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Indicator based analysis of the status of New Zealand blue, mako, and porbeagle sharks in 2018

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M.P. Francis
B. Finucci

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EXECUTIVE SUMMARY

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Cartilaginous fishes generally have low productivity because of their low to moderate growth rates and their low fecundity. Despite their vulnerability to over-fishing, a lack of suitable data means that conventional stock assessments are rarely possible. To address that limitation, this report updates by five years a series of abundance indicators published in 2014 for blue, porbeagle, and mako sharks − three species that are taken primarily as bycatch in the New Zealand surface longline (SLL) fishery. The main data sources were the Fisheries New Zealand (FNZ) commercial catch-effort database for the 2005 to 2018 fishing years and the MPI observer database for the 1993 to 2018 fishing years. Our analyses were restricted to the SLL fishery and divided into two regional strata − North region comprising Fisheries Management Areas (FMAs) 1, 2, 8, and 9, and South region comprising FMAs 5 and 7. The following indicators were calculated: high-CPUE (the proportion of half-degree cells having unstandardised catch per unit effort (CPUE) greater than a specified threshold); proportion-zeroes (the proportion of half-degree cells having zero reported catches in a fishing year); geometric mean index (the geometric mean of the species abundances in catches, for both the catch of all species including teleosts, and the catch of just the three sharks); standardised CPUE (for both commercial and observer data); proportion of males in the catch; and median lengths of males and females.

Since the previous indicators were published, there have been major changes in the SLL fishery. Restrictions were imposed by airlines on the export of shark fins in 2014, and finning of sharks was banned from 2015. Porbeagle shark was added to CITES Appendix II in September 2014, making the export of porbeagle products more complicated. As a result, most pelagic sharks are now discarded dead or released alive. Chartered Japanese longliners ceased fishing in New Zealand waters in 2015, thus terminating an important time series of indicators. These changes have had a profound effect on our ability to monitor stock status of pelagic sharks.

Most of the abundance indicator series presented in this report showed declining trends in recent years, particularly in North region in the 2017 and 2018 fishing years, suggesting a reversal of the previous increasing trends. However, the indicators may not accurately index shark abundance because: (1) Very similar patterns were seen for all three shark species, but it seems unlikely that all three species would decline steeply at the same time; (2) the declines in North region standardised commercial CPUE appear to be too steep to represent real changes in population abundance; (3) observer-based standardised CPUE analyses did not show the same declines as the commercial CPUEs; (4) South region showed little change for all three sharks, so the steep declines seen in North region were not universal; (5) SLL effort has been declining in the EEZ and many pelagic sharks now survive capture by SLL vessels because they are released alive, hence fishing mortality of pelagic sharks has probably declined substantially since 2015.

There are other possible explanations for the observed declines in the abundance indicators: (1) There has been a marine heatwave in New Zealand waters in the last few years and that may have affected the number of sharks migrating into New Zealand waters from the tropics, or their distribution within New Zealand waters; (2) fishers may be avoiding large shark catches since shark finning was banned; (3) sharks that are cut off lines may not be recorded by crew or by observers, leading to an underestimation of catch; (4) deliberate targeting and killing of sharks may have increased recently, leading to localised depletion.

These factors combine to make interpretation of the stock status of the three species problematic. The observer dataset provides the most accurate and long-term record of New Zealand pelagic shark catches

and may give the best insight into pelagic shark abundance trends. Caution is required in interpreting the trends, however. The observer CPUE time series suggest the following long-term trends:

1. Blue shark. Abundance may have declined during the late 1990s and early 2000s and then increased to considerably higher levels by 2015, followed by a decline in 2017–2018 in North region.
2. Mako shark. Abundance in North region appears to have been stable since the late 1990s. The South region index showed a steady decline from the late 1990s to the mid 2000s before stabilising, but that index may not be representative of mako shark abundance in the EEZ.
3. Porbeagle shark. Abundance may have declined in the late 1990s before increasing to higher levels in the late 2000s and early 2010s and declining again in 2017–2018.

The indicators presented here cover only the most recent portion of a longer fishing history that was characterised by greater effort levels, particularly in the 1980s and early 1990s when many foreign fishing vessels held licences. There is no information on the effect of that high fishing effort, and there are no shark catch data from that period, nor effort data from before 1980.

Blue, porbeagle, and mako sharks are generally regarded as wide-ranging, mobile oceanic species. Although this may be true of blue sharks, recent electronic tagging of porbeagle and mako sharks in New Zealand waters has shown that juveniles (which make up a high proportion of the catch of each species) are partly residential in the New Zealand EEZ. Thus, abundance indices for the New Zealand EEZ may not index the entire southwest Pacific populations of those species. To understand trends in the wider pelagic shark stocks of the South Pacific, and to quantify their status in relation to management reference points, quantitative regional stock assessments are now required.

1. INTRODUCTION

Cartilaginous fishes (sharks, skates, rays, and chimaeras) are regarded as vulnerable to overfishing because of their low productivity, which is a result of their low to moderate growth rates, small litter sizes, and long (frequently multi-year) reproductive cycles. About 112 cartilaginous species occur in New Zealand waters, of which 11 are managed under the Quota Management System (QMS) (Ford et al. 2018). Quantitative, model-based stock assessments are not currently available for any of the 44 management units or "stocks" of the 11 QMS species, nor for any of the species that are not in the QMS (Fisheries New Zealand 2018a, 2018b).

Alternative methods have been developed for assessing threats to data-poor stocks of fishes. These methods have the advantage of being more forgiving of data gaps, less reliant on assumptions structuring population dynamics, and are more readily updated than traditional stock assessments. One type of approach has involved various forms of ecological risk assessment. Another approach is to use a series of stock status indicators to assess the response of the population to fishing pressure. Such indicators are usually straightforward to compute (except for standardised catch-per-unit-effort, CPUE) and track over time, thus providing the opportunity to observe trends which can serve as early signals of overexploitation. Interpreted as a suite, indicators of stock status can be useful for initial assessments and/or for prioritising future data collection or analytical work (Clarke et al. 2013).

An indicator approach was adopted as an initial step in the Western and Central Pacific Fisheries Commission's (WCPFC) Shark Research Plan (Clarke et al. 2011; 2013). The concept for the Shark Research Plan was to use the indicator analysis for an initial assessment of population status for all of the WCPFC key shark species and then, having highlighted those in greatest need of further analysis, to proceed with more complex stock assessments. For blue and mako sharks, the WCPFC region probably covers the same stock that is fished in New Zealand and is the subject of the present study.

Three Highly Migratory Species (HMS) of sharks (blue shark *Prionace glauca*, mako shark *Isurus oxyrinchus*, and porbeagle shark *Lamna nasus*) are frequently caught in New Zealand waters. They are taken primarily as bycatch in the tuna longline fishery, but porbeagle sharks are also caught by trawl fisheries (Francis 2019). Indicator analyses were conducted for these three sharks up to the end of the 2012–13 fishing year by Francis et al. (2014). Four types of indicators were developed for each species: distribution, percentage catch composition, standardised CPUE, and median size/sex ratio.

These indicators are developed as annual time series and assessed for their utility in describing trends in stock abundance or status. The indicators can be updated at regular intervals in the future to monitor changes in population status in response to fishing and other impacts, and existing and new management measures. The indicators can also be provided to regional fisheries management organisations (e.g., WCPFC, Commission for the Conservation of Southern Bluefin Tuna, CCSBT) for incorporation into the assessment and management of these HMS sharks over greater spatial scales.

The objectives of this study were:

1. To characterise the bycatch fisheries for the major [pelagic] shark species in NZ waters
2. To update indicator analyses for blue, mako, and porbeagle sharks

This report addresses Objective 2 by extending the study of Francis et al. (2014) by five years to the end of the 2017–18 fishing year. Objective 1 is addressed elsewhere (Francis 2019).

2. GENERAL METHODS

The scope of the study is New Zealand-wide, because the three shark species are each managed as a single stock occurring throughout the Exclusive Economic Zone (EEZ) (Fisheries New Zealand 2018b). The main data sources used were the Fisheries New Zealand (FNZ) catch-effort database *warehou*, and the FNZ observer database *COD*. Data were extracted for relevant periods, i.e., 2004−05 to 2017−18 fishing years for *warehou* and 1992−93 to 2017−18 fishing years for *COD*. The start date for the *warehou* data series was determined by the introduction of the three HMS sharks into the Quota Management System (QMS) in October 2004, and the requirement that all processed and discarded or released HMS sharks be recorded on fishing returns. The start date for the *COD* data series was the date when all observers were accurately distinguishing porbeagle and mako sharks. Hereafter, all years are reported as fishing years (1 October to 30 September), and they are labelled after the second of the two years (e.g., 2004−05 is referred to as 2005).

Our analyses are restricted to the surface longline (SLL) fishery that targets mainly southern bluefin tuna (*Thunnus maccoyii*), bigeye tuna (*T. obesus*), and broadbill swordfish (*Xiphias gladius*) (Griggs et al. 2018). This fishery accounted for 99% of the New Zealand blue shark catch, 94% of the mako shark catch, and 78% of the porbeagle shark catch between 2005 and 2018 (Francis 2019). Commercial catch data were extracted from Tuna Longlining Catch Effort Returns (TLCERs) submitted by SLL fishers to FNZ and entered into *warehou*. Some observer trips or sets in *COD* have previously been flagged as having inaccurate data, ranging from poor species identification to incomplete data recording, and these were omitted from all analyses.

SLL fishing effort is concentrated in two distinct regions of the EEZ – off the north-east coast of North Island and off the west coast of South Island (Francis 2019). As in previous studies (Francis et al. 2014), we analysed data from these two regions separately: North region comprised Fisheries Management Areas (FMAs) 1, 2, 8, and 9, and South region comprised FMAs 5 and 7 (see Appendix 1 for region boundaries). Effort and catches were very low in the remaining FMAs (Francis 2019).

The TLCER data for 2005–2018 contained 36 708 longline sets. Sets outside the New Zealand EEZ, sets having only secondary catch codes, and sets for which the reported catch (by number) exceeded the reported number of hooks on the line were removed leaving 36 679 sets. Twenty-two further sets were removed because they had implausibly high estimated catches of sharks (18 sets with more than 10 t of blue sharks, 1 set with more than 5 t of mako sharks, and 3 sets with more than 5 t of porbeagle sharks). This left a dataset with 36 657 sets.

Set location was taken as the midpoint of the reported start and finish of set positions, and all sets were assigned to half-degree cells on that basis. A cell has a north–south range of 55.6 km (30 nautical miles). The east–west range of a cell depends on the latitude, ranging from 48 km at 30 ºS to 36 km at 50 ºS. Cell height is comparable to the length of domestic longlines (median length 41 km, maximum length about 74 km) but less than that of chartered Japanese longlines (median length 133 km, maximum length 165 km).

TLCERs have separate panels for recording catch that is processed (with some part of the shark being retained), and catch that is discarded or released under Schedule 6 of the Fisheries Act (which allows release of blue, porbeagle, and mako sharks that are alive and likely to survive, or discard dead). Total catches (as both weights and numbers) were calculated by summing the reported processed and discarded/released values. Previous CPUE studies of New Zealand HMS sharks have been based on catch numbers rather than weight (Francis et al. 2001; Griggs & Baird 2013; Francis et al. 2014), because the former are believed to be more accurate than the latter (which are often estimated). Furthermore, there were slightly more records of catch numbers than weights in the TLCER data, indicating that some weights were not reported by fishers. We therefore used catch numbers in preference to catch weight for calculating a CPUE index. The numbers of sets with reported catch number records in the whole TLCER dataset were 29 907 (81.6% of all records) for blue shark, 13 580 (37.0%) for mako shark, and 9169 (25.0%) for porbeagle shark.

Detailed methods relevant to each of the four types of indicators are provided in Sections 4–7.

3. FISHING EFFORT AND OBSERVER COVERAGE

The mean number of SLL hooks set in the New Zealand EEZ declined from 25.8 million per year in 1980–1982 to 2.1 million in 2014–2018 (Figure 1). In the 1980s and early 1990s, the SLL fleet was dominated by foreign licensed vessels (mainly from Japan), but from 1994 onwards, the foreign fleet was reduced to a few vessels (usually four per year) chartered by New Zealand companies. A New Zealand domestic fleet began operating in 1990 and greatly expanded through the 1990s and early 2000s before declining to low levels in recent years. Foreign chartered SLL vessels last fished in New Zealand waters in 2015, so the fishery has been exclusively carried out by New Zealand domestic vessels since 2016.

Since the introduction of blue, mako, and porbeagle sharks into the QMS in 2005, total SLL effort has declined from about 4 million hooks to 2.2 million hooks per year (Figure 2). Most of the effort during that period was contributed by New Zealand domestic vessels operating in North region. Chartered Japanese vessels operated mainly in South region, contributing 0.5–1.1 million hooks per year. Domestic effort was low in South region until 2011, but it has been steady at 0.5–0.7 million hooks per year from 2012 to 2018.

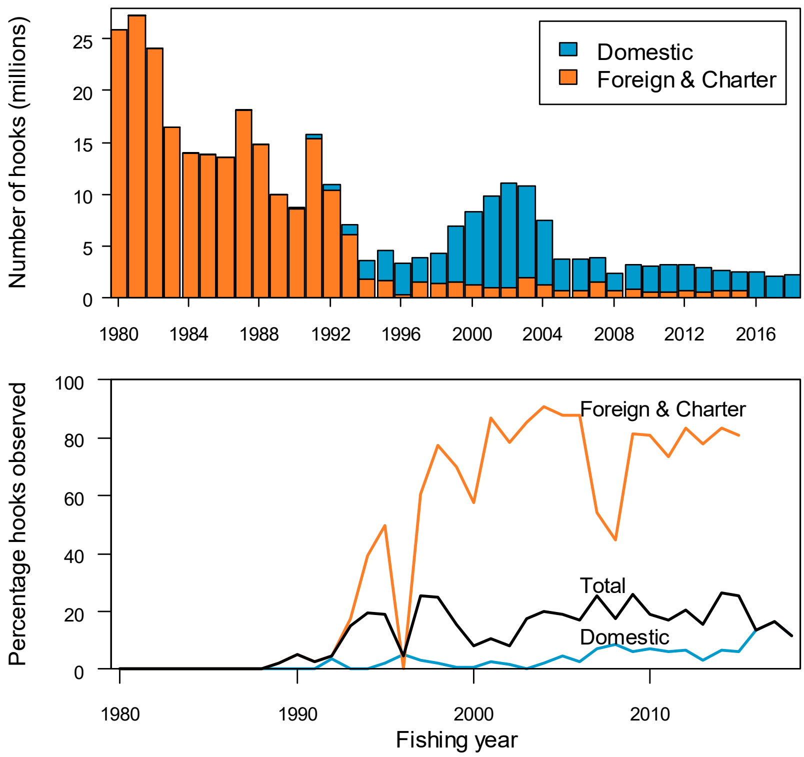


Figure 1: Surface longline fishing effort and observer coverage in the New Zealand EEZ by fishing year. Top: number of hooks set by foreign/charter and New Zealand domestic vessels. Bottom: percentage of hooks observed on foreign/charter and New Zealand domestic vessels. Adapted and extended from Griggs et al. (2018).

The distribution of SLL effort by half-degree cells shows a clear separation between North and South region fisheries in all years (Appendix 1). The spatial distribution of effort in North region was similar in all years, but in South region the effort was deployed over a single contiguous area in some years and split across two disjunct areas in other years.

Observer coverage of the foreign licensed fleet began in 1989 and increased rapidly (Figure 1). From 1997 to 2015, coverage averaged 75.9% of hooks set (Figures 1 and 3). By contrast, observer coverage of the domestic fleet has been much lower, not exceeding 9% before 2015; however, there has been a sharp increase in the last three years, with coverage averaging 14.0% from 2016 to 2018 (Figure 3).

The highest observer coverage was achieved in FMAs 5 and 7 (South region) where the Japanese chartered fleet mainly fished (Figures 4–6). Coverage was lower in FMAs 1, 2, and 9 (North region) where the domestic fleet mainly fished. Observer coverage appears to be spatially representative of the foreign chartered fishing effort since 2005 (Figure 6). However, coverage of the domestic effort was focussed on the northeast coast of North Island and to a lesser extent the west coast of South Island; fishing effort off the west coast of North Island and in FMA 10 south of the Kermadec Islands was poorly represented (Figure 6).

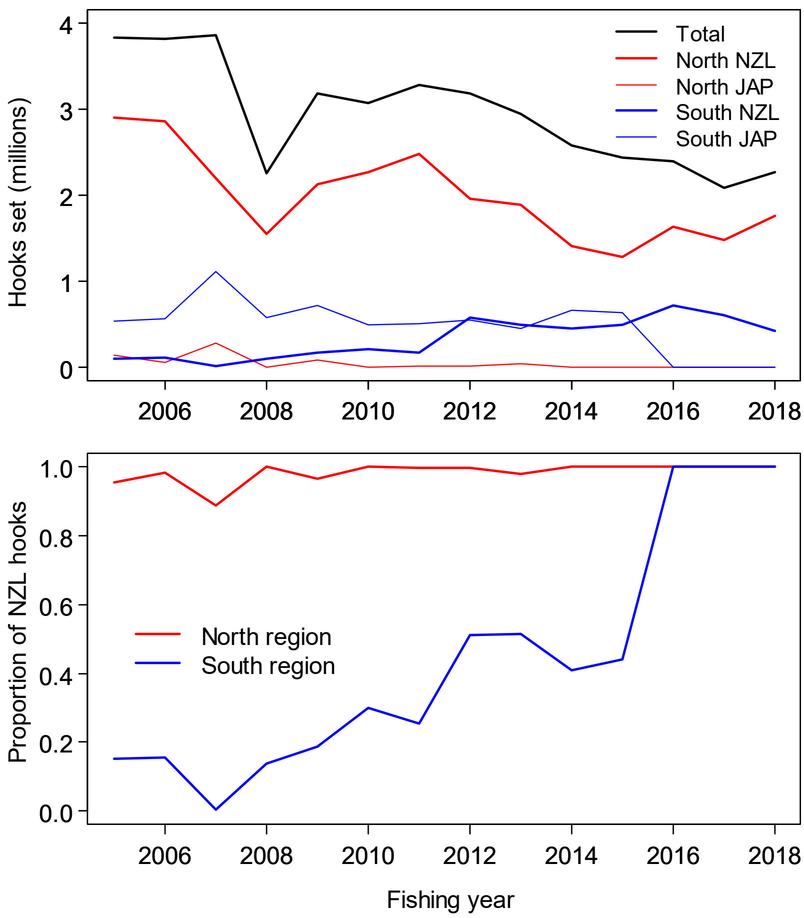


Figure 2: Number (top) and proportion (bottom) of surface longline hooks set 2005–2018 by region and fleet (JAP, chartered Japanese vessels; NZL, New Zealand domestic vessels).

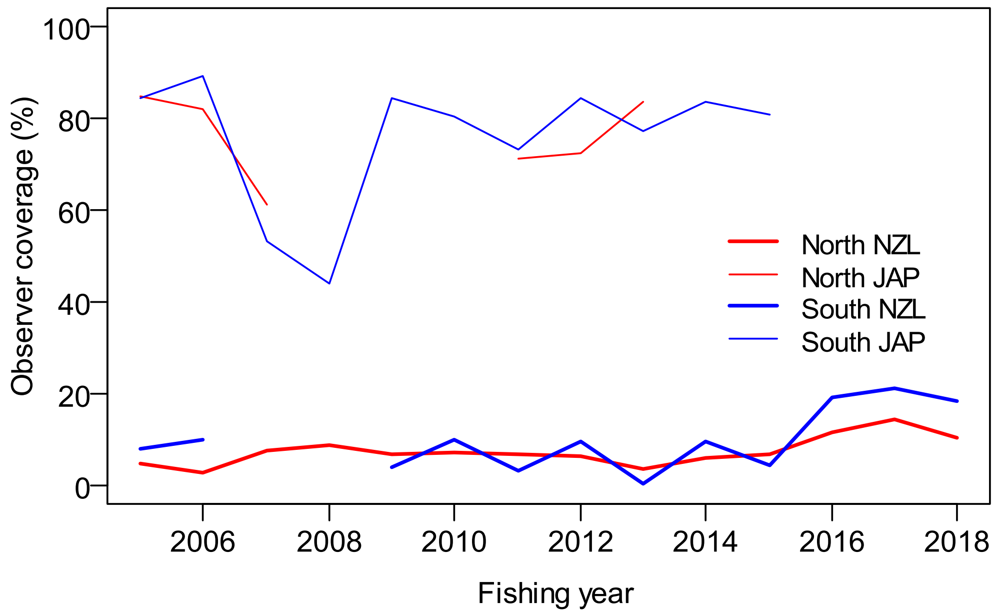


Figure 3: Observer coverage (percentage of hooks observed) of surface longline hooks set 2005–2018 by region and fleet (JAP, chartered Japanese vessels; NZL, New Zealand domestic vessels).

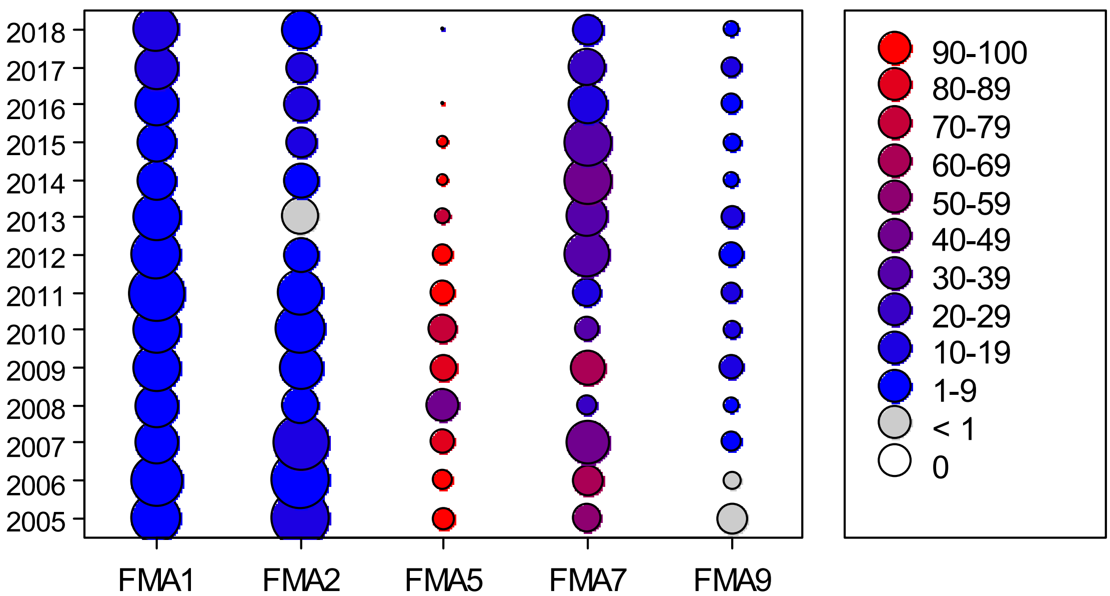


Figure 4: Observer coverage (percentage of hooks observed) by year (2005–2018) and Fisheries Management Area (FMA), all fleets combined. Symbol area is proportional to the number of hooks set.

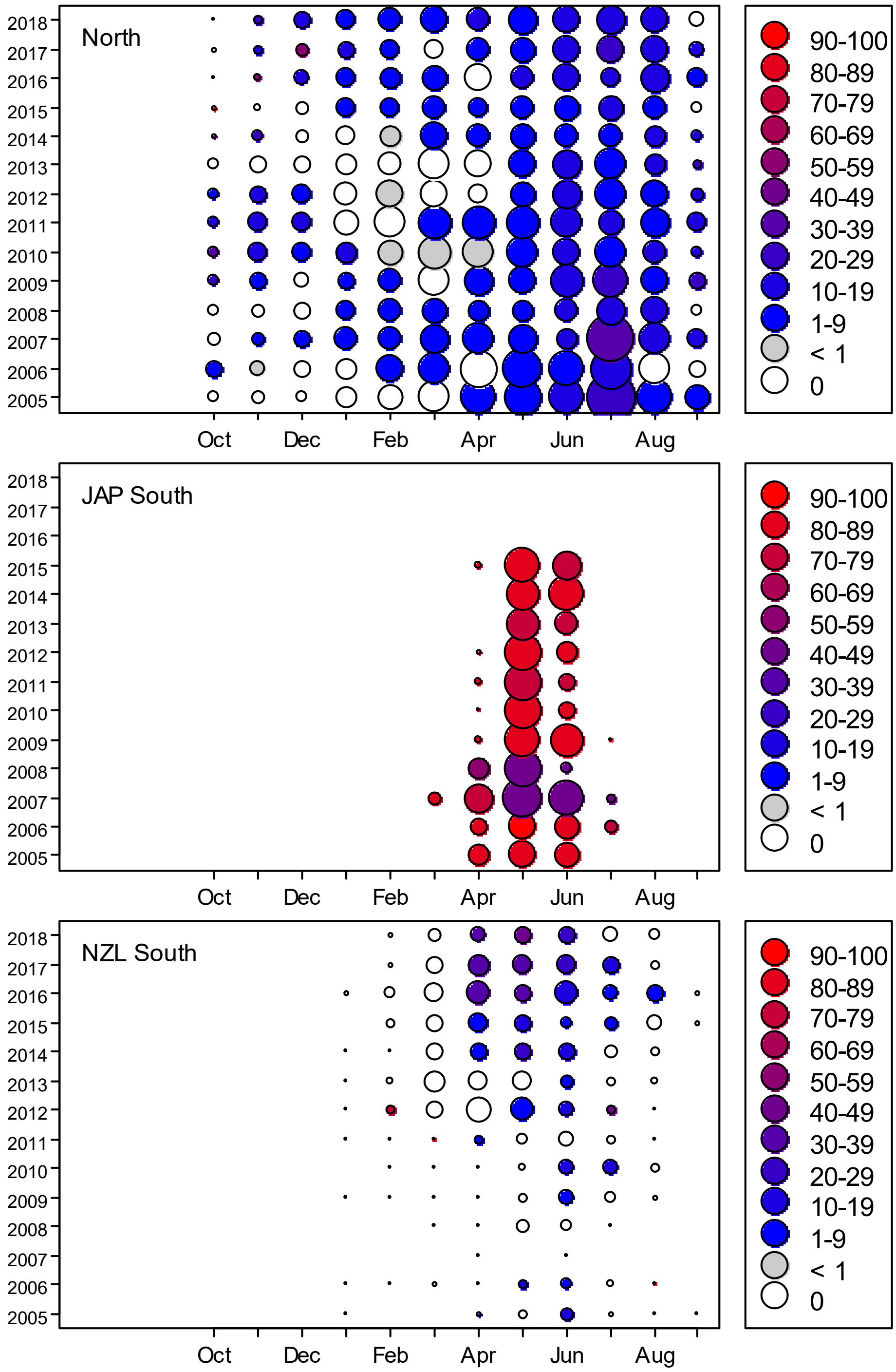


Figure 5: Observer coverage (percentage of hooks observed) by year (2005–2018) and month for (top) North, (middle) Japanese South and (bottom) New Zealand South fisheries. Symbol area is proportional to the number of hooks set.

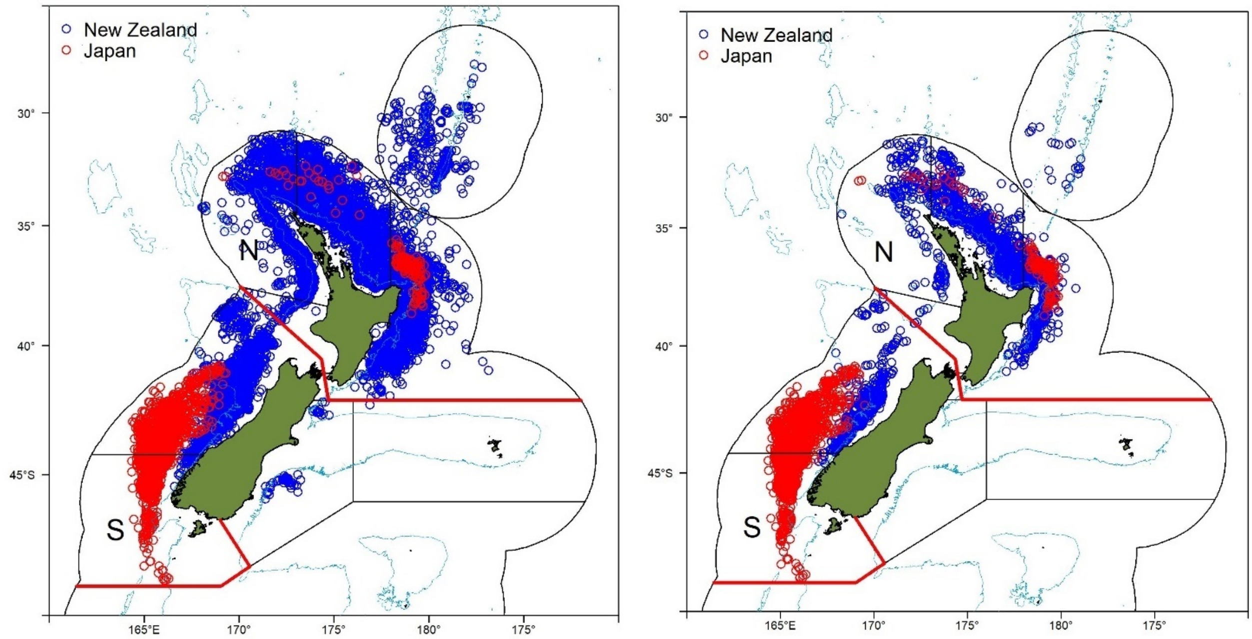


Figure 6: Distribution of commercial (left) and observed (right) surface longline sets 2005–2018 by fleet. North (N) and South (S) regions are demarcated by red lines. NB: Fishing by the Japanese fleet ceased after 2015.

In the most recent four years (2015–2018), spatial coverage of the domestic fleet appears to have improved (Figure 7). However, observer coverage lagged behind fishing effort in North region from March to June and was mostly restricted to the middle of the fishing season (April–June) in South region (Figure 8).

Comparison of annual nominal CPUE calculated from commercial (TLCER) and observer data indicates that, for the Japanese South fleet, there was a very close correlation between the two data sources for all three species (Figure 9). This indicates that reporting of pelagic shark bycatch by chartered Japanese vessels was accurate. However, in North region, there were consistent discrepancies between the two sources, particularly in the early years 2005–2011, with the curves tending to converge in more recent years (Figure 10). This suggests that there was under-reporting of pelagic shark bycatch by commercial vessels during the 2000s and possibly into the 2010s, although the differences might also be at least partly attributable to spatial and/or temporal mis-match between commercial and observed sets.

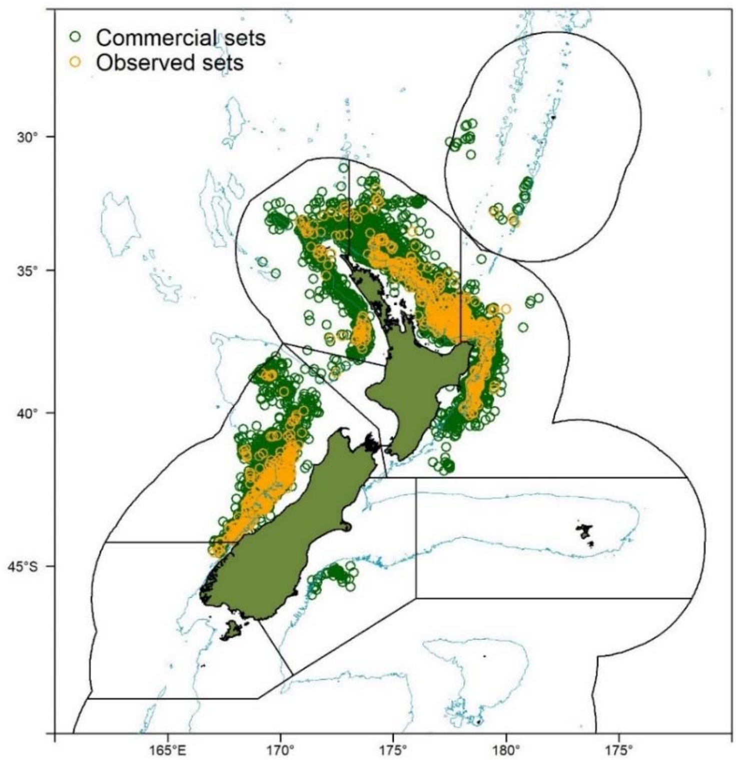


Figure 7: Distribution of New Zealand commercial and observed surface longline sets, 2015–2018.

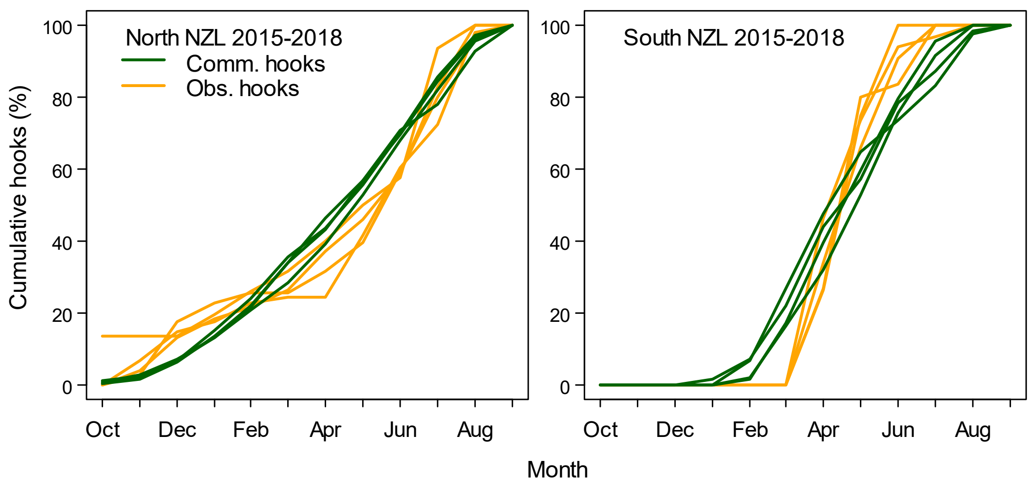


Figure 8: Cumulative monthly distribution of New Zealand commercial and observed surface longline sets, 2015–2018, in (left) North region and (right) South region.

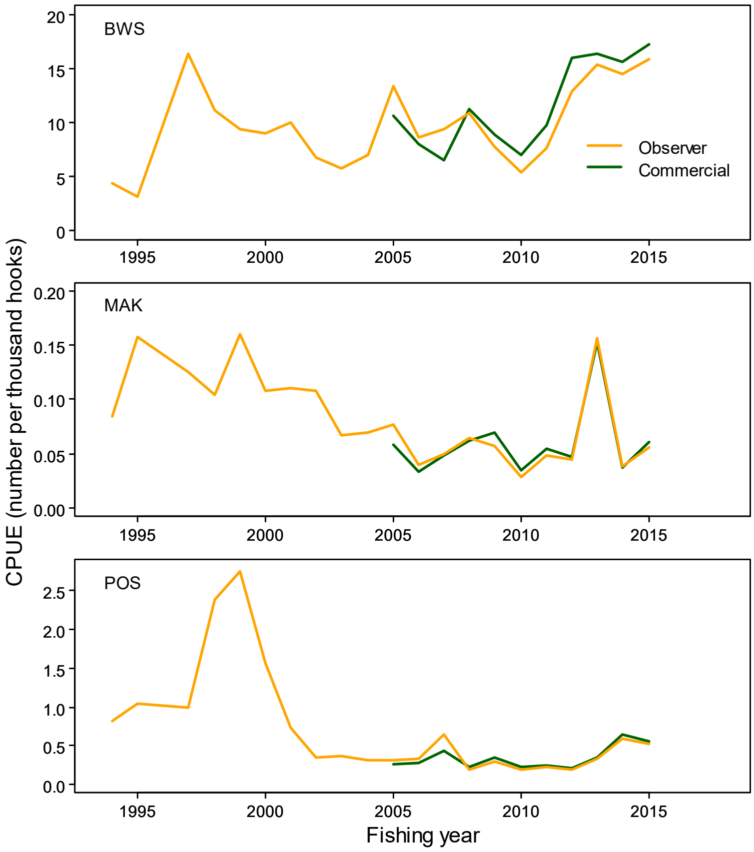


Figure 9: Comparison of annual commercial and observer nominal CPUE by species for the Japanese chartered SLL fleet in South region. BWS, blue shark; MAK, mako shark; POS, porbeagle shark.

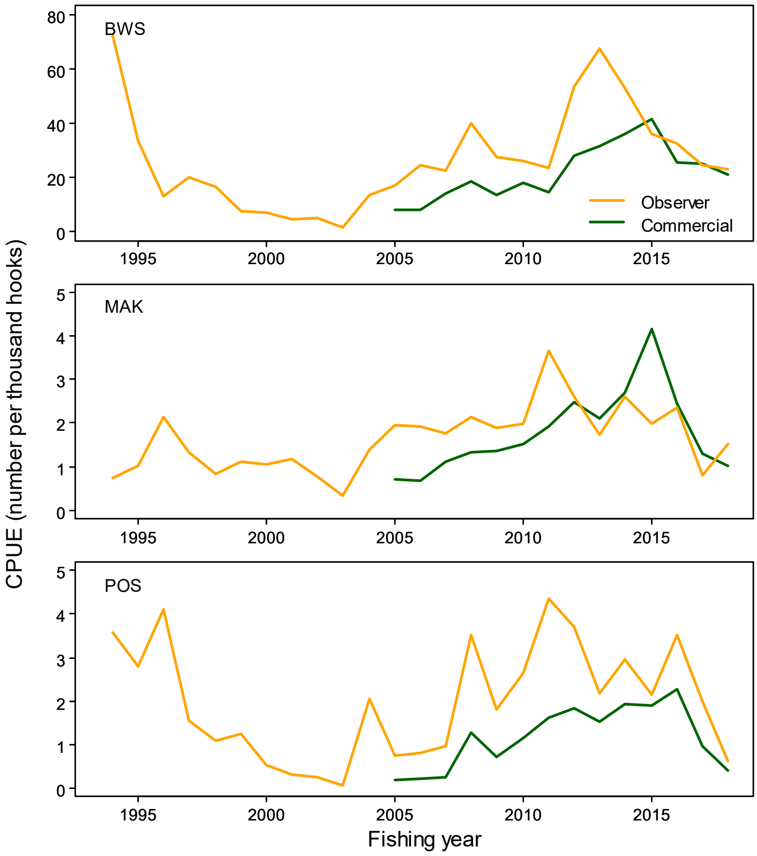


Figure 10: Comparison of annual commercial and observer nominal CPUE for all SLL vessels in North region. BWS, blue shark; MAK, mako shark; POS, porbeagle shark.

4. SURFACE LONGLINE CATCHES

Blue shark

The total estimated weight of blue sharks reported on TLCERs, after removal of implausible outliers, increased steadily from 694 t in 2005 to a peak of 1635 t in 2012, followed by a decline to 887 t in 2017 and an increase to 1118 t in 2018 (Figure 11). The amount of processed and retained catch peaked at 1045 t in 2012 before declining rapidly to negligible levels in 2015. There was a concurrent increase in discarded and released sharks, which comprised nearly all the catch from 2015 onwards. Retained weight values were very close to the Monthly Harvest Return (MHR) values, which were obtained independently from actual landed weights reported to MPI by quota holders, up to 2014, indicating that the TLCER processed weights were accurately reported overall. From 2015 onwards, the MHR values averaged 141 t per year, despite there being negligible blue shark reported on TLCERs as being retained. This does not represent catch taken by other methods, which is negligible for blue sharks (Francis 2019).

The distributions of aggregated catches and CPUE by half-degree cells are shown in Appendices 2 and 3. High catches and catch rates were present throughout North and South regions.

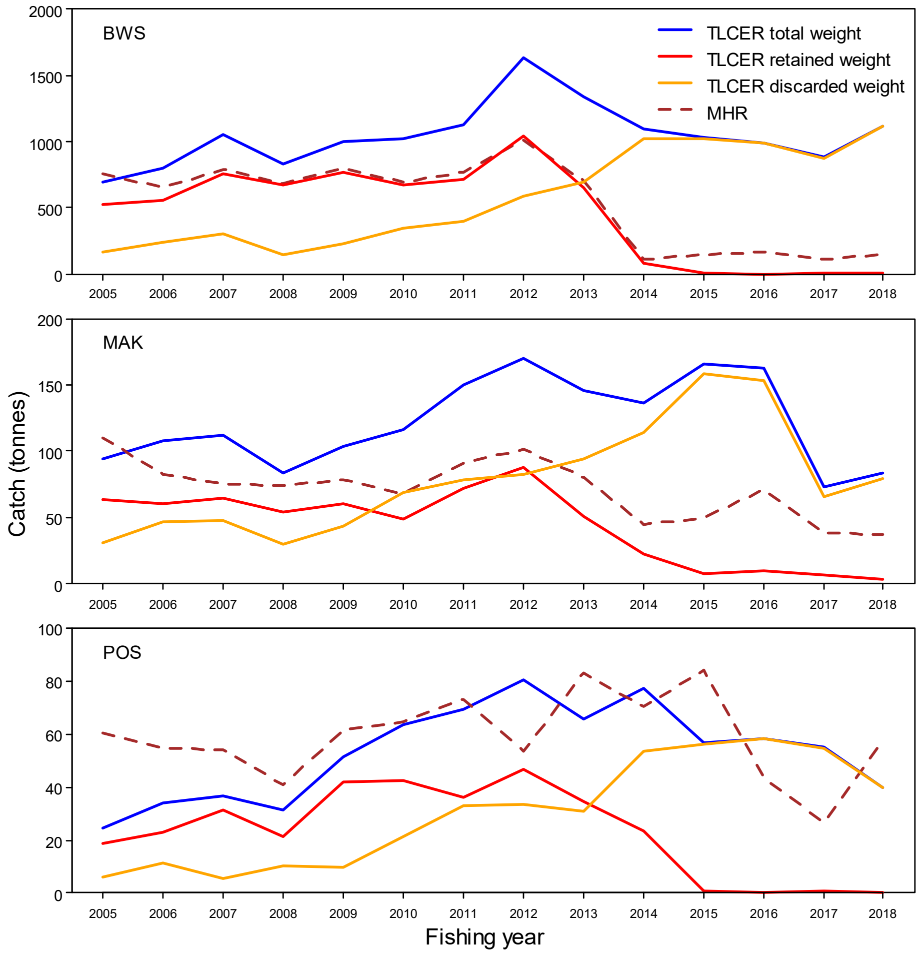


Figure 11: Estimated blue (BWS), mako (MAK), and porbeagle (POS) shark catches (whole weight) in the surface longline fishery for the 2005 to 2018 fishing years as reported on TLCERs. A breakdown of the total weight by retained and discarded/released categories is also provided. Monthly Harvest Return (MHR) landings for all fishing methods are also shown.

Mako shark

The total weight of mako sharks reported on TLCERs increased steadily to peak at 170 t in 2012, then remained relatively stable through to 2016 before declining rapidly by about half in 2017–2018 (Figure 11). The retained catch peaked in 2012 before dropping to negligible levels in 2015–2018. Discarded and released sharks increased concurrently to peak in 2015–2016 before dropping sharply in 2017–2018. Retained weight values were below the MHR values throughout the time series, reflecting the capture of mako sharks in other fisheries (i.e., not SLL) that report their catch on different fishing return forms. However, the discrepancy between MHR and TLCER retained values increased from 2015 onwards.

The distributions of aggregated catches and CPUE by half-degree cells are shown in Appendices 4 and 5. Mako shark catch rates were higher in North region than South region and were greatest between Great Barrier Island and Hawke Bay (off the east coast of North Island).

Porbeagle shark

The total weight of porbeagle sharks reported on TLCERs increased to peak at 80 t in 2012, remained roughly stable until 2014, and then declined to a lower level (average 57 t) in 2014–2017 and declined again in 2018 (to 40 t) (Figure 11). The retained catch peaked in 2012 before dropping to negligible levels in 2015–2018. Discarded and released sharks increased concurrently to peak in 2015–2016 before dropping moderately in 2018. Retained weight values were below the MHR values throughout the time series, reflecting the capture of porbeagle sharks in other fisheries, particularly by midwater trawlers which report their catch on different fishing return forms.

The distributions of aggregated catches and CPUE by half-degree cells are shown in Appendices 6 and 7. Porbeagle catch rates were highest between Great Barrier Island and Hawke Bay and, in some years, off the north-western coast of South Island.

5. DISTRIBUTION INDICATOR ANALYSES

5.1 Introduction

A distribution indicator seeks to monitor trends in the status of a stock by assessing changes in the spatial distribution of the fish (Clarke et al. 2011). An increase in stock abundance may become apparent as an expansion of the range inhabited by the fish, and a decrease may be signalled by a contraction of the range.

5.2 Methods

In this study, we calculated two distribution indicators:

- The *high-CPUE indicator* was the proportion of half-degree cells having unstandardised CPUE greater than a specified threshold in the commercial TLCER data. It was calculated as the number of high-CPUE cells divided by the total number of cells with reported effort. This indicator acts as a measure of the spatial extent of high abundance areas. Observer data were too sparse and limited in their spatial distribution to be useful for this purpose. CPUE was calculated as the total number of sharks caught per cell divided by the total number of hooks set in the cell (in thousands) in each fishing year. Following preliminary tests using a range of potential thresholds, indicator thresholds were arbitrarily set at 25 sharks per 1000 hooks for blue shark and one shark per 1000 hooks for porbeagle and mako sharks.
- A *proportion-zeroes indicator* was calculated as the number of half-degree cells having zero reported catches in a fishing year divided by the total number of cells with reported effort in that year.

For both these indicators, only cells having more than 5000 hooks of fishing effort in a given fishing year were included in the analyses so that extreme catch rates from a small number of sets did not bias the result. A limit of 5000 hooks ensures that each included cell has at least three domestic sets or two foreign charter vessel sets.

Both indicators could be affected by inter-annual variation in the amount and distribution of fishing effort, and targeting. Ideally, the analyses should be restricted to a standard area that was fished every year. However, in our previous analysis (Francis et al. 2014) we assessed the potential impact of inter-annual variation by calculating the high-CPUE indicator for both the full dataset (i.e., all cells fished in a given year) and a reduced dataset of 77 cells that were fished every year. The indicators varied minimally for mako and blue sharks in both North and South regions, and porbeagle shark in North region. For porbeagles in South region, indicator values differed between datasets for individual years but the overall trends were similar. We therefore believe that the indicators are relatively unaffected by the level of inter-annual spatial variation occurring in this dataset.

5.3 Results

Blue shark

In North region, the high-CPUE indicator increased steadily to peak in 2015, followed by an abrupt decline to half that level in 2016–2018 (Figure 12). The Japan South indicator showed a more gentle increase to peak in 2015, the last year for which data were available from that fleet. A new New Zealand South high-CPUE indicator was also calculated from 2012 (effort before that was considered too low to be useful; see Figure 2) to provide a recent index for that region. However, the index was highly variable with a maximum recorded in 2018.

The proportion-zeroes indicator was zero or near zero for all years in both regions (Figure 13), because blue sharks were common enough to be caught in nearly every half-degree cell where the number of hooks deployed exceeded 5000 per year.

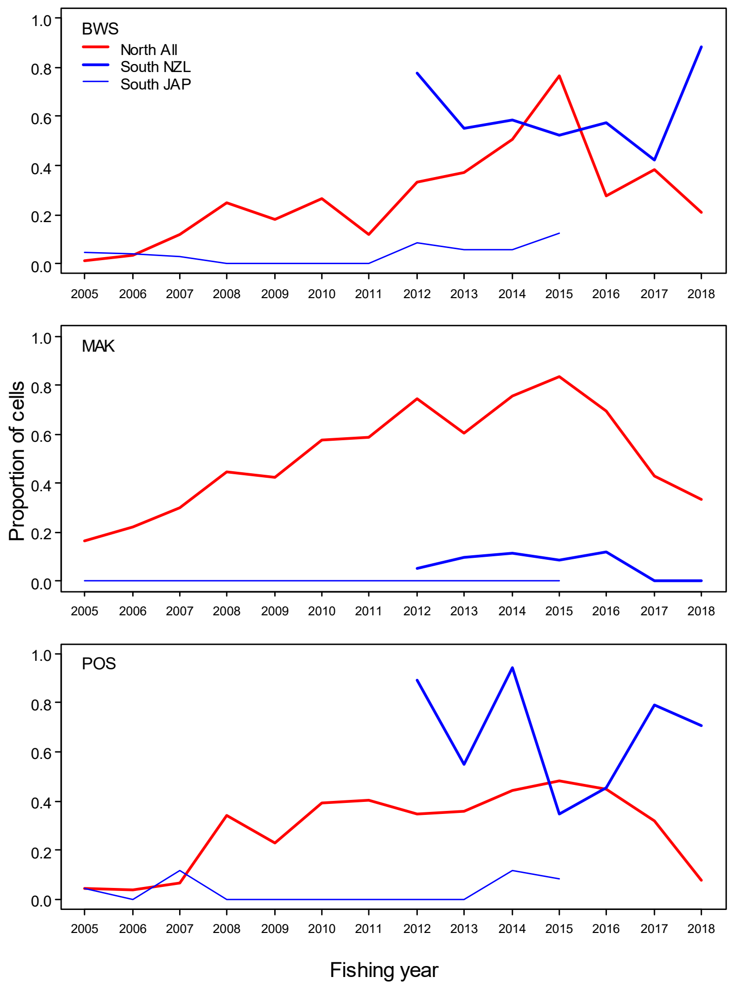


Figure 12: Blue (BWS), mako (MAK), and porbeagle (POS) shark high-CPUE distribution indicators (proportions of 0.5 degree cells having CPUE greater than a given threshold) for North and South regions by fishing year (with South region divided into New Zealand domestic and Japanese chartered fleets).

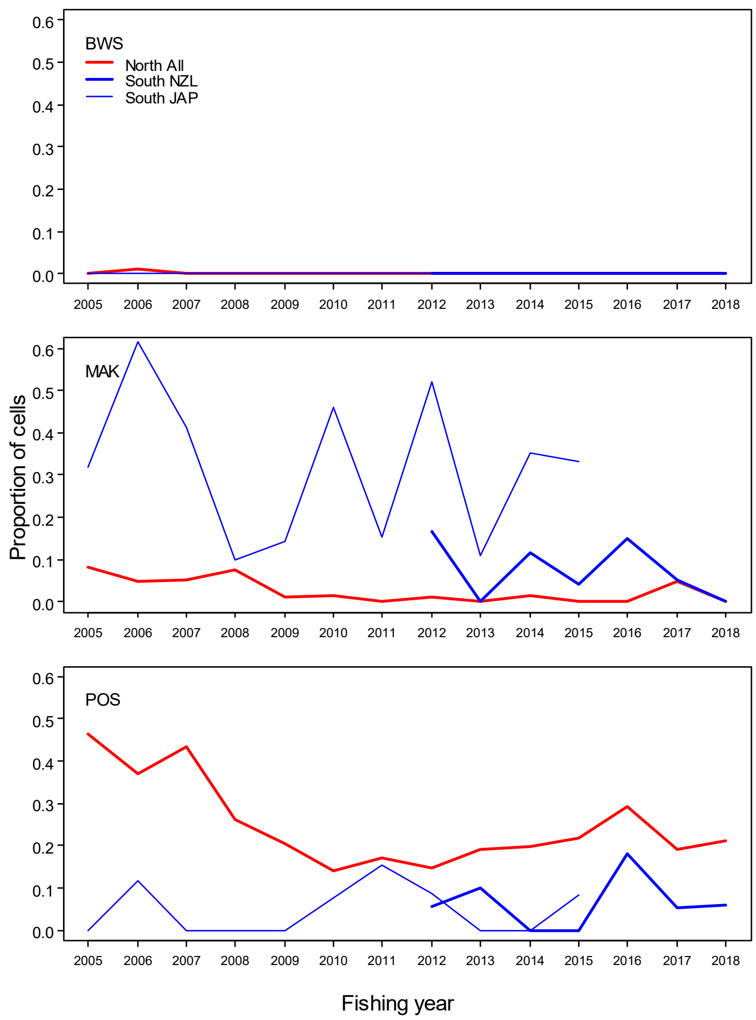


Figure 13: Blue (BWS), mako (MAK), and porbeagle (POS) shark proportion-zeroes distribution indicators (proportions of 0.5 degree cells having zero catches) for North and South regions by fishing year (with South region divided into New Zealand domestic and Japanese chartered fleets).

Mako shark

In North region, the high-CPUE indicator increased steadily to peak in 2015, followed by an abrupt decline to half that level in 2017–2018 (see Figure 12). There were few zeroes in North region, but the proportion-zeroes indicator still declined from 5–8% of cells before 2009 to a mean of 1% thereafter (with a temporary peak at 5% in 2017) (see Figure 13). The preference of mako shark for warmer waters, and the resultant low catch rates in South region, mean that the high-CPUE and proportion-zeroes indicators are relatively uninformative and inappropriate for South region.

Porbeagle shark

The North region high-CPUE indicator increased abruptly to 2008, and then continued increasing slowly to peak in 2015. Thereafter, there was a strong decline to 2018, reaching the lowest level since 2007 (see Figure 12). However, the Japan South region indicator was low and varied little, whereas the New Zealand South indicator was high and highly variable. These indicators may have been affected by the sparse and uneven distribution of fishing effort among years, combined with the often higher CPUE of porbeagles in northern South Island waters closer to the coast than seen in southern offshore waters (see Appendix 7). The North region proportion-zeroes indicator declined steadily to a minimum in 2010 and has increased slowly since then, with some variability (see Figure 13). The South region proportion-zeroes indicators were variable with no overall trend.

5.4 Discussion

The North region high-CPUE indicators peaked in 2015 and then declined steeply to 2018 for all three species of pelagic sharks. The South region high-CPUE indicators were higher for the New Zealand domestic fleet than for the chartered Japanese fleet for all three species, which meant that it was not valid to combine the data for the two fleets into one time series per species. Consequently, the chartered Japanese indicator terminated in 2015 and can provide no information on trends since then. The New Zealand domestic high-CPUE indicators began in 2012, but effort has been low and the indicators were highly variable, casting doubt on their representativeness. Furthermore, mako shark abundance is low in South region, so it is not valid to infer trends for that species in South region. Nevertheless, the proportion-zeroes indicator showed a declining trend over the first half of the time series for South region mako sharks, before becoming stable. The proportion-zeroes indicator for North region mako shark declined through most of the time series (apart from an increase in 2017), and that for porbeagles declined to 2010 and then increased slowly. South region proportion-zeroes indicators were highly variable and are considered unreliable.

6. SPECIES COMPOSITION INDICATOR ANALYSES

6.1 Introduction

Three indicators assessed in this study (distribution, CPUE, and size and sex ratio) measure changes occurring in particular shark species. In contrast, a species composition indicator operates at a multi-species, rather than a single-species, level. By assessing whether certain shark species are becoming more or less dominant in the catch, and assuming that catches reflect abundance (as in the CPUE analysis), the species composition indicator can reflect whether the community as a whole is changing over time. Minimising the risk that fishing activities are driving irreversible changes in natural assemblages is one of the key tenets of ecosystem based fisheries management (Pikitch et al. 2004).

This section assesses species composition in two ways:
1. the proportion of the catch composed of blue, mako, and porbeagle sharks relative to other chondrichthyan fishes and other non-chondrichthyan catch (i.e., five groups assessed); and
2. the relative proportions of blue, mako, and porbeagle sharks in the total catch of these three species (i.e., three groups assessed).

This analysis thus addresses how the proportion of chondrichthyan fishes changes relative to non-chondrichthyan fishes, as well as how the proportions of the three species of interest change relative to each other. For these analyses it would be ideal if changes in catch composition represent changes in the natural assemblage rather than changes in the efficiency of fishing operations, e.g., catchability or targeting, but the latter possibility must be considered.

6.2 Methods

Observer data from SLL vessels were used to assess species composition because it is important to include discarded bycatch species which may not always be reported on TLCERs. Species composition analyses were conducted on fish numbers rather than weight. Most ecological community analyses are based on numbers rather than biomass (Cerfolli et al. 2013). More importantly, use of numbers helps to avoid biases arising from sampling sharks with sex- and life-stage-specific aggregation behaviours (Nakano 1994; Mucientes et al. 2009; Francis 2013); for example, female sharks are often larger than males, and pregnant females in pupping grounds would be larger still.

Shark and non-shark catches by species were tallied by year and divided by the number of hooks fished/observed (in thousand hooks) in that year. Although a simple tally (i.e., without adjusting for effort) would suffice for an analysis based on proportions alone, conversion of the data to a normalised measure of abundance allows for the application of indices which measure both the evenness of the distribution of the species (the similarity of the abundances among species) and their abundance over time (Buckland et al. 2005). For example, if simple proportions are used, catches of 60 blue sharks, 16 mako sharks, and 10 porbeagle sharks in Year A and 30 blue sharks, 8 mako sharks, and 5 porbeagle sharks in Year B would produce the same index value. In contrast, using both proportions among species, and abundance, would give a reduced index value in Year B reflecting the decrease in abundance. Both approaches are vulnerable to under- or mis-reporting biases, but are robust if the biases remain constant over time.

A geometric mean index was found to have the most favourable properties of ten composition indicators evaluated by Van Strien et al. (2012), and it was used in our previous analysis of New Zealand pelagic sharks (Francis et al. 2014). That index is used again in this study. It was calculated as (Buckland et al. 2005; Van Strien et al. 2012)):

$$G_j = \exp\left(\frac{1}{m}\sum_i log\frac{d_{ij}}{d_{i1}}\right)$$

where m is the number of taxonomic groups in the analysis, and d represents the standardised counts for taxonomic group i in year j. The reference year was set at 1997 for the North region and Japan South region indices, consistent with the previous analyses (Francis et al. 2014). For the new New Zealand South region analysis, the reference year was set at 2012 because there were no observer records for 1997 for that dataset.

6.3 Results

The nominal CPUE and geometric mean species composition indicators for blue, mako, and porbeagle sharks in relation to each other (three-group analysis) and in relation to each other, other sharks, and other fish (five-group analysis) are shown in Figures 14 and 15, respectively. The three-group and five-group indicators were very similar, with only one major discrepancy: the New Zealand South three-group indicator for 2013 had a strong peak (corresponding with the high shark CPUE that year) compared with a trough for the five-group indicator in the same year. The indicators usually showed the same patterns as nominal CPUE with two main exceptions: (a) Japan South in the late 1990s had peaks in both the three-group and five-group indices that were not reflected in the CPUE, being driven instead by unusually high catch rates of porbeagle shark; and (b) as mentioned above, the five-group indicator had a trough at a time when overall shark CPUE was the highest in the time series.

In North region, the species composition indicators were high through most of the 1990s, declined to low values through the late 1990s and early 2000s, increased to high levels again through the early-mid 2010s, and then dropped sharply in 2017 and 2018 (Figures 14 and 15). South region indicators showed little temporal pattern form the early 2000s onwards, apart from a possibly spurious peak in 2013 in the New Zealand South three-group indicator.

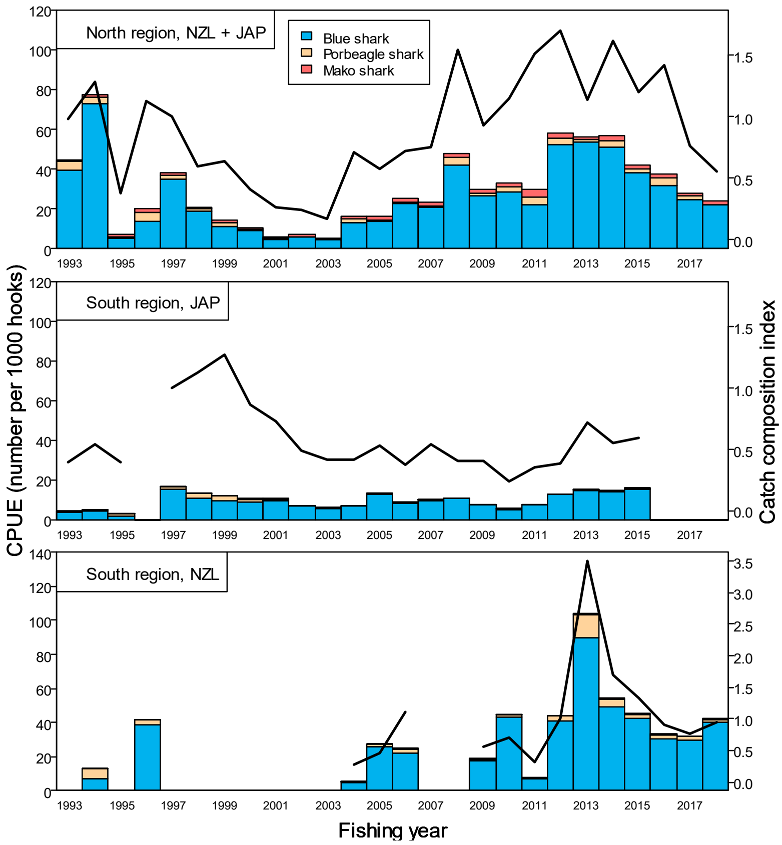


Figure 14: Abundance (nominal CPUE) of blue, mako, and porbeagle sharks in the observer dataset for North region (New Zealand and Japanese vessels combined) and South region (separately for chartered Japanese and New Zealand domestic vessels) (bars). The three-group geometric mean catch composition indicators are shown as solid lines.

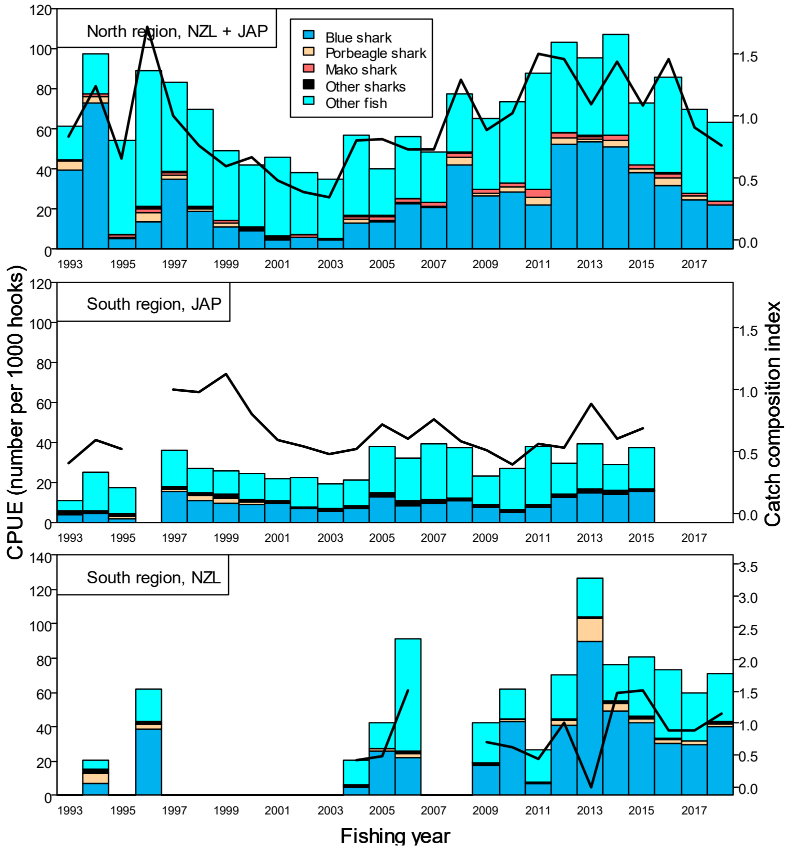


Figure 15: Abundance (nominal CPUE) of blue, mako, porbeagle, and 'other' sharks, and other fish, in the observer dataset for North region (New Zealand and Japanese vessels combined) and South region (separately for chartered Japanese and New Zealand domestic vessels) (bars). The five-group geometric mean catch composition indicators are shown as solid lines.

6.4 Discussion

Although the species composition indicators presented here were based on observer data, the North region species composition indices showed a strong similarity to the North region high-CPUE distribution indices based on commercial (TLCER) data (see Figure 12). This suggests that the species composition indices are driven mainly by overall species abundance, and that the relative abundance of shark species has little effect. Both series were low in 2005, increased during the late 2000s to high values in the early–mid 2010s, and then dropped to low values in 2017–2018. The South region time series were less robust, with gaps in the time series and small samples sizes for the New Zealand South indicator, and termination of the Japan South indicator in 2015. However, the species composition indicators were consistent with the high-CPUE distribution indicators for South region in showing no clear temporal trends.

7. CATCH PER UNIT EFFORT INDICATOR ANALYSES

7.1 Introduction

One of the most common approaches to assessing trends in stock status is to calculate CPUE as an index of abundance. Nominal CPUE indices are simple to compute for the tuna longline fisheries where the number of hooks fished represents a consistent unit of effort. Annual values can be computed as the number of sharks of each species caught per thousand hooks, and, if average catchability is constant, the resulting time trend is expected to indicate the trajectory of stock abundance.

Most blue, mako, and porbeagle sharks caught in New Zealand waters are taken as bycatch by the tuna SLL fishery, which accounted for 99% of the New Zealand blue shark catch, 94% of the mako shark catch, and 78% of the porbeagle shark catch between 2005 and 2018 (Francis 2019). Most of the operations in South region targeted southern bluefin tuna, whereas North region sets mainly targeted bigeye tuna, southern bluefin tuna, and broadbill swordfish.

This work updates CPUE time series for these fisheries from two previous studies, one of which assessed all three species up to 2013 (Francis et al. 2014) and the second of which updated porbeagle shark to 2015 (Francis & Large 2017).

7.2 Methods

CPUE standardisation models were fitted to: (a) two commercial logbook datasets: the Japan South fishery (FMAs 5 and 7; 2005–2015), and the North fishery (all fleets combined; FMAs 1, 2, 8, and 9; 2005–2018); and (b) two observer datasets: the Japan South observer data (1994–2015), and the North fishery observer data (all fleets combined; 1994–2018). This stratification of observer data by region and fleet differs from the approach used earlier in which all observer data were analysed with one model (Francis et al. 2014) but is the same as the stratification used more recently for porbeagle shark (Francis & Large 2017). The observer datasets are based on subsets of the fishing trips represented in the commercial TLCER datasets, but the observer and TLCER data were collected independently by observers and crew respectively. The observer datasets extend back to 1994 compared with back to 2005 for the commercial datasets.

Both the negative binomial model and the zero-inflated negative binomial model (modelling presence/absence and where catch is positive as separate processes) were fitted to each dataset as described in the previous study, with the same sets of predictors offered in earlier studies (Francis et al. 2014; Francis & Large 2017). A polynomial spline was applied to sea surface temperature (SST) with three degrees of freedom based on an examination of the distribution of SST data. The number of hooks fished was specified as an offset. Predictors were selected with stepwise regression using the Akaike Information Criterion (AIC), with a year effect forced into the model, and predictors were only included in the final model if they were significant and explained at least 1% of the deviance. The Vuong likelihood ratio test was employed to determine the best model fit (Vuong 1989).

Model equations:

1. Negative binomial model

Catch of shark ~ year + month + area + target strategy + vessel + bait type + SST + catch of southern bluefin tuna + catch of swordfish + number of hooks

2. Zero-inflated negative binomial model

Positive Counts: Catch of shark ~ year + month + area + target strategy + vessel + bait type + SST + catch of southern bluefin tuna + catch of swordfish + number of hooks

Presence / absence: Catch of shark ~| year + month + area + target strategy + vessel + bait type + SST + catch of southern bluefin tuna + catch of swordfish

7.3 Results

7.3.1 Final datasets and CPUE

The Japan South dataset was the smaller of the TLCER datasets with 1953 records. The dataset was further reduced to 1632 by including only those records from May and June (244 sets removed) and sets in fisheries Statistical Areas 031, 032, 501, 705, and 706 (77 sets removed). These five areas were consistently fished throughout the period 2005–2015, whereas the other areas had only intermittent fishing. The observer data for this region included 3577 records between the period 1994–2015, after removal of records where data on predictors (e.g., SST, target strategy) were missing. No observer records were available in 1996 when Japanese vessels did not participate in the SLL fishery.

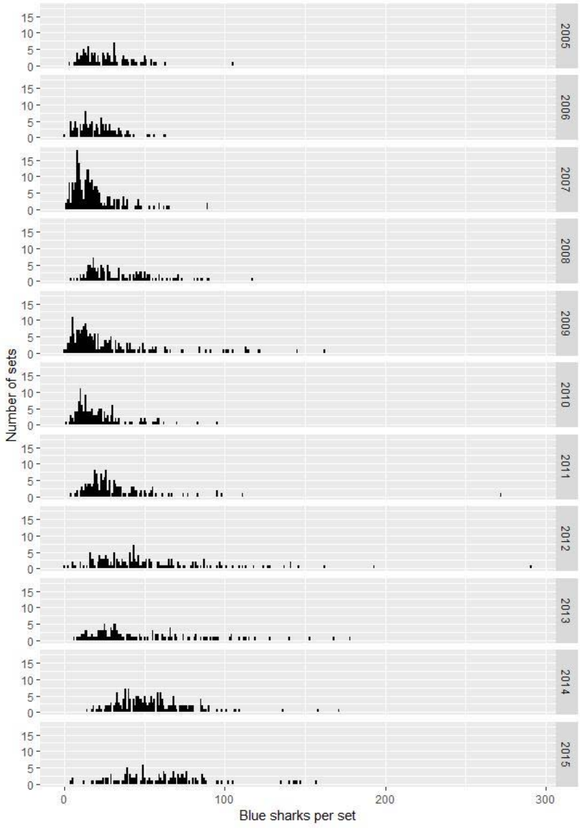
The TLCER North dataset included 28 153 records from 1994 to 2018. After removal of records from statistical areas with low sample sizes (areas 015, 019, 041, 101–103, 206, and 801; 893 sets) and sets missing area data, 27 260 sets remained. The observer data for North region included 2728 records.

Blue shark — Japan South

The Japan South TLCER dataset had the lowest number of zero blue shark catches (n=3) and a mode of 13 blue sharks caught per set (n=47) (Figure 16). In the Japan South observer dataset, there were 37 zero blue shark catches (Figure 17). The mode for the positive catches in this observer dataset was 6 blue sharks (n=124). Both datasets exhibited an increasing trend in the number of blue sharks per set reported over time.

Year, vessel, catch of southern bluefin tuna, and area were identified as the most important predictors in explaining Japan South TLCER blue shark catches (Table 1, Appendix 14). For the observer data, year, vessel, and catch of southern bluefin tuna were selected. The number of sets with zero catches of blue shark remained at nearly zero across the entire time series for both datasets (Figure 18), and, thus, the data were only fitted with the negative binomial model. The diagnostics for the TLCER and observer models indicated very little skew in the residuals and very few outliers (Appendix 8), and the models explained 37% and 29% of the residual deviance, respectively. The introduction and exit of certain fishing vessels influenced the catch of blue shark, and fishing in Statistical Area 501 positively influenced blue shark catch (Appendices 20–21).

The TLCER standardised index of abundance indicated an increase in blue shark catch rates over time until the end of the time series in 2015. This pattern was similar to, but more pronounced, than the nominal index of abundance (Figure 19, left panels). The observer data showed a general upward trend in standardised CPUE throughout the time series (Figure 19, right panels). Two declines (and sequential rebounds) were observed between 2001–2005 and 2008–2012. From 2006 onwards, the trend in the observer standardised index of abundance corresponded with the increasing trend in the TLCER data. The observer standardised index of abundance has increased steadily since 2003, from 2.8 blue sharks/1000 hooks to 18.1 in 2015.



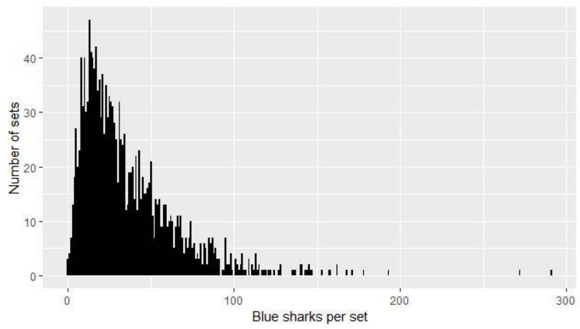


Figure 16: Histograms of blue sharks per set in the Japan South TLCER dataset by year and for the overall time period (*n*=1632 of which three sets recorded zero blue sharks).

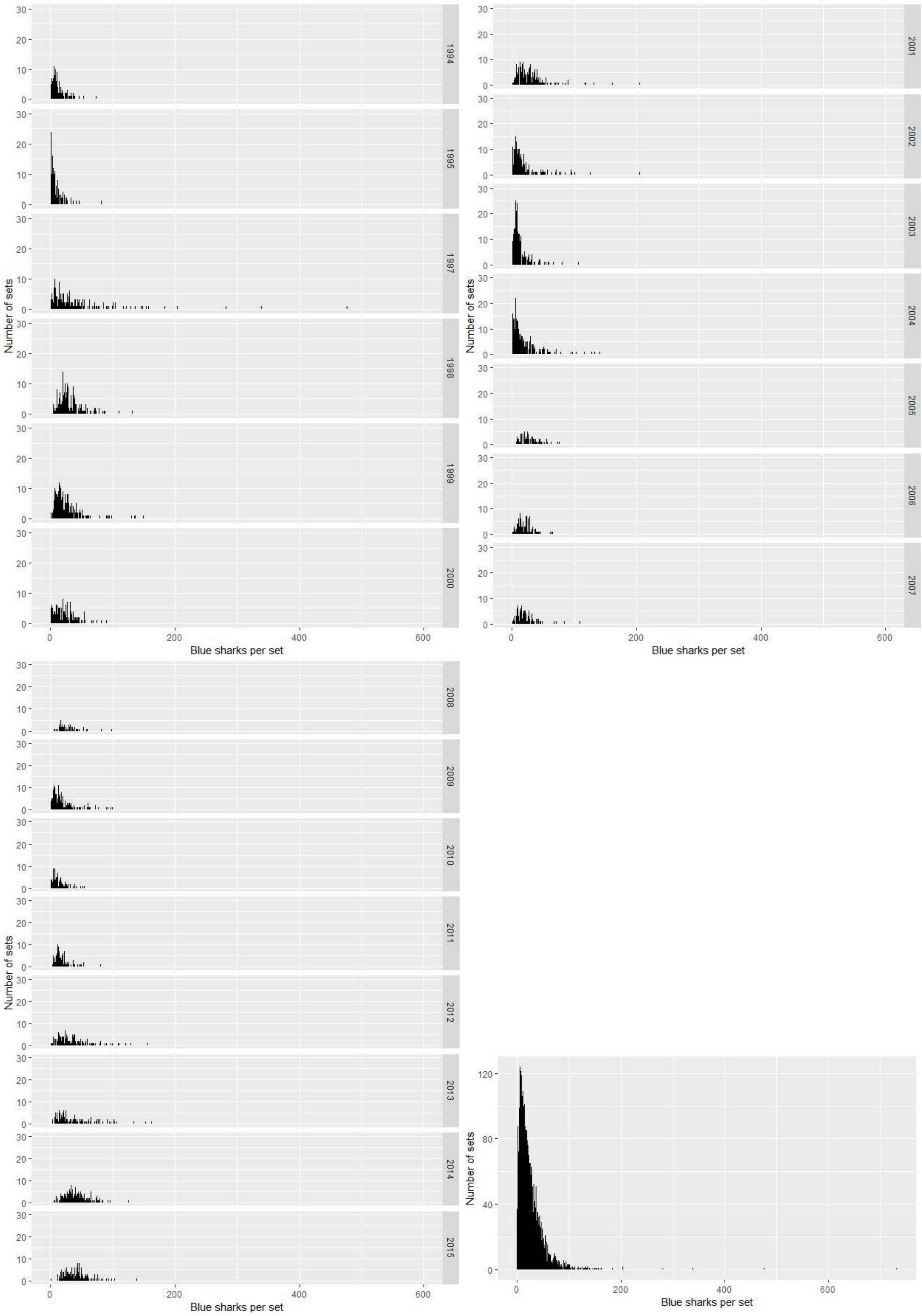


Figure 17: Histograms of blue sharks per set in the Japan South observer dataset by year and for the overall time period (*n*=3577 of which 37 sets recorded zero blue sharks).

Table 1: Results for the CPUE standardisation of blue shark in the Japan South dataset.

Data set	Model selection	Model	% Deviance explained
TLCER	Negative binomial	Catch of blue shark ~ year + vessel + catch of southern bluefin tuna (STN) + area + offset(log(hooks))	Year: 26.5 Vessel: 6.6 Catch of STN: 1.8 Area: 1.9
Observer	Negative binomial	Catch of blue shark ~ year + vessel + catch of southern bluefin tuna + offset(log(hooks))	Year: 21.2 Vessel: 4.6 Catch of STN: 2.8

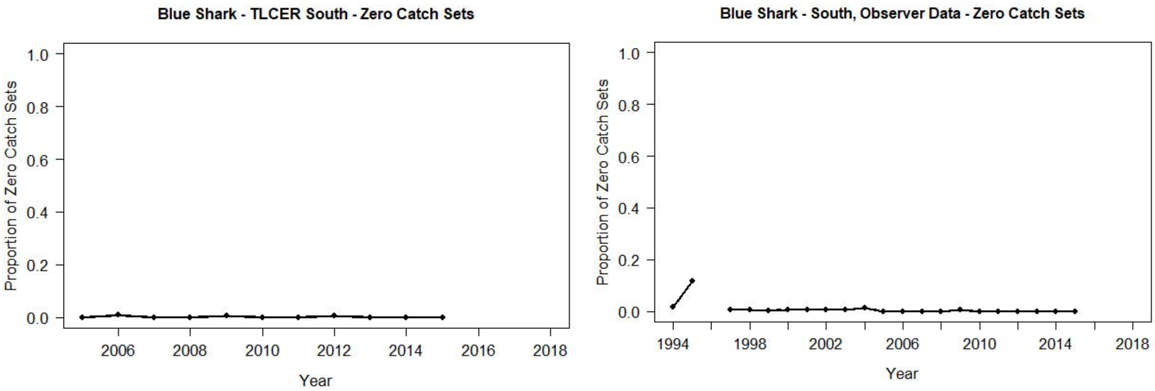


Figure 18: Proportion of sets with zero blue sharks recorded by year in the Japan South fishery based on commercial TLCER data (left) and observer data (right). In the observer dataset, no records were available for 1996.

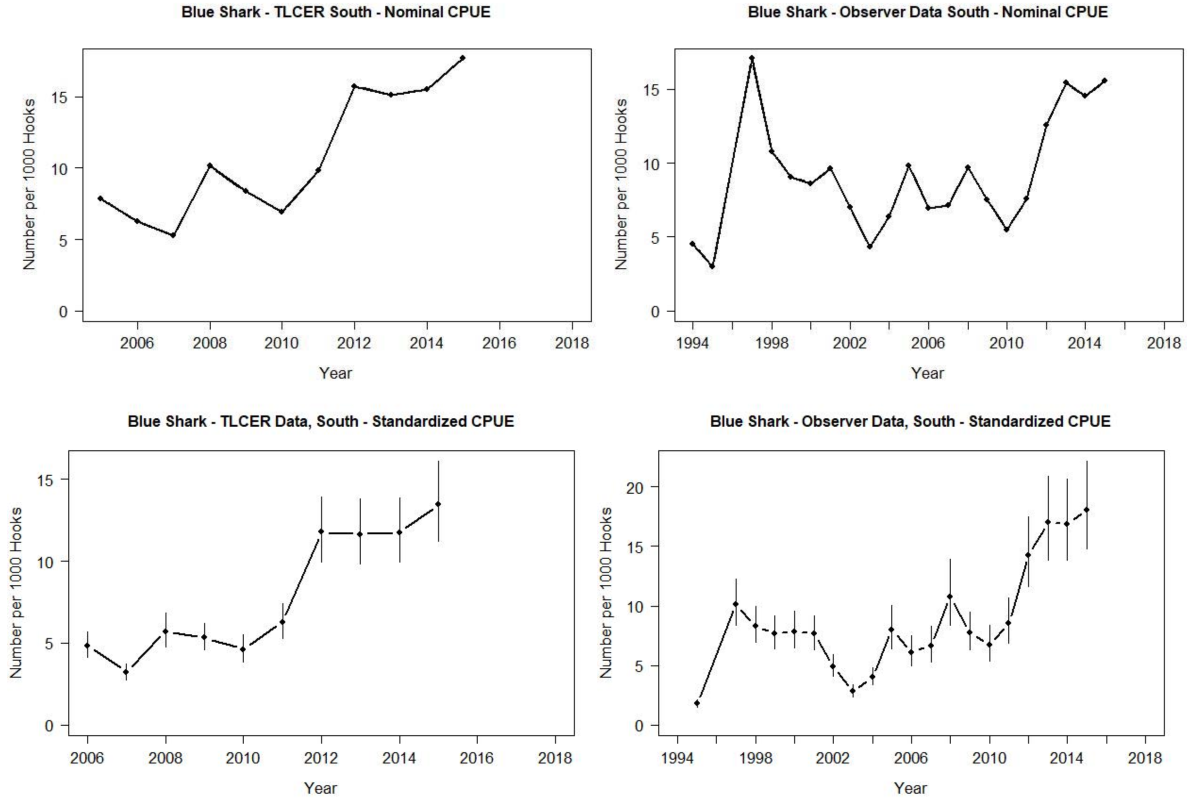


Figure 19: Nominal blue shark CPUE computed as number caught per 1000 hooks fished per year (top panels) and standardised catch per unit effort with 95% confidence intervals (bottom panels) for the Japan South fishery using commercial TLCER data (left) and observer data (right).

Blue shark — North

The number of zero blue shark catches in the North TLCER dataset was 5596, with a mode of 2 blue sharks caught per set (*n*=1616) (Figure 20). In the North observer dataset, there were 135 zero blue shark catches (Figure 21). The mode for the positive catches in this dataset was 1 blue shark (*n*=185). Both datasets appeared to exhibit an increasing trend in the number of blue sharks per set reported over time.

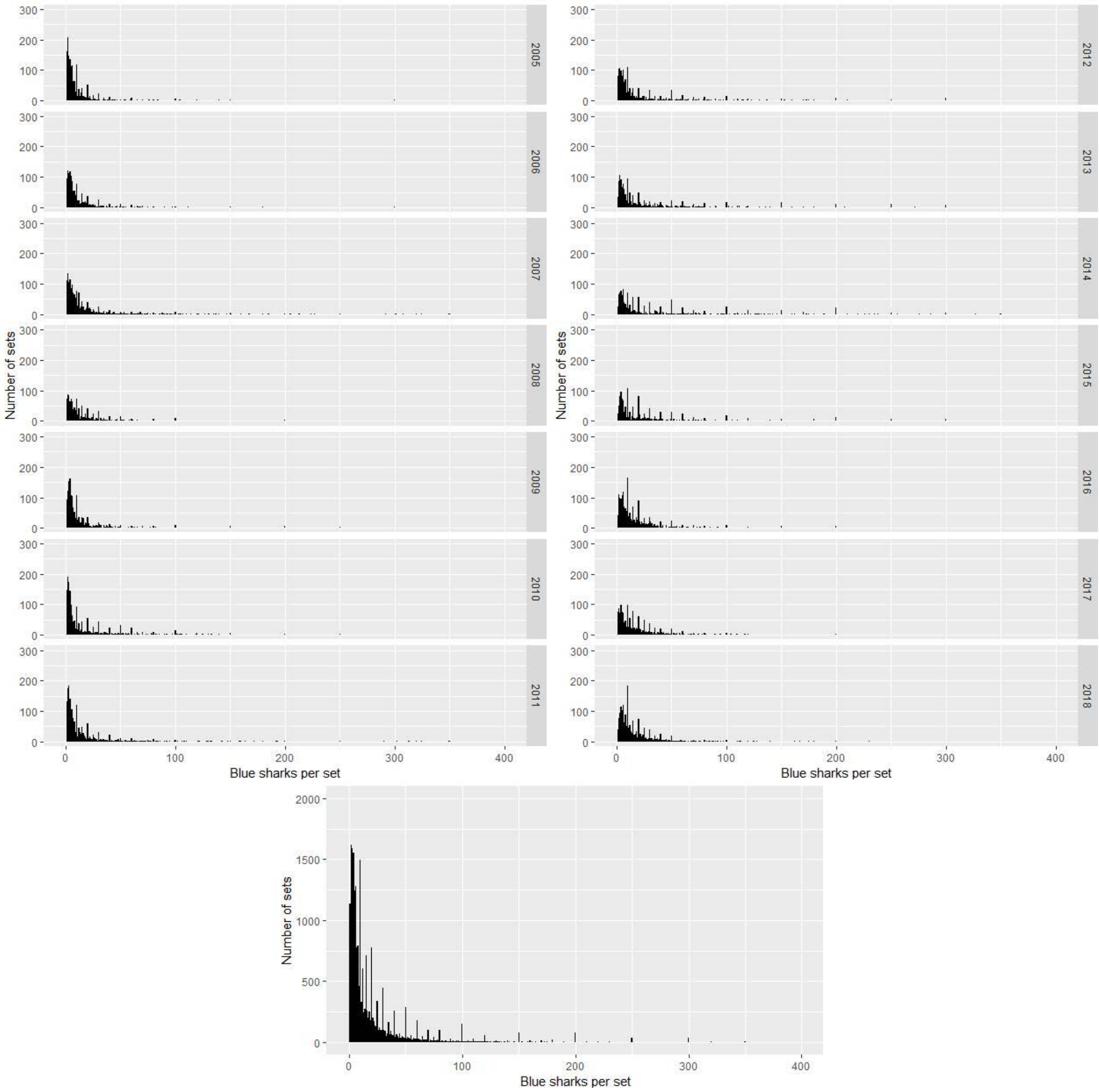


Figure 20: Histograms of blue sharks per set in the North TLCER dataset by year and for the overall time period (*n*=27 260 of which 5596 sets recorded zero blue sharks). Twenty-three sets where more than 400 blue sharks were reported were omitted from the histograms.

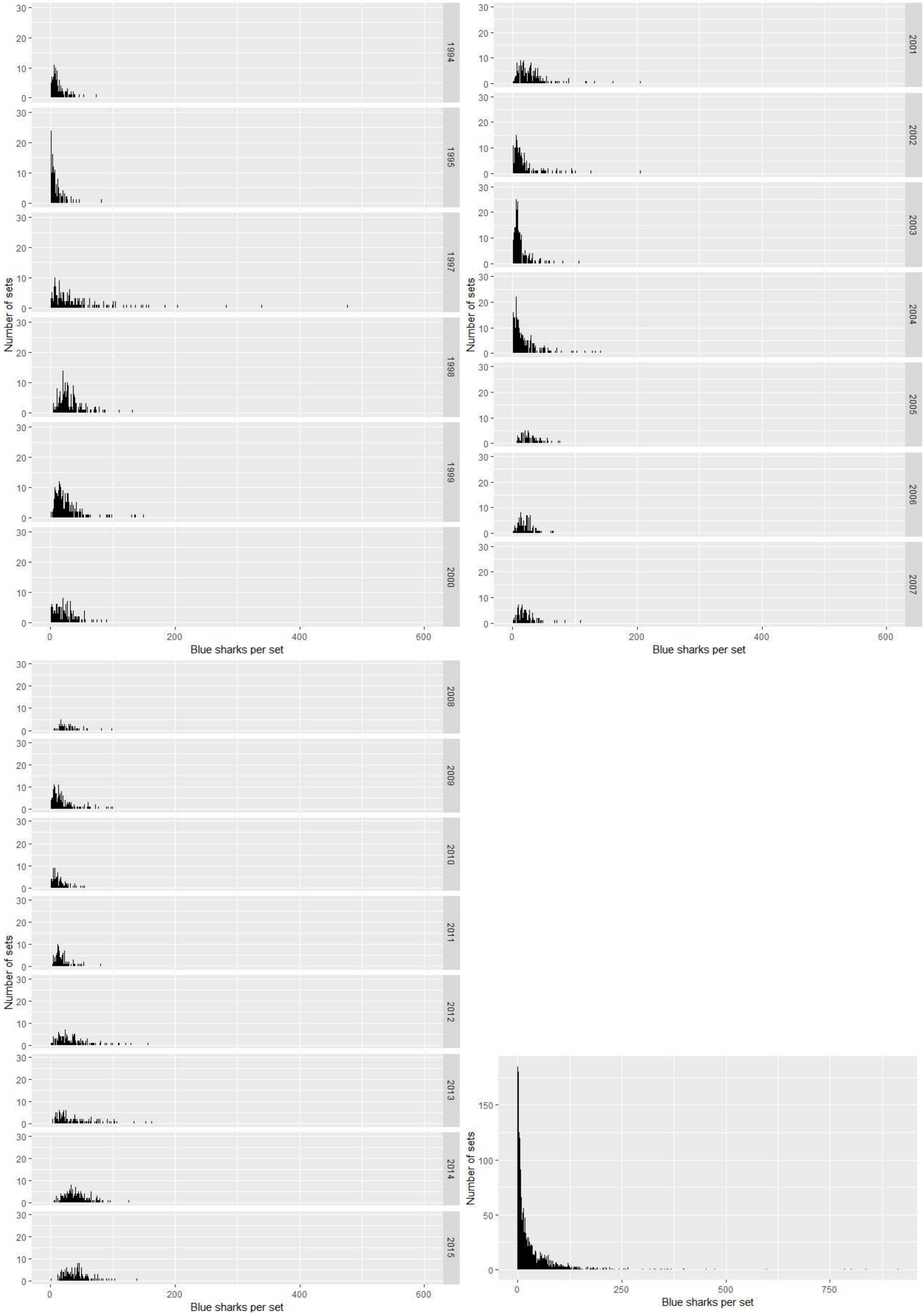


Figure 21: Histograms of blue sharks per set in the North observer dataset by year and for the overall time period (*n*=2728 of which 135 sets recorded zero blue sharks).

The annual proportion of zero catches of blue shark in the North TLCER data ranged from 2–43%, peaking in 2006 and declining over time thereafter (Figure 22, left panel). The zero-inflated negative binomial (ZINB) was selected over the negative binomial model (Vuong likelihood ratio test, $p < 0.05$); however, the ZINB model could not compute the coefficients for area, likely due to the large number of levels (n=25) and, rather than sacrifice the predictive power of the area factor, the negative binomial model was chosen. Year, SST, vessel, area, and month were identified as the most important predictors, and together they explained 45% of the residual deviance (Table 2, Appendix 15). Model diagnostics showed a lack of fit to the data with a poor correlation between observed and predicted values (Appendix 9).

In the North observer data, the number of zero blue shark catches has been consistently low since 2003 (maximum of 20% in 1995, Figure 22, right panel), and, thus, only the negative binomial model was used. The model predictors included year, SST, vessel, month, and target strategy and explained 69% of the residual deviance (Table 2, Appendix 15). Model diagnostics indicated very little skew in the residuals and very few outliers (Appendix 9). Vessel had the largest influence on blue shark catch, and the introduction of additional vessels in the time series in recent years positively affected catch (Appendices 22–23).

Both the nominal and standardised indices of abundance for the TLCER data showed a gradual increase in catches until 2015, followed by a decline (Figure 23, left panels). In the observer data, apart from the high and unlikely estimate (with large standard error bars) in 1995, standardised catch trends were relatively stable until 2012, after which CPUE increased in 2013 and declined thereafter (Figure 23, right panels). Nominal observer catch rates were higher than those reported in the TLCERs, indicating that there may be some underreporting by commercial fishers.

Table 2: Results for the CPUE standardisation of blue shark in the North region datasets.

Data set	Model selection	Model	% Deviance explained
TLCER	Negative binomial	Catch of blue shark ~ year + SST + vessel + area + month + offset(log(hooks))	Year: 5.4 Target: 24.4 Vessel: 10.5 Area: 3.4 Month: 1.9
Observer	Negative binomial	Catch of blue shark ~ year + SST + vessel + month + target strategy + offset(log(hooks))	Year: 21.3 SST: 32.5 Vessel: 11.3 Month: 2.8 Target Strategy: 1.2

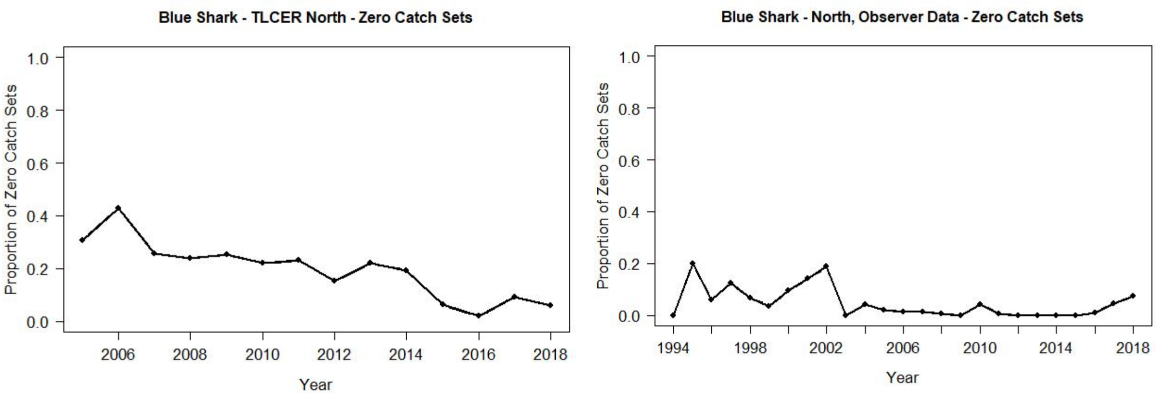


Figure 22: Proportion of sets with zero blue sharks recorded by year in the North fishery based on commercial TLCER data (left) and observer data (right).

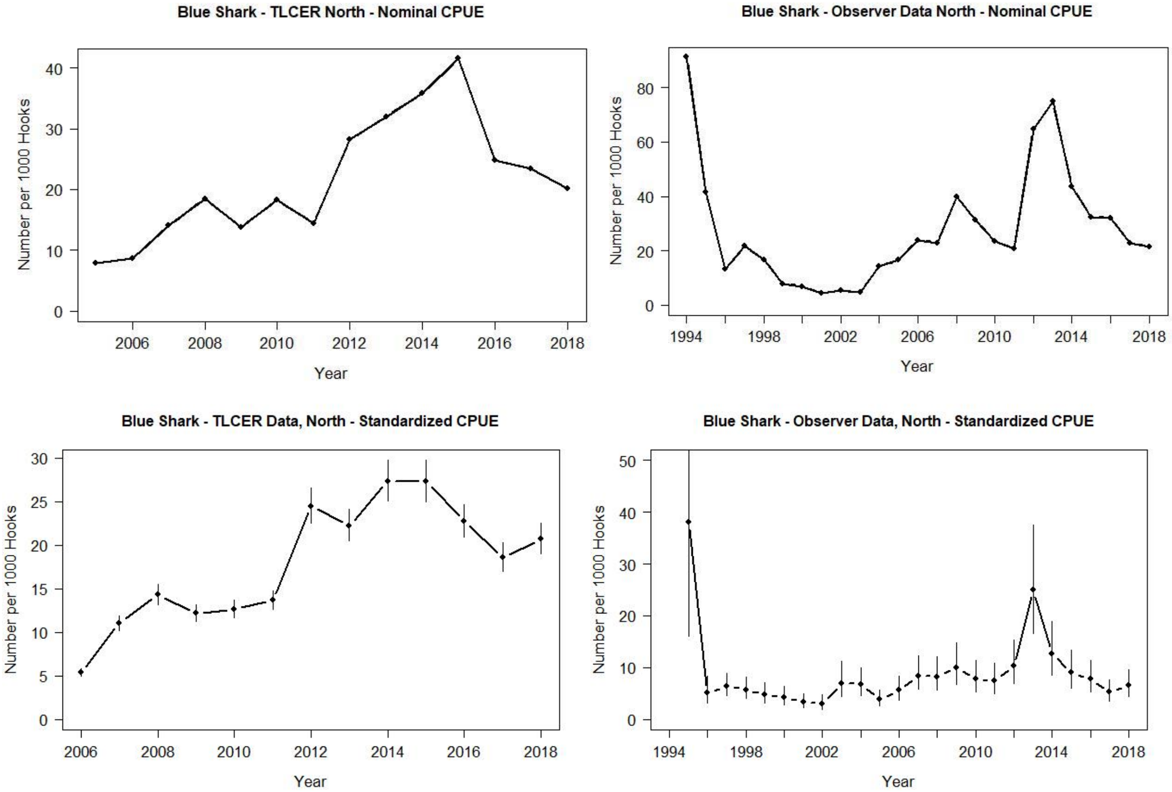


Figure 23. Nominal blue shark CPUE computed as number caught per 1000 hooks fished per year (top panels) and standardised catch per unit effort with 95% confidence intervals (bottom panels) for the North fishery based on commercial TLCER data (left) and observer data (right).

Mako shark — Japan South

The Japan South TLCER dataset had a large number of zero mako shark catches (*n*=1365), with a mode of 1 mako shark caught per set (*n*=231) in positive catches (Figure 24). In the Japan South observer dataset, there were 2863 zero mako shark catches (Figure 25). The mode for positive catches in this dataset was 1 mako shark (*n*=582). The observer data showed a declining trend in the number of reported makos per set.

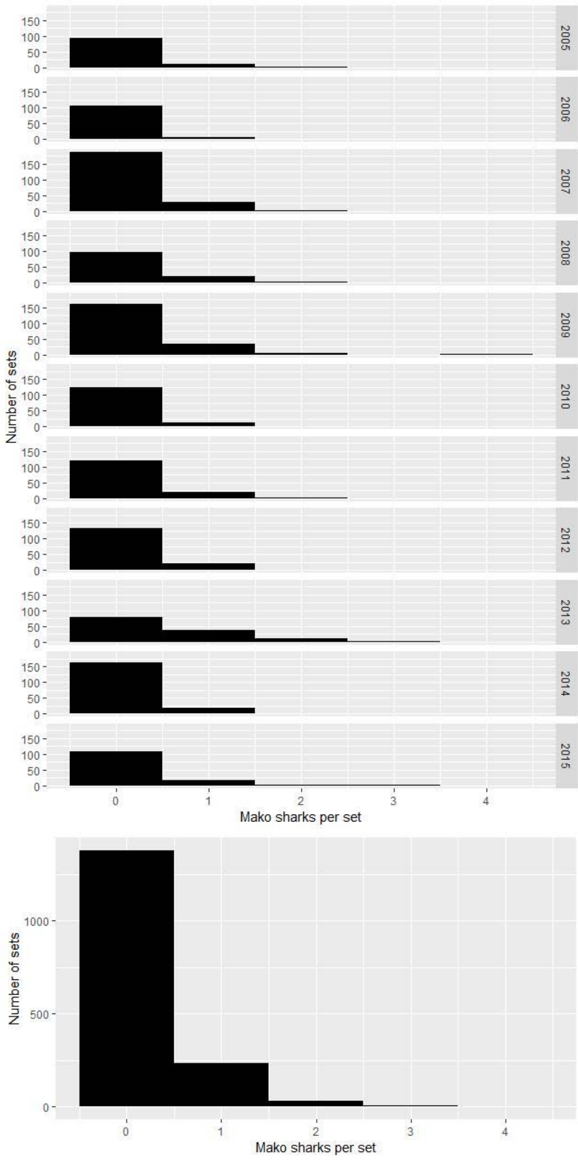


Figure 24: Histograms of mako sharks per set in the Japan South TLCER dataset by year and for the overall time period (*n*=1632 of which 1365 sets recorded zero mako sharks).

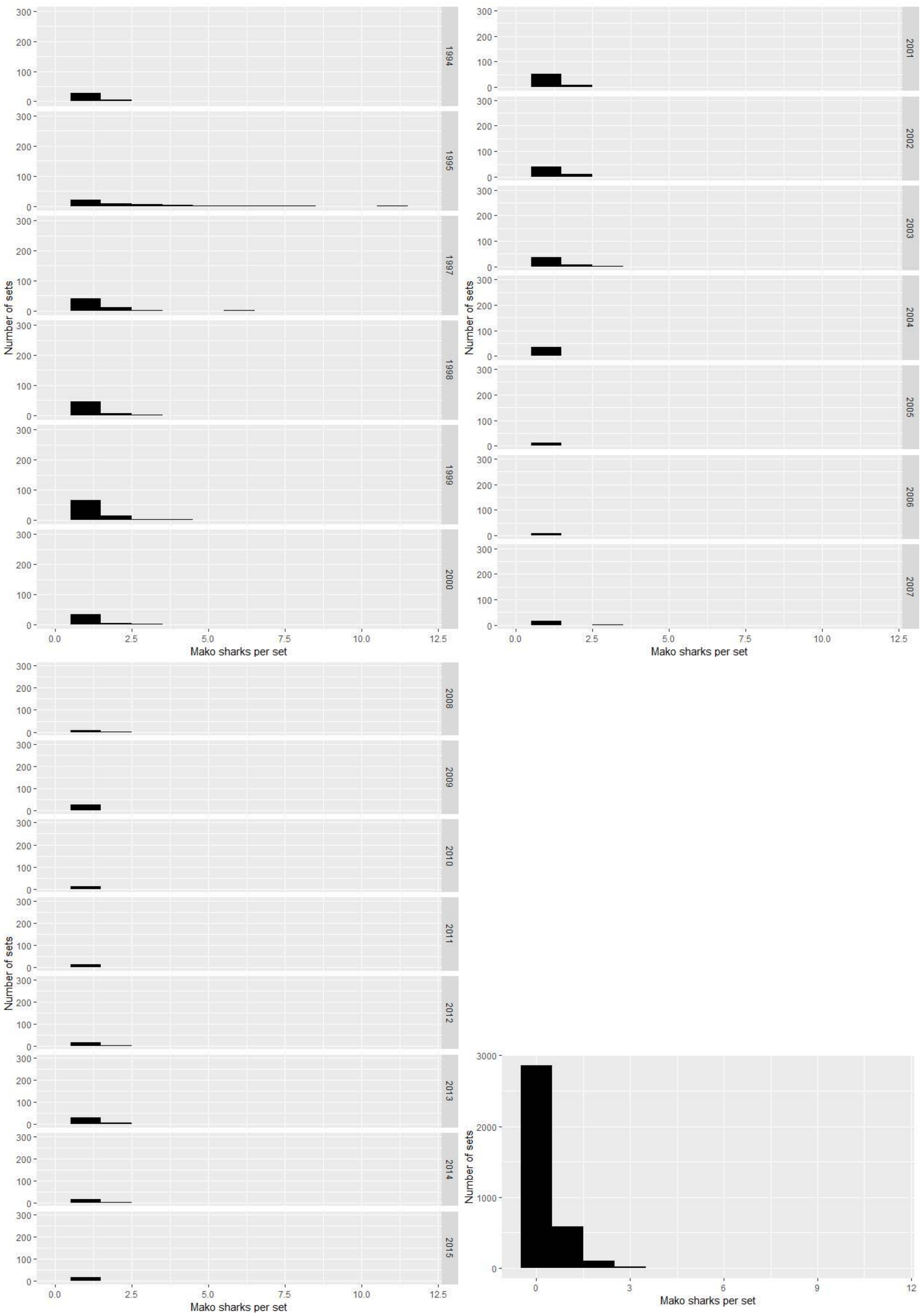


Figure 25: Histograms of mako sharks per set in the Japan South observer dataset by year and for the overall time period (*n*=3577 of which 2863 sets recorded zero mako sharks).

The proportion of zero catches of mako shark in the Japan South TLCER data was high, ranging from 60% to 95% (Figure 26, left panel). Apart from a sudden temporary decline in 2013, the proportion of zero catches has remained above 80%. The ZINB model was selected over the negative binomial model (Vuong likelihood ratio test, $p < 0.05$). Only year and month were identified as predictors (Table 3, Appendix 16), with the negative binomial distribution explaining approximately 10% of the residual deviance (not available from ZINB model). Diagnostics indicate a poor fit of the model to the data with a weak relationship between observed and predicted catches (Appendix 10). Fishing effort in June positively influenced catches (Appendix 24).

In the observer data, the proportion of zero mako shark catches ranged from 66% to 90% and, apart from a sudden temporary decline in 2013, has shown an increase over time (Figure 26, right panel). The negative binomial model was selected over the ZINB model (Vuong likelihood ratio test, $p < 0.05$), with only year and vessel identified as predictors (see Table 3, Appendix 16). The residual deviance explained by the negative binomial model was approximately 10%. Model diagnostics show a lack of fit to the data with a poor correlation between observed and predicted values (Appendix 10). The introduction of two vessels since 2007 positively influenced catches (Appendix 24).

Nominal and standardised indices of abundance of the TLCER data showed similar patterns, with no real trend in abundance (Figure 27, left panels). Nominal and standardised indices of abundance of the observer data showed a decline to about 2003 with no trend thereafter (Figure 27, right panels).

Table 3: Results for the CPUE standardisation of mako shark in the Japan South dataset.

Data set	Model selection	Model	% Deviance explained
TLCER	Zero-inflated negative binomial	Catch of mako shark ~ year + month + offset(log(hooks)) (counts) Catch of mako shark ~ year + month (zeroes)	Year: 7.6 Month: 1.9
Observer	Negative binomial	Catch of mako shark ~ year + vessel + offset(log(hooks))	Year: 7.4 Vessel: 2.2

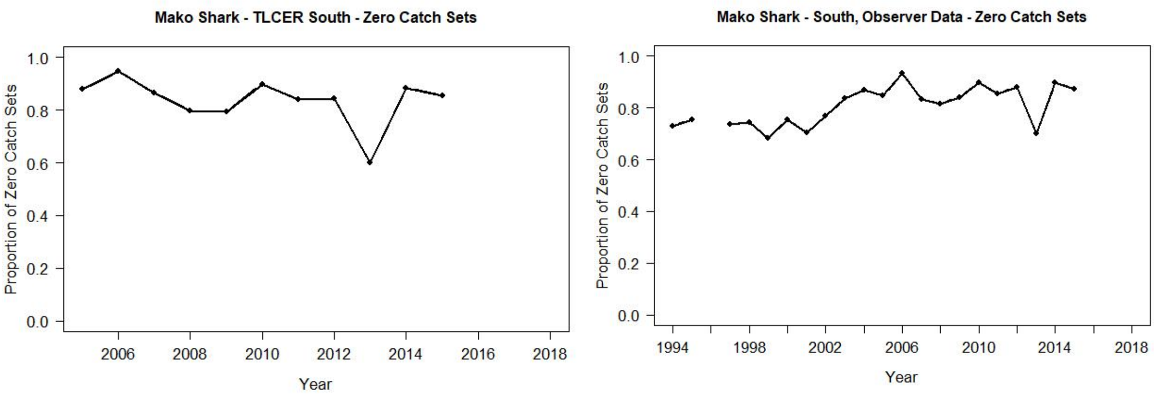


Figure 26: Proportion of sets with zero mako sharks recorded by year in the Japan South fishery based on commercial TLCER data (left) and observer data (right). In the observer dataset, no records were available for 1996.

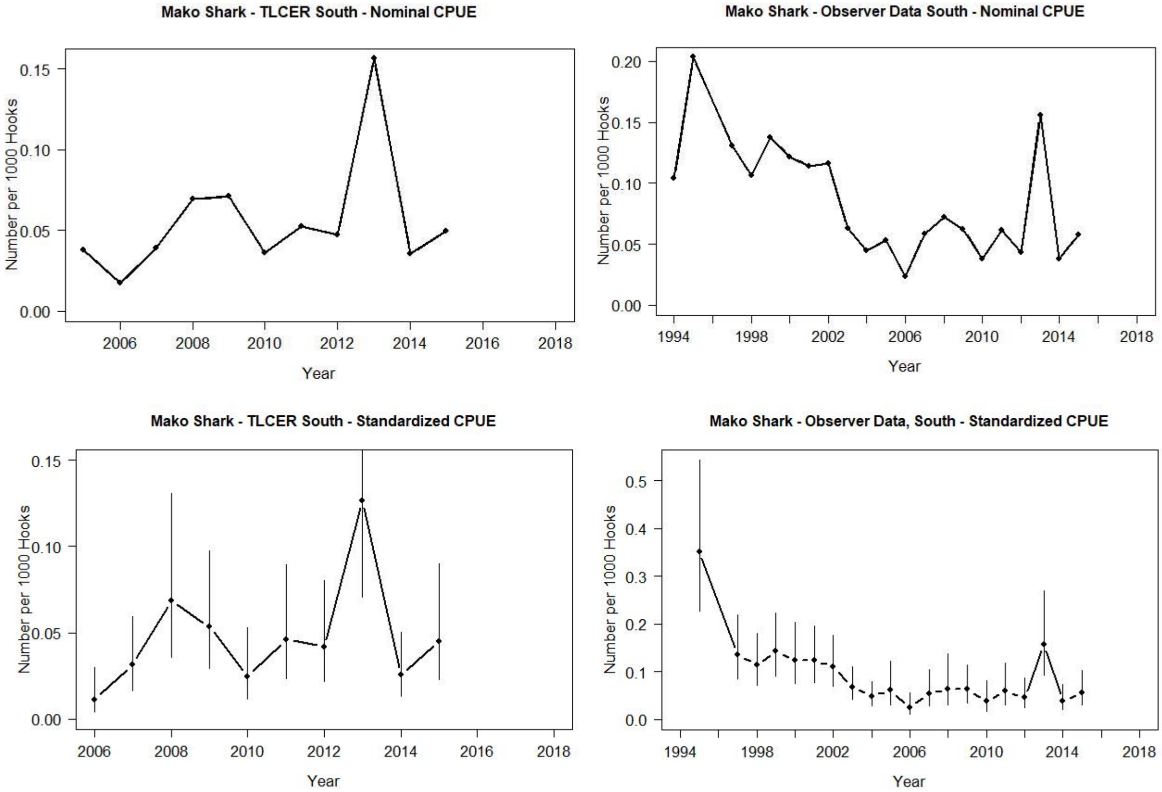


Figure 27. Nominal mako shark CPUE computed as number caught per 1000 hooks fished per year (top panels) and standardised catch per unit effort with 95% confidence intervals (bottom panels) for the Japan South fishery based on commercial TLCER data (left) and observer data (right).

Mako shark — North

The number of zero mako shark catches in the North TLCER dataset was 15 975, with a mode of 1 mako shark caught per set (*n*=3977) in positive catches (Figure 28). In the observer dataset, there were 917 zero catches (Figure 29). The mode for the positive catches in this dataset was 1 mako shark (*n*=657). No trends were observed over time.

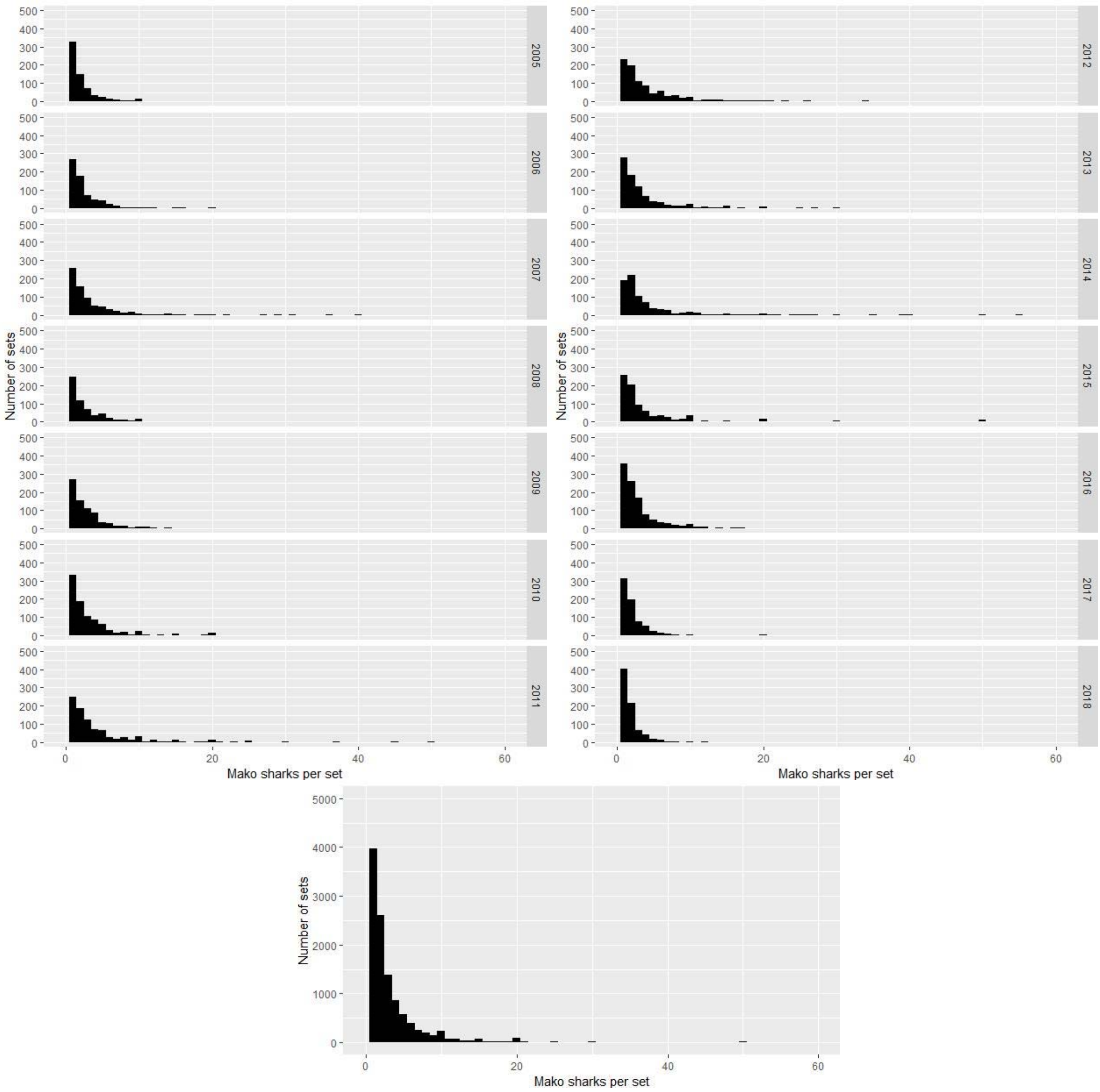


Figure 28: Histograms of mako sharks per set in the North TLCER dataset by year and for the overall time period (*n*=27 260 of which 15 975 sets recorded zero mako sharks). Thirteen sets where more than 60 makos were reported were omitted from the histograms.

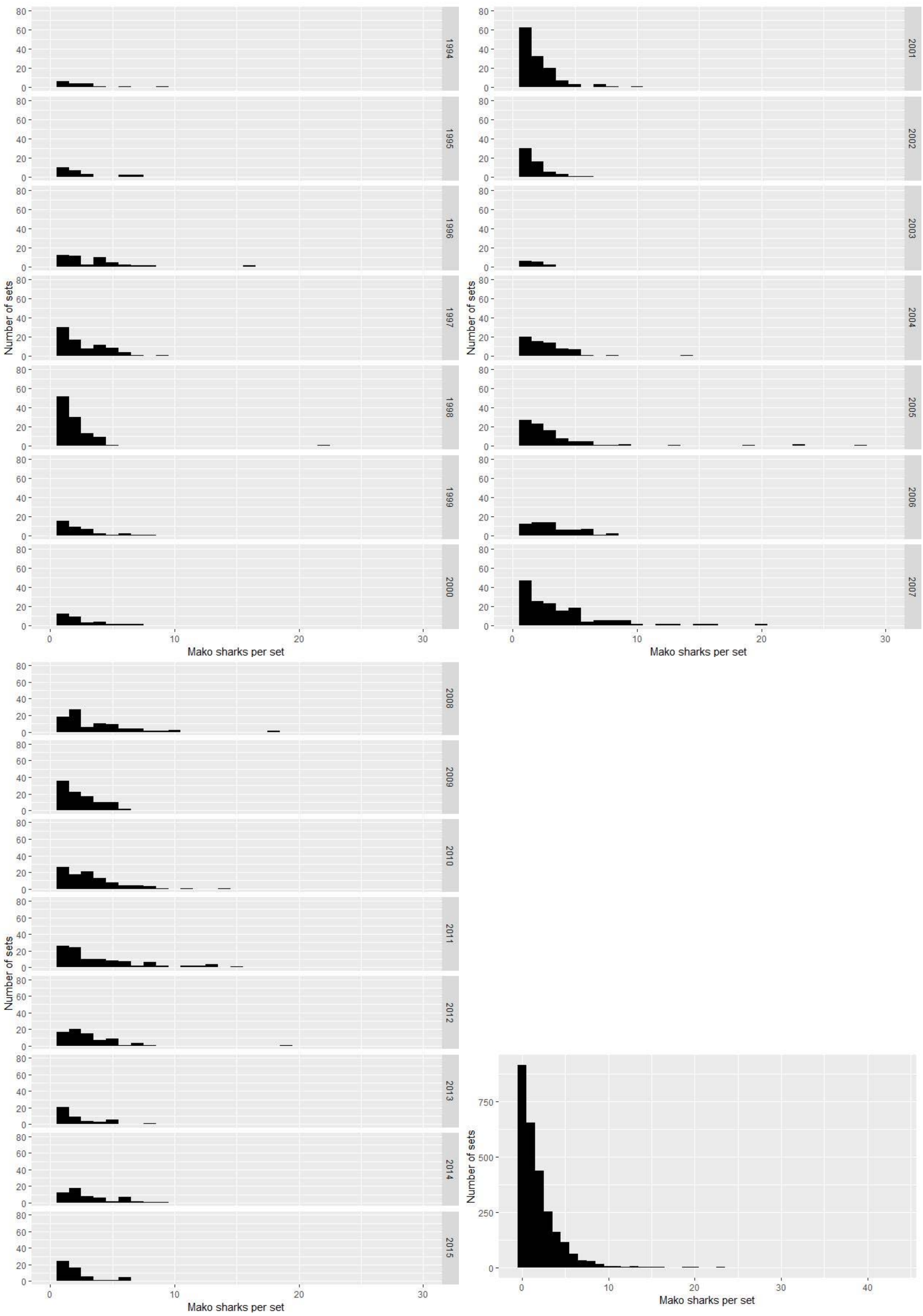


Figure 29: Histograms of mako sharks per set in the North observer dataset by year and for the overall time period (*n*=2728 of which 917 sets recorded zero mako sharks). One set where more than 30 makos were reported was omitted from the histograms.

The proportion of zero catches of mako shark in the North TLCER data ranged from 41% to 71%, and it steadily declined until 2016, then increased in 2017–2018 (Figure 30, left panel). The ZINB was selected over the negative binomial model (Vuong likelihood ratio test, $p < 0.05$); however, the ZINB model could not compute the coefficients for area and rather than sacrifice the predictive power of the area factor, the negative binomial model was chosen. Year, vessel, area, month, and bait were identified as the most important predictors, and together they explained 31% of the residual deviance (Table 4, Appendix 17). Model diagnostics showed a lack of fit to the data with a poor correlation between observed and predicted values (Appendix 11).

In the North observer data, the proportion of zero mako shark catches ranged from 19% to 55% and showed no clear trend over time (Figure 30). The ZINB was selected over the negative binomial model (Vuong likelihood ratio test, $p < 0.05$); however, the ZINB model could not compute the coefficients for vessel and rather than sacrifice the predictive power of the vessel factor, the negative binomial model was chosen. The model predictors include year, vessel, and catch of swordfish and explained 26% of the residual deviance (Table 4, Appendix 17). Model diagnostics showed a lack of fit to the data with a poor correlation between observed and predicted values (Appendix 11). A lower percentage of hooks baited with squid (in the TLCER model) and the introduction of additional vessels in the fleet in recent years (both models) positively influenced mako catches (Appendices 25–26).

The nominal and standardised indices of the TLCER data showed similar trends, with a gradual incline until a peak in 2015 and decline thereafter (Figure 31, left panels). The nominal observer catches were much more variable, with peak catch rates in 2011, followed by staggered declines (Figure 31, right panels). Apart from the high and unlikely estimate in 1995, the standardised observer indices indicated no clear trend over time. Nominal observer catch rates were not consistent with those reported in the TLCER data prior to 2011, indicating there may be some misreporting by commercial fishers in earlier years or that observer coverage was not representative.

Table 4: Results for the CPUE standardisation of mako shark in the North dataset.

Data set	Model selection	Model	% Deviance explained
TLCER	Negative binomial	Catch of mako shark ~ year + vessel + area + month + bait + offset(log(hooks))	Year: 6.5 Vessel: 15.4 Area: 5.4 Month: 2.9 Bait:1.1
Observer	Negative binomial	Catch of mako shark ~ year + vessel + catch of swordfish (SWO) + offset(log(hooks))	Year: 8.5 Vessel: 16.3 SWO: 1.0

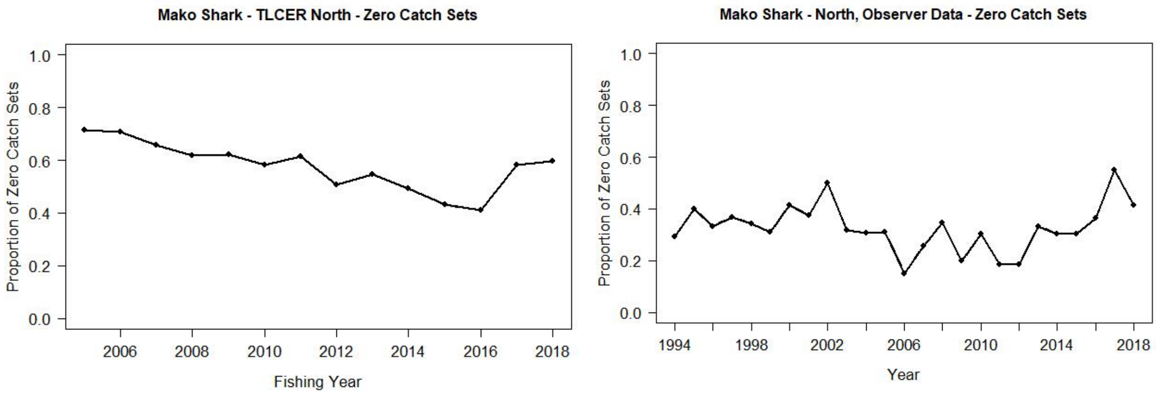


Figure 30: Proportion of sets with zero mako sharks recorded by year in the North fishery based on commercial TLCER data (left) and observer data (right).

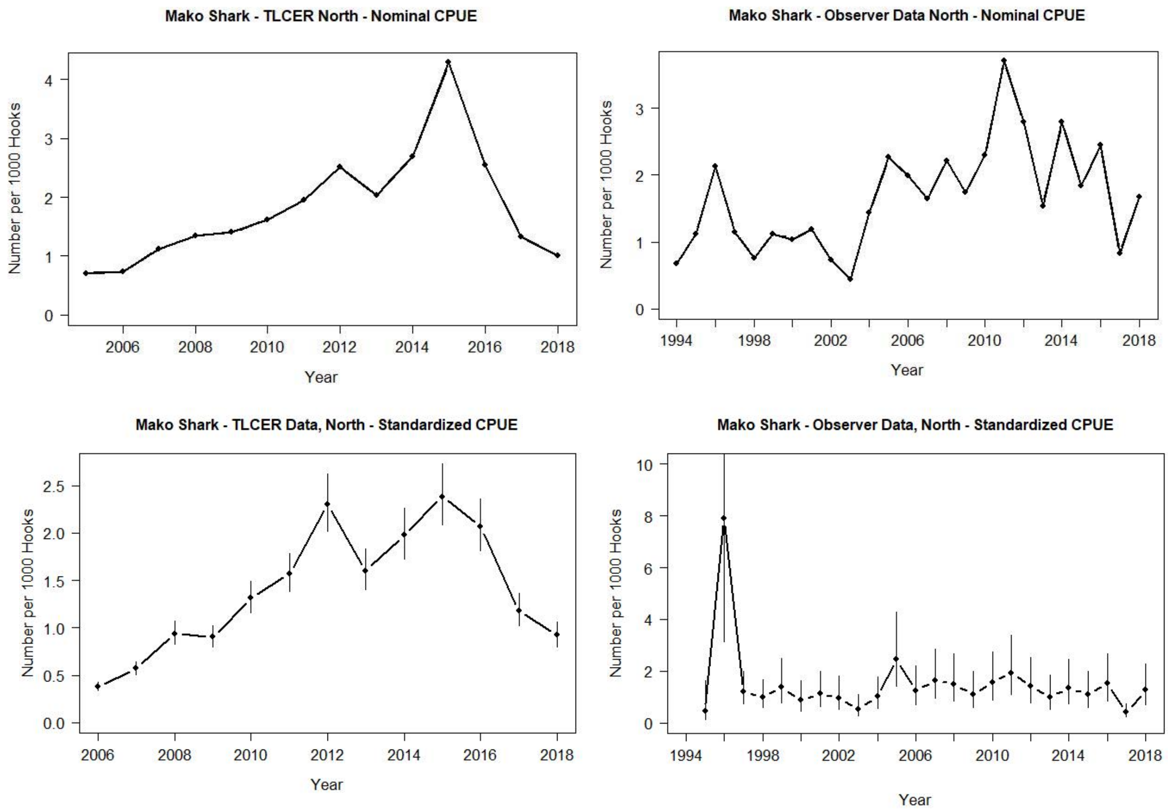


Figure 31: Nominal mako shark CPUE computed as number caught per 1000 hooks fished per year (top panels) and standardised catch per unit effort with 95% confidence intervals (bottom panels) for the North fishery based on commercial TLCER data (left) and observer data (right).

Porbeagle shark — Japan South

The Japan South TLCER dataset had a large number of zero porbeagle shark catches (*n*=712), with a mode of 1 porbeagle shark caught per set (*n*=437) in positive catches (Figure 32). In the Japan South observer dataset, there were 1320 zero porbeagle shark catches (Figure 33). The mode for the positive catches in this dataset was one porbeagle shark (n=904). No trends were observed over time.

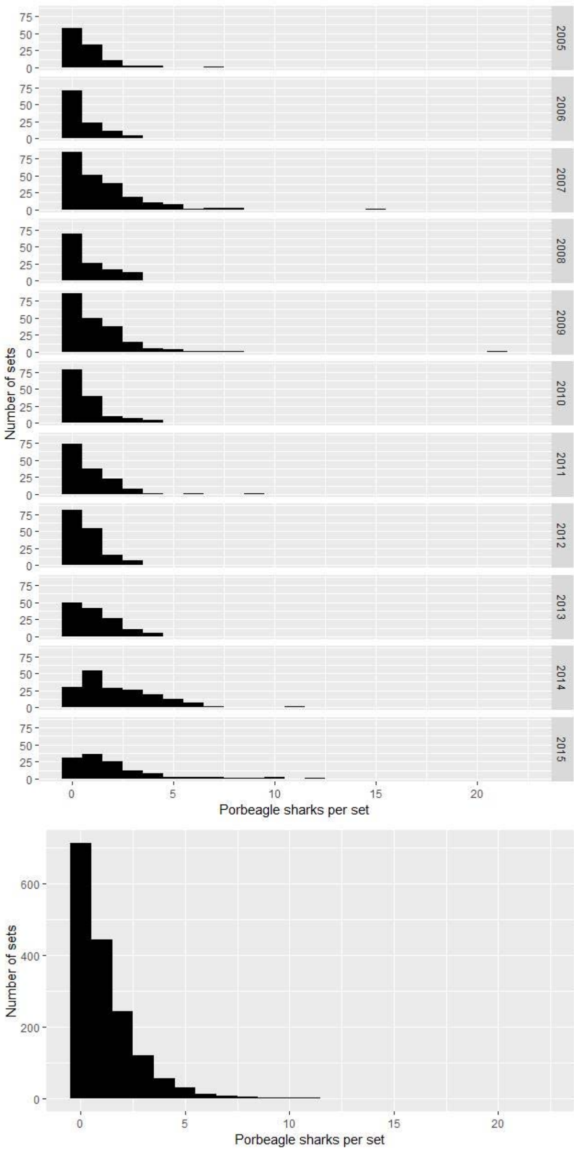


Figure 32: Histograms of porbeagle sharks per set in the Japan South TLCER dataset by year and for the overall time period (*n*=1632 of which 712 sets recorded zero porbeagle sharks).

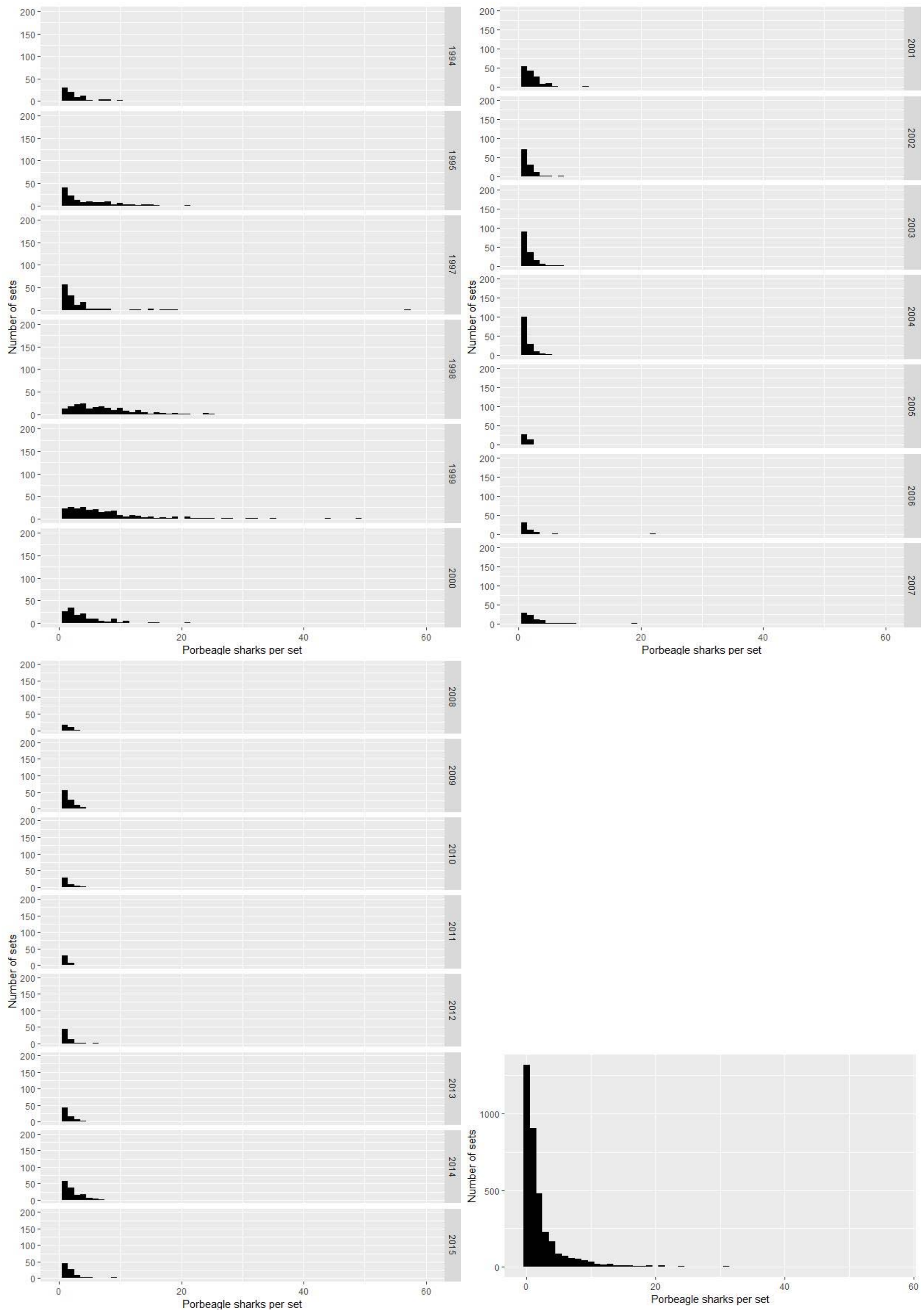


Figure 33: Histograms of porbeagle sharks per set in the Japan South observer dataset by year and for the overall time period (*n*=3577 of which 1320 sets recorded zero porbeagle sharks).

The proportion of zero catches of porbeagle shark in the Japan South TLCER data ranged from 16% to 63% and showed a declining trend (Figure 34, left panel). The negative binomial model was selected over the ZINB model (Vuong likelihood ratio test, $p < 0.05$). Year, month, SST, and vessel were identified as predictors and together they explained 19% of the residual deviance (Table 5; Appendix 18). Diagnostics indicate a poor fit of the model to the data with a weak relationship between observed and predicted catches (Appendix 12).

In the observer data, the proportion of zero porbeagle shark catches ranged from 4% to 66% and showed no clear trend (Figure 34, right panel). The negative binomial model was selected over the ZINB model (Vuong likelihood ratio test, $p < 0.05$), with year, SST, and vessel identified as factors (Table 5, Appendix 18). The residual deviance explained by the negative binomial model was 46%. Diagnostics indicate a poor fit of the model to the data with a weak relationship between observed and predicted catches (Appendix 12). Colder sea surface temperatures, fishing effort in June, and the introduction of additional vessels in 2007 positively influenced catches of porbeagle shark (Appendices 27–28).

Both nominal and standardised CPUE indices for the TLCER data reached the highest levels in 2014–2015 (Figure 35, left panels). In the standardised observer dataset, there was a large spike in 1998–2000, indicating a ca. 6-fold increase in availability or abundance of porbeagles. The spike was followed by a decline to low levels with little subsequent change, apart from an increase in 2014–2015 (Figure 35, right panels).

Table 5: Results for the CPUE standardisation of porbeagle shark in the Japan South dataset.

Data set	Model selection	Model	% Deviance explained
TLCER	Negative binomial	Catch of porbeagle shark ~ year + month + SST + vessel + offset(log(hooks))	Year: 9.9 Month: 3.5 SST: 2.2 Vessel: 1.9
Observer	Negative binomial	Catch of porbeagle shark ~ year + SST + vessel + offset(log(hooks))	Year: 35.3 SST: 3.9 Vessel: 2.7

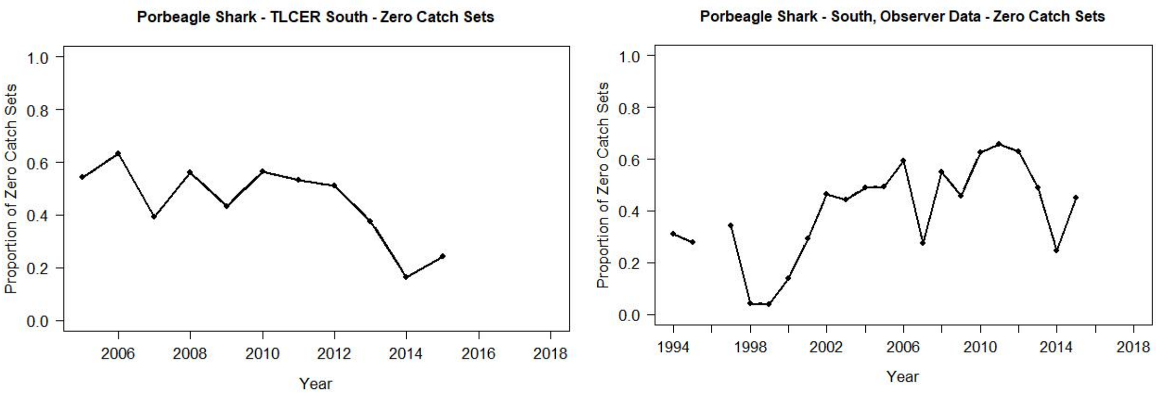


Figure 34: Proportion of sets with zero porbeagle sharks recorded by year in the Japan South fishery based on commercial TLCER data (left) and observer data (right). In the observer dataset, no records were available for the 1996 fishing year.

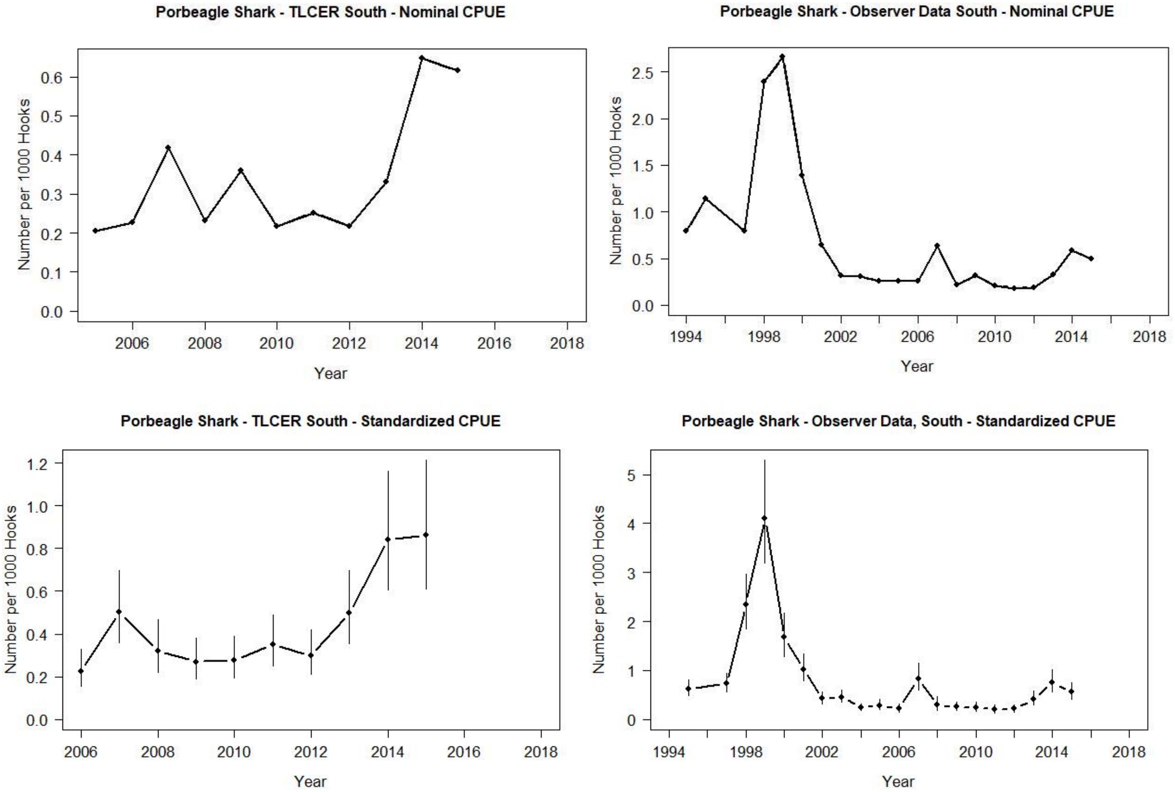


Figure 35: Nominal porbeagle shark CPUE computed as number caught per 1000 hooks fished per year (top panels) and standardised catch per unit effort with 95% confidence intervals (bottom panels) for the Japan South fishery based on commercial TLCER data (left) and observer data (right).

Porbeagle shark — North

The number of zero porbeagle shark catches in the North TLCER dataset was high at 21 430 sets, with a mode of 1 porbeagle shark caught per set (*n*=1468) in positive catches (Figure 36). A larger number of zero catches was reported over time in the TLCER data, with a big and ongoing increase between 2011 and 2012. In the observer dataset, there were 1326 zero catches (Figure 37). The mode for the positive catches in this dataset was 1 porbeagle shark (*n*=420).

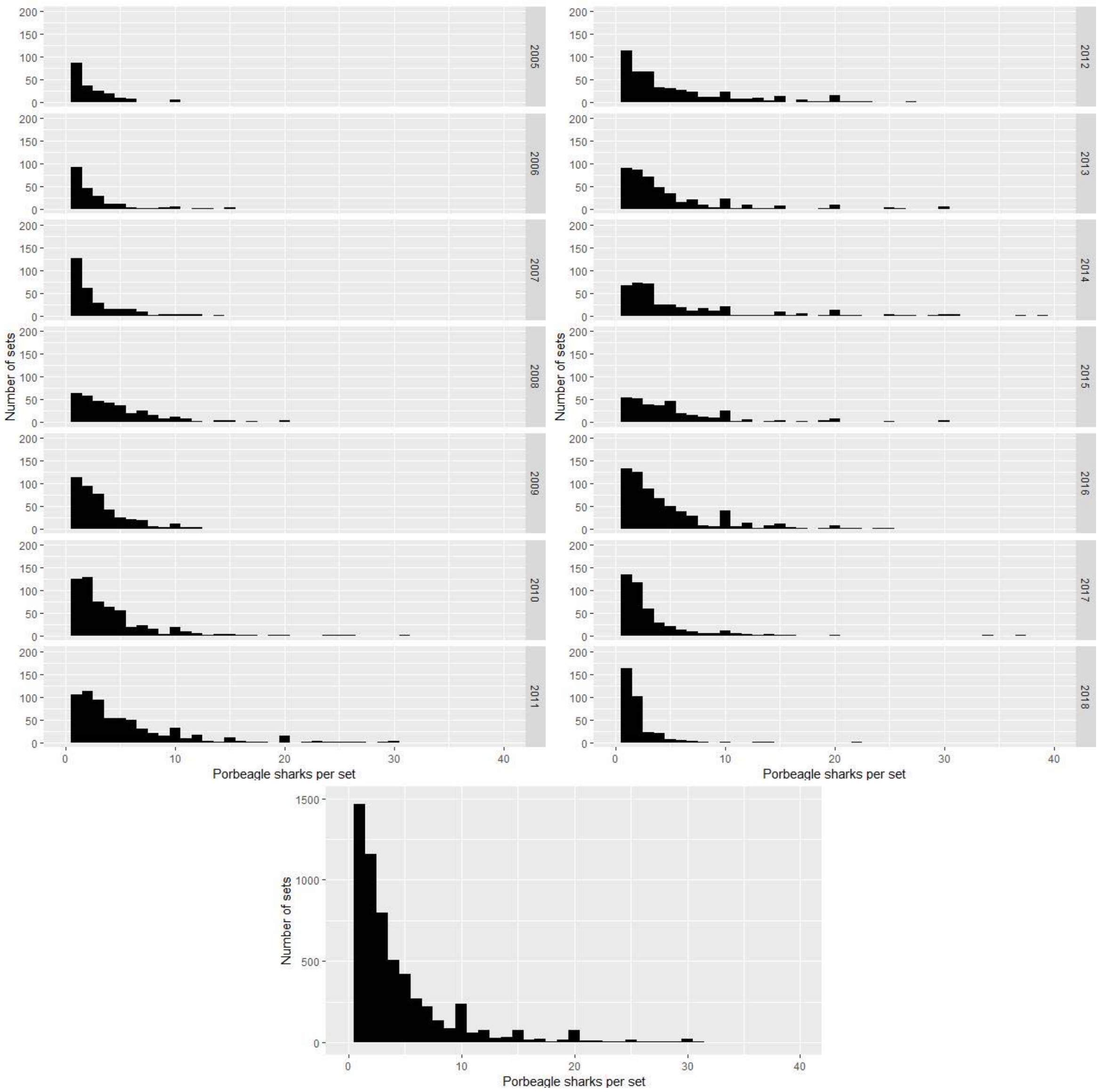


Figure 36: Histograms of porbeagle sharks per set in the North TLCER dataset by year and for the overall time period (*n*=27 260 of which 21 430 sets recorded zero porbeagle sharks). Seven sets where more than 40 porbeagles were reported were omitted from the histograms.

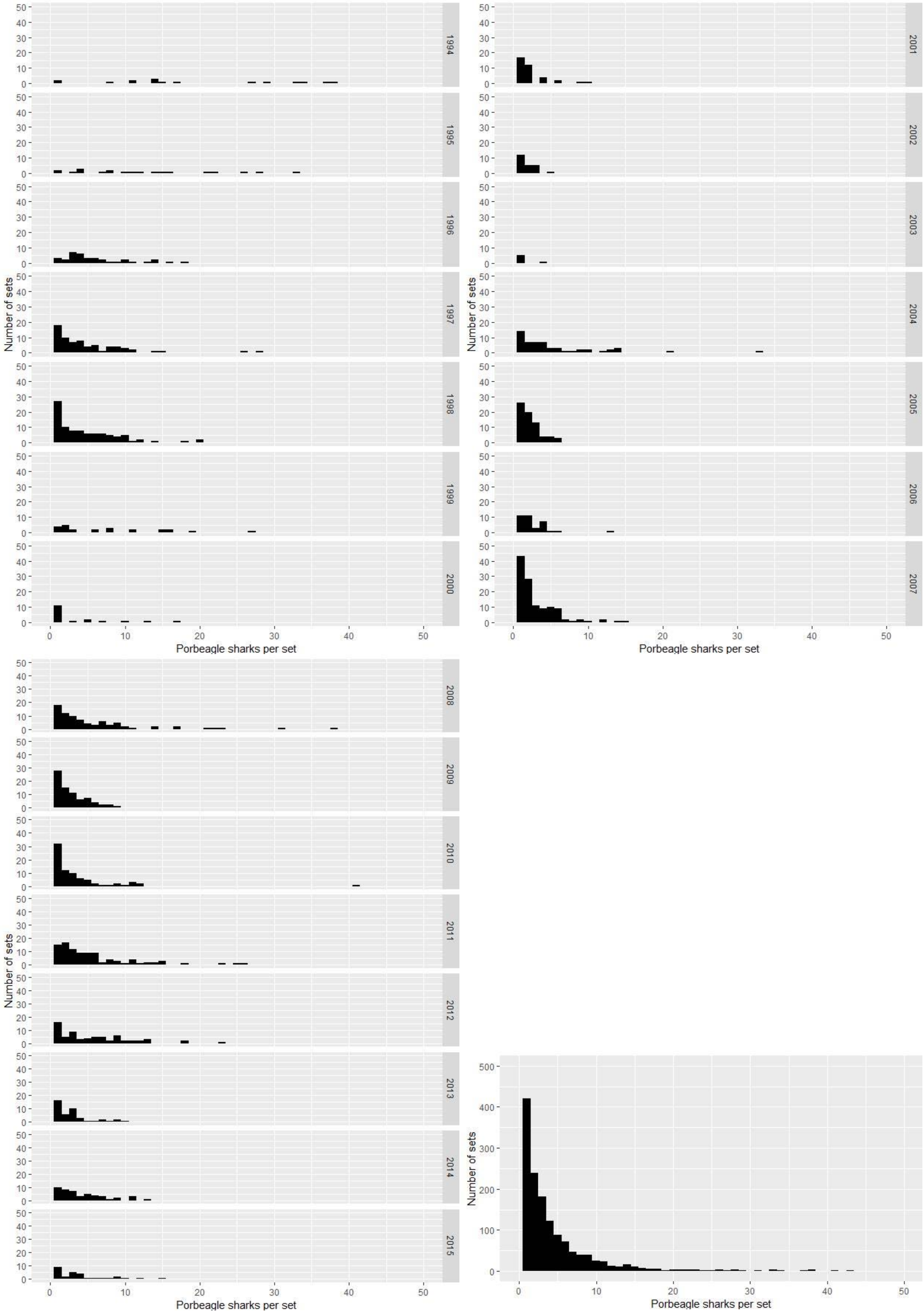


Figure 37: Histograms of porbeagle sharks per set in the North observer dataset by year and for the overall time period (*n*=2728 of which 1326 sets recorded zero porbeagle sharks). Two sets where more than 50 porbeagles were reported were omitted from the histograms.

The proportion of zero catches of porbeagle shark in the North TLCER data was high, ranging from 64% to 92% (Figure 38). Zero catches of porbeagle shark gradually declined until 2016, and then increased in 2017–2018. The ZINB model was selected over the negative binomial model (Vuong likelihood ratio test, $p < 0.05$); however, the ZINB model could not compute the coefficients for area and rather than sacrifice the predictive power of the area factor, the negative binomial model was chosen. Year, vessel, SST, area, and month were identified as the most important predictors and together they explained 50% of the residual deviance (Table 6, Appendix 19). Model diagnostics show a lack of fit to the data with a poor correlation between observed and predicted values (Appendix 13).

In the North observer data, the proportion of zero porbeagle shark catches ranged from 24% to 82%, peaking in 2001 and again in 2018 (Figure 38). The ZINB was selected over the negative binomial model (Vuong likelihood ratio test, $p < 0.05$); however, the ZINB model could not compute the coefficients for vessel and rather than sacrifice the predictive power of the vessel factor, the negative binomial model was chosen. The model predictors include year, vessel, FMA, month, and bait and together they explained 57% of the residual deviance (Table 6, Appendix 19). Model diagnostics showed a lack of fit to the data with a poor correlation between observed and predicted values (Appendix 13). Vessels, fishing in FMA 2, fishing mid-year (calendar year), and using a high percentage of squid bait positively influenced porbeagle catches (Appendices 29–30).

The standardised TLCER data indicated a peak abundance in 2011, followed by some decline, a spike in 2016, and further decline to levels similar to those observed in 2006–2007 (Figure 39). The standardised observer data show a similar, but not so pronounced, trend over the TLCER time period and no clear trend over the entire time series. Nominal observer catches were higher than those reported in the TLCER nominal catches, indicating there may be some underreporting by commercial vessels.

Table 6: Results for the CPUE standardisation of porbeagle shark in the North dataset.

Data set	Model selection	Model	% Deviance explained
TLCER	Negative binomial	Catch of porbeagle shark ~ year + vessel + SST + area + month + offset(log(hooks))	Year: 11.1 Vessel: 18.9 SST: 11.2 Area: 6.6 Month: 2.0
Observer	Negative binomial	Catch of porbeagle shark ~ year + vessel + FMA + month + bait + offset(log(hooks))	Year: 17.8 Vessel: 29.2 FMA: 4.9 Month: 3.6 Bait: 1.7

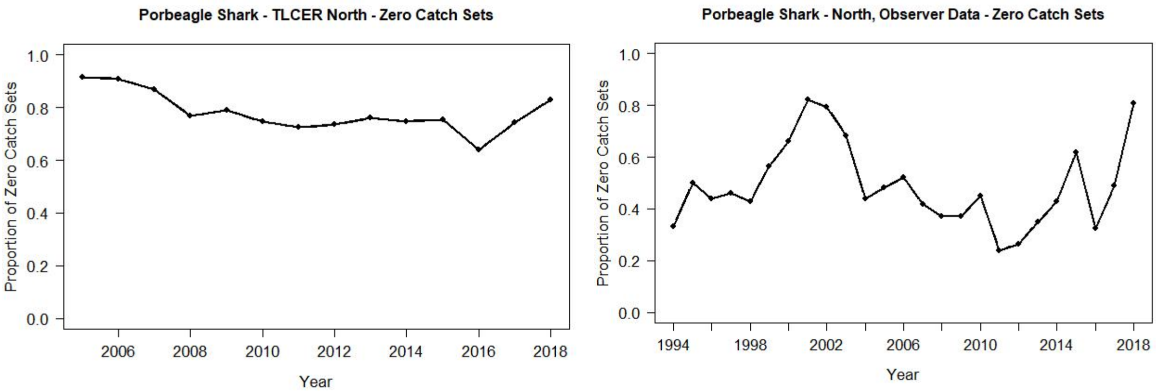


Figure 38: Proportion of sets with zero porbeagle sharks recorded by year in the North fishery based on commercial TLCER data (left) and observer data (right).

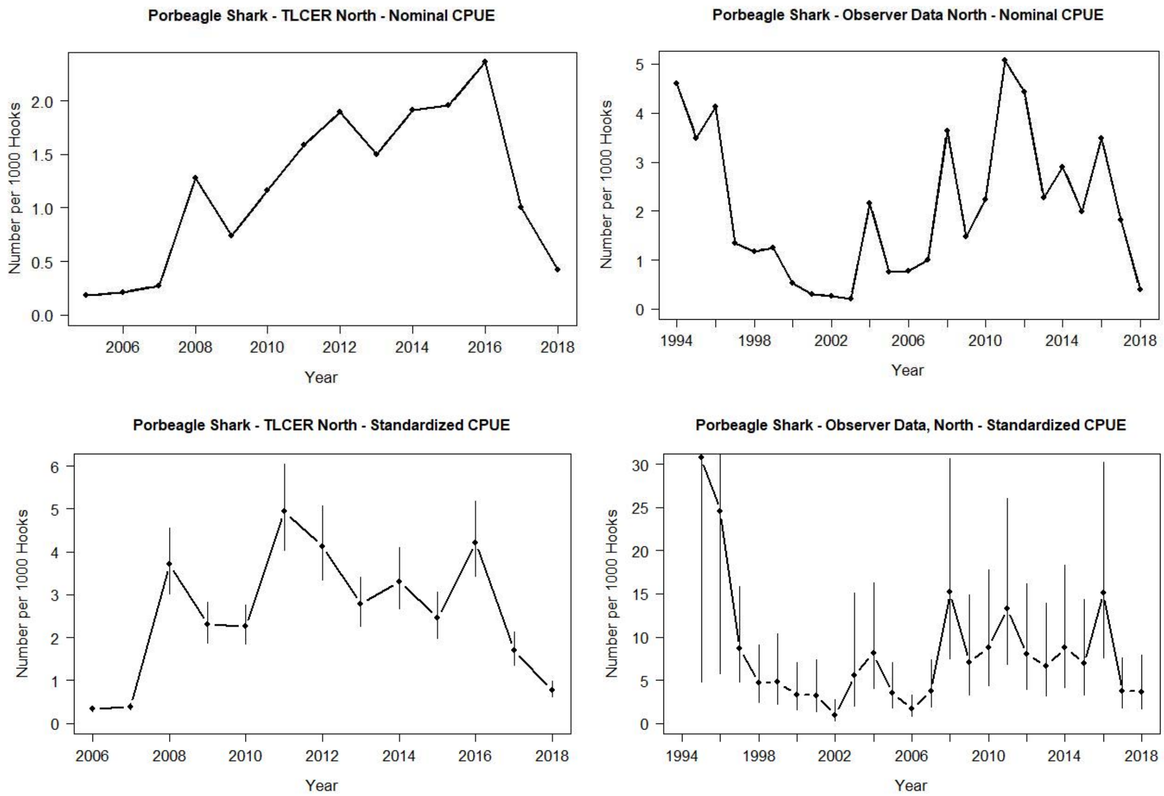


Figure 39: Nominal porbeagle shark CPUE computed as number caught per 1000 hooks fished per year (top panels) and standardised catch per unit effort with 95% confidence intervals (bottom panels) for the North fishery based on commercial TLCER data (left) and observer data (right).

7.3.2 Comparison of CPUE indices

All CPUE indices produced in this section were scaled to the geometric mean (from the 2006–2018 fishing years) and plotted in a combined figure for each species (Figure 40). CPUE indices for the New Zealand South commercial fleet are also presented for comparison. This area was not treated as a main indicator in this study because of the low fishing effort (see Figure 2) and high variability in the trend pre–2012. However, post–2012 New Zealand South commercial trends were found to contradict some trends indicated by the other CPUE indices, which may suggest these indices are not representative of true change in abundance and may instead be indicative of availability to the fishery (i.e., animal movement).

Blue shark

The Japan South commercial and observer trends were very similar and steadily increased from 2010 to the end of the time series in 2015. The Japan South indices were consistently higher than those from the North region. The North indices also showed similar trends over time, apart from the sharp peak in the observer data in 2013. Until that time, the observer indices were higher than the commercial indices, and vice versa post–2013. From 2012, the New Zealand South commercial index remained stable, with a small decline in 2017 and a sharp increase in 2018.

Mako shark

The Japan South commercial and observer trends were very similar and showed no trend over time, apart from the sharp peak in 2013. The North commercial data showed a peak in 2015 and decline thereafter. The North observer data were highly variable and, from 2012, produced lower indices than the commercial indices except for 2018. The New Zealand South commercial index was highly variable, but from 2012 onwards it followed a similar trend to that of the North observer index.

Porbeagle shark

The Japan South commercial and observer trends were very similar, with some increase since 2012. The commercial indices remained stable in the final year of the time series (2015), whereas the observer indices showed some decline. The North commercial and observer indices showed similar, highly variable trends across the time series, converged in 2016, and declined steeply in the most recent years (more so in the commercial data). The New Zealand South commercial indices were also highly variable, but showed an increasing trend since 2015.

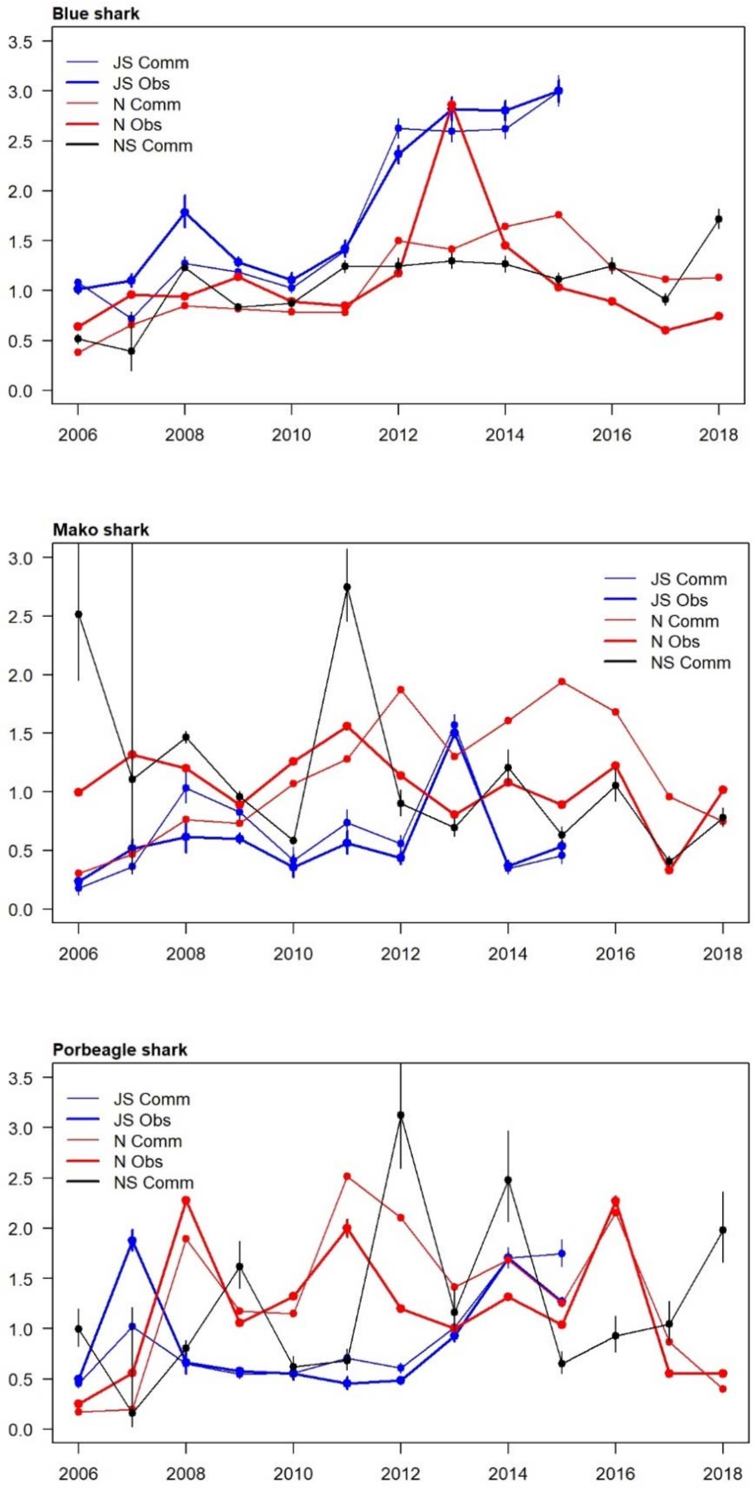


Figure 40: CPUE indices for blue (top), mako (middle), and porbeagle (bottom) sharks from commercial and observer data in Japan South and North regions from 2006 to 2018, scaled to the geometric mean. New Zealand South indices are also shown for comparison.

7.4 Discussion

Trends in the proportion of zeroes and standardised CPUE are summarised in Table 7. There were some inconsistencies among trends for each species in North and South regions, and some observed annual CPUE variations were too large and/or occurred over too short a timeframe to accurately represent changes in population biomass.

A marine heatwave generated anomalously high Tasman Sea SSTs in 2017–18 (Salinger et al. 2019) and may have affected the availability or catchability of pelagic sharks. SST was an important predictor for some of the blue shark and porbeagle models, but was not a primary predictor for any mako datasets. Catch rates of blue shark are correlated with SST, with higher catch rates occurring at temperatures less than 20 °C (Large 2015). Mean SST reported by SLL vessels in March–August, when most of the SLL fishing occurs (Francis 2019), showed no important changes in North region between 2005 and 2018 (Figure 41). In South region, SST was relatively stable for the Japanese chartered fleet which fished mainly offshore; but for the New Zealand domestic fleet, which fished closer to shore, mean SST increased in the early 2010s followed by a stable period since 2014. This suggests that, over the period when most SLL fishing effort occurs, the recent marine heatwave may not have been a major factor in driving shark availability, and SST does not appear to explain the large changes in CPUE seen during 2016–2018. However, a more detailed analysis using remote-sensed SST and ocean colour data might reveal changes in large-scale oceanography that may have affected the spatial distribution of pelagic sharks.

Table 7. Summary of trends in standardised abundance indices and zero catches by species, fishery, and data type. Model selection includes negative binomial (NB) or zero-inflated negative binomial (ZINB).

Species	Fishery	Data	Years	Zero catches	Model	CPUE trend
Blue shark	Japan South	Commercial	2006–2015	No trend (near zero)	NB	Increasing
	Japan South	Observer	1995–2015	No trend (near zero)	NB	Increasing
	North	Commercial	2006–2018	Declining	NB	Peaked in 2014–2015, then declined
	North	Observer	1995–2018	Declined to 2016 then increased	NB	Declining since 2013
Mako shark	Japan South	Commercial	2006–2015	No trend	ZINB	No trend
	Japan South	Observer	1995–2015	No trend since 2003	NB	Decreased to 2006 then stable at low levels
	North	Commercial	2006–2018	Declined to 2016 then increased	NB	Increased to 2015 then declined
	North	Observer	1995–2018	No trend	NB	No trend
Porbeagle	Japan South	Commercial	2006–2015	Declined since 2012	NB	Stable 2006–2013 but increased 2014–2015
	Japan South	Observer	1995–2015	No trend	NB	Stable since early 2000s but increased 2014–2015
	North	Commercial	2006–2018	Declined then stable to 2016, then increased	NB	Decline since 2011, particularly 2017–2018
	North	Observer	1995–2018	Variable with no clear trend	NB	Declined in 1990s followed by increase and stability 2008–2016 and decrease 2017–2018

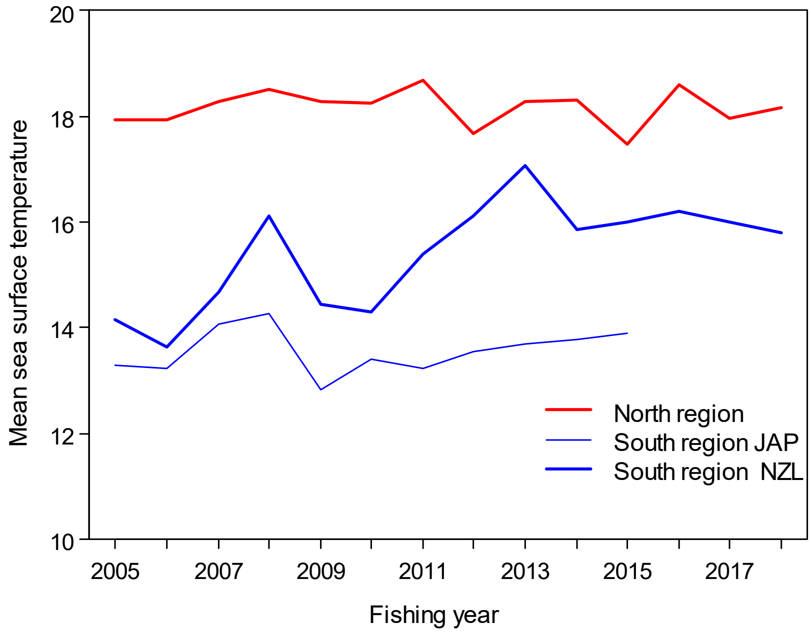


Figure 41: Mean sea surface temperature (°C) reported by commercial surface longliners in March–August in North region and in South region by the Japanese (JAP) and New Zealand (NZL) fleets.

8. MEDIAN SIZE AND SEX RATIO INDICATOR ANALYSES

8.1 Introduction

Exploitation of a fish population may lead to a reduction in the mean age of individuals in the population, and this in turn can lead to a shift in the length distribution towards smaller size classes (Goodyear 2003). Consequently, trends in fish size can be a useful indicator of population status (Clarke et al. 2011) and may even provide information on the level of exploitation that a fish stock is experiencing (Francis & Smith 1995). Clarke et al. (2011) examined trends in median length of five species of sharks in tropical waters north of New Zealand, including blue and mako sharks. They found significant declines in most combinations of spatial strata and sex for blue and mako sharks. Because the sizes of sharks differ by sex (females typically grow larger and heavier than males), it is important to examine indicators on a sex-specific basis where possible (Clarke et al. 2011). Length is a better measure of size than weight because the former does not fluctuate with reproductive or other seasonal factors, or stomach fullness. The median length is preferred over the mean length because the median is less likely to be influenced by outliers.

The sex ratio of a shark population may also be a useful indicator of its status. Heavy exploitation could lead to a preferential loss of females because they tend to be larger and older than males. Thus if the median length in a population declines, it may also affect the sex ratio. Additionally, male and female sharks often segregate spatially (Mucientes et al. 2009), and this has been reported in HMS sharks in New Zealand waters: in South region, blue shark catches are dominated by females and mako shark catches by males (Francis 2013). If fishing activity is concentrated in areas favoured by one sex, then an imbalance in the sex ratio could be created.

Using observer data, Francis et al. (2014) calculated the proportion of males of each of the three shark species in the New Zealand SLL catch, stratified by region, between 1993 and 2013. They also analysed trends in median shark length, stratified by sex and region. Those analyses are extended here to 2018.

8.2 Methods

Length-frequency distributions and sex ratios were calculated for each shark species using data collected by observers during 445 trips aboard SLL vessels. Following omission of some trips for which there was a clear bias towards measurements ending in zero, uncertainty about the accuracy of the length measurements, species identification problems, or other data quality issues, 396 trips remained for analysis of length distributions (see Francis et al. (2014) for further details). Some of the trips omitted on the basis of length inconsistencies had reliable data on the sex of sharks, so they were included in the analysis of sex ratios.

Observers measured sharks using one or both of two measurements: fork length (FL) and ‘Length2’. Before 2002, most Length2 measurements were of precaudal length (PCL; tip of snout to the precaudal pit in front of the tail fin). After 2002, most Length2 measurements were of total length (TL). In 2002, some trips used PCL and others used TL. Fork length was adopted as the measurement standard in this study. For sharks having no FL measurement, FL was estimated from Length2 (if recorded) (see Francis et al. (2014) for further details).

When large numbers of sharks (particularly blue sharks) were caught on a longline set, observers may not have been able to record data from individual fish. In these cases, observers counted (‘tallied’) the sharks but did not measure and sex them or record other data such as the time of landing, fate, or processing method. Significant proportions of the blue sharks caught on some trips were tallied, or important data were not collected, leading to potential biases in length-frequency distributions or the proportion of males. These biases were considered in detail by Francis (2013). Tallied sharks were necessarily excluded from subsequent analyses. Sex ratios and median lengths were calculated for strata having sample sizes of 50 or more.

8.3 Results

The percentage of sharks measured and sexed by observers has been declining for all species, particularly in the last few years (Figure 42). This is partly a result of the increased discarding and live release of pelagic sharks. Consequently, the sample sizes of sharks available for estimating sex ratios and median sizes have declined, making it difficult to obtain good estimates; this is most noticeable for mako shark for which sample sizes have failed to meet the 50-shark threshold in most recent years (Figure 43).

The proportion of males in the observed SLL catches showed no long-term trends for any of the three shark species (Figure 43). However, the blue shark sex ratio appeared to follow a regular cycle of about 7 years, with inverse patterns in North and South regions. This suggests that there may be inter-annual variation in the movement of male and/or female blue sharks throughout the New Zealand EEZ.

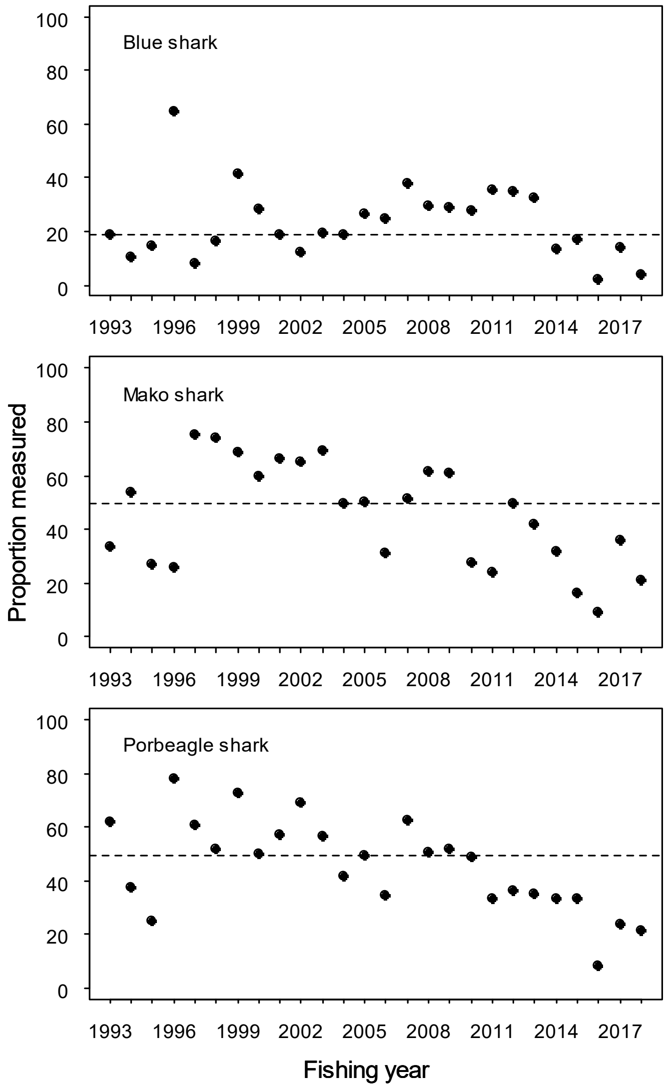


Figure 42: Percentages of blue, mako, and porbeagle sharks measured by observers on surface longliners, by year during 1993−2018. The horizontal dashed line indicates the percentage for the whole time series.

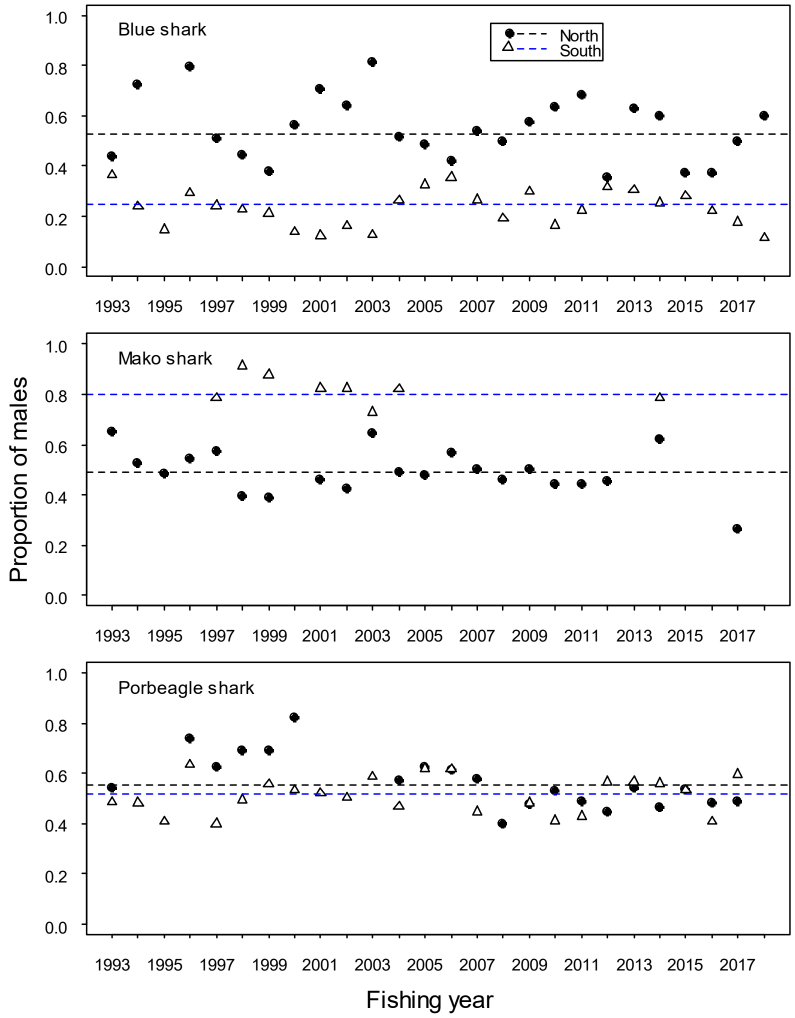


Figure 43: Proportions of male blue, mako, and porbeagle sharks observed on surface longlines, by region and year during 1993−2018. The horizontal dashed lines indicate the proportions of males for the whole time series in each region. Only year-region combinations with sample sizes greater than 50 are shown.

For blue sharks in the North region, there was a slight overall bias towards males (53%) but the sex ratio varied markedly among years, with females dominant in some years. In the South region, blue shark catches were dominated by females, with only 25% males across all years. North region catches were skewed towards males because of the presence of mature adult males as well as juveniles, and southern catches were dominated by females because of a large number of sub-adults (Francis 2013).

The mako shark sex ratio was relatively stable over time in the North and South regions (although the time series of adequate sample sizes was short in South region and has terminated in both regions since 2013). There were equal numbers of males and females in the North region (49% males), but there was a strong bias towards males in the South region (80% males).

The proportion of male porbeagle sharks in the North region was generally higher in the first one-third of the time series than subsequently. Overall, there were similar numbers of males and females in North and South regions (55% and 52% males respectively).

Trends in median fork length for blue, mako, and porbeagle sharks are shown for North and South regions in Figures 44 and 45. For South region, the separate graphs are shown for the Japanese chartered fleet and the New Zealand domestic fleet because these fleets typically fished different areas. Male blue sharks showed considerable inter-annual variability in North region because of varying proportions of adult males in the observed catches (Francis 2013). Male blue sharks in South region, and female blue sharks in both regions, showed less inter-annual variability. In some years, the New Zealand domestic fleet tended to catch slightly smaller blue sharks than the Japanese chartered fleet. There were no overall trends in blue shark median length for either sex or region, but there was a decline for both sexes in the last few years, particularly in 2017–2018 in North region.

Sample sizes of mako and porbeagle sharks were too small to extend the previous plots of median length beyond 2012. Mako sharks of both sexes in North region showed an early period of relatively high median lengths (140−200 cm in 1997−2003) followed by a period of lower, stable lengths (110−130 cm in 2005−2011) and an upswing in 2012 (140 cm). This pattern was also reflected in the 95th percentile length. There were too few data from South region to identify trends.

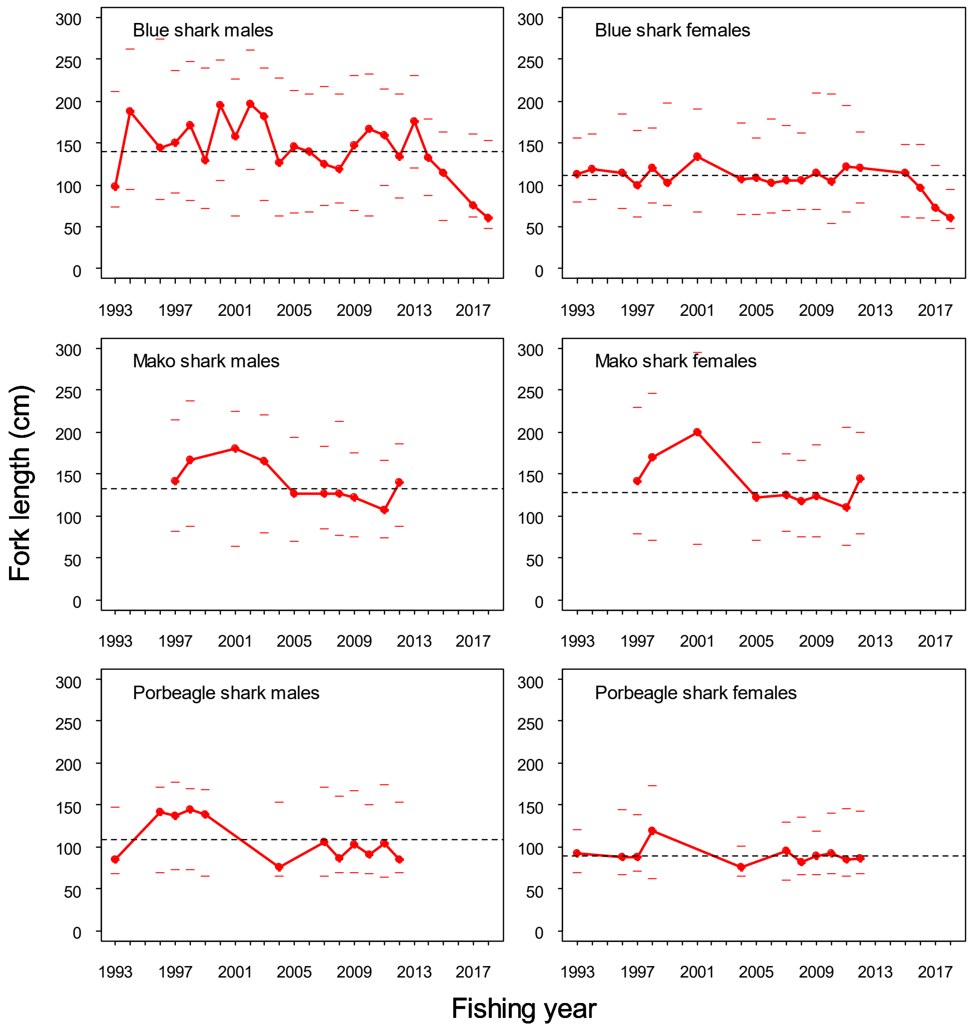


Figure 44: Median fork length of male and female blue, mako, and porbeagle sharks observed on surface longlines in North region, 1993−2018. The dashes show the 5th and 95th percentiles of fork length. Only years with sample sizes greater than 50 are shown.

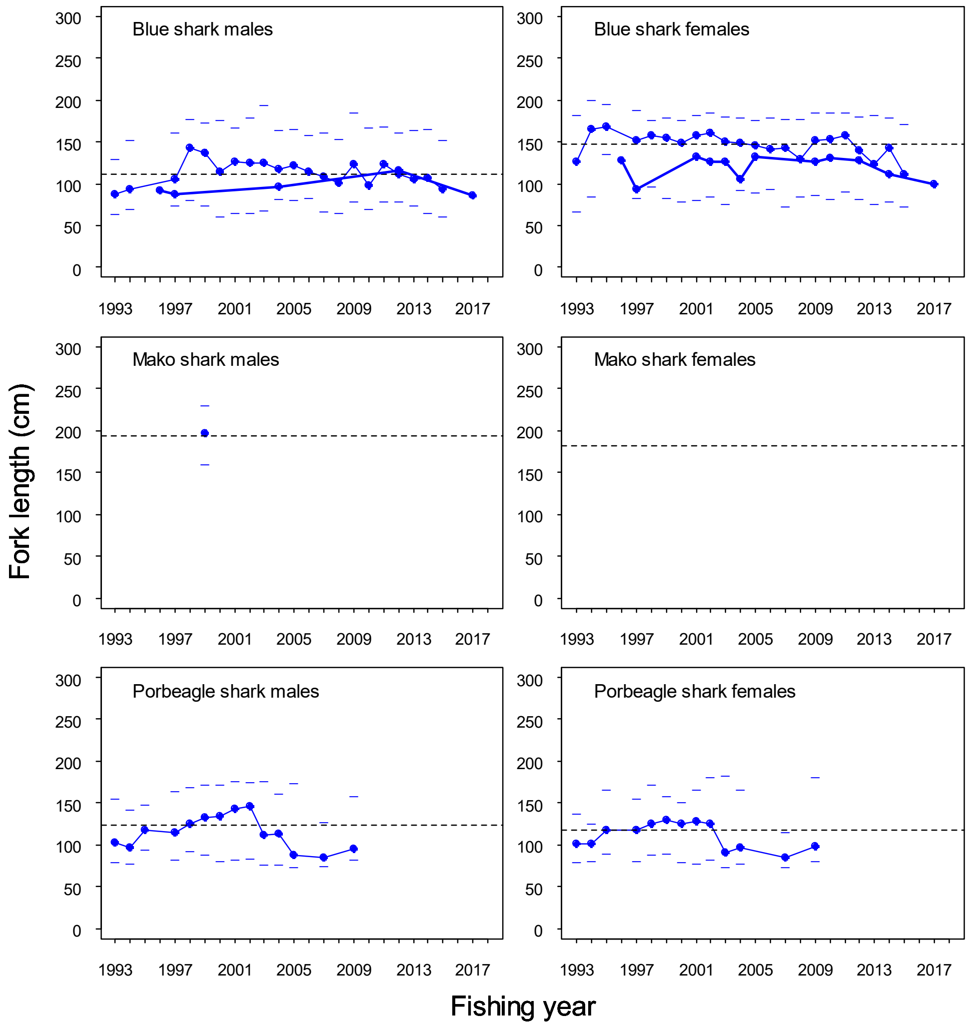


Figure 45: Median fork length of male and female blue, mako, and porbeagle sharks observed on surface longlines in South region, 1993−2018. Thin lines are for the Japanese South fleet, and thick lines in the blue shark panels are for the New Zealand South fleet. The dashes show the 5th and 95th percentiles of fork length. Only years with sample sizes greater than 50 are shown.

Male porbeagles in North region showed an early period of relatively high median fork length (about 140 cm from 1996 to 1999) followed by a period of lower median length (75−130 cm from 2004 onwards). The higher early values were the result of a higher proportion of adults than in later years. North region female porbeagles showed no temporal trend in length. In South region, both sexes of porbeagles showed a slow increase from about 100 cm to about 150 cm (males) and 130 cm (females) in 2002, followed by a rapid decline to initial levels of about 100 cm. These trends correspond with an initial increase in the proportion of adults followed by length distributions dominated by juveniles (Francis 2013).

8.4 Discussion

Apart from steep declines in North region blue shark median length in 2017–2018, there were no clear temporal trends in sex ratio for any combination of species, sex, or region. Sex ratios were close to equality for all three species in the North region (albeit with high inter-annual variation for blue sharks). In the South region, blue shark catches were dominated by females, mako shark catches by males, and porbeagle shark catches had similar proportions of both sexes. In combination, the spatial variation in length composition and sex ratios indicate that blue and mako sharks segregate spatially by size and sex, whereas porbeagles are more uniformly distributed but with a higher proportion of juveniles in the north and subadults in the south. Spatial segregation and sexual segregation are common in sharks and have been reported for pelagic sharks elsewhere in the Pacific (Nakano et al. 1985; Nakano 1994; Nakano & Nagasawa 1996; Mucientes et al. 2009).

Unfortunately, the interpretation of shark length-frequency distributions obtained from observer data is confounded by trends in fisher and observer practices (Clarke et al. 2013; Francis 2013). With the banning of shark finning in New Zealand waters, most blue, mako, and porbeagle sharks have been discarded or released alive since 2014 (Francis 2019). Fishers now tend to release sharks by cutting the traces while they are still in the water, making it increasingly difficult for observers to determine the size, sex, and sometimes even the species of shark. Consequently, the amount of data recorded by observers on the size and sex composition of the shark bycatch has plummeted. The data may also be biased because fishers may be more likely to bring small sharks aboard the boat (to retrieve their hooks) than large sharks. Such a change in fisher behaviour probably explains the steep drop in the median lengths of both male and female blue sharks in North region in 2017–2018. With median lengths less than 70 cm in those two years, the measured sharks must have included a high proportion of neonates and 0+ sharks. These recent changes have effectively invalidated the use of median length and sex ratio as indicators of stock health because they no longer index the population being caught by SLL.

9. DISCUSSION

Abundance indicators for blue, mako, and porbeagle sharks were previously estimated up to 2013 by Francis et al. (2014). They concluded that "*None of the indicators suggested that any of the shark species were declining in either North or South regions. In fact, most of the distribution and catch composition indicators suggested positive trends for all three species in North region, and some indicators also suggested positive trends for all species in South region*". The present report updates the same indicators with five more years of data (to 2018), during which time there have been major changes in the SLL fishery, which takes most of the New Zealand catch of these species. Restrictions were imposed by airlines on the export of shark fins from New Zealand in 2014, and finning of sharks was banned from 2015. Additionally, porbeagle shark was added to CITES Appendix II in September 2014, making the export of porbeagle products from New Zealand more complicated. These changes have resulted in most pelagic sharks being discarded dead or released alive from SLL vessels, and a major reduction in the amount of biological data collected by observers. Furthermore, Japanese chartered longliners ceased fishing in New Zealand waters in 2015, thus terminating the time series of indicators based on the Japanese South fishery. These changes in the operation of the fishery, the quantum of data collected, and the continuity of the indicator time series have had a profound effect on our ability to monitor stock status of pelagic sharks.

Most of the abundance indicator series presented in this report showed declining trends in recent years, particularly in North region in 2017–2018, suggesting a reversal of the previous increasing trends. Taken at face value, these changes suggest there has been a decline in the abundance of pelagic sharks in New Zealand's EEZ. However, there are a number of reasons why the indicators may not accurately index shark abundance:

1. Very similar patterns were seen for all three shark species, particularly the steep declines in North region in 2017 and 2018. It seems unlikely that the abundance of all three species would decline so steeply at the same time.
2. The declines in North region standardised commercial CPUE appear to be too steep to represent real changes in population abundance.
3. The observer-based standardised CPUE analyses did not show the same declines as the commercial fishery based CPUEs.
4. South region showed little change for mako, blue, or porbeagle sharks, so the steep declines seen in North region were not observed across the whole EEZ.
5. SLL effort has been declining in the EEZ (down from about 4 million hooks in 2005 to about 2.5 million in 2018). Furthermore, many pelagic sharks now survive capture by SLL vessels because they are released alive. Post-release mortality of mako sharks has recently been estimated to be about 15% after 60 days (WCPFC, unpublished data), indicating that survival rates are high (this conclusion probably also applies to blue and porbeagle sharks). Hence fishing mortality of pelagic sharks has probably declined substantially since 2015, so there is no obvious driver for a sudden decrease in pelagic shark abundance.

There are other possible explanations for the observed declines in the abundance indicators:

1. There has been a marine heatwave in New Zealand waters in the last few years with Tasman Sea temperatures being considerably higher than normal. Although our simple analysis of SST recorded by vessels in March–August showed no trend in North region, a more detailed analysis might reveal large-scale changes in oceanography that could influence the spatial distribution of pelagic sharks. We found an inverse, cyclical pattern in the proportion of male blue sharks in North and South regions, suggesting sex-specific latitudinal movements of that species. Tagging data confirm that all three shark species migrate latitudinally within New Zealand waters and to and from tropical waters to the north (Francis et al. 2015; 2019). Changes in North region indicators may reflect variation in the number of sharks migrating into New Zealand waters from the tropics.
2. There is anecdotal evidence that some fishers have been avoiding large shark catches since shark finning was banned, because they are seen as a nuisance rather than a valuable resource. Avoidance might include moving to areas with fewer sharks, or modifying gear setting procedures or gear setup to avoid catching sharks, all of which would affect the abundance indicators.

3. Sharks that are cut off lines while still some distance from the vessel may not be recorded by crew or by observers, leading to an underestimation of shark catch.
4. Blue shark abundance can be reduced over time by intensive fishing and discarding of sharks (Large 2015), and the same may apply to other shark species. There is anecdotal evidence of deliberate targeting and killing of sharks by some tuna longliners, and this may have increased recently, leading to localised depletion.

The abundance indicators reported here have been compromised by changes in the fisheries they monitor, under-reporting by commercial fishers, and reduced collection of data by observers. They may also have been invalidated by avoidance of sharks by SLLs and changes in shark availability resulting from shark movement. These factors combine to make interpretation of the stock status of the three species problematic.

The observer dataset provides the most accurate and long-term record of New Zealand pelagic shark catches and may give the best insight into pelagic shark abundance trends. Caution is required in interpreting the trends, however. North region observer coverage has been low and unrepresentative of the fishery; the termination of the Japan South observer series in 2015 means there is no measure of current shark status there; and observer CPUE is vulnerable to some of the factors mentioned above, particularly fisher avoidance of sharks and shark movement. The observer CPUE time series suggest the following long-term trends (bearing in mind that the indices for 2017–2018 may be unreliable):
1. Blue shark. Abundance may have declined during the late 1990s and early 2000s, and then increased to considerably higher levels by 2015, followed by a decline in 2017–2018 in North region (see Figures 19 and 23, bottom right panels).
2. Mako shark. Abundance in North region appears to have been stable since the late 1990s (see Figure 31, bottom right panel). The South region index showed a steady decline from the late 1990s to the mid 2000s before stabilising (see Figure 27, bottom right panel), but mako shark abundance is lower in South region than in North region, so that index may not be representative of mako shark abundance in the EEZ.
3. Porbeagle shark. Abundance may have declined in the late 1990s (although the large peaks in the mid–late 1990s may be spurious) before increasing to higher levels in the late 2000s and early 2010s and declining again in 2017–2018 (see Figures 35 and 39, bottom right panels).

The observer CPUE indicators cover only the most recent portion of a longer fishing history that was characterised by greater effort levels (see Figure 1). SLL fishing effort in the New Zealand EEZ was high in the 1980s and early 1990s, when many foreign fishing vessels held licences. The SLL fleet set 10–25 million hooks per year over that period compared with fewer than 10 million hooks per year since 1993 and fewer than 4 million hooks since 2005 (see Figures 1 and 2). There is no information on the effect of the high fishing effort of the 1980s and early 1990s, and there are no shark catch data from that period, nor effort data from before 1980.

Blue, porbeagle, and mako sharks are generally regarded as wide-ranging, mobile oceanic species. Although this may be true of blue sharks, recent electronic tagging of porbeagle and mako sharks in New Zealand waters has shown that juveniles (which make up a high proportion of the catch of each species) are partly residential in the New Zealand EEZ. Tagged porbeagles make seasonal north-south movements within the EEZ (some also move outside the EEZ), being found further north in winter and further south in summer (Francis et al. 2015). Similarly, tagged juvenile mako sharks have spent 42–100% of their time inside the EEZ during deployments of 5–19 months (Francis et al. 2019). Thus abundance indices for the New Zealand EEZ may not index the entire southwest Pacific populations of those species.

Pelagic shark populations inside the EEZ may have been affected by fishing effort outside the EEZ, but the extent of any impact is unknown. SLL effort in the Southern Hemisphere has recently been quantified and shows relatively low fishing effort in temperate and subtropical waters of the southwest Pacific, with higher intensity hotspots in tropical areas around and north of Fiji and New Caledonia (Francis & Hoyle 2019). Larger-scale stock assessments are warranted. A stock status assessment of the entire Southern Hemisphere range of porbeagle shark found that the impact of fishing was low (Hoyle et al. 2017), but similar assessments have not been carried out for blue or mako shark. To understand trends in the wider HMS shark stocks of the South Pacific, and to quantify their status in relation to management reference points, quantitative regional stock assessments are now required.

10. ACKNOWLEDGEMENTS

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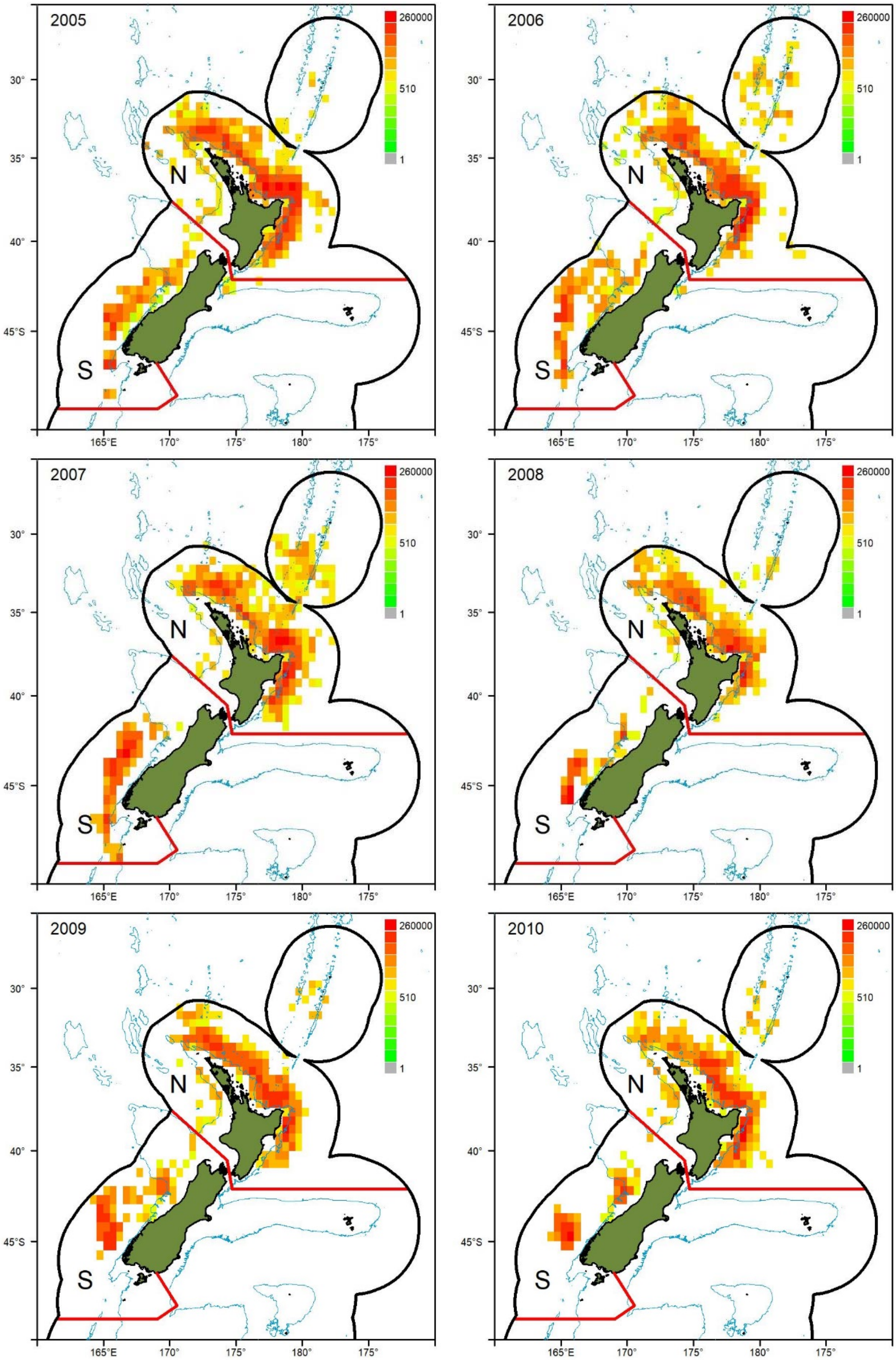
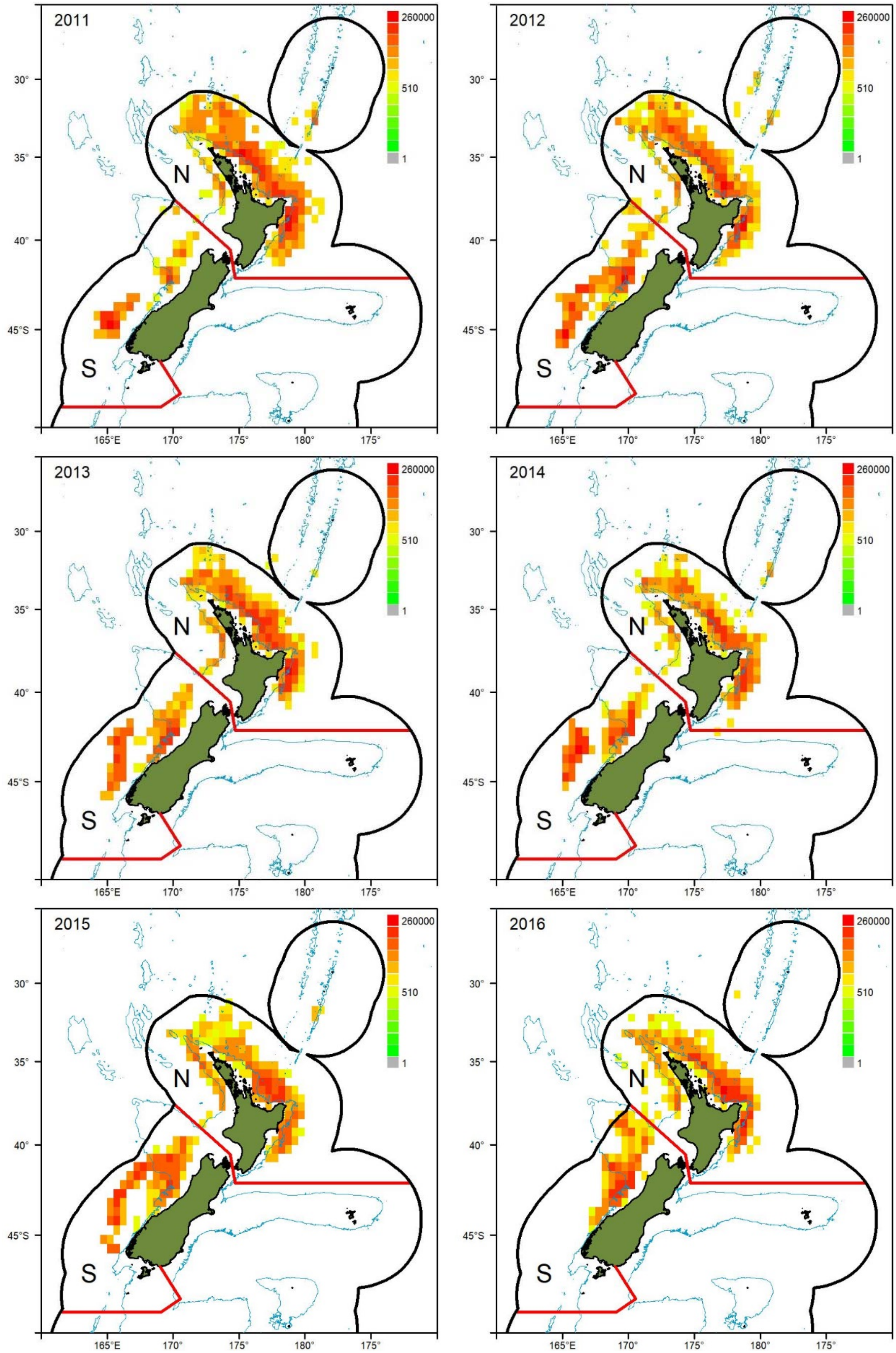
APPENDICES

Appendix 1: Number of hooks set by the surface longline fishery in 0.5 degree cells in the EEZ, by fishing year for 2005–2018. Note the log scale used for the colour palette. Depth contour = 1000 m. Red lines indicate the boundaries of North (N) and South (S) regions.



Appendix 1: ***continued***



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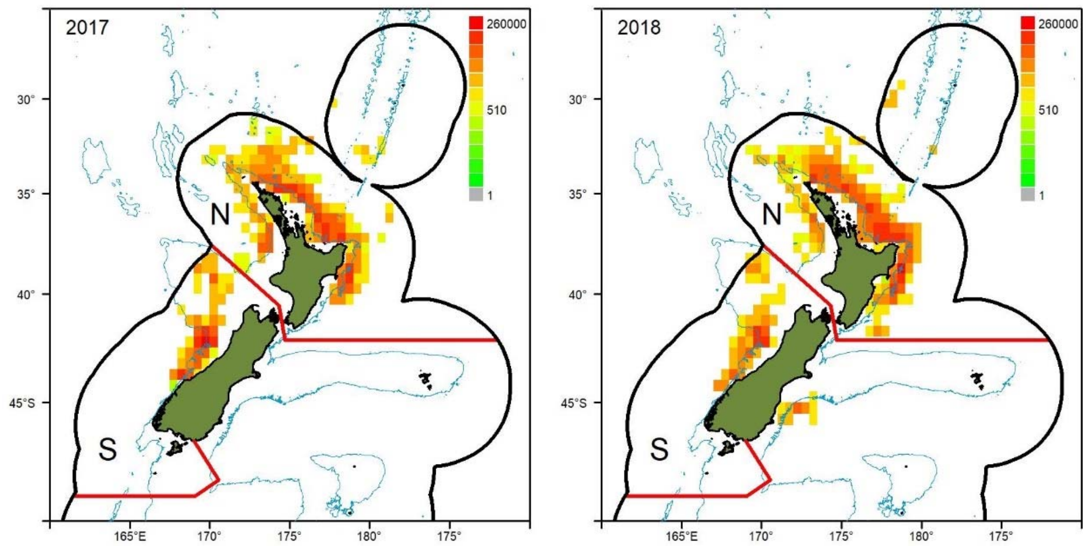
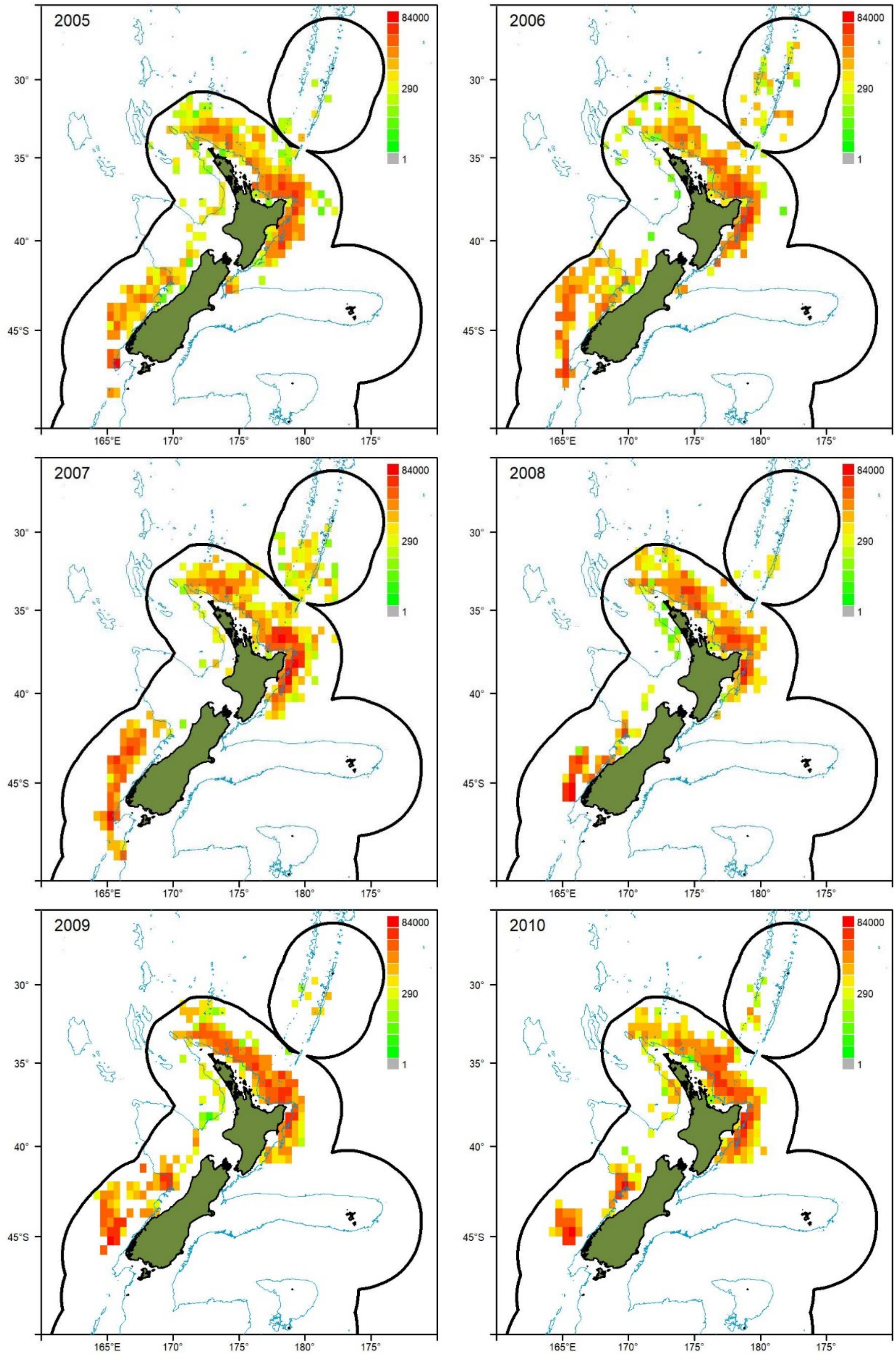


Appendix 2: Blue shark catches (kg) by the surface longline fishery in 0.5 degree cells in the EEZ, by fishing year for 2005–2018. Note the log scale used for the colour palette. Depth contour = 1000 m.



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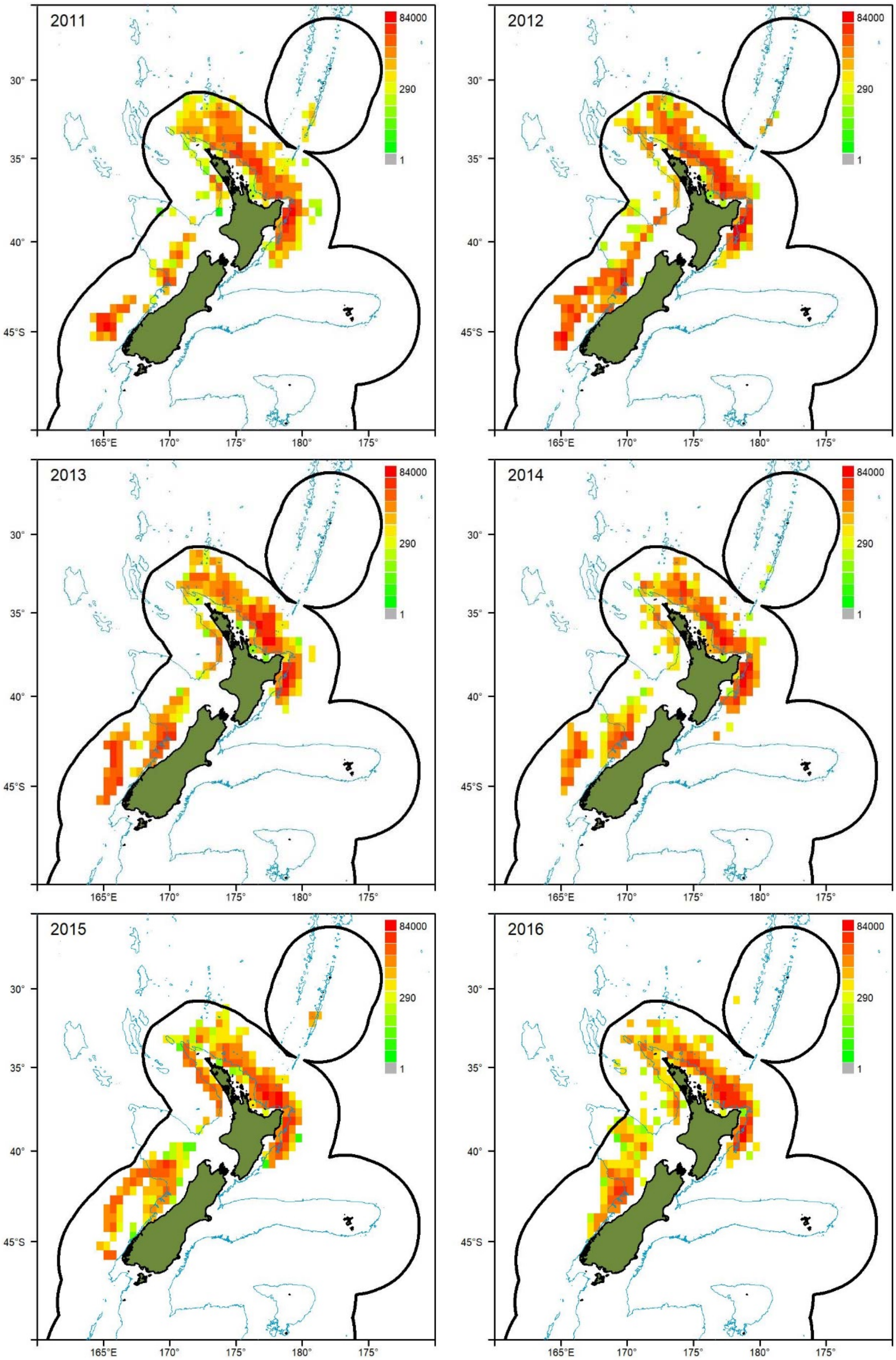

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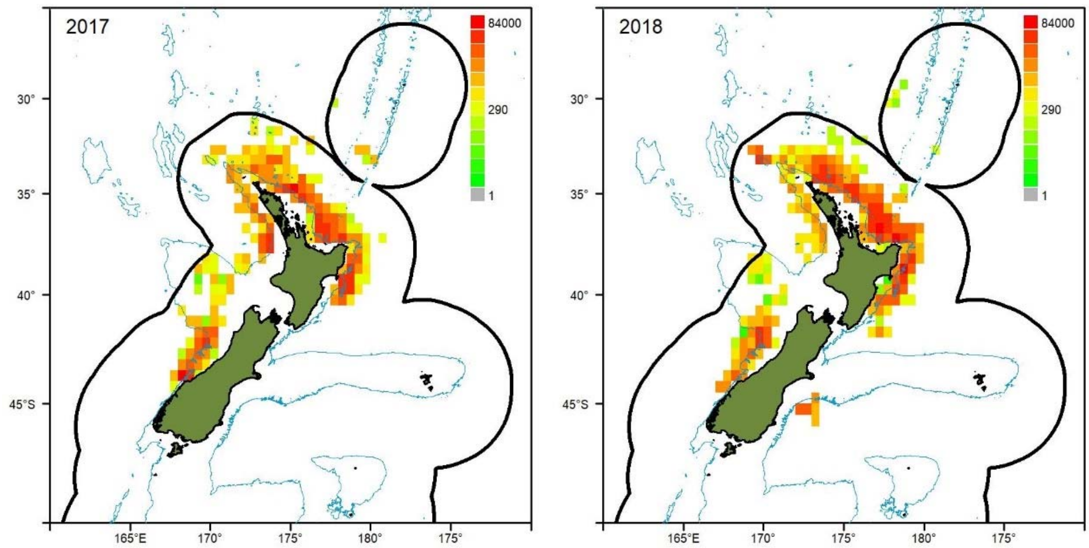
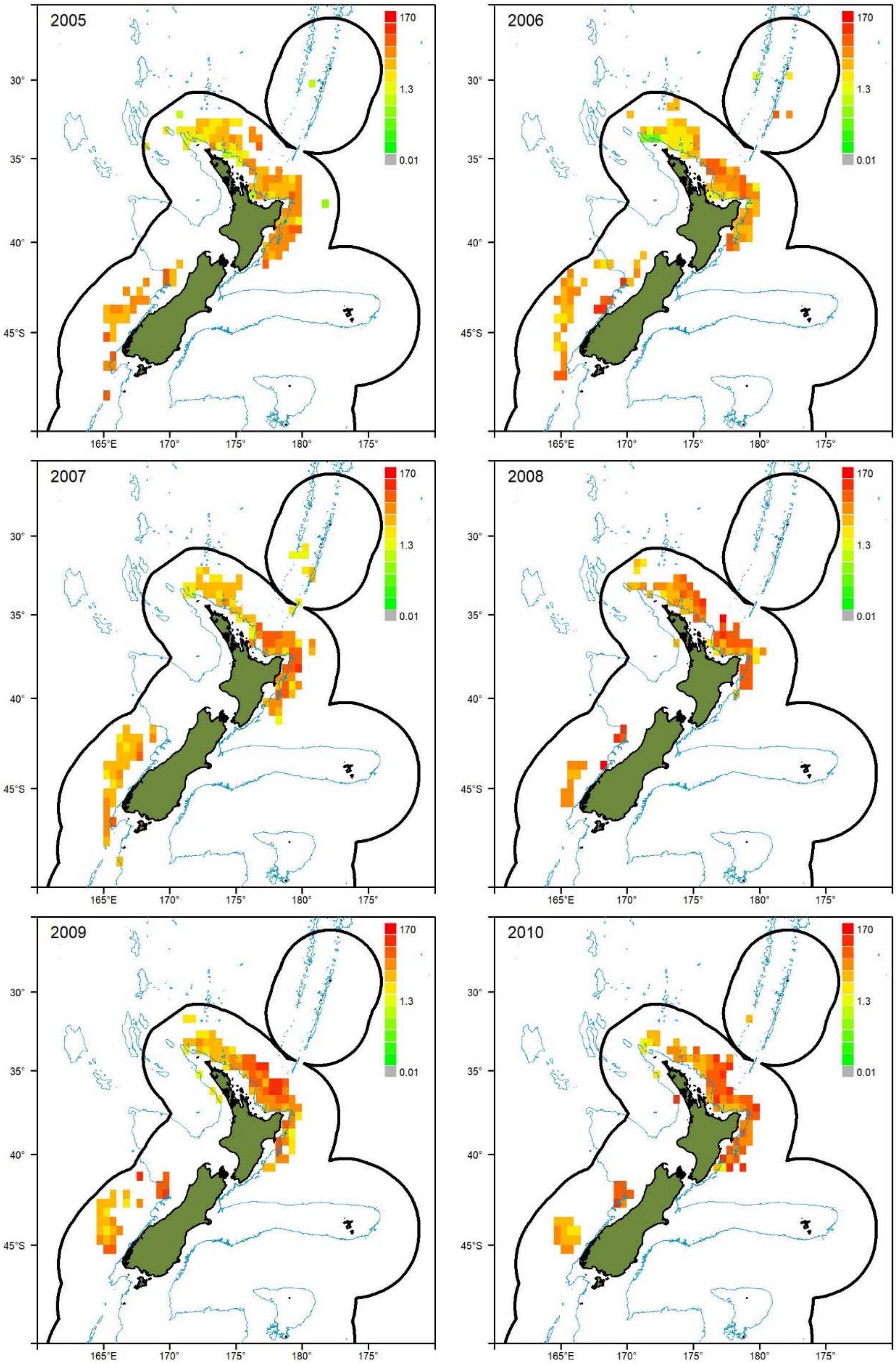


Appendix 3: Blue shark catch rates (number per 1000 hooks) by the surface longline fishery in 0.5 degree cells in the EEZ, by fishing year for 2005–2018. Note the log scale used for the colour palette. Depth contour = 1000 m.



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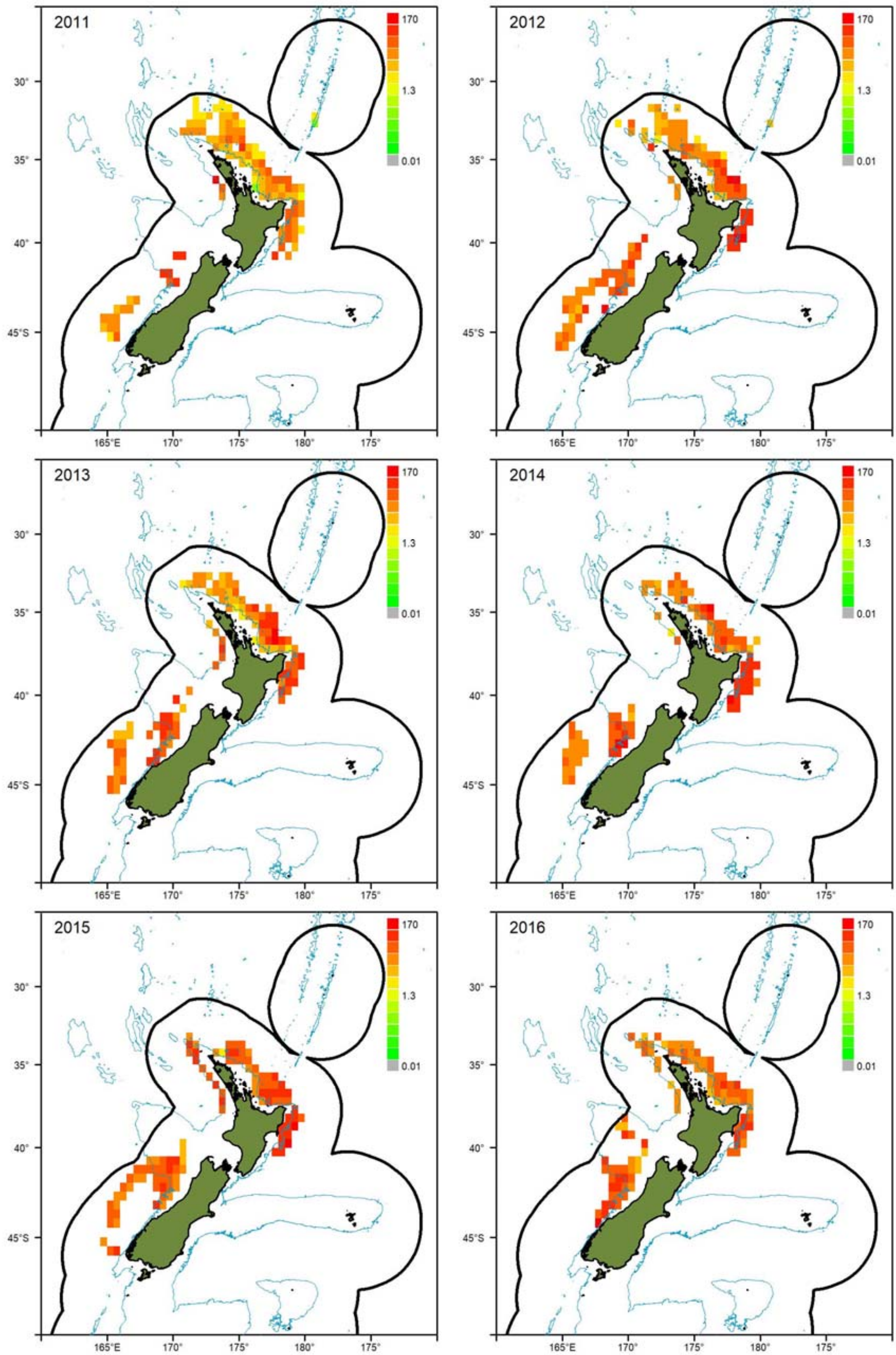

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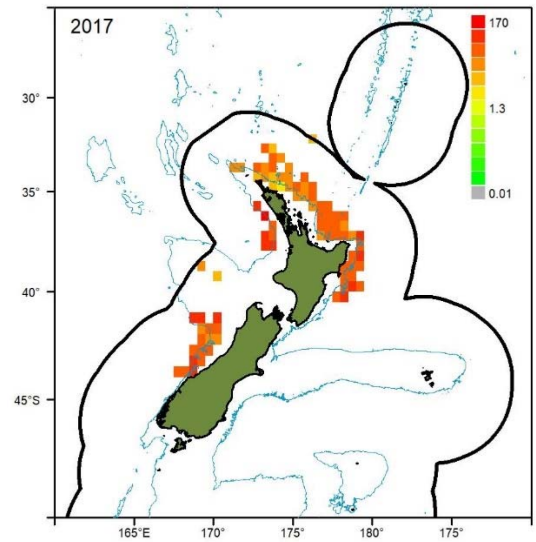
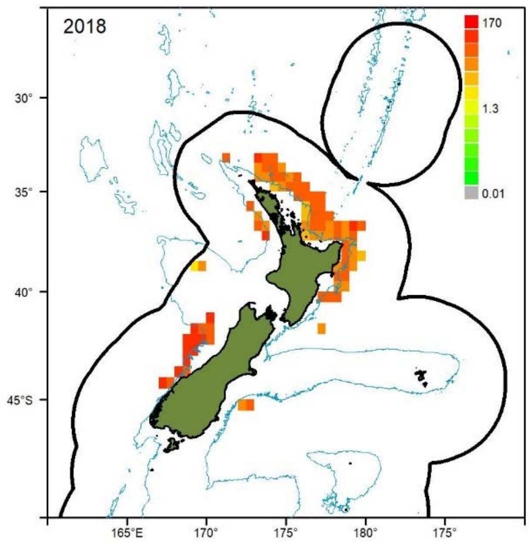
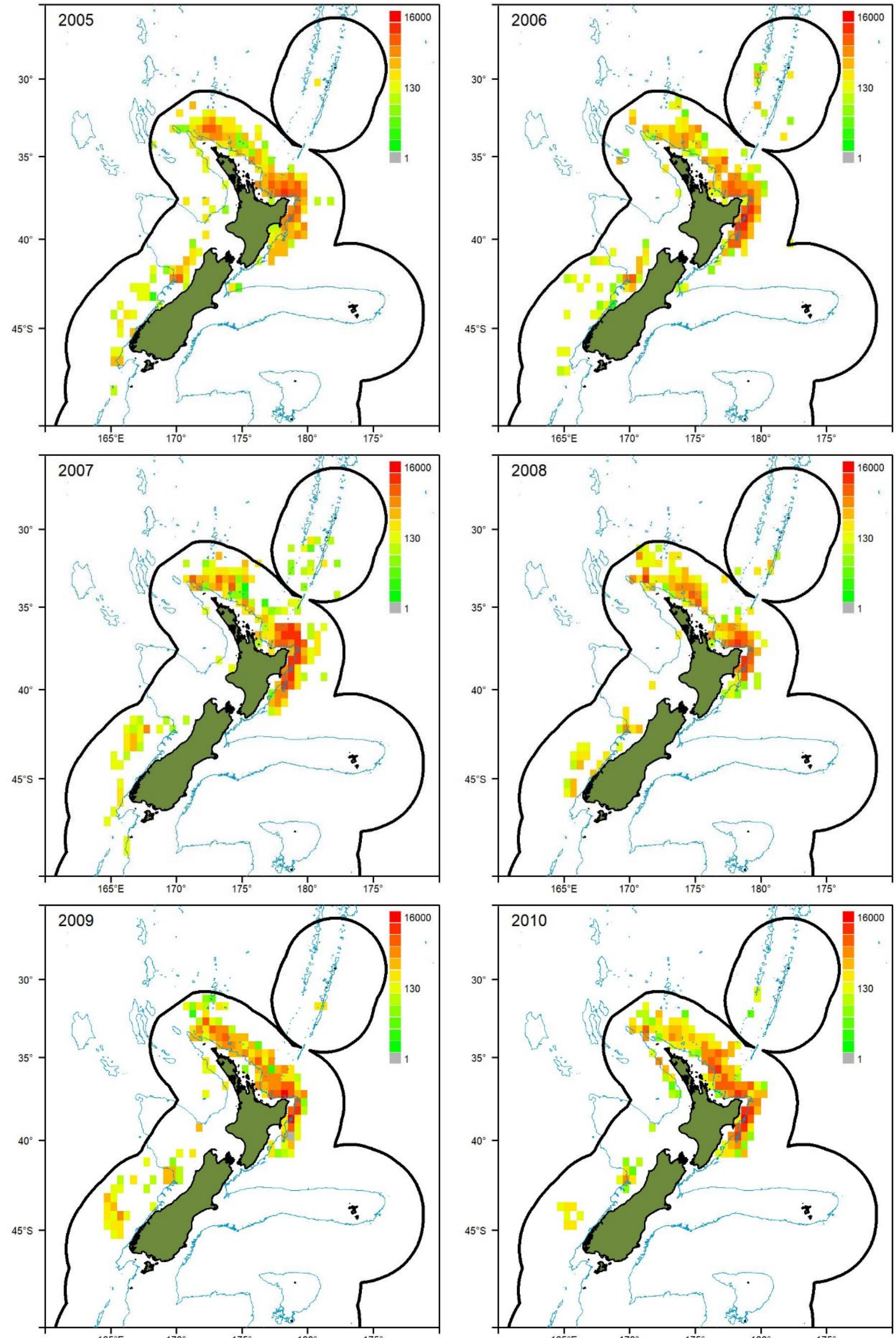




Appendix 4: Mako shark catches (kg) by the surface longline fishery in 0.5 degree cells in the EEZ, by fishing year for 2005–2018. Note the log scale used for the colour palette. Depth contour = 1000 m.



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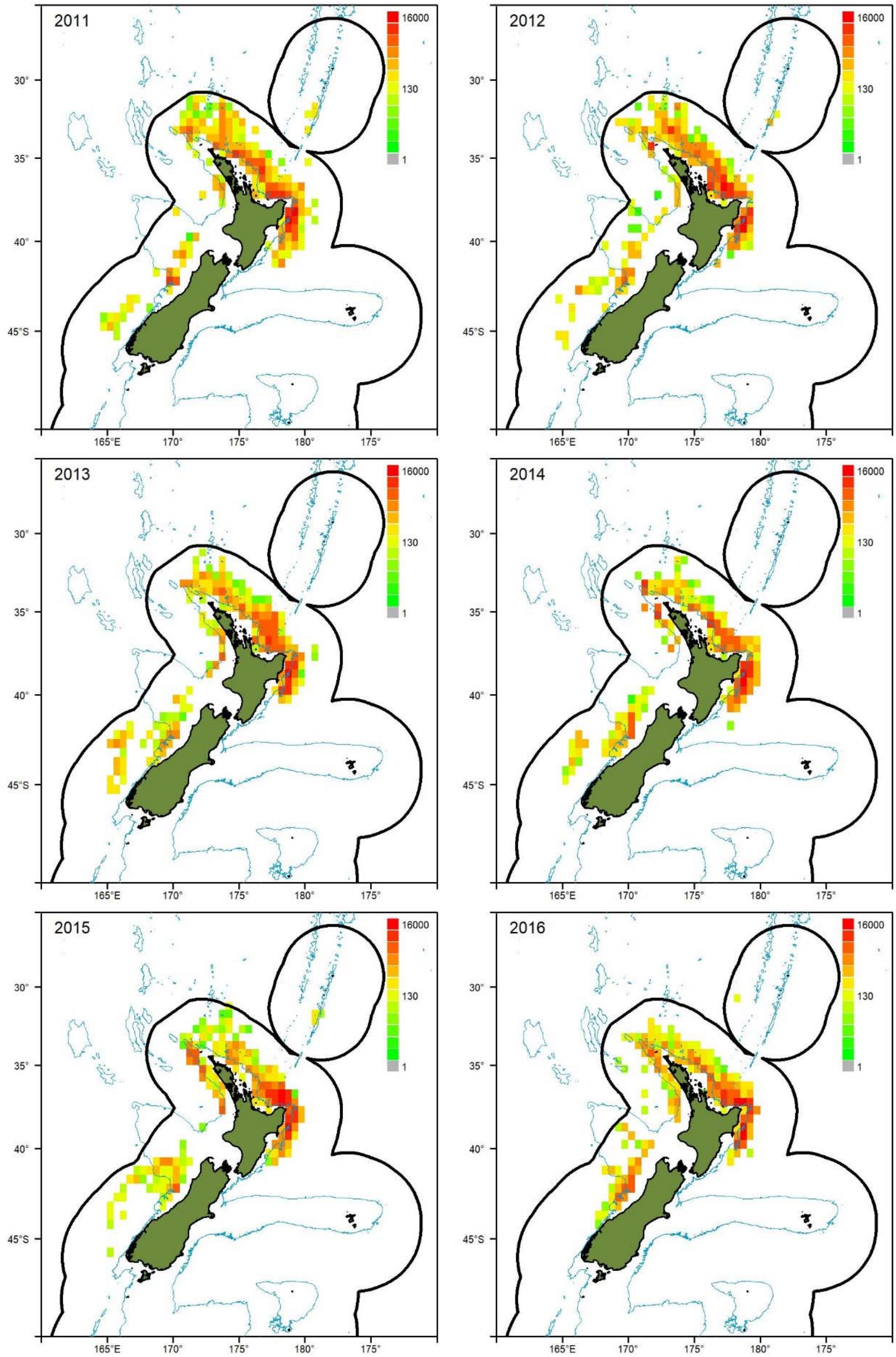

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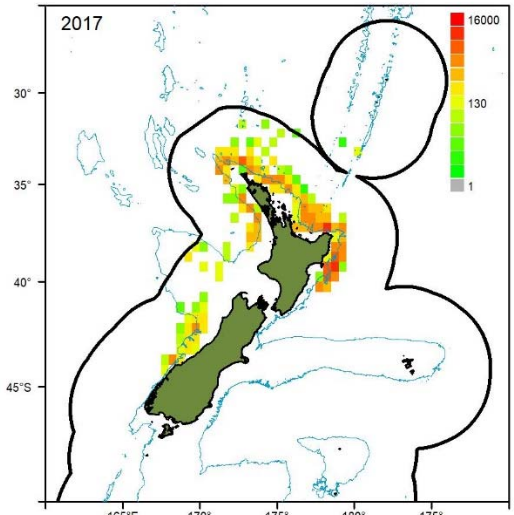
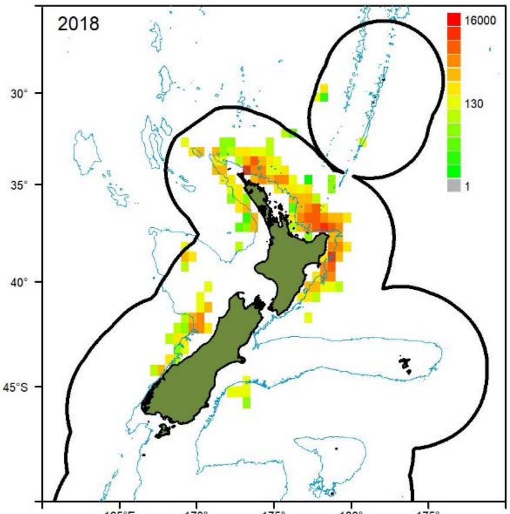
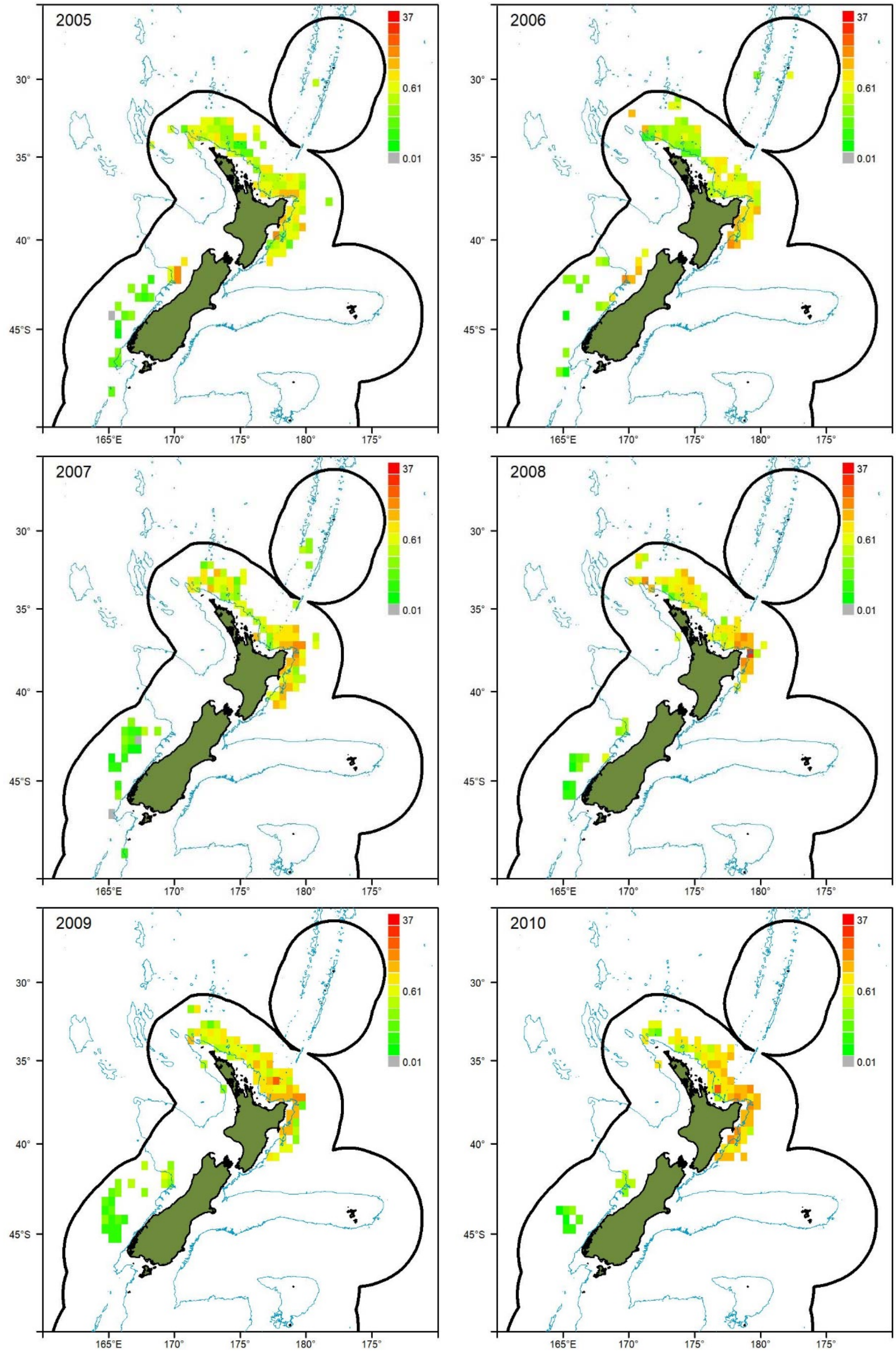




Appendix 5: Mako shark catch rates (number per 1000 hooks) by the surface longline fishery in 0.5 degree cells in the EEZ, by fishing year for 2005–2018. Note the log scale used for the colour palette. Depth contour = 1000 m.



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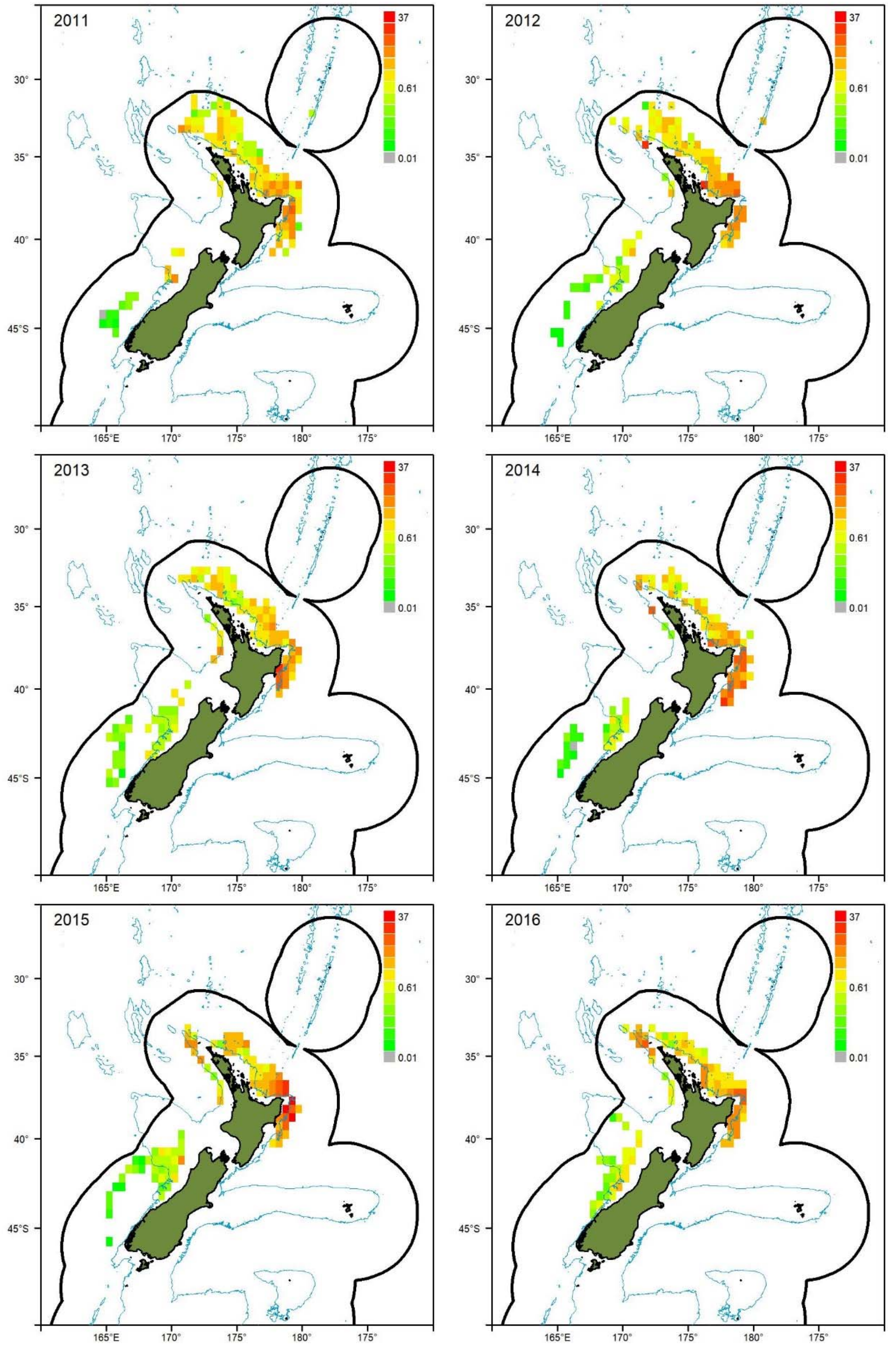

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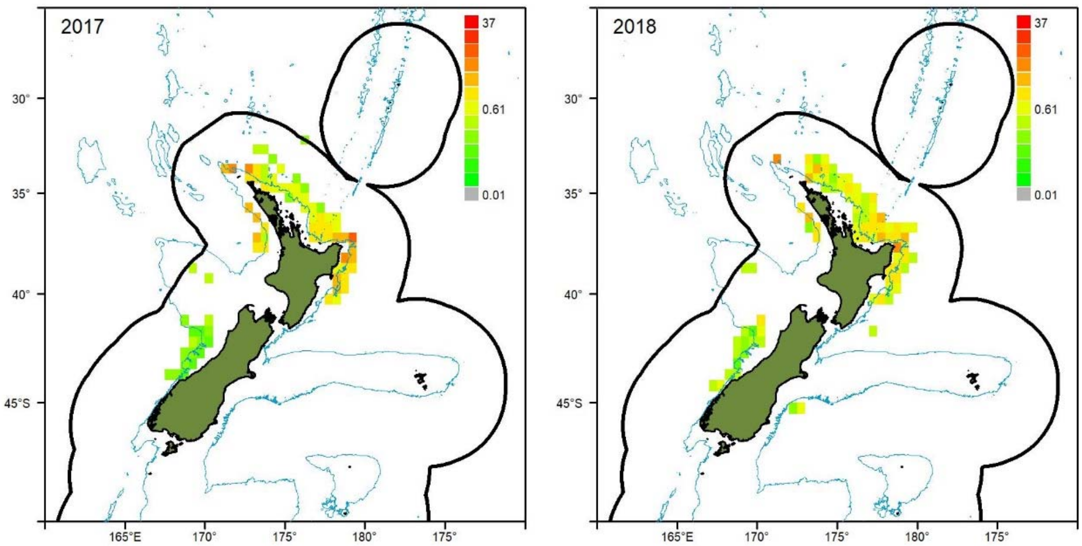
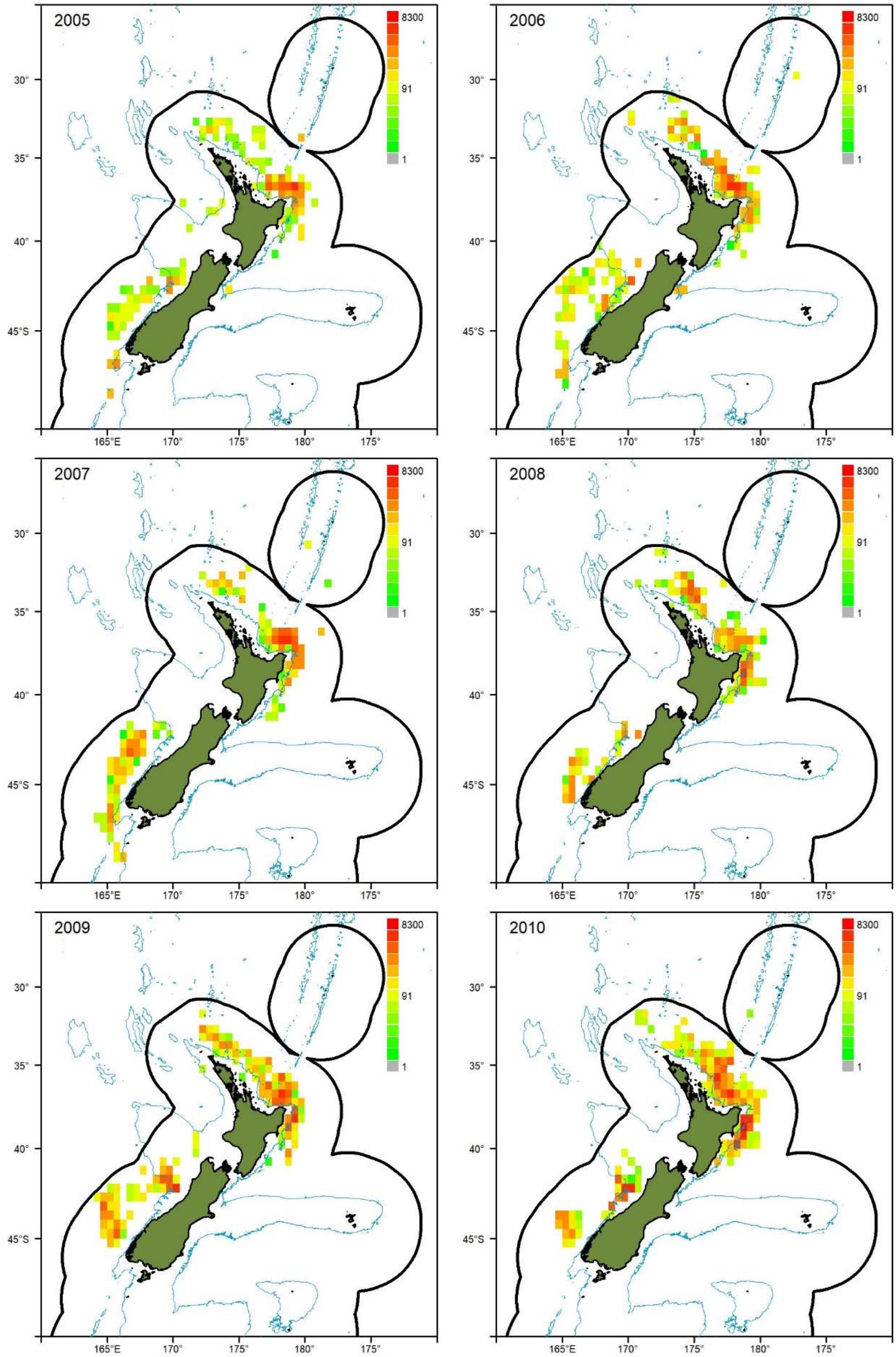


Appendix 6: Porbeagle shark catches (kg) by the surface longline fishery in 0.5 degree cells in the EEZ, by fishing year for 2005–2018. Note the log scale used for the colour palette. Depth contour = 1000 m.



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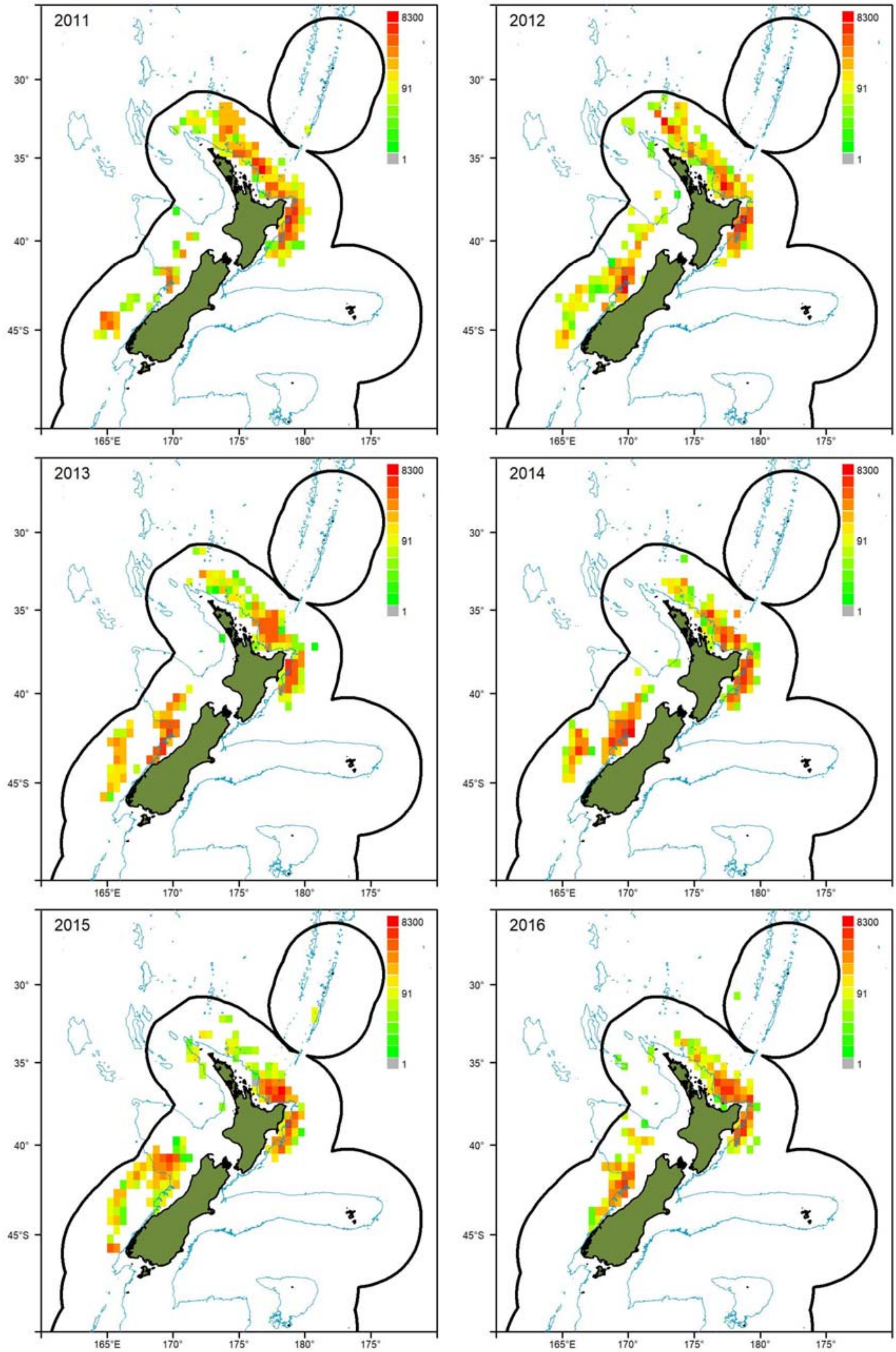

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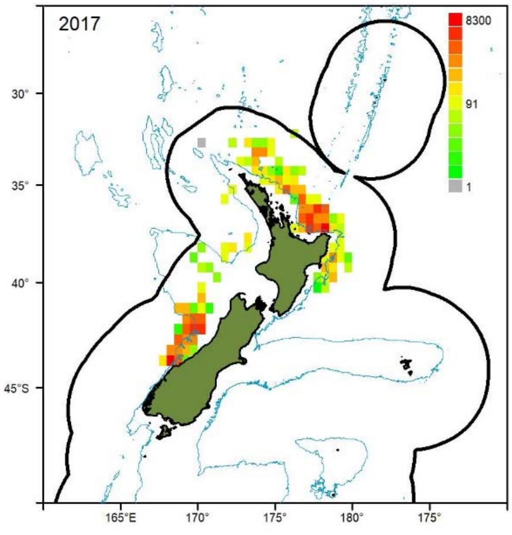
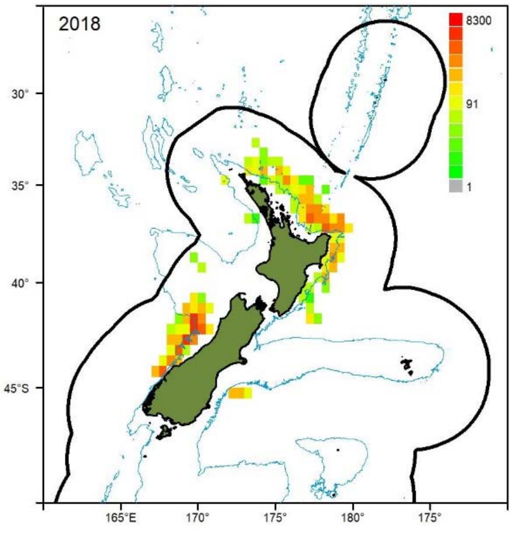
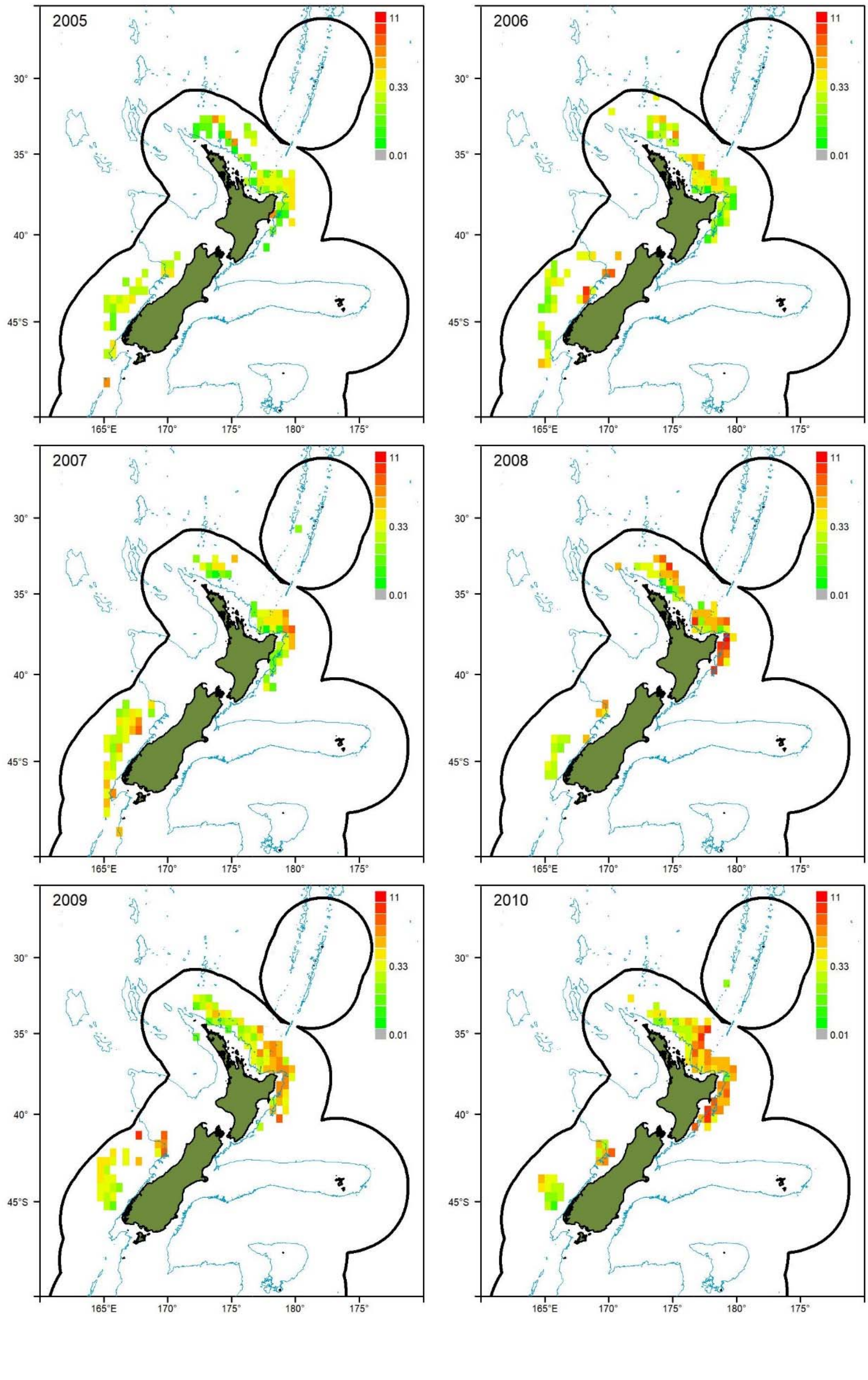




Appendix 7: Porbeagle shark catch rates (number per 1000 hooks) by the surface longline fishery in 0.5 degree cells in the EEZ, by fishing year for 2005–2018. Note the log scale used for the colour palette. Depth contour = 1000 m.



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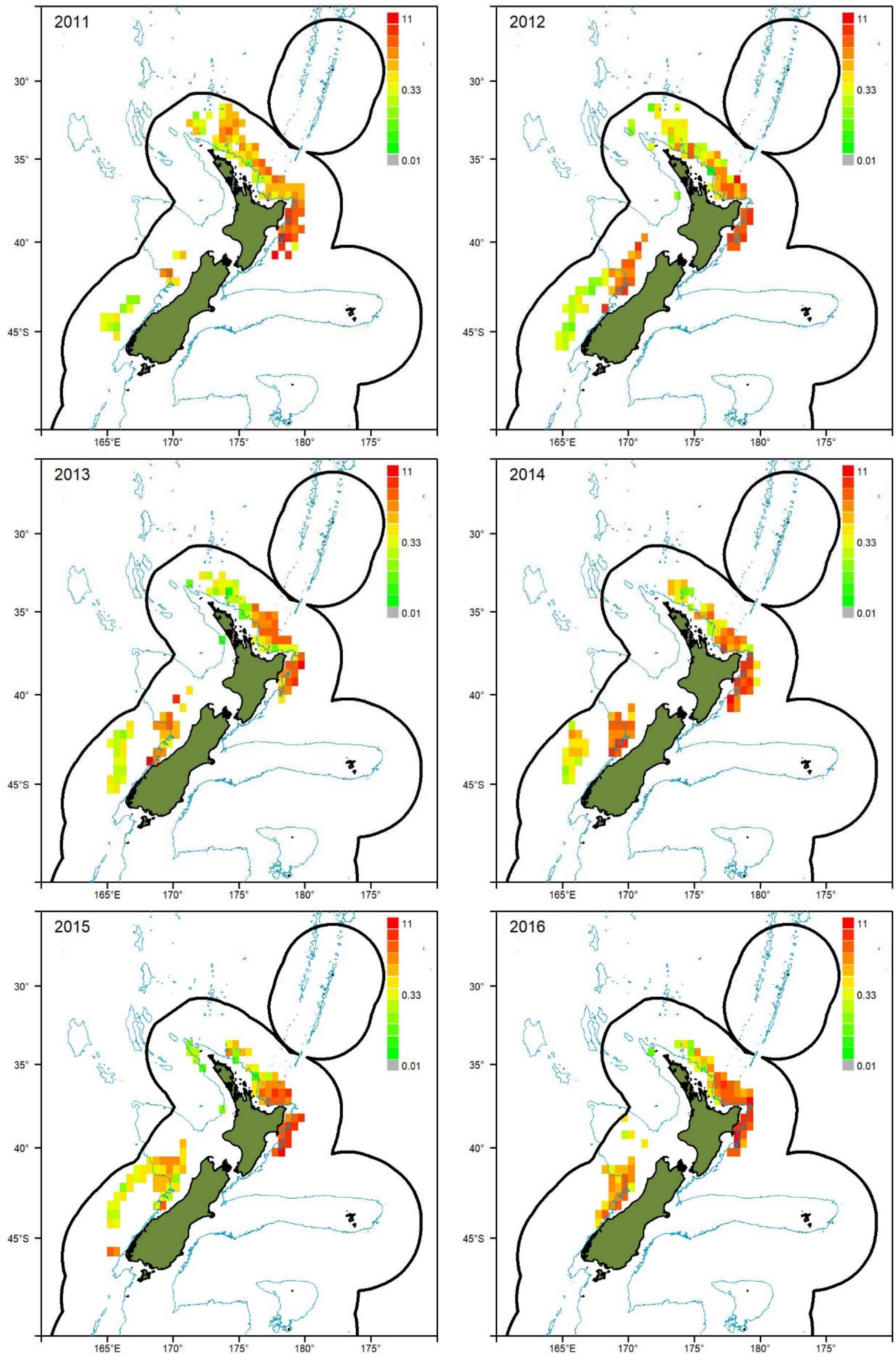

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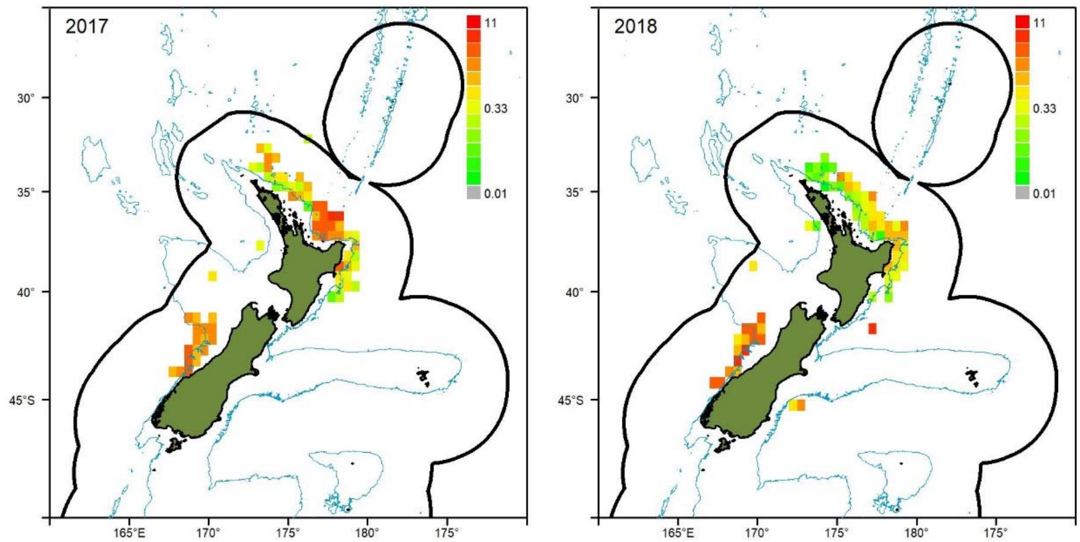
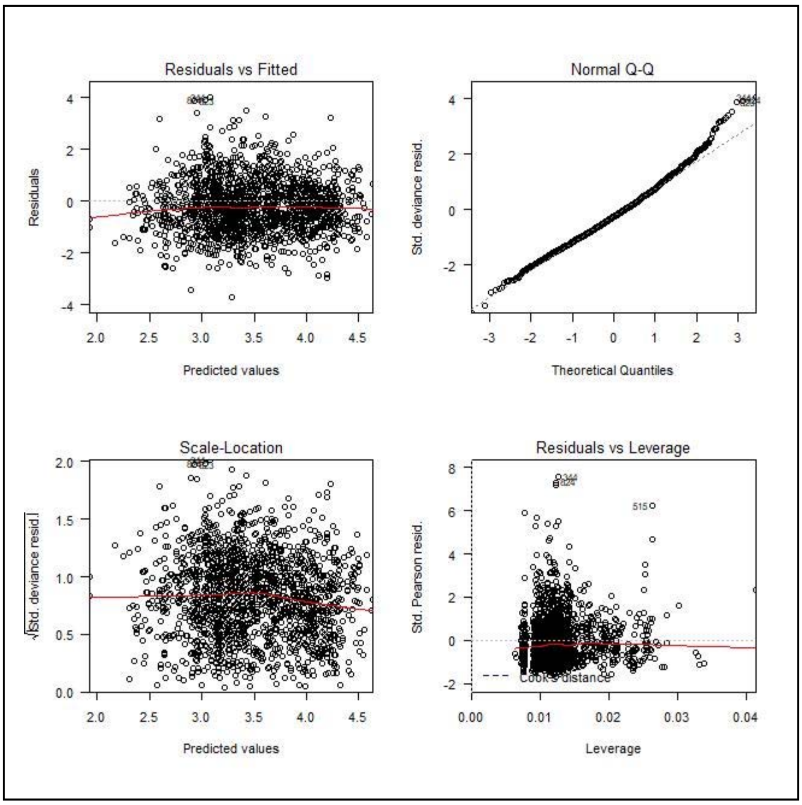
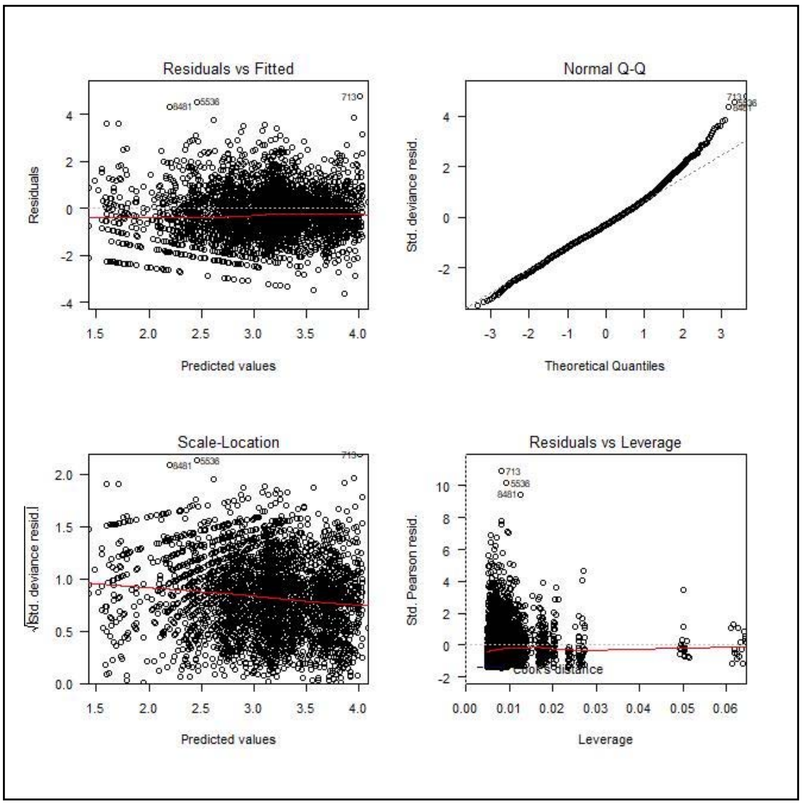
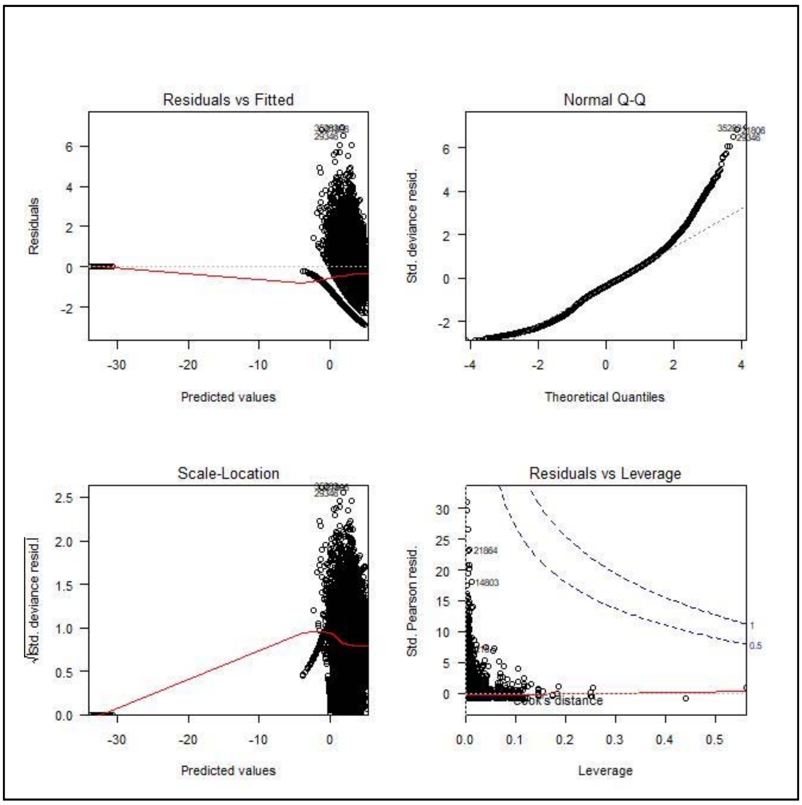


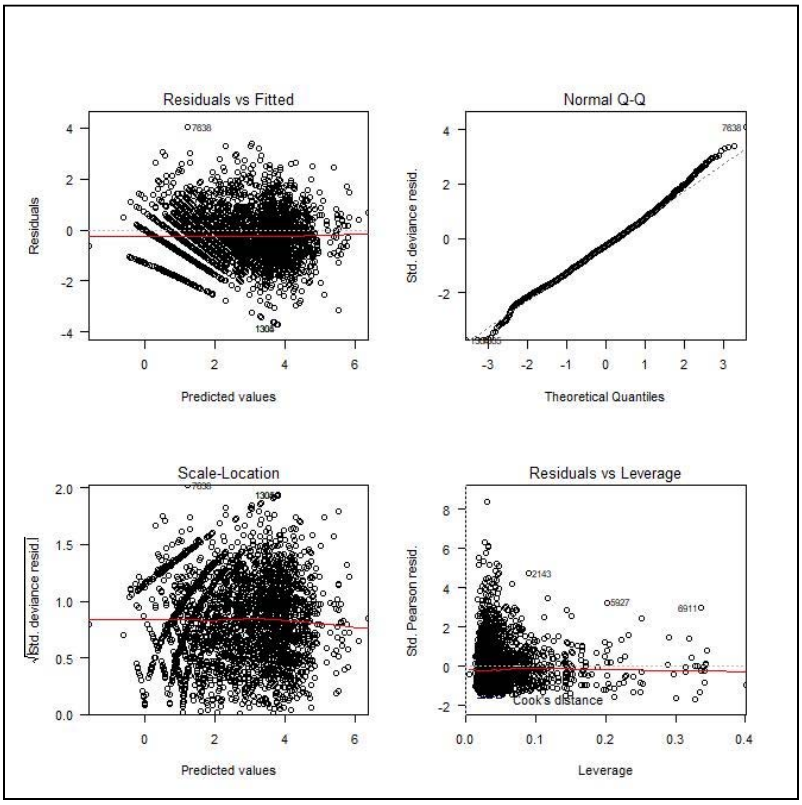
Appendix 8: Blue shark catches in Japan South dataset. Model diagnostics for TLCER (top) and observer (bottom) data, both fitted with a negative binomial model.



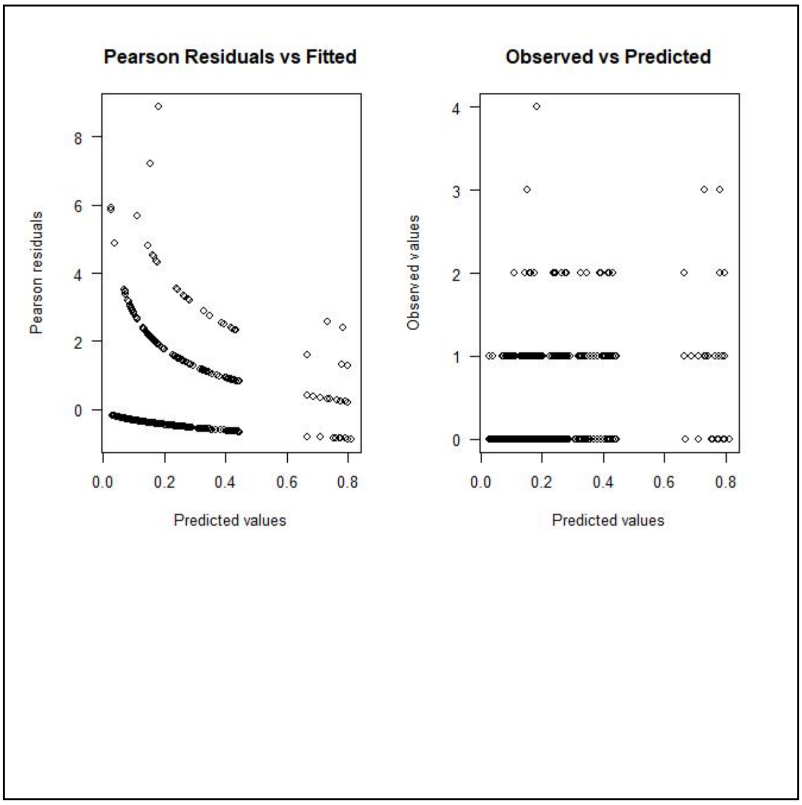


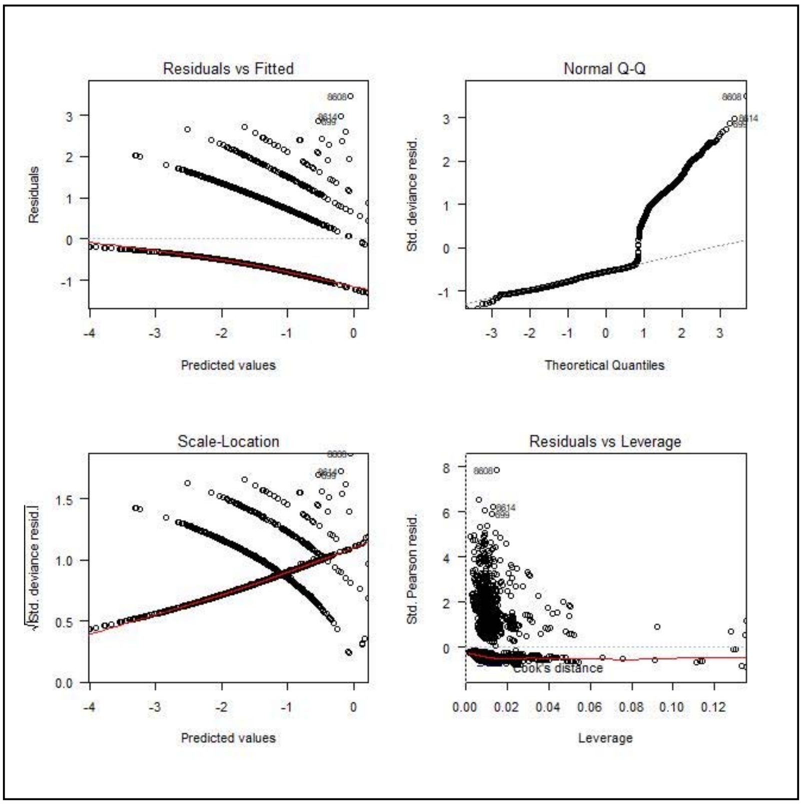
Appendix 9: Blue shark catches in North dataset. Model diagnostics for TLCER (top) and observer (bottom) data, both fitted with a negative binomial model.



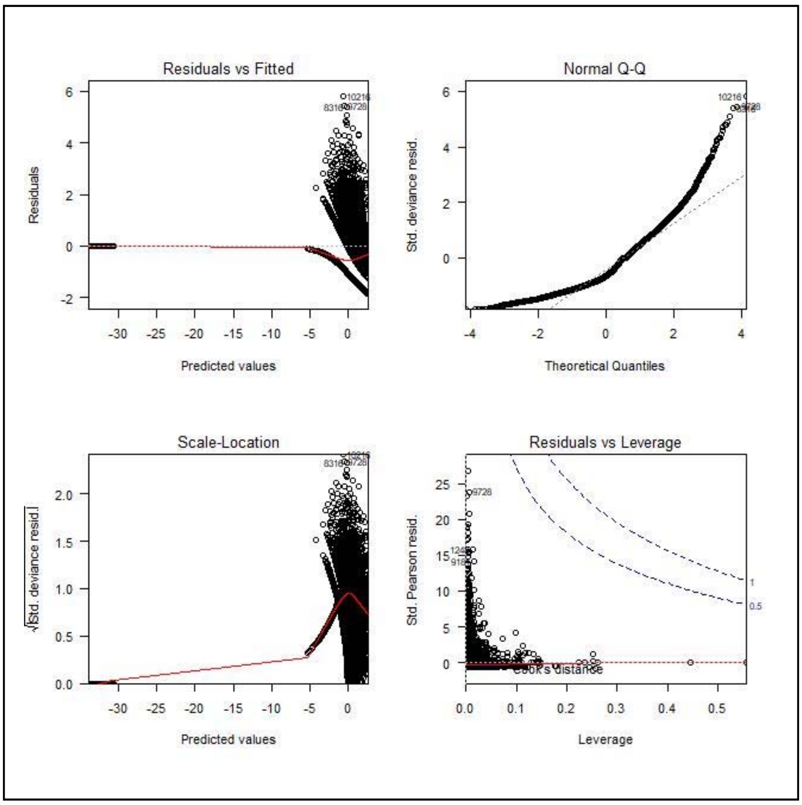


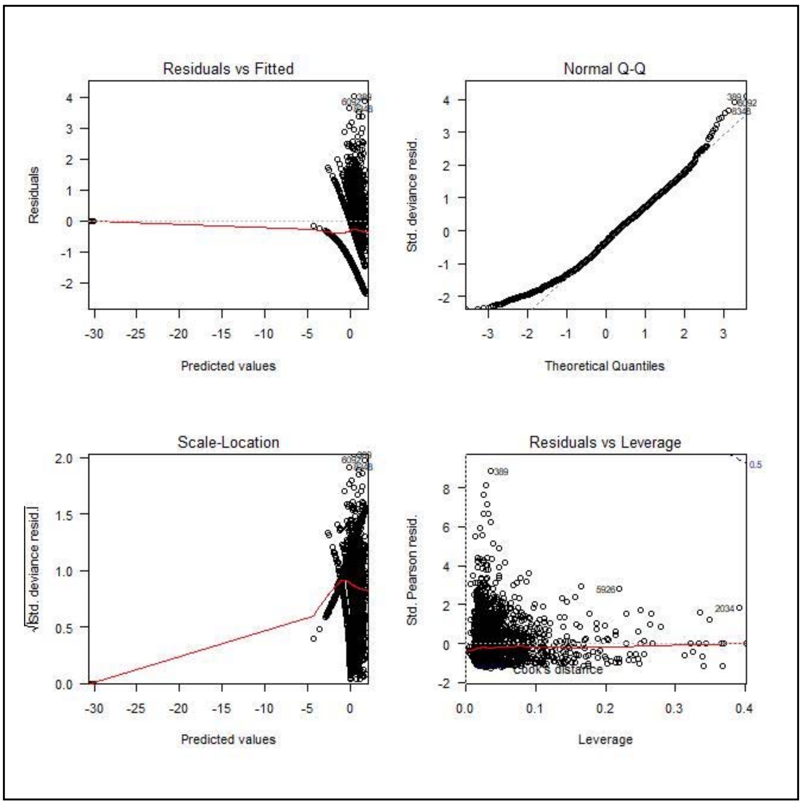
Appendix 10: Mako shark catches in Japan South dataset. Model diagnostics for TLCER (top) and observer (bottom) data, fitted with a zero inflated negative binomial model and a negative binomial model, respectively.



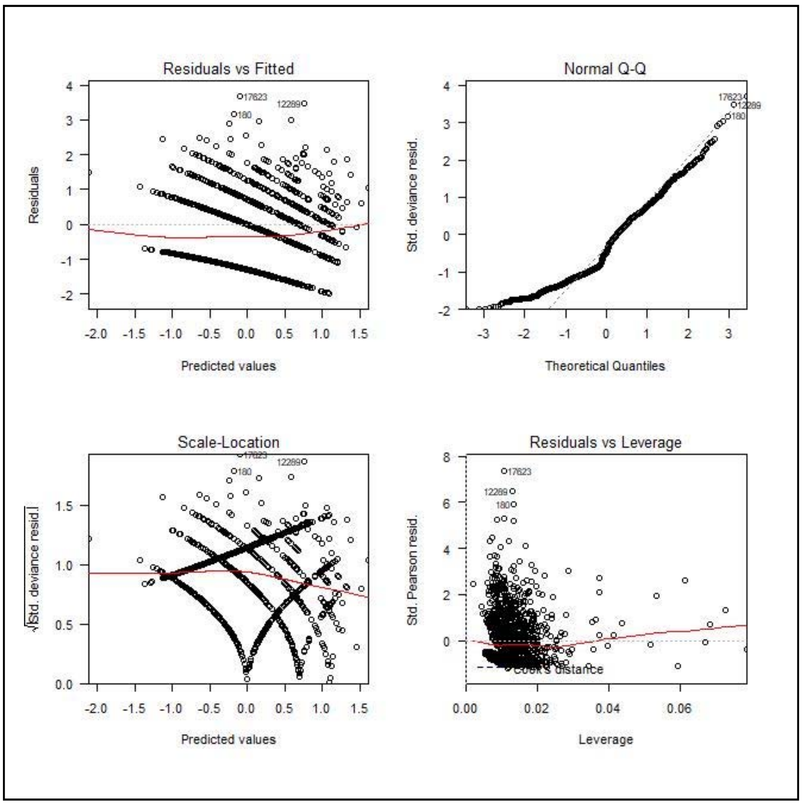


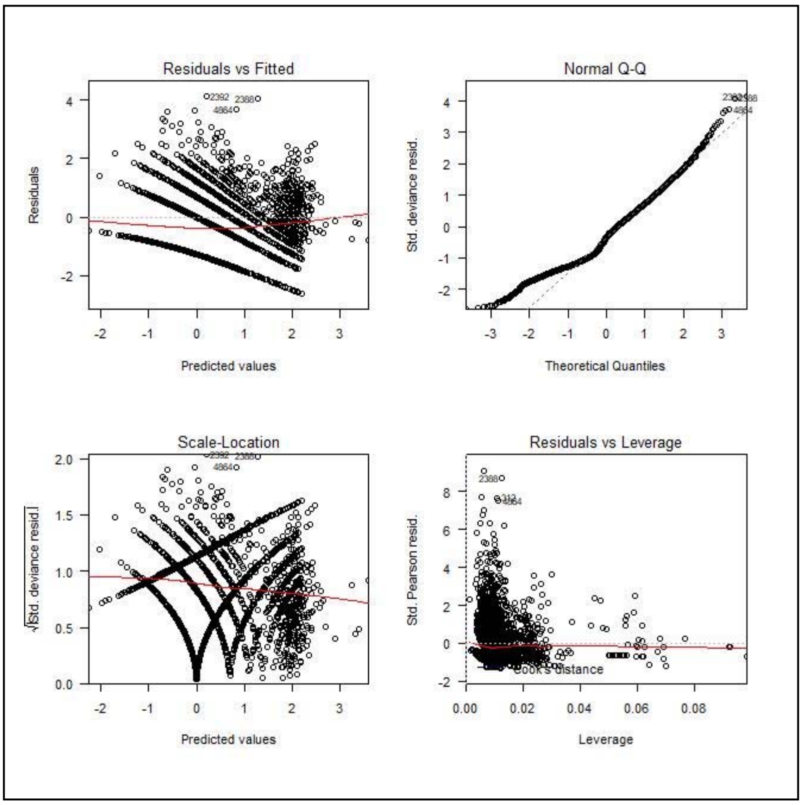
Appendix 11: Mako shark catches in North dataset. Model diagnostics for TLCER (top) and observer (bottom) data, both fitted with a negative binomial model.



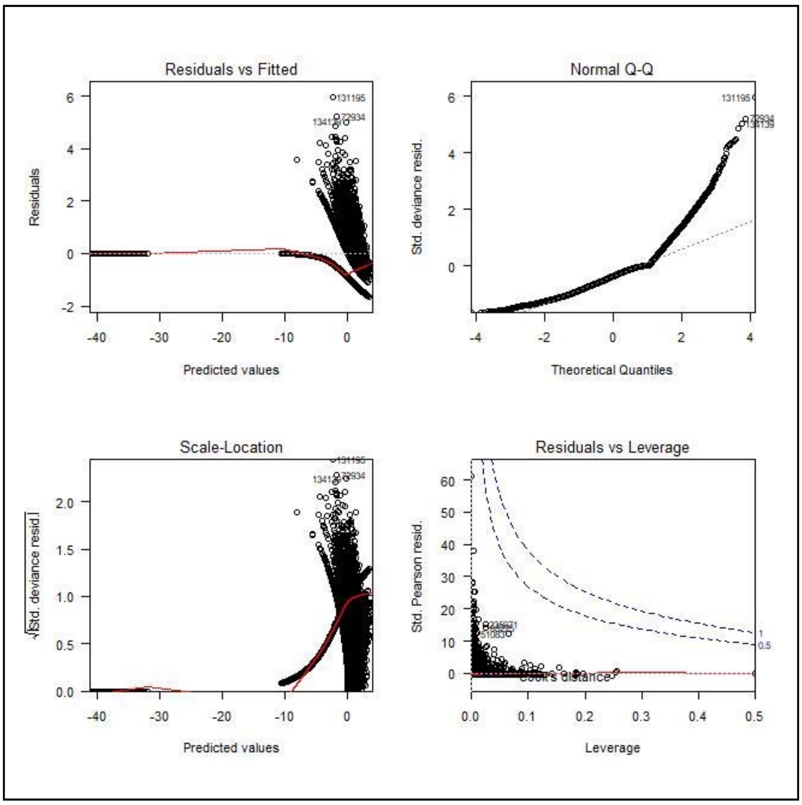


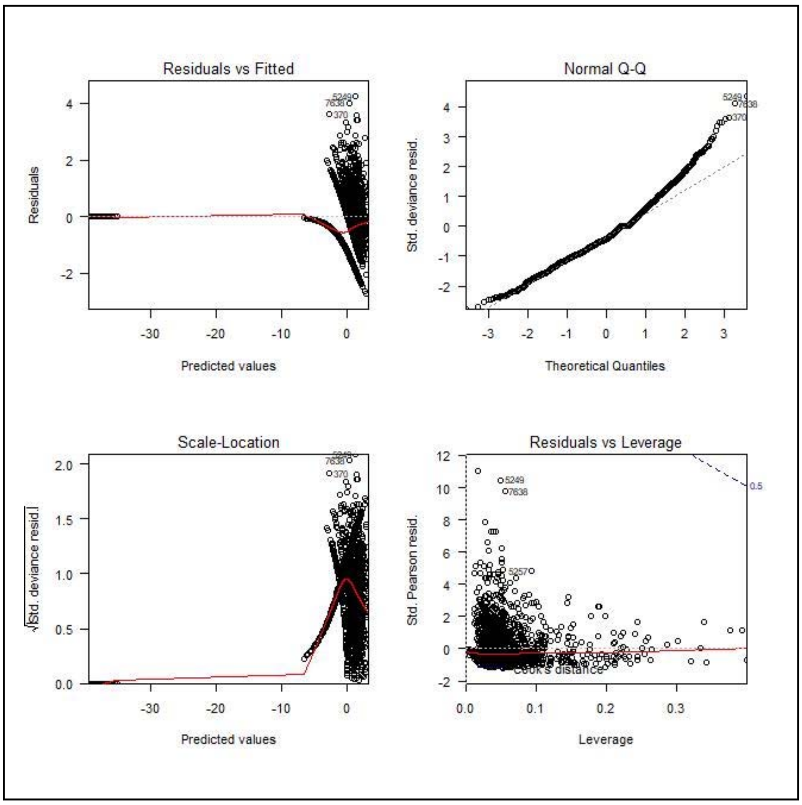
Appendix 12: Porbeagle shark catches in Japan South dataset. Model diagnostics for TLCER (top) and observer (bottom) data, both fitted with a negative binomial model.



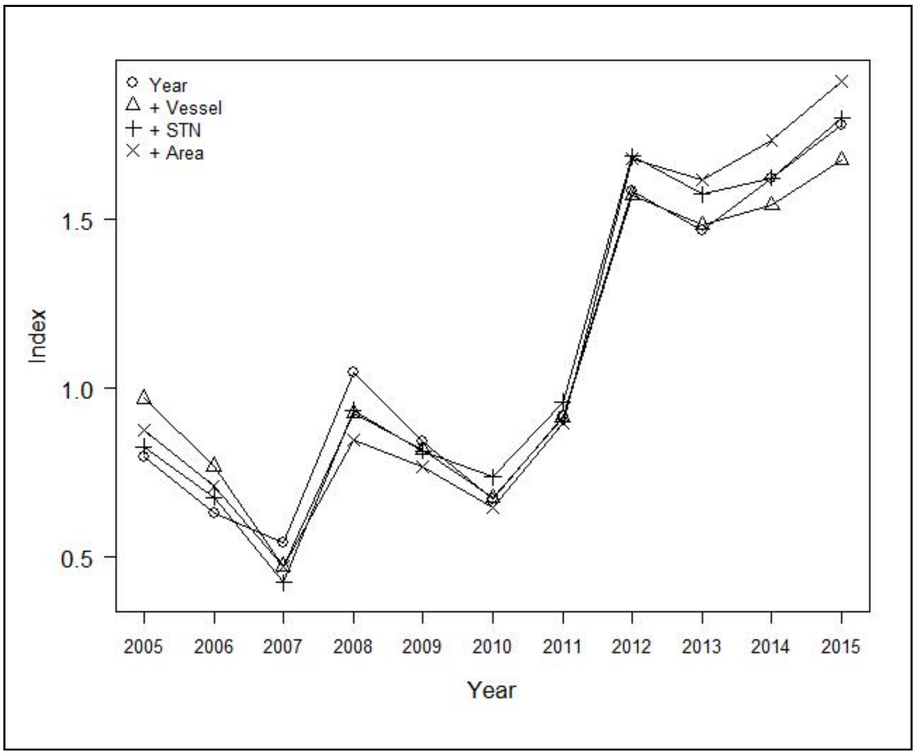


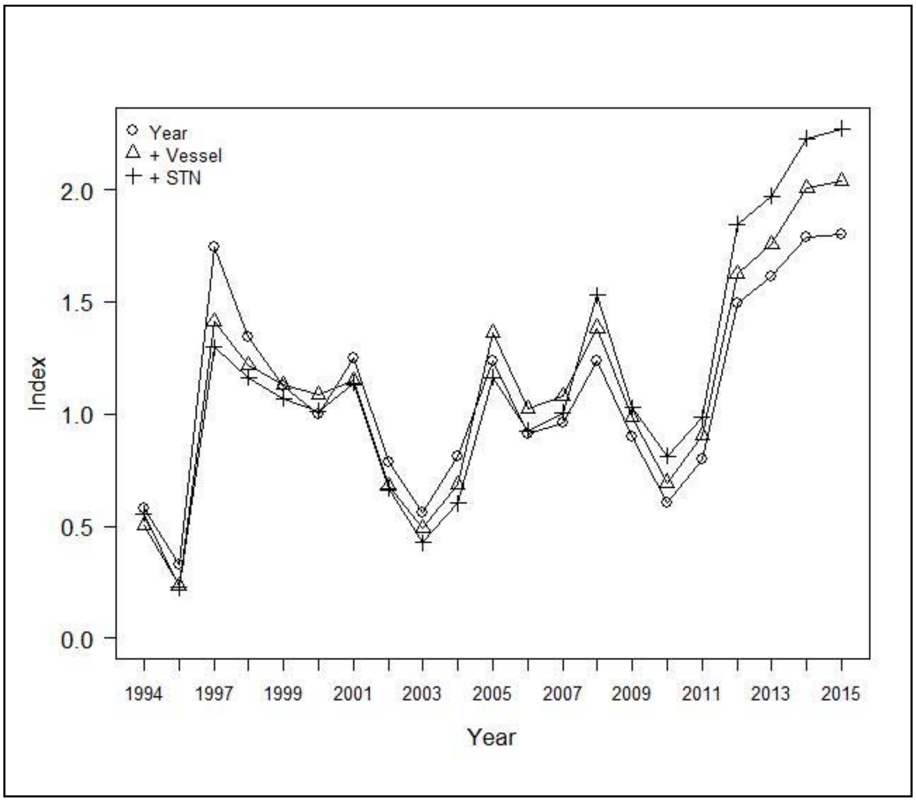
Appendix 13: Porbeagle shark catches in North dataset. Model diagnostics for TLCER (top) and observer (bottom) data, both fitted with a negative binomial model.



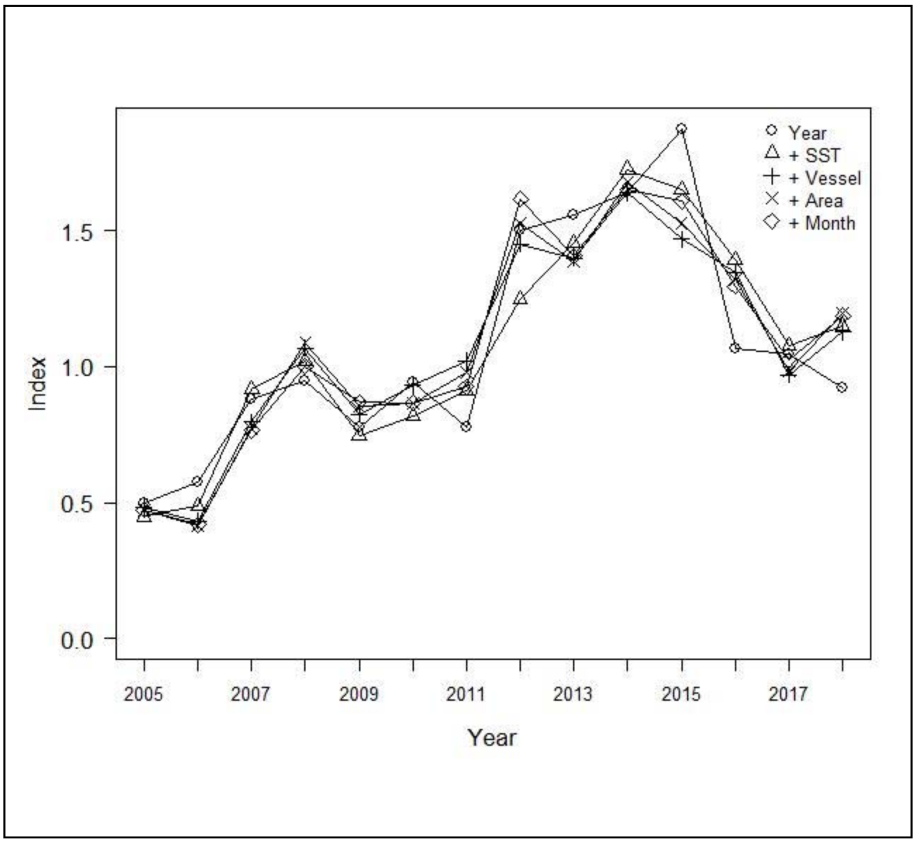


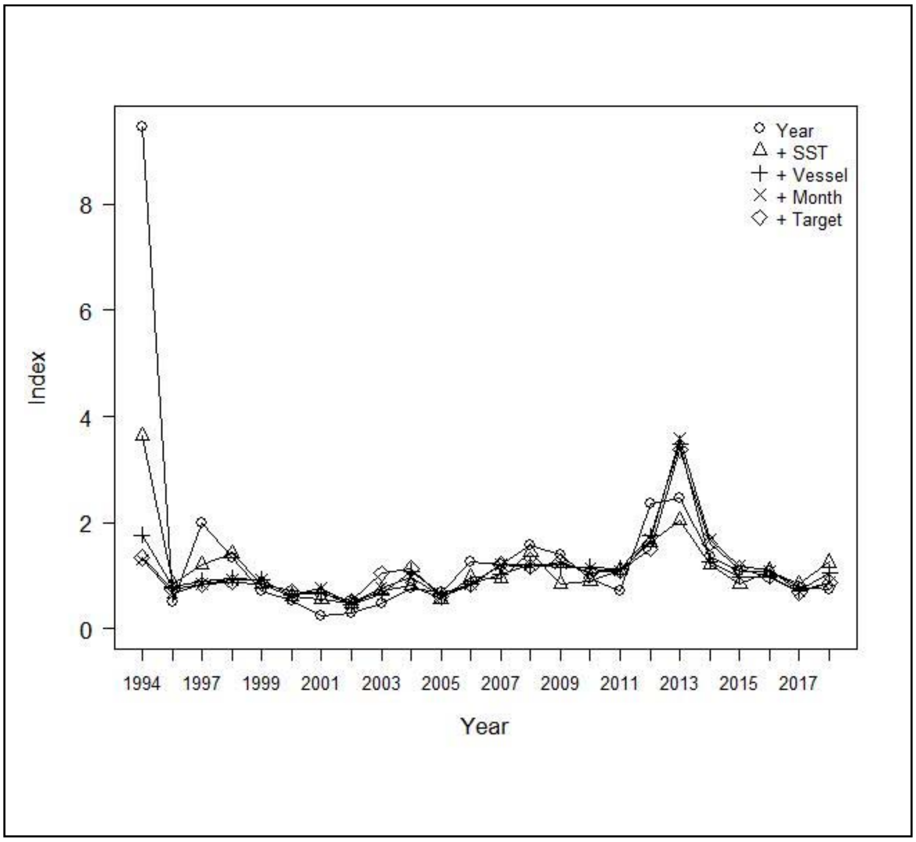
Appendix 14: Blue shark catches in Japan South dataset. CPUE standardised for year effects and other sequentially added variables for TLCER (top) and observer (bottom) data. STN is catch of southern bluefin tuna.



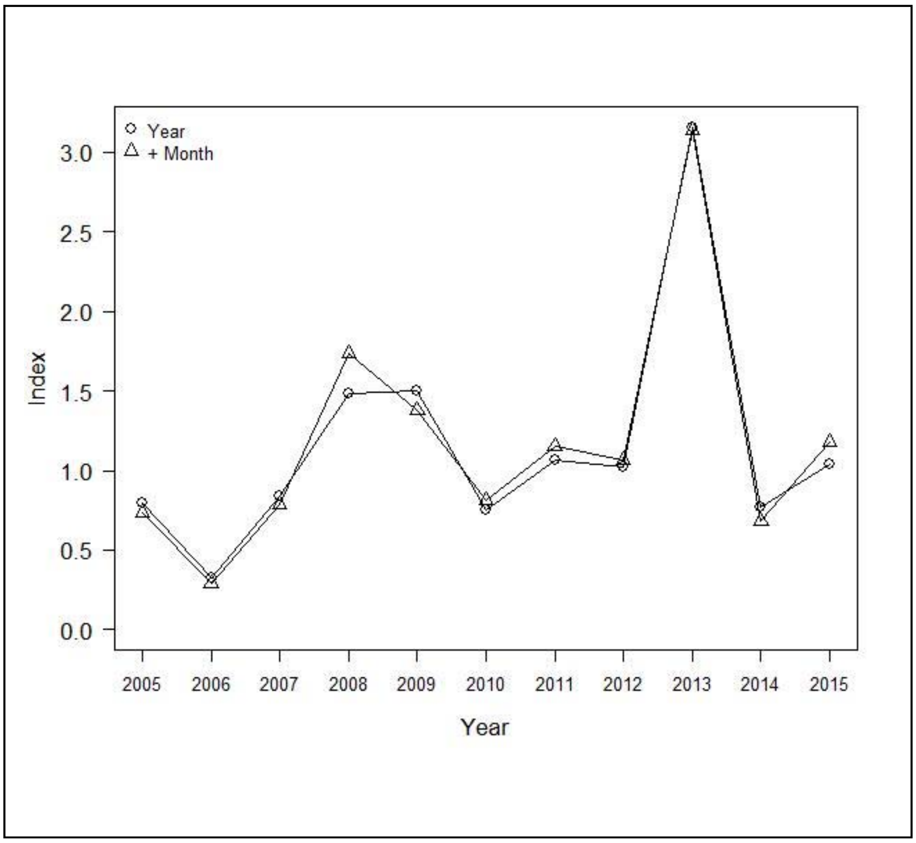


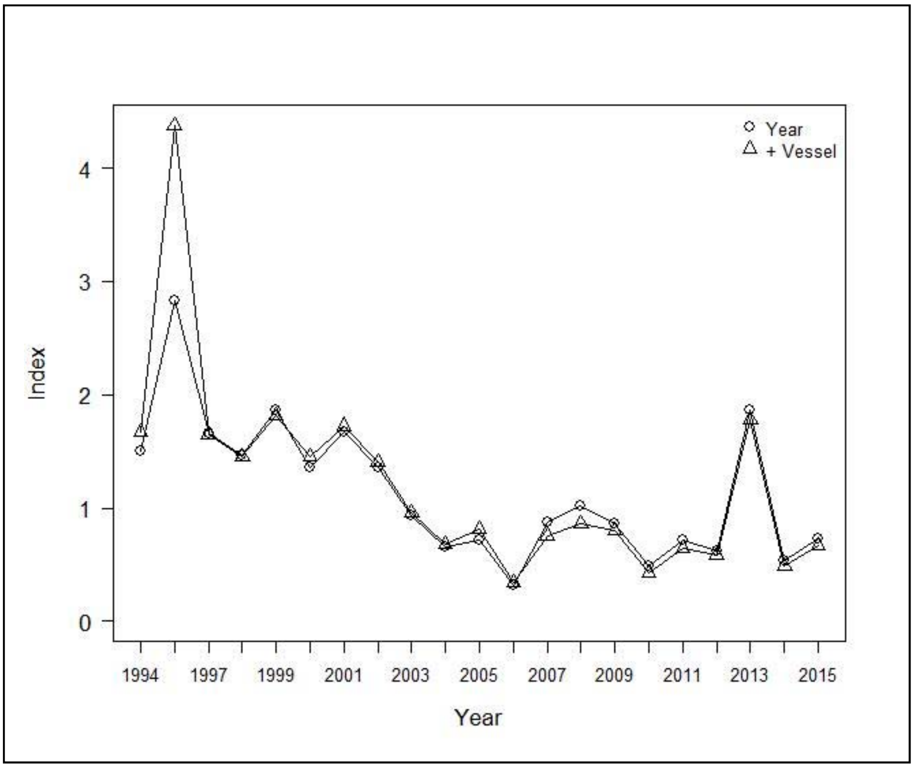
Appendix 15: Blue shark catches in North dataset. CPUE standardised for year effects and other sequentially added variables for TLCER (top) and observer (bottom) data.



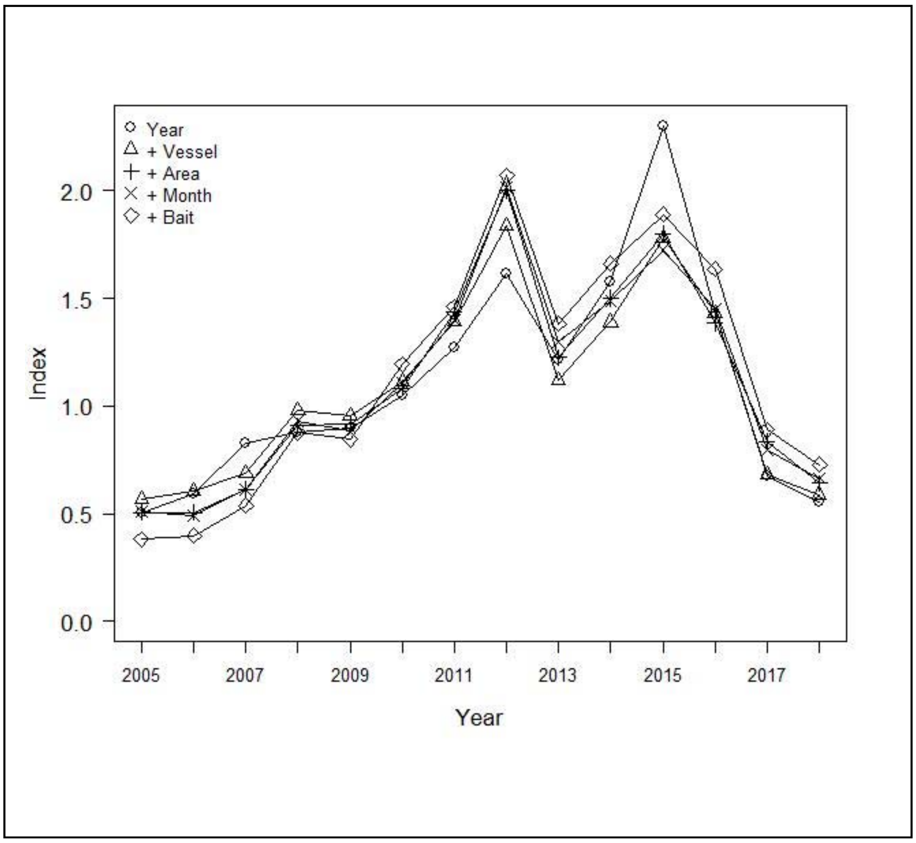


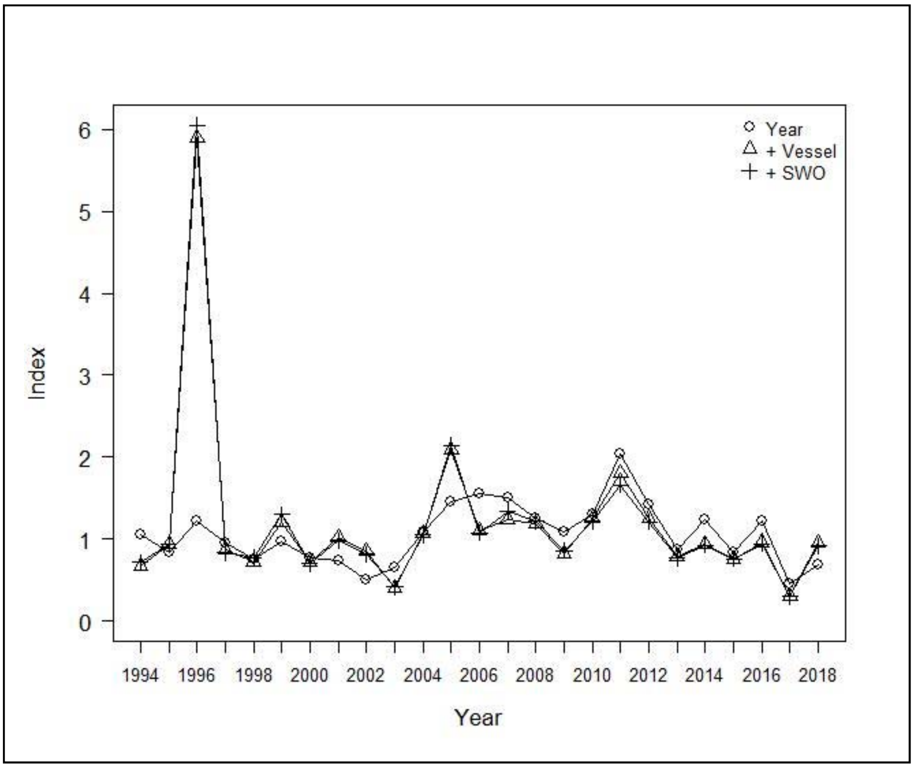
Appendix 16: Mako shark catches in Japan South dataset. CPUE standardised for year effects and other sequentially added variables for TLCER (top) and observer (bottom) data.



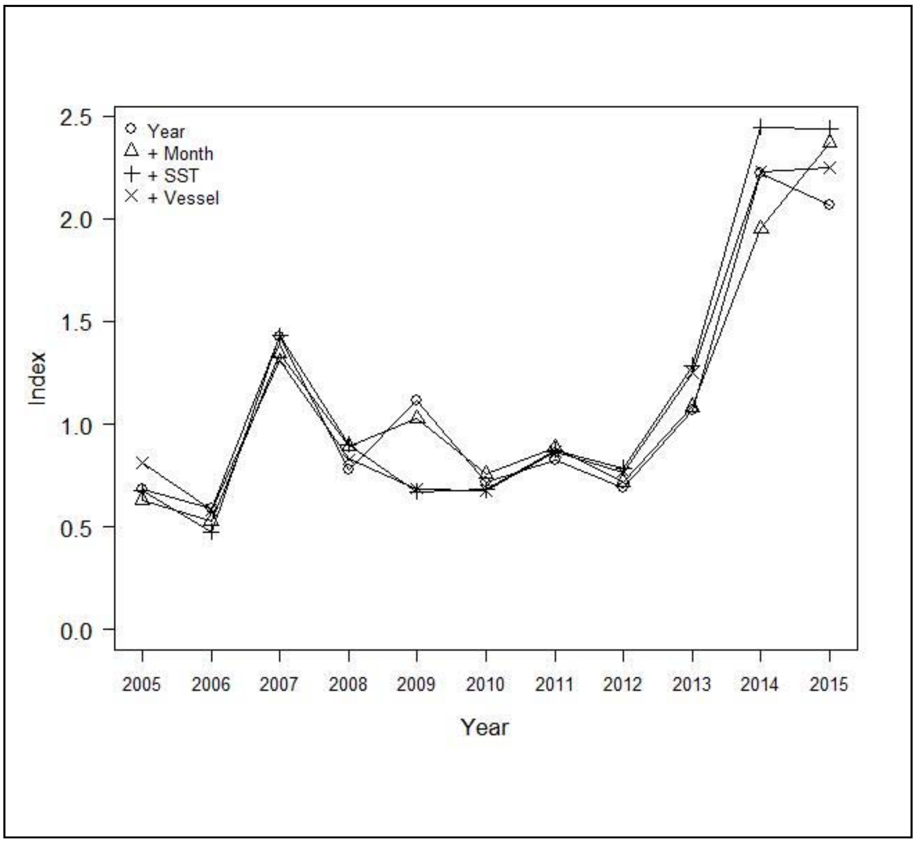


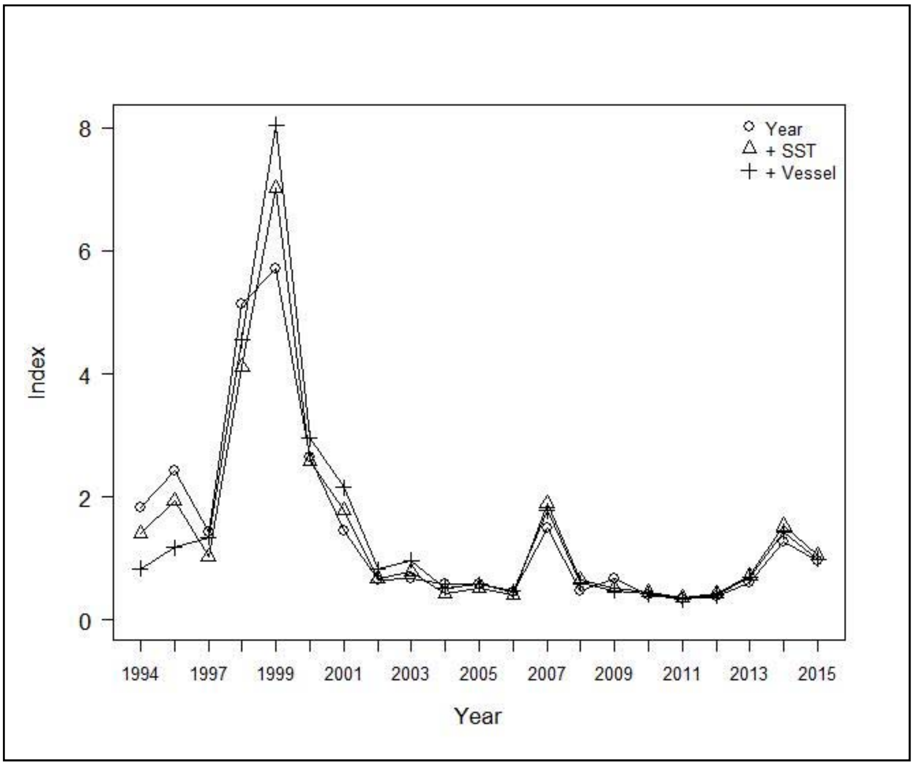
Appendix 17: Mako shark catches in North dataset. CPUE standardised for year effects and other sequentially added variables for TLCER (top) and observer (bottom) data. SWO is catch of broadbill swordfish.



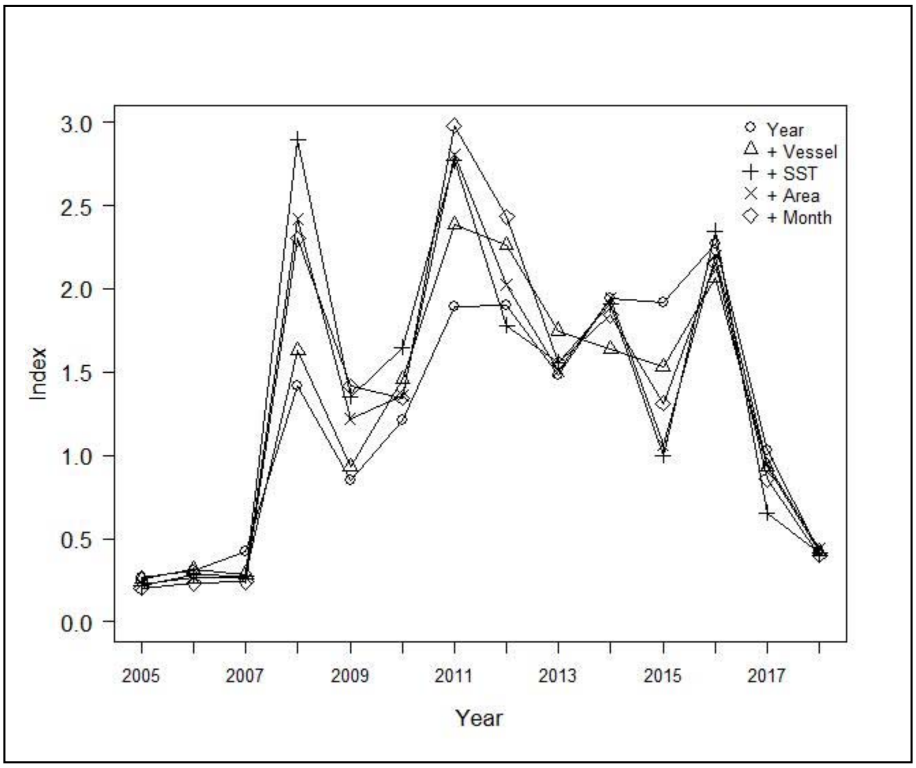


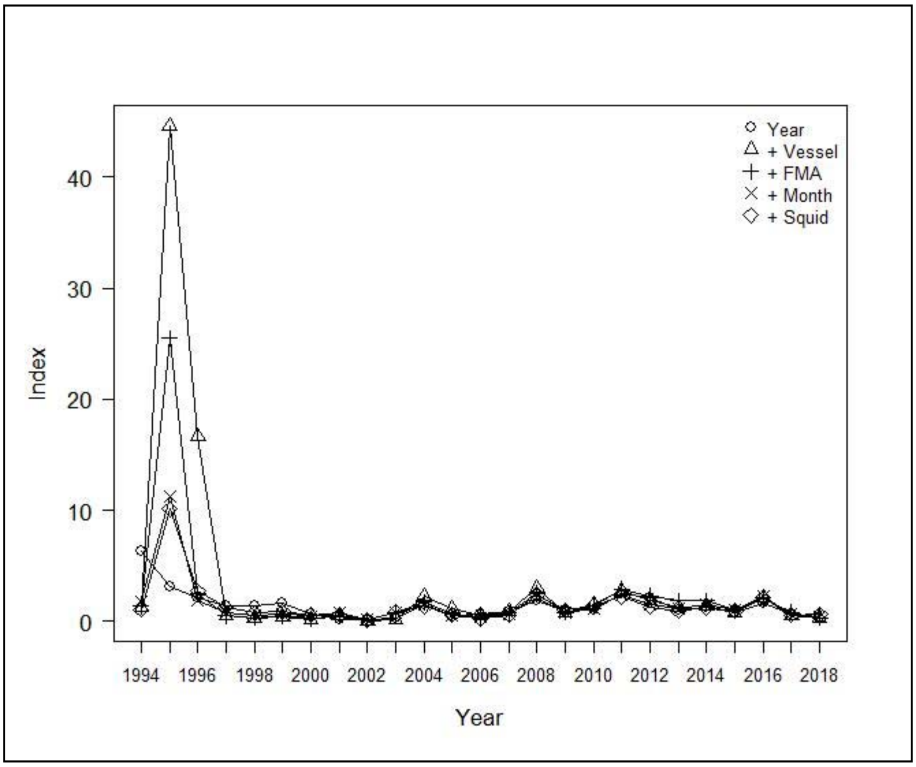
Appendix 18: Porbeagle shark catches in Japan South dataset. CPUE standardised for year effects and other sequentially added variables for TLCER (top) and observer (bottom) data.



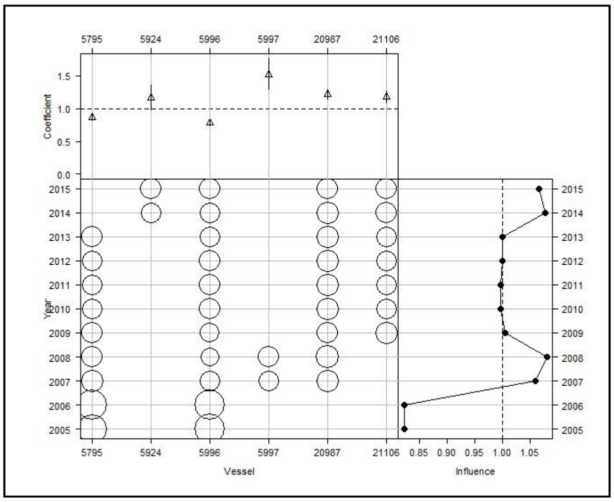


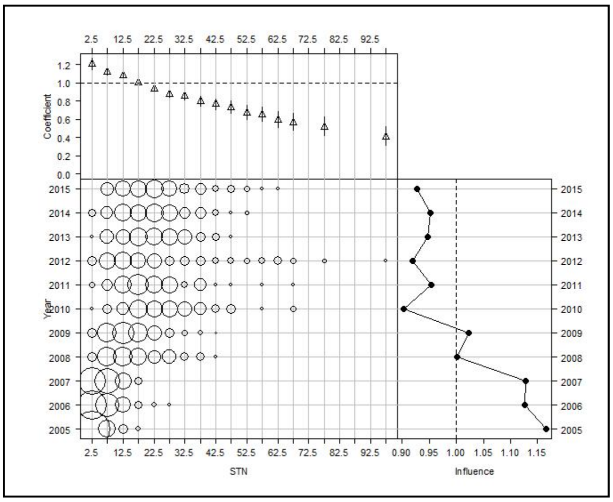
Appendix 19: Porbeagle shark catches in North dataset. CPUE standardised for year effects and other sequentially added variables for TLCER (top) and observer (bottom) data.

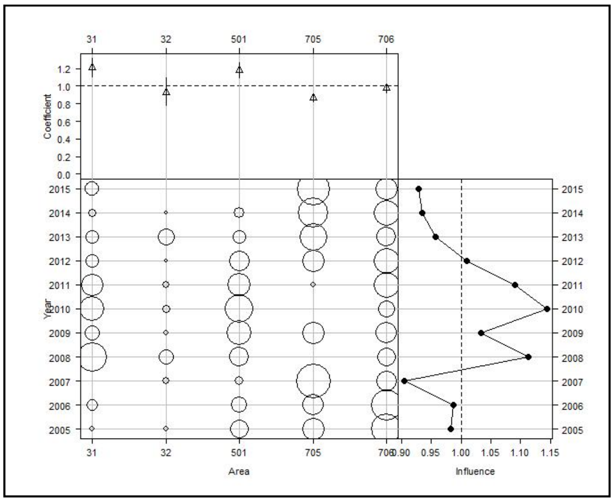




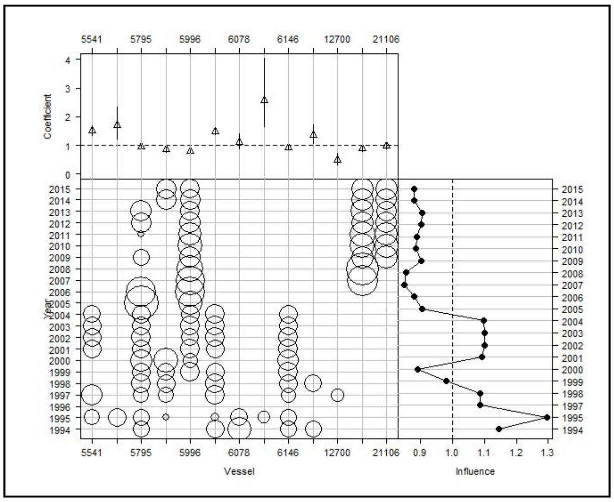
Appendix 20: Influence plots (Bentley et al. 2012) for the explanatory variables vessel, catches of southern bluefin tuna (STN), and area (as New Zealand General Statistical Area) in the negative binomial model of blue shark CPUE for the Japan South TLCER dataset.

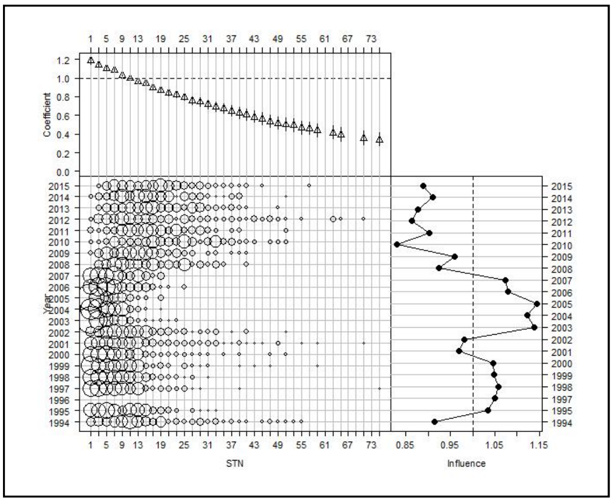




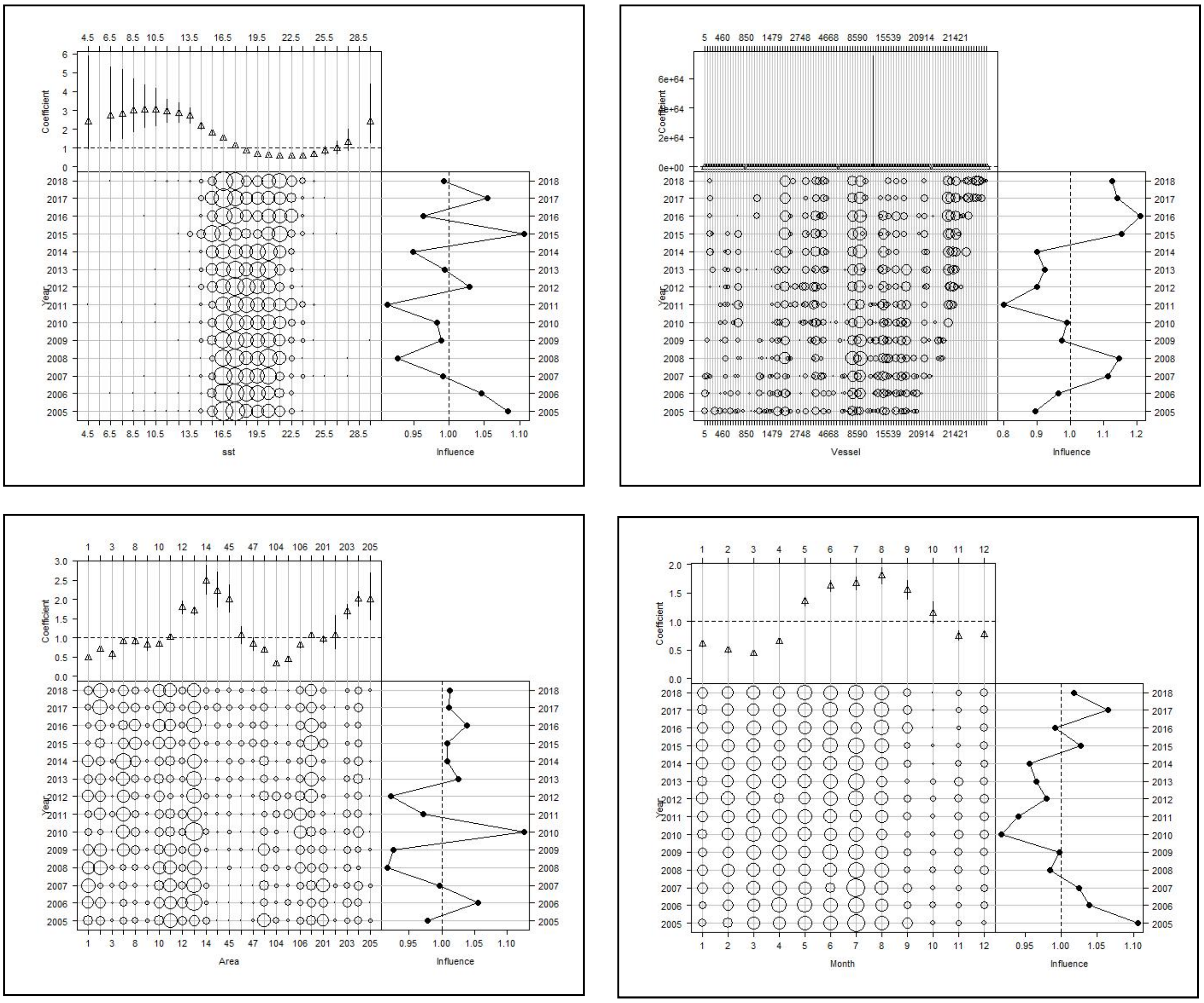


Appendix 21: Influence plots (Bentley et al. 2012) for the explanatory variables vessel and catches of southern bluefin tuna (STN) in the negative binomial model of blue shark CPUE for the Japan South observer dataset.

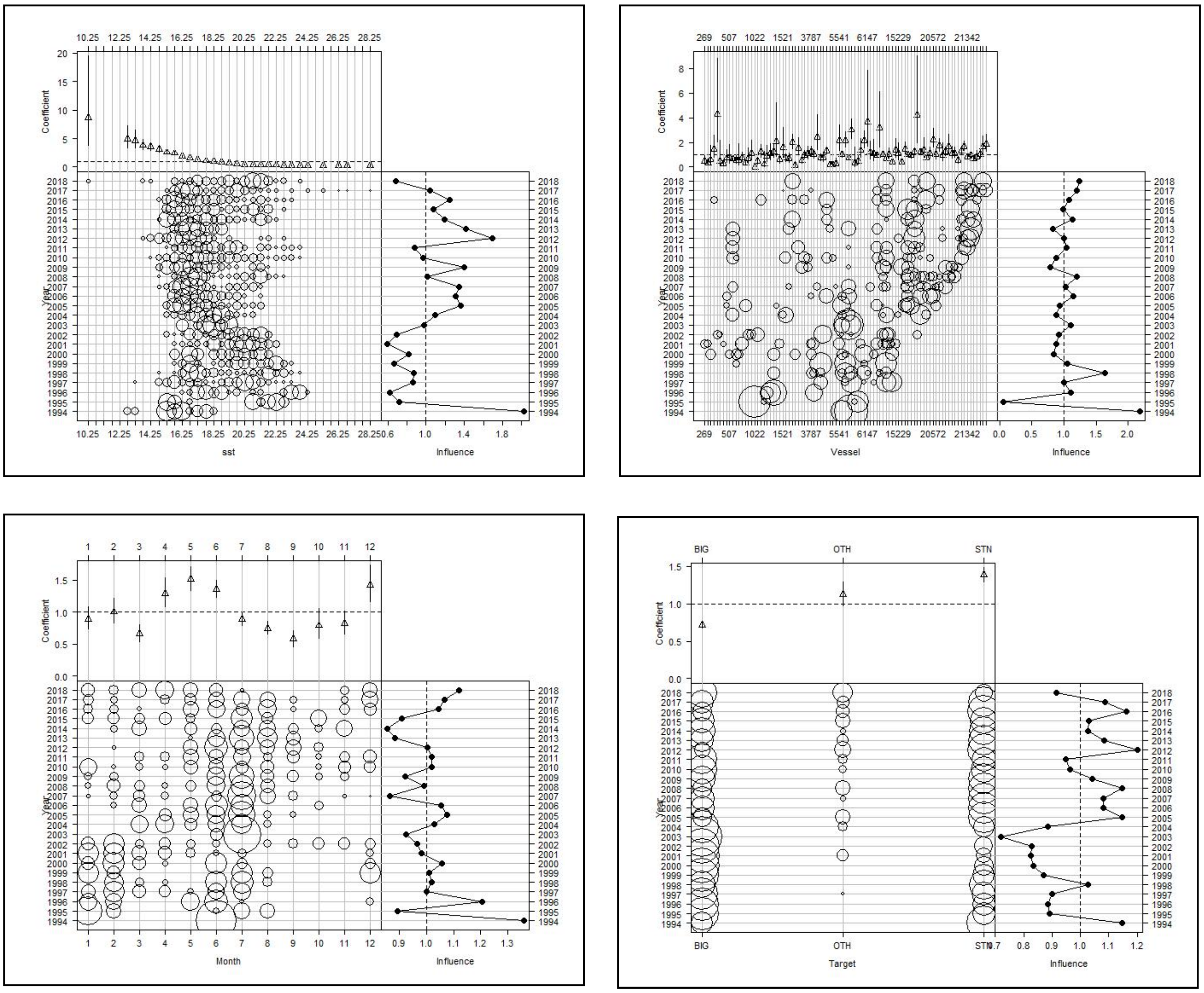




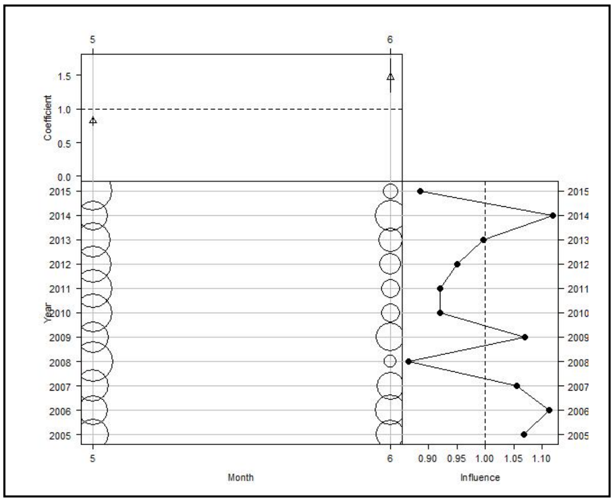
Appendix 22: Influence plots (Bentley et al. 2012) for the explanatory variables sea surface temperature (SST), vessel, area (as New Zealand General Statistical Area), and month (where 1 is January) in the negative binomial model of blue shark CPUE for the North TLCER dataset.

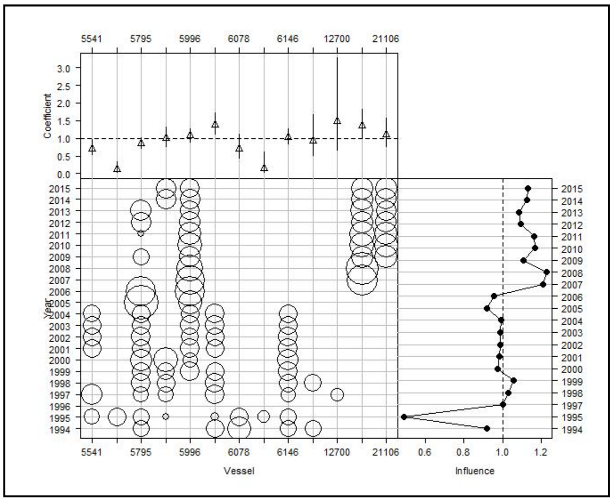


Appendix 23: Influence plots (Bentley et al. 2012) for the explanatory variables sea surface temperature (SST), vessel, month (month 1 = January), and target (BIG is bigeye tuna, STN is southern bluefin tuna) in the negative binomial model of blue shark CPUE for the North observer dataset.

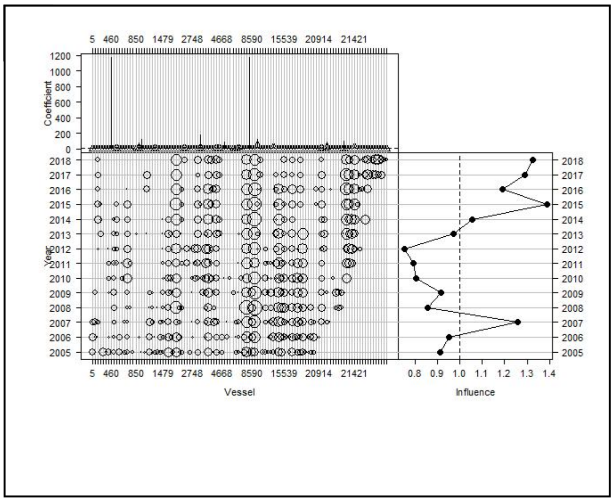


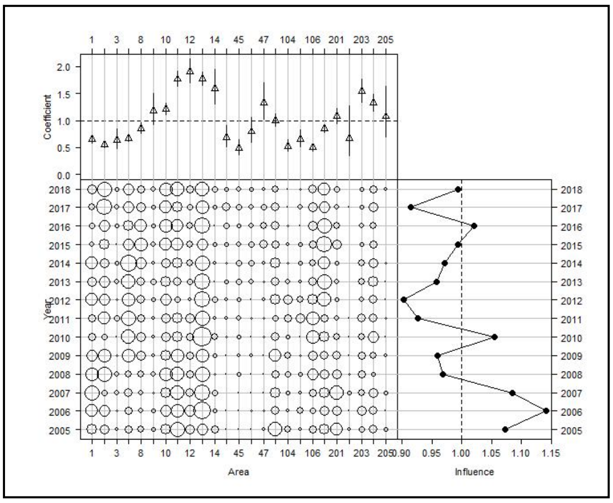
Appendix 24: Influence plots (Bentley et al. 2012) for the explanatory variables month (where 5 is May and 6 in June, TLCER data) and vessel (observer data) of mako shark CPUE for the Japan South datasets.

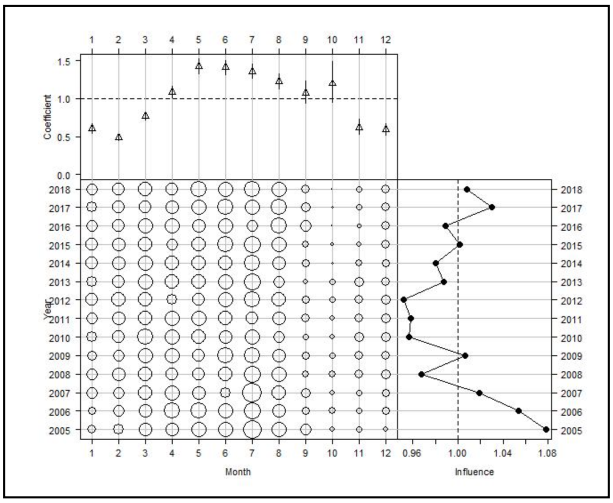


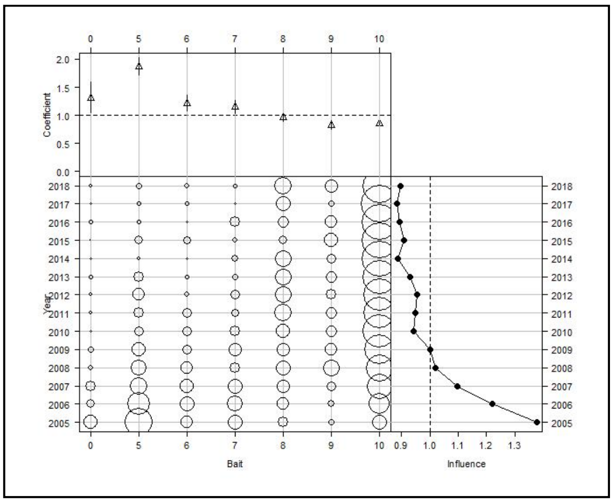


Appendix 25: Influence plots (Bentley et al. 2012) for the explanatory variables vessel, area (as New Zealand General Statistical Area), month (where 1 is January), and bait in the negative binomial model of mako shark CPUE for the North TLCER dataset.

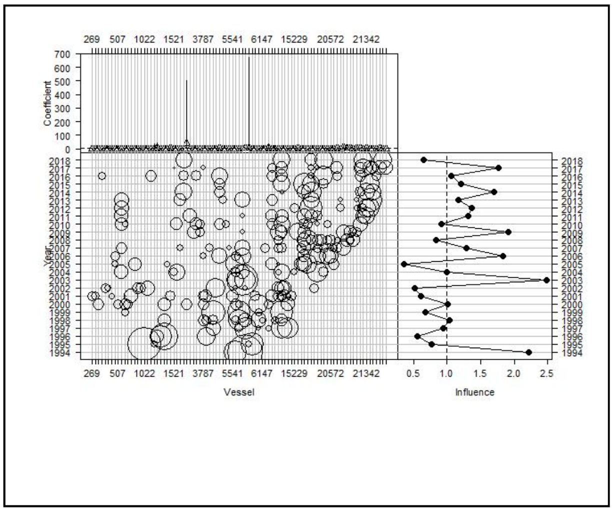


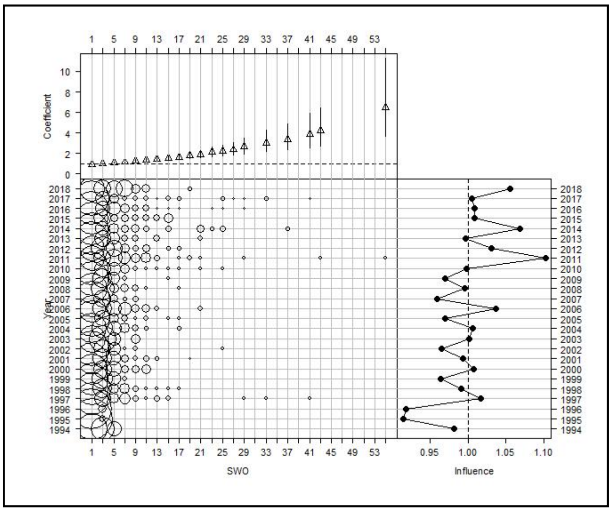




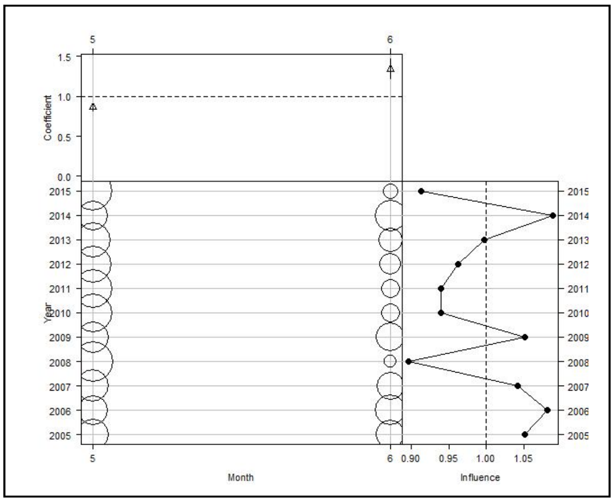


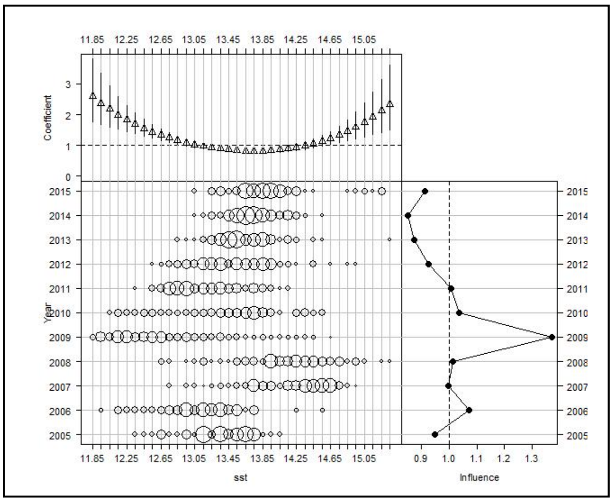
Appendix 26: Influence plots (Bentley et al. 2012) for the explanatory variables vessel and catches of swordfish (SWO) in the negative binomial model of mako shark CPUE for the North observer dataset.

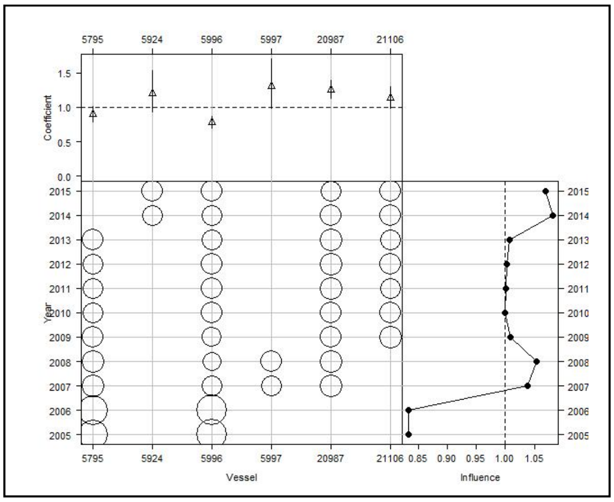




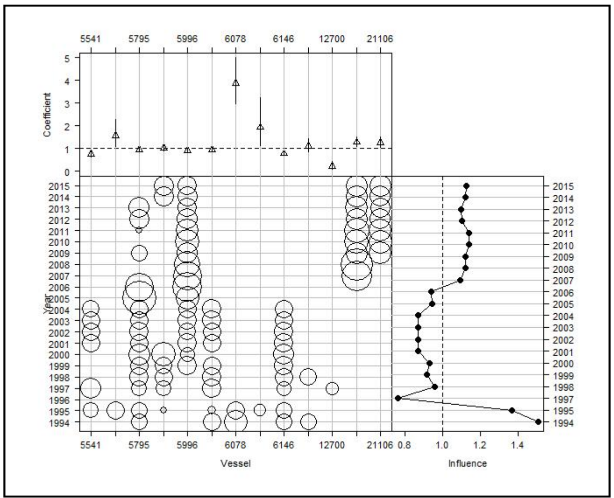
Appendix 27: Influence plots (Bentley et al. 2012) for the explanatory variables month (where 5 is May and 6 is June), sea surface temperature (SST), and vessel in the negative binomial model of porbeagle shark CPUE for the Japan South TLCER dataset.

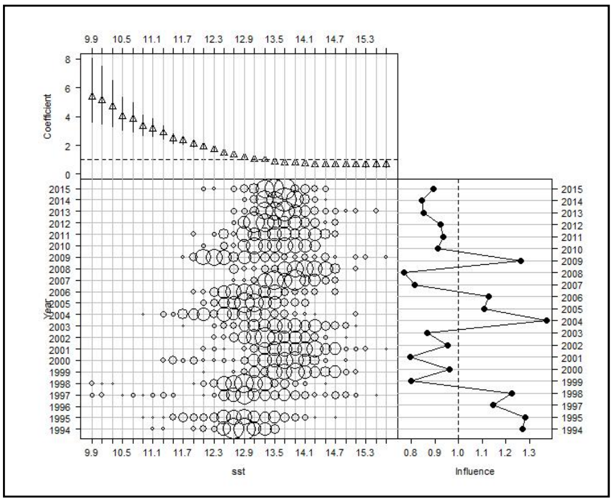




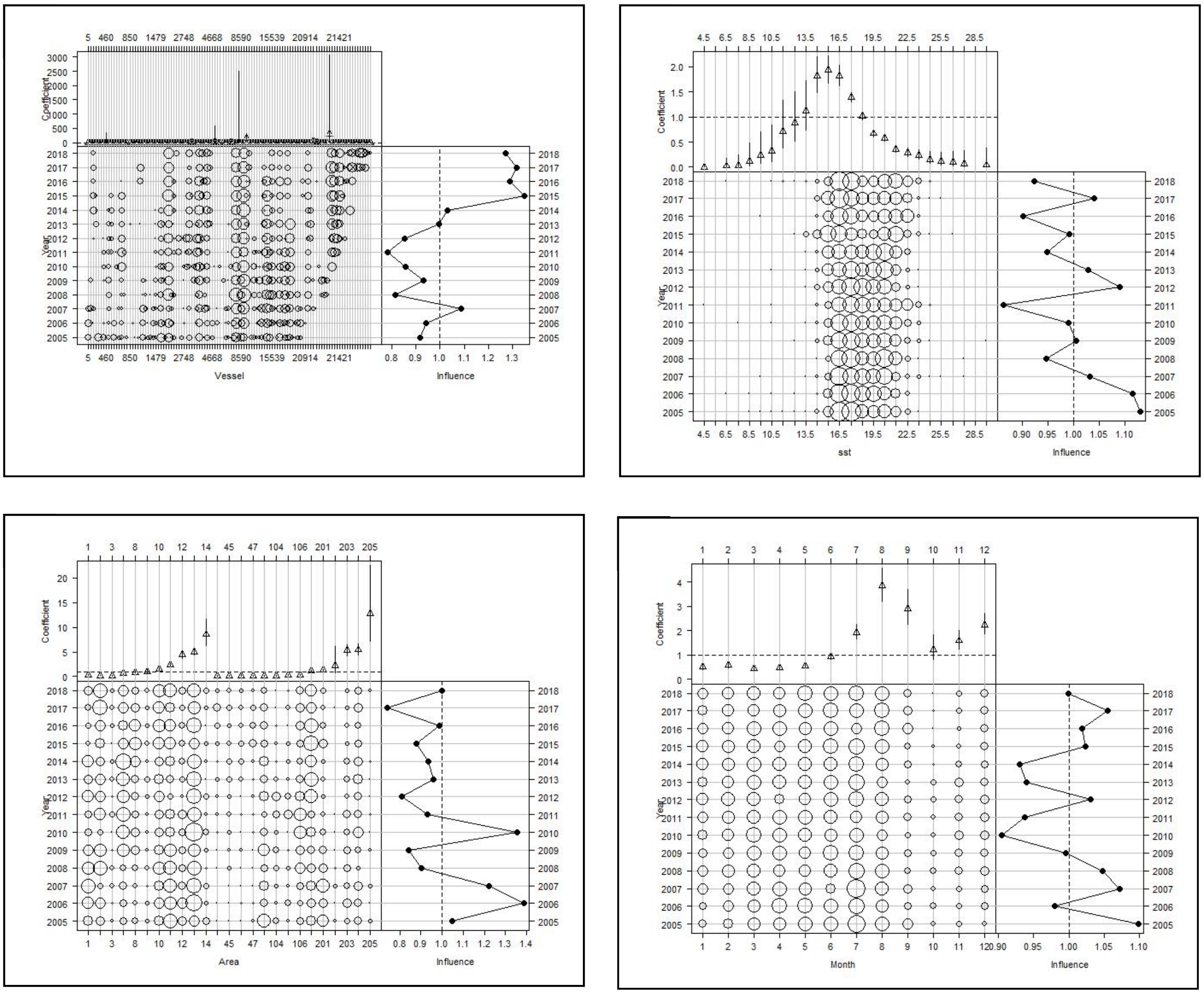


Appendix 28: Influence plots (Bentley et al. 2012) for the explanatory variables vessel, and sea surface temperature (SST) in the negative binomial model of porbeagle shark CPUE for the Japan South observer dataset.





Appendix 29: Influence plot (Bentley et al. 2012) for the explanatory variables vessel, SST, area (as New Zealand General Statistical Area), and month (where 1 is January) in the negative binomial model of porbeagle shark CPUE for the North TLCER dataset.



Appendix 30: Influence plot (Bentley et al. 2012) for the explanatory variables vessel, FMA, month (where 1 is January), and bait in the negative binomial model of porbeagle shark CPUE for the North observer dataset.