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Tini a Tangaroa

Characterisation and CPUE indices for swordfish (*Xiphias gladius*) from the New Zealand tuna longline fishery, 1993 to 2019

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EXECUTIVE SUMMARY

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Swordfish (*Xiphias gladius*) are a highly migratory species, widespread in the Pacific Ocean, with the New Zealand region encompassing only a small part of the species' range. Although a number of different stock structures have been proposed for swordfish, there is no clear evidence of subpopulations across the Pacific. Despite some degree of regional connectivity, swordfish are susceptible to local depletion and data from tagged individuals suggest foraging site fidelity in New Zealand waters.

This report provides a descriptive analysis of the catch and effort data for swordfish in the New Zealand surface longline fishery and updated catch per unit effort (CPUE) indices using commercial catch effort and remote-sensed environmental variables. Data were divided into four series: all vessels in the fishery from 1993 to 2019 and from 2004 to 2019, and a selected core fleet from 1999 to 2019 and from 2004 to 2019. The later time series incorporated operational changes in the fishery, including the recording of light sticks and bait type, when swordfish were introduced into the Quota Management System in 2004.

All models showed similar CPUE trends over time which were comparable with the previous iteration of this work: CPUE gradually increased in each time series, reaching a peak in 2012 and 2013, followed by a steady decline to the present day. Indices for the most recent years are similar to those at the beginning of the time series. The fishing season (*Year-quarter*) explained most of the deviance in all models, and *night fraction* (the fraction of the set soak time during the hours of darkness) was an important variable in all the models. When separated by quarter year the models showed similar patterns, with the highest CPUE indices occurring in the first quarter (January-March) for most of the time series, particularly since 2007.

An additional index using *Year* instead of *Year-quarter* was also investigated for the core vessels series. The annual index showed a variable trend that was mostly consistent with the *Year-quarter* index; however, the annual CPUE index peaked in 2011, earlier than the *Year-quarter* index in 2013. This earlier peak is likely to be influenced by the higher than usual catches of swordfish reported in Quarter 3 between 2010 and 2013.

1. INTRODUCTION

Swordfish (*Xiphias gladius*) are a highly migratory species, widespread in the Pacific Ocean from at least 50° N to 50° S in the western Pacific Ocean (Unwin et al. 2006). The New Zealand region encompasses only a small part of the species' range. Although several different stock structures have been proposed for swordfish, there is no clear evidence of subpopulations across the Pacific (Lu et al. 2016). Despite some degree of regional connectivity, swordfish are susceptible to local depletion (Ward et al. 2008) and data from tagged individuals suggest foraging site fidelity in New Zealand waters (Holdsworth et al. 2010).

Swordfish catches were first reported by foreign licensed Japanese longliners operating in New Zealand in the late 1970s. By the early 1990s, this fleet was largely replaced by a domestic fleet which grew rapidly in numbers during the 1990s and subsequently dominated effort and landings in the northern (north of 40° S) longline fishery (Anderson et al. 2013). The commercial catch of swordfish in New Zealand is taken in the surface longline fishery (Griggs et al. in press). It is either specifically targeted or caught as bycatch when targeting bigeye tuna (*Thunnus obesus*) and, to a lesser extent, southern bluefin tuna (*Thunnus maccoyii*). Swordfish have been caught around much of New Zealand and the adjacent high seas areas, but most of the historical catch has come from north of 40° S (Anderson et al. 2013). Swordfish catches vary considerably by season; they are greatest in the first and second quarters of the calendar year, lower in the third quarter, and lowest in the fourth quarter (Griggs & Richardson 2005).

Swordfish were introduced into the New Zealand Quota Management System (QMS) in October 2004 under a single Quota Management Area (QMA) and with an annual Total Allowable Commercial Catch (TACC) of 885 t, which has remained unchanged. Before the introduction of the TACC, targeting of swordfish was prohibited, although retention of swordfish caught as bycatch in other target fisheries was permitted. Swordfish can be legally discarded under the provisions of Schedule 6 of the Fisheries Act (1996) if there is a chance they will survive, it is done immediately, and if they are small (less than 1.25 m long from lower jaw to fork length). However, most of the swordfish caught are landed (Griggs et al. in press).

Swordfish have certain behavioural characteristics which can be taken advantage of by longline fishers to increase the likelihood of capture. One of these is their crepuscular diving behaviour. Swordfish move into surface waters at dusk and remain there during the hours of darkness, returning to deeper water (below 600 m and as deep as 900 m) at dawn and staying there during daylight hours (Carey & Robison 1981) except for occasional excursions to the surface — especially by larger fish (Holdsworth et al. 2010). Another is that catch rates of swordfish are known to be better when there is a bright moon (e.g., Bigelow et al. 1999). This influence of light on swordfish behaviour is recognised by fishers, and catch rates can be increased by attaching luminescent light sticks at intervals along the longline. Although the use of light sticks in the New Zealand tuna longline fishery pre-dates the introduction of swordfish into the QMS (to attract some tuna species to the lines if not swordfish) this information was not recorded on catch-effort forms until 2003.

The first comprehensive analysis of New Zealand swordfish catch per unit effort (CPUE) used Catch Effort and Landing Returns from the tuna longline fishery to generate standardised CPUE indices by year and quarter (Unwin et al. 2006). The study was later updated with a focus on the more fully developed domestic fishery (the years 1998 to 2007) and a core set of experienced vessels (Unwin et al. 2009). The most recent analysis was conducted in 2012, and this indicated a decline in CPUE between 1993 and 2004, followed by an increasing CPUE to a level higher than that of any previous year in the series (Anderson et al. 2013). It was suspected that changes in operational procedures (e.g., use of light sticks) were at least partially responsible for changes in swordfish catch rates (and the increasing CPUE trend).

This report addresses the Fisheries New Zealand project SWO2019-01: Characterisation of the fishery and analysis of CPUE for swordfish from the commercial longline fishery in New Zealand waters. The specific research objectives for this project were:

- To characterise the commercial longline fishery for swordfish in New Zealand waters
- To carry out unstandardised and standardised CPUE analyses of catch and effort data from the commercial longline fishery for swordfish in New Zealand waters

2. METHODS

2.1 Data sources and fisheries characterisation

Set by set catch-effort data from the New Zealand tuna longline fishery are recorded with the newly introduced Electronic Reporting System (ERS) (since 2018), and historically, on Tuna Longline Catch Effort Returns (TLCERs) and Catch, Effort and Landing Returns (CELRs). The data recorded on these forms includes the location, date, and other operational variables (e.g., number of hooks, hooks per basket, line length), and the catch (as both number of fish and total weight) of all fish species landed. Groomed commercial surface longline data from TLCER and CELR forms and ERS were extracted from the database *tuna* between the period 1 January 1993 to 30 December 2019 and were subjected to a further set of error-checking procedures.

Hook numbers considered to be errors were checked and corrected where possible. Records considered to be errors were those where hook number was either missing, was an unlikely low or high value, was less than the number of baskets, or was clearly entered in the wrong field. Each record was checked against the recorded hook numbers for the sets on the same trip immediately before and after that on which the error occurred. These were used to assign a corrected hook number where possible, or hook number was moved or swapped where it had clearly been recorded in the wrong field, e.g., where hook number was transposed with basket number or line length. Some records had hook numbers with one digit too many (e.g., 500 was recorded as 5000) or too few (e.g., 500 was recorded as 50) which may have been data entry errors. Corrections were also made to obvious latitude/longitude errors, and each set was assigned to a Fisheries Management Areas (FMA) based on its starting position.

After grooming and removal of missing values for predictor variables, 85 896 records were available for the characterisation (86% of total data). The characterisation included longline data from all FMAs.

2.2 Environmental data

In addition to the operational data available from the catch-effort records, a set of independent environmental variables with potential to influence swordfish distribution and local abundance were obtained for the analysis: estimated sea surface temperature (SST), SST anomaly, Sea Surface Height (SSH), and current velocity variables at the start position and date of each set.

The SST estimates used were based on the Reynold’s Optimum Interpolation Sea Surface Temperature Analysis (Reynolds et al. 2007, Banzon et al. 2016). This analysis is produced daily on a one-quarter degree grid and incorporates in situ and satellite SSTs in addition to SST values simulated from known sea ice cover. Before the analysis is computed, the satellite data are adjusted for biases using the method of Reynolds et al. (2007) and Banzon et al. (2016). The bias correction improves the large-scale accuracy of the Optimum Interpolation. The SST value for each set was determined by finding the nearest SST data point to the start position for the same day. The one-quarter degree SST grid provided a resolution of approximately 25 km. SST anomaly is essentially the difference between the estimated SST and the mean SST for the location and time of year.

The SSH values for the start of each set were determined using a web-based product (http://www.aviso.oceanobs.com/en/altimetry.html) which is the reference version of the Maps of Absolute Dynamic Topography (MADT) dataset. This is a spatially analysed combination of 10-day repeat measurements of sea surface height anomaly with the Mean Dynamic Topography (the part of mean SSH due to permanent currents, corresponding to the mean SSH minus the geoid). SSH is related to the integrated density of the water through the entire depth of the ocean — because less dense (warm, less salty) water stands taller than more dense (cold, saltier) water. The nature of ocean variability around New Zealand means that almost all the variability in SSH results from changes in surface water temperature. Thus, highs in SSH correspond to areas with higher mean temperatures and vice versa.

The slopes in the sea surface due to variability in SSH result in currents that run along the lines of constant height (in the same way that winds flow along isobars in weather maps) which means that the estimates of SSH can also be used to supply estimates of the surface current field. In this study, the magnitude of the current at the start of each set was estimated from the SSH data.

The SSH and current velocity data have resolutions of about 20–30 km latitude, 30 km longitude, and 7 days. Estimates for these values at the start of each set were determined from the nearest data point to the set location, on the nearest day.

2.3 CPUE analysis

The CPUE analysis for the New Zealand domestic longline fishery for swordfish was updated using the seven years of additional data available since the last analysis (Anderson et al. 2013). The CPUE models constructed were based on set-by-set operational data (71 882 records from selected FMAs) using a year-quarter time step over the period 1 January 1993 to 30 December 2019 (Table 1.1 in Appendix 1). The response variable fitted in the analysis models was number of fish caught per 1000 hooks (Table 1.1). The year-quarter index term was 'forced' as the first 'explanatory' term in the CPUE model standardisations.

The catch-effort data used were limited to data reported from within the New Zealand Exclusive Economic Zone (EEZ) and within FMAs 1, 2, and 9 (Figure 1). This varied slightly from the previous analysis in which catch-effort data came from within the EEZ, and north of a line at 36° S off the west coast and 42° S off the east coast (Anderson et al. 2013). Both analyses therefore excluded all of the southern bluefin tuna fishery off the west coast of the South Island, which was predominately fished by foreign charter vessels (FCVs) (until 2015) and accounted for 35.8% and 40.8% of the total estimated swordfish catch (in weight and numbers, respectively) between 1993 and 2019.

In addition to the independently derived environmental variables described above, a set of predictors with a potential influence on swordfish CPUE were selected or derived from the operational records for consideration in the CPUE model (Table 1.1 in Appendix 1). Time at start of set (*TSOS*) was adjusted to represent the nearest hour relative to midnight, a useful reference point with an essentially night-time fishery. Recent effort (*n10d50k*) was calculated for each set to quantify the level of local fishing effort. This was defined as the number of longline sets within a 50-km radius of the set (based on the start of set location) during the previous 10 days. Moon phase (the fraction of the illumination provided by a full moon) was calculated from an astronomical algorithm (Meeus 1991). For grooming purposes, a ratio of 25 hooks per basket (*hooks per basket*) and a ratio of 1000 or less light sticks per 1000 hooks (*light stick rate*) were agreed upon by the Fisheries New Zealand Highly Migratory Species Working Group.

As in previous iterations of this work (Unwin et al. 2009, Anderson et al. 2013), a generalised additive model was used to allow smoothed fits of model covariates, with a quasi-poisson error distribution used to account for the large number of zero catches and over-dispersion of the data relative to the poisson distribution (Maunder & Punt 2004). Predictors were accepted into the model when they explained at least 1% of the residual deviance.

To remove any undue influence in the models from part-time vessels in the fishery a core set of experienced vessels was identified, defined as vessels which had fished in at least half of the previous 20 years (1999–2019), including at least one of the most recent two years. This set of 15 core vessels accounted for only 7% of all vessels, but 29% of total effort and 39% of the total swordfish catch (in number of fish) for the 1999–2019 period. There was considerable overlap of vessels across years in the core dataset, ensuring that year-effects in models using this dataset would be properly linked. Three of the 15 vessels had fished in each year (see Figure 1.1 in Appendix 1).

Separate CPUE standardisation models were constructed for the following data series:

- All vessel long series, 1993–2019
- All vessel short series, 2004–2019
- Core vessel long series, 1999–2019
- Core vessel short series, 2004–2019

The short series models covered the recent period since the introduction of swordfish into the QMS, and this allowed information on light stick usage and bait type to be offered as covariate terms in the model standardisations (Table 1.1 in Appendix 1).

At the behest of the Fisheries New Zealand Highly Migratory Working Group, an additional CPUE standardisation was undertaken to derive an annual "year" instead of "year-quarter" index using the core vessel long series (1999–2019) data. For this model run an additional "seasonal-quarter" covariate term (January-March, April-June, July-September, October-December) was offered to the model to standardise for the observed seasonal CPUE shift (Table 1.1).

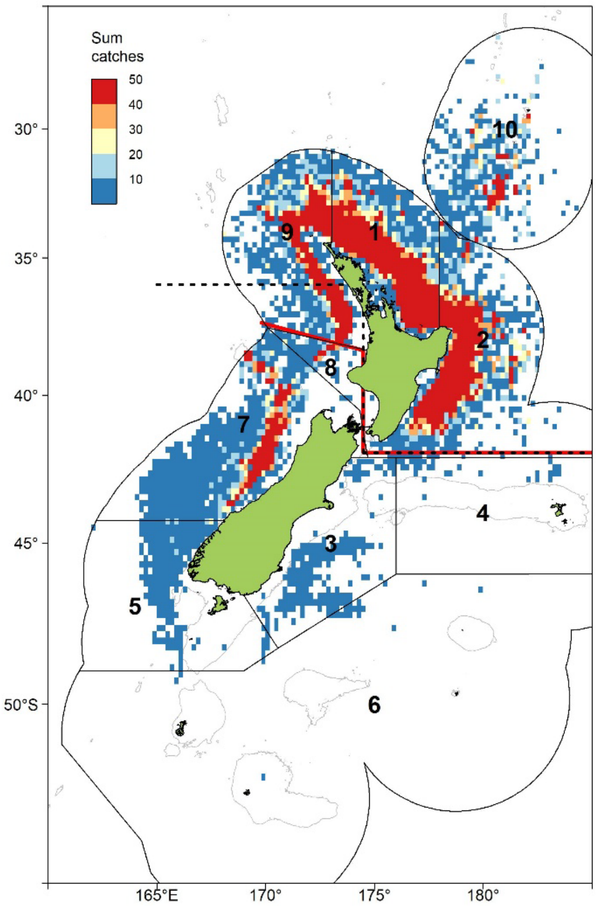

Figure 1: Density plot of all swordfish catch (in number of fish) from the New Zealand tuna longline fishery from 1993 to 2019 within each 0.2° cell. Fisheries Management Areas (FMAs) are indicated by the black lines. The red line indicates division of data included for the catch-per-unit-effort (CPUE) analysis. The cut-off for data inclusion in the previous assessment is indicated by the black dashed line (Anderson et al. 2013).

3. RESULTS

3.1 Fishery characterisation

The spatial distribution of the tuna longline fishery and reported swordfish catches have changed over time (see Figure 2.1 in Appendix 2). In the 1990s, areas of large swordfish catches were restricted to the northeastern area off the North Island (Bay of Plenty). Leading up to 2004 when swordfish was introduced into the QMS, the spatial extent of swordfish catches grew extensively around the North Island and extended far from the continental shelf and along the west coast of the South Island. After 2004, the spatial extent of catches contracted to the north and northeast of the North Island, with some catch reported from the Kermadec Region (FMA 10) as well. By the 2010s, highest catches were from along the west coasts of the North and South islands and few catches were recorded from the Kermadec Region. In the most recent years (2017 onwards), areas of high swordfish catches were concentrated in discrete locations along the continental shelf of the North Island and off the west coast of the South Island.

Swordfish catch (in number of fish) has predominantly been reported from FMA 1 and FMA 2 (Figure 2). Up to 2012, at least 80% of swordfish catch came from these two FMAs. Since 2013, more catch has been reported from FMA 9 (up to approximately 40% in 2016), and the proportion of catch from FMA 7 has increased since 2013. The proportion of catch from FMA 10 peaked in 2006 (at approximately 20%) and has been negligible in the past decade. The proportion of effort (in 1000s of hooks) shows a similar pattern, with most effort occurring in FMA 1 and FMA 2. There has been an increasing proportion of effort in FMA 7, which, since 2012, has accounted for up to 40% of the effort. Effort from FMA 9 has remained relatively consistent through the time series at approximately 10%. There has been some effort in FMA 3 in the past two years (2018, 2019); the last reports from there were in 2001.

The mean swordfish size in weight varied by FMA (Figure 3). In northern New Zealand (FMAs 1, 2, 9, 10), the mean annual size has been near the overall mean of 52 kg. The largest swordfish were reported from FMA 5 and FMA 7, where swordfish were reported at weights twice and sometimes four times the overall mean size (up to 198 kg in FMA 5 in 2015). In the primary fishing FMAs (FMAs 1, 2, 9), there was a general trend of swordfish size declining below the mean size of 52 kg to around 2012, then subsequently increasing to levels at or above the overall mean size in the most recent years.

Within FMAs 1, 2, and 9, the main target species has been bigeye tuna (*Thunnus obesus*) (Figure 4). Target fishing for southern bluefin tuna (*T. maccoyii*), which was generally the second-most targeted species, increased throughout the time series and, since 2014, took over as the primary target species. Targeting for other species, primarily other tuna species such as albacore tuna (*T. alalunga*) and Pacific bluefin tuna (*T. orientalis*) has remained low, particularly since the introduction of swordfish into the QMS in 2004. Targeting of swordfish remained low (under 10% of sets) until 2013, and it has fluctuated around 20% of sets since then.

Catch rates for swordfish in FMAs 1, 2, and 9 have always been highest in the first half of the calendar year, particularly from January to March (Figure 5). Catch rates during this time rose steadily after 2004, peaked in 2013 and 2015, and have declined considerably to 2019. Swordfish catch rates have generally been low in the second half of the year but increased considerably during the period 2009–2014. The number of swordfish caught was generally highest in Quarter 2 (with a maximum of 5299 fish in 2001) until 2011 when the number of fish caught became higher in Quarter 1 (maximum of 5792 fish in 2013) (see Table 2.1 in Appendix 2). Reported swordfish catch has always been lowest in Quarter 3 and Quarter 4; however, Quarter 3 exhibited a considerable increase in catch around the early 2000s (1999–2002) and again a decade later (2011 and 2012) with nearly 2400 swordfish reported annually.

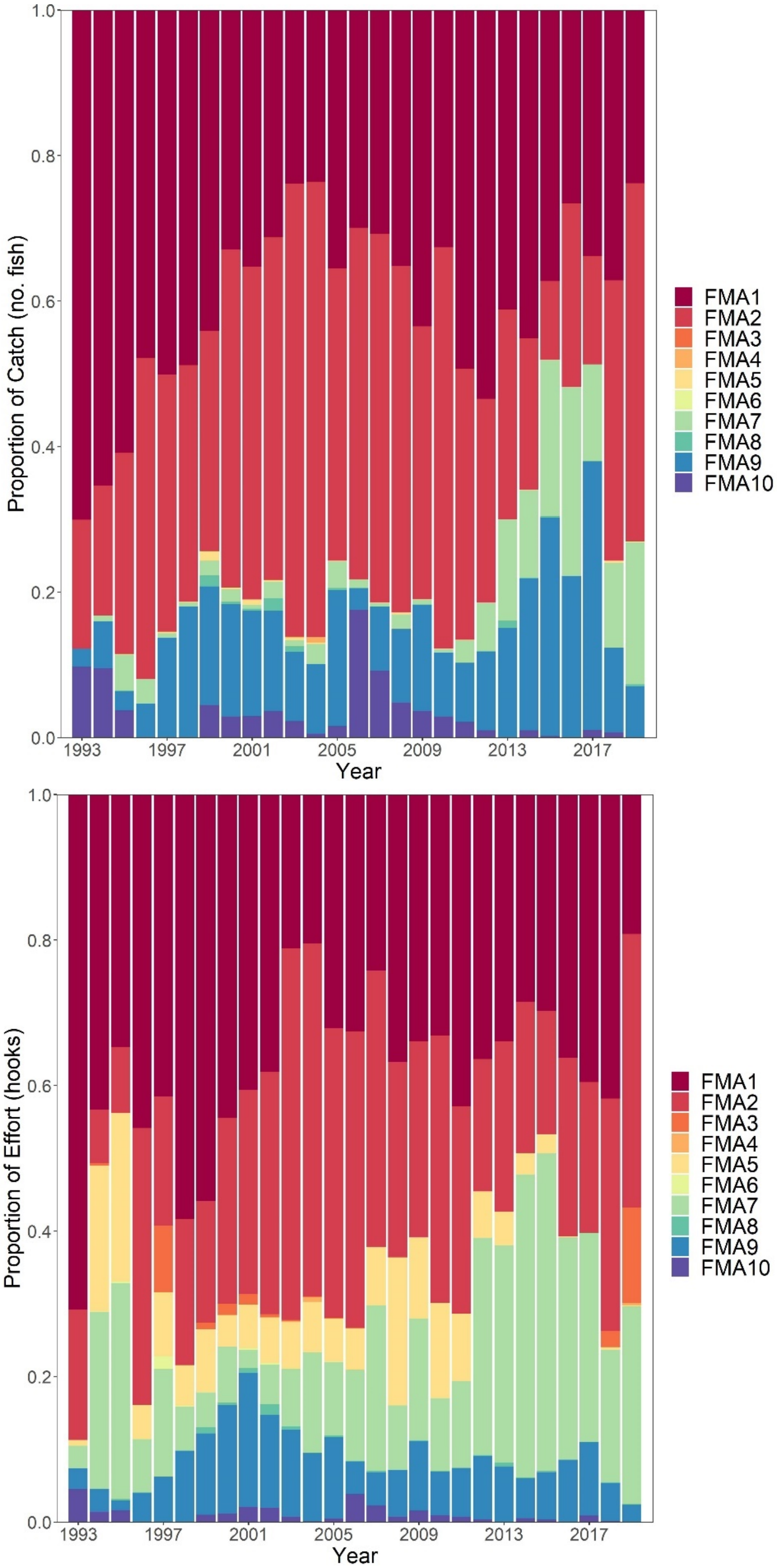

Figure 2: By FMA, proportion of swordfish catch (number of fish, top) and proportion of effort (hook numbers, bottom) where swordfish was reported

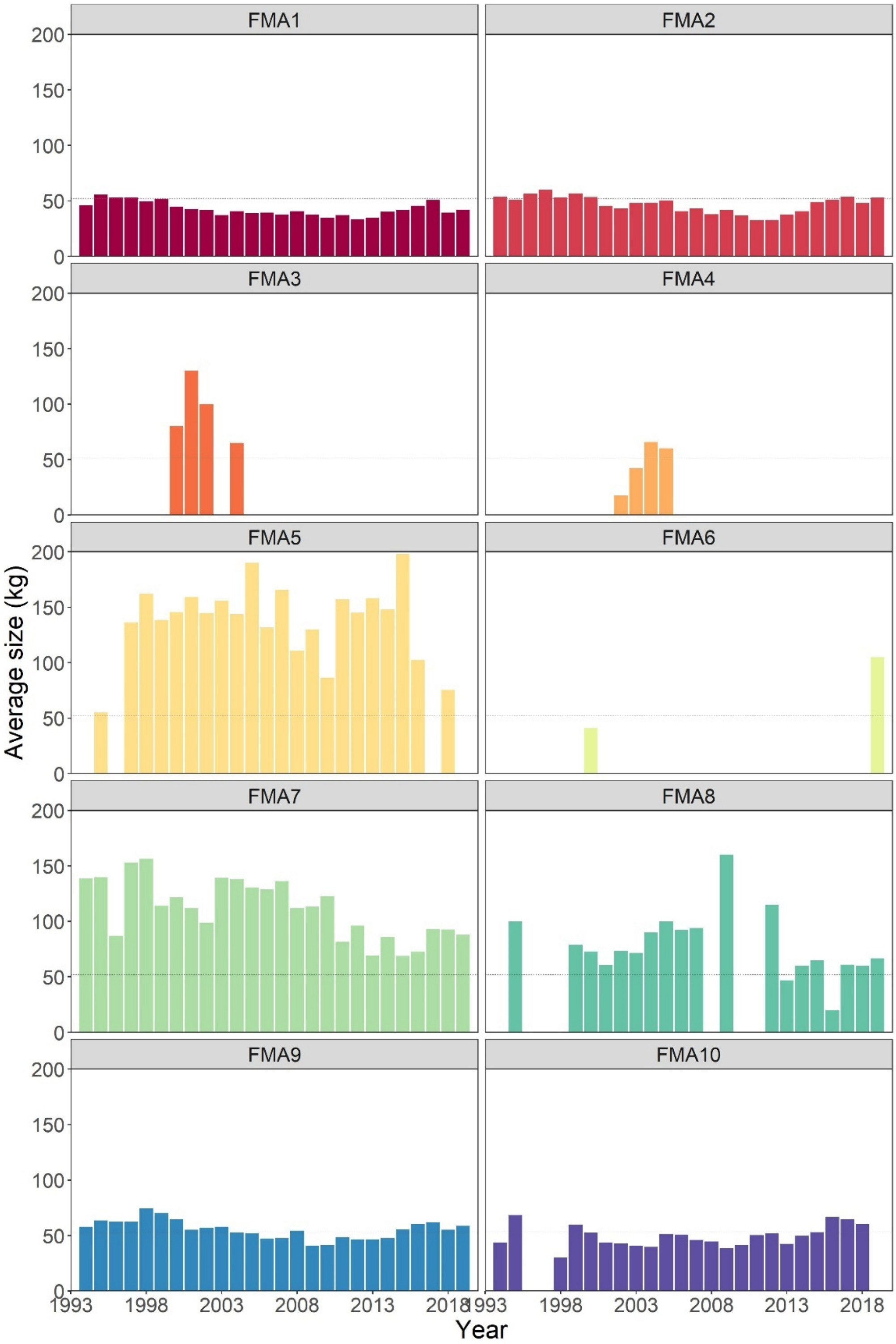

Figure 3: Annual mean swordfish size (kg) by FMA. Grey lines indicate overall mean size (52 kg).

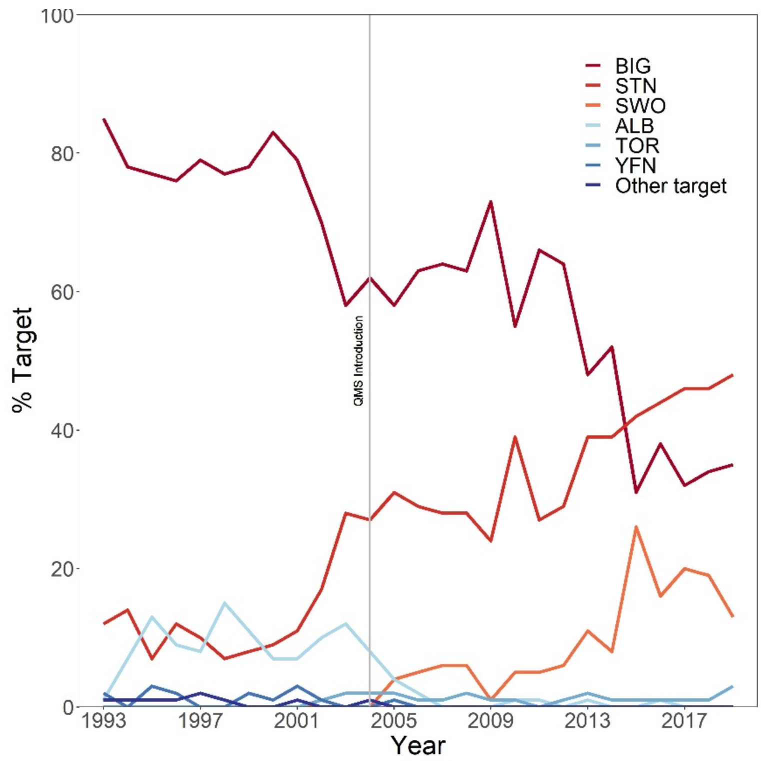

Figure 4: The main target species where swordfish catch was recorded from longline sets in FMAs 1, 2, and 9 (bigeye tuna, BIG; southern bluefin tuna, STN; swordfish, SWO; albacore, ALB; Pacific bluefin tuna, TOR; yellowfin tuna, YFN). Swordfish introduction into the Quota Management System (QMS) in 2004 is indicated by the grey line.

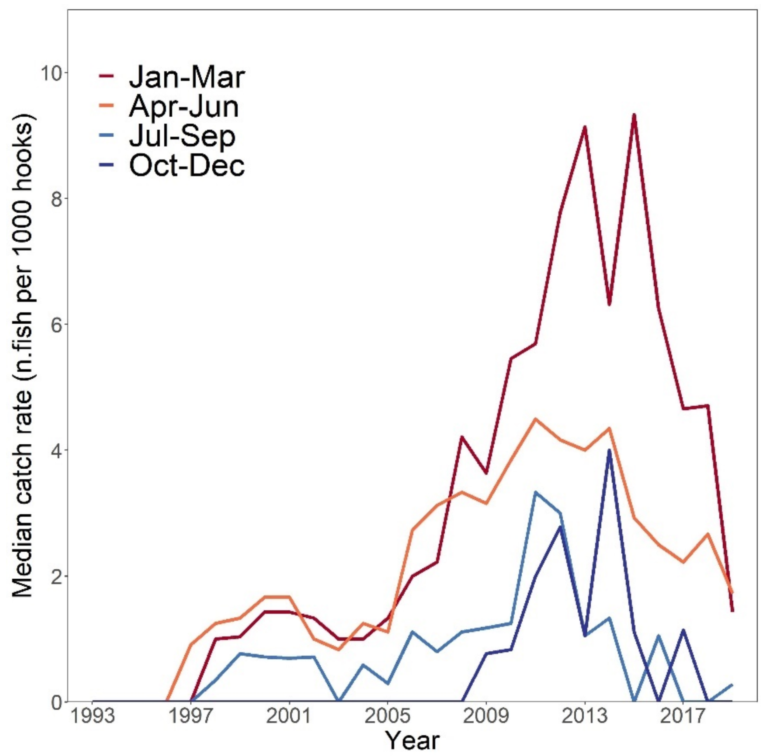

Figure 5: Median catch rate (number of swordfish per 1000 hooks) by quarter-year (January-March, April-June, July-September, October-December) for FMAs 1, 2, and 9.

3.2 CPUE analysis

3.2.1 Predictor variables

Changes in recorded and derived operational variables and independently estimated environmental variables associated with the longline sets used in the CPUE analysis are shown in Figure 6.

The percentage of sets where no swordfish catch was recorded declined from approximately 70% in 1993 to less than 10% in 2012. This may indicate an increase in effective targeting of swordfish over time, an increase in reporting swordfish catch, or an increase in abundance during this time period. From 2012, zero swordfish catch sets have been increasing and, in most recent years, approximately 35% of lines set reported no swordfish.

There have been several changes in the fishery over time. The mean annual number of hooks per basket, set start time (hours from midnight), and day length (hours from sunrise to sunset) have gradually declined across the time series. The annual mean number of hooks currently sits at around ten hooks per basket, and the mean time at which sets are deployed has shifted from one hour after midnight, to nearly two hours before midnight in recent years. The mean day length associated with set deployment has shown some variability across the time series but has declined slightly from nearly 0.60 to 0.56. Recent effort (number of sets within 50 km during the previous 10 days) showed an increasing trend leading up to 2004, and a swift decline to variable yet low levels since. A similar pattern was observed in distance from the nearest hill, with vessels fishing further from under-sea features leading up to 2004 and remaining close to them since.

Mean soak time increased rapidly leading up to 2004, from less than 0.4 hours in 1993 to approximately 0.63 hours in 2004. After 2004, mean annual soak time varied somewhat by year, but showed a gradual declining trend to a present-day value of approximately 0.58 hours. The number of light sticks and the percentage of squid bait used showed dramatic increases from 2004 onwards, which corresponds to the time at which these operational variables were able to be reported. Light sticks have been used in nearly every set since. The percentage of squid bait gradually increased to nearly 100% by 2013; a small decline in use was observed in the most recent years of the time series. Night fraction (the fraction of the set soak time during the hours of darkness) has gradually risen from less than 0.45 to 0.55.

Moon fullness (fraction of the illumination provided by a full moon) has shown a variable but increasing trend from just under 0.5 to approximately 0.58 in recent years. Sea surface height (SSH), a measure of thermal energy of the entire water column at the start position of the set, has been steadily increasing across the time series, from less than 0 to over 0.1 in recent years, suggesting a slight shift of effort into warmer bodies of water. Sea surface temperature (SST) has shown some variability but a relatively stable trend, with fishing occurring at temperatures between 18 and 19°C.

Mean annual trends for latitude, longitude, and current were highly variable and showed no trend across the time series. Most fishing occurred at latitudes between 36° S and 36.5° S and at longitudes between 176° E and 177° E.

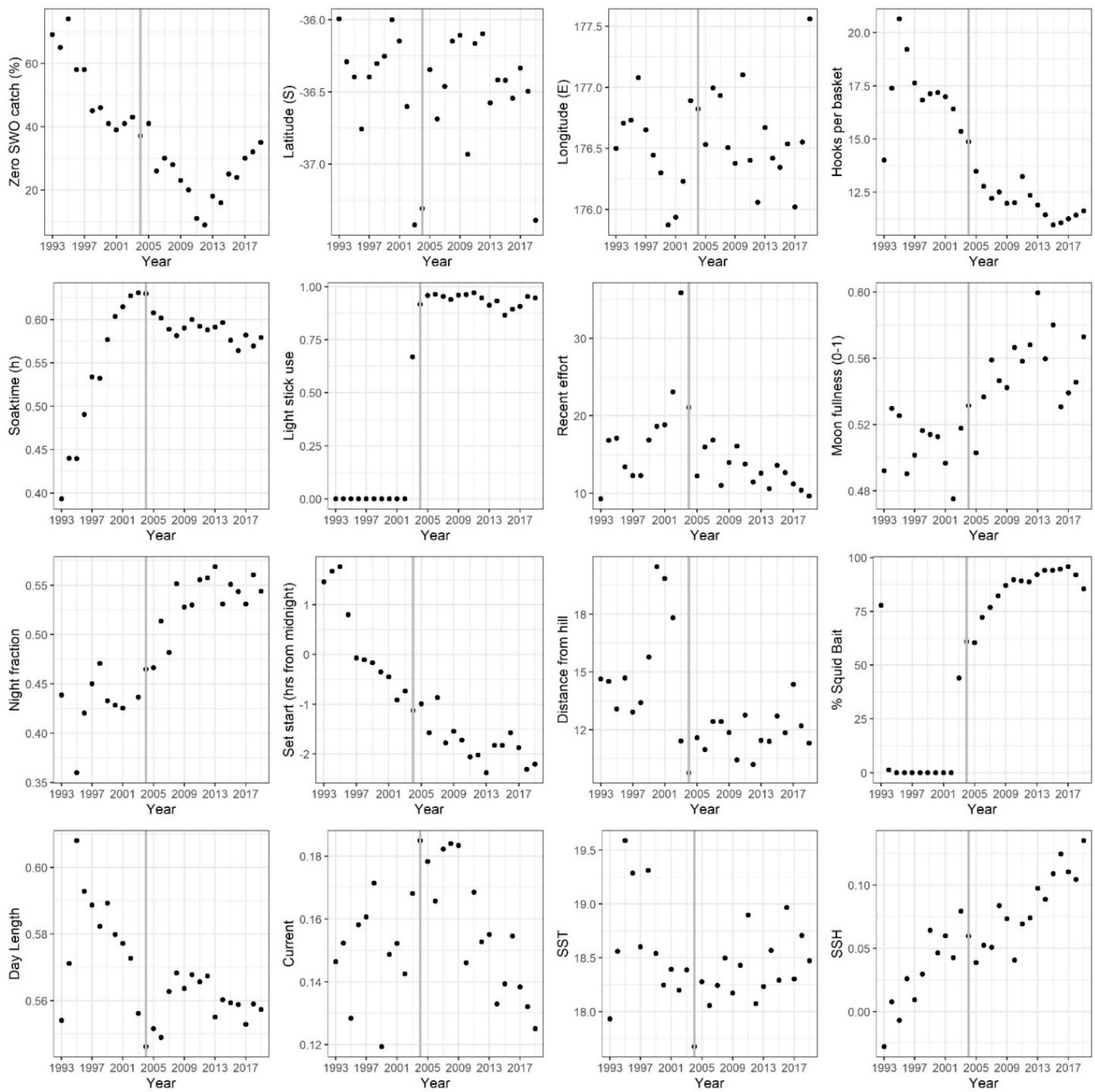

Figure 6: Changes in recorded and derived operational variables and independently estimated environmental variables associated with the longline sets used in the CPUE analyses. With the exception of zero swordfish catch (first panel), annual means are plotted. Swordfish introduction into the QMS in 2004 is indicated by the grey vertical line.

Annual catch of swordfish increased during the late 1990s and early 2000s, following a similar pattern of increasing effort, and peaked in 2002 at nearly 13 000 fish (Figure 7). Swordfish catch declined during the mid-2000s, peaked again to similar previous levels by 2011, and steadily declined thereafter. Effort (hooks per year) sharply declined after peaking in 2002 (at 8 million hooks). The rate of decline slowed after 2005 but a gradual decline continued – to approximately 1.5 million hooks in recent years. Across the time series, the catch rate of swordfish gradually increased, peaked during 2011–2013 at six swordfish/1000 hooks, and then declined to 2.2 swordfish/1000 hooks in 2019.

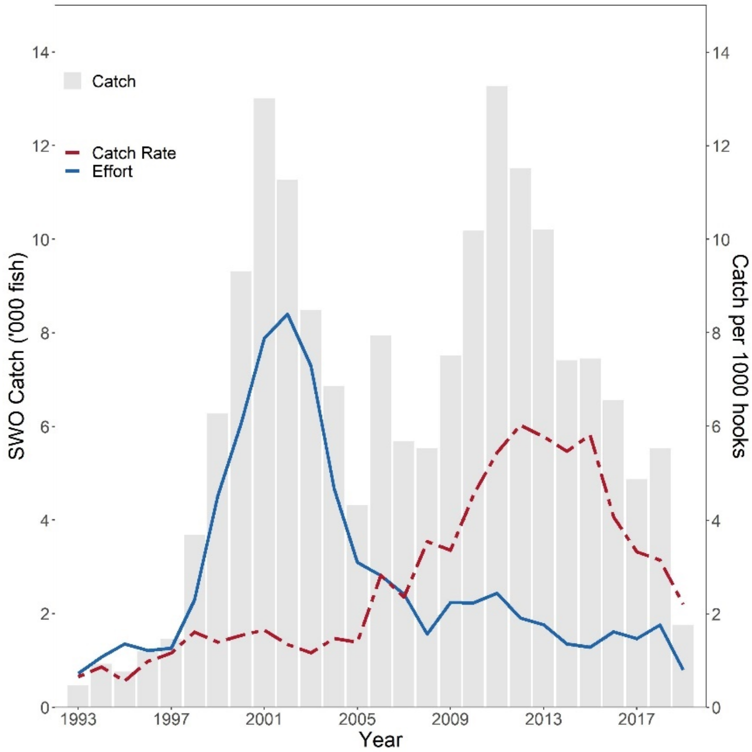

Figure 7: Annual swordfish catch (thousands of fish, grey bars), effort (millions of hooks, solid blue line), and catch rate (number of swordfish per thousand hooks, broken red line) in the New Zealand tuna longline fishery in FMAs 1, 2, and 9.

3.2.2 All-vessels series CPUE standardisations

A total of 270 and 142 unique vessels were included in the all-vessels series 1993–2019 (long) and 2004–2019 (short) time series, respectively. In both all-vessels series models, *year-quarter* explained the largest amount of the residual deviance, accounting for 33% and 30% for long and short time series models, respectively (Table 1). The long time series model also selected *Vessel*, *night fraction*, and *hooks per basket* and explained just under 50% of the residual deviance (R^2 = 45.7%). The short time series model also selected *night fraction* and *Vessel*, as well as *light stick rate*, and accounted for 47% of the deviance (R^2 = 41.5%). Diagnostic plots for both series indicated moderate fits and are shown in Appendix 3 (Figure 3.1).

In the long time series, the effect of *Vessel* was highly variable (Figure 3.2 in Appendix 3). *Night fraction* had an increasingly positive effect on CPUE, peaking around 0.8, and *hooks per basket* had a negative effect on CPUE, declining rapidly to approximately 10 hooks per basket before levelling off. In the short time series, *Vessel* and *night fraction* also had variable and positive influences on CPUE, as shown in the long time series (Figure 3.3). Similar to *night fraction*, *light stick rate* also had an increasingly positive influence on CPUE.

Both series showed very similar trends to the indices in the previous study (Anderson et al. 2013) for overlapping years (Figure 8). As observed previously, there was a strong seasonal fluctuation in the CPUE, with higher CPUE in the first two quarters of each year. The short time series showed less interannual variability in CPUE trend than the long time series, but both series showed similar trends: increasing CPUE until 2012 and 2013, followed by steady declines to CPUE comparable to those at the beginning of the time series (1990s).

3.2.3 CPUE, core-vessels series CPUE standardisations

In both short and long core-vessels series models, *year-quarter* explained the largest amount of the residual deviance, accounting for 34% and 32% for long and short time series models, respectively (Table 1). This is further shown by step plots in Figure 3.4 and Figure 3.5 in Appendix 3. The long time series model also selected *hooks per basket*, *night fraction*, and *Vessel* and explained approximately 55% of the residual deviance (R^2 = 49.7%). This was the model with the greatest explanatory power. The short time series model also included the predictors *night fraction*, *light stick rate*, and an interaction term between *start longitude* and *start latitude*, together accounting for 50% of the deviance (R^2 = 43.3%). Diagnostic plots for both series indicated moderate fits and are shown in Appendix 3 (Figure 3.6).

The influence of predictors in the core-vessels series were very similar to those in the all-vessels series: the influence of individual vessels was highly variable, *night fraction* and *light stick rate* positively influenced CPUE, and *hooks per basket* had a negative influence on CPUE (Figure 3.7 and 3.8 in Appendix 3). In the longitude-latitude interaction, CPUE was positively influenced at higher latitudes away from central longitudes (Figure 3.8).

The core-vessels series models also showed very similar trends to the all-vessels series models (Figure 8). All models showed increasing CPUE trends until 2013 (the last year of the previous analysis) and have steadily declined since. All model indices are reported in Table 3.2 in Appendix 3.

3.2.4 CPUE indices comparisons by year-quarter

When separated by annual quarters, all models show similar patterns, with the highest CPUE indices occurring in the first quarter (January-March) for most of the time series, particularly since 2007 onwards (Figure 9). Quarter 2 (April-June) had the second highest CPUE, followed by Quarter 3 (July-September) and Quarter 4 (October-December). In 2011 and 2012, Quarter 3 had higher than usual CPUE and, in 2014, the CPUE indices in Quarter 4 were high, higher than Quarter 2 and nearly matching Quarter 1.

Table 1: Variables retained in order of decreasing explanatory value by each model (all-vessels series and core-vessels series) and each time series (1993–2019 and 2004–2019 for the all-vessels series, 1999–2019 and 2004–2019 for the core-vessels series) and the percentage of the deviance explained with the addition of each variable. Variables not included in the final models are in italics.

1993–2019 (all-vessels), 1999–2019 (core-vessels)

	All-vessels series		Core-vessels series
Variable	% deviance explained	Variable	% deviance explained
Year-quarter	33.6	Year-quarter	34.5
Vessel	41.5	Hooks per Basket	45.7
Night Fraction	46.7	Night Fraction	53.4
Hooks per Basket	49.7	Vessel	54.7
Time at start of set	*49.8*	*Longitude*	*55.7*

2004–2019

	All-vessels series		Core-vessels series
Variable	% deviance explained	Variable	% deviance explained
Year-quarter	30.3	Year-quarter	32.0
Night Fraction	38.5	Night Fraction	42.3
Light stick rate	43.3	Light stick rate	47.1
Vessel	46.8	Longitude*Latitude	49.8
Time at start of set	*45.6*		

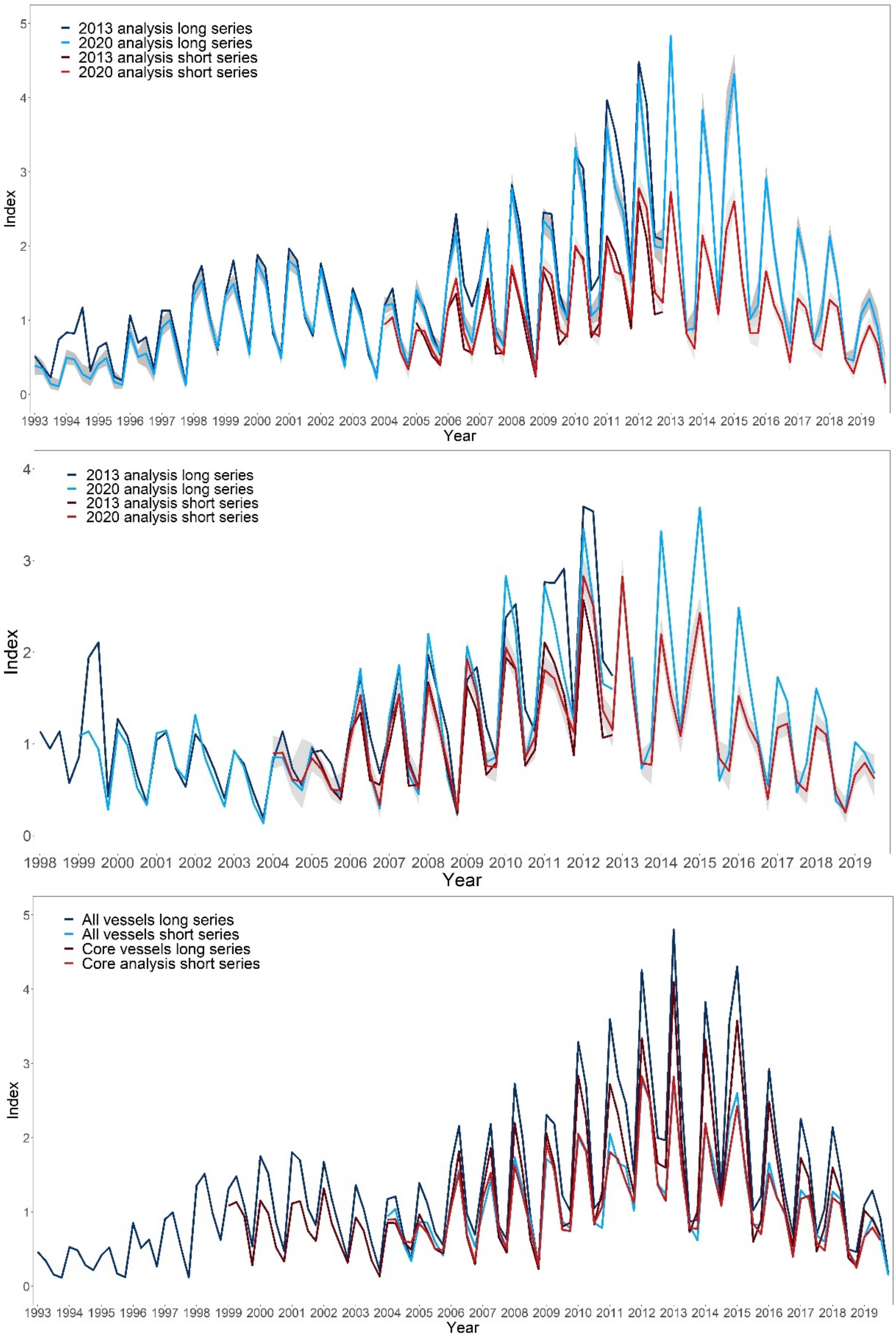

Figure 8: Comparison of CPUE indices for the all-vessels series (top panel), core-vessels series (middle panel), and all-vessels series combined (bottom panel) for each of the time series (1993–2019 and 2004–2019 for the all-vessels series and 1999–2019 and 2004–2019 for the core-vessels series). All series are scaled to their geometric mean. Standard errors are indicated in grey.

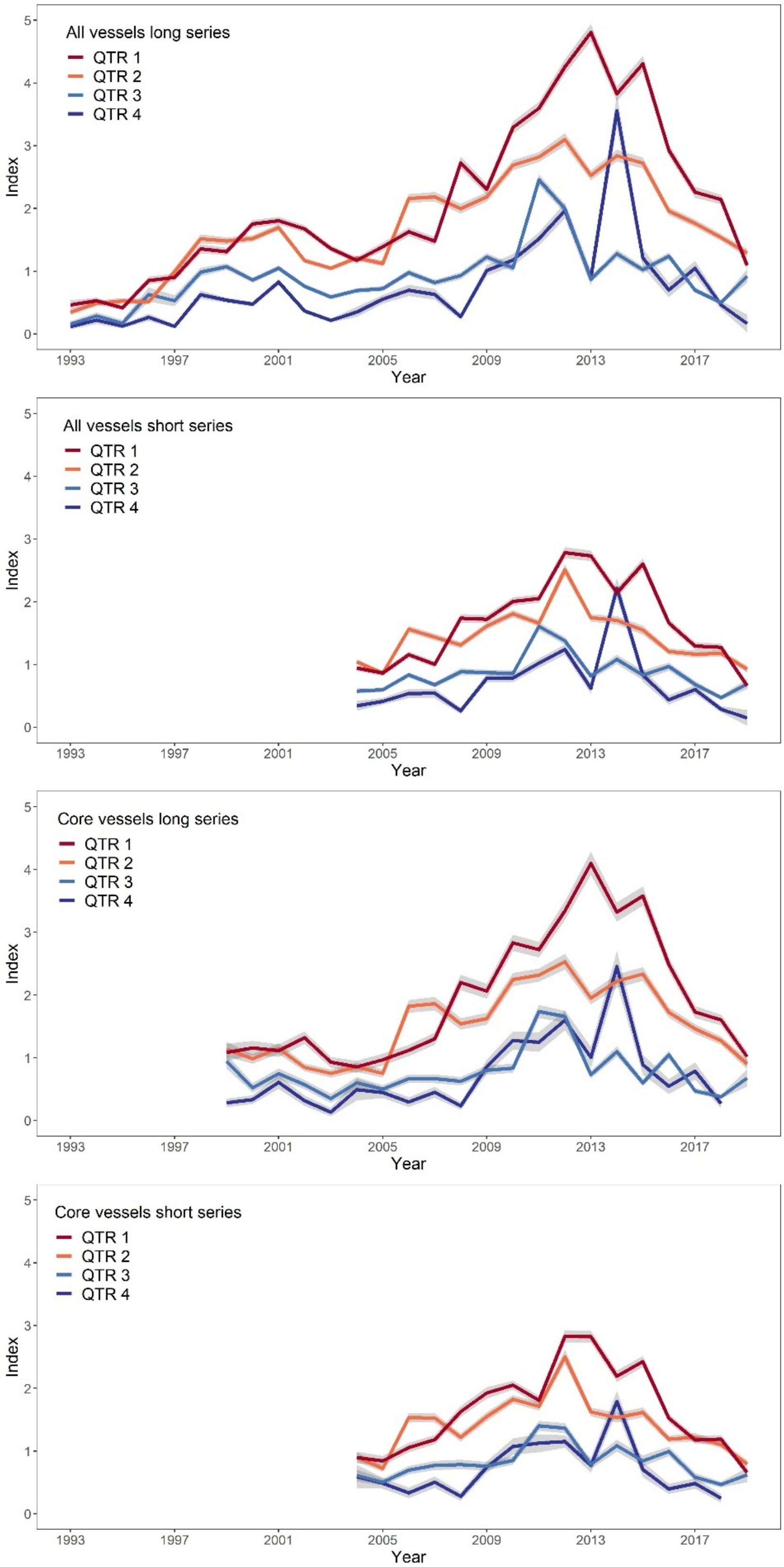

Figure 9: The four CPUE series split by annual quarters, all-vessels series (1993–2019, top panel), all-vessels series (2004–2019, second panel), core-vessels series (1999–2019, third panel), and core-vessels series (2004–2019, bottom panel). Standard errors are indicated by grey shading.

3.2.5 Annual (Year) CPUE series

Diagnostic plots and effects of the term variables for the annual "year" index are reported in Appendix 3 (Figure 3.9 and Figure 3.10). Like the year-quarter index, *night fraction*, *hooks per basket*, and *Vessel* were selected as the most important model predictors (Table 3.1 in Appendix 3). *Seasonal-quarter* was also selected as an important variable (adding over 2% deviance), explaining 8.0% of the residual deviance. The annual year index showed a variable trend that was mostly consistent with the year-quarter index; however, the year CPUE index peaked in 2011, earlier than the year-quarter index in 2013 (Figure 3.11). This earlier peak is likely to be influenced by the higher than usual catches of swordfish reported in Quarter 3 between 2010–2013 (see Table 2.1 in Appendix 2).

3.2.6 Appropriateness of quasi-poisson hurdle models for swordfish CPUE standardisations

To be consistent with previous swordfish CPUE analyses, quasi-poisson hurdle models were used for the CPUE standardisations (Unwin et al. 2009, Anderson et al. 2013). However, the normality of the residual plots from all the CPUE standardisations was less than ideal (Figures 3.1, 3.6, and 3.9 in Appendix 3) suggesting the quasi-poisson may not necessarily be the best choice of model for conducting swordfish CPUE standardisations. To investigate this, the Year-Quarter (1999–2019) core vessels analysis was rerun using an alternative negative binomial hurdle model. The negative binomial model residual plots were better than those fitted with the quasi-poisson distribution (Figure 3.12); however, the change in error distribution had minimal effect on the overall CPUE trend (Figure 3.13).

4. DISCUSSION

The CPUE time series from the previous iteration of this work ended at 2012, a time when the CPUE series was increasing and at the highest equivalent point of the updated analyses. At that time, this trend conflicted with other CPUE series in the south Pacific region, which did not show any increase in CPUE (Anderson et al. 2013). The current Western and Central Pacific Fisheries Commission (WCPFC) stock assessment for the wider South Pacific swordfish fishery showed large declines in spawning biomass between the late 1990s and 2010, with less of a decline followed thereafter (Takeuchi et al. 2017). It was estimated that the South Pacific swordfish was not overfished nor experiencing overfishing and there was no evidence to support increases in recent recruitment. However, given the nature of the fishery, which catches mainly larger, older swordfish, it was determined that fishery catches were not informative in regard to recruitment dynamics (Takeuchi et al. 2017, Western Central Pacific Fisheries Commission (WCPFC) Scientific Committee 2019). The updated analysis here shows a gradual decline in CPUE since the last assessment, a trend which is now more consistent with what is observed in the wider region.

Surface longlining within the New Zealand EEZ has seen a large reduction in effort in the past few decades, from 25.8 million hooks set per year in 1980–1982 to 2.1 million hooks in 2014–2018 (Francis & Finucci 2019). Most effort is now restricted to along the continental shelf-break, especially around northern New Zealand. However, there has been increasing longline effort (and swordfish catch) reported from along the west coast of the South Island and Challenger Plateau in FMA 7, where the annual mean swordfish size is considerably larger than reported in FMAs 1, 2, and 9. This area was regularly fished previously by foreign licensed vessels (mainly Japanese) until 2015, but fishing is now carried out exclusively by New Zealand domestic vessels. If effort, and swordfish catch, continues in this area in the future, it may be worth exploring the incorporation of FMA 7 into the next iteration of this work.

In all four CPUE models, the year-quarter predictor explained most of the residual deviance (approximately 30%), indicating time of year is the most important factor in explaining swordfish catch. Operation variables including *night fraction* and the *number of light sticks* are also important predictors of swordfish catch. None of the environmental oceanographic variables were found to be important predictors. In the east Pacific, swordfish was more likely to be caught as bycatch near dynamic ocean structures where water masses meet (Scales et al. 2018). These structures, known as Langrangian coherent structures (LCS) have been found to aggregate prey, predators, and fishers, and may be of importance to swordfish elsewhere in the Pacific. LSC are not understood in New Zealand at this time. Information on swordfish migration patterns around New Zealand is also limited, restricted to one study conducted in 2006 from individuals caught by surface longline vessels operating northeast of New Zealand (Holdsworth et al. 2010).

The Fisheries New Zealand Highly Migratory Species Working Group suggested that the size frequency distributions from the market sampling reports should be evaluated to determine if they support the changes in the average fish size reported from the fisher returns. This information was not available for this analysis but may be worth investigating in future work.

Given the poor fits of the residual plots, an alternative model approach may be better suited for future analysis. The model incorporating a negative binominal error distribution appeared to have a better fit than the quasi-poisson distribution and should be considered in future analysis. CPUE indices for swordfish catch rate data from the WCPFC have been investigated with lognormal generalised linear models (GLM) defined by year-quarter and geographic regions (Hoyle et al. 2013). More recent work for other pelagic species has also incorporated cluster analyses to explore factors contributing to differing patterns between fleets, spatially, and through time, and to identify effort groups with similar fishing behaviour and targeting (Hoyle et al. 2019). The New Zealand longline fishery has exhibited a number of changes since the 1990s, including introduction of tunas, billfish, and pelagic sharks into the QMS and, for some species, Schedule 6 of the Fisheries Act (a fish may be returned to the waters if it is likely to survive), reduction in effort, cessation of foreign chartered surface longline vessels in 2015, and changes in observer coverage (see Francis & Finucci 2019). Many of these changes are likely to have influenced the fishery CPUE reported here.

5. ACKNOWLEDGMENTS

Thanks to members of the Highly Migratory Species Fisheries Assessment Working Group for useful discussions on this work, Ian Doonan, Matt Dunn, and Vidette McGregor (NIWA) for their assistance with the analysis, and to Adele Dutilloy (NIWA) for reviewing this report. This work was funded by Fisheries New Zealand project SWO2019-01.

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APPENDIX 1

Table 1.1: Predictors used in the swordfish catch-per-unit-effort (CPUE) models

Dependent variable	
Catch-per-unit-effort (CPUE)	Number of fish per 1000 hooks (rounded to the nearest whole number).
Categorical predictor variables	
*Year-quarter (*Year-quarter*)	Calendar year and quarter, Jan–Mar = 1, etc.; all-data model, 108 levels, core-data model, 83 levels, late-series model, 63 levels.
or	
*Year	Calendar year only, core data (21 levels).
Fisheries Management Area (*FMA*)	FMA 1, FMA 2, FMA 9; 3 levels.
Target species (*target*)	Albacore (ALB), bigeye (BIG), southern bluefin (STN), swordfish (SWO), other (OTHER); 5 levels.
Time at start of set (*TSOS*)	Nearest hour relative to midnight (-11 to +12), 24 levels.
Vessel (*Vessel*)	Coded vessel registration number (all-data model, 270 and 142 levels; core-data models, 15 levels).
Seasonal-quarter	Seasonal 3-monthly quarters evenly defined between January 1st to December 31st (offered to "Year" index CPUE model only, 4 levels)
Continuous predictor variables	
Latitude (*start latitude*)	Latitude (in decimal degrees) at start of set.
Longitude (*start longitude*)	Longitude (in decimal degrees) at start of set.
Latitude*Longitude	Spatial interaction term
Recent effort (*n10d50k*)	Number of sets within 50 km during the previous 10 days.
Soak-time (*soak time*)	Hours from start of set to start of haul.
Hooks per basket (*hooks per basket*)	The number of hooks per basket (i.e. between floats)
Moon phase (*moonbright*)	The fraction of the illumination provided by a full moon (0–1).
Day length (*daylength*)	Length of day (sunrise to sunset, hours).
Night fraction (*night fraction*)	Fraction of the set (soaktime) during the hours of darkness.
Sea surface temperature (*SST*)	Estimated from remotely sensed data – see text (°C).
SST anomaly (*SSTanom*)	Estimated from remotely sensed data – see text (°C).
Sea surface height (*SSH*)	Estimated from remotely sensed data – see text (metres).
Current speed (*CRNTspd*)	Derived from SSH – see text (cm s^{-1}).
Light stick rate (*light stick rate*)	Number of light sticks per 1000 hooks (late-series model only).
Squid bait % (*Bait_Squid_pct*)	Percentage of hooks baited with squid (late-series model only).
Distance from nearest hill (*nm.hill*)	Distance (nm) from the nearest underwater hill.

* Predictive CPUE index term always 'forced' as first model 'explanatory' term. Note: Year-quarter was not offered in the annual (Year) model.

Figure 1.1: Bubble plot with the relative annual effort (number of sets) by each vessel selected in the core fleet between 1999–2019. The area of the circles is proportional to the number of sets. Vessels represented by unique numeric code on y-axis.

APPENDIX 2

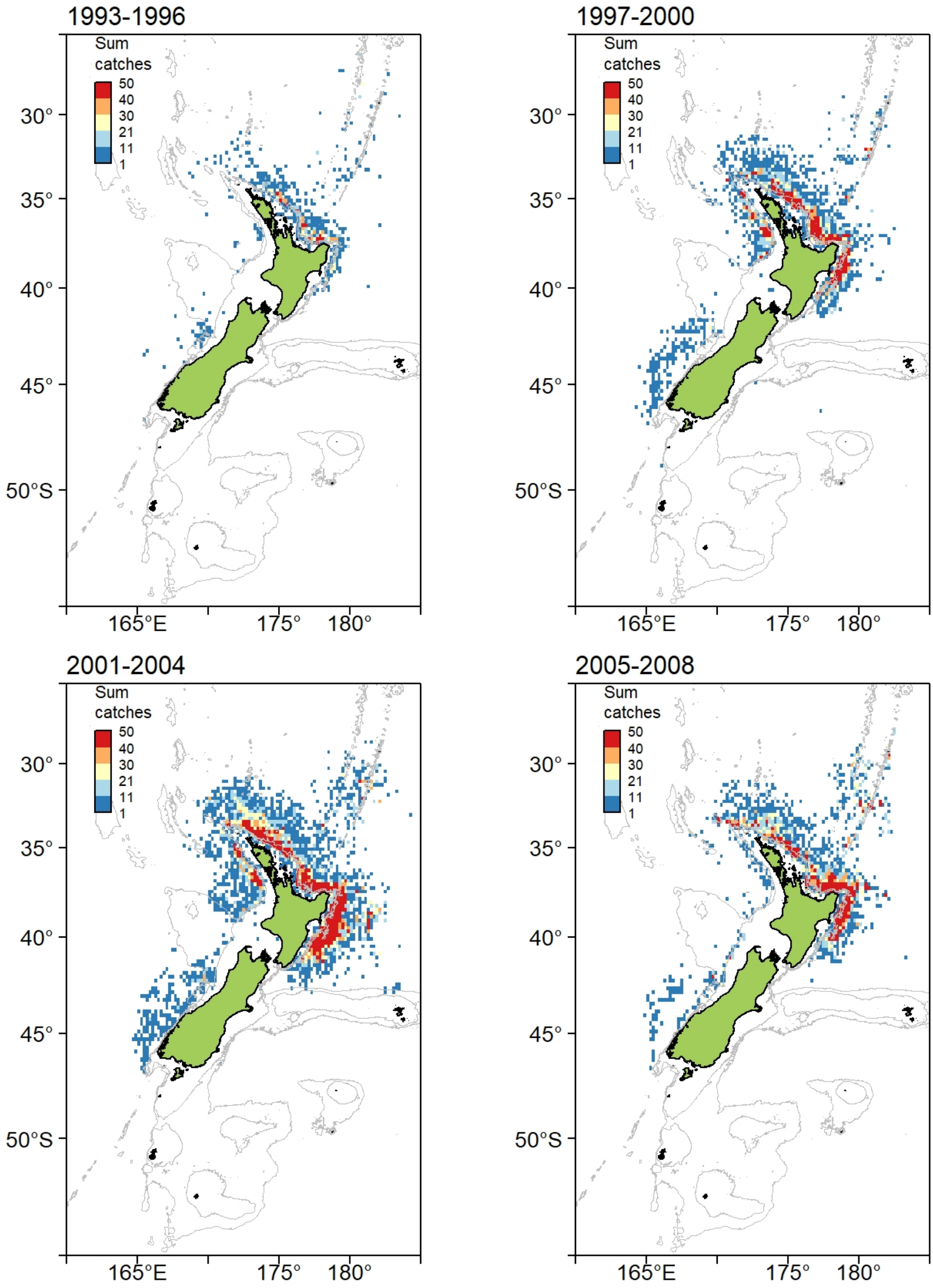


Figure 2.1: Density plots of swordfish catches (in number of fish) from the tuna longline fishery within each 0.2° cell.

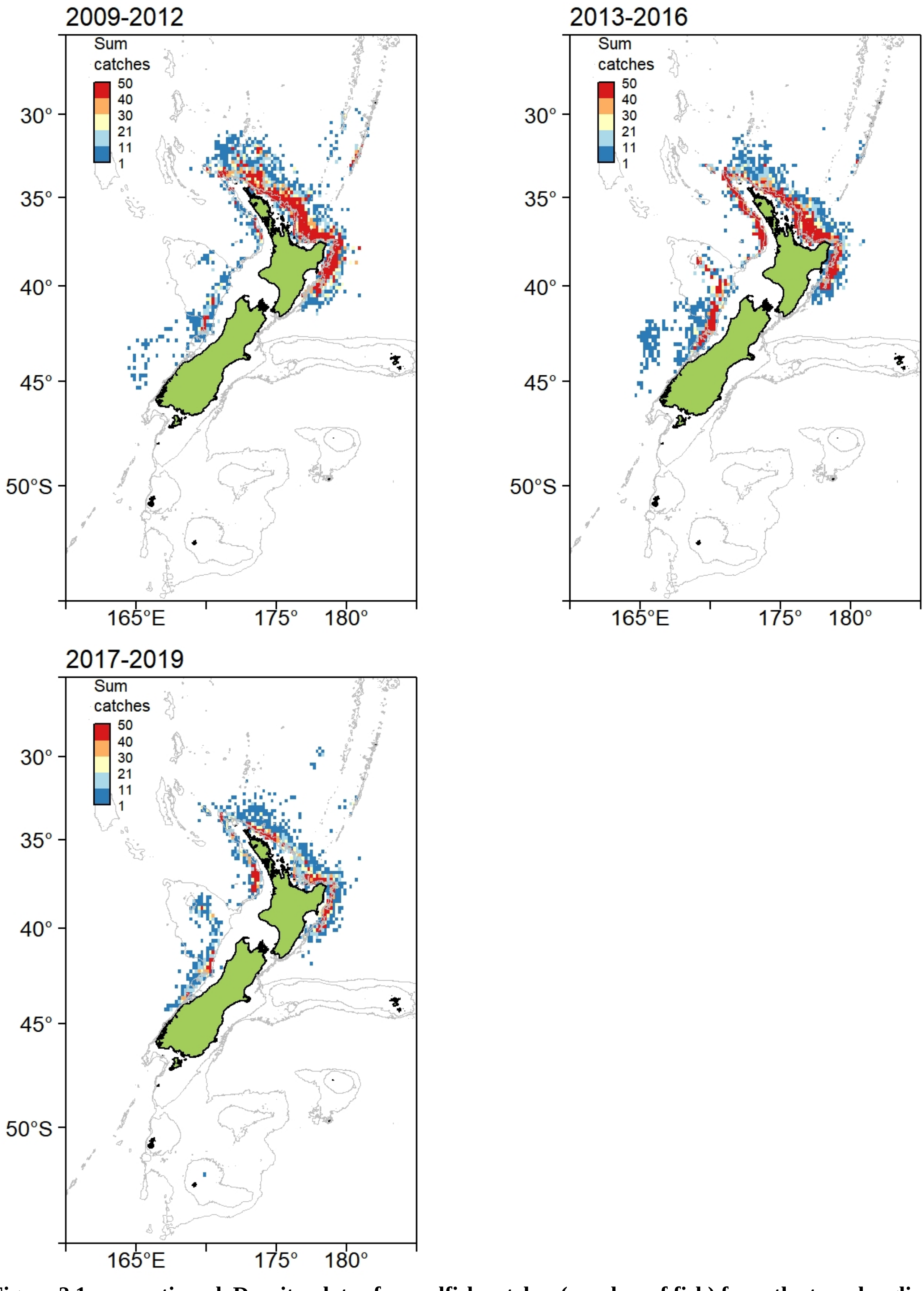


Figure 2.1: — continued. Density plots of swordfish catches (number of fish) from the tuna longline fishery within each 0.2° cell.

Table 2.1: Swordfish catch (number of fish) by year-quarter in Fisheries Management Areas (FMAs) 1, 2, and 9. Data were extracted until the end of the 2019 calendar year. The very small number of fish recorded in Quarter 4 of 2019 (2) is due to limited fishing activity (only 94 sets in December 2019 across all New Zealand waters).

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
1993	87	307	30	17
1994	335	461	54	34
1995	421	163	19	46
1996	594	431	57	48
1997	536	791	75	31
1998	1 039	1 619	688	225
1999	1 706	2 362	1 556	595
2000	3 184	4 247	1 249	479
2001	3 931	5 299	2 374	1 115
2002	4 210	4 708	1 823	403
2003	3 009	4 509	775	136
2004	1 942	3 877	974	54
2005	1 229	1 919	992	171
2006	1 790	4 590	1 382	166
2007	1 537	2 985	977	128
2008	2 545	2 079	803	72
2009	2 405	3 518	1 213	374
2010	4 322	4 577	932	344
2011	5 140	5 056	2 398	577
2012	5 182	3 233	2 327	707
2013	5 792	3 537	719	141
2014	3 359	2 802	711	517
2015	3 851	2 906	537	157
2016	3 218	2 341	901	90
2017	1 611	2 494	561	202
2018	2 588	2 276	534	116
2019	597	976	176	2

APPENDIX 3

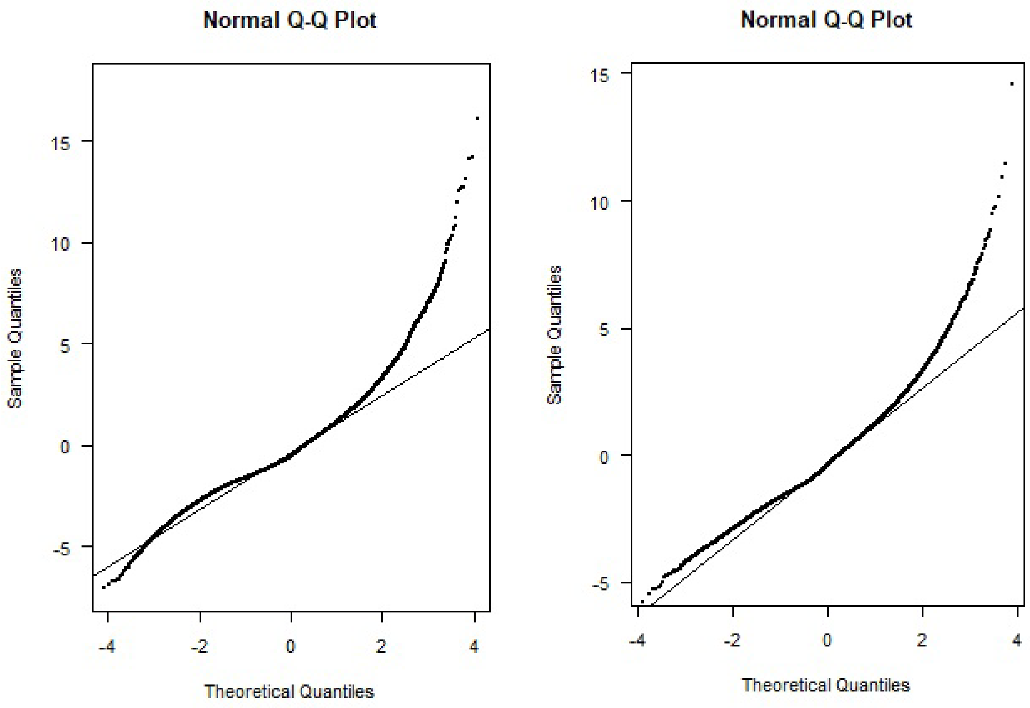


Figure 3.1: Normality diagnostic residual plots for the all-vessels final CPUE models, 1993–2019 series (left) and 2004–2019 series (right).

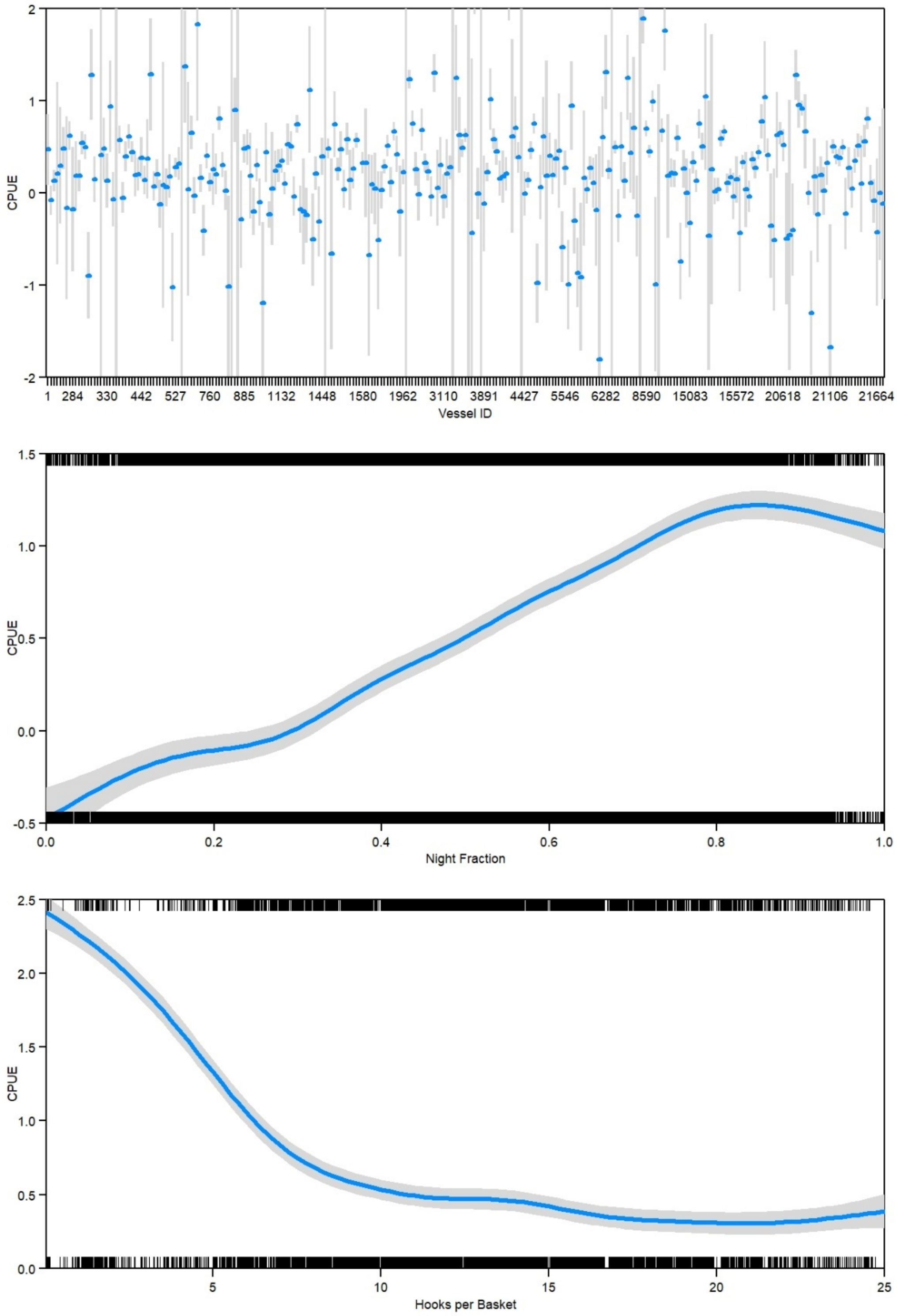


Figure 3.2: Effect of explanatory variables on CPUE in the all-vessels long series (1993–2019) final fitted model, *Vessel* (top panel), *night fraction* (middle panel), and *hooks per basket* (bottom panel).

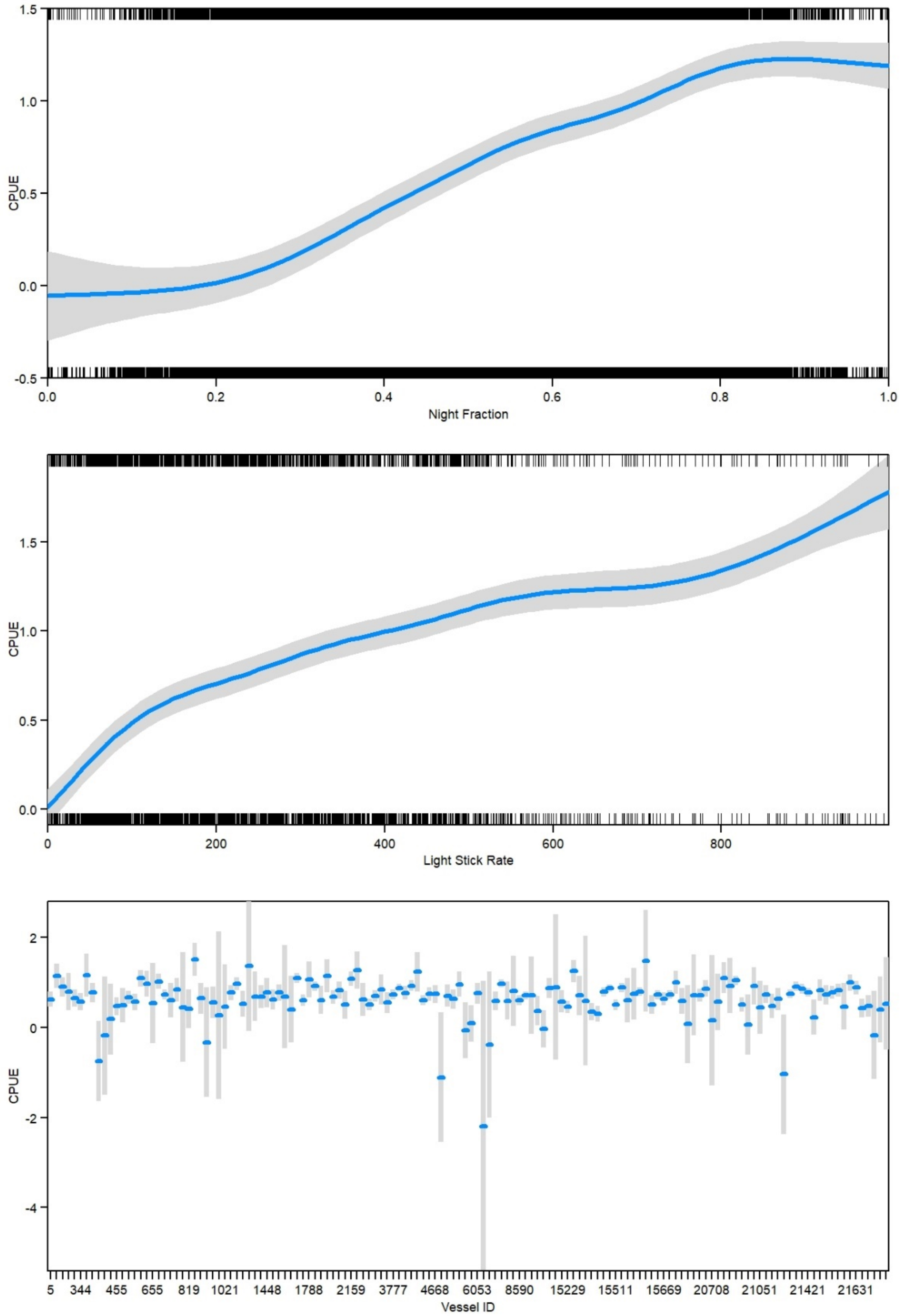


Figure 3.3: Effect of explanatory variables on CPUE in the all-vessels short series (2004–2019) final fitted model *night fraction* (top panel), *light stick rate* (middle panel), and *Vessel* (bottom panel).

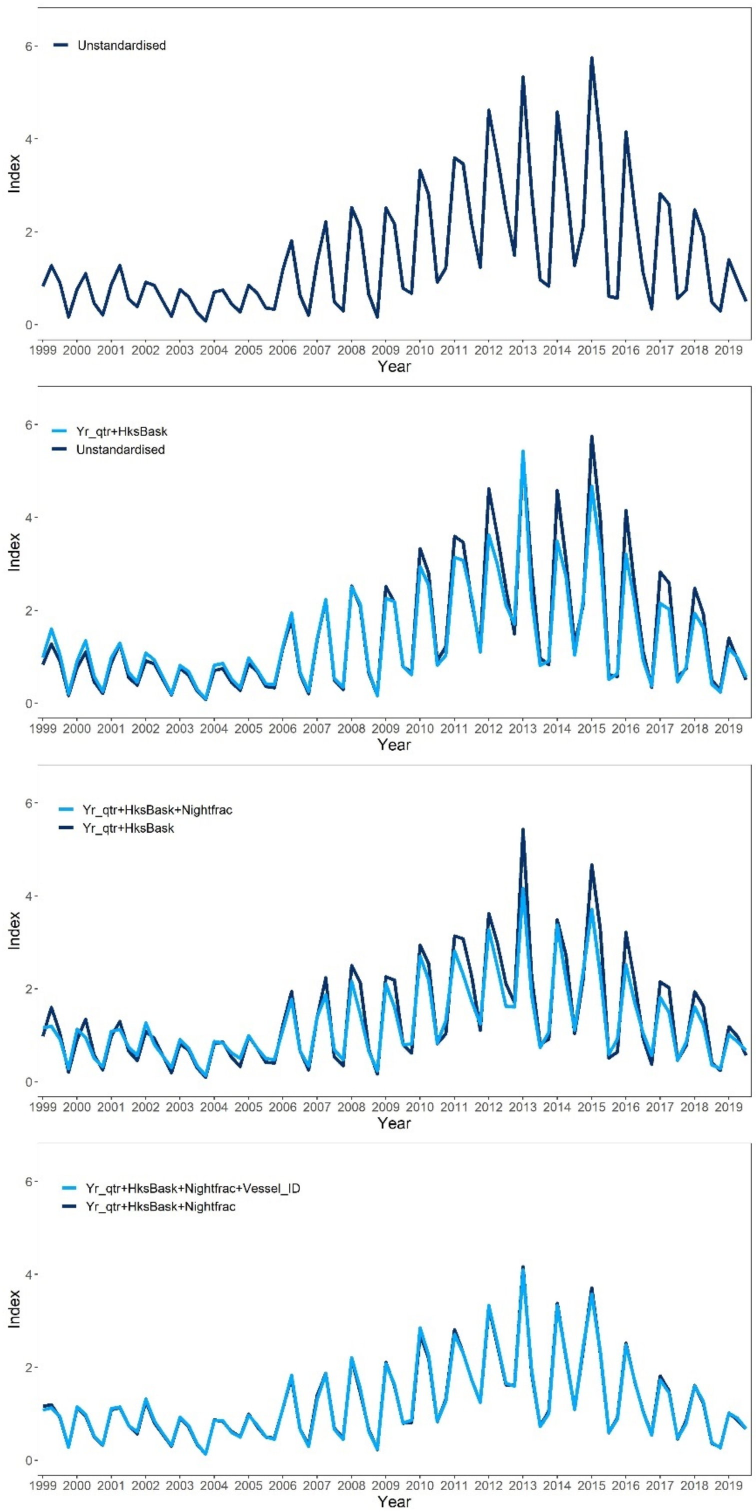


Figure 3.4: Step plots showing the effect on the CPUE index as each variable is added to the model for the core vessels series: 1999–2019.

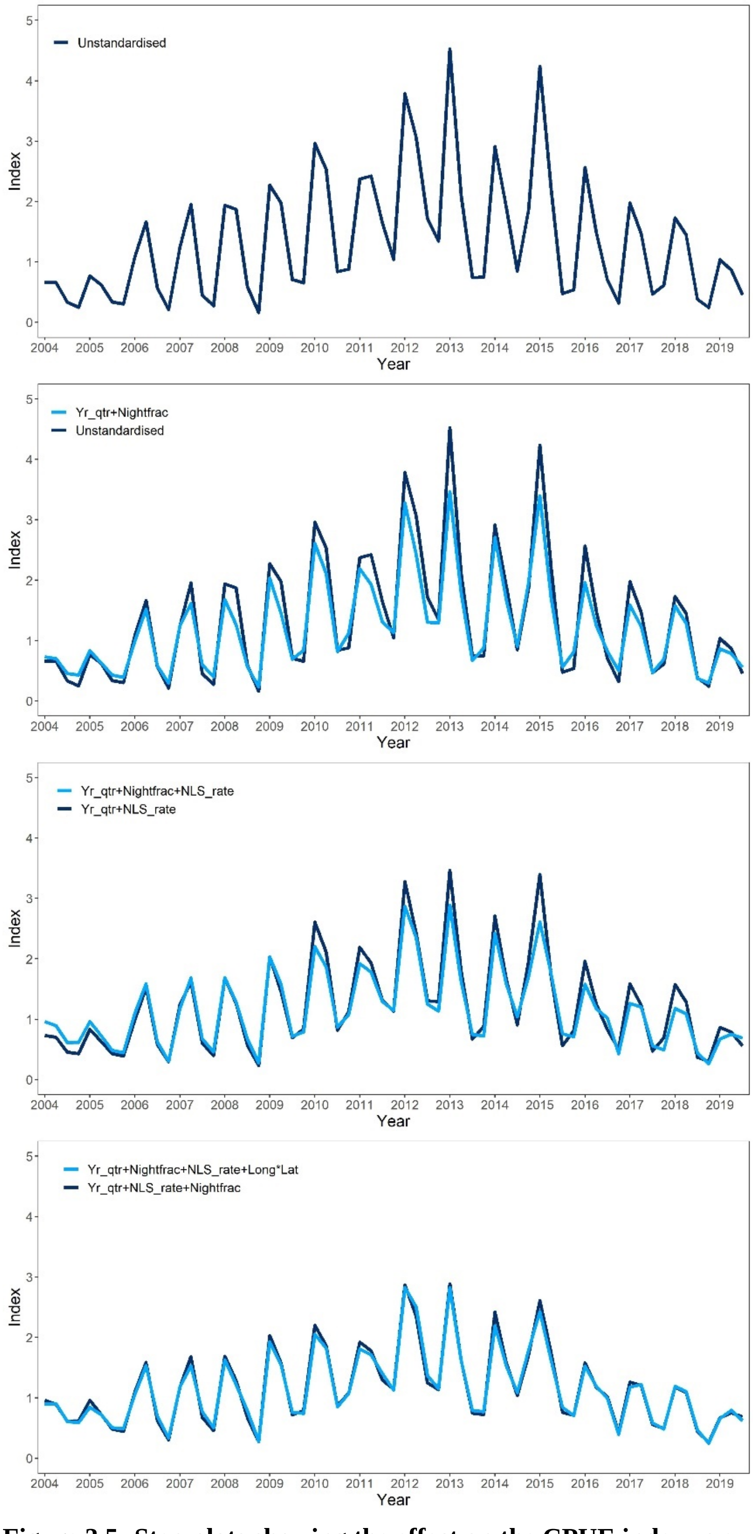
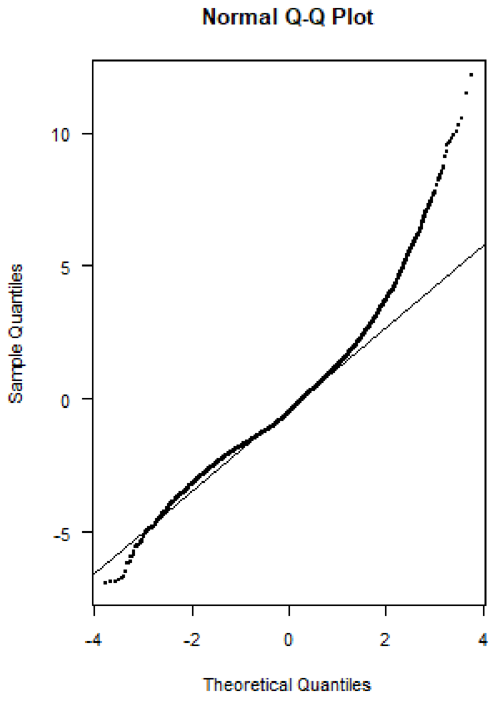


Figure 3.5: Step plots showing the effect on the CPUE index as each variable is added to the model for the core vessels series: 2004–2019.



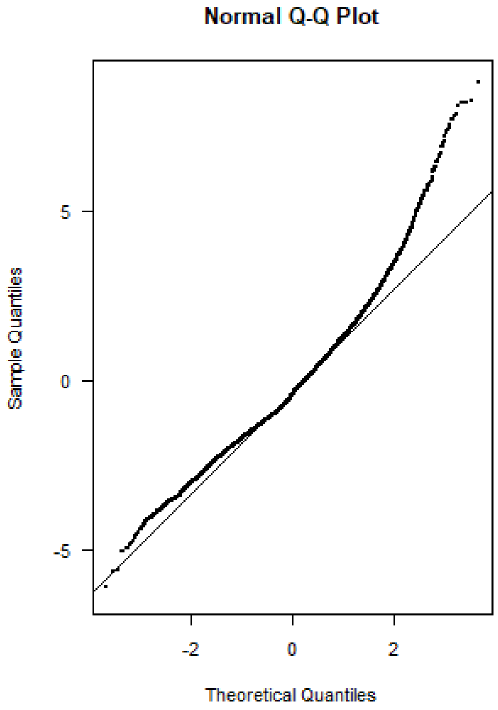


Figure 3.6: Normality diagnostic residual plots for the core vessels final CPUE models, 1999–2019 series (left) and 2004–2019 series (right).

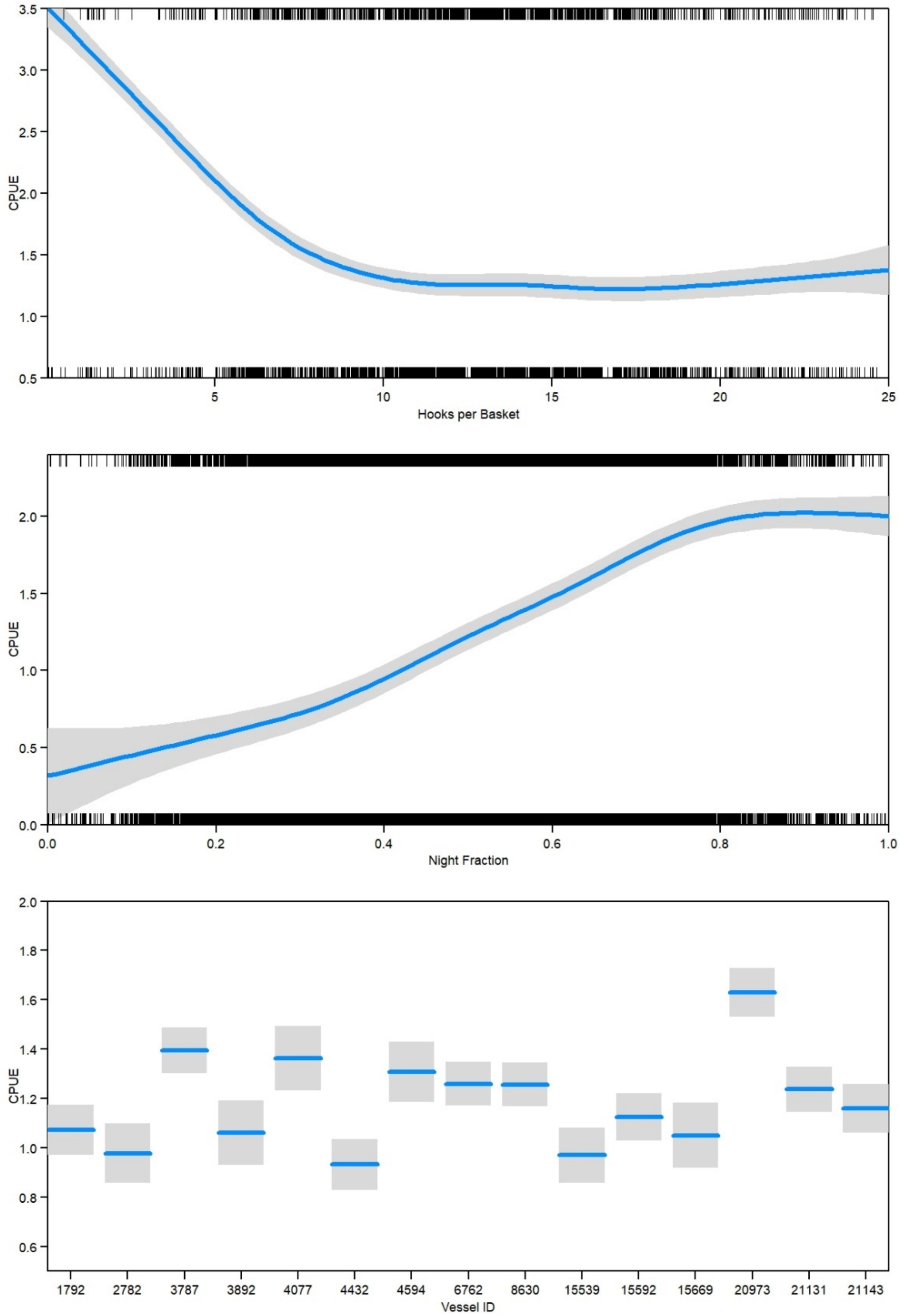


Figure 3.7: Effect of explanatory variables on CPUE in the core-vessels long series (1999–2019) final fitted model *hooks per basket* (top panel), *night fraction* (middle panel), and *Vessel* (bottom panel).

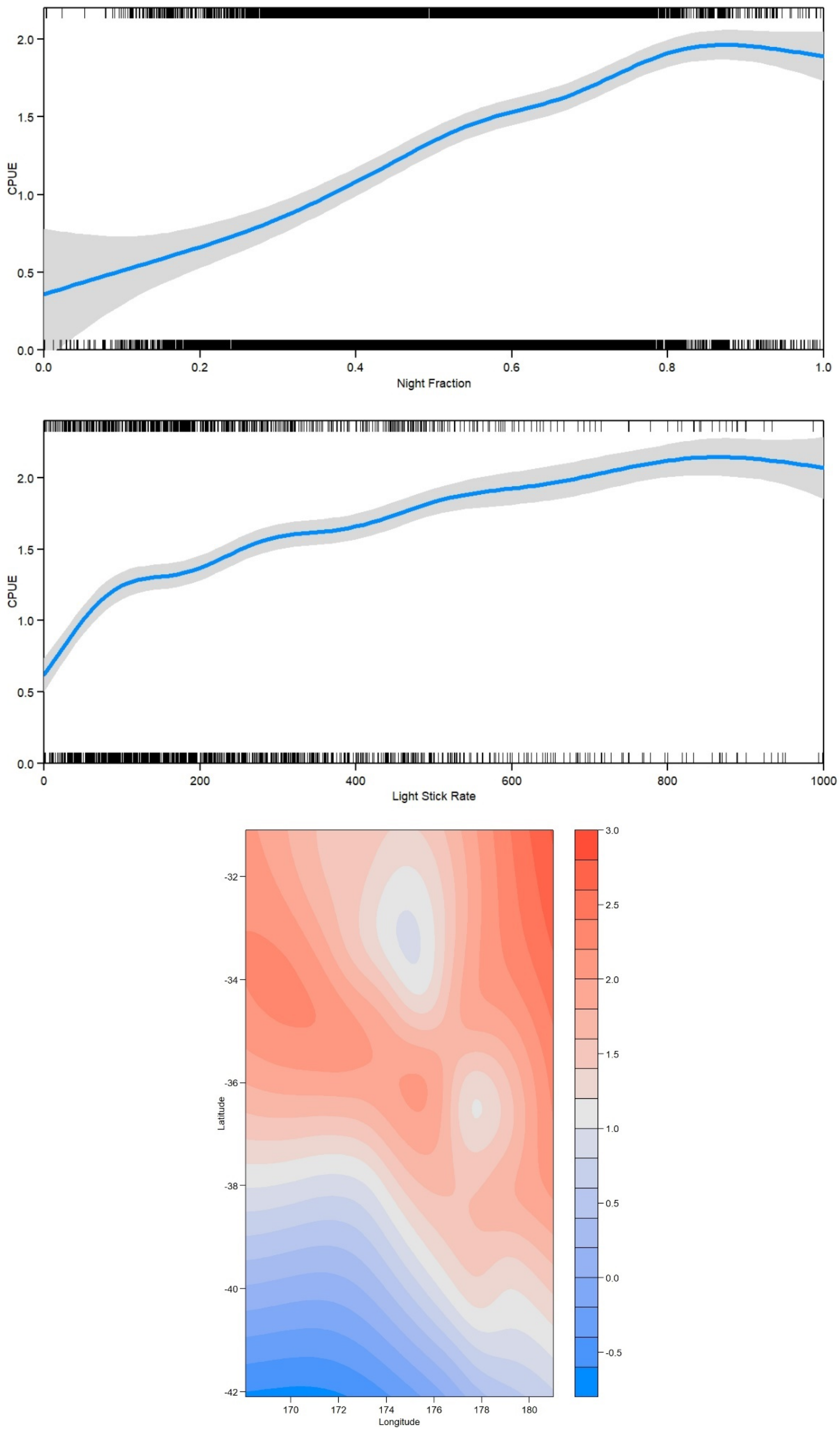


Figure 3.8: Effect of explanatory variables on CPUE in the core-vessels short series (2004–2019) final fitted model), ***night fraction*** **(top panel),** ***light stick rate*** **(middle panel), and** ***longitude-latitude*** **interaction term (bottom panel).**

Table 3.1: Variables retained in order of decreasing explanatory value in the annual (Year) core-vessels (1999–2019) CPUE model and the percentage of the deviance explained with the addition of each variable.

Variable	Core Series % deviance explained
Year	18.2
Night Fraction	36.2
Seasonal Quarter	44.3
Hooks per Basket	51.5
Vessel	52.9

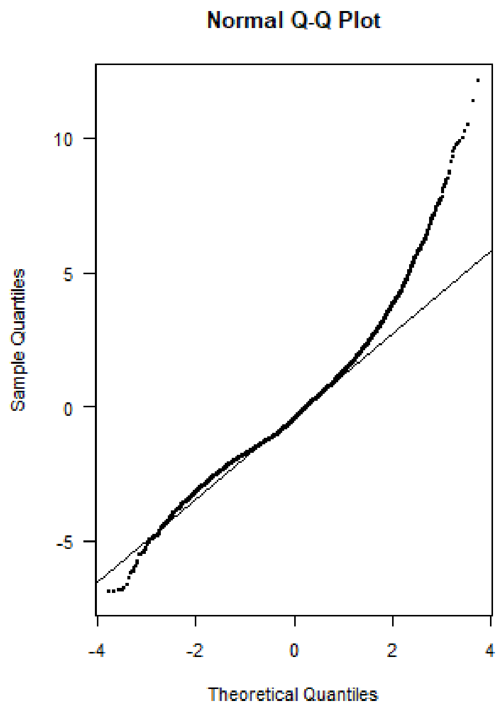


Figure 3.9: Normality diagnostic residual plot for the annual (Year) core-vessels (1999–2019) CPUE model.

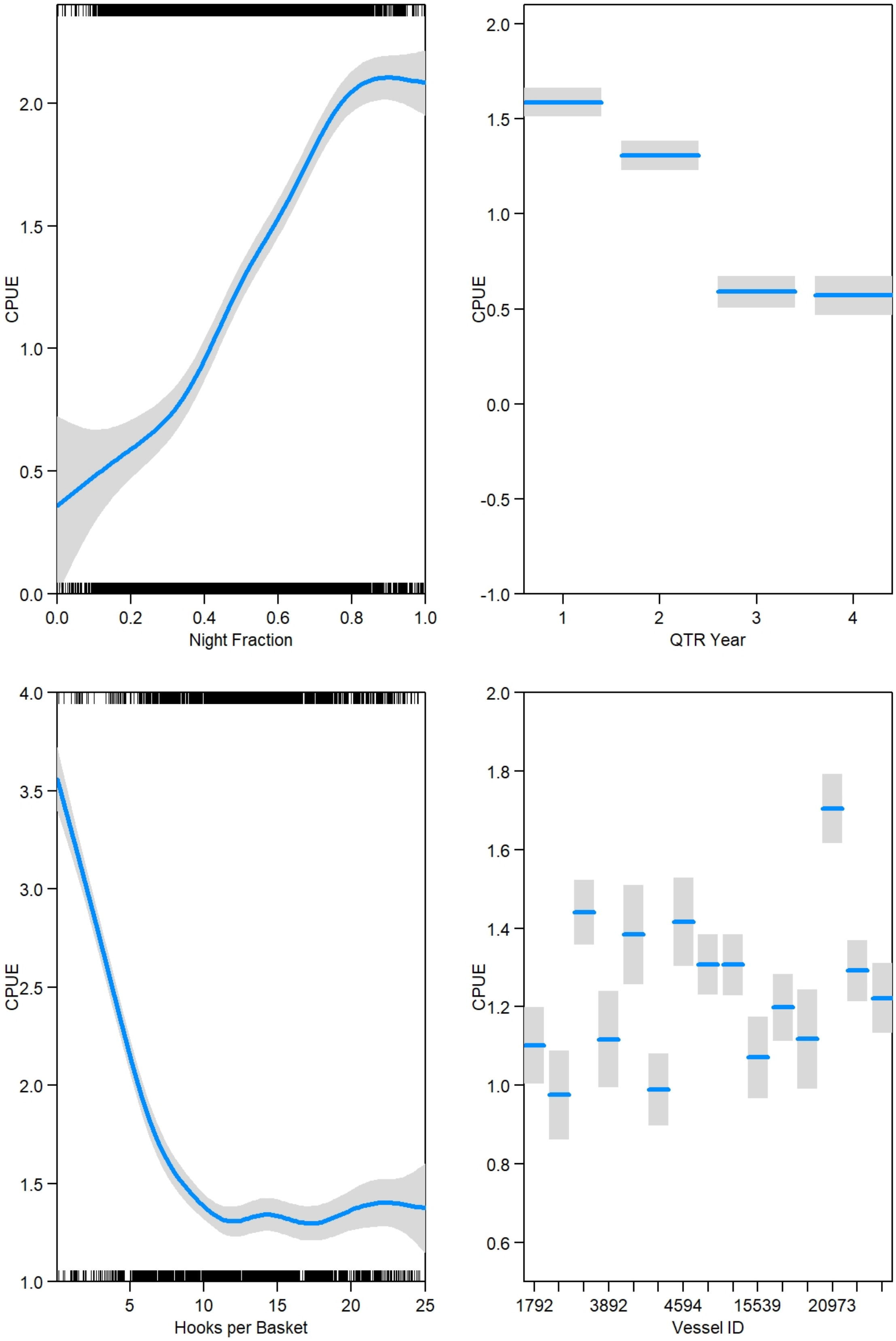


Figure 3.10: Effect of explanatory variables on CPUE in the annual core-vessels short series (1999–2019) final fitted model from top right: *night fraction*, *Year-quarter*, *hooks per basket*, and *Vessel*.

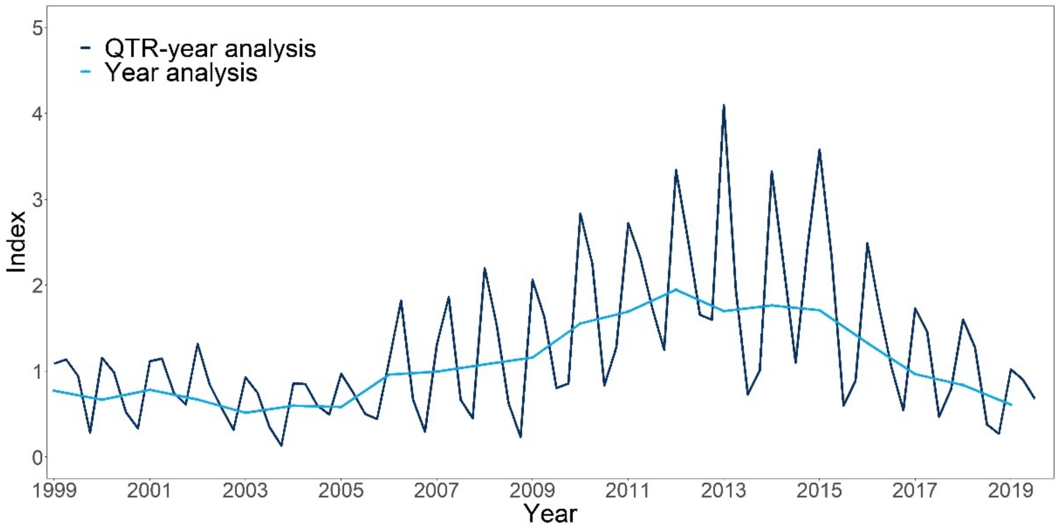


Figure 3.11: Comparison of CPUE indices for the core-vessels series (1999–2019) by year (annual) and by year-quarter, both scaled to their geometric mean.

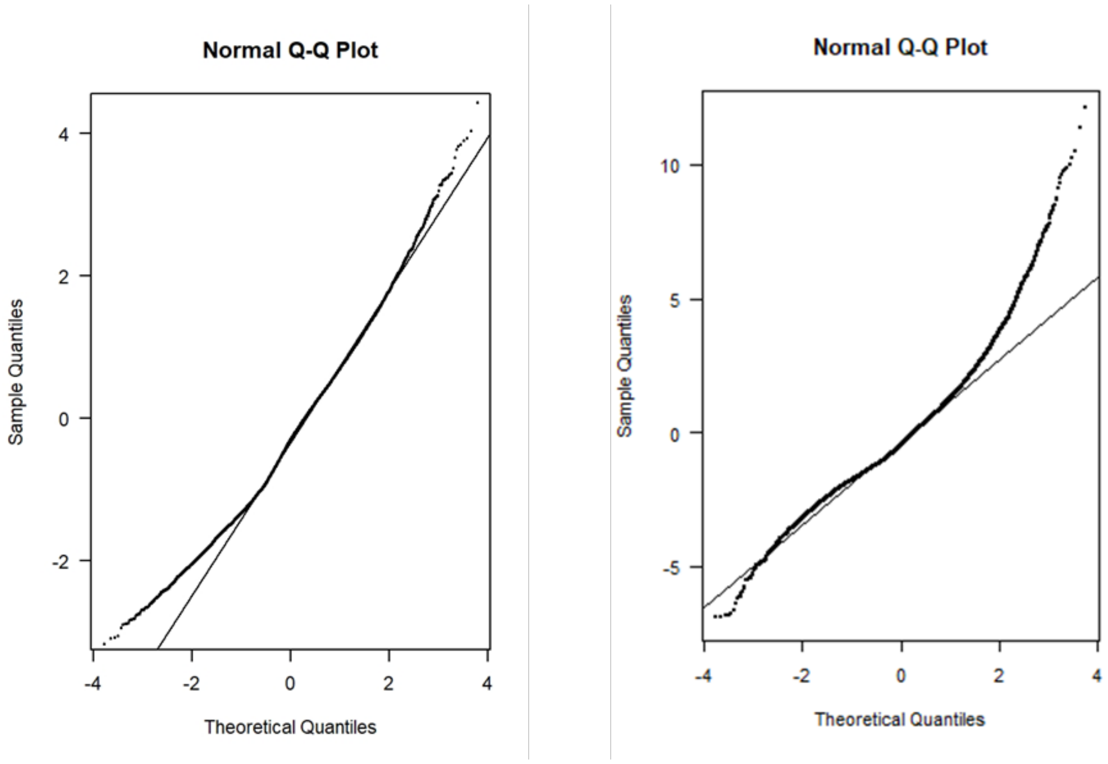


Figure 3.12: Comparative normality diagnostic residual plots for the annual core-vessels (1999–2019) CPUE year-quarter model with quasi-poisson distribution (right) and a negative binomial distribution (left).

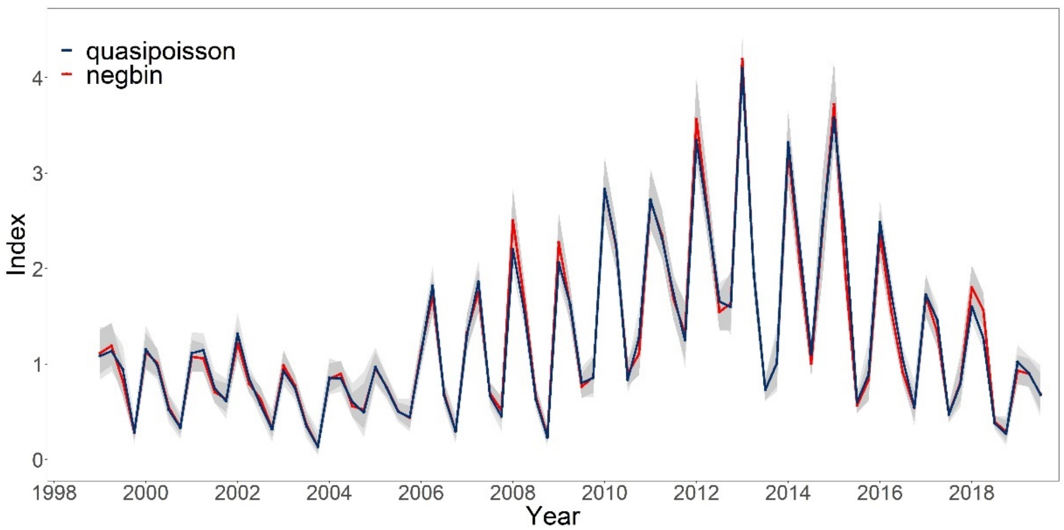


Figure 3.13: Comparison of CPUE indices for the core-vessels series (1999–2019) using a quasi-poisson distribution and a negative binomial (negbin) distribution, both scaled to their geometric mean.

Table 3.2: Model indices and standard error (SE). (Continued on next 2 pages)

QTR Year	All Vessels Long Index	All Vessels Long SE	All Vessels Short Index	All Vessels Short SE	Core Vessels Long Index	Core Vessels Long SE	Core Vessels Short Index	Core Vessels Short SE
1993_01	0.46	0.08	-	-	-	-	-	-
1993_02	0.34	0.04	-	-	-	-	-	-
1993_03	0.16	0.04	-	-	-	-	-	-
1993_04	0.12	0.04	-	-	-	-	-	-
1994_01	0.53	0.05	-	-	-	-	-	-
1994_02	0.49	0.04	-	-	-	-	-	-
1994_03	0.29	0.06	-	-	-	-	-	-
1994_04	0.22	0.06	-	-	-	-	-	-
1995_01	0.42	0.04	-	-	-	-	-	-
1995_02	0.52	0.05	-	-	-	-	-	-
1995_03	0.17	0.05	-	-	-	-	-	-
1995_04	0.12	0.03	-	-	-	-	-	-
1996_01	0.85	0.06	-	-	-	-	-	-
1996_02	0.52	0.04	-	-	-	-	-	-
1996_03	0.63	0.11	-	-	-	-	-	-
1996_04	0.27	0.06	-	-	-	-	-	-
1997_01	0.90	0.06	-	-	-	-	-	-
1997_02	1.00	0.06	-	-	-	-	-	-
1997_03	0.53	0.09	-	-	-	-	-	-
1997_04	0.12	0.03	-	-	-	-	-	-
1998_01	1.36	0.07	-	-	-	-	-	-
1998_02	1.52	0.07	-	-	-	-	-	-
1998_03	0.99	0.07	-	-	-	-	-	-
1998_04	0.62	0.07	-	-	-	-	-	-
1999_01	1.31	0.06	-	-	1.09	0.14	-	-
1999_02	1.48	0.06	-	-	1.14	0.12	-	-
1999_03	1.07	0.05	-	-	0.94	0.11	-	-
1999_04	0.54	0.04	-	-	0.28	0.07	-	-
2000_01	1.75	0.06	-	-	1.15	0.12	-	-
2000_02	1.52	0.05	-	-	0.99	0.08	-	-
2000_03	0.86	0.04	-	-	0.52	0.07	-	-
2000_04	0.48	0.04	-	-	0.33	0.07	-	-
2001_01	1.81	0.06	-	-	1.12	0.10	-	-
2001_02	1.70	0.05	-	-	1.15	0.08	-	-
2001_03	1.05	0.04	-	-	0.75	0.08	-	-
2001_04	0.83	0.05	-	-	0.61	0.10	-	-
2002_01	1.68	0.06	-	-	1.32	0.10	-	-
2002_02	1.17	0.04	-	-	0.85	0.06	-	-
2002_03	0.76	0.04	-	-	0.57	0.07	-	-
2002_04	0.37	0.03	-	-	0.32	0.08	-	-
2003_01	1.36	0.05	-	-	0.93	0.09	-	-
2003_02	1.05	0.03	-	-	0.75	0.06	-	-
2003_03	0.59	0.04	-	-	0.35	0.07	-	-
2003_04	0.22	0.03	-	-	0.13	0.07	-	-
2004_01	1.17	0.05	0.94	0.05	0.86	0.10	0.90	0.09
2004_02	1.21	0.04	1.04	0.04	0.85	0.07	0.90	0.07
2004_03	0.69	0.04	0.58	0.04	0.60	0.09	0.61	0.09
2004_04	0.35	0.08	0.34	0.08	0.49	0.17	0.59	0.19
2005_01	1.39	0.07	0.87	0.05	0.97	0.10	0.85	0.08
2005_02	1.12	0.05	0.86	0.04	0.75	0.07	0.72	0.06
2005_03	0.72	0.04	0.60	0.04	0.50	0.06	0.51	0.06
2005_04	0.55	0.07	0.41	0.05	0.44	0.09	0.49	0.09
2006_01	1.63	0.07	1.16	0.05	1.12	0.09	1.06	0.07
2006_02	2.16	0.07	1.56	0.05	1.82	0.10	1.53	0.07
2006_03	0.98	0.05	0.83	0.04	0.67	0.07	0.70	0.06
2006_04	0.70	0.09	0.54	0.08	0.30	0.08	0.33	0.08
2007_01	1.48	0.07	1.00	0.05	1.30	0.10	1.18	0.07
2007_02	2.19	0.08	1.44	0.05	1.86	0.11	1.53	0.08
2007_03	0.82	0.05	0.68	0.04	0.67	0.07	0.77	0.07
2007_04	0.63	0.09	0.54	0.08	0.45	0.09	0.50	0.09
2008_01	2.73	0.10	1.74	0.07	2.20	0.12	1.63	0.09

QTR Year	All Vessels Long Index	All Vessels Long SE	All Vessels Short Index	All Vessels Short SE	Core Vessels Long Index	Core Vessels Long SE	Core Vessels Short Index	Core Vessels Short SE
2008_02	2.00	0.08	1.31	0.05	1.54	0.09	1.22	0.06
2008_03	0.93	0.06	0.88	0.06	0.63	0.07	0.79	0.08
2008_04	0.28	0.05	0.26	0.05	0.23	0.06	0.28	0.07
2009_01	2.31	0.09	1.72	0.07	2.06	0.12	1.93	0.09
2009_02	2.18	0.07	1.61	0.06	1.62	0.09	1.55	0.07
2009_03	1.23	0.06	0.87	0.05	0.80	0.08	0.76	0.07
2009_04	1.01	0.09	0.78	0.07	0.86	0.11	0.75	0.09
2010_01	3.29	0.10	2.01	0.07	2.83	0.13	2.05	0.07
2010_02	2.69	0.08	1.81	0.06	2.25	0.11	1.82	0.07
2010_03	1.05	0.06	0.85	0.05	0.84	0.07	0.85	0.07
2010_04	1.18	0.10	0.79	0.07	1.28	0.15	1.07	0.13
2011_01	3.60	0.10	2.05	0.07	2.72	0.13	1.81	0.08
2011_02	2.82	0.08	1.66	0.05	2.32	0.10	1.71	0.07
2011_03	2.46	0.09	1.61	0.07	1.74	0.10	1.40	0.08
2011_04	1.51	0.11	1.02	0.08	1.25	0.16	1.13	0.14
2012_01	4.26	0.12	2.78	0.09	3.34	0.15	2.83	0.10
2012_02	3.10	0.10	2.51	0.09	2.53	0.13	2.50	0.11
2012_03	2.00	0.08	1.38	0.06	1.66	0.09	1.37	0.08
2012_04	1.97	0.13	1.24	0.08	1.60	0.16	1.15	0.10
2013_01	4.80	0.14	2.73	0.09	4.10	0.18	2.82	0.09
2013_02	2.53	0.08	1.74	0.06	1.95	0.10	1.62	0.07
2013_03	0.87	0.05	0.82	0.05	0.73	0.06	0.79	0.07
2013_04	0.89	0.12	0.62	0.08	1.01	0.17	0.77	0.12
2014_01	3.83	0.12	2.14	0.08	3.32	0.15	2.19	0.09
2014_02	2.84	0.09	1.70	0.07	2.22	0.11	1.53	0.07
2014_03	1.28	0.07	1.08	0.07	1.10	0.08	1.09	0.10
2014_04	3.56	0.25	2.22	0.16	2.45	0.26	1.79	0.17
2015_01	4.31	0.13	2.60	0.09	3.58	0.15	2.43	0.09
2015_02	2.72	0.09	1.55	0.07	2.34	0.11	1.62	0.08
2015_03	1.02	0.06	0.83	0.08	0.60	0.05	0.84	0.09
2015_04	1.21	0.15	0.83	0.11	0.89	0.16	0.71	0.12
2016_01	2.93	0.09	1.66	0.06	2.49	0.11	1.52	0.06
2016_02	1.96	0.07	1.21	0.05	1.72	0.08	1.19	0.06
2016_03	1.24	0.06	0.97	0.06	1.05	0.07	1.00	0.08
2016_04	0.70	0.11	0.44	0.07	0.54	0.12	0.40	0.08
2017_01	2.26	0.09	1.29	0.06	1.73	0.10	1.18	0.07
2017_02	1.76	0.06	1.17	0.06	1.46	0.08	1.22	0.07
2017_03	0.70	0.05	0.68	0.05	0.47	0.05	0.58	0.06
2017_04	1.05	0.12	0.60	0.07	0.79	0.14	0.48	0.08
2018_01	2.14	0.08	1.27	0.06	1.60	0.09	1.19	0.07
2018_02	1.54	0.06	1.18	0.05	1.27	0.07	1.10	0.05
2018_03	0.50	0.03	0.47	0.04	0.38	0.04	0.47	0.05
2018_04	0.46	0.07	0.29	0.05	0.27	0.08	0.25	0.07
2019_01	1.09	0.07	0.66	0.05	1.02	0.08	0.66	0.06
2019_02	1.29	0.07	0.93	0.05	0.90	0.08	0.79	0.07
2019_03	0.92	0.11	0.69	0.08	0.68	0.14	0.62	0.11
2019_04	0.17	0.14	0.15	0.12	-	-	-	-

Table 3.2: — continued. Model indices and standard error (SE).

Year	Annual (Year) Index	Annual (Year) SE
1999	0.77	0.06
2000	0.67	0.04
2001	0.78	0.04
2002	0.67	0.04
2003	0.52	0.03
2004	0.60	0.04
2005	0.58	0.04
2006	0.96	0.05
2007	0.99	0.05
2008	1.08	0.05
2009	1.16	0.05
2010	1.55	0.06
2011	1.69	0.07
2012	1.95	0.08
2013	1.70	0.07
2014	1.77	0.08
2015	1.71	0.07
2016	1.33	0.06
2017	0.97	0.05
2018	0.84	0.04
2019	0.61	0.04