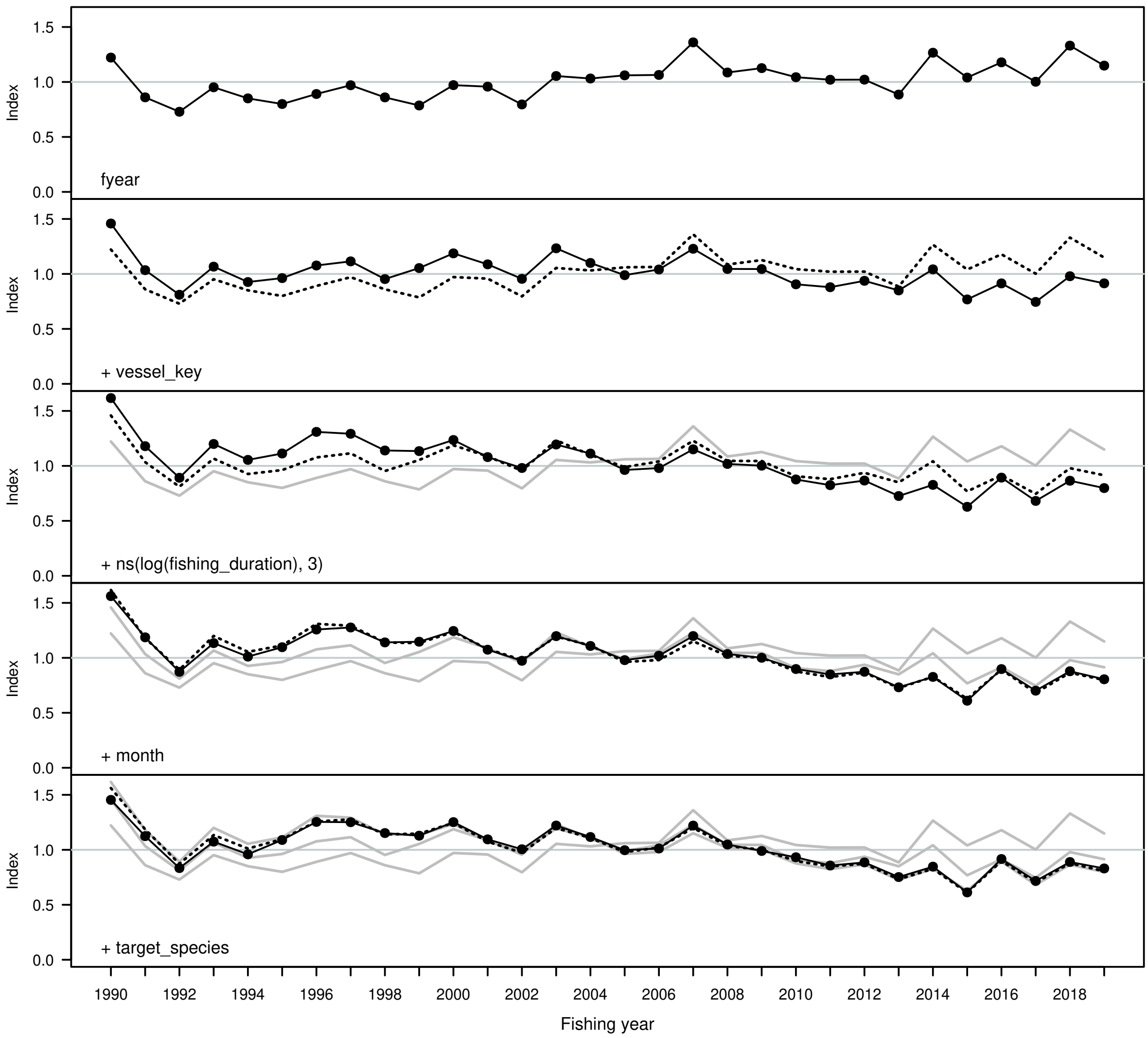

Figure G-69: Stepwise plot for the positive lognormal model for SCH 2/3 BT trip showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

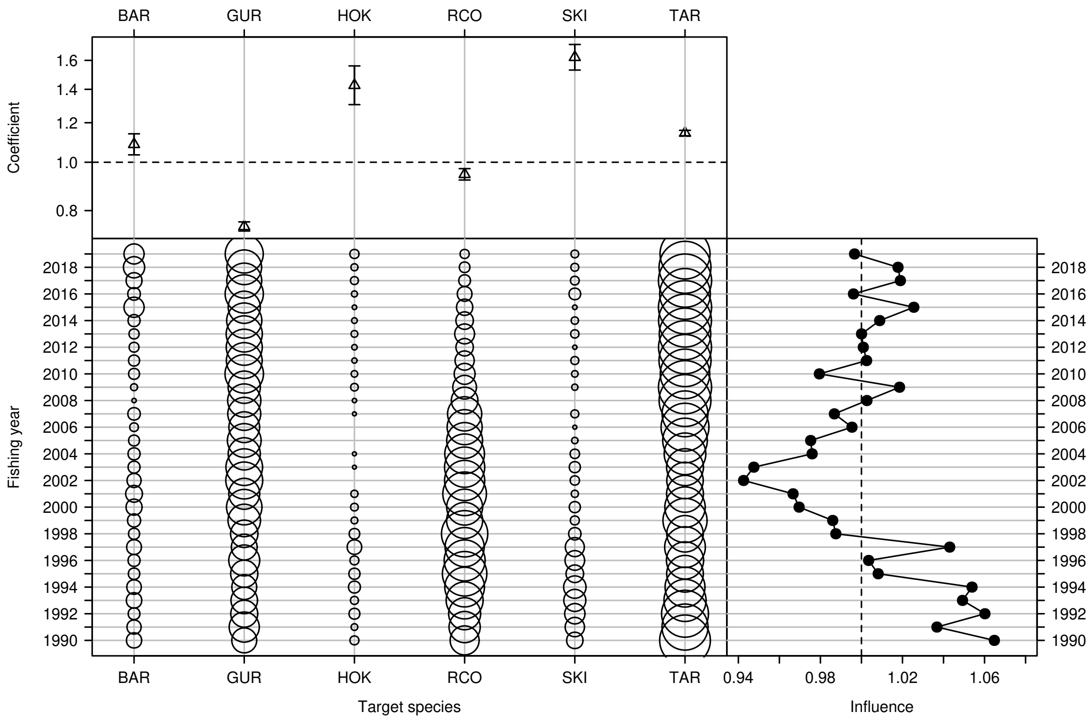

Figure G-70: Influence plot for target species for the lognormal model of school shark in SCH 2/3 BT trip, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

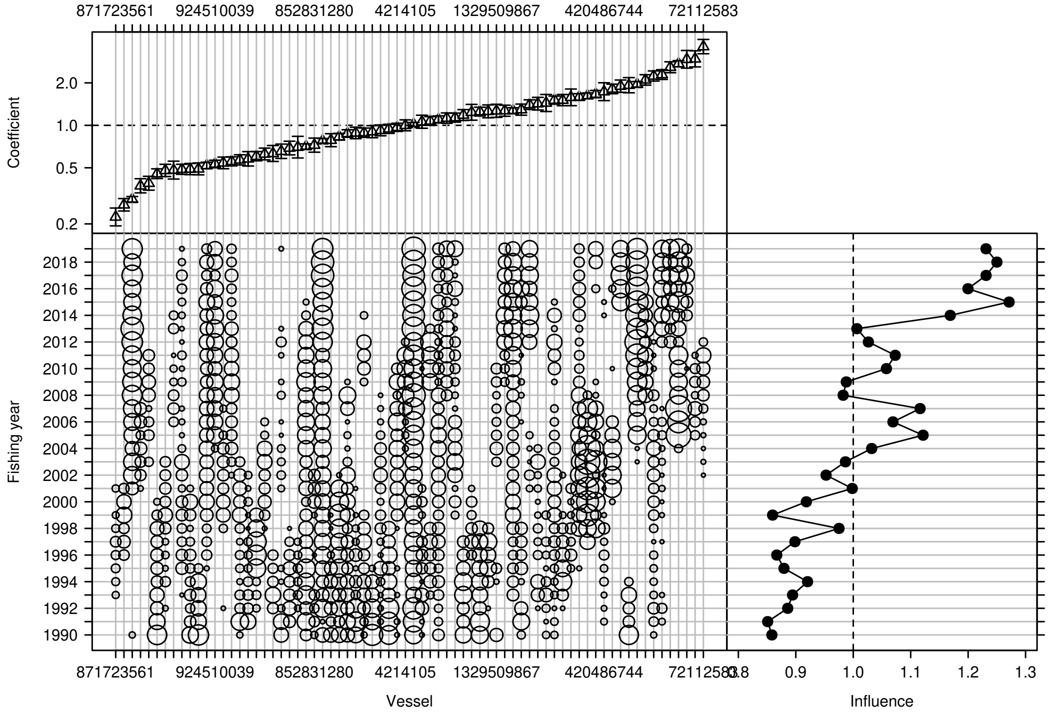

Figure G-71: Influence plot for vessel for the lognormal model of school shark in SCH 2/3 BT trip, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

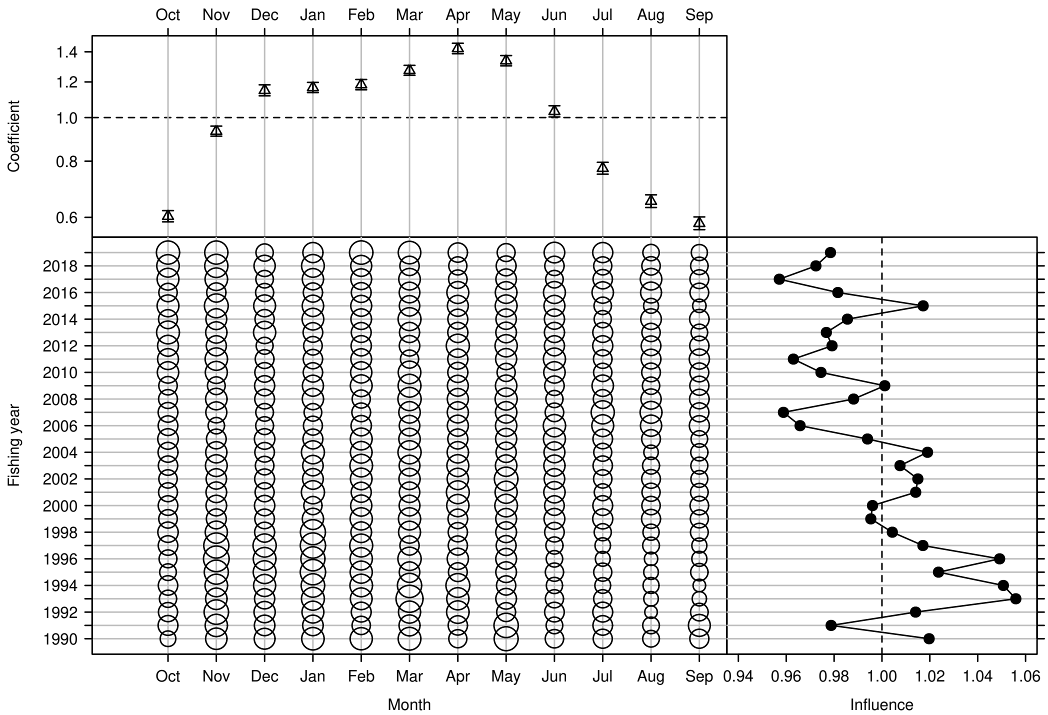

Figure G-72: Influence plot for month for the lognormal model of school shark in SCH 2/3 BT trip, showing model coefficients for each month (top panel), the distribution of observations over time across each month (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

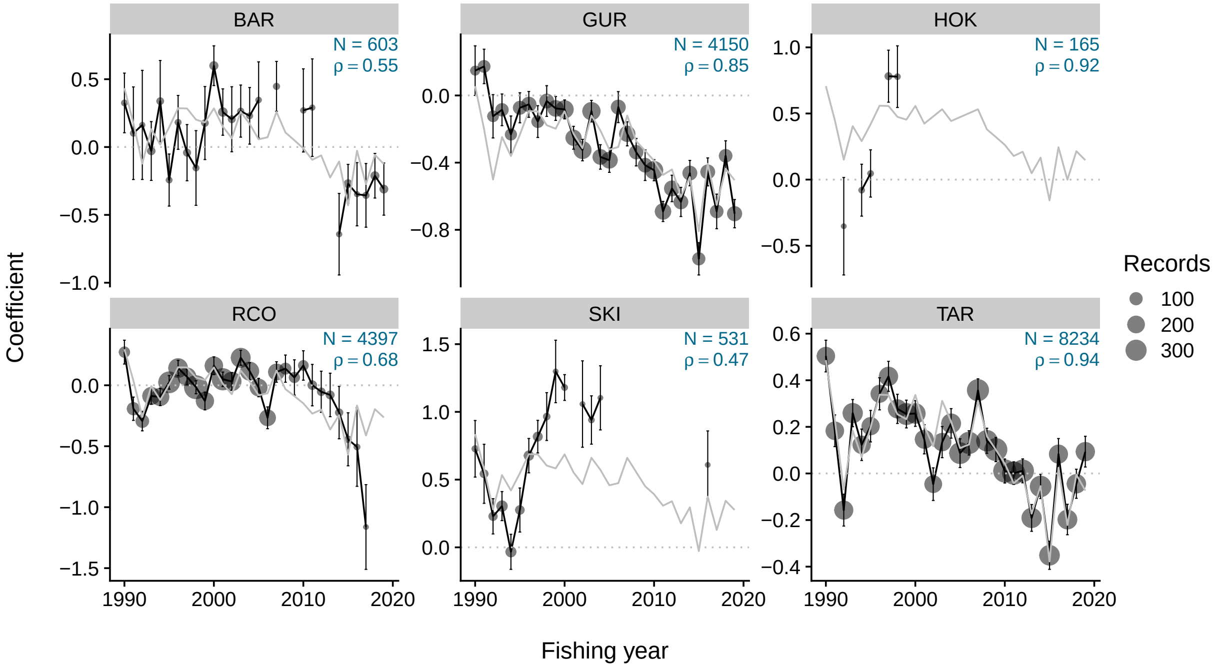

Figure G-73: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 2/3 BT trip, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

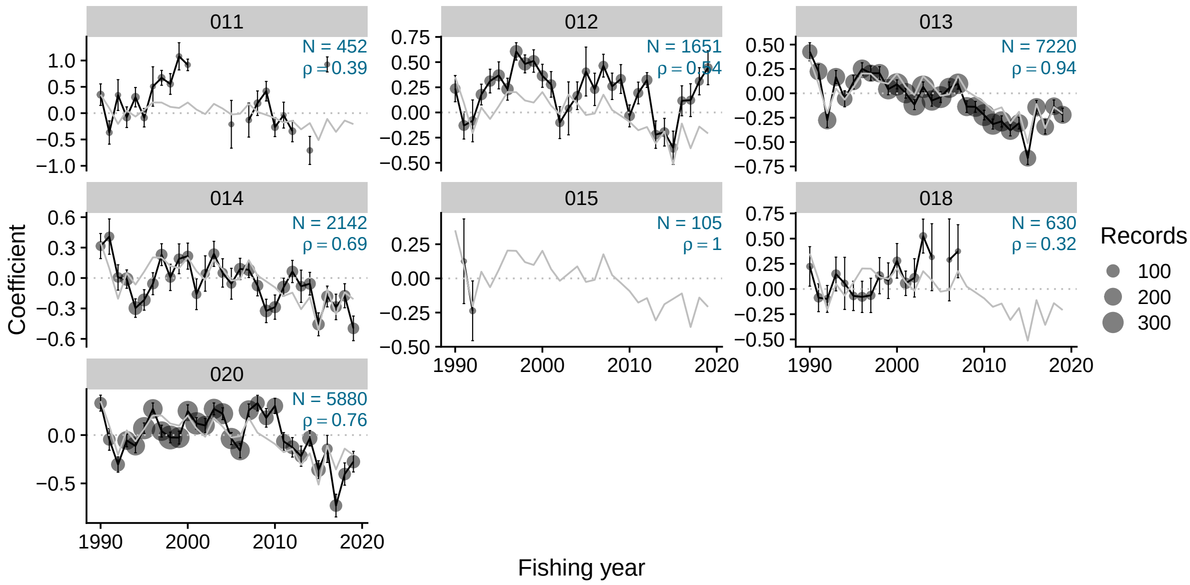

Figure G-74: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 2/3 BT trip, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-30: Standardised binomial, positive (lognormal) and combined indices for SCH 2/3 BT trip, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5^{th}	97.5^{th}
1990	0.787	1.456	1.146	0.926	1.378
1991	0.871	1.125	0.980	0.833	1.124
1992	0.619	0.833	0.516	0.396	0.645
1993	0.823	1.075	0.884	0.749	1.015
1994	0.734	0.961	0.705	0.578	0.842
1995	0.849	1.090	0.925	0.799	1.054
1996	0.927	1.252	1.160	1.025	1.293
1997	0.870	1.250	1.088	0.952	1.238
1998	0.957	1.153	1.103	0.987	1.217
1999	1.146	1.128	1.293	1.156	1.453
2000	1.258	1.255	1.578	1.370	1.834
2001	1.118	1.096	1.225	1.104	1.386
2002	1.118	1.006	1.125	1.006	1.257
2003	1.154	1.222	1.410	1.258	1.595
2004	1.143	1.122	1.282	1.140	1.455
2005	0.997	0.998	0.996	0.899	1.097
2006	1.092	1.016	1.111	0.990	1.249
2007	1.104	1.220	1.348	1.202	1.519
2008	1.151	1.051	1.210	1.059	1.402
2009	1.128	0.991	1.118	0.982	1.283
2010	1.195	0.933	1.114	0.972	1.304
2011	1.227	0.859	1.053	0.905	1.246
2012	1.152	0.886	1.021	0.892	1.180
2013	1.039	0.752	0.782	0.684	0.892
2014	0.967	0.849	0.821	0.716	0.939
2015	0.882	0.613	0.541	0.457	0.630
2016	1.083	0.920	0.997	0.853	1.165
2017	0.973	0.714	0.695	0.593	0.805
2018	0.981	0.891	0.875	0.749	1.003
2019	1.088	0.831	0.905	0.774	1.052

G.7 Chatham Rise (SCH 4) bottom longline (daily effort)

Table G-31: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 4 BLL daily.

Variable	Value
Label	BLL4_daily
Forms	CEL, LCE, ERS - Lining, LTC
Period	2003-10-01 to 2019-09-30
Resolution	Daily
Core fleet (min years)	3
Core fleet (min trips)	3
Target species	HPB, SCH, BNS, LIN
Statistical areas	020, 021, 049, 050, 051, 052, 401, 402, 403, 404, 407, 410

Table G-32: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 4 BLL daily. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (1000 hooks)	Catch (t)	Positive rate
2004	6	93	433	4 353.6	59.14	56.35
2005	7	76	576	7 660.6	116.96	70.83
2006	7	66	550	7 436.4	81.73	50.00
2007	9	100	674	8 190.9	59.57	50.30
2008	10	114	760	8 378.0	99.20	51.97
2009	9	78	575	7 778.4	144.98	58.96
2010	6	97	611	8 341.2	159.85	70.21
2011	9	83	683	8 796.8	159.80	67.20
2012	9	87	654	8 361.1	206.88	73.39
2013	10	101	738	8 728.8	127.08	61.52
2014	11	119	857	9 558.1	115.71	47.49
2015	9	90	759	8 324.7	162.65	61.26
2016	9	84	770	10 307.5	184.34	54.94
2017	10	81	774	10 440.7	218.18	60.98
2018	8	91	807	9 545.8	174.92	52.91
2019	9	69	671	7 587.5	108.51	43.96

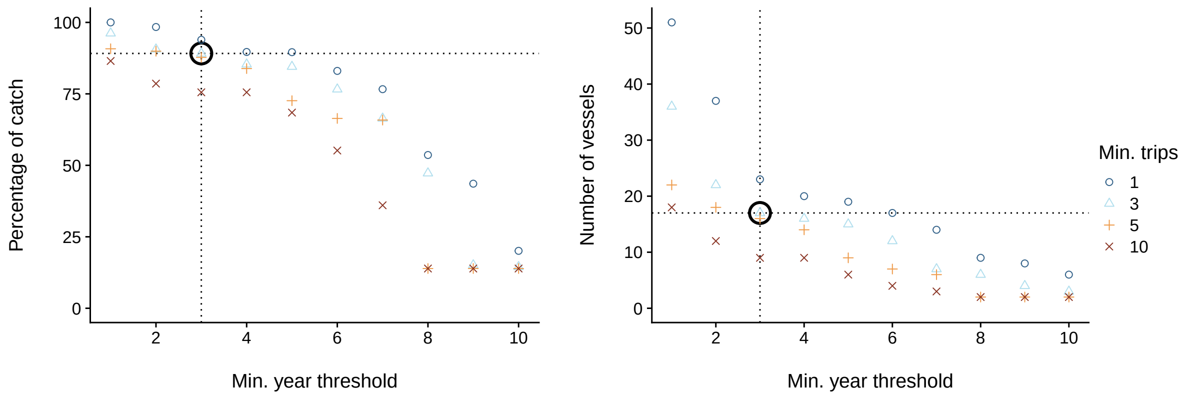

Figure G-75: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 4 BLL daily. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

Figure G-76: Proportion of school shark catch retained by the core fleet in SCH 4 BLL daily (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

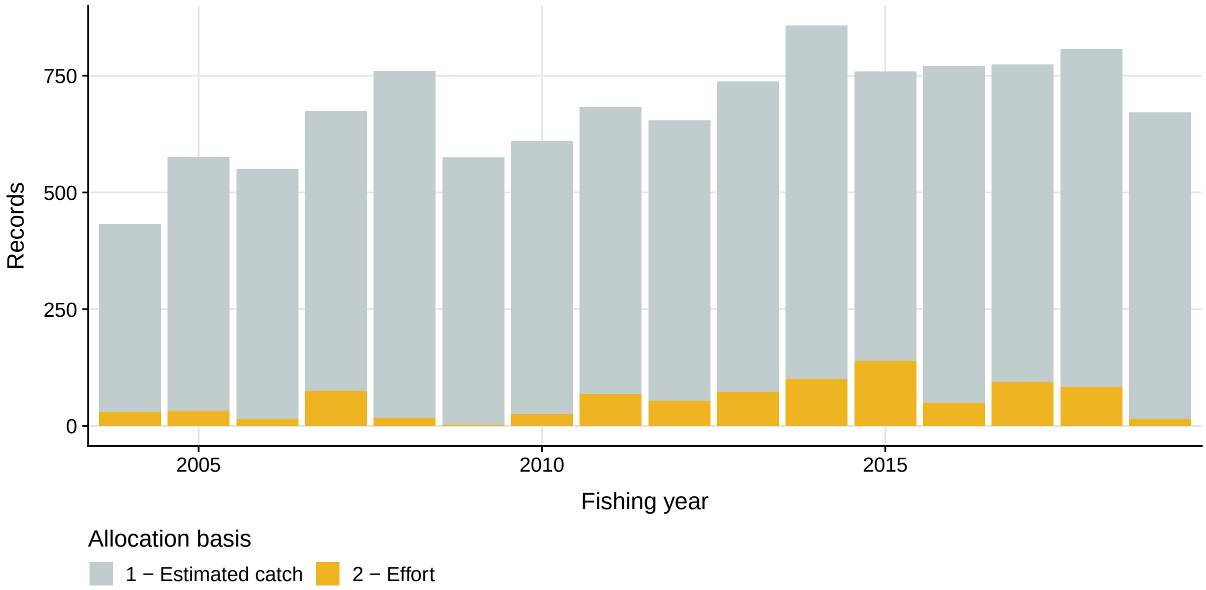

Figure G-77: Number of records by fishing year for the core fleet in SCH 4 BLL daily. Records with landings allocated based on estimated catch are highlighted in yellow.

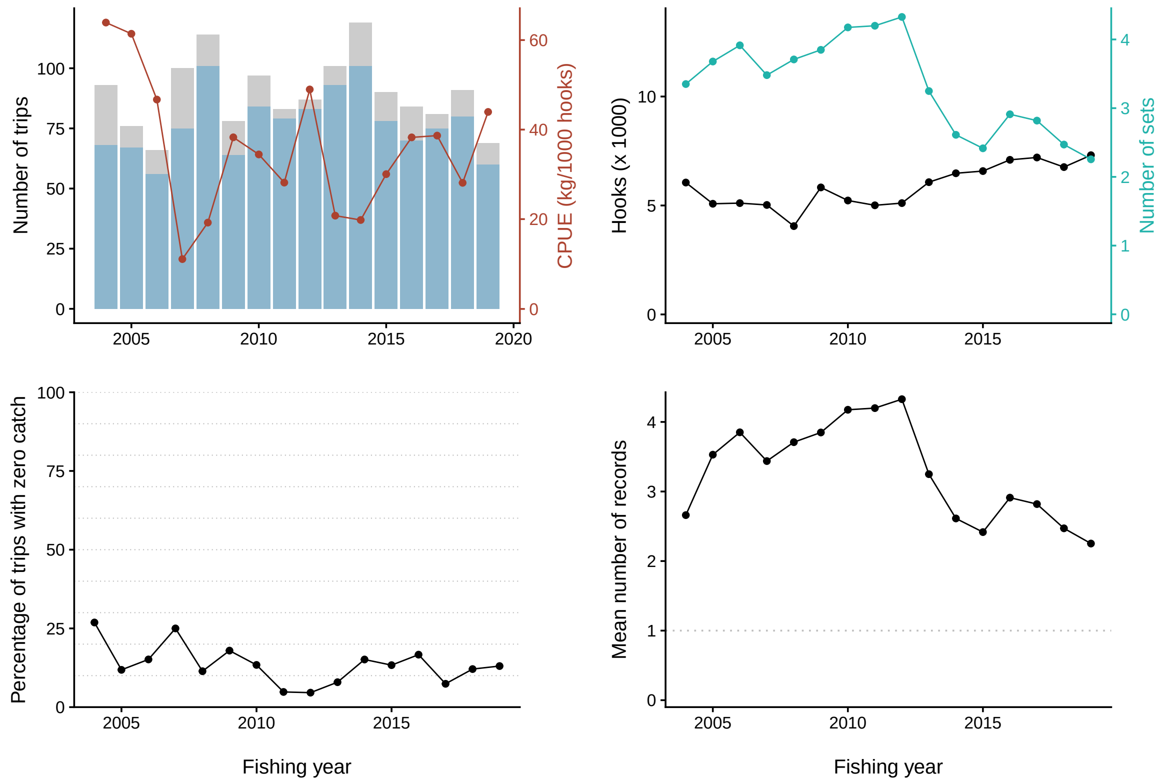

Figure G-78: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 4 BLL daily, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all daily records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the daily resolution over time.

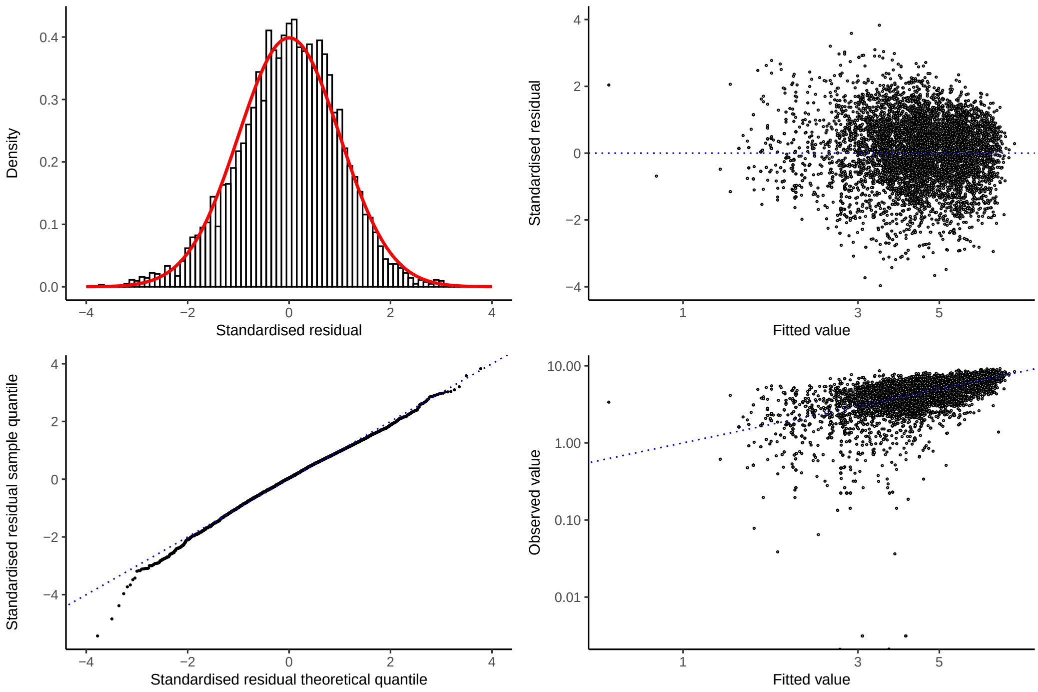

Figure G-79: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 4 BLL daily: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-33: Summary of stepwise selection for binomial occurrence model for SCH 4 BLL daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	14.00	14529	2.20	2.20	*
+ target_species	3.00	12618	15.10	12.90	*
+ vessel_key	16.00	12295	17.50	2.40	*
+ month	11.00	12074	19.20	1.60	*
+ effort_num	1.00	11913	20.30	1.10	*
+ stat_area	11.00	11833	21.00	0.70	
+ ns(log(total_hook_num), 3)	3.00	11812	21.10	0.20	

Table G-34: Summary of stepwise selection for positive catch model for SCH 4 BLL daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	14.00	25672	2.30	2.30	*
+ target_species	3.00	23105	35.00	32.70	*
+ ns(log(total_hook_num), 3)	3.00	22346	42.40	7.40	*
+ vessel_key	16.00	22070	45.20	2.70	*
+ stat_area	11.00	21798	47.70	2.50	*
+ month	11.00	21717	48.50	0.80	

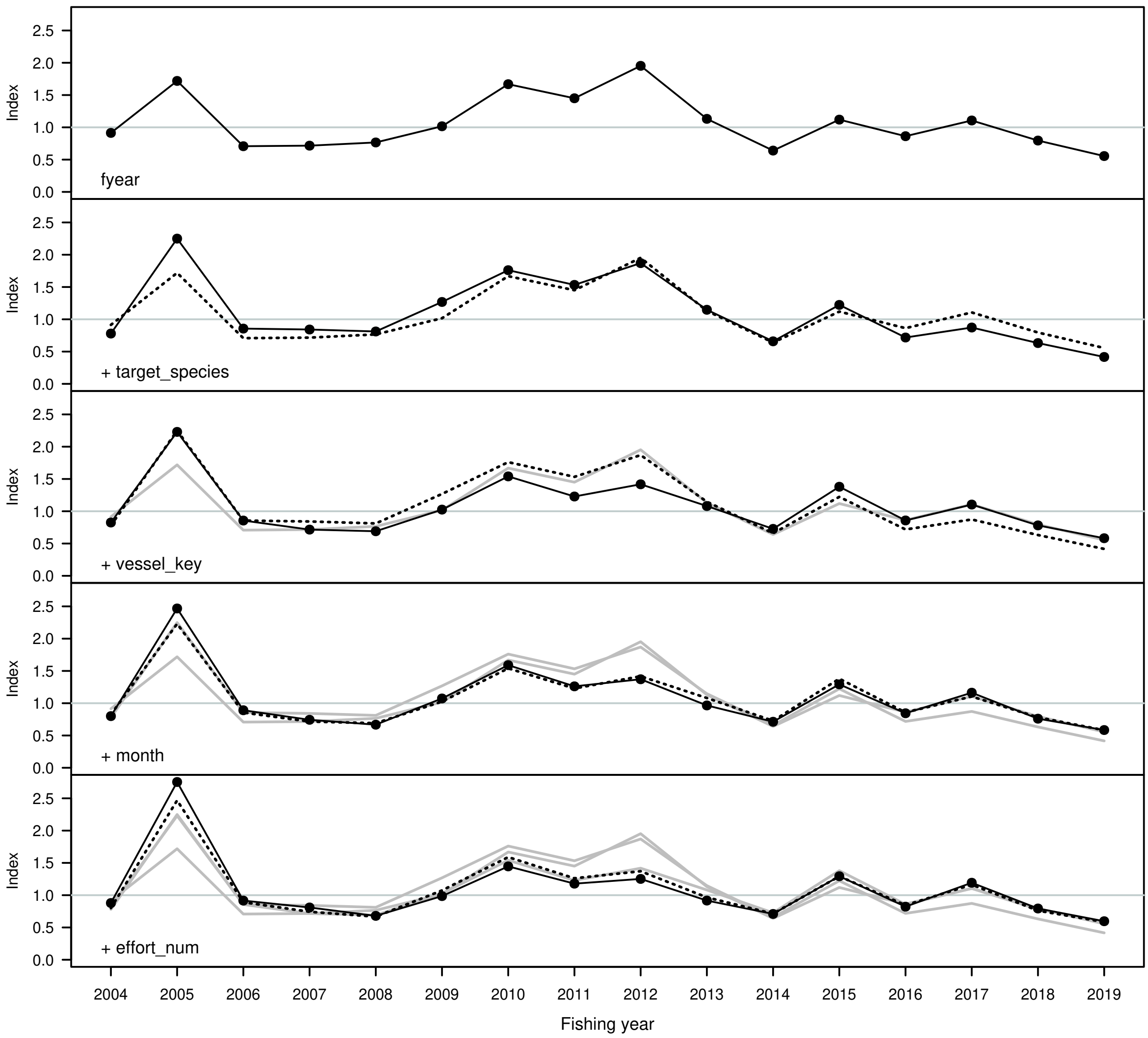

Figure G-80: Stepwise plot for the binomial occurrence model for SCH 4 BLL daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

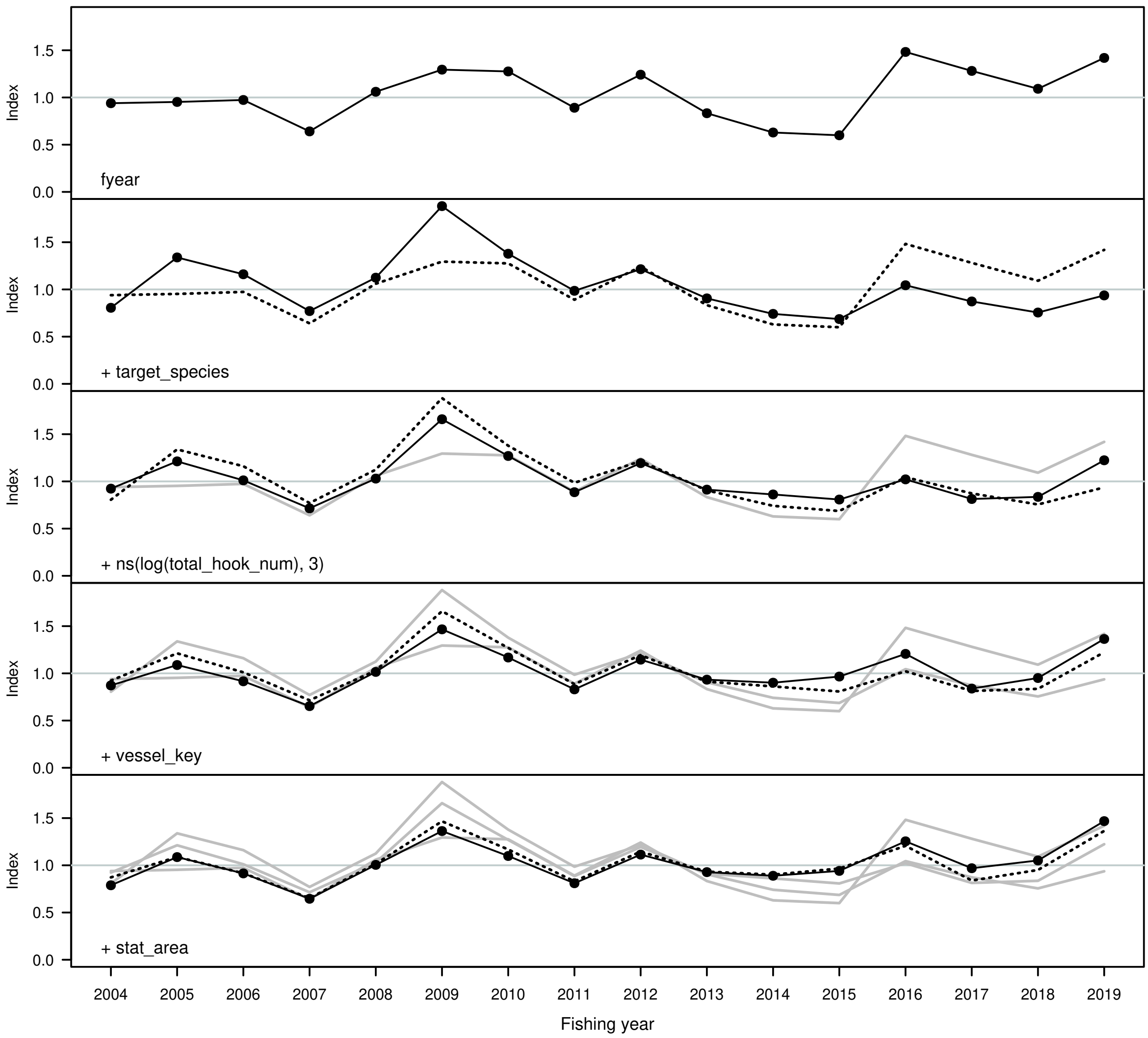

Figure G-81: Stepwise plot for the positive lognormal model for SCH 4 BLL daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

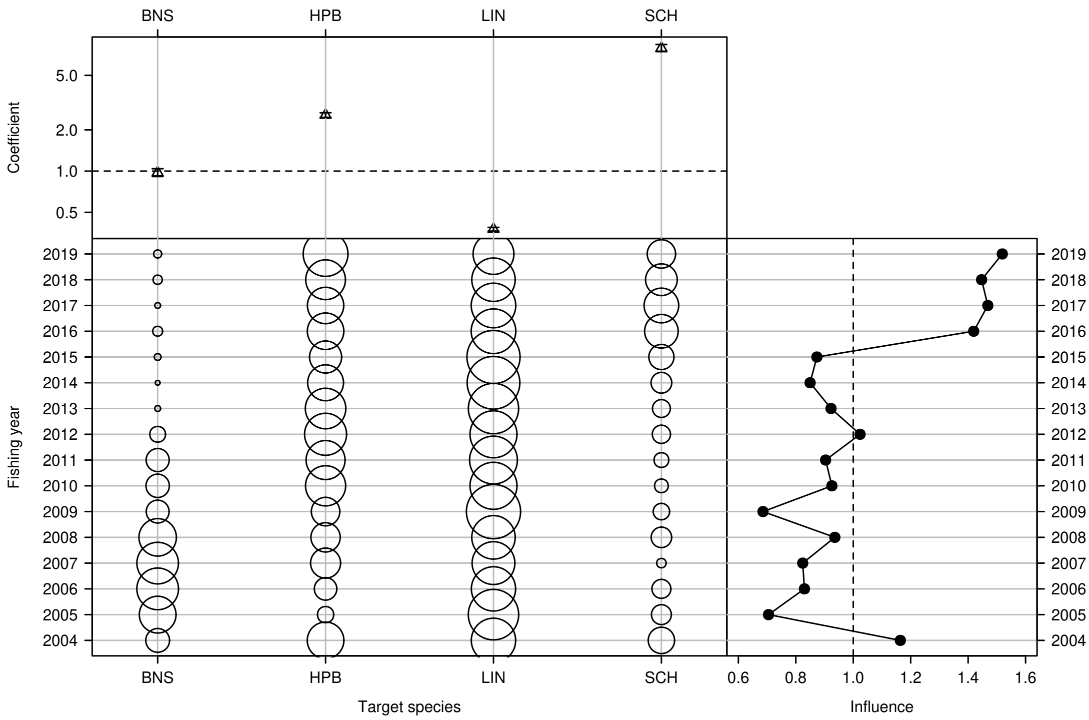

Figure G-82: Influence plot for target species for the lognormal model of school shark in SCH 4 BLL daily, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

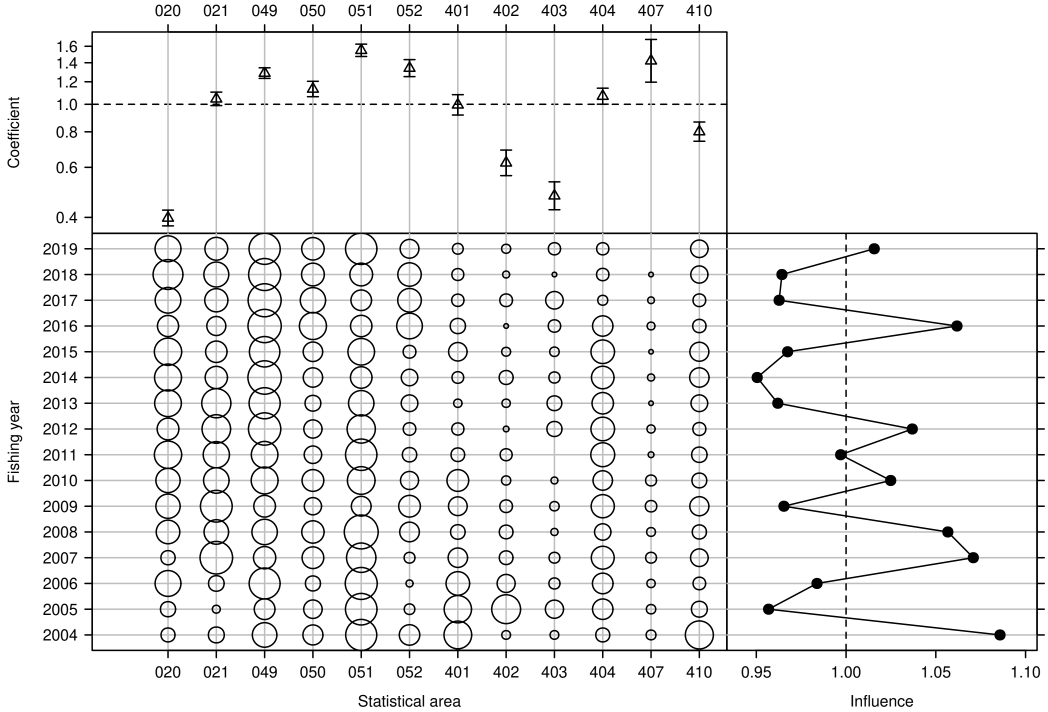

Figure G-83: Influence plot for statistical area for the lognormal model of school shark in SCH 4 BLL daily, showing model coefficients for each statistical area (top panel), the distribution of observations over time across each statistical area (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

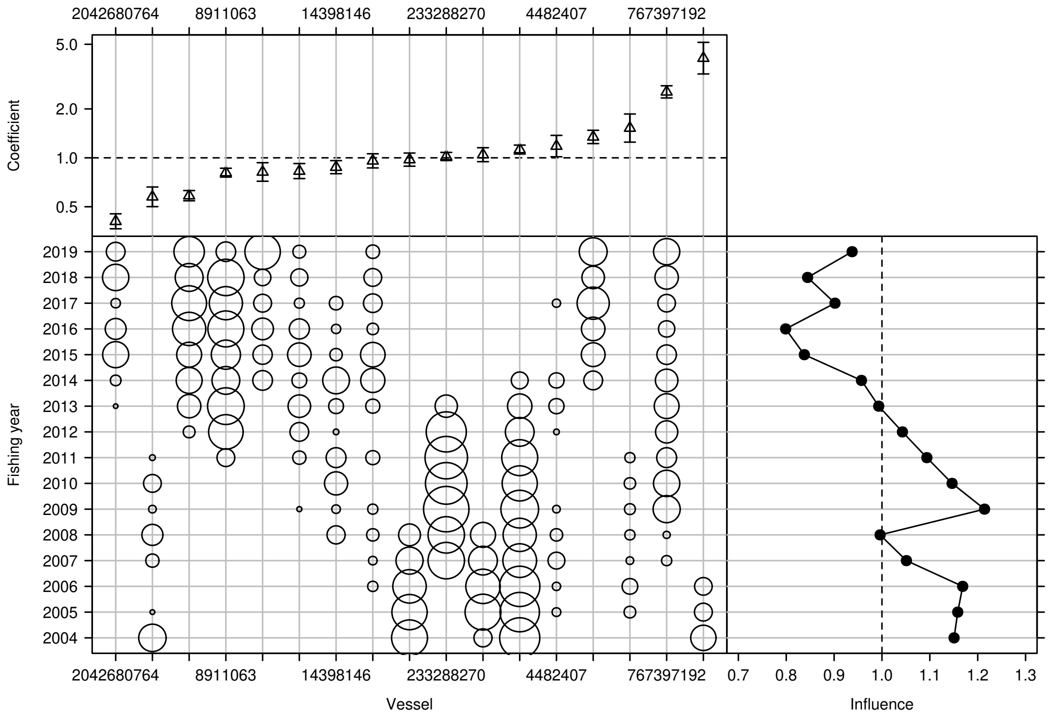

Figure G-84: Influence plot for vessel for the lognormal model of school shark in SCH 4 BLL daily, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

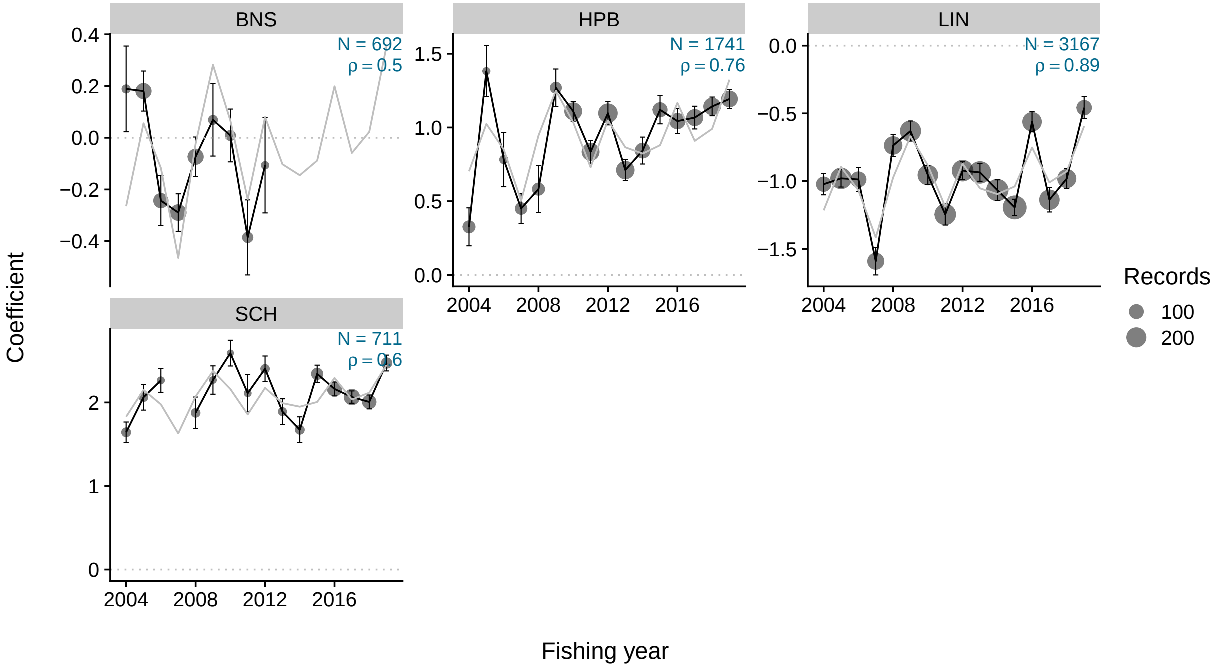

Figure G-85: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 4 BLL daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

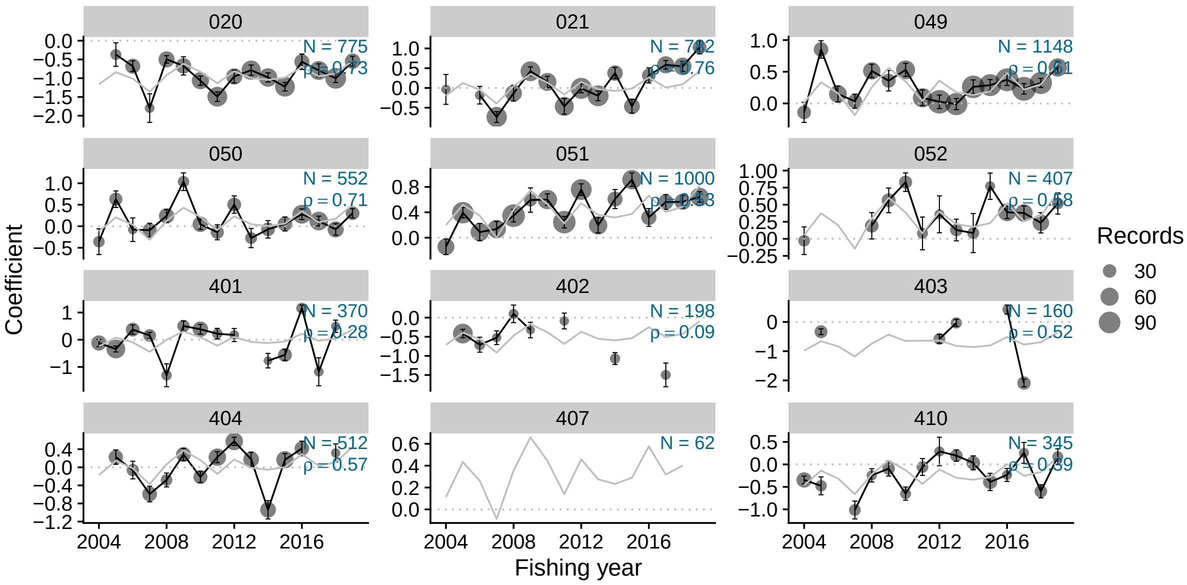

Figure G-86: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 4 BLL daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-35: Standardised binomial, positive (lognormal) and combined indices for SCH 4 BLL daily, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5^{th}	97.5^{th}
2004	0.962	0.791	0.760	0.600	0.932
2005	1.369	1.092	1.495	1.233	1.814
2006	0.980	0.914	0.895	0.727	1.086
2007	0.927	0.647	0.600	0.500	0.714
2008	0.852	1.007	0.858	0.720	1.002
2009	1.010	1.373	1.386	1.174	1.632
2010	1.160	1.099	1.274	1.088	1.477
2011	1.081	0.813	0.878	0.761	1.020
2012	1.106	1.114	1.231	1.066	1.425
2013	0.981	0.931	0.913	0.787	1.045
2014	0.872	0.893	0.778	0.655	0.917
2015	1.118	0.943	1.055	0.895	1.234
2016	0.934	1.259	1.176	0.990	1.386
2017	1.087	0.974	1.059	0.897	1.247
2018	0.920	1.051	0.966	0.807	1.134
2019	0.798	1.481	1.182	0.954	1.473

G.8 Lower SCH 3 & SCH 5 set net (daily effort)

Table G-36: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 3/5 SN daily.

Variable	Value
Label	SN35_daily
Forms	CEL, NCE, ERS - Netting
Period	1989-10-01 to 2019-09-30
Resolution	Daily
Core fleet (min years)	4
Core fleet (min trips)	3
Target species	SPO, SCH, SPD, ELE
Statistical areas	022, 024, 025, 026, 027, 029, 030, 031, 032, 033

Table G-37: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 3/5 SN daily. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (net length [km])	Catch (t)	Positive rate
1990	23	428	610	1 331.2	350.92	81.15
1991	22	483	702	1 489.8	397.86	70.51
1992	23	554	690	1 350.4	455.82	70.58
1993	23	528	665	1 258.3	455.01	75.19
1994	29	855	1 001	1 814.4	553.71	78.82
1995	28	881	1 061	1 922.9	608.26	81.15
1996	30	851	984	1 805.1	593.95	81.91
1997	29	802	974	1 841.6	529.66	85.73
1998	30	809	945	1 766.5	572.25	85.19
1999	28	762	924	1 753.1	614.16	85.28
2000	27	663	783	1 460.4	599.71	83.52
2001	28	781	906	1 636.4	553.35	83.44
2002	23	647	783	1 434.9	540.76	86.08
2003	26	851	1 043	2 025.7	670.35	79.58
2004	25	837	1 033	2 004.2	628.20	73.77
2005	25	779	965	1 934.8	690.90	86.84
2006	22	1 005	1 218	2 279.1	597.75	74.38
2007	22	802	1 025	1 756.7	673.15	78.54
2008	20	817	1 111	2 247.6	739.90	80.74
2009	21	768	1 004	1 984.5	667.36	85.96
2010	19	752	973	1 955.3	758.86	89.83
2011	19	774	998	2 101.2	643.59	85.77
2012	18	707	918	2 042.4	676.44	86.93
2013	19	699	973	2 261.9	722.97	87.15
2014	18	653	973	2 304.6	690.59	83.25
2015	18	682	994	2 260.3	644.05	88.33
2016	16	591	856	2 014.8	630.76	90.54
2017	15	493	793	2 002.0	609.22	86.38
2018	14	539	768	1 882.8	629.00	87.37
2019	14	511	741	1 754.6	514.14	83.00

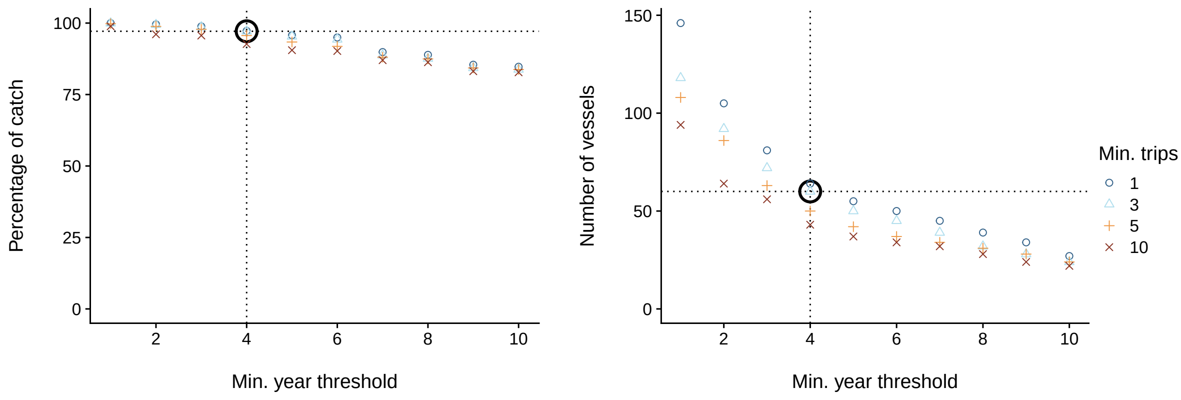

Figure G-87: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 3/5 SN daily. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

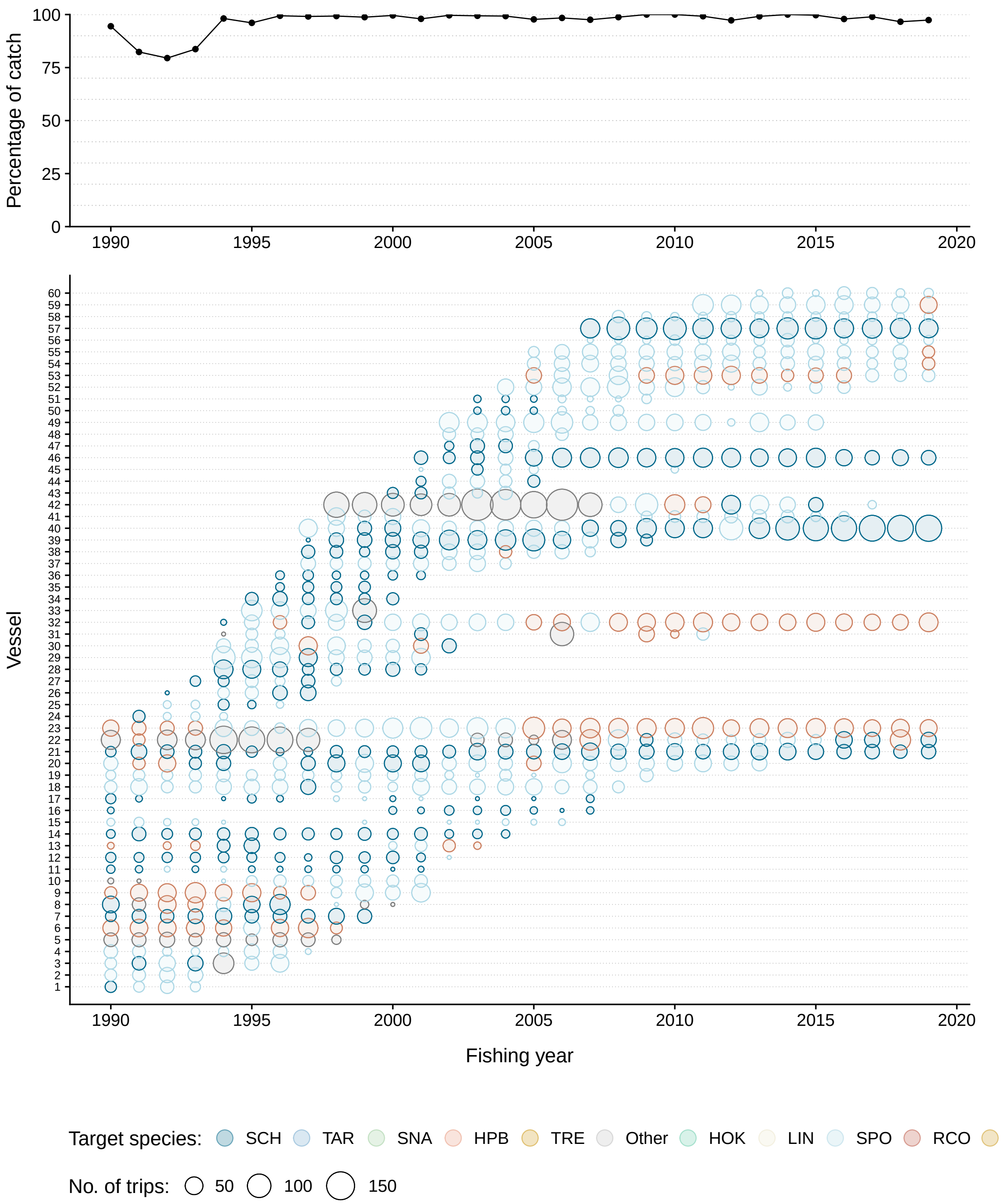

Figure G-88: Proportion of school shark catch retained by the core fleet in SCH 3/5 SN daily (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

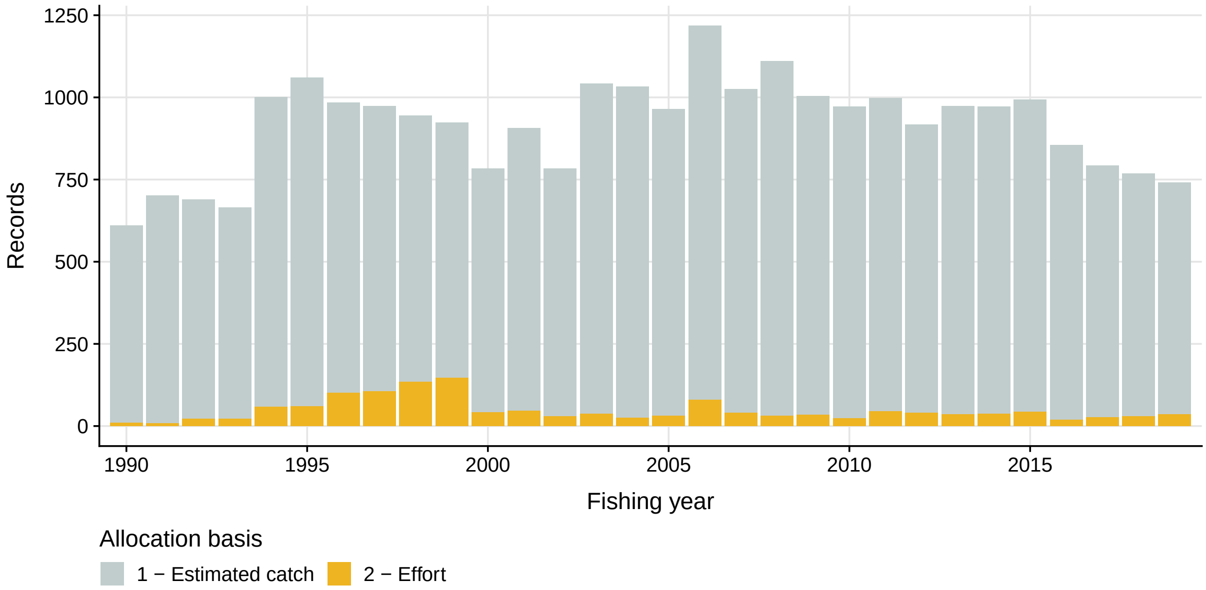

Figure G-89: Number of records by fishing year for the core fleet in SCH 3/5 SN daily. Records with landings allocated based on estimated catch are highlighted in yellow.

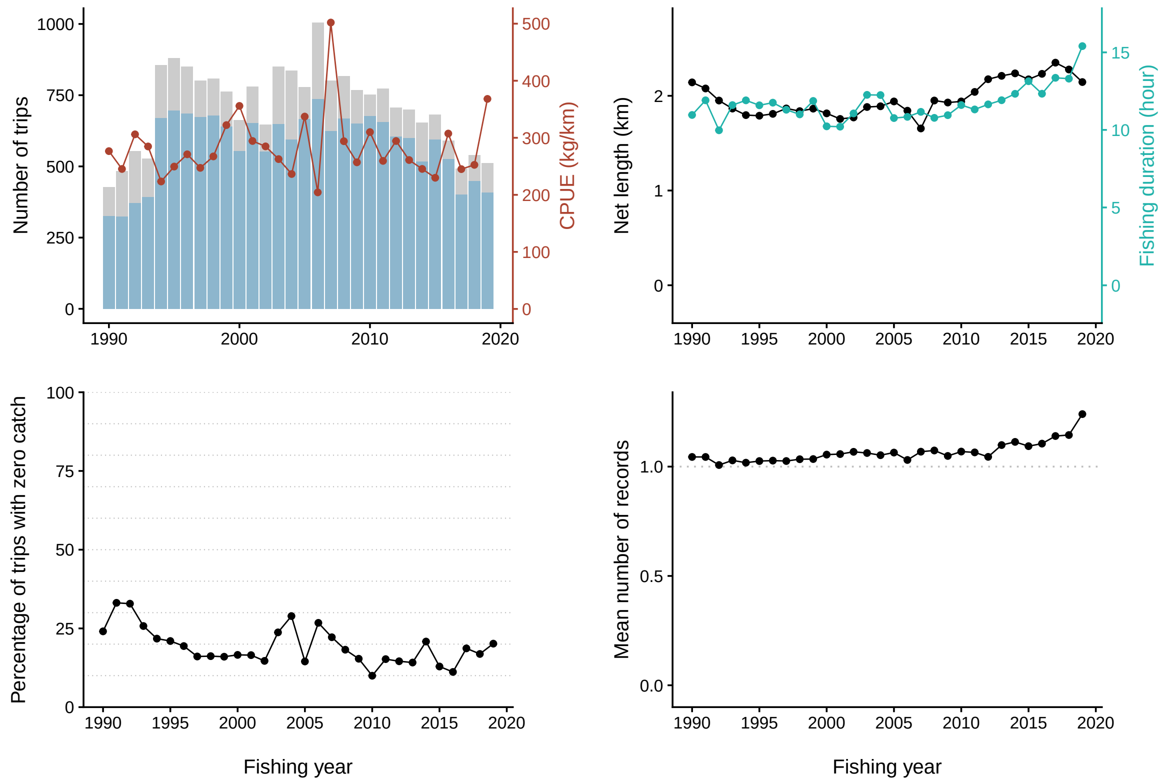

Figure G-90: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 3/5 SN daily, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all daily records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the daily resolution over time.

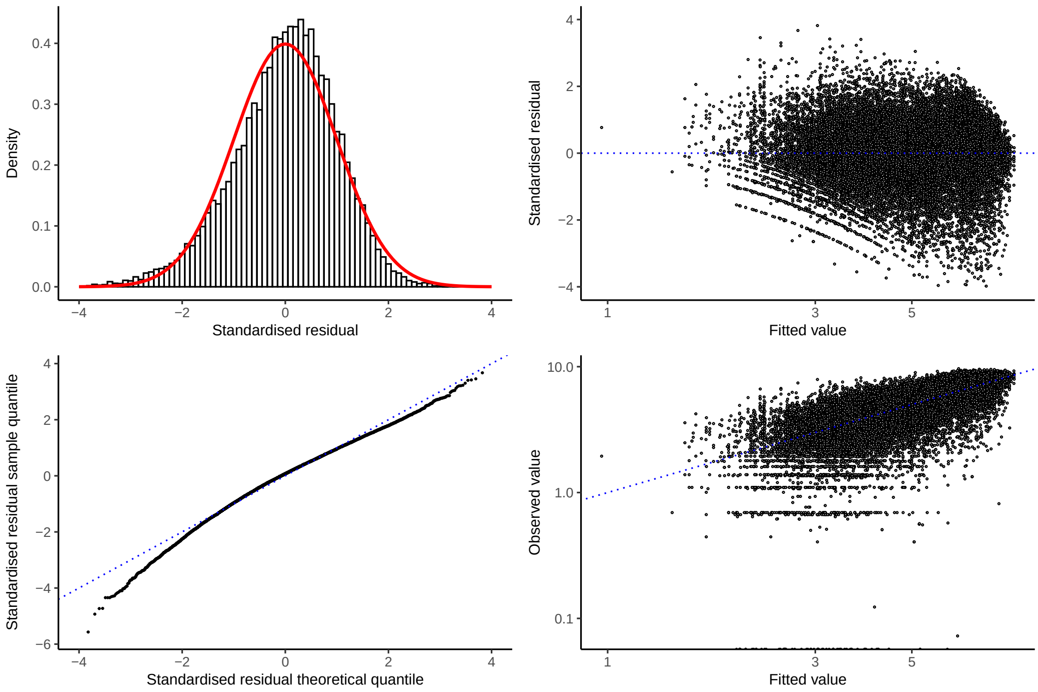

Figure G-91: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 3/5 SN daily: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-38: Summary of stepwise selection for binomial occurrence model for SCH 3/5 SN daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	24872	1.90	1.90	*
+ vessel_key	59.00	21875	14.20	12.30	*
+ month	11.00	20483	19.80	5.60	*
+ target_species	3.00	19398	24.10	4.30	*
+ stat_area	9.00	19215	24.90	0.80	
+ ns(log(total_net_length), 3)	3.00	19158	25.20	0.20	

Table G-39: Summary of stepwise selection for positive catch model for SCH 3/5 SN daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	96375	0.90	0.90	*
+ vessel_key	59.00	79668	52.80	51.90	*
+ target_species	3.00	77340	57.50	4.60	*
+ stat_area	9.00	76581	58.90	1.40	*
+ month	11.00	75550	60.80	1.90	*
+ ns(log(total_net_length), 3)	3.00	75128	61.50	0.70	

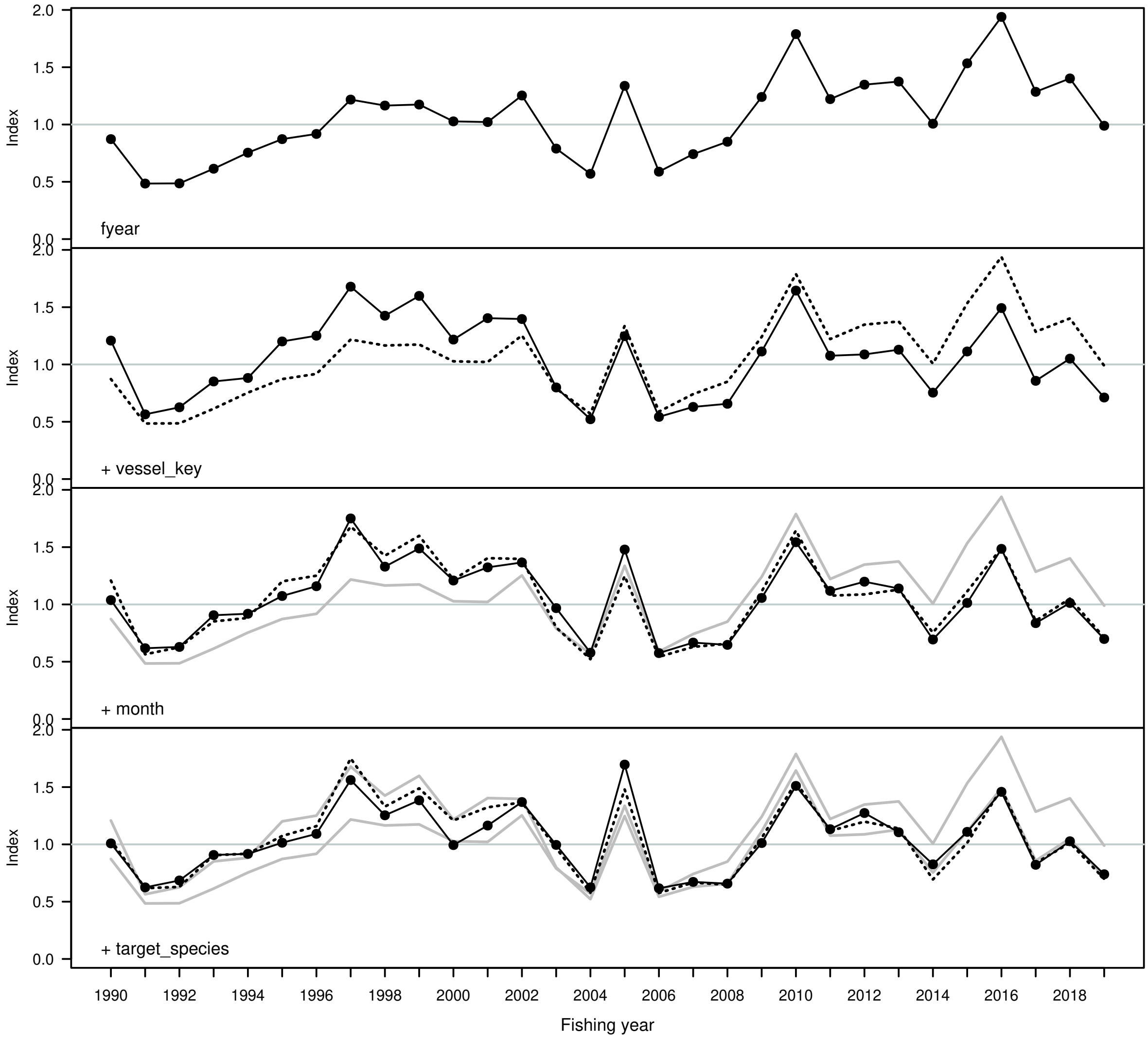

Figure G-92: Stepwise plot for the binomial occurrence model for SCH 3/5 SN daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

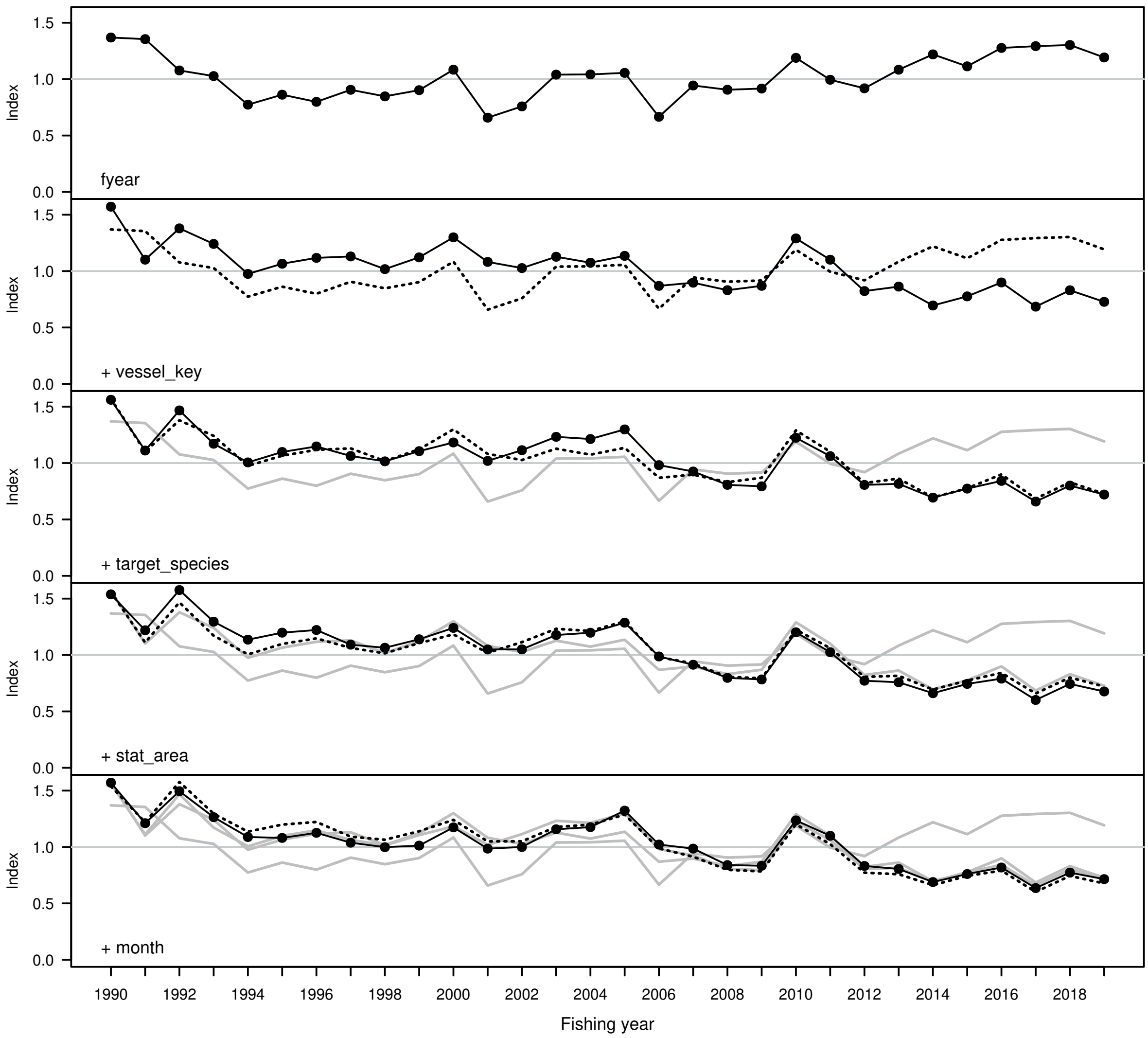

Figure G-93: Stepwise plot for the positive lognormal model for SCH 3/5 SN daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

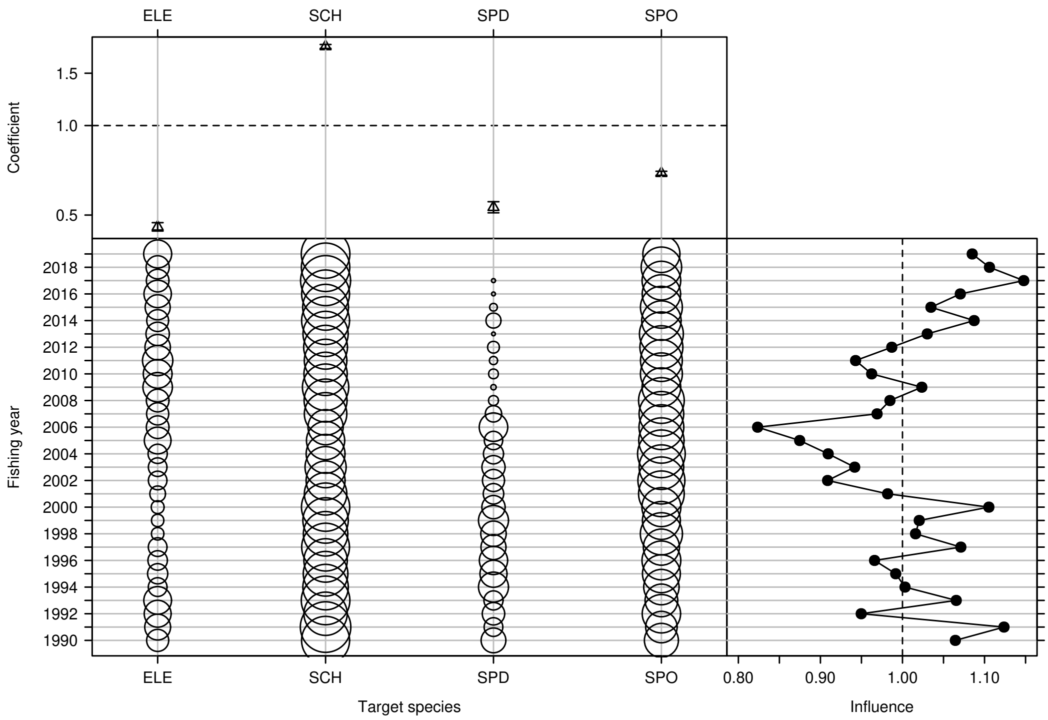

Figure G-94: Influence plot for target species for the lognormal model of school shark in SCH 3/5 SN daily, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

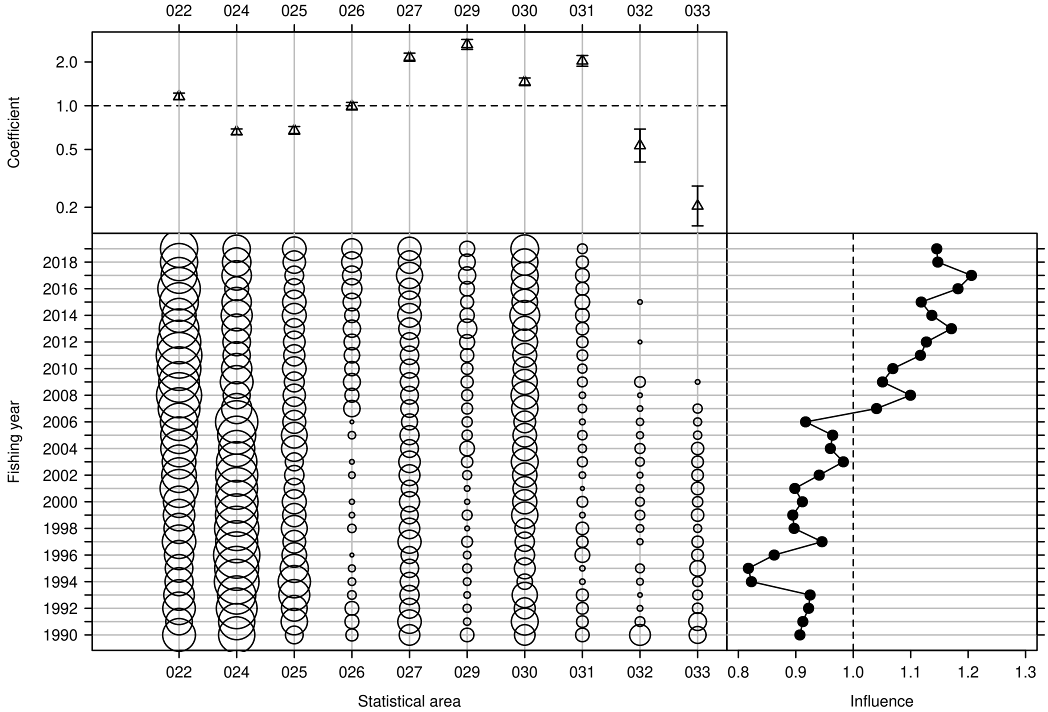

Figure G-95: Influence plot for statistical area for the lognormal model of school shark in SCH 3/5 SN daily, showing model coefficients for each statistical area (top panel), the distribution of observations over time across each statistical area (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

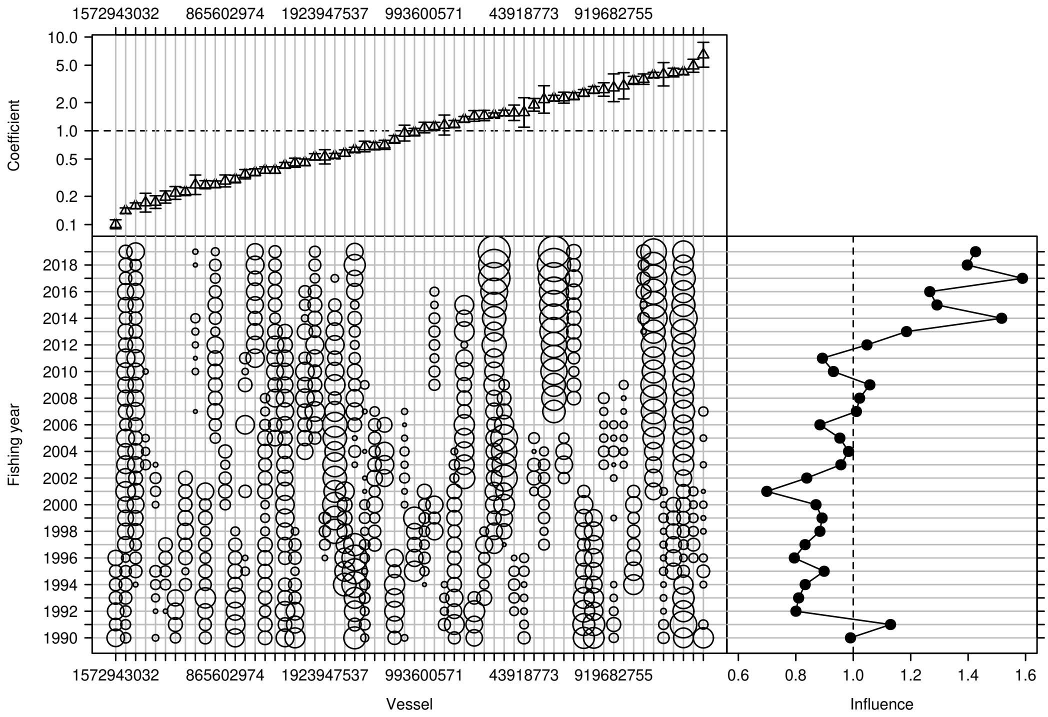

Figure G-96: Influence plot for vessel for the lognormal model of school shark in SCH 3/5 SN daily, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

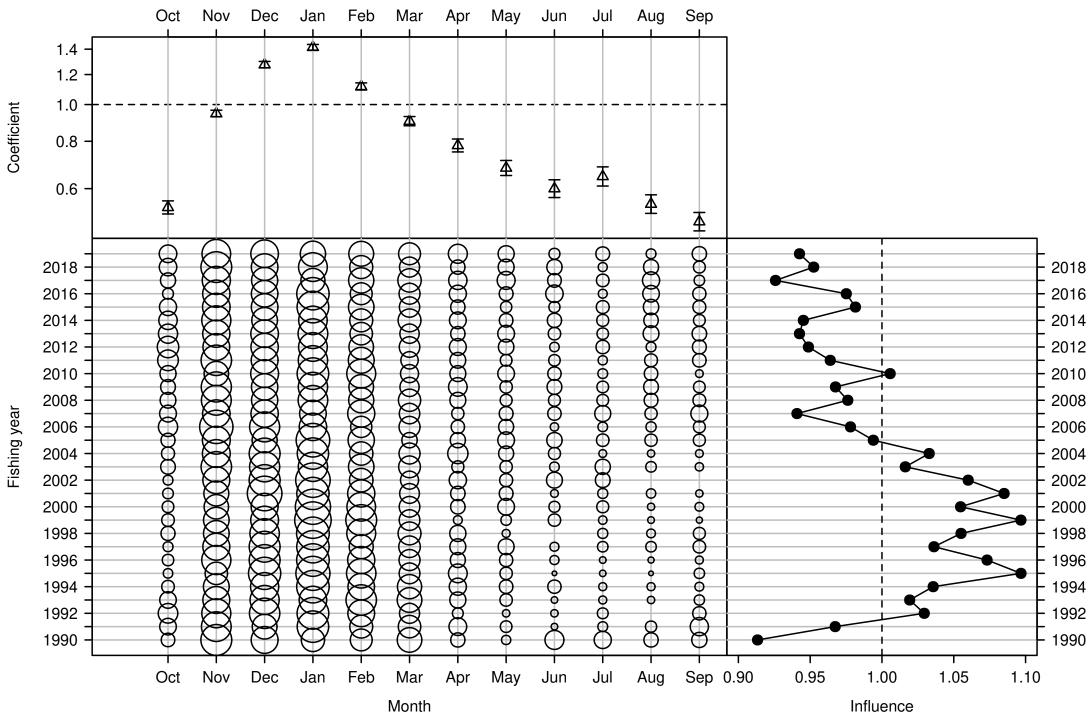

Figure G-97: Influence plot for month for the lognormal model of school shark in SCH 3/5 SN daily, showing model coefficients for each month (top panel), the distribution of observations over time across each month (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

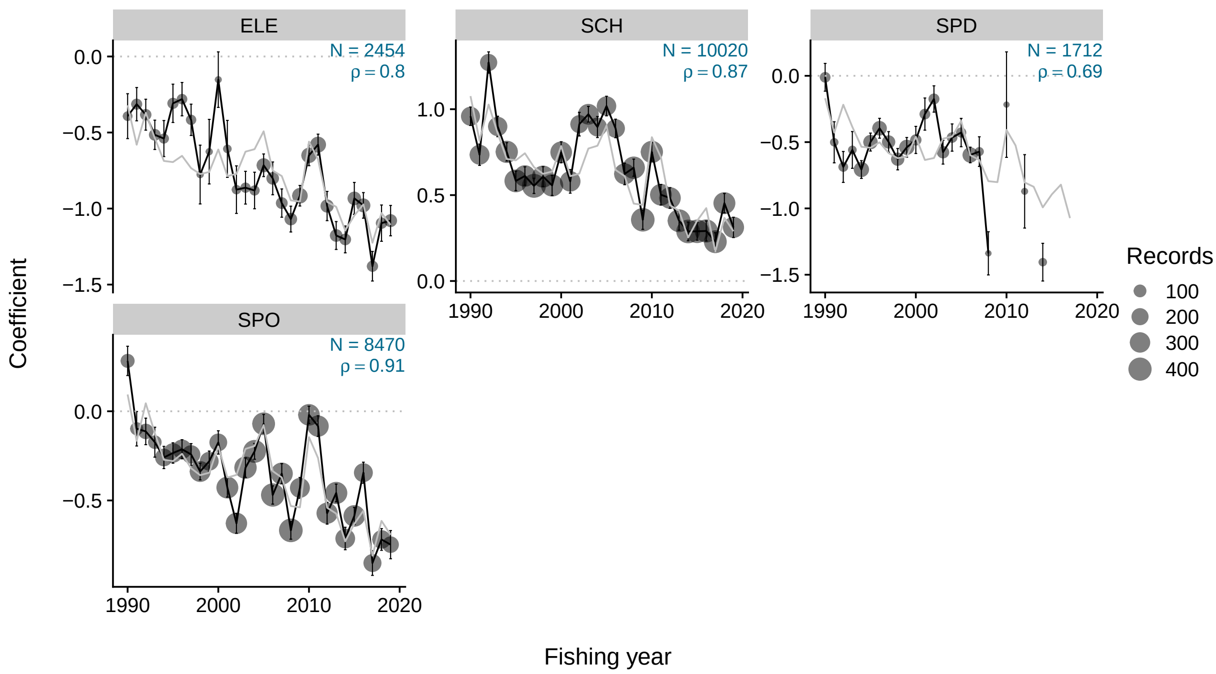

Figure G-98: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 3/5 SN daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

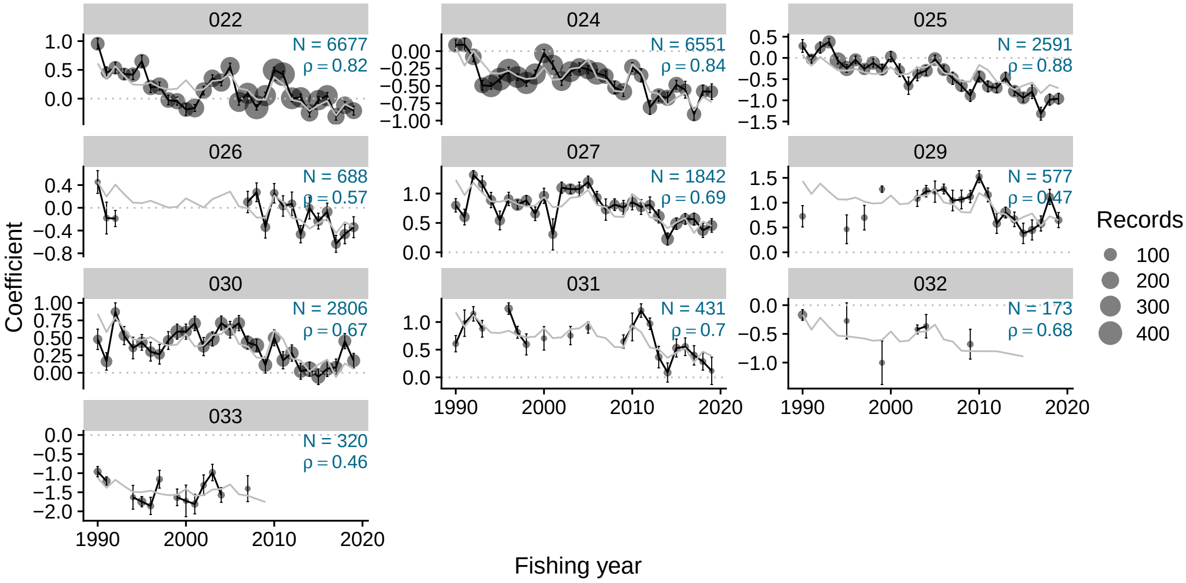

Figure G-99: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 3/5 SN daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-40: Standardised binomial, positive (lognormal) and combined indices for SCH 3/5 SN daily, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5th	97.5th
1990	1.008	1.574	1.586	1.401	1.809
1991	0.904	1.214	1.097	0.962	1.253
1992	0.925	1.497	1.385	1.207	1.586
1993	0.987	1.268	1.252	1.099	1.419
1994	0.990	1.090	1.079	0.976	1.194
1995	1.009	1.081	1.091	0.982	1.204
1996	1.023	1.128	1.154	1.034	1.270
1997	1.081	1.039	1.124	1.011	1.242
1998	1.046	1.000	1.046	0.943	1.151
1999	1.062	1.012	1.075	0.968	1.189
2000	1.004	1.178	1.183	1.055	1.329
2001	1.034	0.984	1.018	0.916	1.124
2002	1.060	1.001	1.061	0.953	1.177
2003	1.007	1.156	1.163	1.056	1.285
2004	0.903	1.173	1.060	0.950	1.177
2005	1.092	1.322	1.444	1.309	1.596
2006	0.900	1.021	0.919	0.829	1.012
2007	0.921	0.987	0.910	0.821	1.005
2008	0.917	0.840	0.771	0.696	0.846
2009	1.009	0.834	0.841	0.761	0.927
2010	1.076	1.238	1.332	1.213	1.462
2011	1.030	1.100	1.133	1.026	1.239
2012	1.051	0.835	0.877	0.799	0.969
2013	1.026	0.805	0.826	0.751	0.902
2014	0.968	0.690	0.668	0.601	0.732
2015	1.027	0.761	0.782	0.710	0.865
2016	1.070	0.821	0.878	0.791	0.976
2017	0.966	0.636	0.615	0.545	0.691
2018	1.012	0.774	0.783	0.701	0.870
2019	0.945	0.717	0.677	0.602	0.752

G.9 Lower SCH 3 & SCH 5 bottom longline (daily effort)

Table G-41: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 3/5 BLL daily.

Variable	Value
Label	BLL35_daily
Forms	CEL, LCE, ERS - Lining, LTC
Period	1989-10-01 to 2019-09-30
Resolution	Daily
Core fleet (min years)	3
Core fleet (min trips)	3
Target species	HPB, SCH, BNS, LIN
Statistical areas	023, 024, 025, 026, 029, 030, 031, 032, 033

Table G-42: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 3/5 BLL daily. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (1000 hooks)	Catch (t)	Positive rate
1990	5	24	107	105.7	7.78	69.16
1991	5	31	149	135.5	3.06	38.93
1992	9	66	358	859.1	8.59	34.36
1993	11	78	379	810.6	15.79	34.83
1994	10	63	343	1 740.1	15.05	34.99
1995	13	92	382	1 260.8	17.65	39.27
1996	12	122	434	1 329.4	12.75	41.94
1997	11	114	378	1 815.1	10.89	36.77
1998	11	66	325	1 995.7	5.96	32.62
1999	14	89	374	2 045.1	20.44	48.66
2000	11	115	368	656.0	17.07	51.36
2001	10	94	372	630.1	34.25	56.18
2002	12	100	361	606.8	26.20	53.74
2003	11	112	392	704.4	39.69	59.69
2004	10	96	368	642.2	30.60	48.10
2005	11	102	434	954.5	30.40	36.64
2006	9	100	400	672.6	32.87	54.25
2007	11	111	508	1 153.0	35.84	44.29
2008	12	111	481	1 009.3	47.98	44.49
2009	12	116	423	1 057.5	37.84	41.61
2010	11	106	416	1 138.4	40.99	48.56
2011	10	109	438	1 110.8	27.24	57.76
2012	10	110	451	1 173.4	23.78	51.88
2013	10	92	347	809.1	22.83	62.25
2014	13	98	419	1 300.6	33.42	54.89
2015	10	90	346	990.5	24.58	54.05
2016	10	99	433	1 215.7	47.55	53.58
2017	10	93	433	1 249.7	58.64	48.96
2018	8	88	348	1 334.8	77.13	67.24
2019	9	81	319	1 040.3	43.10	61.44

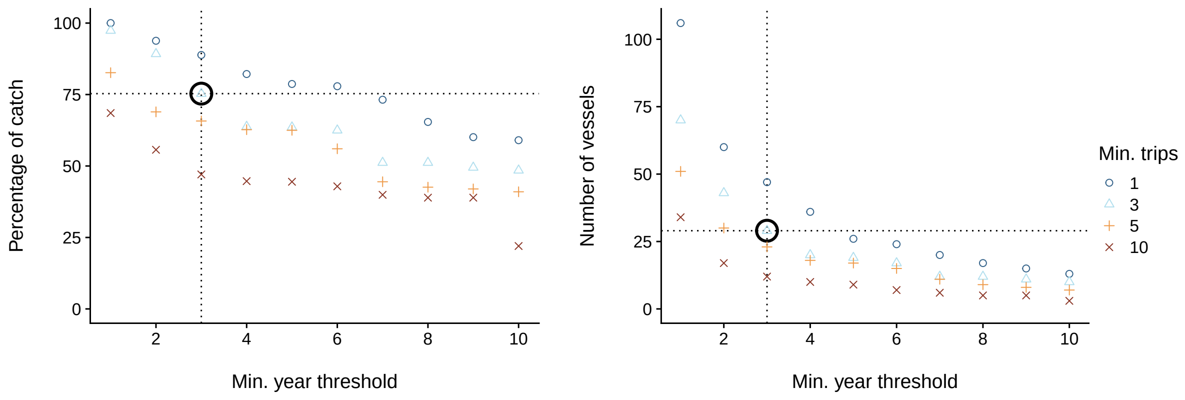

Figure G-100: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 3/5 BLL daily. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

Figure G-101: Proportion of school shark catch retained by the core fleet in SCH 3/5 BLL daily (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

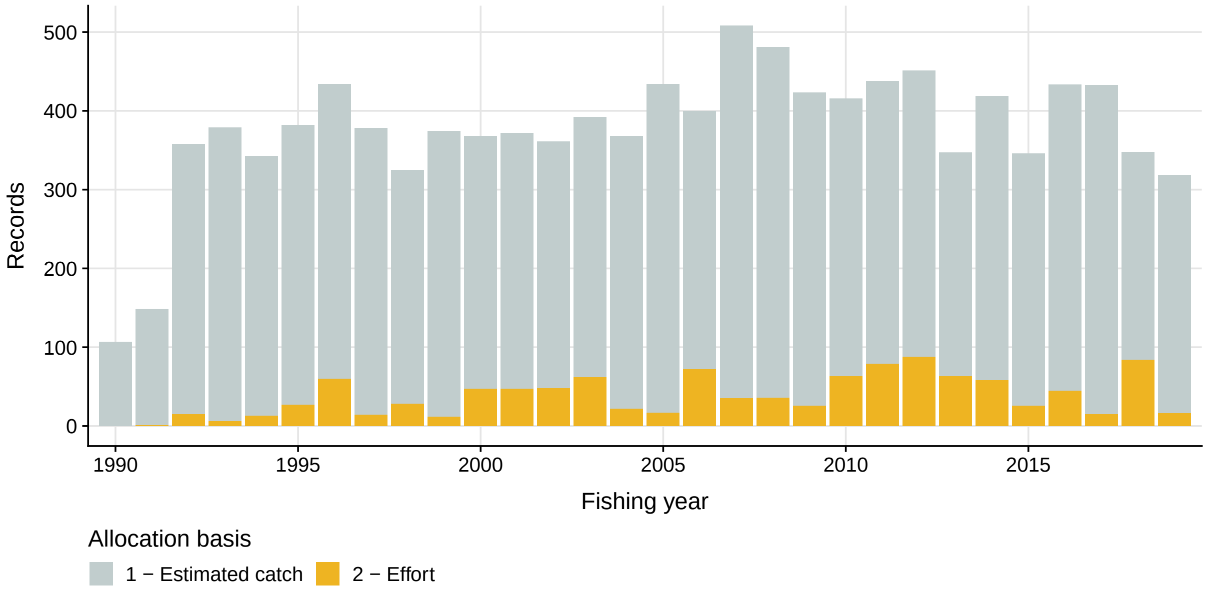

Figure G-102: Number of records by fishing year for the core fleet in SCH 3/5 BLL daily. Records with landings allocated based on estimated catch are highlighted in yellow.

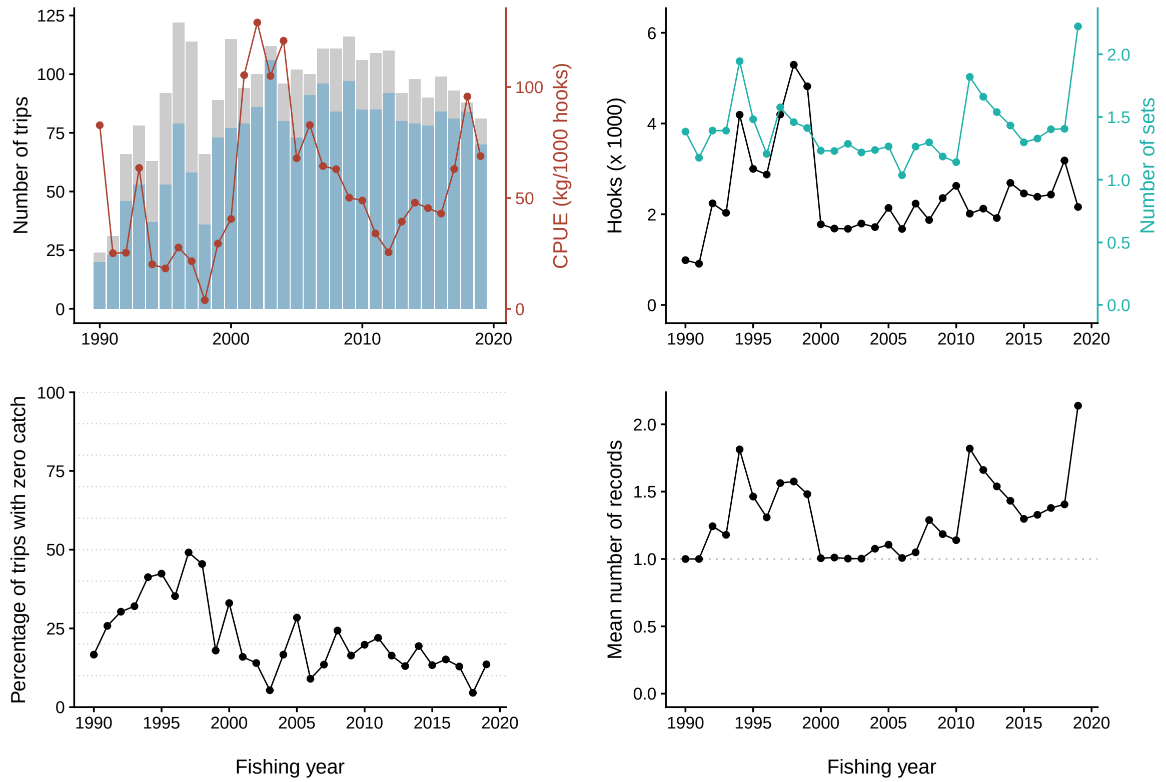

Figure G-103: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 3/5 BLL daily, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all daily records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the daily resolution over time.

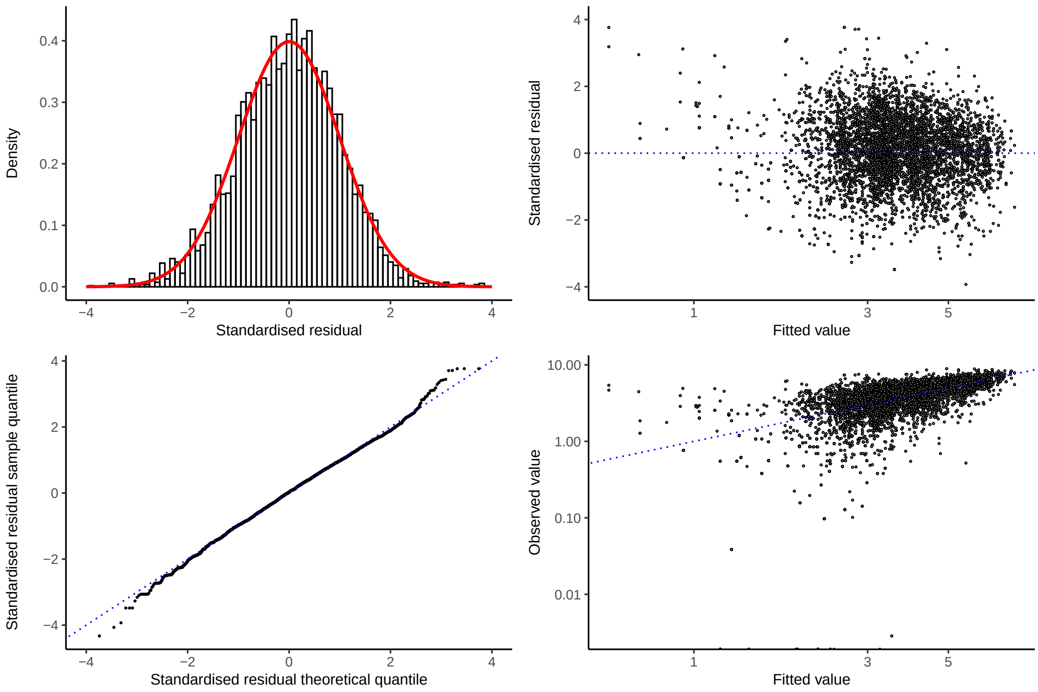

Figure G-104: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 3/5 BLL daily: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-43: Summary of stepwise selection for binomial occurrence model for SCH 3/5 BLL daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	15301	2.50	2.50	*
+ target_species	3.00	14338	8.70	6.20	*
+ vessel_key	28.00	13859	12.10	3.40	*
+ month	11.00	13699	13.30	1.20	*
+ effort_num	1.00	13630	13.70	0.50	
+ stat_area	8.00	13567	14.30	0.50	
+ ns(log(total_hook_num), 3)	3.00	13527	14.50	0.30	

Table G-44: Summary of stepwise selection for positive catch model for SCH 3/5 BLL daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	21348	4.30	4.30	*
+ target_species	3.00	19616	30.40	26.10	*
+ vessel_key	28.00	19128	37.00	6.60	*
+ month	11.00	18764	41.30	4.30	*
+ stat_area	8.00	18385	45.40	4.10	*
+ ns(log(total_hook_num), 3)	3.00	18320	46.10	0.70	
+ effort_num	1.00	18310	46.20	0.10	

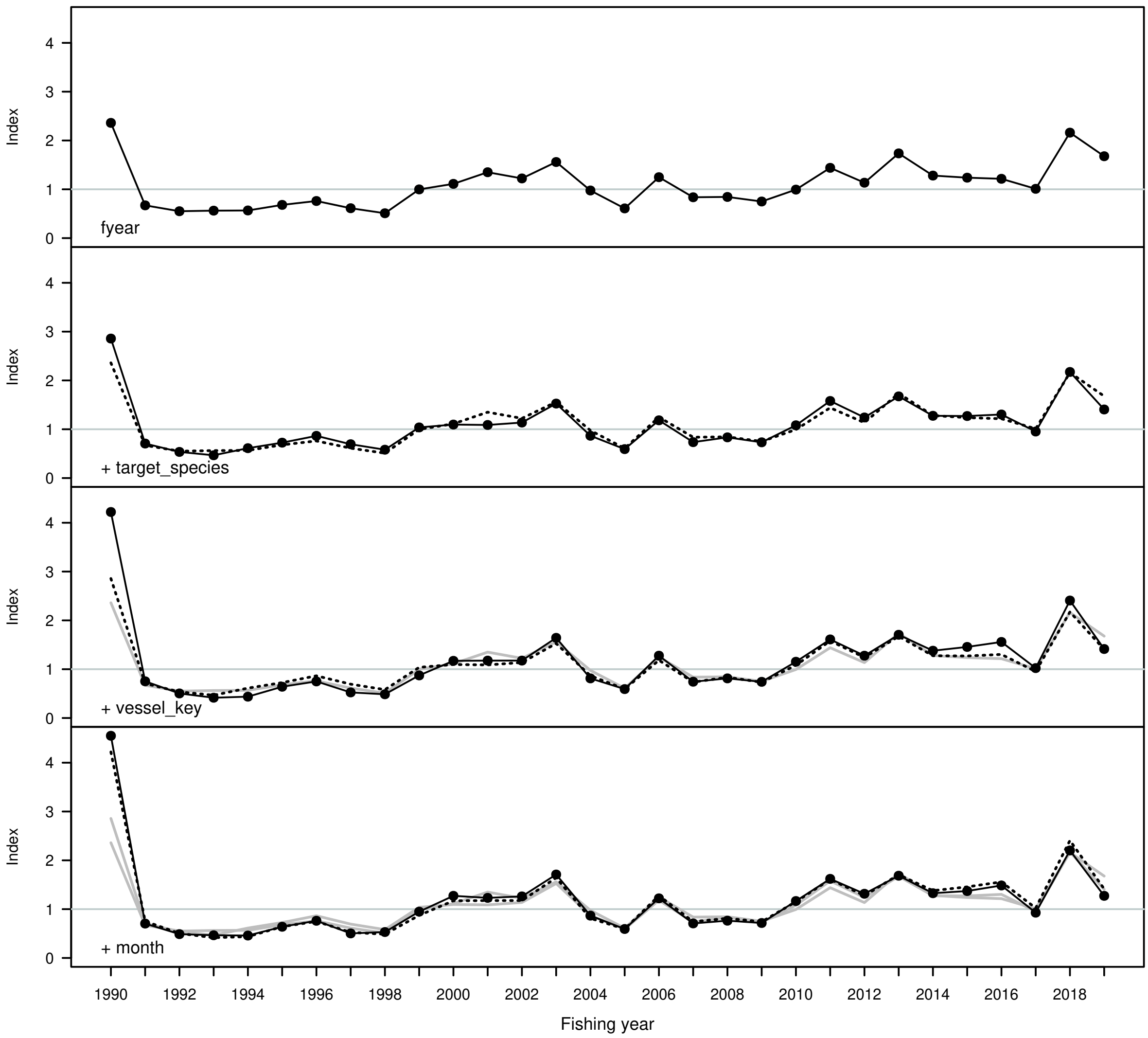

Figure G-105: Stepwise plot for the binomial occurrence model for SCH 3/5 BLL daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

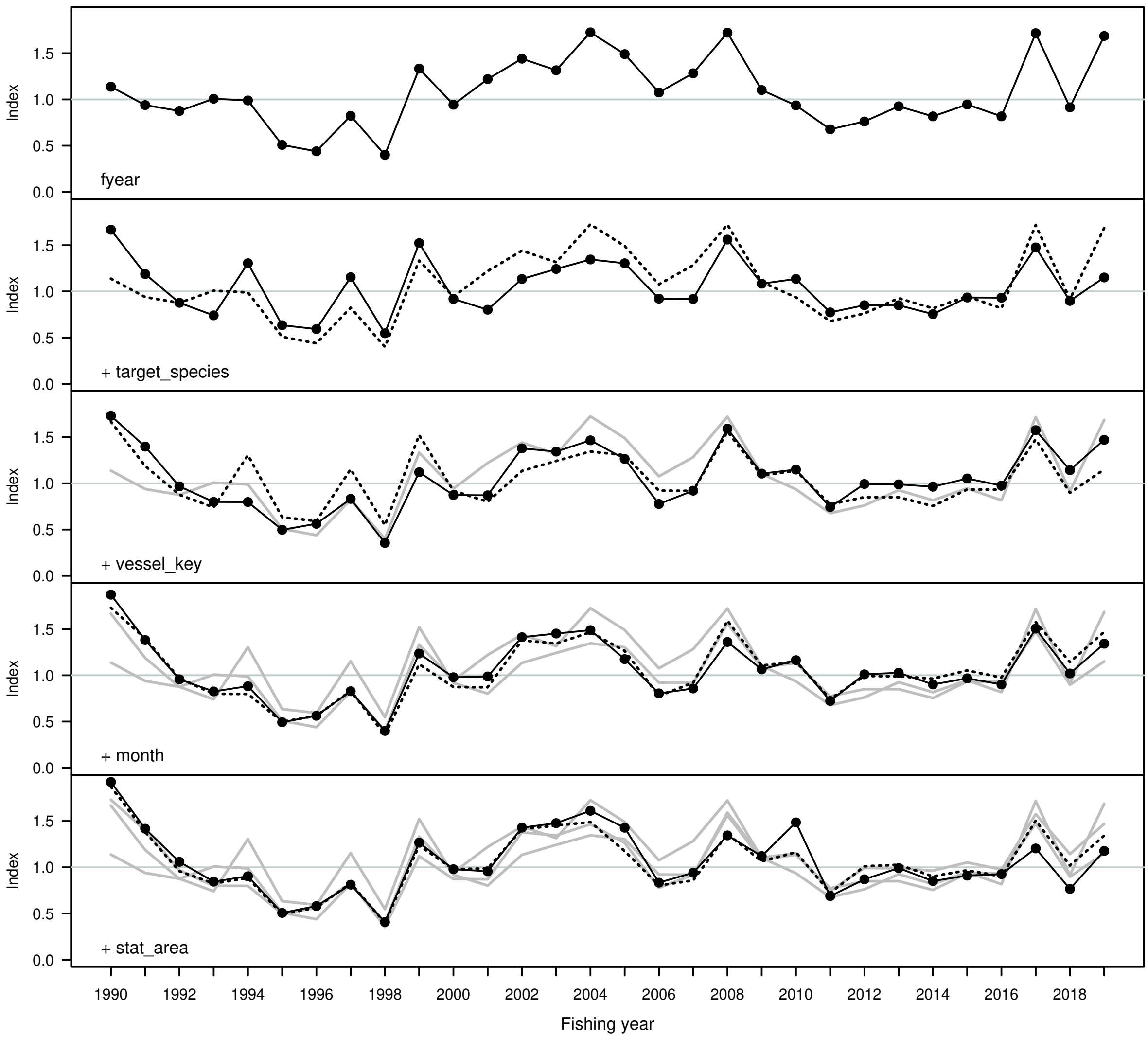

Figure G-106: Stepwise plot for the positive lognormal model for SCH 3/5 BLL daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

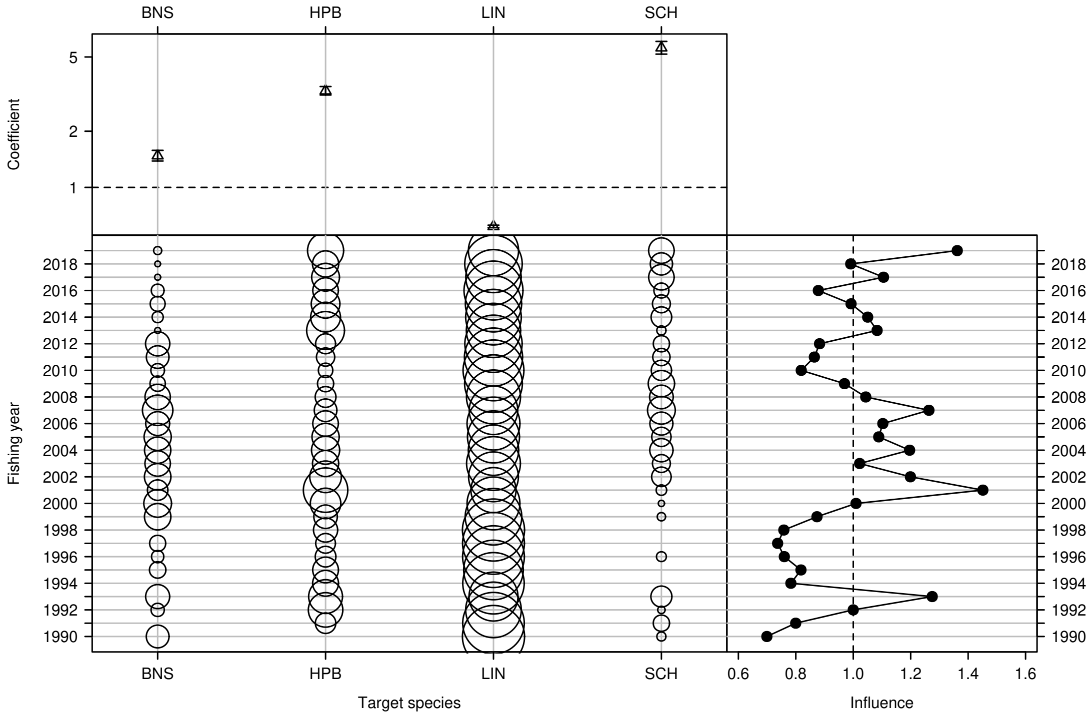

Figure G-107: Influence plot for target species for the lognormal model of school shark in SCH 3/5 BLL daily, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

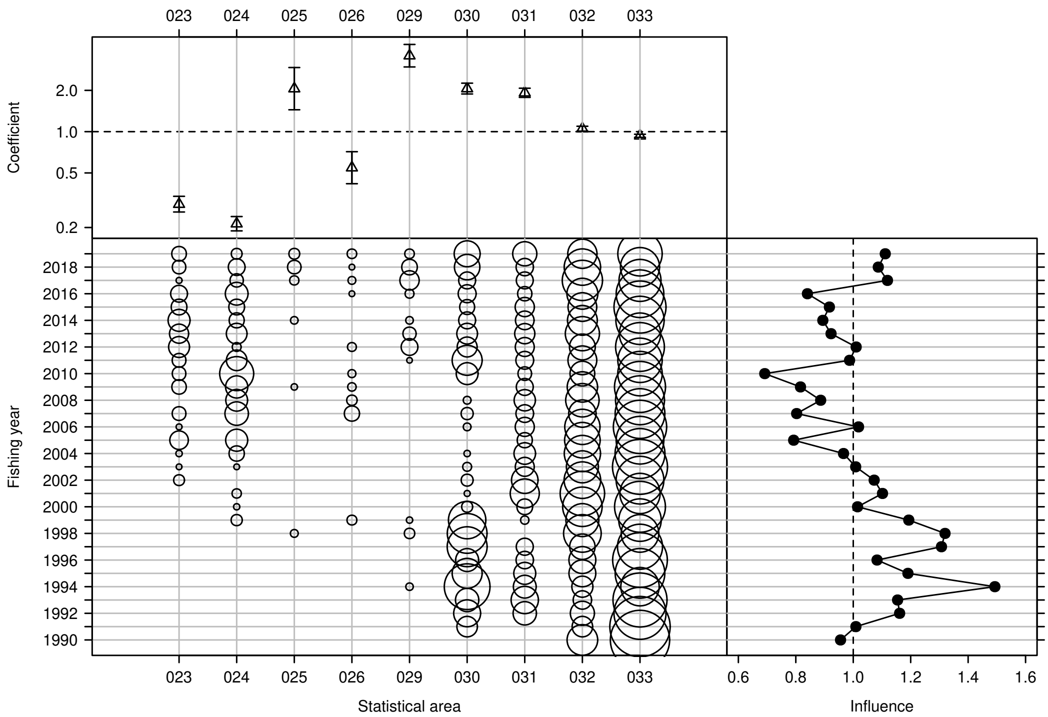

Figure G-108: Influence plot for statistical area for the lognormal model of school shark in SCH 3/5 BLL daily, showing model coefficients for each statistical area (top panel), the distribution of observations over time across each statistical area (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

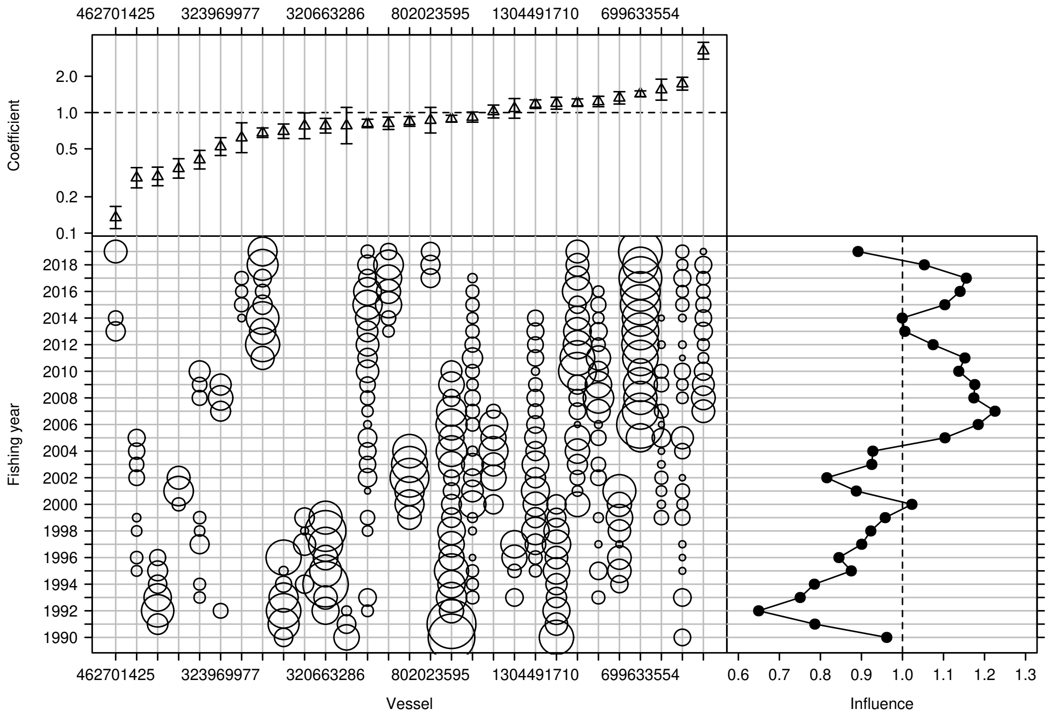

Figure G-109: Influence plot for vessel for the lognormal model of school shark in SCH 3/5 BLL daily, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

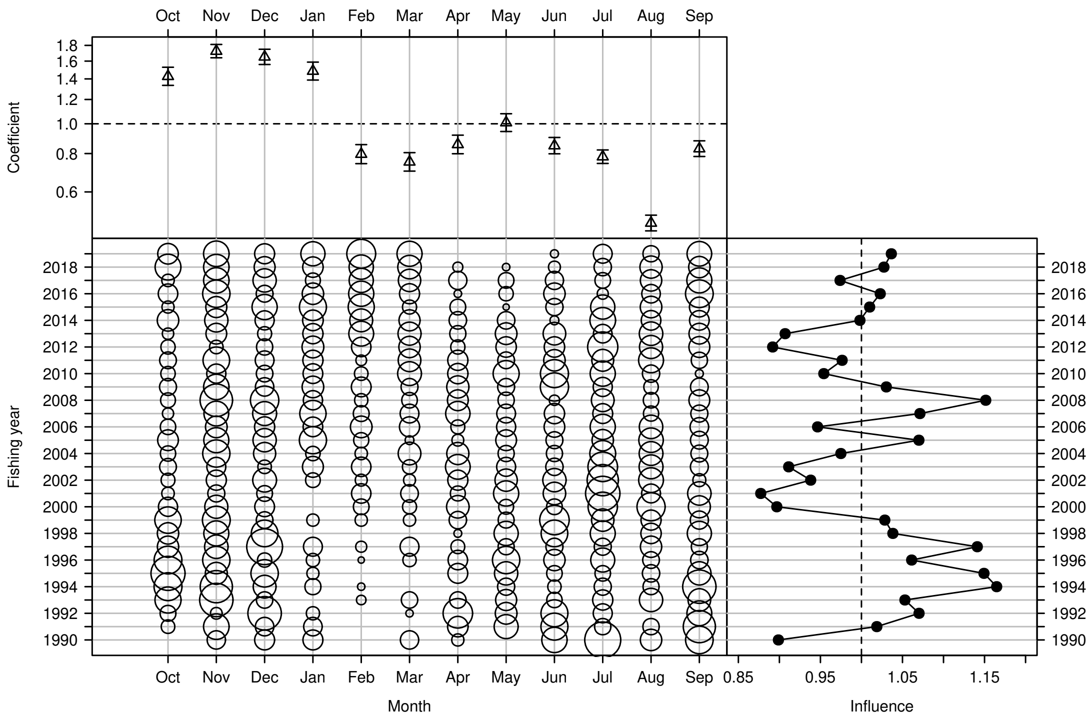

Figure G-110: Influence plot for month for the lognormal model of school shark in SCH 3/5 BLL daily, showing model coefficients for each month (top panel), the distribution of observations over time across each month (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

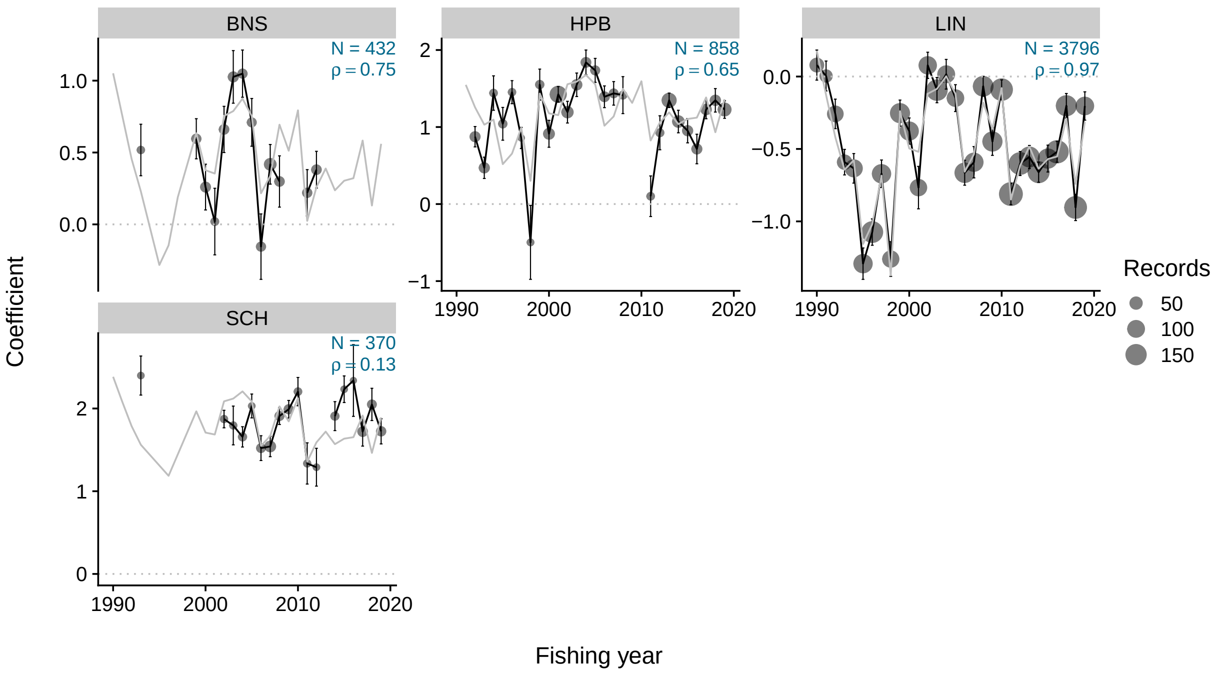

Figure G-111: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 3/5 BLL daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

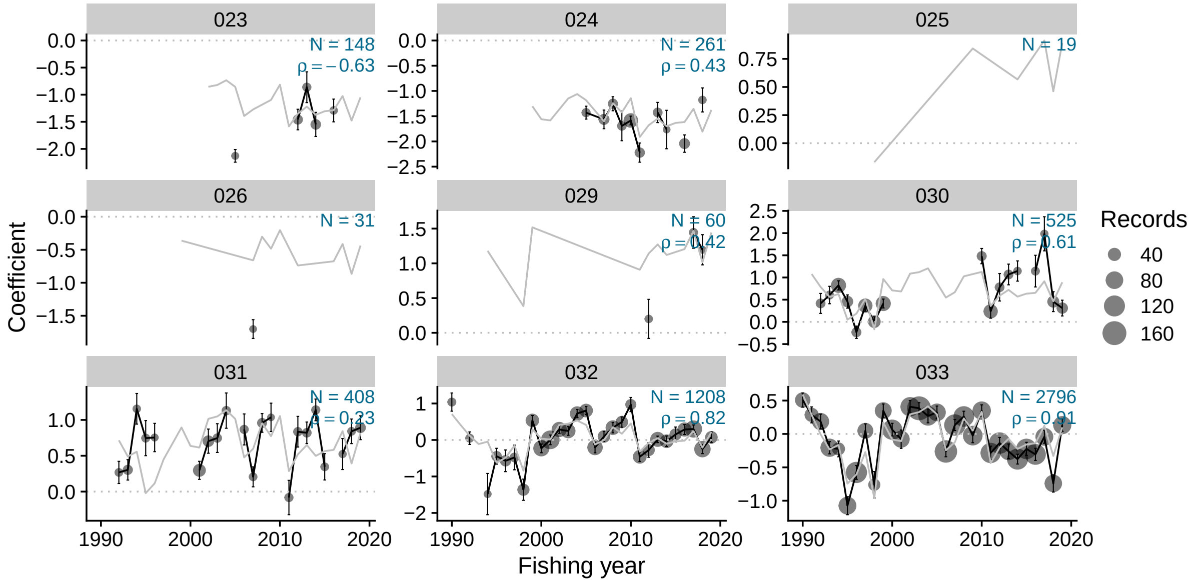

Figure G-112: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 3/5 BLL daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-45: Standardised binomial, positive (lognormal) and combined indices for SCH 3/5 BLL daily, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5^{th}	97.5^{th}
1990	2.193	1.959	4.286	2.570	7.103
1991	0.811	1.432	1.162	0.704	1.777
1992	0.615	1.068	0.657	0.450	0.912
1993	0.592	0.850	0.503	0.345	0.690
1994	0.588	0.912	0.536	0.363	0.748
1995	0.753	0.513	0.386	0.286	0.512
1996	0.858	0.584	0.501	0.383	0.651
1997	0.633	0.813	0.515	0.355	0.720
1998	0.661	0.412	0.272	0.186	0.374
1999	1.000	1.279	1.279	0.979	1.646
2000	1.199	0.988	1.185	0.921	1.524
2001	1.174	0.963	1.131	0.870	1.460
2002	1.195	1.427	1.707	1.310	2.238
2003	1.422	1.483	2.108	1.609	2.717
2004	0.940	1.620	1.522	1.153	1.972
2005	0.715	1.424	1.019	0.737	1.319
2006	1.173	0.838	0.983	0.778	1.237
2007	0.814	0.944	0.769	0.583	0.974
2008	0.857	1.359	1.164	0.891	1.455
2009	0.823	1.132	0.932	0.702	1.199
2010	1.140	1.488	1.697	1.307	2.144
2011	1.383	0.692	0.957	0.753	1.223
2012	1.227	0.873	1.070	0.846	1.333
2013	1.413	0.999	1.411	1.086	1.818
2014	1.229	0.853	1.049	0.828	1.292
2015	1.257	0.913	1.148	0.885	1.487
2016	1.316	0.929	1.224	0.964	1.551
2017	0.981	1.213	1.190	0.886	1.547
2018	1.614	0.770	1.242	0.897	1.652
2019	1.202	1.176	1.413	1.072	1.863

G.10 Lower SCH 3 & SCH 5 bottom trawl (trip effort)

Table G-46: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 3/5 BT trip.

Variable	Value
Label	BT35_trip
Forms	CEL, TCP, TCE, ERS - Trawl
Period	1989-10-01 to 2019-09-30
Resolution	Trip
Core fleet (min years)	5
Core fleet (min trips)	5
Target species	BAR, RCO, TAR, ELE, GUR, FLA
Statistical areas	022, 024, 025, 026, 028, 030, 032, 033

Table G-47: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 3/5 BT trip. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (tows)	Catch (t)	Positive rate
1990	44	2 075	2 075	8 816	39.26	24.14
1991	45	2 344	2 344	10 415	43.00	25.64
1992	55	2 347	2 347	10 378	48.29	31.91
1993	58	2 556	2 556	12 376	51.98	33.80
1994	60	2 544	2 544	11 202	32.22	27.56
1995	58	2 933	2 933	11 658	52.31	28.64
1996	60	2 964	2 964	12 706	85.33	31.11
1997	64	3 208	3 208	15 105	55.72	33.20
1998	62	3 390	3 390	15 898	52.76	31.74
1999	62	3 554	3 554	16 184	83.75	37.54
2000	63	2 809	2 809	14 214	93.77	43.40
2001	62	2 230	2 230	12 943	71.94	42.60
2002	63	2 244	2 244	12 975	81.49	40.91
2003	64	2 587	2 587	15 344	92.05	41.86
2004	59	2 611	2 611	13 543	59.06	29.34
2005	57	2 530	2 530	13 017	68.78	33.08
2006	59	2 230	2 230	11 911	83.11	36.23
2007	55	1 831	1 831	11 005	59.71	39.38
2008	56	1 539	1 539	8 986	35.81	33.92
2009	50	1 770	1 770	9 303	34.58	29.44
2010	49	1 756	1 756	9 761	51.78	38.84
2011	53	1 646	1 646	8 753	41.80	37.24
2012	49	1 826	1 826	9 591	32.33	32.26
2013	52	2 066	2 066	10 670	33.07	30.54
2014	52	2 179	2 179	10 677	45.71	34.47
2015	53	1 727	1 727	8 718	42.46	41.52
2016	50	1 984	1 984	9 436	56.71	43.09
2017	49	1 941	1 941	9 068	38.59	40.39
2018	46	1 618	1 618	7 503	53.85	37.76
2019	43	1 370	1 370	7 114	35.88	43.80

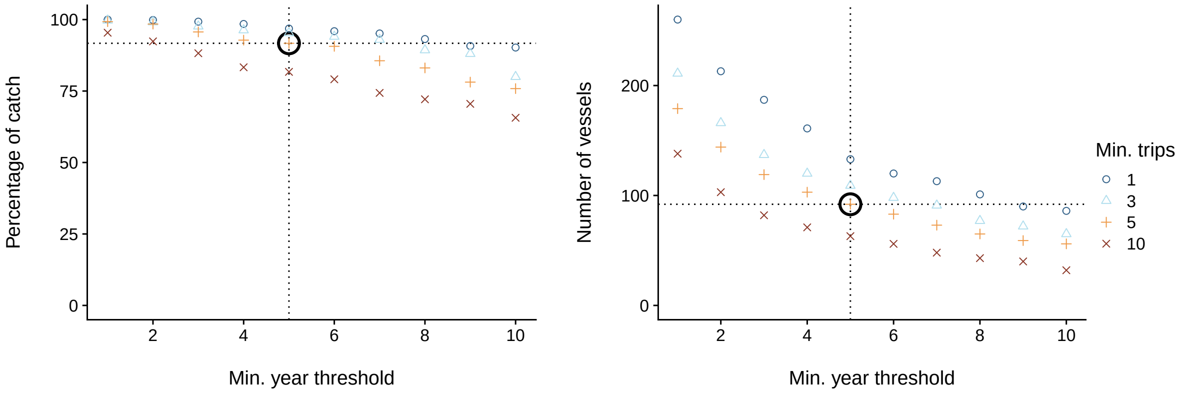

Figure G-113: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 3/5 BT trip. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

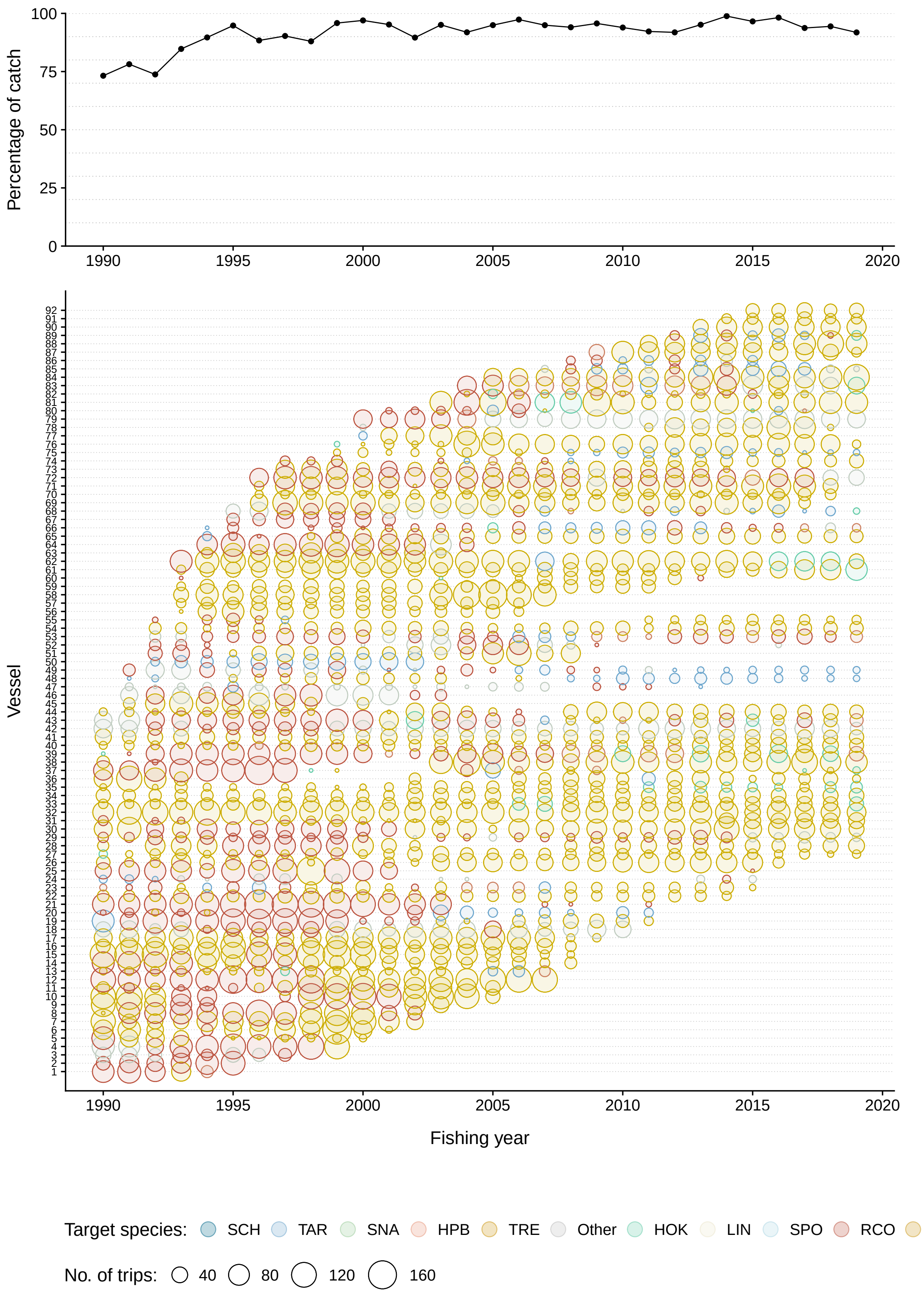

Figure G-114: Proportion of school shark catch retained by the core fleet in SCH 3/5 BT trip (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

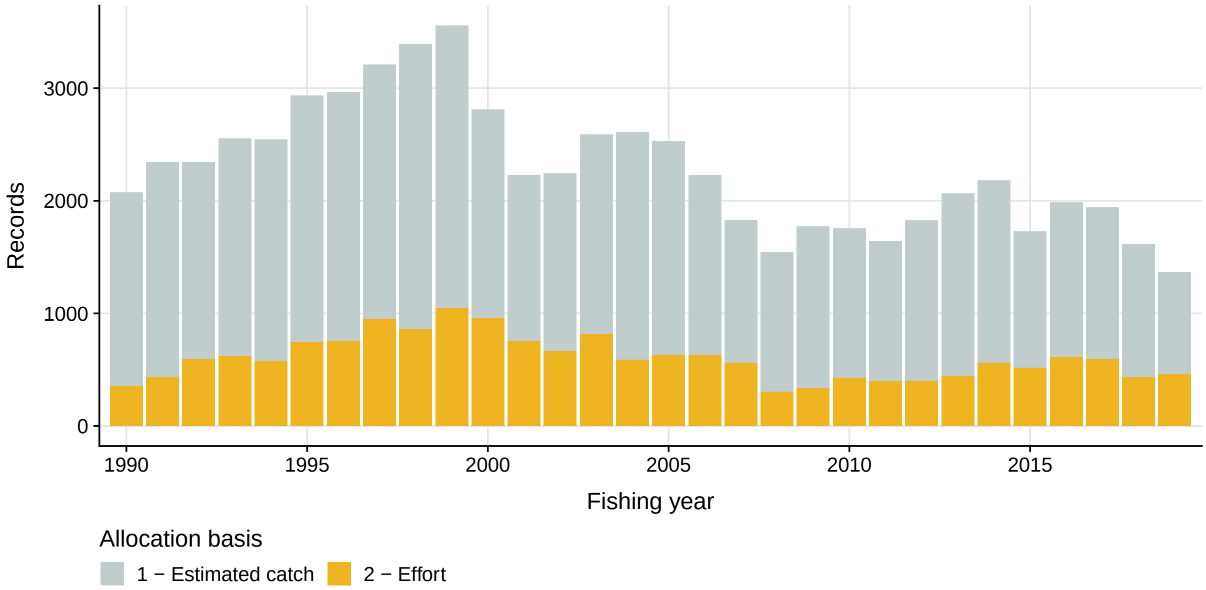

Figure G-115: Number of records by fishing year for the core fleet in SCH 3/5 BT trip. Records with landings allocated based on estimated catch are highlighted in yellow.

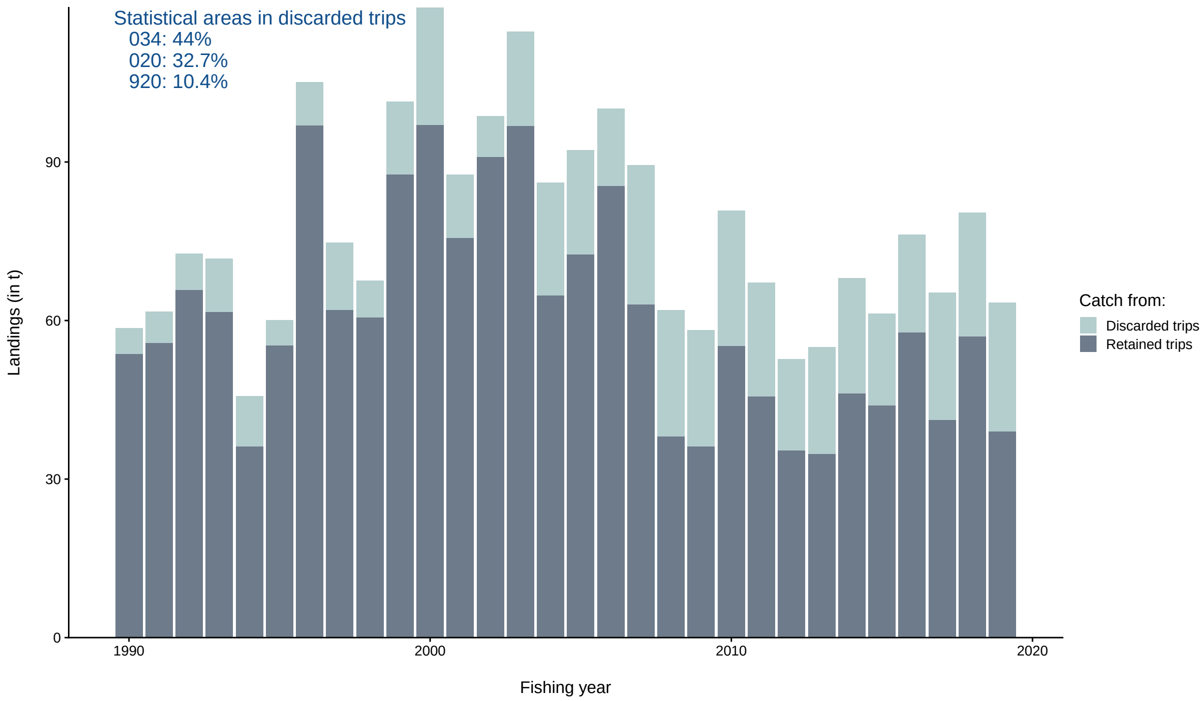

Figure G-116: Total landings and landings retained in the analysis for SCH 3/5 BT trip for the full fleet following data preparation to remove trips spanning multiple catch-per-unit-effort (CPUE) units. The top three statistical areas most often present in the omitted trips are noted in the top-left corner, including the corresponding proportion of discarded trips.

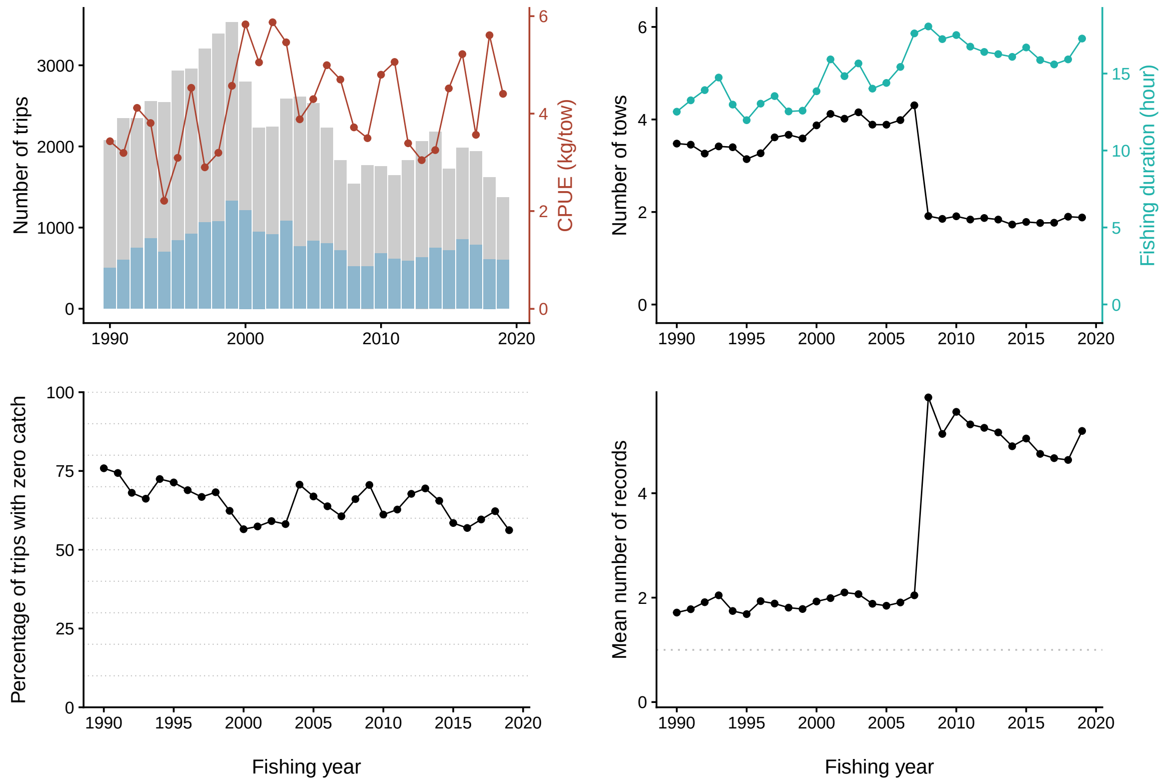

Figure G-117: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 3/5 BT trip, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all trip records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the trip resolution over time.

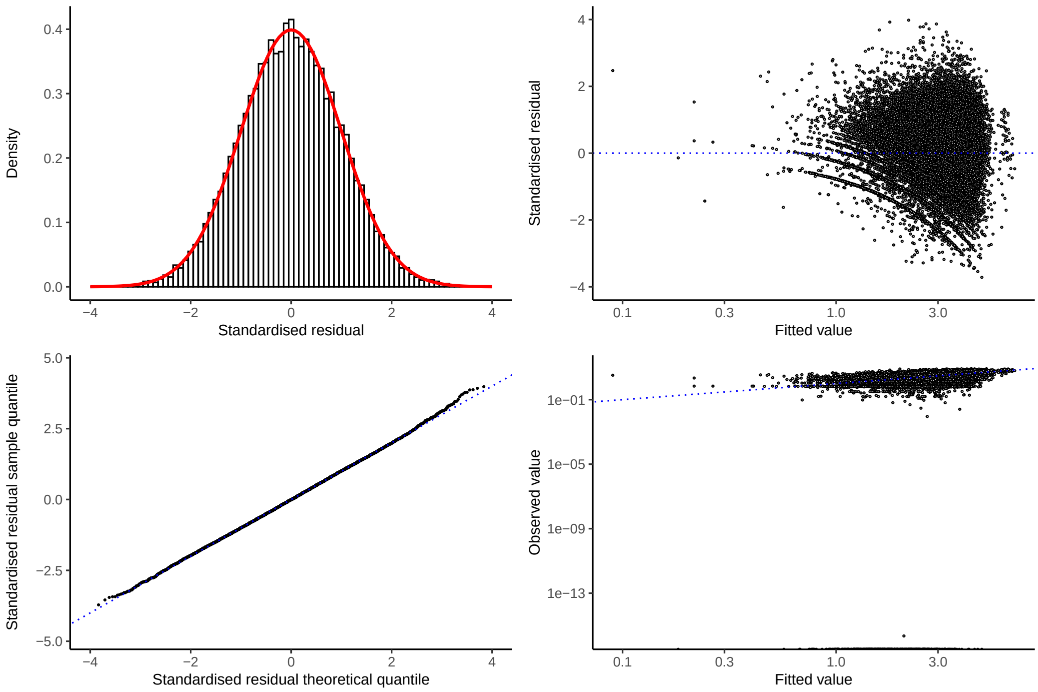

Figure G-118: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 3/5 BT trip: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-48: Summary of stepwise selection for binomial occurrence model for SCH 3/5 BT trip. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	87603	1.00	1.00	*
+ vessel_key	91.00	72971	17.80	16.70	*
+ month	11.00	68675	22.60	4.90	*
+ ns(log(fishing_duration), 3)	3.00	66250	25.40	2.70	*
+ stat_area	7.00	65055	26.80	1.40	*
+ target_species	5.00	64706	27.20	0.40	
+ effort_num	1.00	64663	27.20	0.10	

Table G-49: Summary of stepwise selection for positive catch model for SCH 3/5 BT trip. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	90185	1.40	1.40	*
+ vessel_key	91.00	83375	26.50	25.10	*
+ ns(log(fishing_duration), 3)	3.00	80783	34.10	7.60	*
+ month	11.00	80391	35.20	1.10	*
+ stat_area	6.00	80076	36.10	0.90	
+ target_species	5.00	79887	36.60	0.50	
+ effort_num	1.00	79875	36.70	0.00	

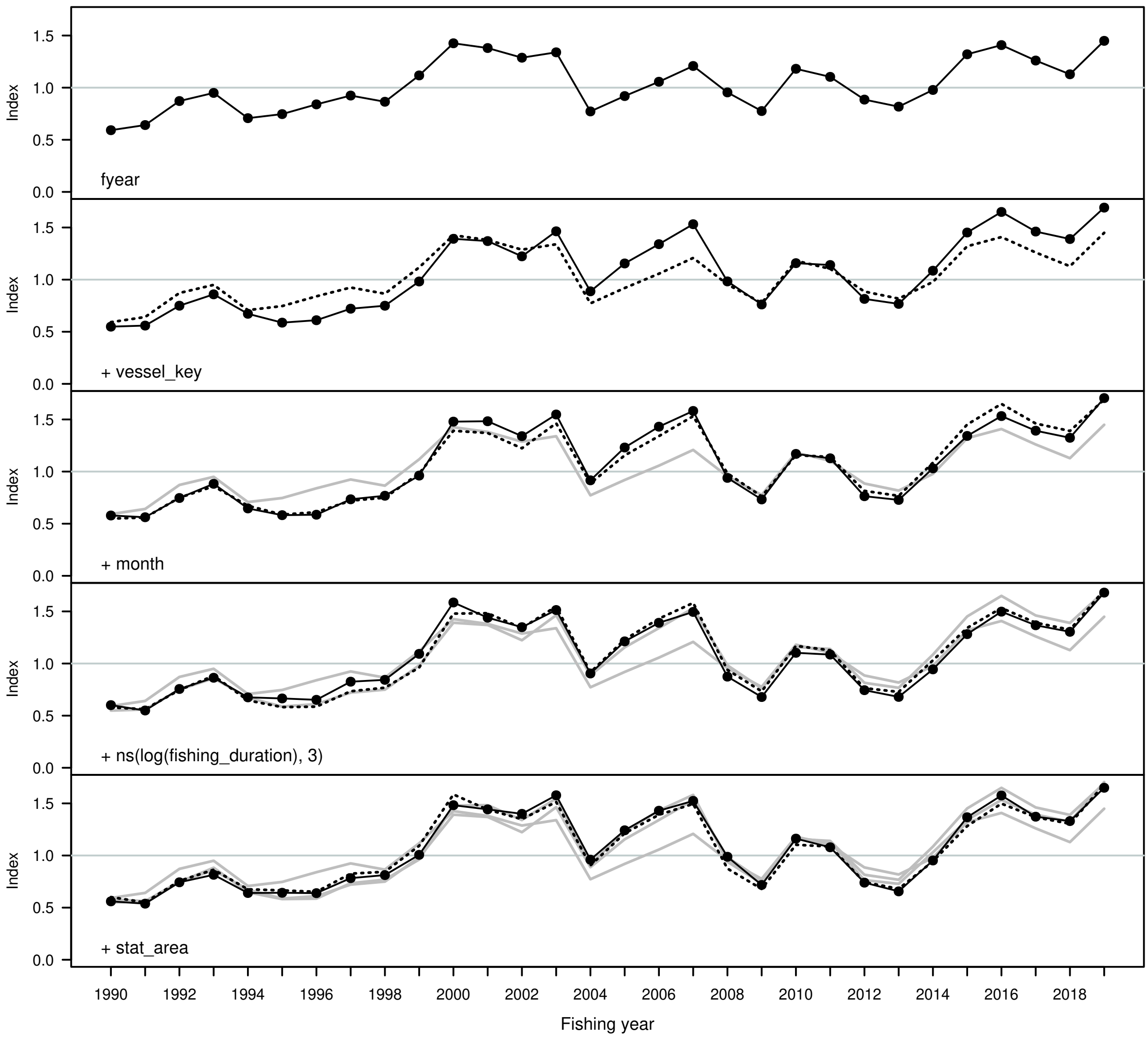

Figure G-119: Stepwise plot for the binomial occurrence model for SCH 3/5 BT trip showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

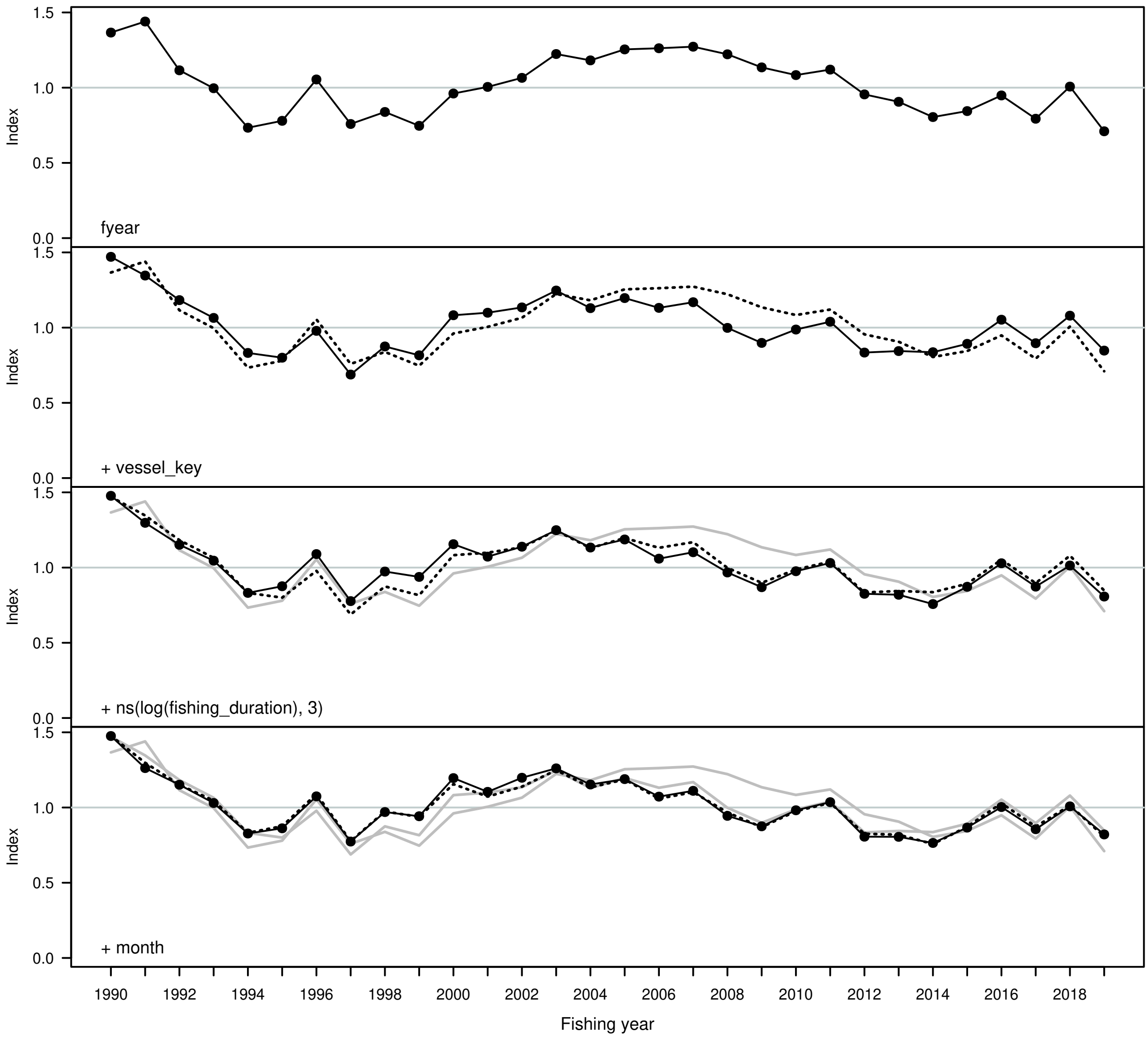

Figure G-120: Stepwise plot for the positive lognormal model for SCH 3/5 BT trip showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

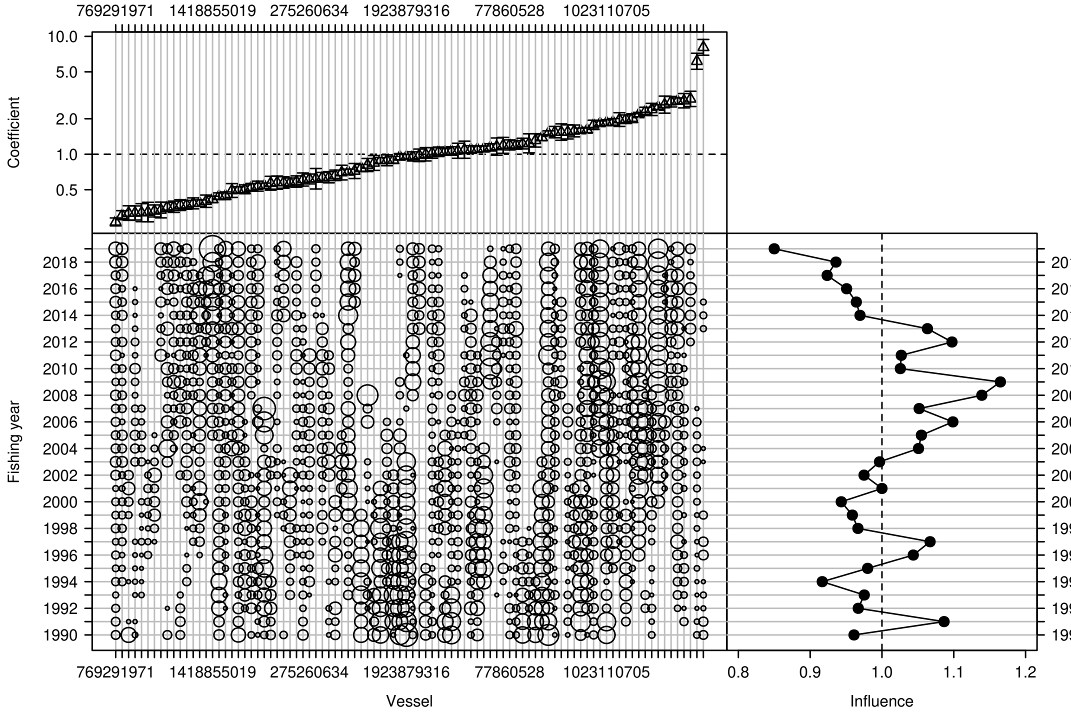

Figure G-121: Influence plot for vessel for the lognormal model of school shark in SCH 3/5 BT trip, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

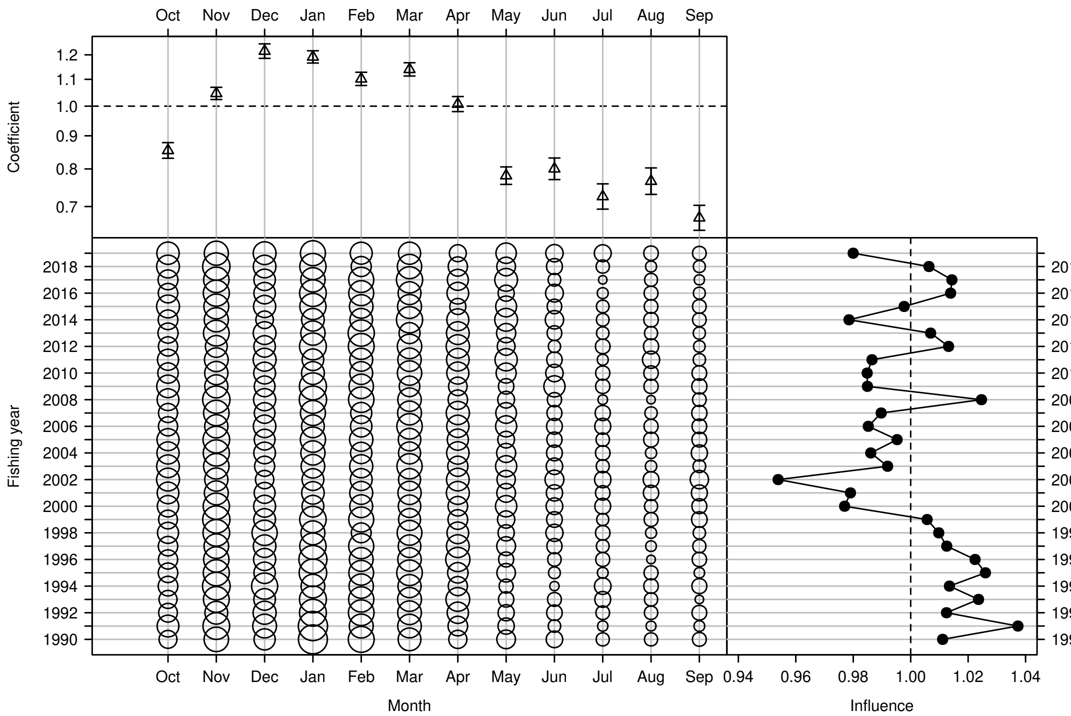

Figure G-122: Influence plot for month for the lognormal model of school shark in SCH 3/5 BT trip, showing model coefficients for each month (top panel), the distribution of observations over time across each month (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

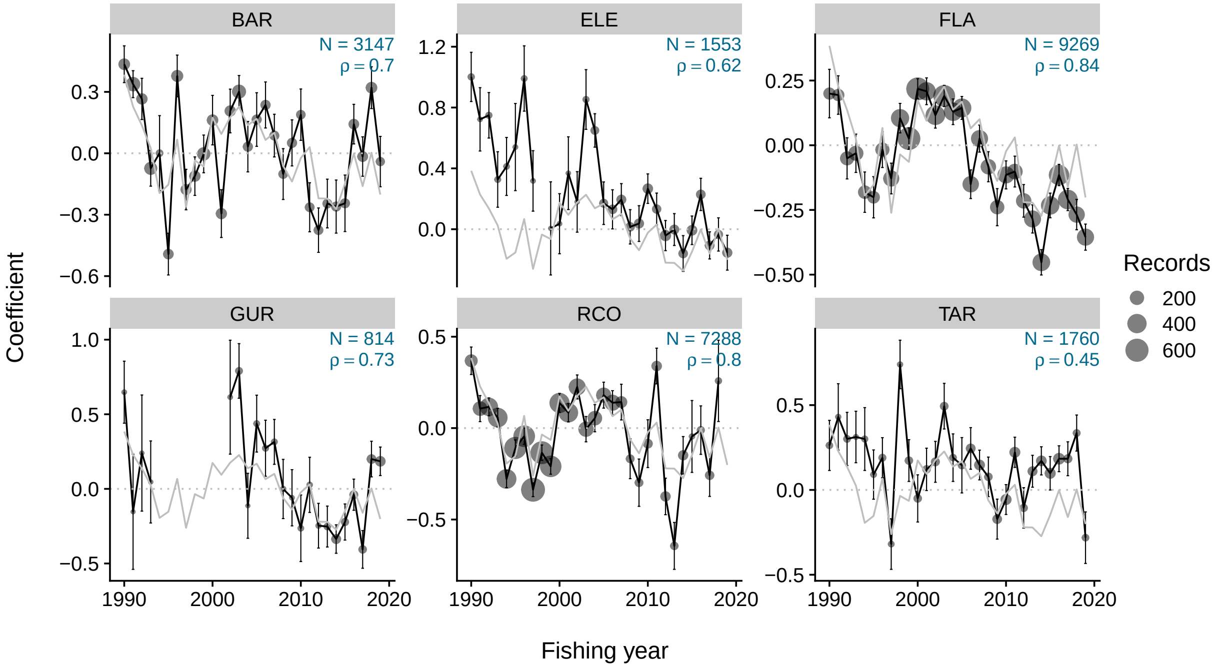

Figure G-123: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 3/5 BT trip, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

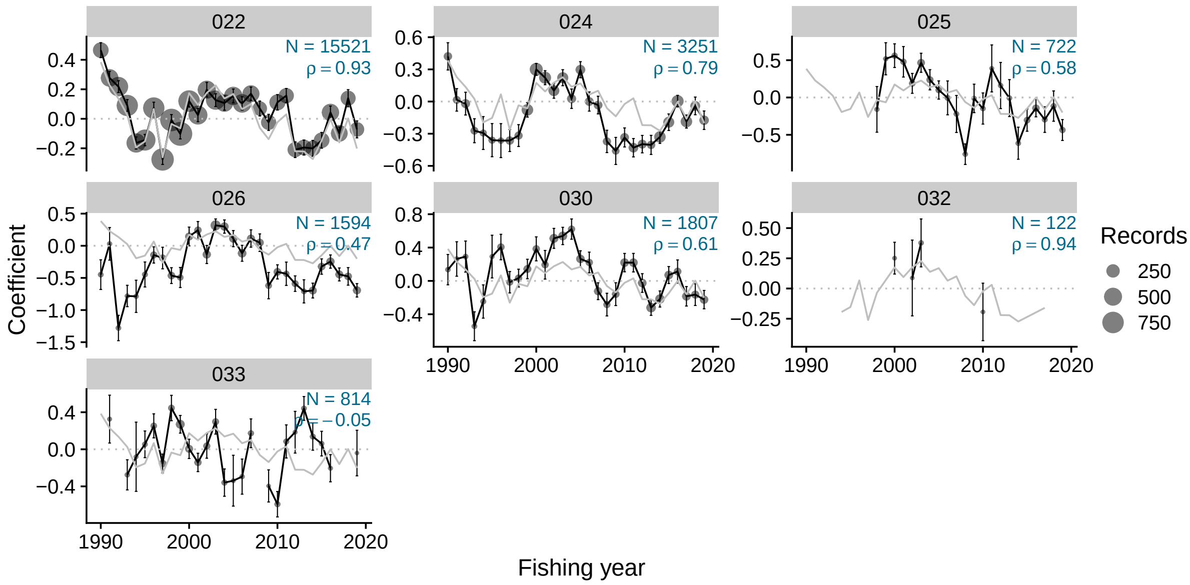

Figure G-124: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 3/5 BT trip, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-50: Standardised binomial, positive (lognormal) and combined indices for SCH 3/5 BT trip, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5th	97.5th
1990	0.677	1.478	1.001	0.858	1.167
1991	0.657	1.262	0.829	0.709	0.954
1992	0.833	1.152	0.959	0.840	1.081
1993	0.886	1.031	0.914	0.812	1.022
1994	0.749	0.828	0.621	0.539	0.709
1995	0.749	0.864	0.647	0.574	0.729
1996	0.746	1.074	0.801	0.712	0.899
1997	0.863	0.775	0.669	0.603	0.738
1998	0.886	0.972	0.861	0.779	0.955
1999	1.018	0.941	0.957	0.876	1.041
2000	1.279	1.196	1.530	1.372	1.697
2001	1.260	1.105	1.393	1.242	1.554
2002	1.239	1.199	1.486	1.328	1.672
2003	1.323	1.262	1.671	1.497	1.854
2004	0.989	1.156	1.143	1.015	1.275
2005	1.158	1.189	1.377	1.225	1.547
2006	1.253	1.072	1.344	1.184	1.507
2007	1.299	1.111	1.443	1.280	1.631
2008	1.006	0.950	0.955	0.833	1.091
2009	0.814	0.876	0.713	0.609	0.818
2010	1.112	0.982	1.093	0.963	1.241
2011	1.063	1.037	1.102	0.959	1.245
2012	0.830	0.809	0.671	0.582	0.772
2013	0.762	0.806	0.614	0.535	0.701
2014	0.982	0.764	0.750	0.660	0.839
2015	1.224	0.869	1.063	0.944	1.202
2016	1.323	1.003	1.326	1.170	1.487
2017	1.226	0.858	1.052	0.935	1.184
2018	1.204	1.011	1.217	1.066	1.381
2019	1.356	0.822	1.114	0.957	1.279

G.11 SCH 7, SCH 8 & lower SCH 1W set net (daily effort)

Table G-51: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 7/8/1W SN daily.

Variable	Value
Label	SN781_daily
Forms	CEL, NCE, ERS - Netting
Period	1989-10-01 to 2019-09-30
Resolution	Daily
Core fleet (min years)	5
Core fleet (min trips)	5
Target species	SNA, TRE, SPO, GUR, SCH, SPD
Statistical areas	016, 017, 034, 035, 036, 037, 038, 039, 040, 041, 042

Table G-52: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 7/8/1W SN daily. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (net length [km])	Catch (t)	Positive rate
1990	18	462	593	1 196.0	189.88	71.50
1991	17	478	599	1 183.7	211.92	71.12
1992	21	666	886	1 762.8	239.93	59.37
1993	22	895	1 187	2 157.7	277.76	50.80
1994	27	895	1 279	2 676.7	347.81	55.90
1995	28	1 118	1 475	2 820.2	333.34	48.41
1996	27	736	1 092	2 230.1	318.94	54.49
1997	26	618	939	2 044.5	268.67	54.53
1998	25	641	935	1 904.1	314.91	61.82
1999	25	691	1 013	2 036.0	300.45	60.91
2000	24	573	874	1 857.0	263.74	61.56
2001	24	651	1 045	2 085.8	358.06	56.75
2002	20	474	850	1 761.9	298.59	63.65
2003	21	346	656	1 398.8	196.54	60.82
2004	19	424	882	1 798.2	259.92	65.53
2005	18	300	791	1 749.6	213.79	64.35
2006	17	216	714	1 684.4	282.69	67.23
2007	17	245	742	2 004.9	390.39	78.98
2008	16	258	690	1 912.6	300.30	77.83
2009	15	253	591	1 559.3	300.52	81.73
2010	14	267	588	1 571.3	232.78	73.81
2011	15	244	615	1 582.1	305.84	79.19
2012	16	279	585	1 484.1	229.78	74.19
2013	10	182	463	1 329.0	223.58	79.05
2014	9	161	435	1 277.8	219.38	80.69
2015	9	174	457	1 386.0	200.35	76.59
2016	9	170	514	1 560.9	211.79	80.35
2017	9	167	437	1 334.8	179.94	76.20
2018	7	169	444	1 229.8	167.86	72.97
2019	7	124	322	869.8	100.59	76.71

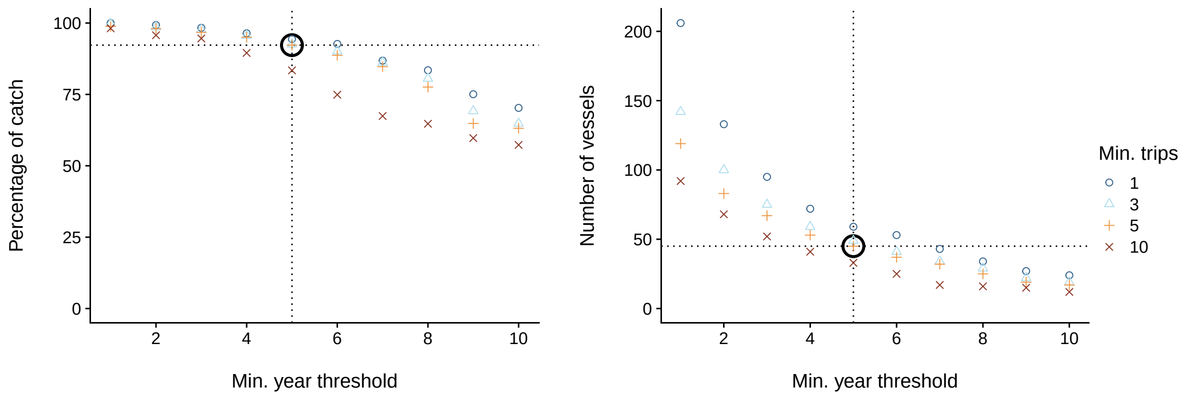

Figure G-125: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 7/8/1W SN daily. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

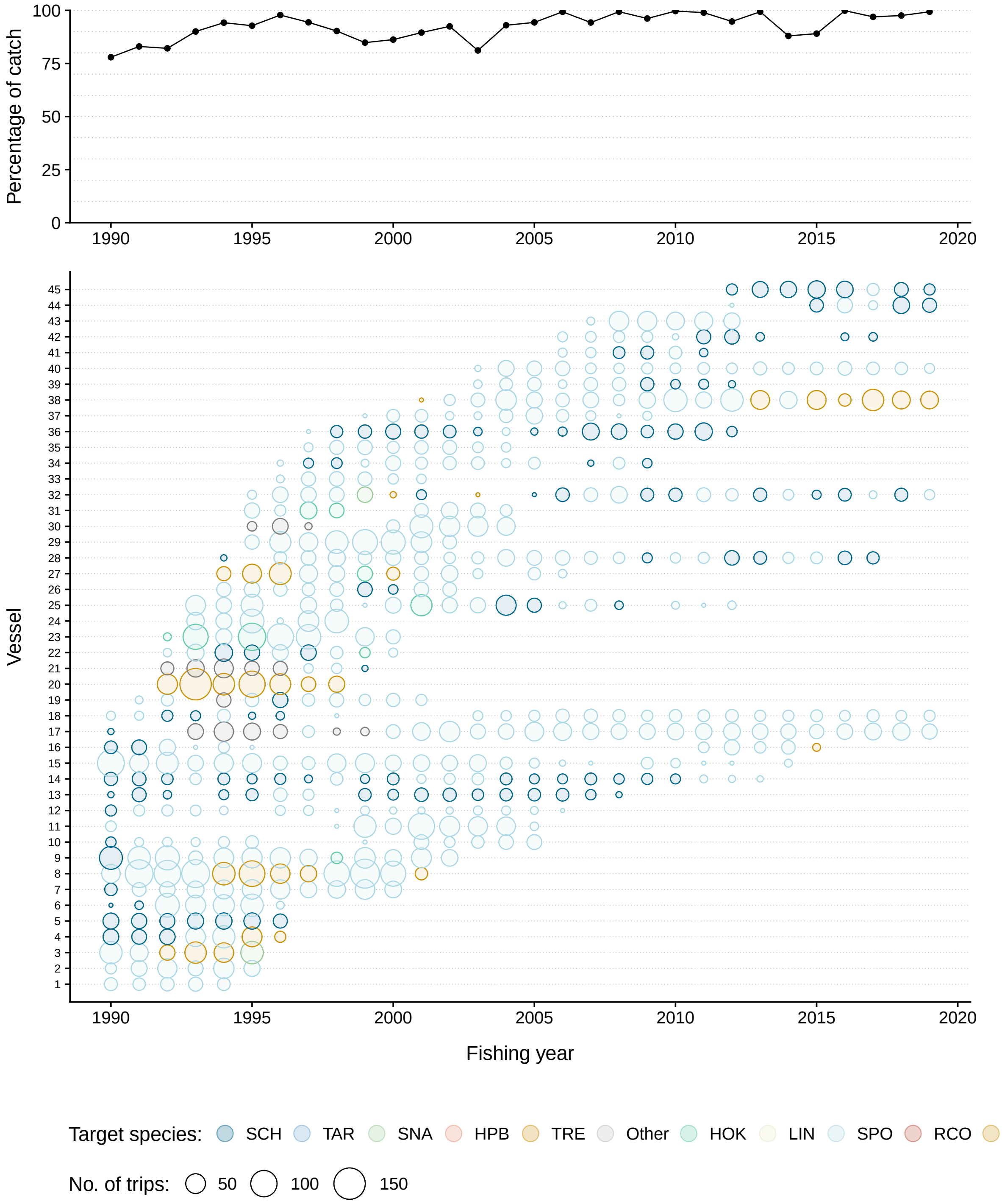

Figure G-126: Proportion of school shark catch retained by the core fleet in SCH 7/8/1W SN daily (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

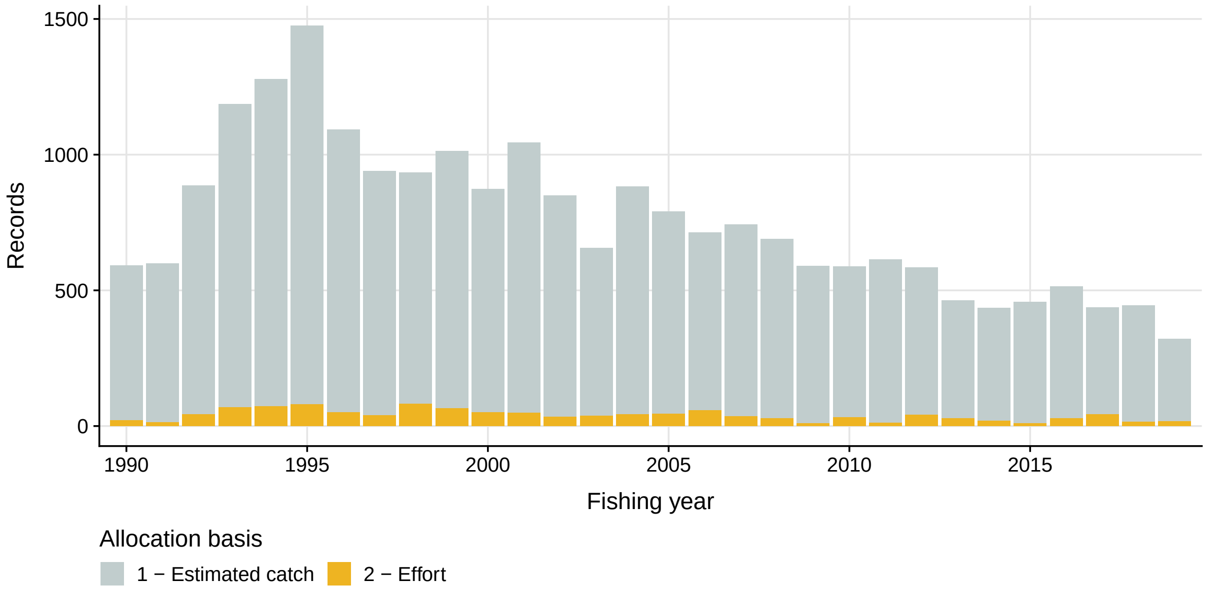

Figure G-127: Number of records by fishing year for the core fleet in SCH 7/8/1W SN daily. Records with landings allocated based on estimated catch are highlighted in yellow.

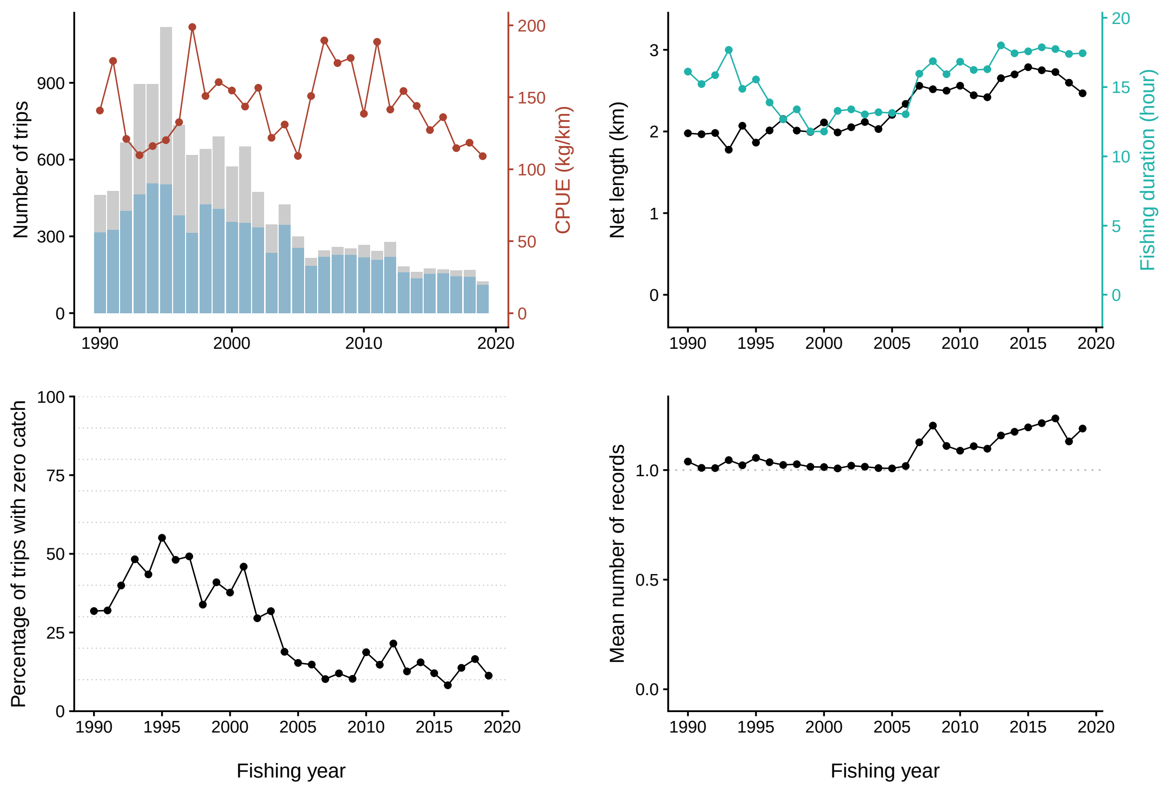

Figure G-128: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 7/8/1W SN daily, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all daily records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the daily resolution over time.

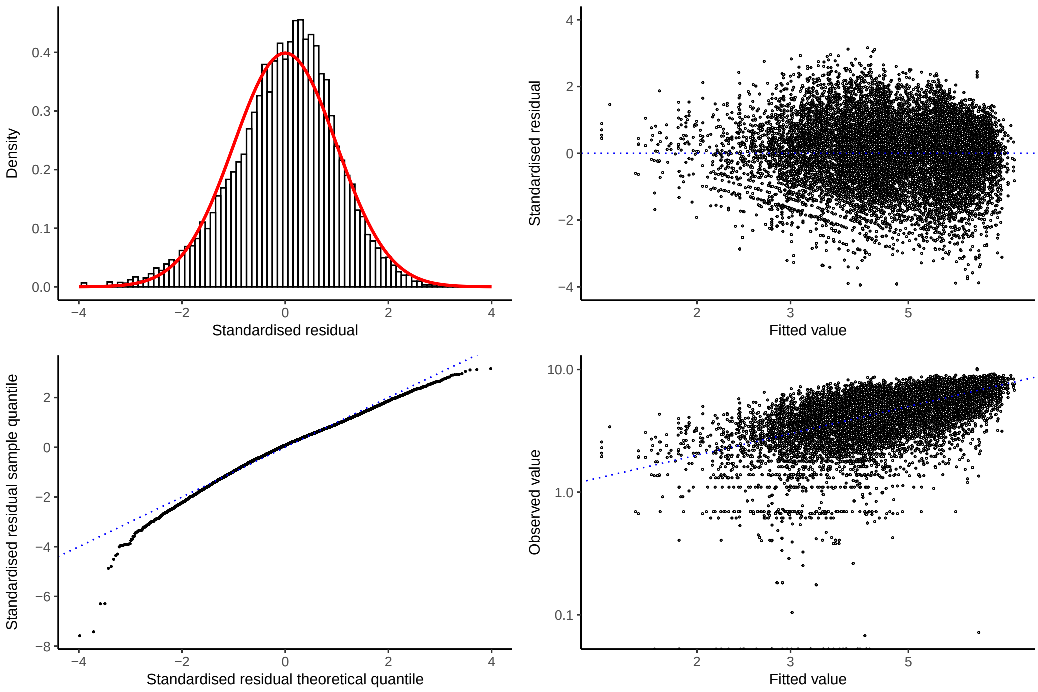

Figure G-129: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 7/8/1W SN daily: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-53: Summary of stepwise selection for binomial occurrence model for SCH 7/8/1W SN daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	28470	3.60	3.60	*
+ target_species	5.00	24022	18.70	15.10	*
+ vessel_key	44.00	22357	24.60	6.00	*
+ month	11.00	21858	26.40	1.80	*
+ stat_area	10.00	21566	27.50	1.10	*
+ ns(log(total_net_length), 3)	3.00	21447	27.90	0.40	

Table G-54: Summary of stepwise selection for positive catch model for SCH 7/8/1W SN daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	60619	1.80	1.80	*
+ target_species	5.00	55370	31.40	29.50	*
+ vessel_key	44.00	52836	42.60	11.20	*
+ stat_area	10.00	52169	45.20	2.60	*
+ month	11.00	51783	46.70	1.50	*
+ ns(log(total_net_length), 3)	3.00	51583	47.40	0.70	

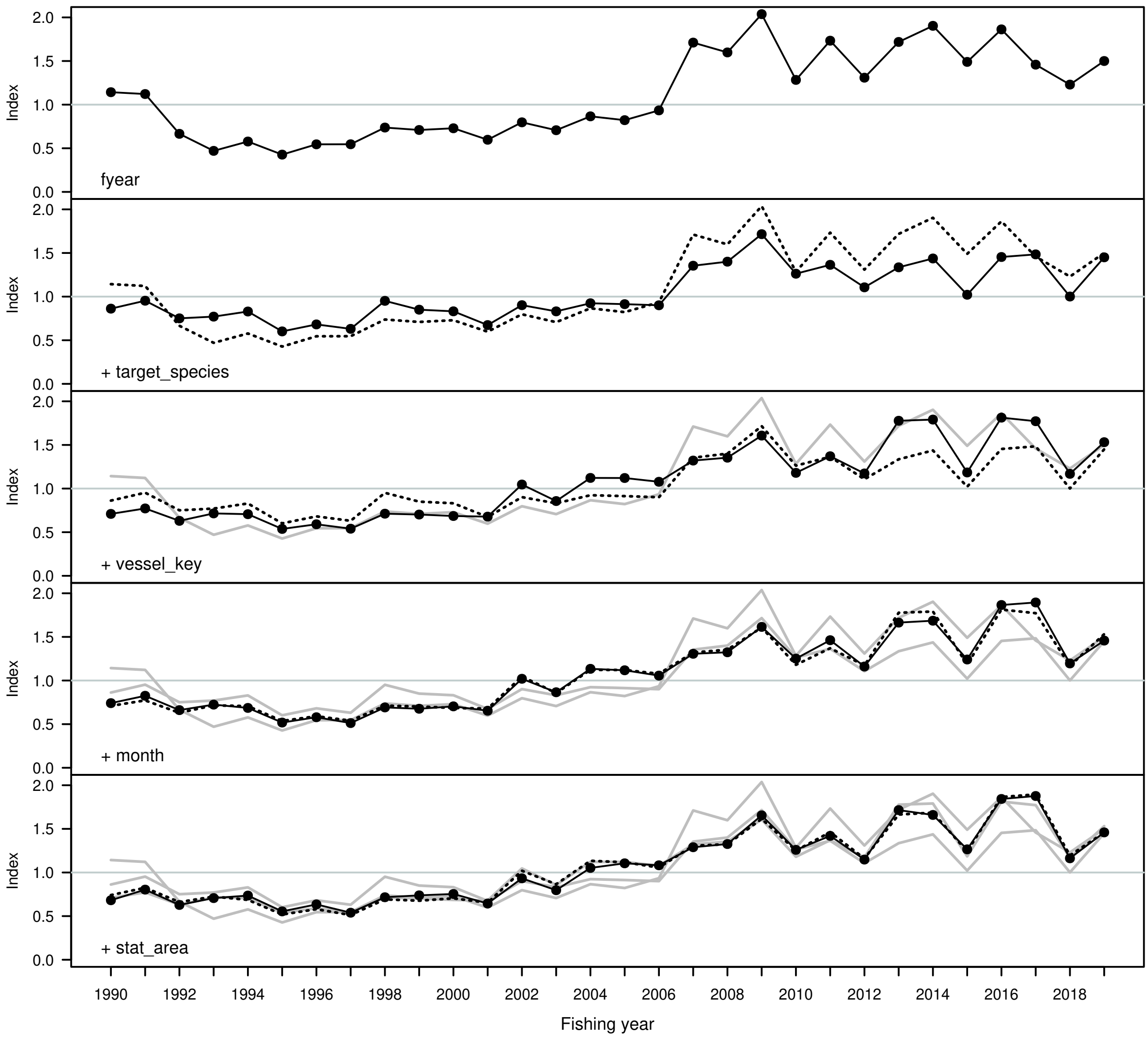

Figure G-130: Stepwise plot for the binomial occurrence model for SCH 7/8/1W SN daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

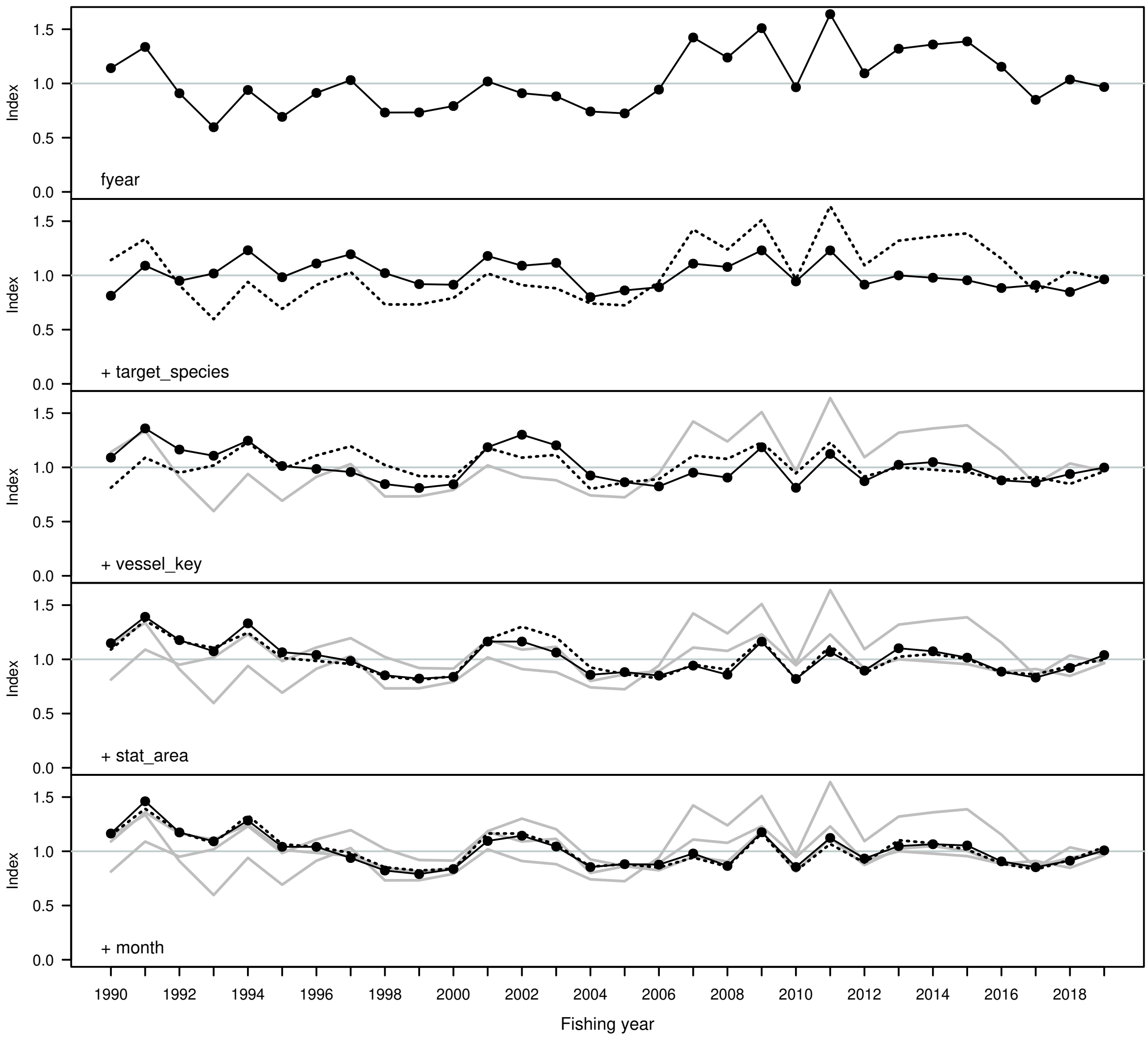

Figure G-131: Stepwise plot for the positive lognormal model for SCH 7/8/1W SN daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

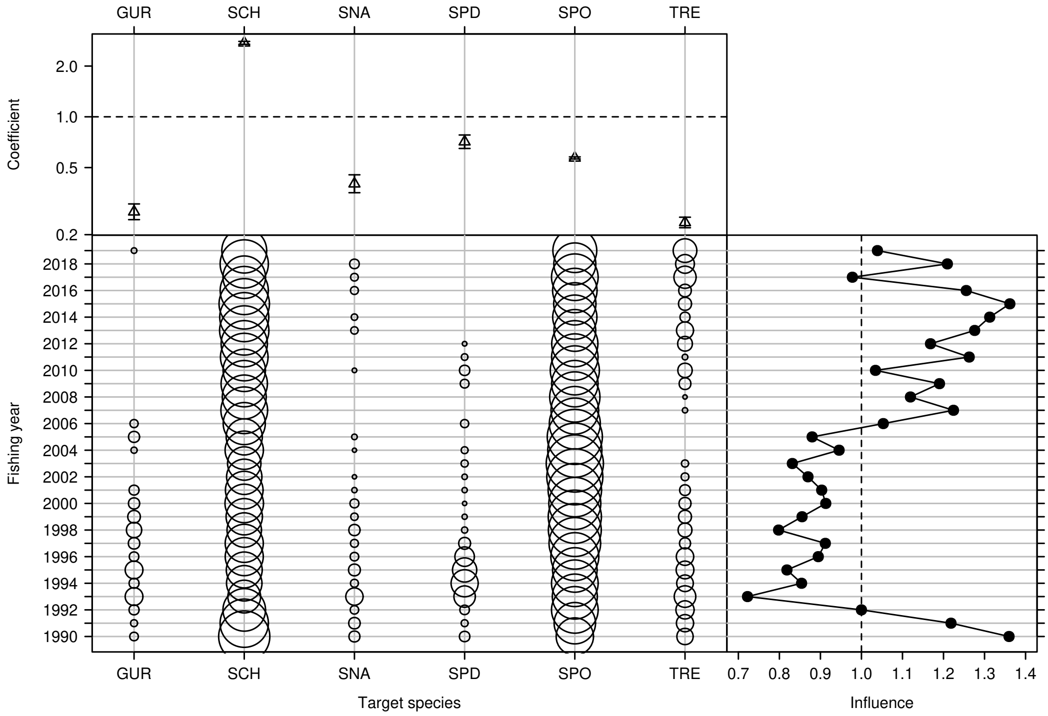

Figure G-132: Influence plot for target species for the lognormal model of school shark in SCH 7/8/1W SN daily, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

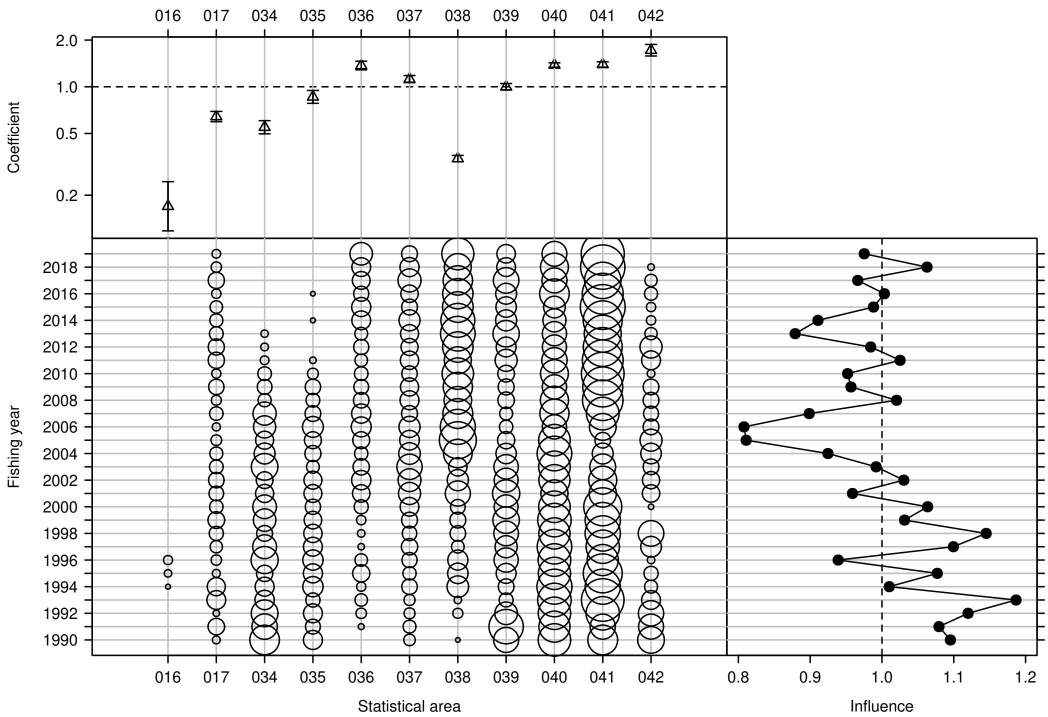

Figure G-133: Influence plot for statistical area for the lognormal model of school shark in SCH 7/8/1W SN daily, showing model coefficients for each statistical area (top panel), the distribution of observations over time across each statistical area (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

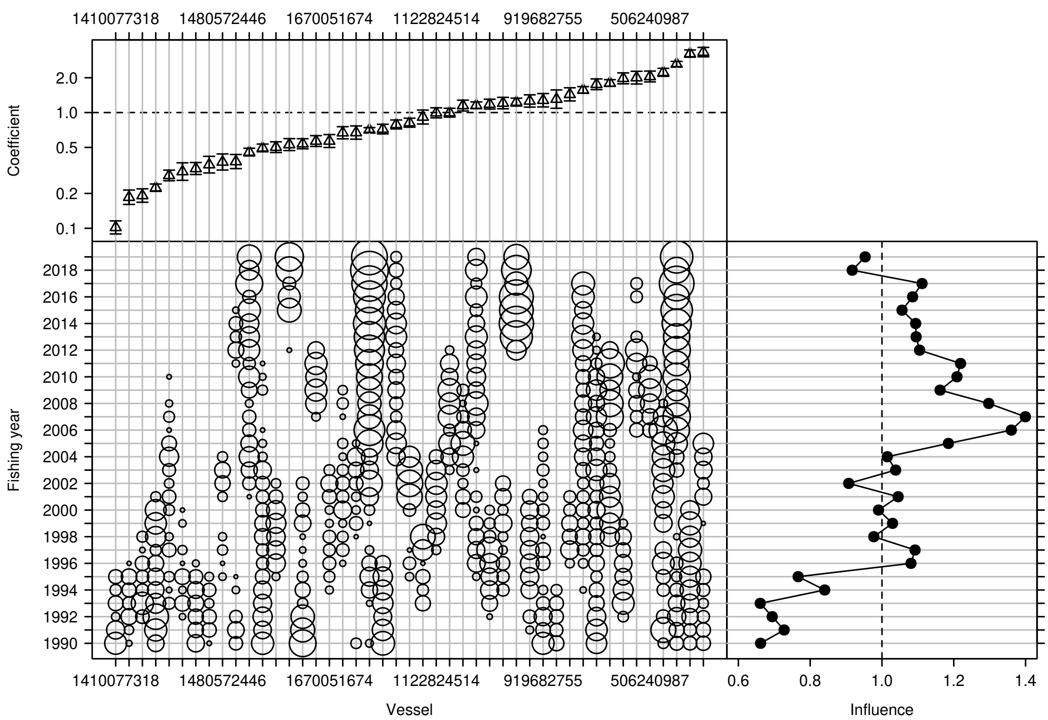

Figure G-134: Influence plot for vessel for the lognormal model of school shark in SCH 7/8/1W SN daily, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

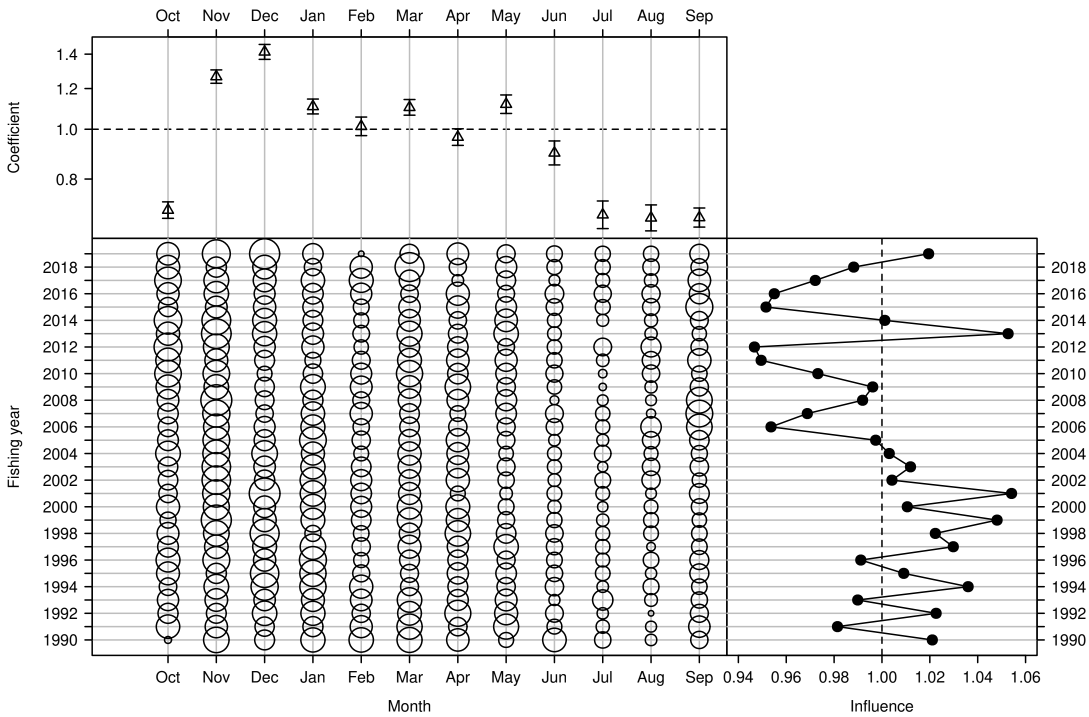

Figure G-135: Influence plot for month for the lognormal model of school shark in SCH 7/8/1W SN daily, showing model coefficients for each month (top panel), the distribution of observations over time across each month (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

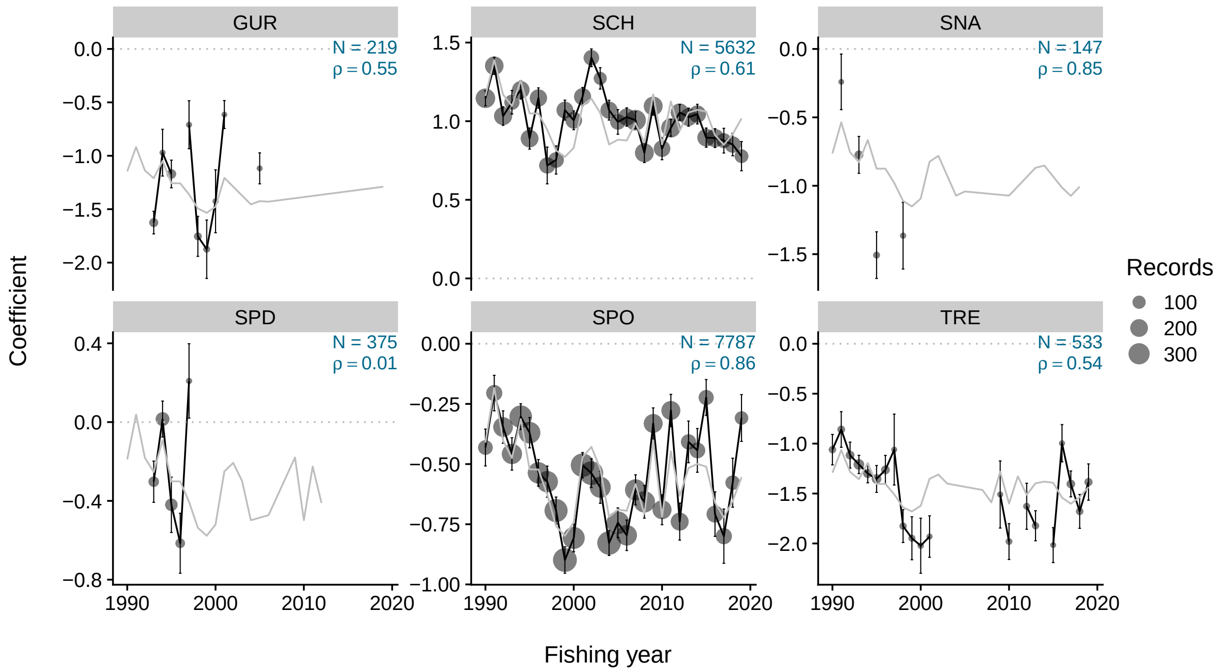

Figure G-136: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 7/8/1W SN daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

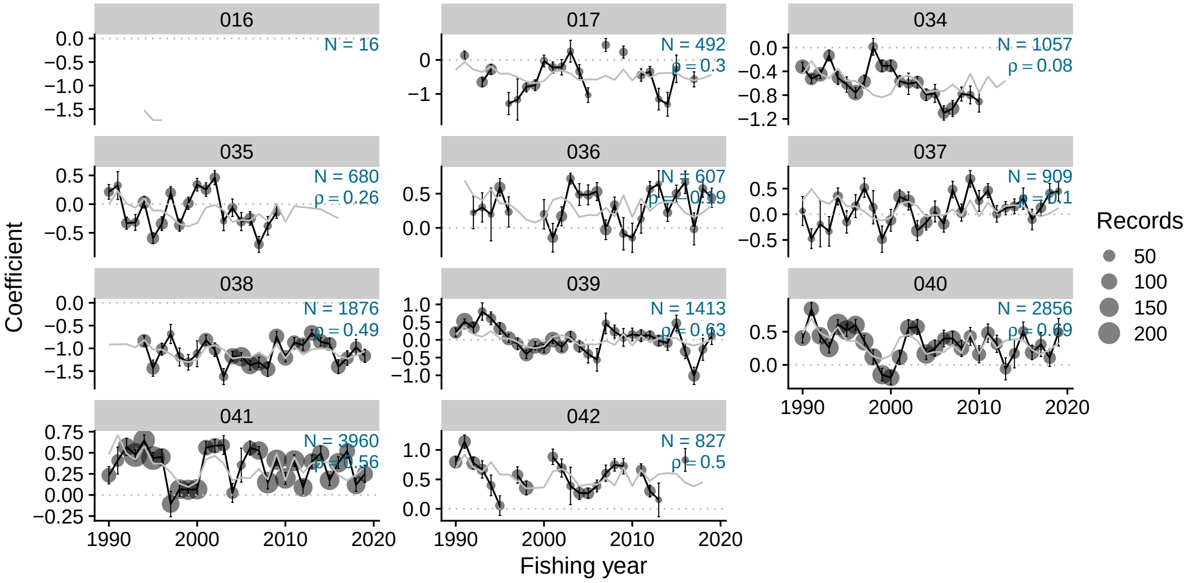

Figure G-137: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 7/8/1W SN daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-55: Standardised binomial, positive (lognormal) and combined indices for SCH 7/8/1W SN daily, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5^{th}	97.5^{th}
1990	0.916	1.167	1.069	0.881	1.270
1991	0.961	1.466	1.408	1.181	1.634
1992	0.893	1.173	1.048	0.886	1.214
1993	0.927	1.097	1.017	0.874	1.162
1994	0.937	1.284	1.204	1.050	1.375
1995	0.861	1.041	0.896	0.756	1.031
1996	0.896	1.043	0.935	0.803	1.064
1997	0.850	0.942	0.801	0.663	0.934
1998	0.930	0.823	0.765	0.658	0.885
1999	0.937	0.792	0.742	0.643	0.842
2000	0.943	0.838	0.790	0.681	0.910
2001	0.901	1.098	0.989	0.841	1.144
2002	0.996	1.142	1.138	0.984	1.298
2003	0.956	1.046	1.000	0.850	1.178
2004	1.023	0.857	0.877	0.765	1.003
2005	1.034	0.884	0.914	0.789	1.045
2006	1.031	0.878	0.905	0.786	1.027
2007	1.066	0.981	1.046	0.920	1.187
2008	1.072	0.870	0.932	0.801	1.082
2009	1.113	1.182	1.316	1.129	1.531
2010	1.062	0.855	0.909	0.777	1.058
2011	1.086	1.128	1.225	1.066	1.422
2012	1.043	0.937	0.977	0.840	1.131
2013	1.119	1.050	1.175	0.986	1.378
2014	1.113	1.069	1.191	0.988	1.423
2015	1.063	1.056	1.122	0.950	1.323
2016	1.131	0.911	1.030	0.864	1.214
2017	1.133	0.855	0.969	0.818	1.164
2018	1.047	0.916	0.960	0.795	1.133
2019	1.092	1.013	1.106	0.902	1.363

G.12 SCH 7, SCH 8 & lower SCH 1W bottom longline (daily effort)

Table G-56: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 7/8/1W BLL daily.

Variable	Value
Label	BLL781_daily
Forms	CEL, LCE, ERS - Lining, LTC
Period	1989-10-01 to 2019-09-30
Resolution	Daily
Core fleet (min years)	4
Core fleet (min trips)	5
Target species	SNA, HPB, SCH, BNS, LIN
Statistical areas	016, 017, 018, 034, 035, 036, 037, 038, 039, 040, 041, 042, 801

Table G-57: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 7/8/1W BLL daily. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (1000 hooks)	Catch (t)	Positive rate
1990	10	99	167	99.8	54.48	58.08
1991	11	148	259	273.9	64.08	59.46
1992	16	157	293	335.8	110.70	61.09
1993	18	200	427	585.4	109.47	49.41
1994	22	222	469	656.4	134.39	50.11
1995	20	306	584	760.1	150.65	49.83
1996	21	280	614	906.7	179.74	56.68
1997	22	240	572	917.6	142.02	58.04
1998	22	231	570	923.0	135.53	55.44
1999	23	230	584	978.3	142.25	58.73
2000	23	234	509	668.0	114.35	56.19
2001	20	198	507	734.2	95.40	54.24
2002	17	193	406	508.3	112.13	59.11
2003	19	207	456	571.5	96.03	52.19
2004	19	188	462	628.7	142.47	57.58
2005	16	182	478	826.6	141.54	56.28
2006	18	147	424	687.8	126.37	59.91
2007	16	201	462	850.2	75.37	55.41
2008	13	92	251	569.3	50.36	59.36
2009	15	159	352	588.9	87.88	74.43
2010	15	116	298	485.9	93.62	76.51
2011	13	139	396	782.6	137.35	74.49
2012	12	124	346	771.5	91.41	75.72
2013	12	126	401	904.2	110.08	74.31
2014	14	125	387	1 147.7	152.57	74.16
2015	15	168	485	1 378.6	174.07	76.08
2016	15	167	501	1 625.4	214.75	74.65
2017	12	163	470	1 565.1	217.70	77.45
2018	12	120	366	1 379.9	198.39	75.68
2019	11	103	332	1 239.3	110.34	67.17

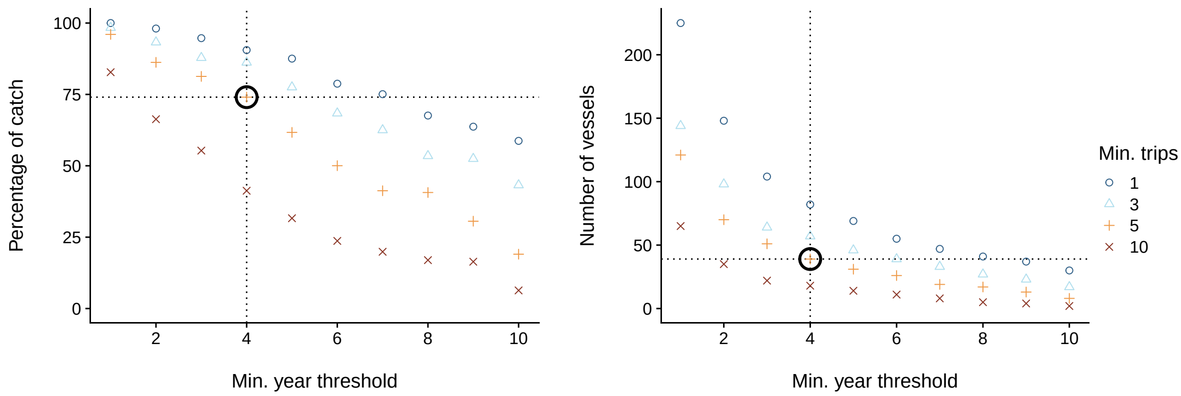

Figure G-138: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 7/8/1W BLL daily. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

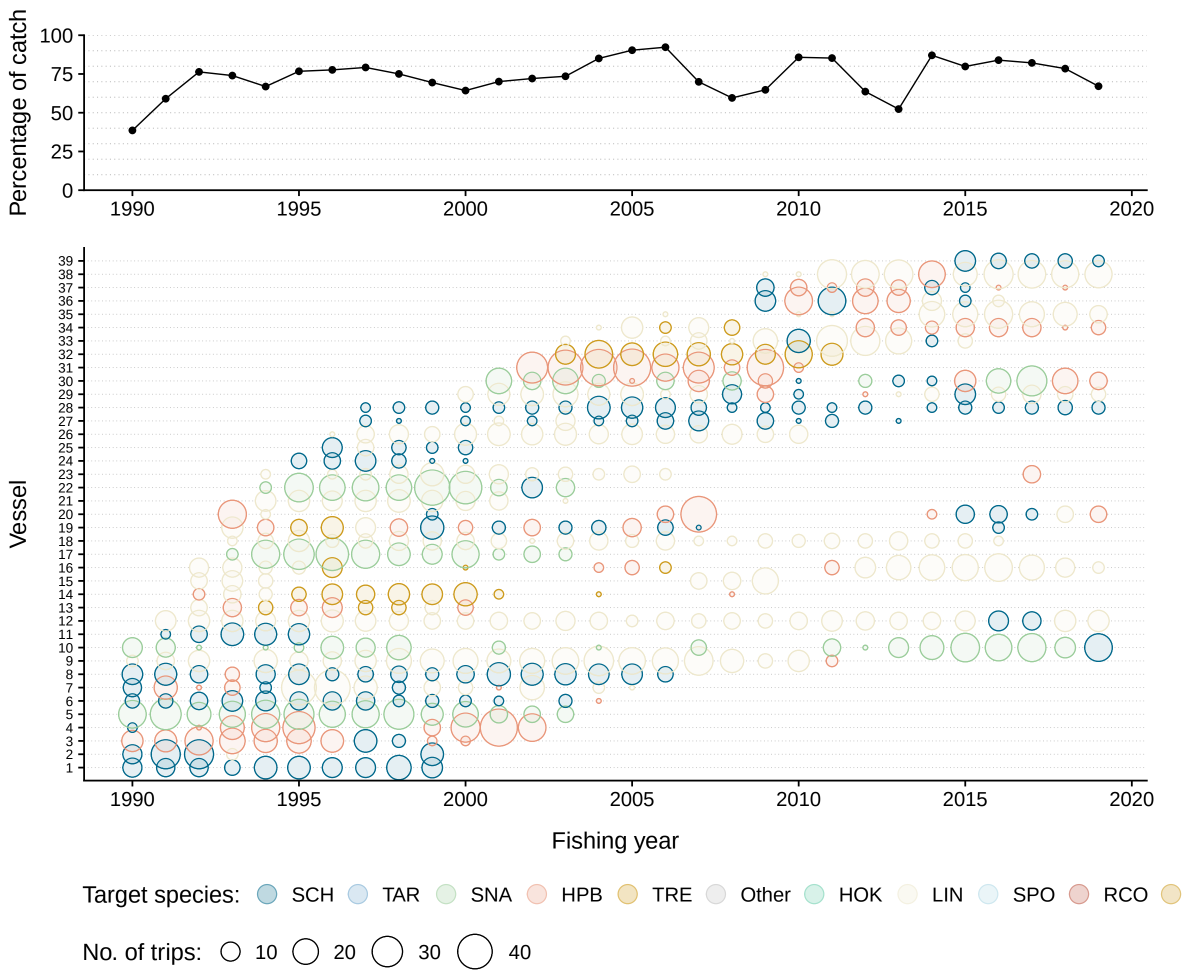

Figure G-139: Proportion of school shark catch retained by the core fleet in SCH 7/8/1W BLL daily (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

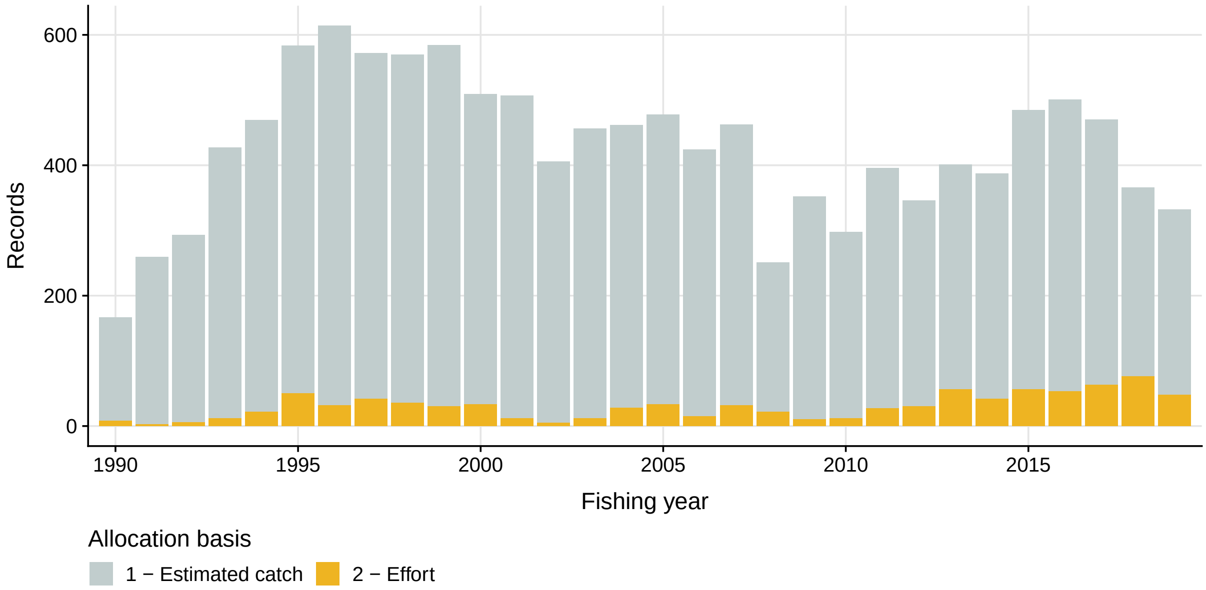

Figure G-140: Number of records by fishing year for the core fleet in SCH 7/8/1W BLL daily. Records with landings allocated based on estimated catch are highlighted in yellow.

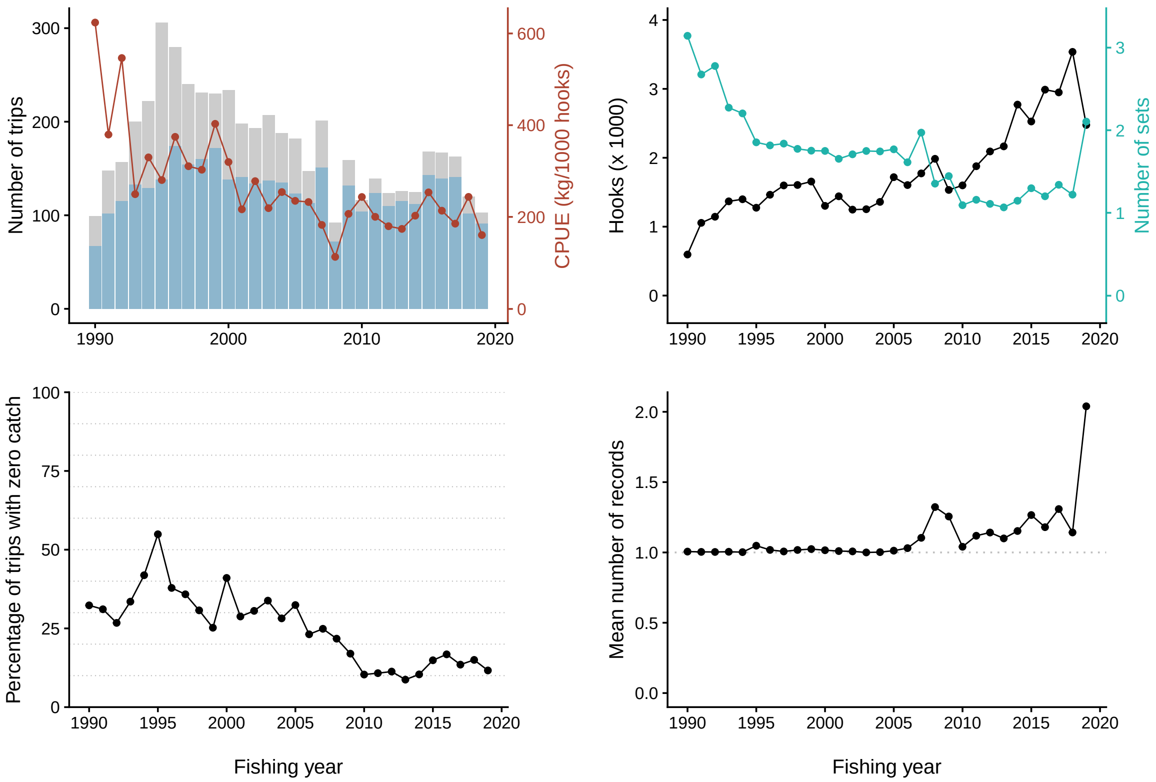

Figure G-141: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 7/8/1W BLL daily, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all daily records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the daily resolution over time.

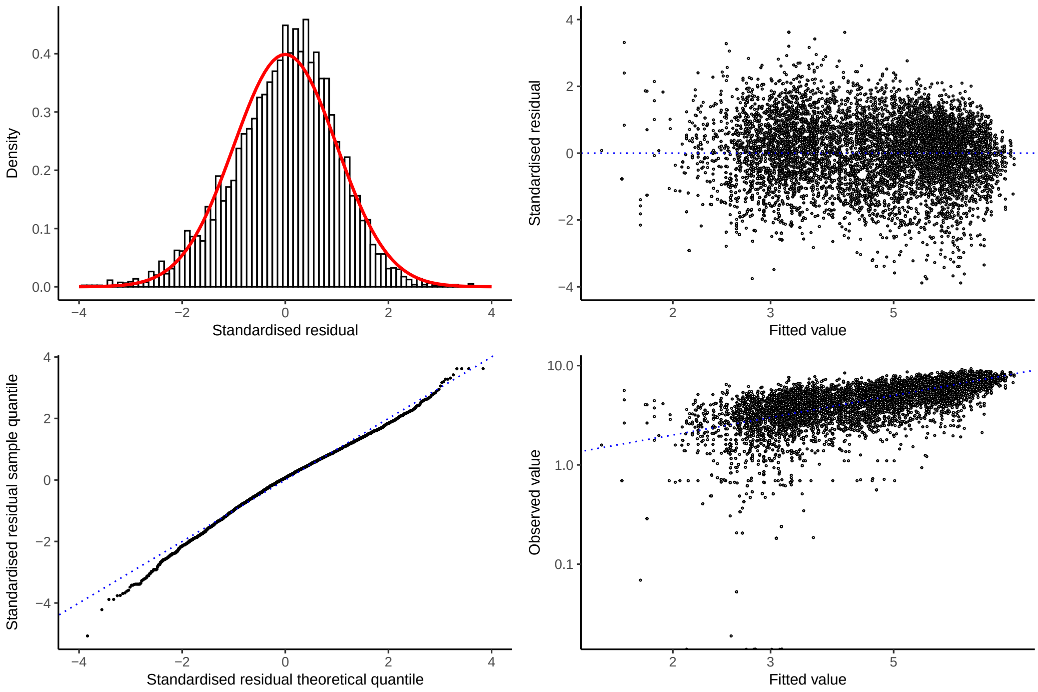

Figure G-142: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 7/8/1W BLL daily: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-58: Summary of stepwise selection for binomial occurrence model for SCH 7/8/1W BLL daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	16626	3.00	3.00	*
+ target_species	4.00	12989	24.30	21.40	*
+ vessel_key	39.00	12479	27.80	3.40	*
+ month	11.00	12345	28.70	0.90	
+ stat_area	12.00	12290	29.10	0.50	
+ ns(log(total_hook_num), 3)	3.00	12254	29.40	0.20	

Table G-59: Summary of stepwise selection for positive catch model for SCH 7/8/1W BLL daily. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	33154	1.20	1.20	*
+ target_species	4.00	27482	51.40	50.20	*
+ vessel_key	39.00	26471	57.60	6.20	*
+ month	11.00	26220	59.00	1.40	*
+ stat_area	12.00	25933	60.60	1.60	*
+ ns(log(total_hook_num), 3)	3.00	25748	61.50	0.90	
+ effort_num	1.00	25690	61.80	0.30	

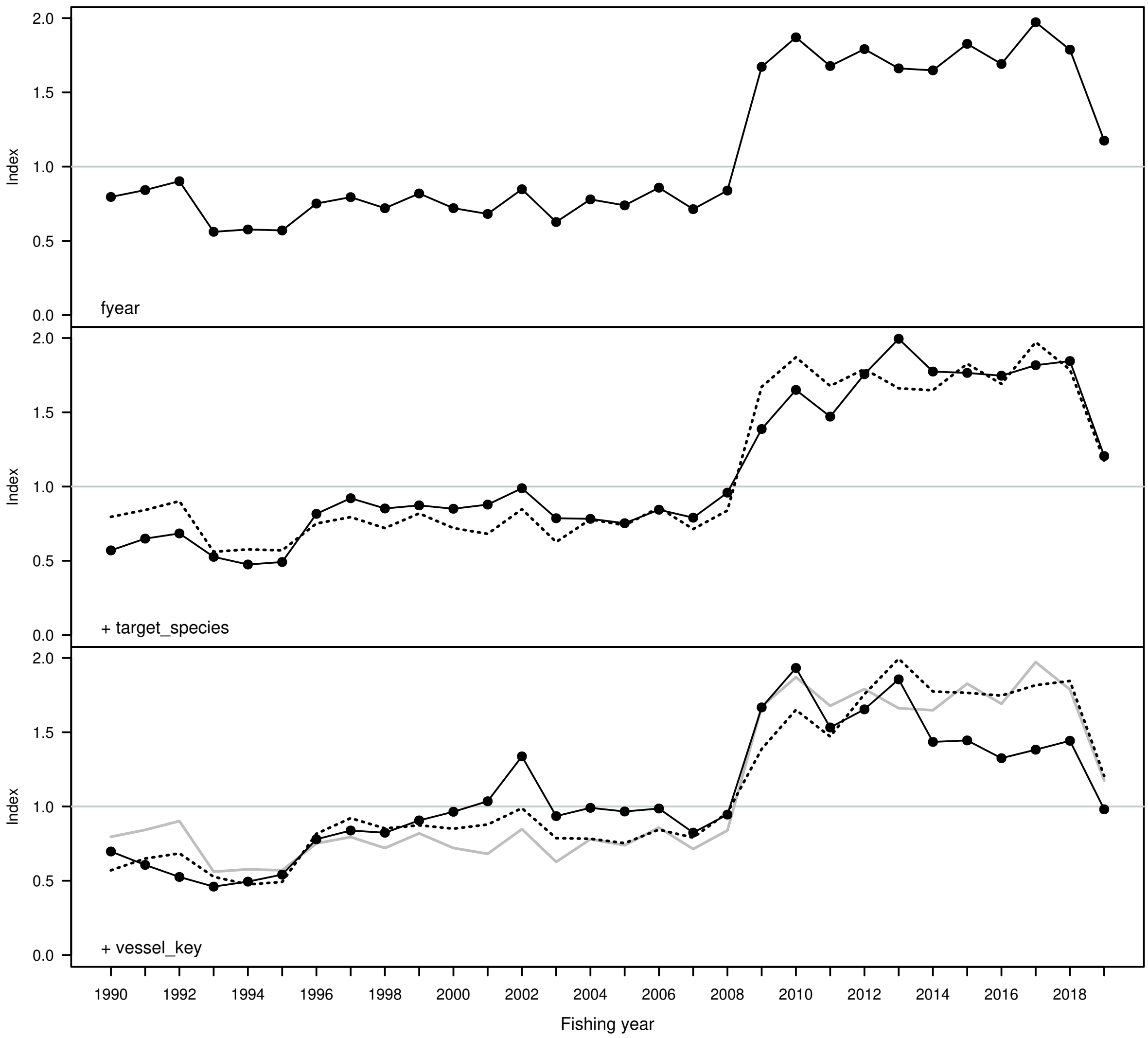

Figure G-143: Stepwise plot for the binomial occurrence model for SCH 7/8/1W BLL daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

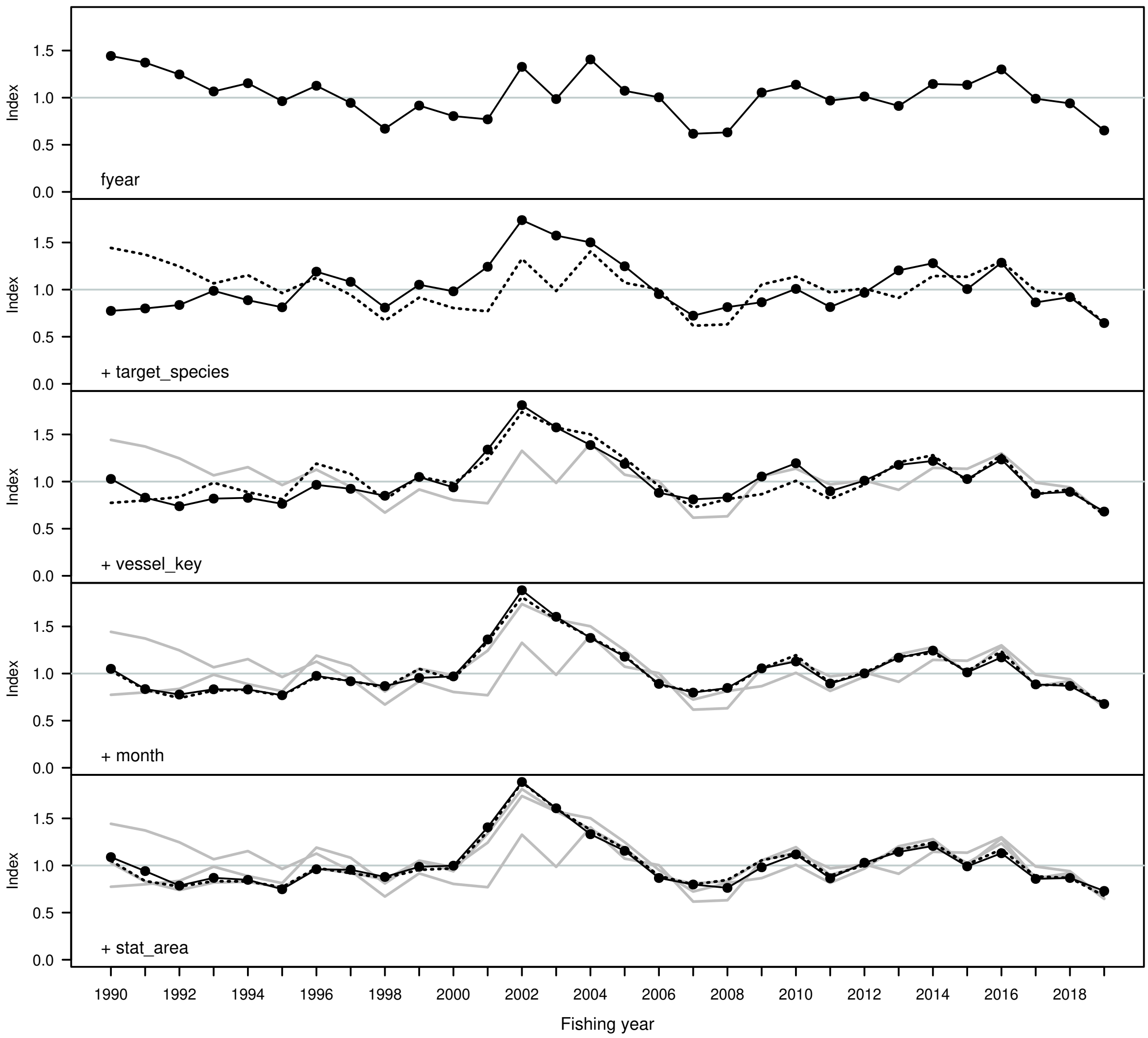

Figure G-144: Stepwise plot for the positive lognormal model for SCH 7/8/1W BLL daily showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

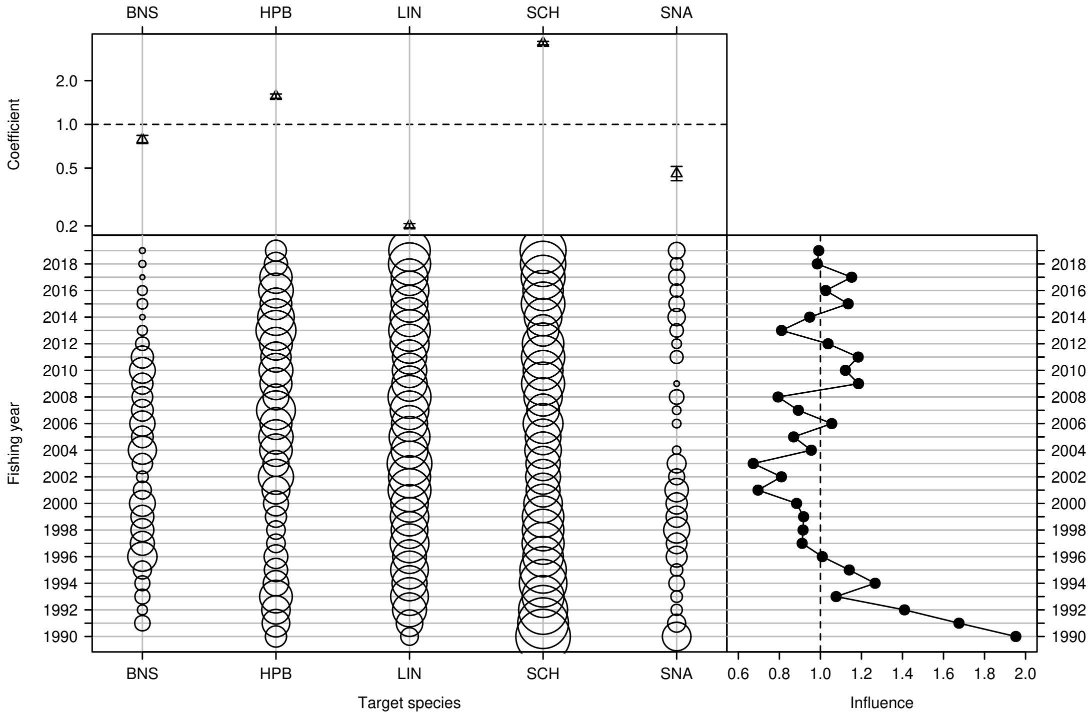

Figure G-145: Influence plot for target species for the lognormal model of school shark in SCH 7/8/1W BLL daily, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

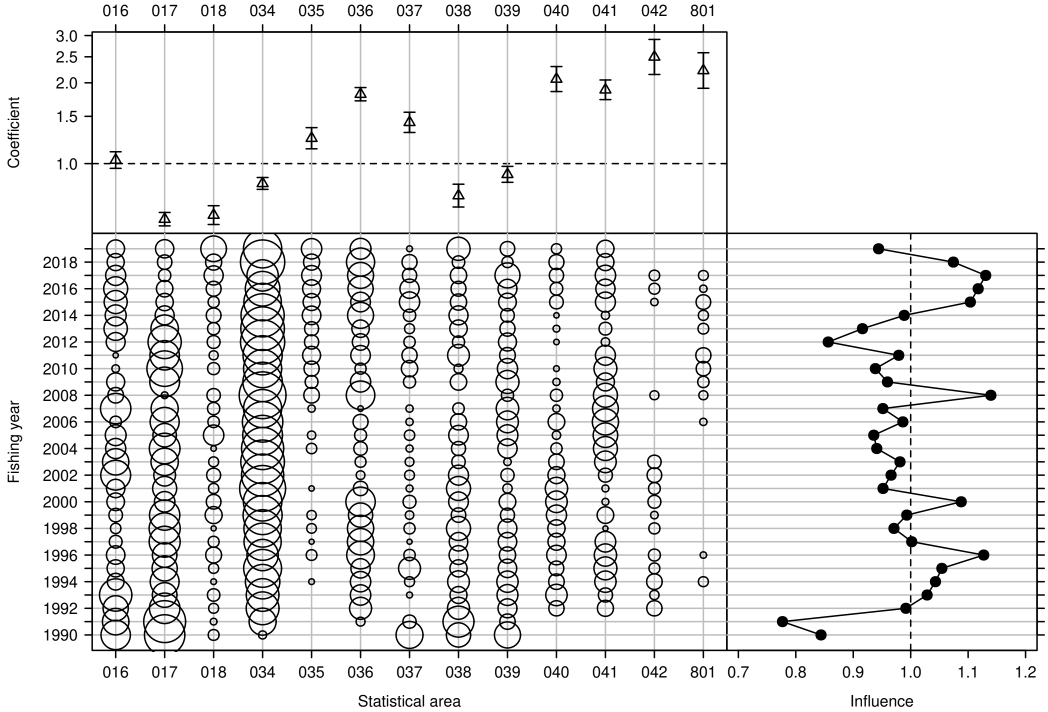

Figure G-146: Influence plot for statistical area for the lognormal model of school shark in SCH 7/8/1W BLL daily, showing model coefficients for each statistical area (top panel), the distribution of observations over time across each statistical area (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

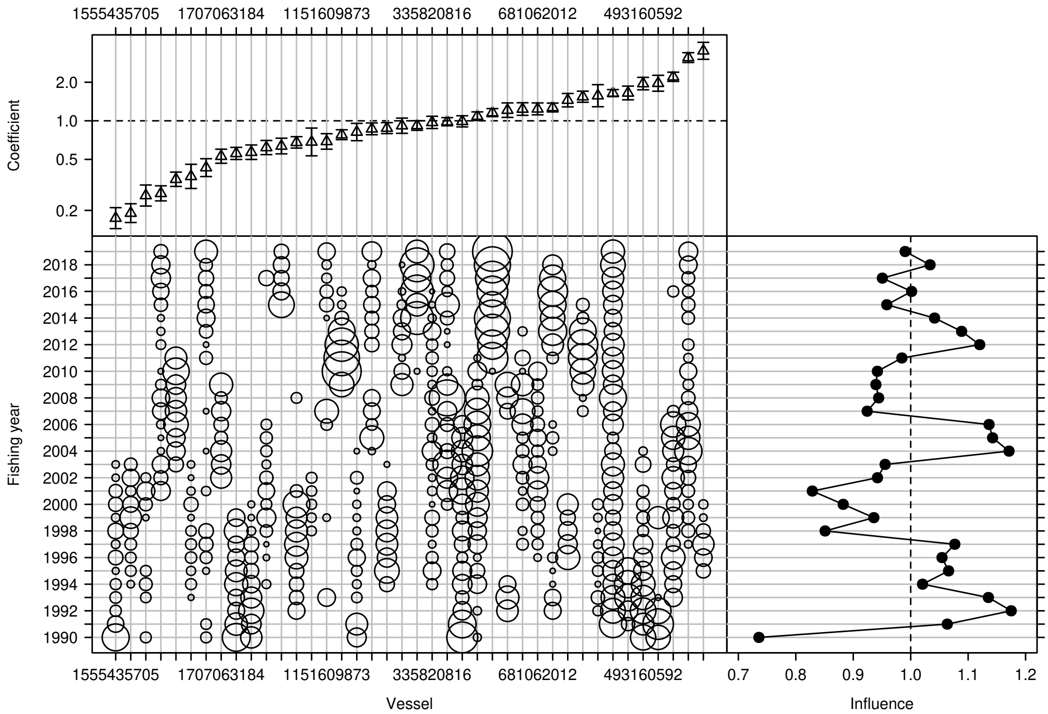

Figure G-147: Influence plot for vessel for the lognormal model of school shark in SCH 7/8/1W BLL daily, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

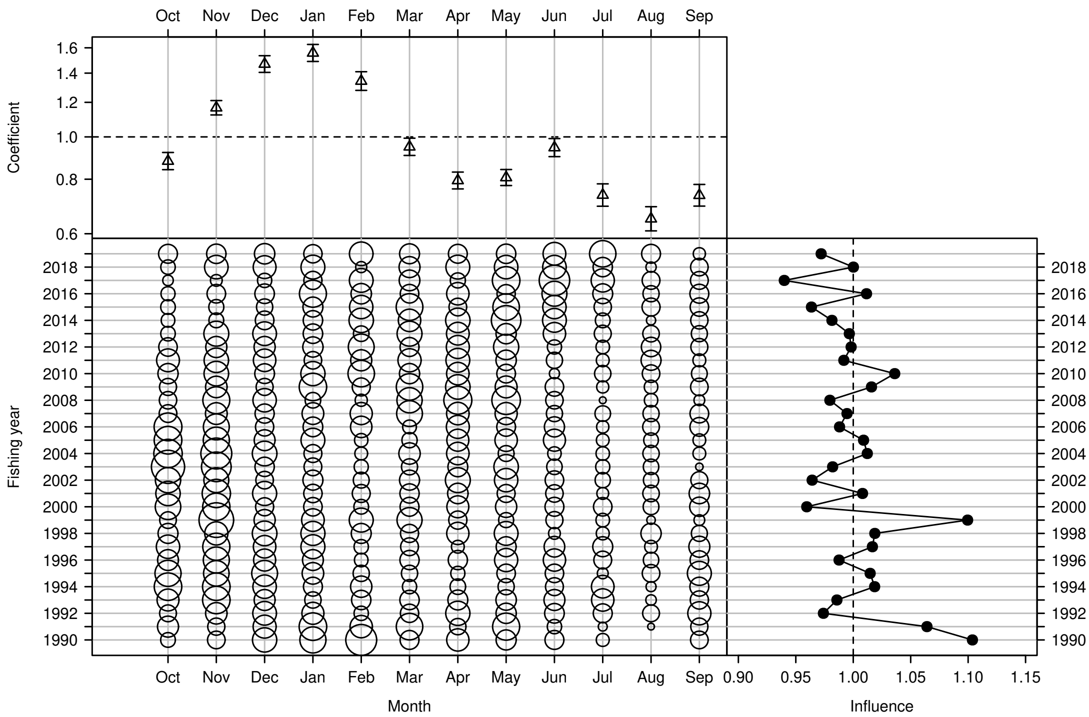

Figure G-148: Influence plot for month for the lognormal model of school shark in SCH 7/8/1W BLL daily, showing model coefficients for each month (top panel), the distribution of observations over time across each month (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

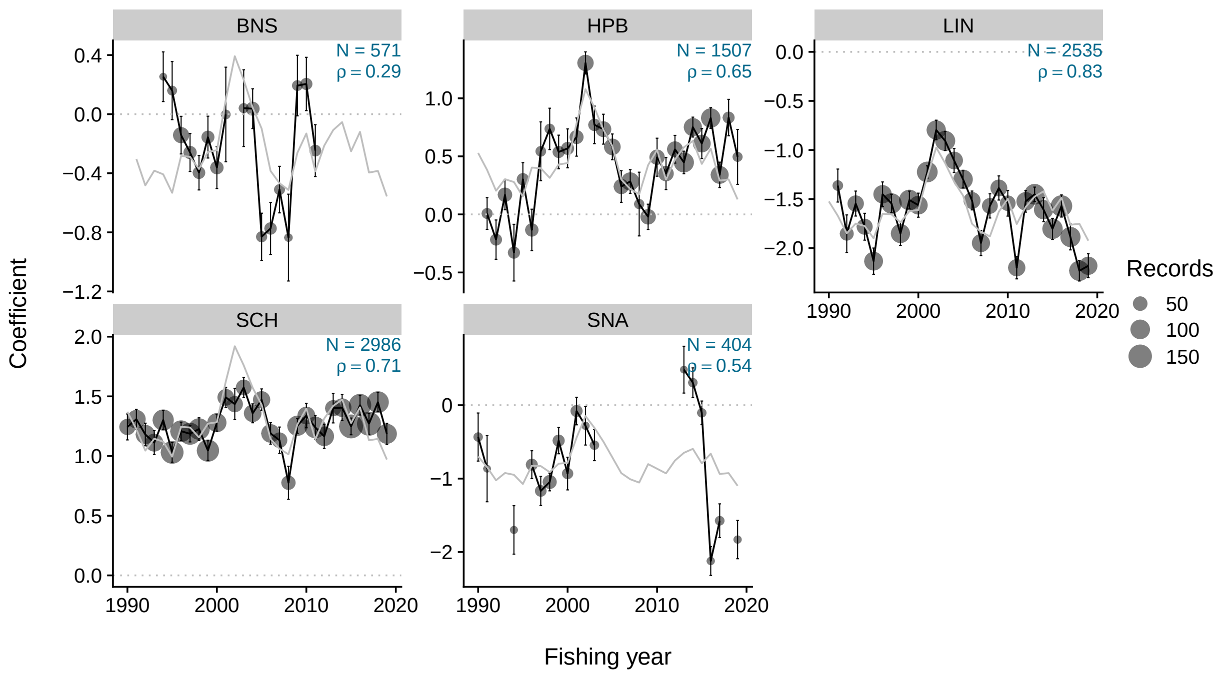

Figure G-149: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 7/8/1W BLL daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

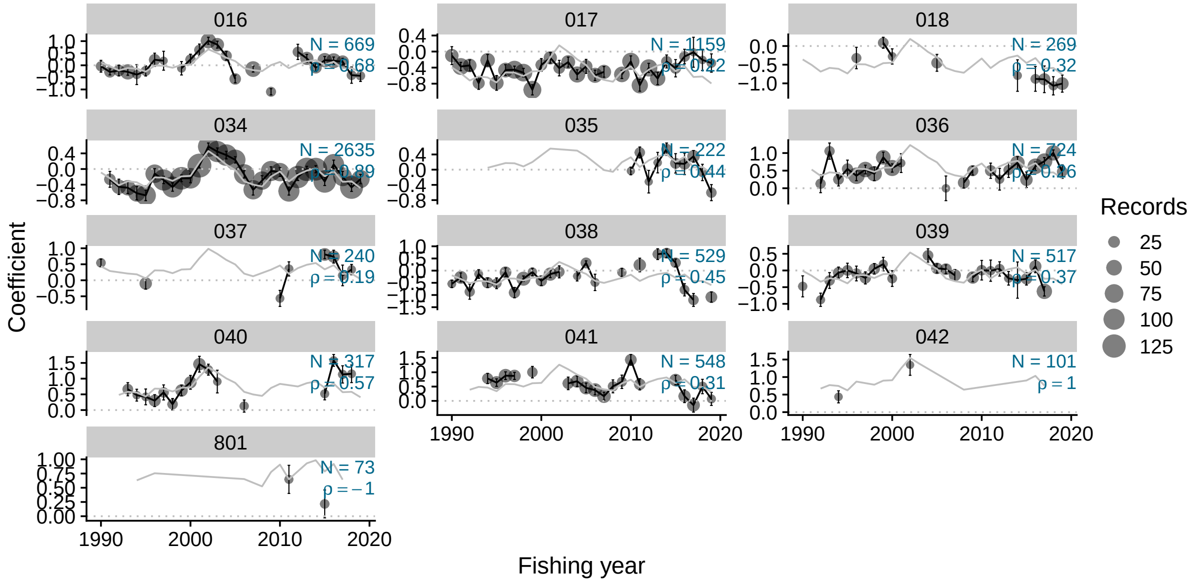

Figure G-150: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 7/8/1W BLL daily, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-60: Standardised binomial, positive (lognormal) and combined indices for SCH 7/8/1W BLL daily, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5^{th}	97.5^{th}
1990	0.885	1.097	0.971	0.678	1.305
1991	0.834	0.945	0.789	0.584	1.034
1992	0.781	0.791	0.617	0.482	0.776
1993	0.733	0.872	0.640	0.503	0.800
1994	0.757	0.852	0.645	0.517	0.788
1995	0.791	0.752	0.595	0.495	0.709
1996	0.928	0.963	0.894	0.752	1.050
1997	0.954	0.959	0.915	0.771	1.067
1998	0.951	0.885	0.842	0.708	0.977
1999	0.985	0.987	0.973	0.821	1.146
2000	1.004	1.003	1.007	0.854	1.176
2001	1.031	1.405	1.448	1.208	1.701
2002	1.113	1.878	2.091	1.750	2.442
2003	0.996	1.607	1.601	1.332	1.886
2004	1.014	1.338	1.357	1.137	1.601
2005	1.009	1.161	1.171	0.994	1.381
2006	1.014	0.872	0.884	0.739	1.043
2007	0.952	0.797	0.759	0.639	0.895
2008	0.996	0.768	0.765	0.599	0.953
2009	1.179	0.984	1.160	0.957	1.371
2010	1.216	1.118	1.359	1.118	1.655
2011	1.154	0.870	1.003	0.834	1.186
2012	1.174	1.033	1.212	1.009	1.454
2013	1.210	1.149	1.390	1.174	1.632
2014	1.138	1.213	1.380	1.156	1.630
2015	1.137	0.993	1.128	0.959	1.318
2016	1.113	1.136	1.264	1.064	1.472
2017	1.126	0.859	0.967	0.821	1.144
2018	1.137	0.871	0.990	0.827	1.168
2019	1.013	0.733	0.742	0.605	0.895

G.13 SCH 7, SCH 8 & lower SCH 1W bottom trawl (trip effort)

Table G-61: Definition for the dataset used in the catch-per-unit-effort (CPUE) standardisation for the CPUE unit SCH 7/8/1W BT trip.

Variable	Value
Label	BT781_trip
Forms	CEL, TCP, TCE, ERS - Trawl
Period	1989-10-01 to 2019-09-30
Resolution	Trip
Core fleet (min years)	5
Core fleet (min trips)	5
Target species	TAR, GUR, BAR, TRE, FLA, SNA, RCO, STA, HOK
Statistical areas	016, 017, 034, 035, 036, 037, 038, 039, 040, 041, 042

Table G-62: Summary of dataset for the core fleet data used for the catch-per-unit-effort (CPUE) standardisation in SCH 7/8/1W BT trip. Records represent one row in the dataset; fishing years are labelled by the second year in the time period.

Fishing year	Vessels	Trips	Records	Effort (tows)	Catch (t)	Positive rate
1990	58	1 649	1 649	9 386	74.99	45.06
1991	64	1 568	1 568	9 387	48.47	42.60
1992	68	1 734	1 734	10 932	49.25	35.18
1993	75	2 259	2 259	15 384	62.45	43.29
1994	74	1 739	1 739	12 584	55.45	44.68
1995	80	1 960	1 960	13 878	71.06	50.92
1996	77	2 115	2 115	15 430	107.86	50.59
1997	82	2 264	2 264	16 718	101.72	55.48
1998	79	2 055	2 055	14 166	90.54	55.18
1999	77	1 903	1 903	14 294	147.56	69.31
2000	68	1 440	1 440	11 155	117.47	75.76
2001	66	1 308	1 308	10 780	131.18	69.72
2002	65	1 282	1 282	10 506	96.61	69.97
2003	65	1 166	1 166	9 772	97.40	66.64
2004	68	1 338	1 338	11 263	93.39	66.29
2005	64	1 342	1 342	11 553	88.02	62.59
2006	68	1 395	1 395	11 691	86.80	58.71
2007	63	1 514	1 514	12 242	80.00	57.53
2008	58	1 102	1 102	8 624	106.29	69.69
2009	52	1 077	1 077	8 719	134.12	70.57
2010	52	1 230	1 230	10 300	159.32	71.06
2011	51	949	949	7 777	133.01	75.24
2012	53	1 083	1 083	8 542	139.51	78.30
2013	53	1 141	1 141	8 807	144.50	77.04
2014	50	1 077	1 077	8 323	121.50	79.02
2015	48	893	893	6 575	93.51	70.88
2016	48	1 040	1 040	8 095	110.58	74.90
2017	46	1 087	1 087	8 140	106.44	69.09
2018	42	964	964	7 384	103.49	66.18
2019	39	777	777	6 239	85.27	75.80

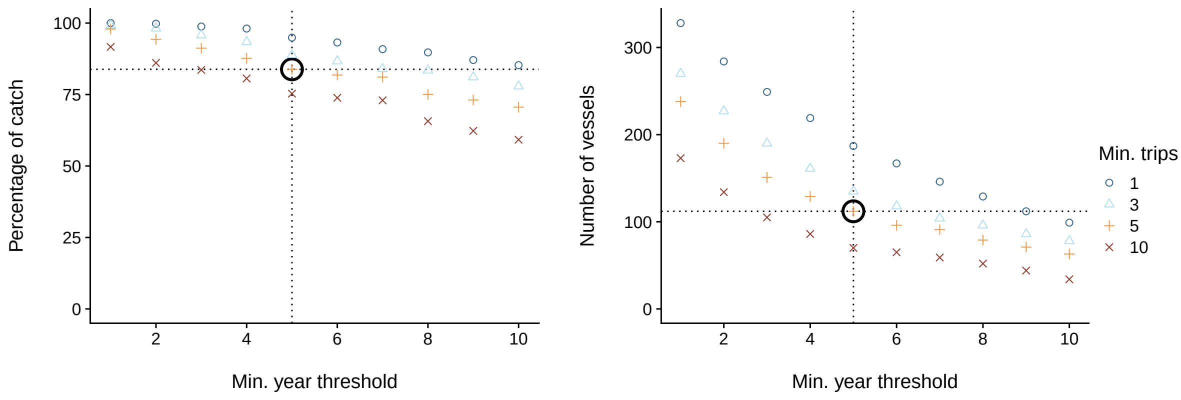

Figure G-151: Impact of core fleet selection criteria on the percentage of school shark catch (left) and the number of vessels (right) retained for the catch-per-unit-effort (CPUE) standardisation for the CPUE SCH 7/8/1W BT trip. Minimum threshold of year of activity is defined in the abscissa, minimum number of trips per year is shown as coloured symbols. Horizontal and vertical dotted lines intersecting at the black circle show the core fleet criteria used in the analysis.

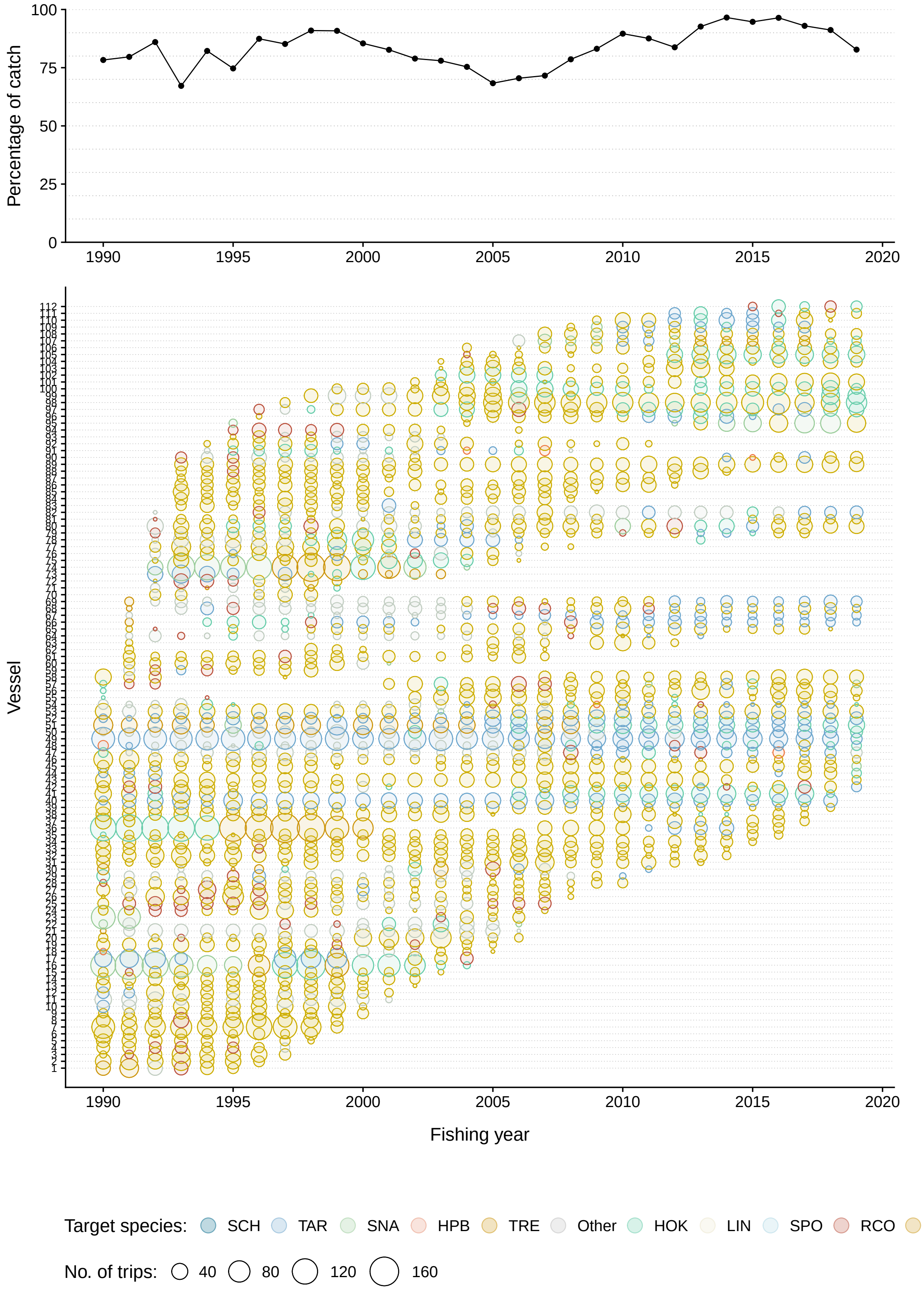

Figure G-152: Proportion of school shark catch retained by the core fleet in SCH 7/8/1W BT trip (top) and activity by each vessel over time (bottom). Vessels are represented by horizontal lines shown in order of first activity date in the fleet. The circles scale with the number of trips during the fishing year, coloured by the target species most frequently reported by the vessel on fishing events within the year.

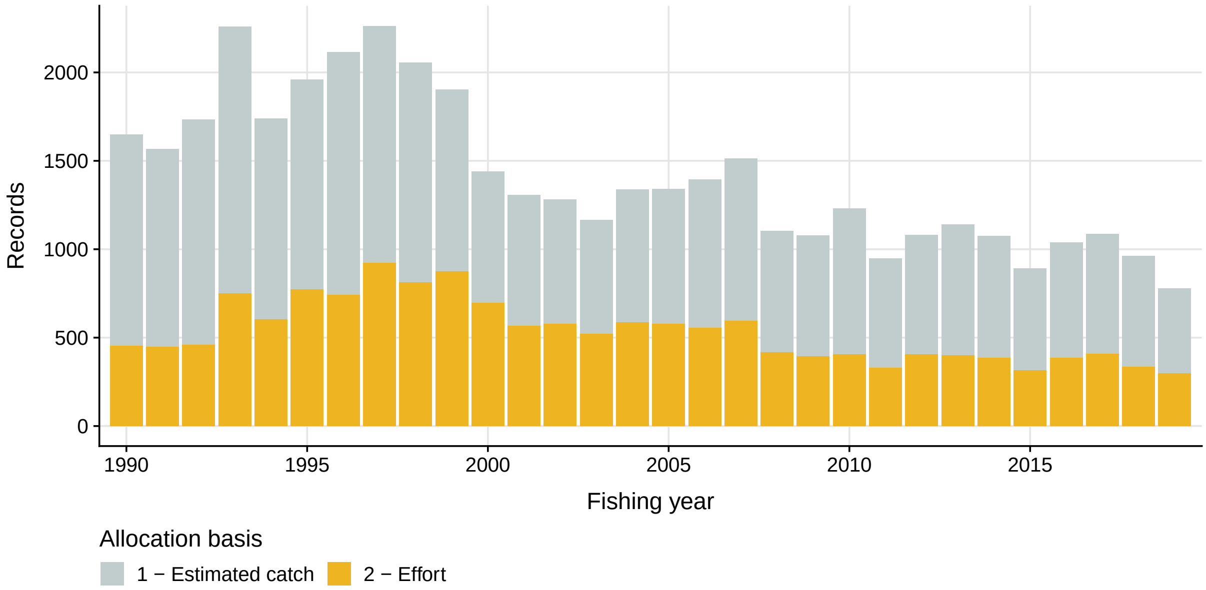

Figure G-153: Number of records by fishing year for the core fleet in SCH 7/8/1W BT trip. Records with landings allocated based on estimated catch are highlighted in yellow.

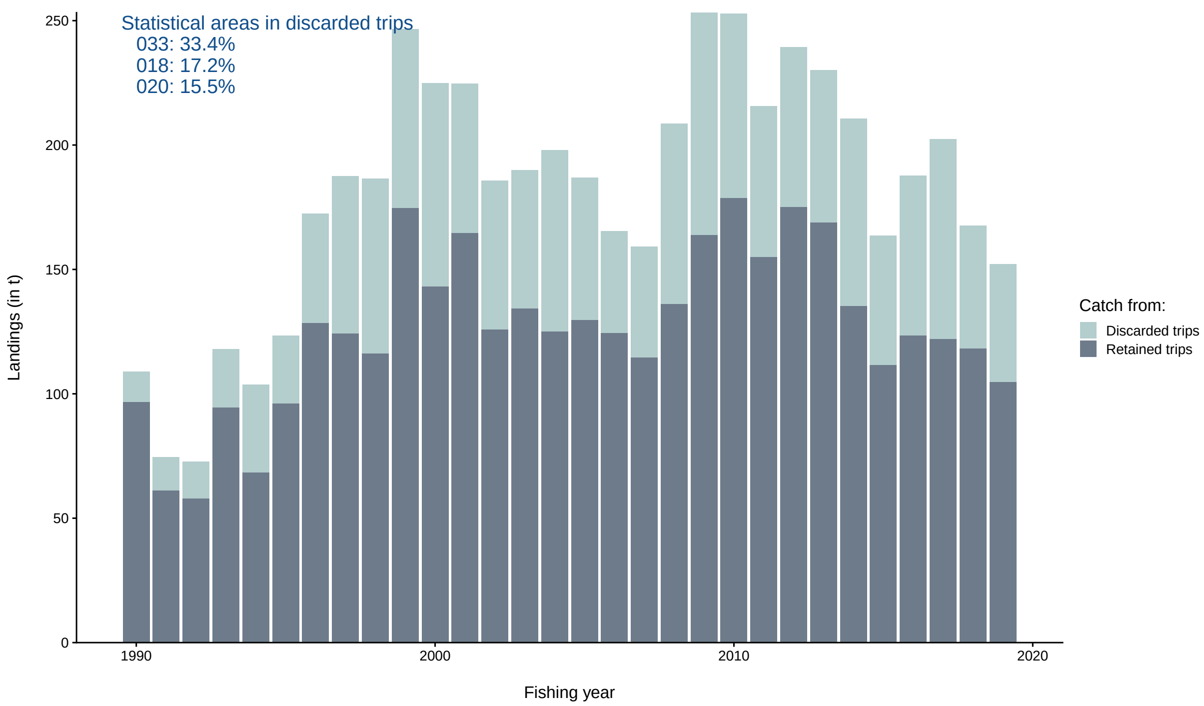

Figure G-154: Total landings and landings retained in the analysis for SCH 7/8/1W BT trip for the full fleet following data preparation to remove trips spanning multiple catch-per-unit-effort (CPUE) units. The top three statistical areas most often present in the omitted trips are noted in the top-left corner, including the corresponding proportion of discarded trips.

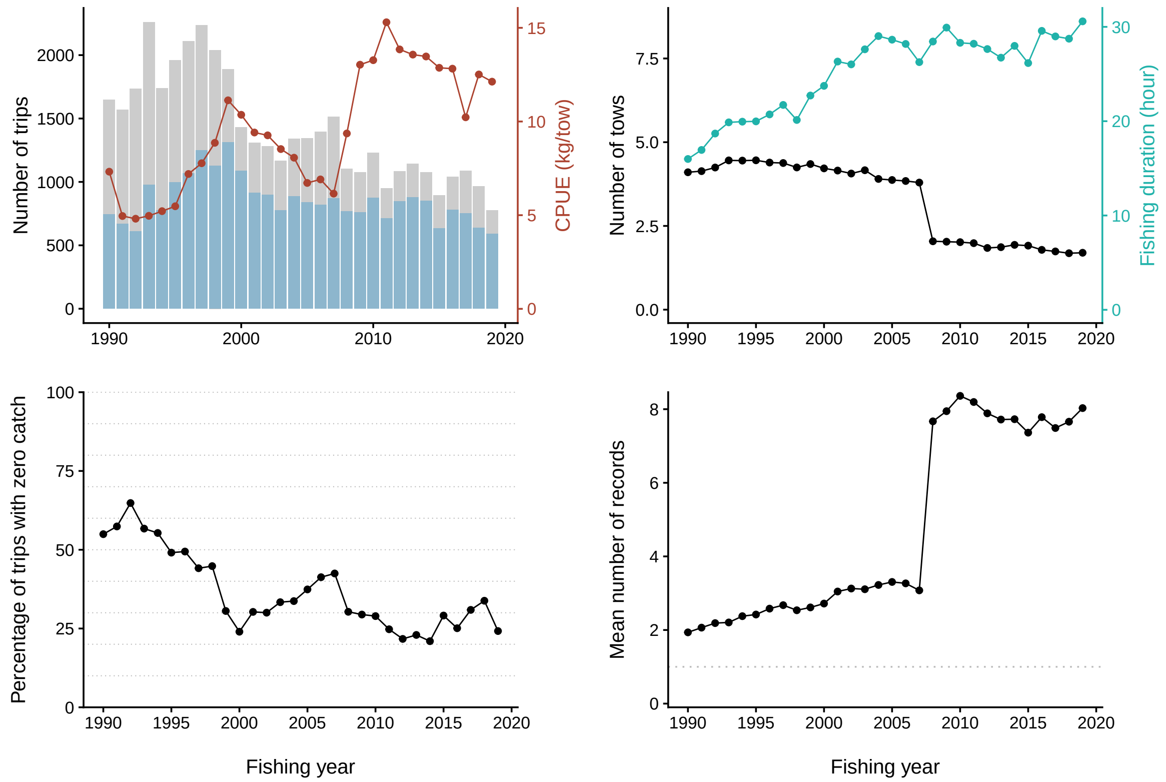

Figure G-155: Top left: Total number of trips (grey) and number of trips with positive school shark (blue) for the core fleet in SCH 7/8/1W BT trip, with catch-per-unit-effort (CPUE) (mean value for records across positive trips) shown in red. Top right: Mean annual value for two metrics of effort across all trip records in the year. Bottom left: Percentage of trips with zero school shark by fishing year for the core fleet. Bottom right: Mean number of records included in the effort stratum at the trip resolution over time.

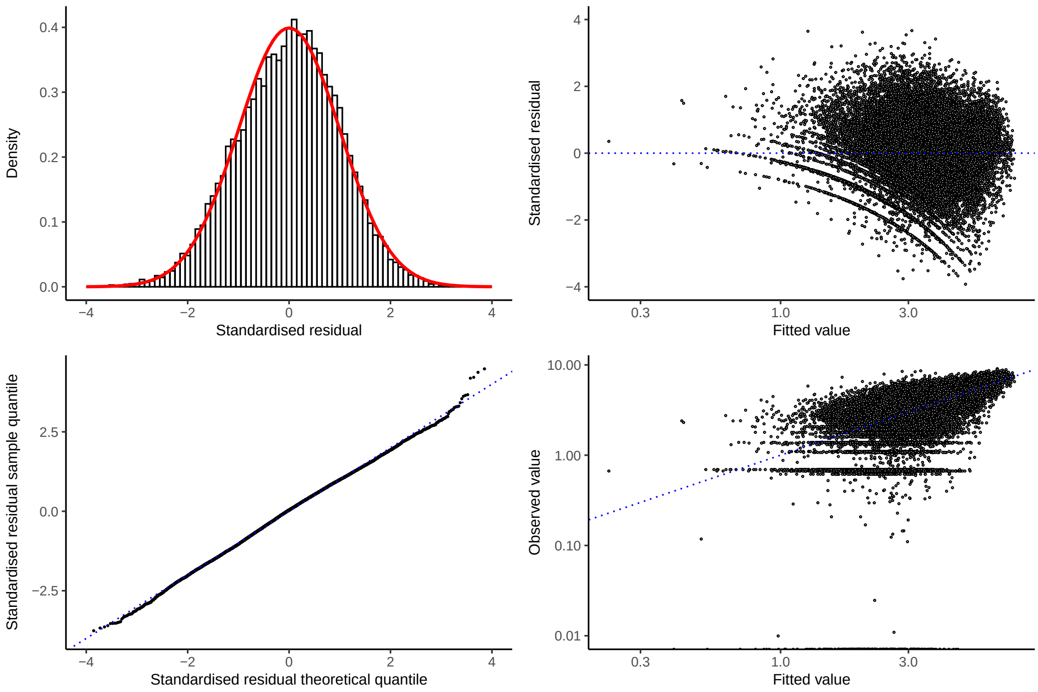

Figure G-156: Residual diagnostics for the log-normal error distribution used for the positive index in SCH 7/8/1W BT trip: distribution of standardised residuals with expected shape under normality shown in red (top left), standardised residuals against fitted values (top right), quantile-quantile plot of standardised residuals (bottom left) and observed against fitted values (bottom right).

Table G-63: Summary of stepwise selection for binomial occurrence model for SCH 7/8/1W BT trip. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Model covariate	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	54180	4.90	4.90	*
+ vessel_key	111.00	48613	15.10	10.20	*
+ ns(log(fishing_duration), 3)	3.00	46837	18.20	3.10	*
+ target_species	8.00	46220	19.30	1.10	*
+ month	11.00	45625	20.40	1.10	*
+ stat_area	10.00	45337	21.00	0.50	
+ effort_num	1.00	45325	21.00	0.00	

Table G-64: Summary of stepwise selection for positive catch model for SCH 7/8/1W BT trip. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Predictor	DF	AIC	% deviance	Add % dev	Included
+ fyear	28.00	99177	1.70	1.70	*
+ vessel_key	111.00	89048	34.20	32.60	*
+ ns(log(fishing_duration), 3)	3.00	86720	39.90	5.70	*
+ target_species	8.00	85448	42.90	2.90	*
+ month	11.00	84958	44.00	1.10	*
+ stat_area	10.00	84796	44.40	0.40	
+ effort_num	1.00	84751	44.50	0.10	

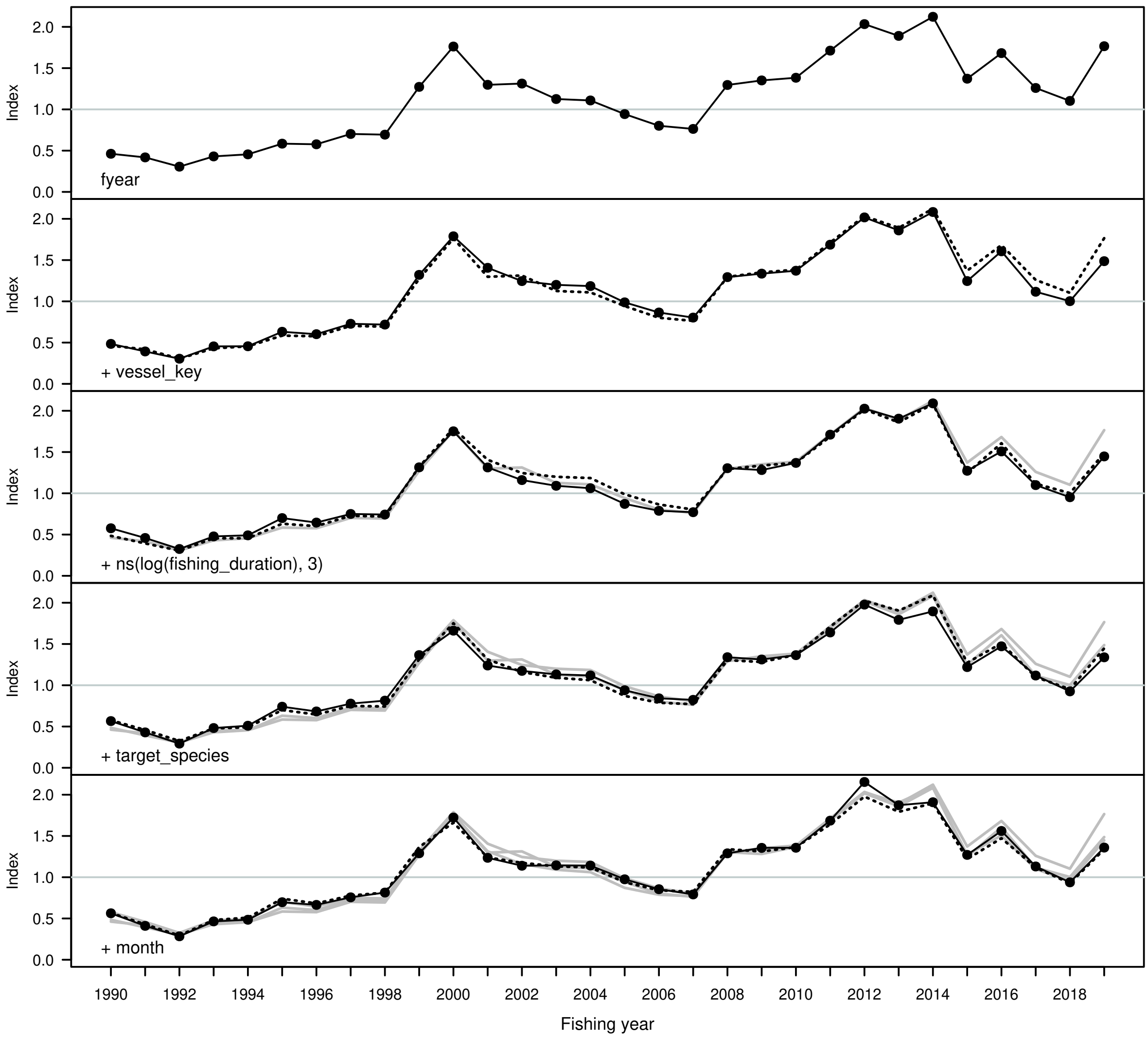

Figure G-157: Stepwise plot for the binomial occurrence model for SCH 7/8/1W BT trip showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

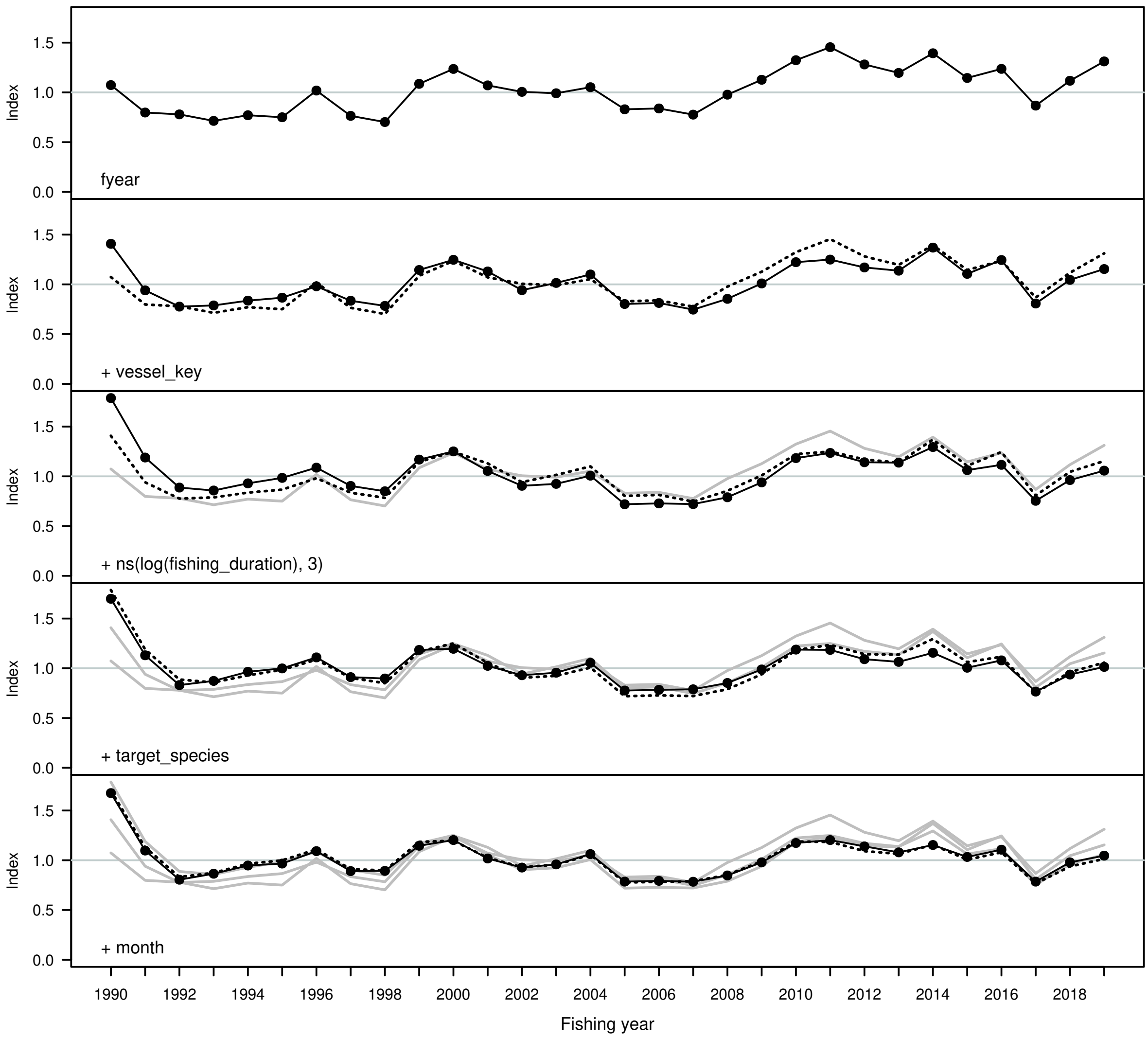

Figure G-158: Stepwise plot for the positive lognormal model for SCH 7/8/1W BT trip showing the cumulative impact of additional covariates on standardised indices. New covariates were added from top to bottom panels, with the additional covariate indicated in the bottom-left corner. Updated catch-per-unit-effort (CPUE) index is shown in black, index from the previous step is in dash, and indices from previous steps are shown in grey. Horizontal grey-blue line shows the level of no change (Index = 1) for the index as a reference.

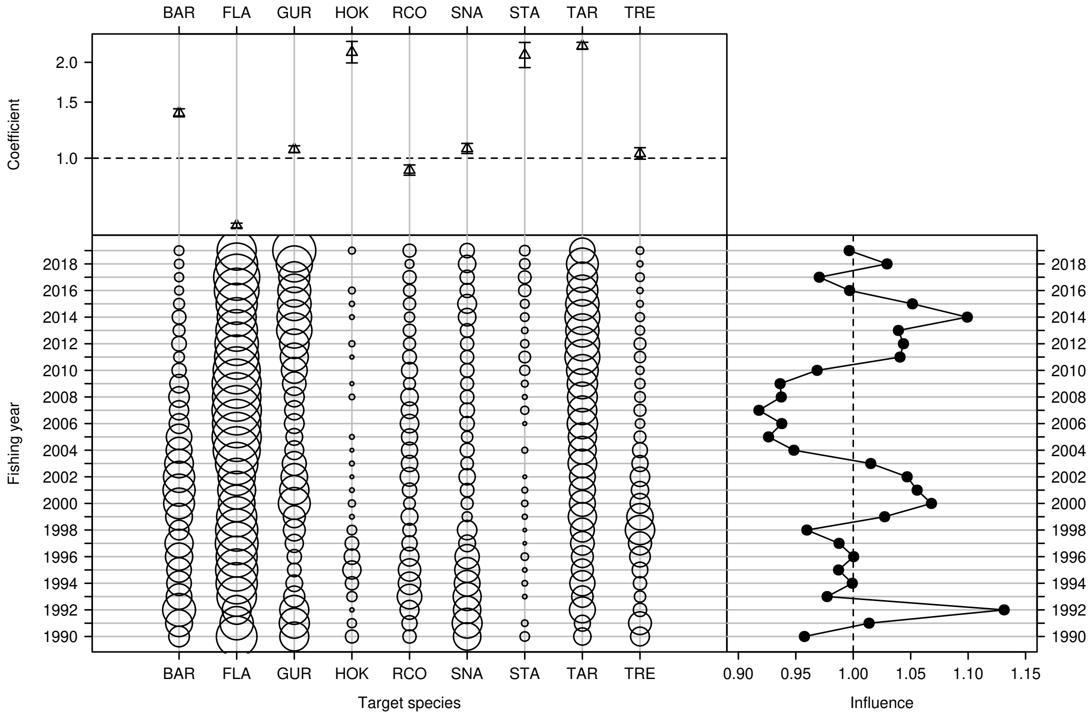

Figure G-159: Influence plot for target species for the lognormal model of school shark in SCH 7/8/1W BT trip, showing model coefficients for each target species (top panel), the distribution of observations over time across each target species (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

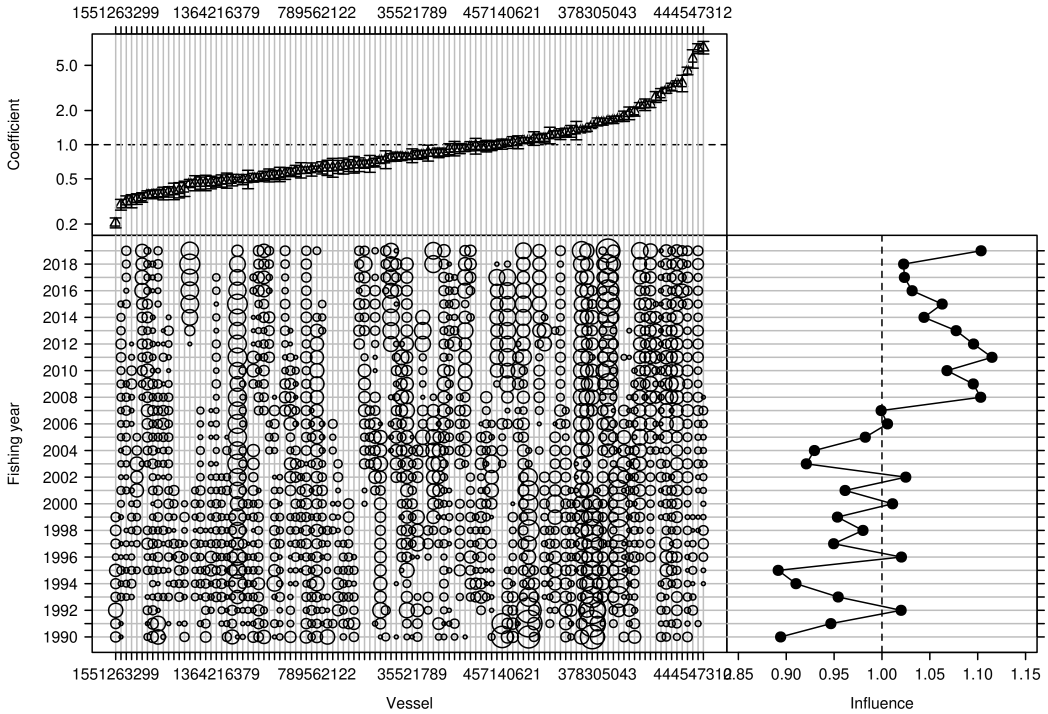

Figure G-160: Influence plot for vessel for the lognormal model of school shark in SCH 7/8/1W BT trip, showing model coefficients for each vessel (top panel), the distribution of observations over time across each vessel (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

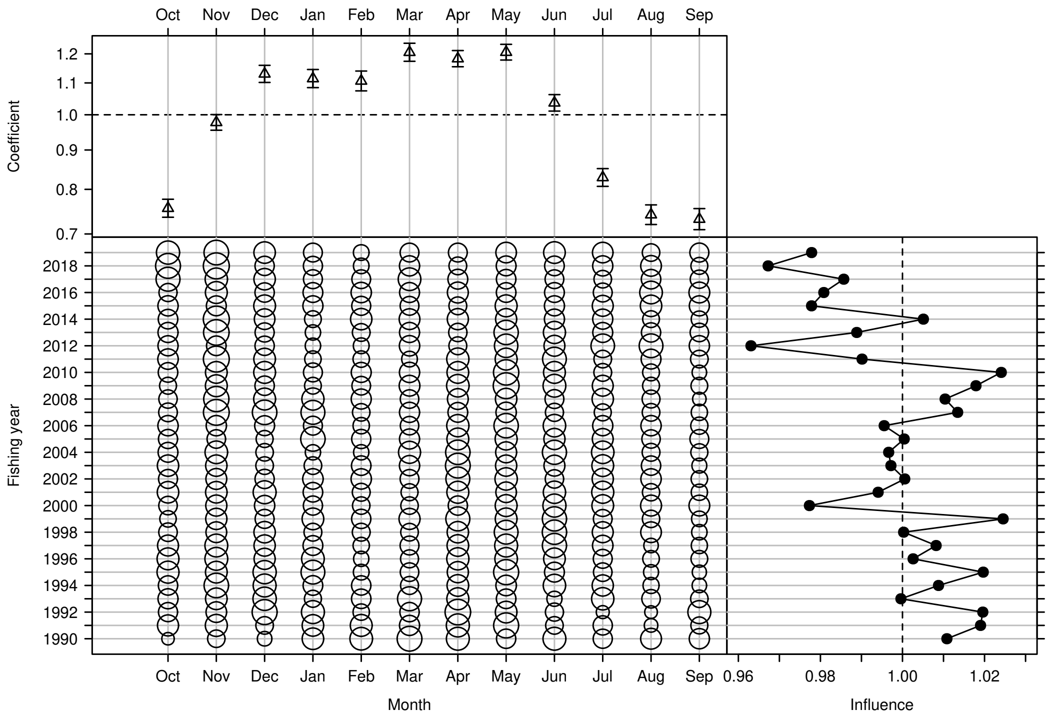

Figure G-161: Influence plot for month for the lognormal model of school shark in SCH 7/8/1W BT trip, showing model coefficients for each month (top panel), the distribution of observations over time across each month (bottom-left panel) and the influence metric by fishing year for this covariate (bottom-right panel).

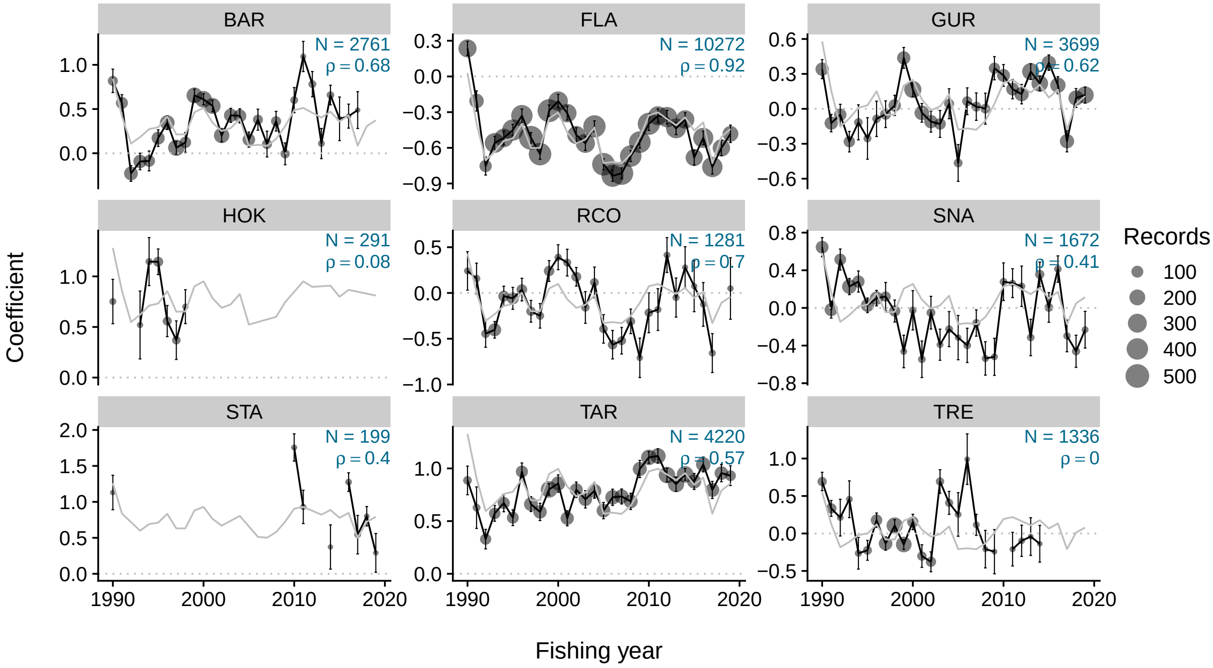

Figure G-162: Residual-implied coefficients (RICs) for target species for the lognormal model of school shark in SCH 7/8/1W BT trip, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

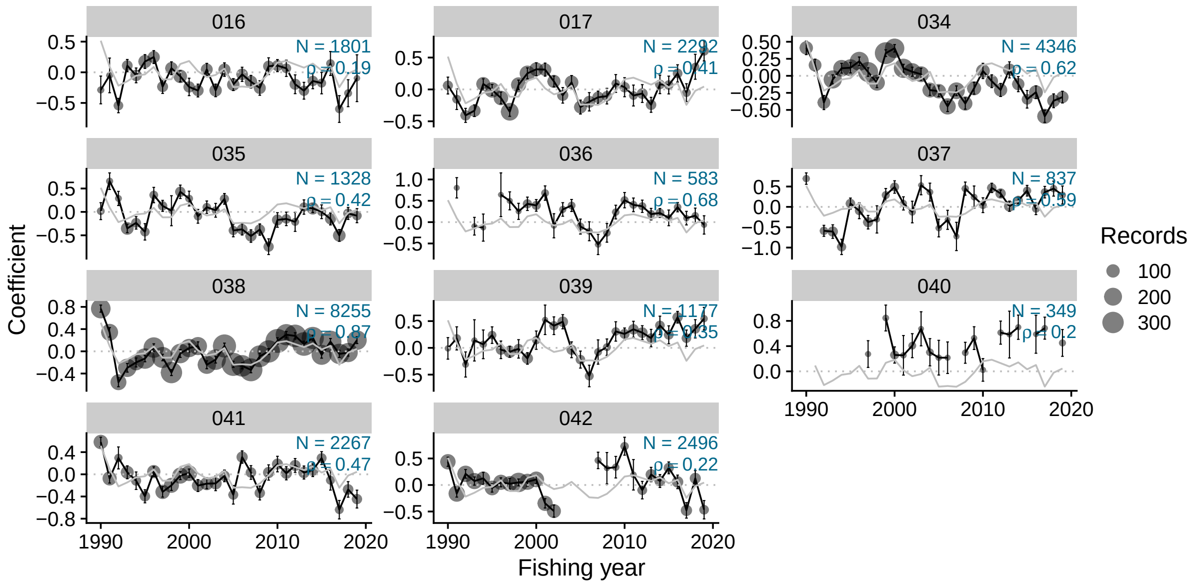

Figure G-163: Residual implied coefficients (RICs) for statistical area for the lognormal model of school shark in SCH 7/8/1W BT trip, with the model coefficients by fishing year shown as grey line. Number of records by level and the correlation (ρ) between the overall year coefficients and the RICs is shown in the top-right corner. Size of the circle scales with the number of records for each fishing year.

Table G-65: Standardised binomial, positive (lognormal) and combined indices for SCH 7/8/1W BT trip, with the 95% confidence interval for the combined index. Indices shown are the mean for each year of 1000 geometric-mean-centered draws from the estimated distribution of standardised series.

Fishing year	Binomial	Positive	Combined	2.5^{th}	97.5^{th}
1990	0.785	1.677	1.316	1.148	1.484
1991	0.652	1.102	0.718	0.610	0.832
1992	0.512	0.804	0.411	0.335	0.489
1993	0.702	0.866	0.608	0.531	0.687
1994	0.720	0.949	0.684	0.592	0.777
1995	0.876	0.967	0.847	0.764	0.931
1996	0.854	1.095	0.935	0.842	1.029
1997	0.910	0.891	0.811	0.737	0.882
1998	0.942	0.895	0.842	0.772	0.921
1999	1.131	1.148	1.297	1.190	1.410
2000	1.241	1.203	1.494	1.350	1.659
2001	1.116	1.020	1.138	1.030	1.256
2002	1.084	0.925	1.003	0.903	1.103
2003	1.083	0.961	1.041	0.938	1.161
2004	1.082	1.065	1.152	1.038	1.276
2005	1.017	0.787	0.800	0.724	0.888
2006	0.963	0.794	0.764	0.690	0.843
2007	0.929	0.785	0.729	0.657	0.809
2008	1.130	0.850	0.961	0.862	1.063
2009	1.152	0.978	1.126	1.004	1.251
2010	1.152	1.174	1.353	1.218	1.505
2011	1.232	1.205	1.484	1.318	1.649
2012	1.316	1.141	1.502	1.329	1.700
2013	1.270	1.079	1.371	1.210	1.540
2014	1.276	1.154	1.473	1.313	1.666
2015	1.126	1.031	1.161	1.039	1.300
2016	1.204	1.104	1.330	1.188	1.482
2017	1.079	0.787	0.849	0.764	0.942
2018	1.001	0.977	0.978	0.867	1.107
2019	1.151	1.045	1.203	1.067	1.358

APPENDIX H: Comparison of standardised indices by region across effort resolutions

H.1 Far North & SCH 1E set net

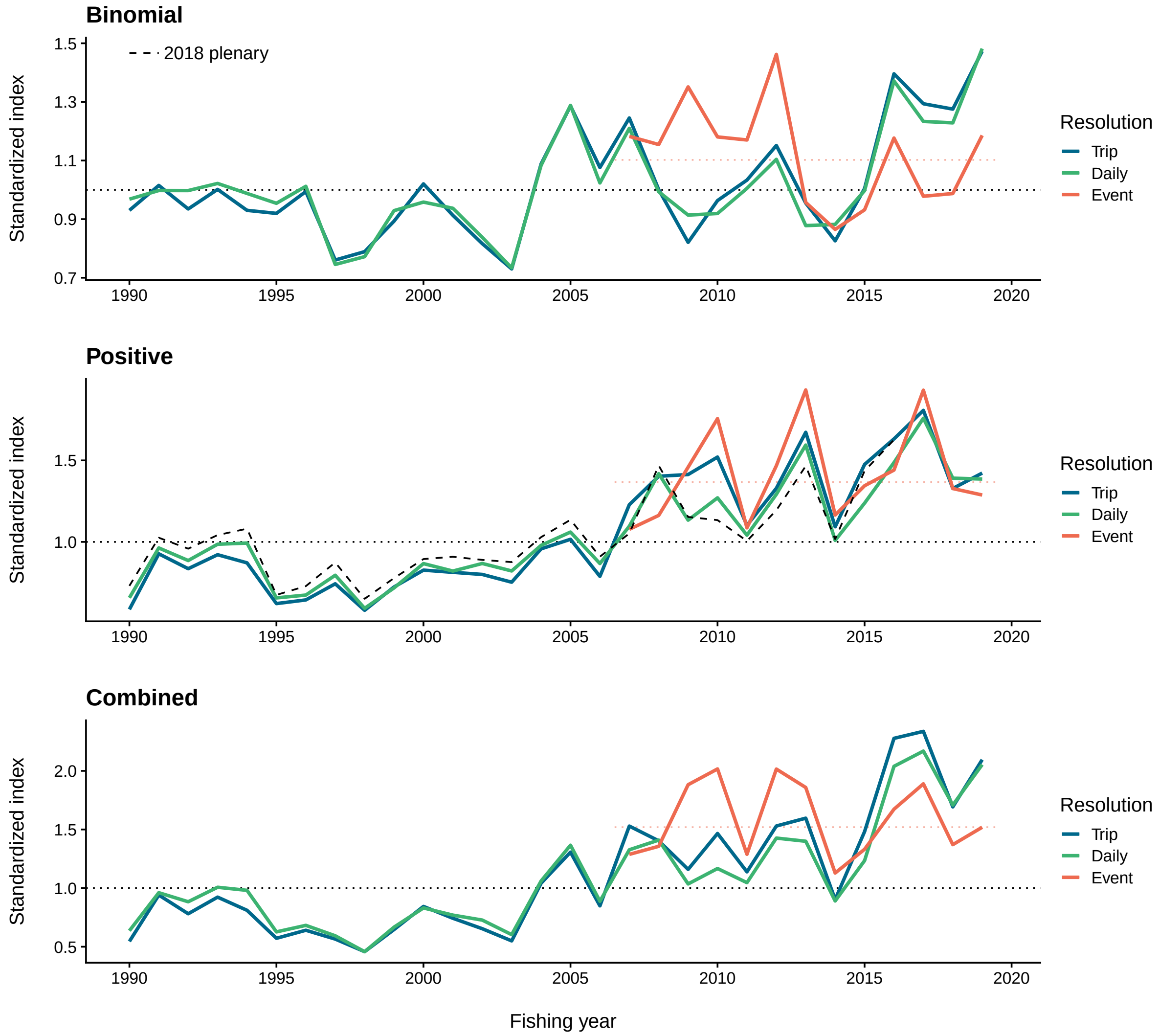

Figure H-1: Comparison of standardised indices developed at the event, daily and trip resolution for Far North & SCH 1E set net. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.2 Far North & SCH 1E bottom longline

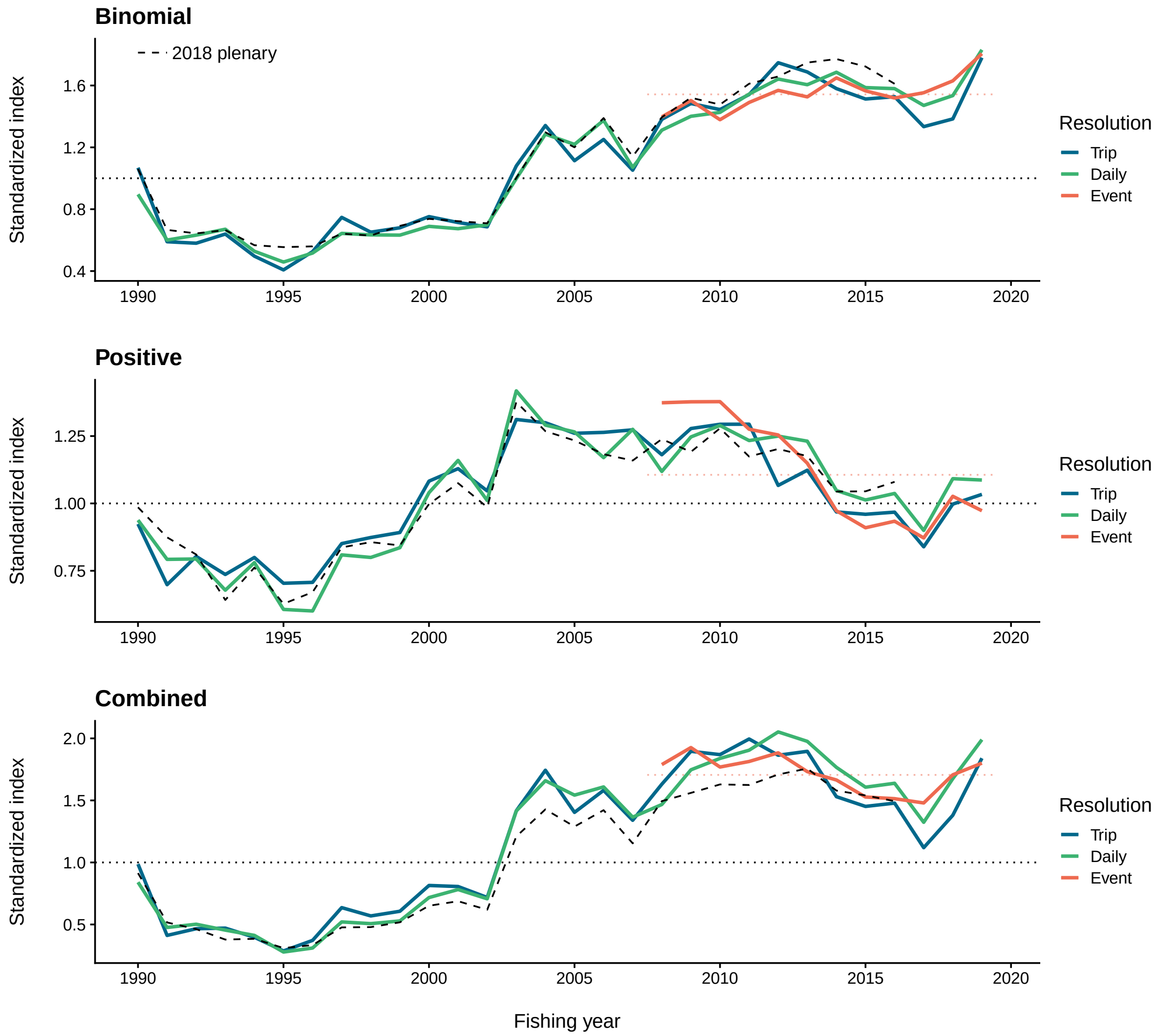

Figure H-2: Comparison of standardised indices developed at the event, daily and trip resolution for Far North & SCH 1E bottom longline. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.3 Far North & SCH 1E bottom trawl

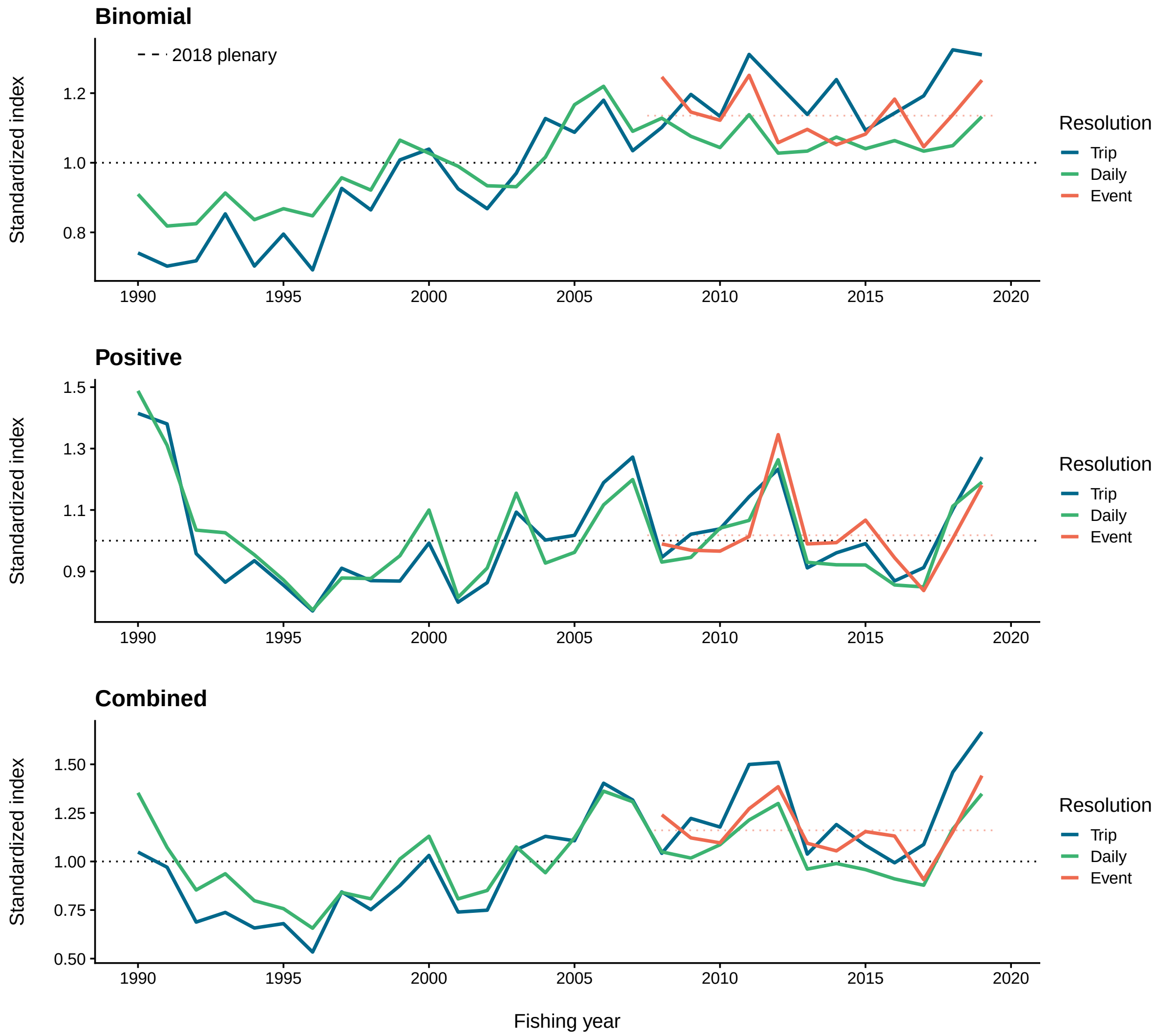

Figure H-3: Comparison of standardised indices developed at the event, daily and trip resolution for Far North & SCH 1E bottom trawl. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.4 SCH 2 & top of SCH 3 set net

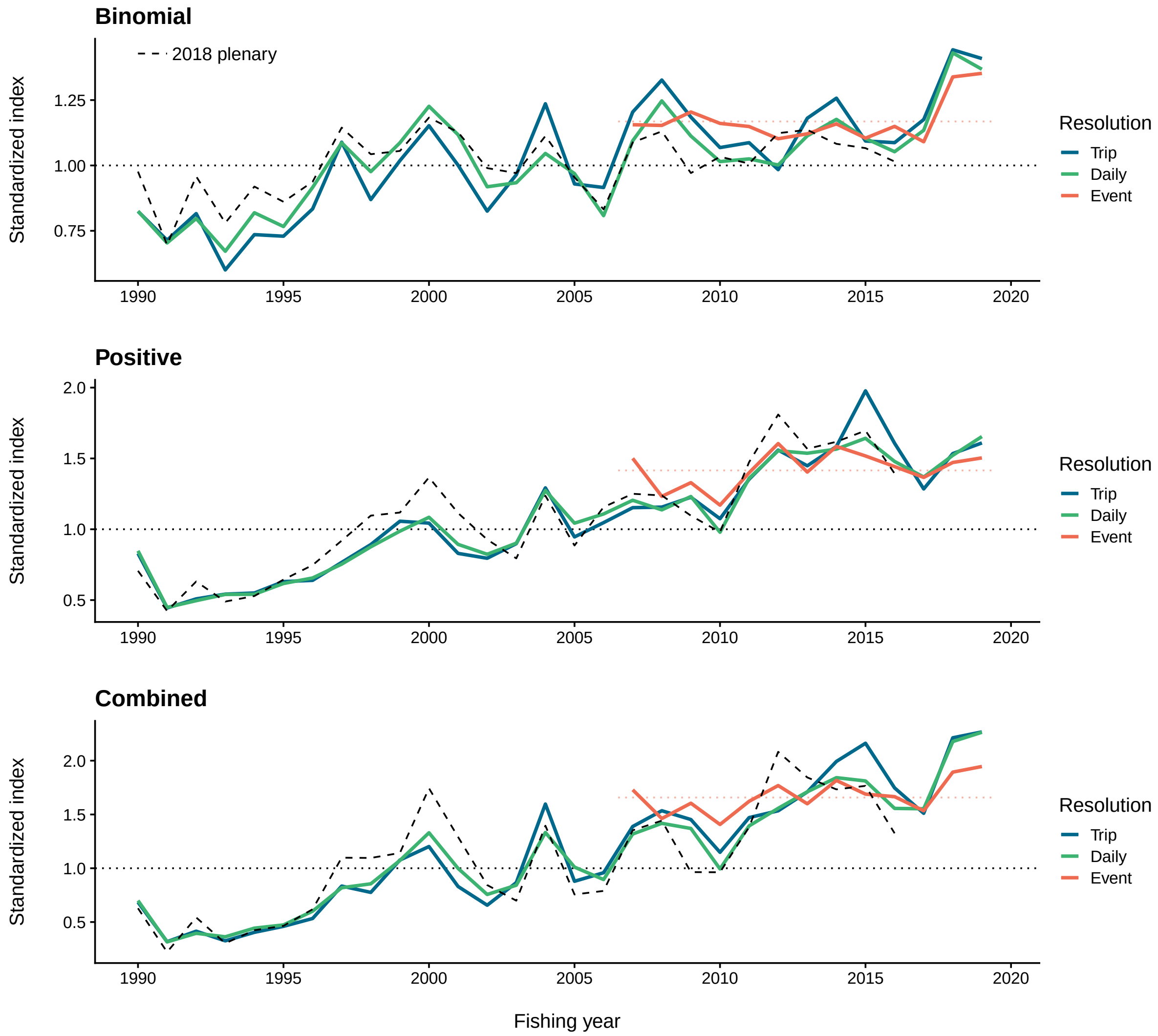

Figure H-4: Comparison of standardised indices developed at the event, daily and trip resolution for SCH 2 & top of SCH 3 set net. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.5 SCH 2 & top of SCH 3 bottom longline

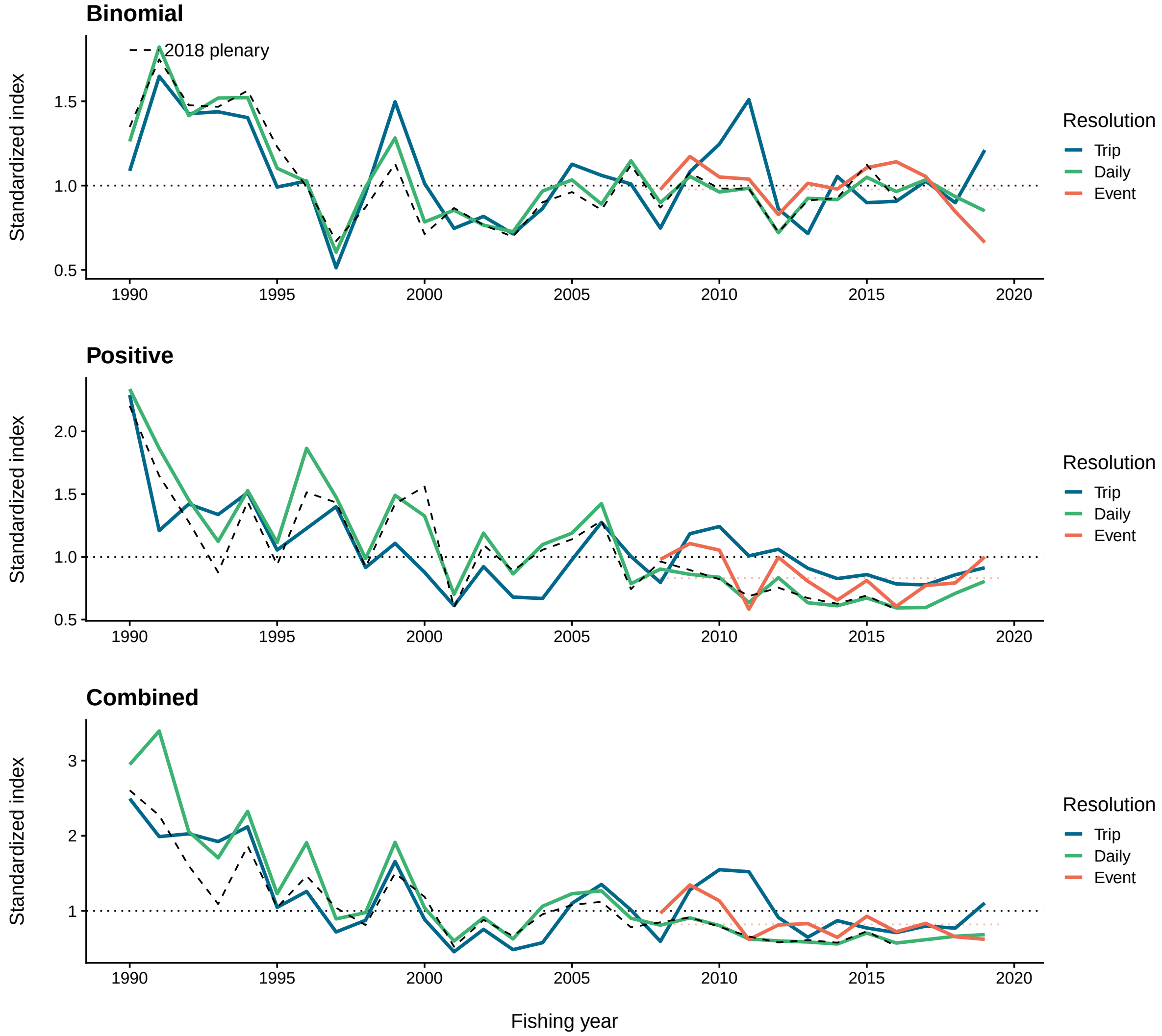

Figure H-5: Comparison of standardised indices developed at the event, daily and trip resolution for SCH 2 & top of SCH 3 bottom longline. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.6 SCH 2 & top of SCH 3 bottom trawl

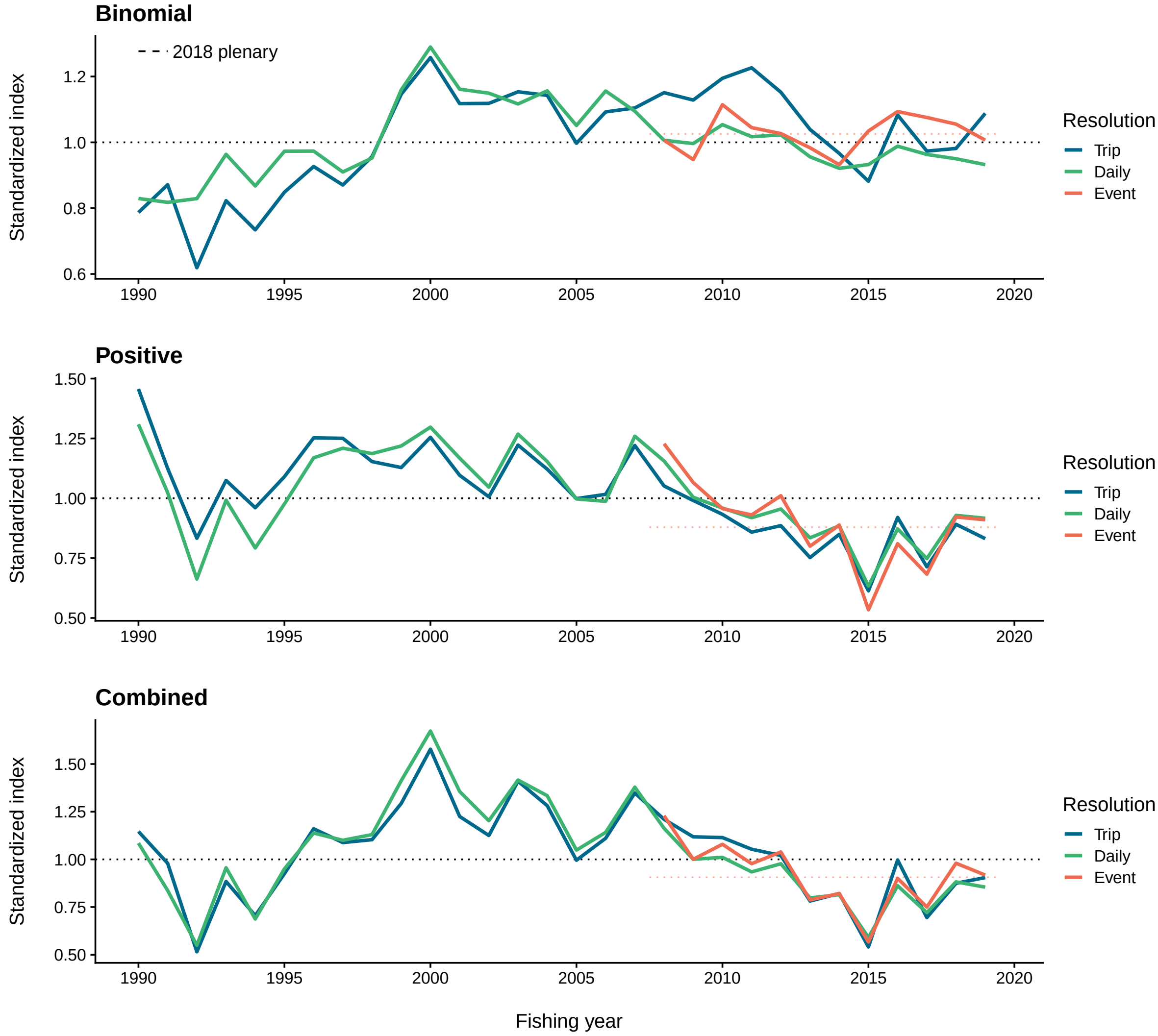

Figure H-6: Comparison of standardised indices developed at the event, daily and trip resolution for SCH 2 & top of SCH 3 bottom trawl. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.7 Chatham Rise (SCH 4) bottom longline

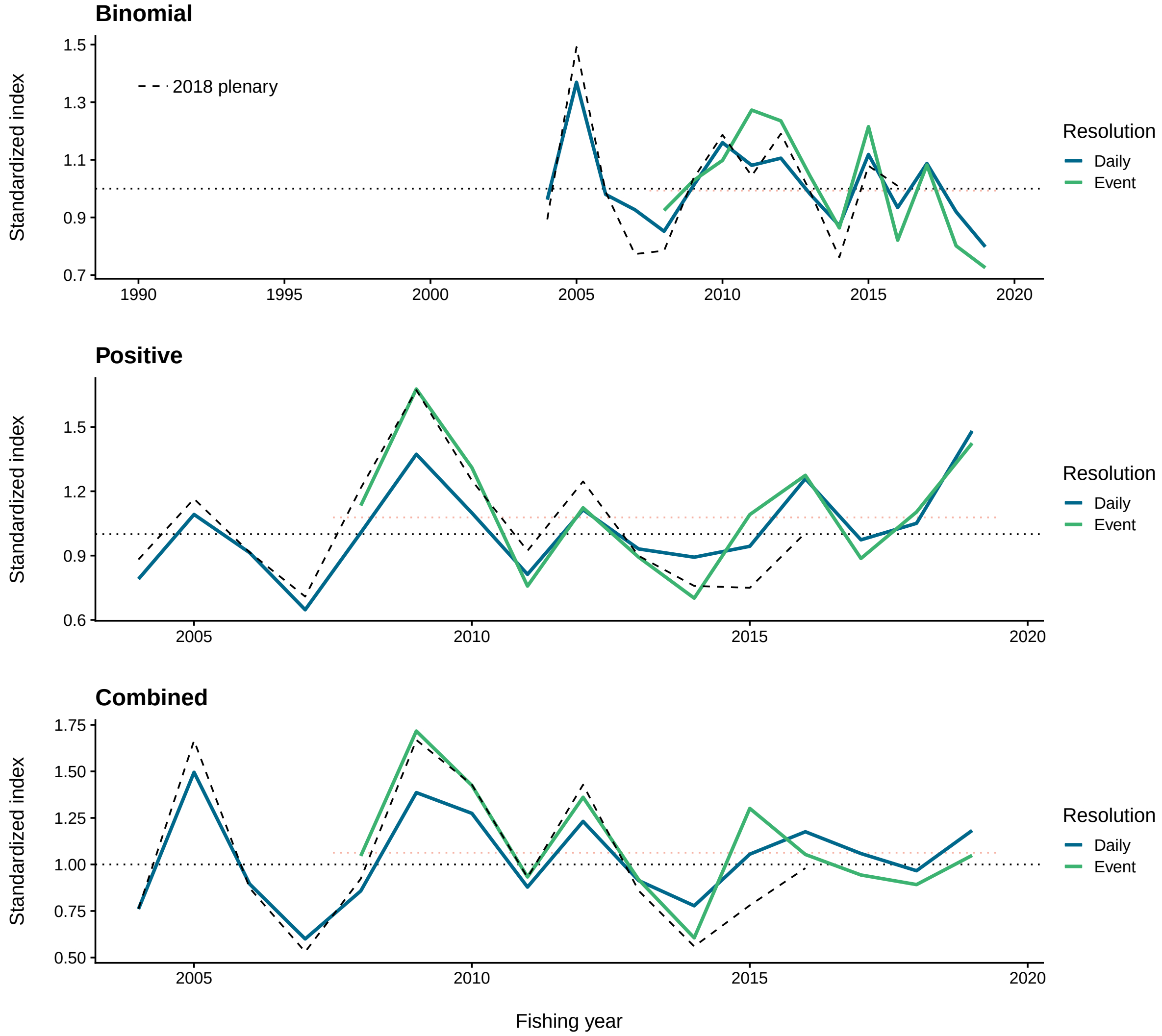

Figure H-7: Comparison of standardised indices developed at the event and daily resolution for Chatham Rise (SCH 4) bottom longline. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.8 Lower SCH 3 & SCH 5 set net

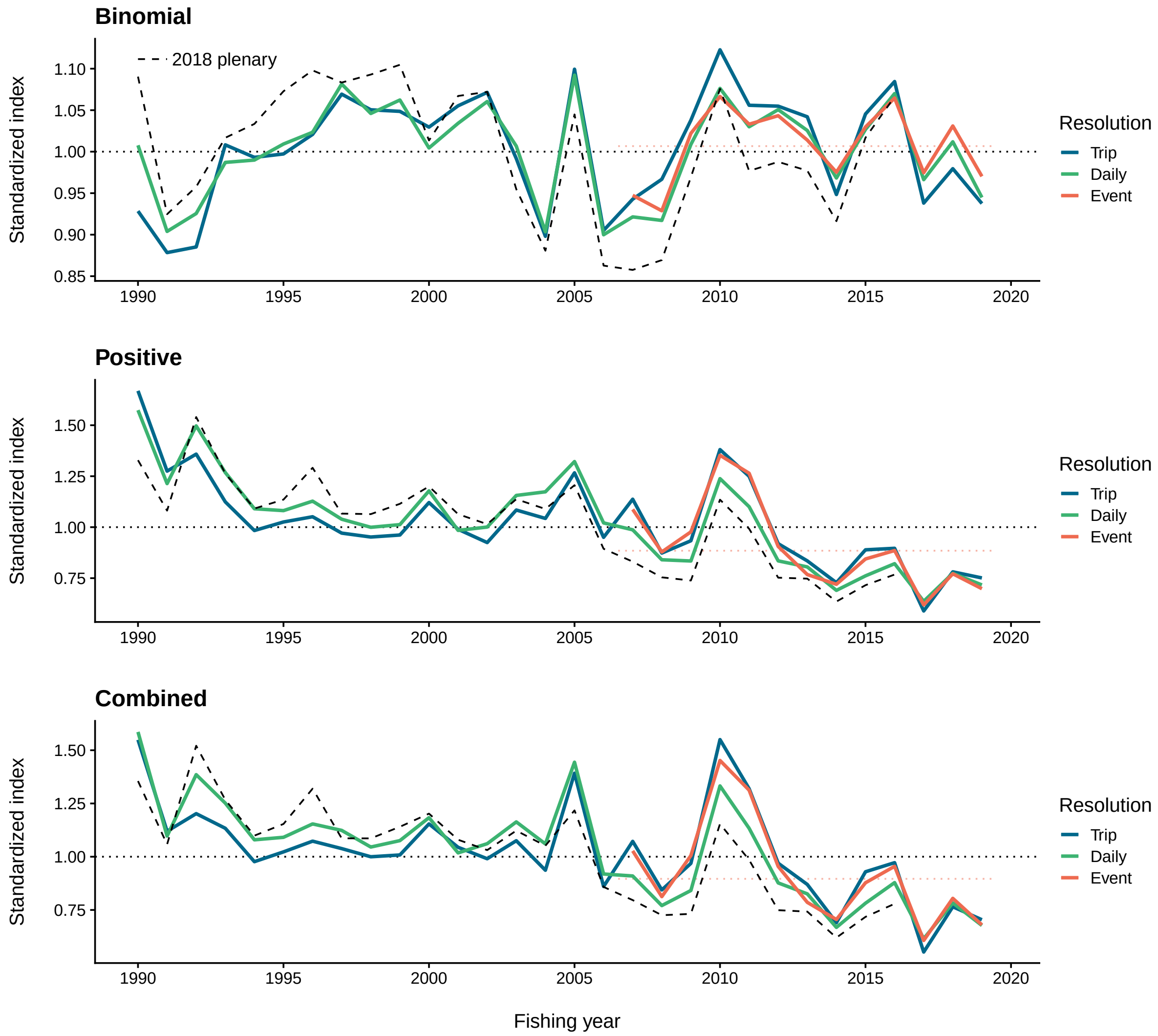

Figure H-8: Comparison of standardised indices developed at the event, daily and trip resolution for Lower SCH 3 & SCH 5 set net. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.9 Lower SCH 3 & SCH 5 bottom longline

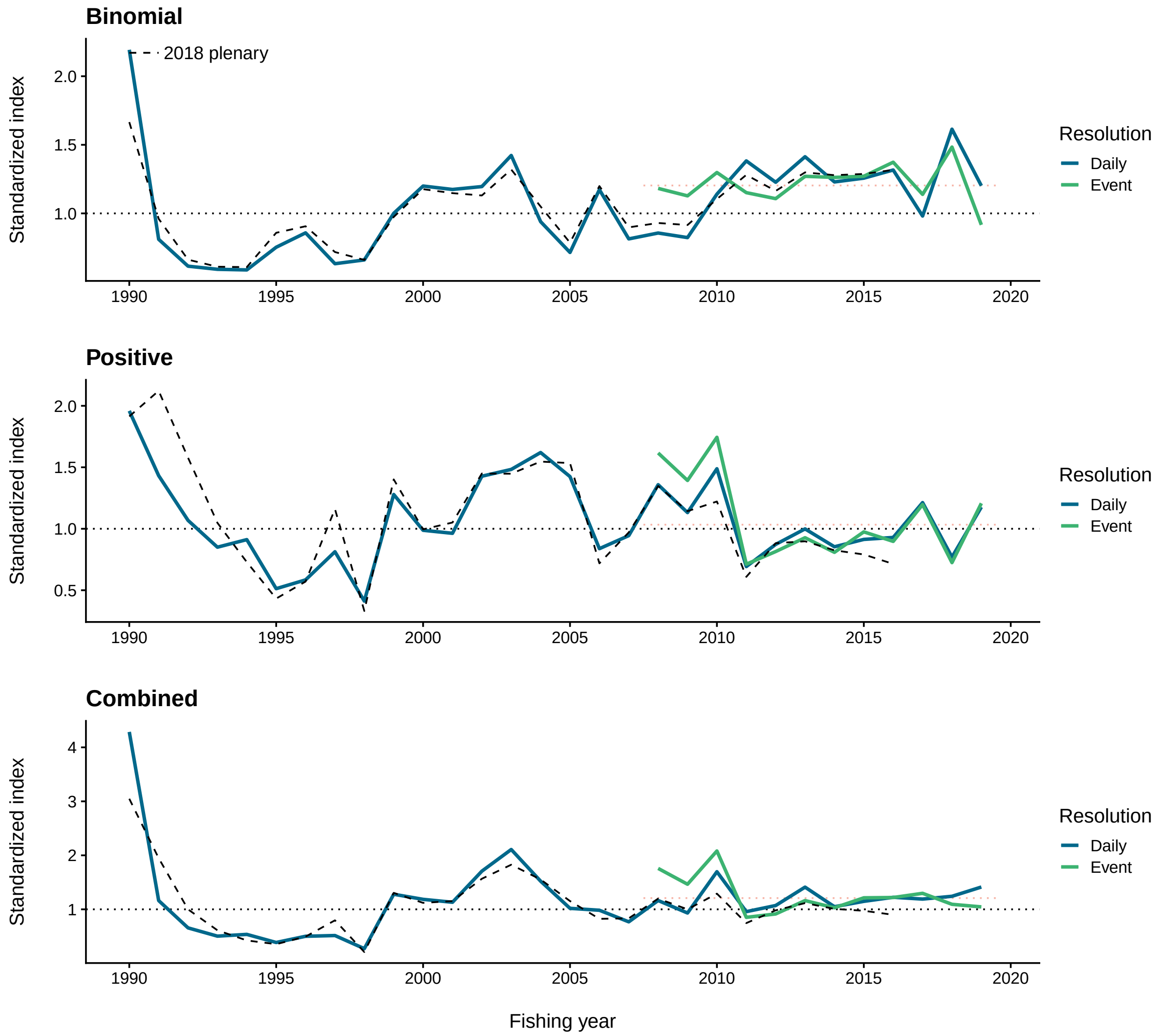

Figure H-9: Comparison of standardised indices developed at the event and daily resolution for Lower SCH 3 & SCH 5 bottom longline. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.10 Lower SCH 3 & SCH 5 bottom trawl

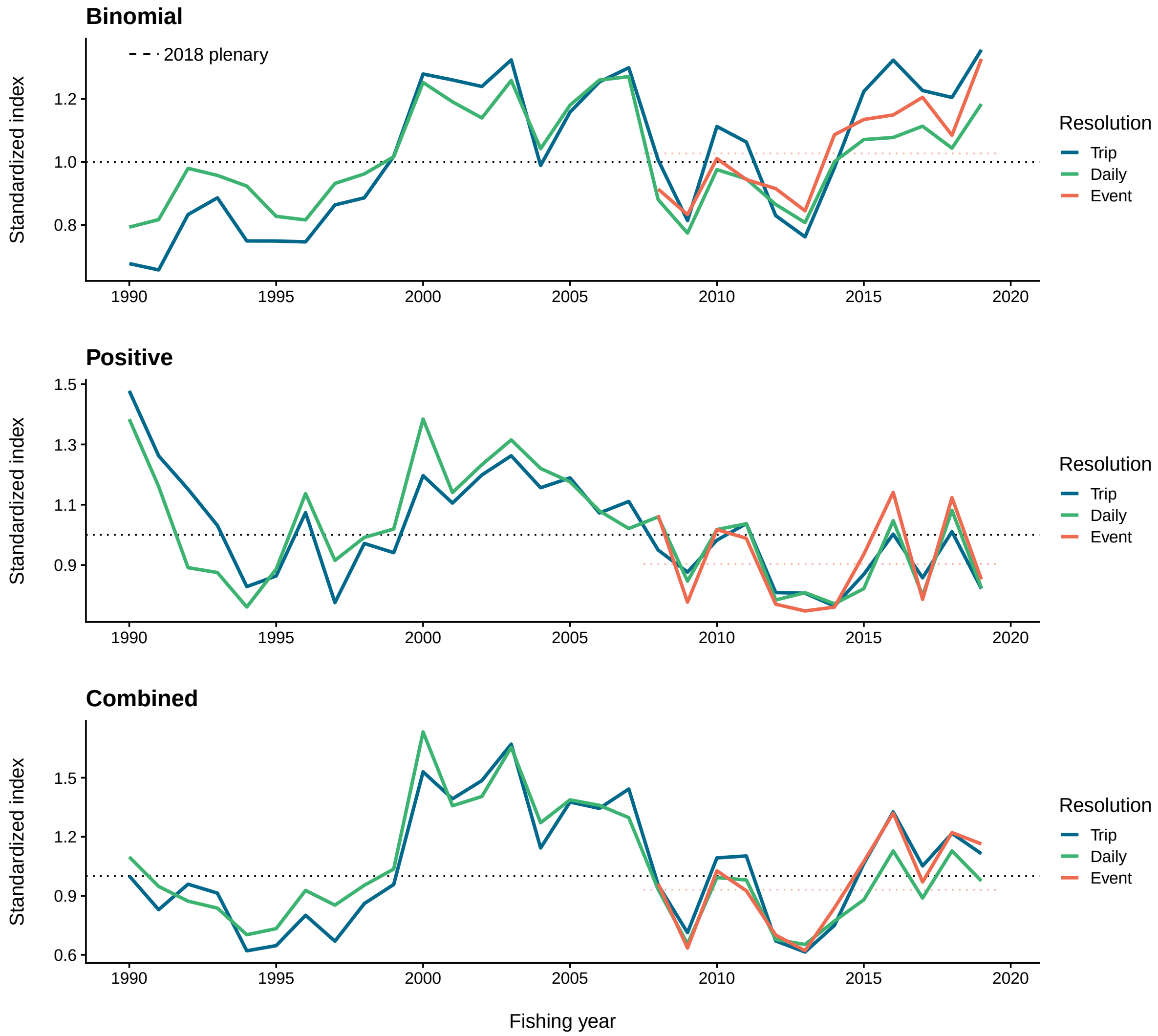

Figure H-10: Comparison of standardised indices developed at the event, daily and trip resolution for Lower SCH 3 & SCH 5 bottom trawl. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.11 SCH 7, SCH 8 & lower SCH 1W set net

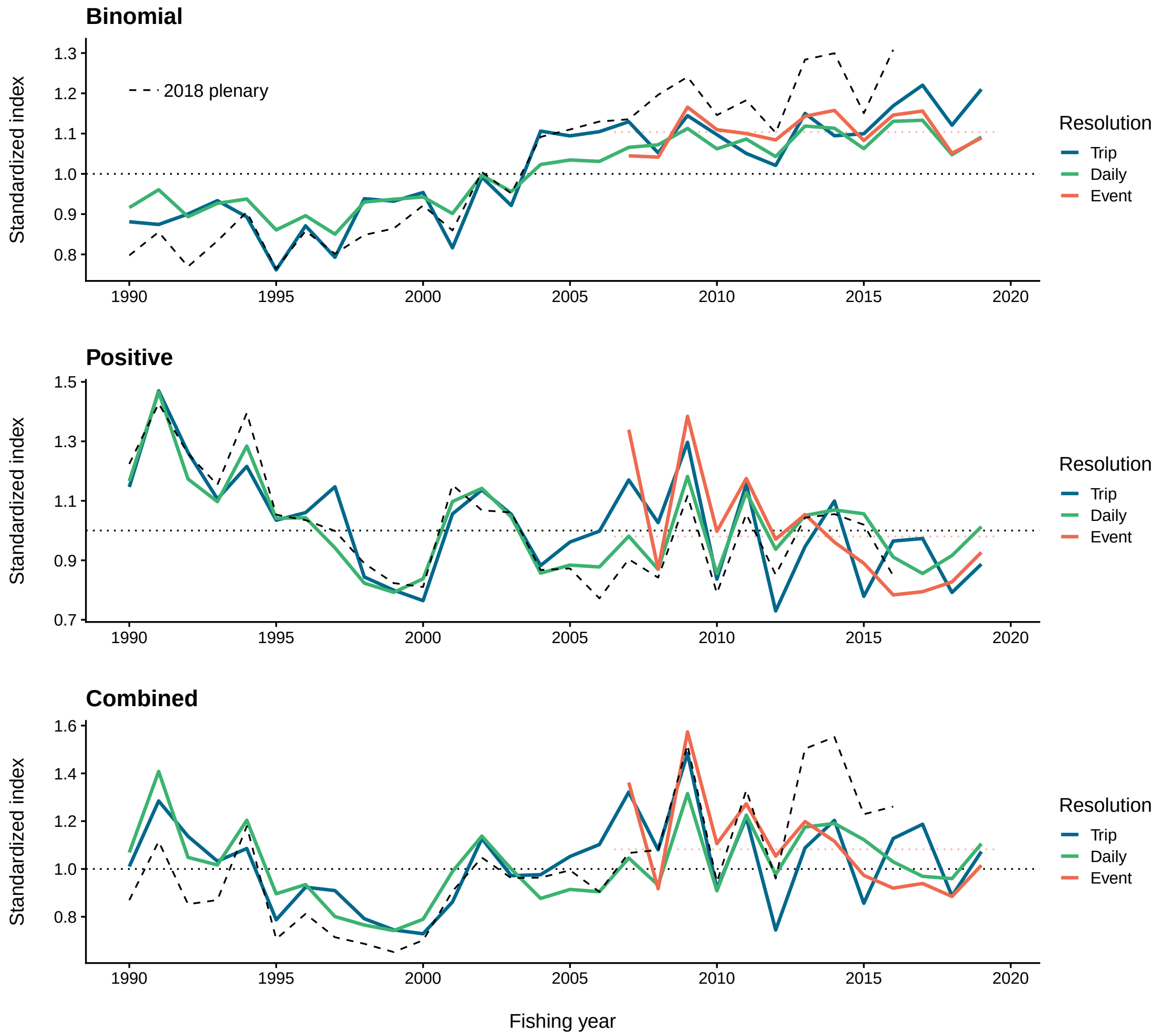

Figure H-11: Comparison of standardised indices developed at the event, daily and trip resolution for SCH 7, SCH 8 & lower SCH 1W set net. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.12 SCH 7, SCH 8 & lower SCH 1W bottom longline

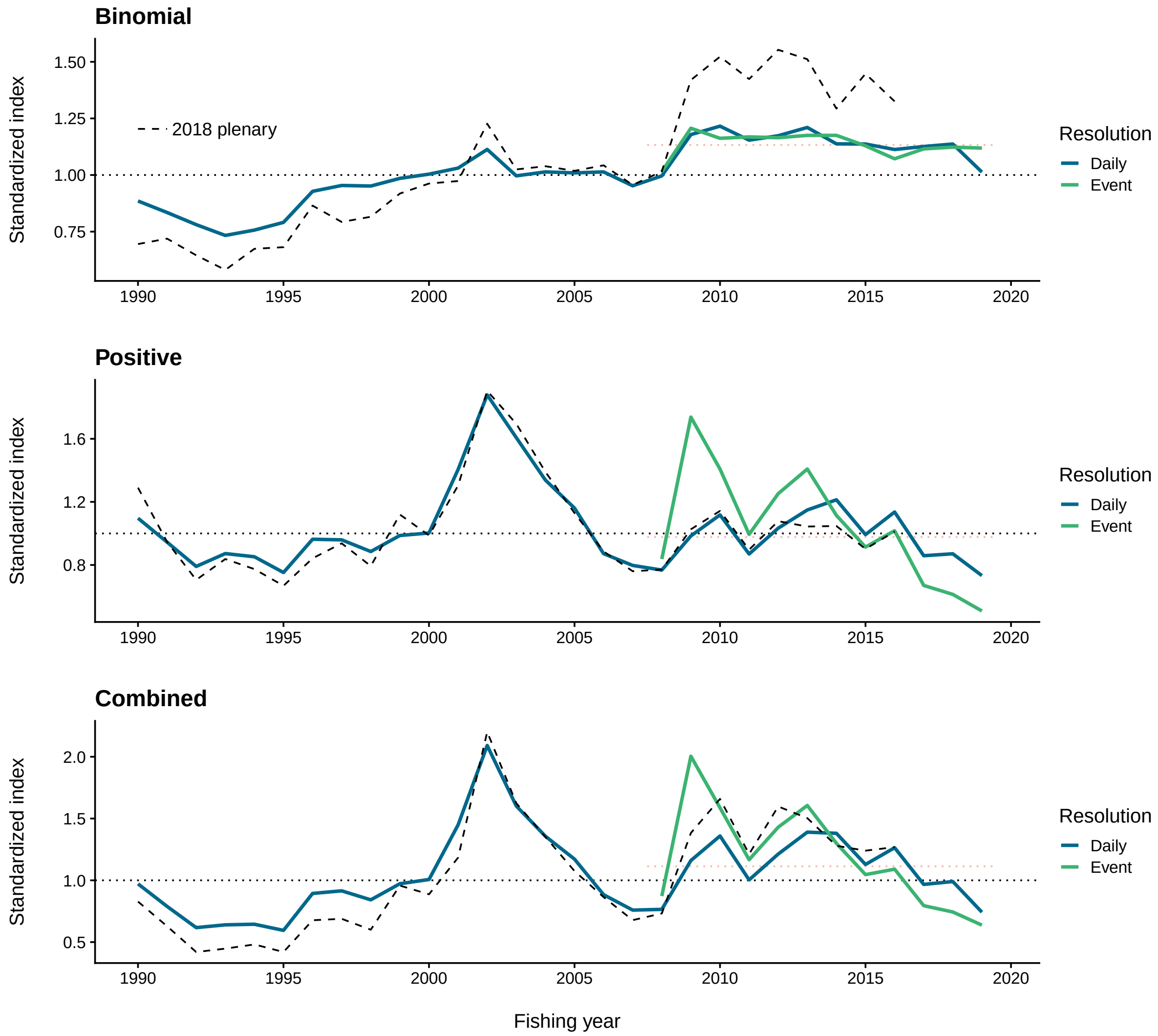

Figure H-12: Comparison of standardised indices developed at the event and daily resolution for SCH 7, SCH 8 & lower SCH 1W bottom longline. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

H.13 SCH 7, SCH 8 & lower SCH 1W bottom trawl

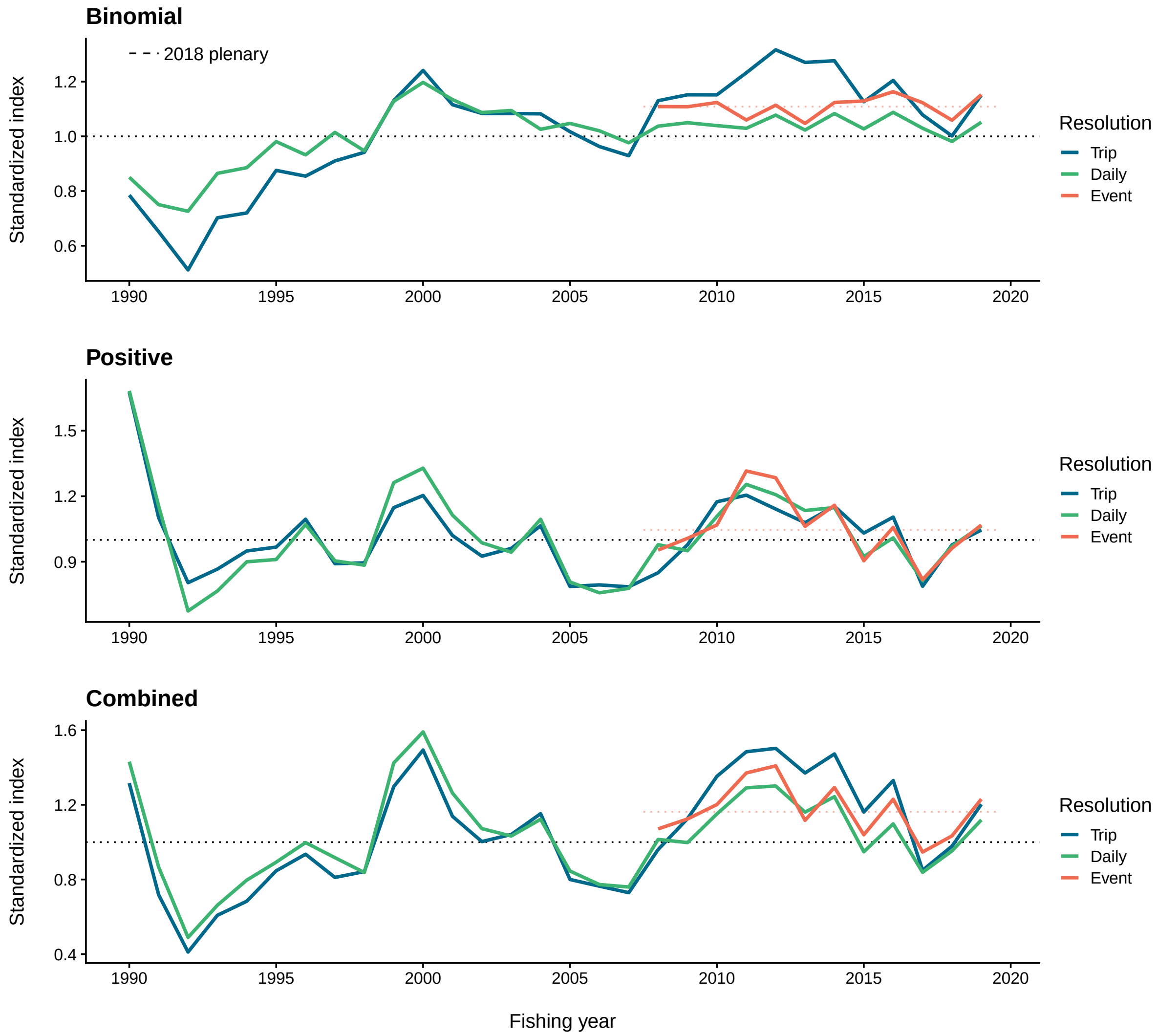

Figure H-13: Comparison of standardised indices developed at the event, daily and trip resolution for SCH 7, SCH 8 & lower SCH 1W bottom trawl. The event index was centred around the mean value for the trip and daily indices for the time period where they overlap (dotted red line). Standardised indices from the Fisheries Assessment Plenary 2018 (developed in Dunn & Bian 2018) are shown in a dashed line when available.

APPENDIX I: Corrected standardised indices from Dunn & Bian (2018)

Table I-1: Standardised binomial, positive (lognormal) and corrected combined indices for SCH 2 & top of SCH 3 set net from Dunn & Bian (2018), with the standard error for the lognormal index. All series have been geometric-mean-centered.

Fishing year	Binomial	Positive	SE	Combined
1990	0.98	0.71	0.14	0.67
1991	0.70	0.42	0.11	0.24
1992	0.96	0.63	0.08	0.58
1993	0.78	0.49	0.07	0.32
1994	0.92	0.53	0.06	0.45
1995	0.86	0.64	0.07	0.50
1996	0.94	0.75	0.06	0.66
1997	1.14	0.92	0.06	1.17
1998	1.04	1.10	0.06	1.17
1999	1.06	1.12	0.06	1.22
2000	1.18	1.37	0.05	1.86
2001	1.13	1.11	0.05	1.38
2002	0.99	0.93	0.06	0.90
2003	0.97	0.79	0.06	0.75
2004	1.11	1.24	0.07	1.49
2005	0.95	0.89	0.07	0.81
2006	0.83	1.16	0.09	0.84
2007	1.09	1.25	0.07	1.45
2008	1.13	1.24	0.07	1.54
2009	0.97	1.10	0.07	1.03
2010	1.03	0.98	0.07	1.03
2011	1.01	1.47	0.07	1.48
2012	1.12	1.81	0.07	2.23
2013	1.14	1.57	0.07	1.97
2014	1.08	1.62	0.07	1.85
2015	1.07	1.70	0.07	1.89
2016	1.01	1.39	0.07	1.42

Table I-2: Standardised binomial, positive (lognormal) and corrected combined indices for Lower SCH 3 & SCH 5 set net from Dunn & Bian (2018), with the standard error for the lognormal index. All series have been geometric-mean-centered.

Fishing year	Binomial	Positive	SE	Combined
1990	1.09	1.33	0.06	1.36
1991	0.92	1.08	0.05	1.06
1992	0.96	1.54	0.05	1.52
1993	1.02	1.26	0.05	1.27
1994	1.03	1.09	0.04	1.10
1995	1.07	1.14	0.04	1.16
1996	1.10	1.29	0.04	1.32
1997	1.08	1.07	0.04	1.09
1998	1.09	1.06	0.04	1.09
1999	1.10	1.11	0.04	1.14
2000	1.01	1.20	0.04	1.20
2001	1.07	1.06	0.04	1.08
2002	1.07	1.01	0.04	1.03
2003	0.95	1.14	0.04	1.12
2004	0.88	1.09	0.04	1.05
2005	1.04	1.21	0.04	1.22
2006	0.86	0.89	0.04	0.86
2007	0.86	0.83	0.04	0.80
2008	0.87	0.75	0.04	0.73
2009	0.97	0.74	0.04	0.73
2010	1.08	1.13	0.04	1.16
2011	0.98	0.99	0.04	0.99
2012	0.99	0.75	0.04	0.75
2013	0.98	0.75	0.04	0.74
2014	0.92	0.64	0.04	0.62
2015	1.02	0.72	0.04	0.72
2016	1.07	0.77	0.04	0.78

Table I-3: Standardised binomial, positive (lognormal) and corrected combined indices for SCH 7, SCH 8 & lower SCH 1W set net from Dunn & Bian (2018), with the standard error for the lognormal index. All series have been geometric-mean-centered.

Fishing year	Binomial	Positive	SE	Combined
1990	0.80	1.22	0.06	0.88
1991	0.86	1.43	0.05	1.13
1992	0.77	1.26	0.05	0.87
1993	0.83	1.15	0.05	0.88
1994	0.91	1.40	0.04	1.20
1995	0.76	1.05	0.04	0.72
1996	0.86	1.03	0.04	0.82
1997	0.80	1.00	0.05	0.73
1998	0.85	0.89	0.05	0.70
1999	0.86	0.82	0.05	0.66
2000	0.92	0.81	0.05	0.71
2001	0.86	1.15	0.05	0.92
2002	1.00	1.07	0.05	1.06
2003	0.95	1.06	0.05	0.98
2004	1.09	0.87	0.04	0.98
2005	1.11	0.87	0.05	1.01
2006	1.13	0.77	0.05	0.92
2007	1.14	0.90	0.04	1.08
2008	1.20	0.84	0.05	1.10
2009	1.24	1.12	0.05	1.54
2010	1.15	0.79	0.05	0.96
2011	1.18	1.06	0.05	1.35
2012	1.10	0.85	0.05	0.97
2013	1.28	1.04	0.06	1.53
2014	1.30	1.06	0.06	1.58
2015	1.15	1.02	0.06	1.25
2016	1.31	0.85	0.06	1.28

Table I-4: Standardised binomial, positive (lognormal) and corrected combined indices for Far North & SCH 1E bottom longline from Dunn & Bian (2018), with the standard error for the lognormal index. All series have been geometric-mean-centered.

Fishing year	Binomial	Positive	SE	Combined
1990	1.06	0.99	0.05	1.05
1991	0.67	0.87	0.05	0.59
1992	0.64	0.81	0.05	0.53
1993	0.66	0.64	0.04	0.43
1994	0.57	0.76	0.04	0.44
1995	0.55	0.63	0.04	0.35
1996	0.56	0.67	0.04	0.38
1997	0.64	0.84	0.04	0.55
1998	0.63	0.86	0.04	0.55
1999	0.69	0.84	0.04	0.59
2000	0.74	1.00	0.04	0.74
2001	0.72	1.08	0.03	0.79
2002	0.71	0.99	0.04	0.71
2003	1.00	1.38	0.03	1.38
2004	1.30	1.27	0.03	1.63
2005	1.20	1.23	0.04	1.47
2006	1.39	1.18	0.04	1.63
2007	1.14	1.16	0.04	1.32
2008	1.39	1.24	0.03	1.71
2009	1.52	1.19	0.03	1.79
2010	1.48	1.28	0.03	1.86
2011	1.61	1.17	0.03	1.86
2012	1.66	1.20	0.03	1.96
2013	1.75	1.18	0.03	2.01
2014	1.77	1.04	0.03	1.81
2015	1.72	1.04	0.03	1.76
2016	1.61	1.08	0.03	1.71

Table I-5: Standardised binomial, positive (lognormal) and corrected combined indices for SCH 2 & top of SCH 3 bottom longline from Dunn & Bian (2018), with the standard error for the lognormal index. All series have been geometric-mean-centered.

Fishing year	Binomial	Positive	SE	Combined
1990	1.35	2.20	0.19	2.70
1991	1.75	1.65	0.12	2.35
1992	1.48	1.28	0.08	1.66
1993	1.47	0.88	0.08	1.13
1994	1.56	1.44	0.08	1.93
1995	1.23	0.94	0.09	1.08
1996	0.99	1.51	0.09	1.52
1997	0.67	1.43	0.10	1.08
1998	0.87	0.92	0.10	0.84
1999	1.13	1.42	0.08	1.55
2000	0.71	1.56	0.10	1.23
2001	0.87	0.59	0.08	0.54
2002	0.77	1.10	0.09	0.91
2003	0.70	0.89	0.09	0.69
2004	0.90	1.06	0.08	0.99
2005	0.96	1.14	0.08	1.12
2006	0.86	1.29	0.07	1.16
2007	1.12	0.74	0.07	0.81
2008	0.87	0.96	0.07	0.88
2009	1.08	0.89	0.07	0.95
2010	0.98	0.82	0.07	0.82
2011	0.98	0.69	0.06	0.68
2012	0.72	0.75	0.07	0.60
2013	0.91	0.67	0.08	0.63
2014	0.93	0.63	0.07	0.60
2015	1.12	0.69	0.07	0.75
2016	0.92	0.58	0.08	0.55

Table I-6: Standardised binomial, positive (lognormal) and corrected combined indices for Lower SCH 3 & SCH 5 bottom longline from Dunn & Bian (2018), with the standard error for the lognormal index. All series have been geometric-mean-centered.

Fishing year	Binomial	Positive	SE	Combined
1990	1.67	1.91	0.13	3.19
1991	0.96	2.12	0.15	2.04
1992	0.66	1.58	0.13	1.05
1993	0.61	1.05	0.11	0.64
1994	0.61	0.73	0.13	0.44
1995	0.86	0.43	0.10	0.37
1996	0.91	0.57	0.09	0.52
1997	0.72	1.16	0.11	0.83
1998	0.66	0.33	0.12	0.22
1999	0.97	1.40	0.09	1.37
2000	1.18	1.00	0.08	1.17
2001	1.15	1.05	0.08	1.21
2002	1.13	1.45	0.08	1.64
2003	1.32	1.45	0.07	1.91
2004	1.05	1.55	0.08	1.62
2005	0.79	1.53	0.09	1.21
2006	1.20	0.72	0.07	0.86
2007	0.90	0.97	0.07	0.87
2008	0.93	1.35	0.08	1.25
2009	0.92	1.14	0.08	1.05
2010	1.10	1.22	0.08	1.35
2011	1.28	0.61	0.07	0.78
2012	1.16	0.88	0.08	1.03
2013	1.30	0.90	0.08	1.17
2014	1.28	0.82	0.08	1.05
2015	1.29	0.79	0.09	1.02
2016	1.32	0.71	0.08	0.94

Table I-7: Standardised binomial, positive (lognormal) and corrected combined indices for Chatham Rise (SCH 4) bottom longline from Dunn & Bian (2018), with the standard error for the lognormal index. All series have been geometric-mean-centered.

Fishing year	Binomial	Positive	SE	Combined
2004	0.89	0.88	0.08	0.79
2005	1.49	1.16	0.06	1.73
2006	0.99	0.92	0.06	0.90
2007	0.77	0.71	0.06	0.55
2008	0.78	1.21	0.05	0.96
2009	1.03	1.67	0.06	1.73
2010	1.19	1.25	0.05	1.48
2011	1.04	0.92	0.05	0.96
2012	1.19	1.25	0.05	1.48
2013	0.99	0.90	0.05	0.89
2014	0.76	0.76	0.06	0.58
2015	1.08	0.75	0.06	0.81
2016	1.01	1.01	0.07	1.02

Table I-8: Standardised binomial, positive (lognormal) and corrected combined indices for SCH 7, SCH 8 & lower SCH 1W bottom longline from Dunn & Bian (2018), with the standard error for the lognormal index. All series have been geometric-mean-centered.

Fishing year	Binomial	Positive	SE	Combined
1990	0.70	1.29	0.12	0.88
1991	0.72	0.95	0.09	0.67
1992	0.65	0.71	0.09	0.45
1993	0.58	0.84	0.08	0.48
1994	0.67	0.77	0.07	0.51
1995	0.68	0.67	0.07	0.45
1996	0.86	0.84	0.06	0.72
1997	0.79	0.94	0.06	0.74
1998	0.82	0.79	0.06	0.64
1999	0.92	1.12	0.06	1.02
2000	0.96	0.99	0.07	0.95
2001	0.97	1.30	0.06	1.27
2002	1.23	1.90	0.07	2.35
2003	1.02	1.70	0.07	1.74
2004	1.04	1.39	0.07	1.44
2005	1.02	1.13	0.07	1.15
2006	1.04	0.89	0.07	0.92
2007	0.96	0.76	0.07	0.72
2008	1.02	0.77	0.08	0.78
2009	1.42	1.03	0.07	1.48
2010	1.52	1.14	0.07	1.77
2011	1.42	0.90	0.07	1.30
2012	1.55	1.08	0.07	1.71
2013	1.51	1.04	0.07	1.61
2014	1.29	1.05	0.08	1.37
2015	1.45	0.90	0.07	1.33
2016	1.33	1.01	0.07	1.36

APPENDIX J: Computation of total catches by catch-per-unit-effort (CPUE) monitoring unit for the Fisheries Assessment Plenary

The stock status overview included as part of the Fisheries Assessment Plenary (Fisheries New Zealand 2021) includes an estimate of fishing intensity derived as the ratio of the stock's total catch to the index of abundance (e.g., a standardised catch-per-unit-effort (CPUE) series).

For school shark, the statistical area definition for the CPUE monitoring units varies slightly between fishing methods, based on the spatial delineation of each gear fishing effort within the general area of the CPUE unit.

For the purpose of computing fishing intensity, a universal set of statistical areas for each CPUE monitoring unit was defined to be used across all fishing gears (Table J-1). This approach was used to ensure that all measures of fishing intensity for the same CPUE monitoring unit are based on total catches from the same area definition. This spatial definition was used to compute the total catch by gear for each CPUE unit from allocated catch.

The allocation procedure can result in a substantial amount of catches being discarded (e.g., for fishing trips landing catch to multiple quota management areas (QMAs) that fished in straddling statistical codes). For this reason, the allocated catches were first scaled up to match landings reported in Quota Management Report (QMR) and Monthly Harvest Return (MHRs) statistics. The following procedure was used to compute total catches for the fishing intensity metric:

- allocated catches were summed by year and QMAs, and the ratio of annual landings from QMR and MHR reports by QMA to the corresponding summed allocated catches was computed:

$$R_{QMA,yr} = \frac{C_{QMA,yr}}{\sum A_{QMA,yr}},$$

  where C are the catches (t) reported in QMR and MHR statistics for the QMA and year combination, and A are all allocated catches that were assigned to a given QMA and year as part of the catch allocation procedure;

- allocated catches at their original (daily or event) resolution were multiplied by the ratio $R_{QMA,yr}$ for the QMA/year where they occur;

- scaled allocated catches were summed up by CPUE monitoring unit and year using the spatial definition for CPUE monitoring units (defined in Table J-1).

Table J-1: Statistical area codes used to define the area used to compute total catch by catch-per-unit-effort (CPUE) monitoring unit for the Fisheries Assessment Plenary 2021.

CPUE monitoring unit	Statistical area codes
Far North & SCH 1E	043, 044, 045, 046, 047, 048, 001, 002, 003, 004, 005, 006, 007, 008, 009, 010, 102, 103, 104, 105, 106, 107
SCH 2 & top of SCH 3	011, 012, 013, 014, 015, 018, 020, 201, 202, 203, 204, 205, 206
Chatham Rise (SCH 4)	019, 021, 049, 050, 051, 052, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412
Lower SCH 3 & SCH 5	022, 023, 024, 025, 026, 027, 028, 029, 030, 031, 032, 033, 501, 502, 503, 504, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 617, 618, 619, 624, 625, 620, 621, 706
SCH 7, SCH 8 & lower SCH 1W	016, 017, 034, 035, 036, 037, 038, 039, 040, 041, 042, 801, 101, 701, 702, 703, 704, 705