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Analysis of stock status and related indicators for key shark species of the Western Central Pacific Fisheries Commission

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Contents

1 Introduction

The status of the many shark species, espically those designated as (*key shark species*) in the western and central Pacific Ocean was is under review and instead of doing a southern blue shark stock assessment you all asked for this. An indicator analysis of blue, mako, thresher, silky and oceanic white tip sharks in the waters of the WCPO.

We didn't do any fancy assessment work or models, but rather make colorul plots and tabulate laregly useless statistics (the geometric mean of the sandardized counts of other sharks has decreased relative to the base year but is comparable to the initial year). All in all this paper should give you a good understanding of the uncertainty regarding any species population viability, and even more confusioin regarding what we can, have or would do about it. Becauses sharks are often caught as bycatch in the Pacific tuna fisheries (though some directed mixed species fisheries, sharks and tunas/billfish, do exist) sharks are doomed.

While we cannot specify a percent reduction in fishing mortality of approximately needed for any specific species to reach MSY levels in the western central Pacific Ocean, we do know that- based on modeling of the factors influenciing the catch rate - the most effective way to improve population outlook would be the banning of shark lines.

This paper presents an analysis of Secretariat of the Pacific Community - Oceanic Fisheries Programme (SPC-OFP) data holdings for sharks taken in longline and purse seine fisheries in the Western and Central Pacific Ocean (WCPO). The framework for the analysis is a series of indicators of fishing pressure and stock status that were first described in the Shark Research Plan presented to the sixth meeting of the Western and Central Pacific Fisheries Commission's (WCPFC) Scientific Committee (SC6; Clarke and Harley 2010). A preliminary indicator-based analysis of SPC data holdings was presented to the Commission in December 2010 (Clarke et al. 2010) with an extinsive review of the fisheries and data sources presented to SC7 (Clarke et al. 2011).

2 General Methods

2.1 Description of Data

The primary source of catch information regarding sharks is the SPC held observer data which, despite low coverage in all regions (Table 1 - Observer coverage by region NEED TO MAKE) has a significant amount of information regarding operational characteristics as well as the fate and condition of sharks caught. In addition to the observer data, SPC holds operational logsheet and aggregate data on shark catches by longline fisheries. The operational data submitted to the SPC are at a higher spatial resolution, and are useful for catch estimation, but in practice the utility is limited by the lack of data provision by species for shark (Table 2 Logsheet coverage by region % that ID sharks to species), especially in equatorial regions where the majority of the longline effort occurs Aggregate coverage rates are on par with the coverage rates of the operational logsheet data sets, although coverage differs greatly by region (Table 3). Historical coverage rates are poor partly because prior to February 2011 sharks were not amongst the species for which data provision was required (WCPFC 2013); since that time, data provision for 13 species designated by WCPFC as key shark species is mandatory . Under CMM 2007-01, required levels of Regional Observer Programme (ROP) coverage in longline fisheries are set to rise to 5% from June 2012 in most areas, but annual average values have been <1% in recent years (for the entire WCPO). With some notable exceptions (e.g. northeast and southwest of Hawaii), most observed sets occurred within Exclusive Economic Zones (EEZs). A thorough explanation of the SPC held fisheries data and its utility for shark related analyses can be found in Clarke et al. (2011).

Building on the work of Clarke et al (2011) this indicator analysis uses the six WCPFC statistcal areas as defined in the 2010 WCPFC bigeye tuna stock assessment As noted in Clarke et al 2011 these regions are somewhat arbitrarily assigned to the key shark pecies. However given the fact that the predominant source of fishing mortality for these species are the longline fisheries targeting tropical tunas (as well as billfish and occasionally sharks), these regions adequetly capture the important characteristics of the fisheries. Also, for ease of understanding and comparison to the previous analysis we opted to keep the same regions.

2.2 Longline Fishery Data

SPC holds logsheet data on shark catches by longline fisheries at the operational and aggregate levels. Due to its higher spatial resolution, operational-level data would in theory be preferred for indicator analysis but in this case its geographic coverage is limited due to lack of data provision with respect to shark catches. (could make some tables Tables 2 and 3 - still need to make). Sets for which at least one shark of any type was recorded in operational-level logsheet data held by SPC-OFP are distributed widely throughout the study area (red points). However, this picture is somewhat misleading due to overplotting as only 41% of the operational-level sets plotted recorded any sharks. This is in contrast to the observer data in which 93% of the sets recorded at least one shark.

This is not necessarily due to miss reporting, wheras prior to February 2011 sharks were not amongst the species for which data provision was required (WCPFC 2011); since that time data provision for the 13 species designated by WCPFC as key shark species is mandatory. This plot does not distinguish between key shark species and other shark species because only 16% of the reported sets recorded any species-specific shark catches. Clarke et al (2011b) note that most historical species-specific shark catch data are provided by a small number of flag States (Clarke et al 2011b).

Given the relatively low level of coverage in the operational-level logsheets, a more complete characterization of the longline fishery requires the use of aggregated (5x5 degree grid) data. Effort and reported shark catch data by flag at the aggregated level have a lower degree of spatial resolution but in most cases are raised to represent the entire WCPO longline fishery (Figures 3 and 4). Sets with observer present onboard, are shown for comparison but have a finer degree of spatial resolution due to observer record keeping. The observer data were plotted in red on the Under CMM 2007-01, required levels of Regional Observer Programme

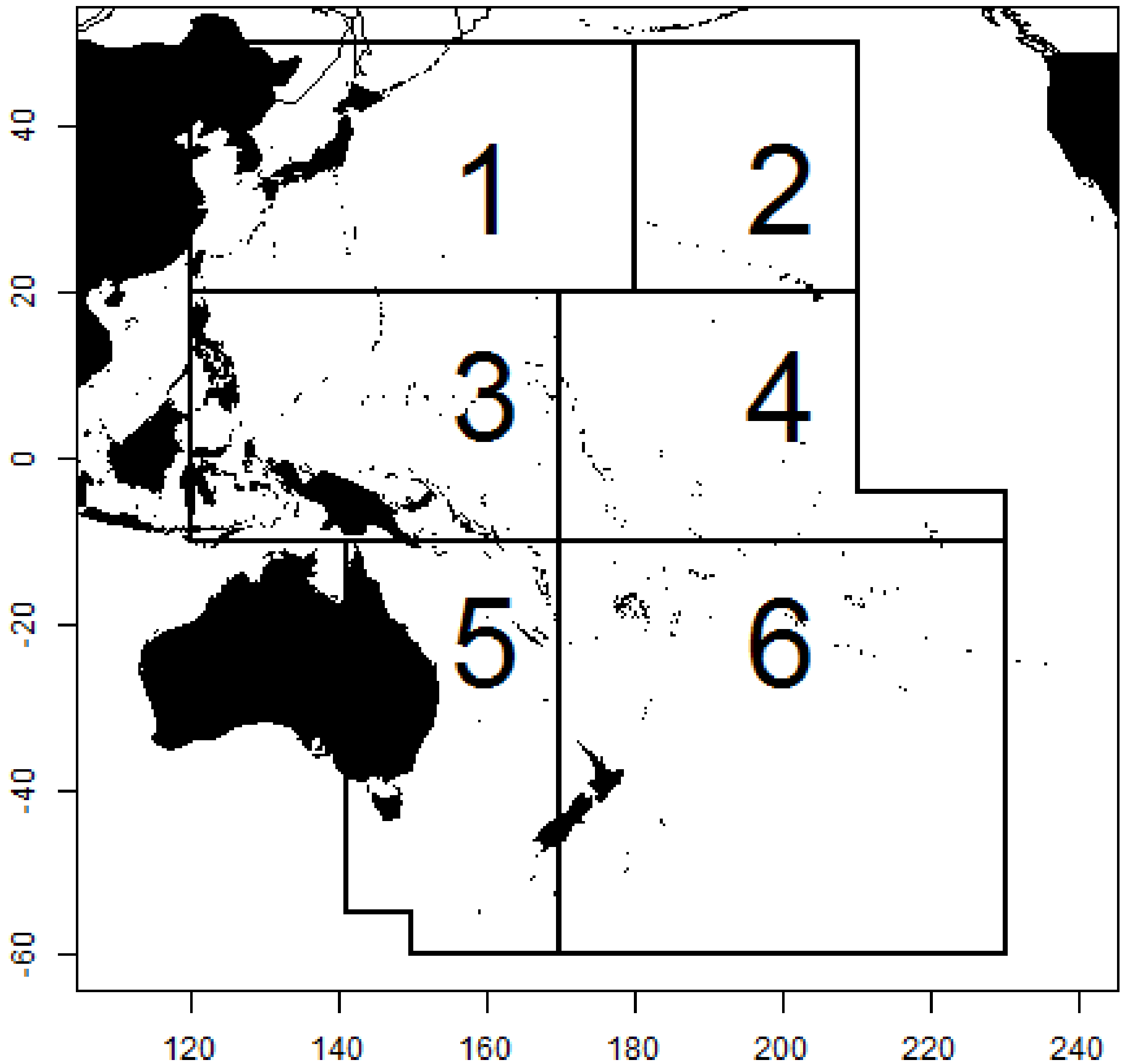

Figure 1: Map of WCPO and regions used for the analysis.

(ROP) coverage in longline fisheries are set to rise to 5% in June 2012 but annual average values have been on the order of 1%-2%.

A comparison of longline effort by flad and the number of sharks recorded in logsheets was constructed by showing the top four fishing nations (in the WCPO as a whole) and aggregating the rest of the flag states to an other group. If the fishing practices and reporting practices were more or less consistent across flags the numbers of sharks reported would be proportional, by flag, to the effort.

Comprehensive data on shark catches at high spatial resolution are available from observer

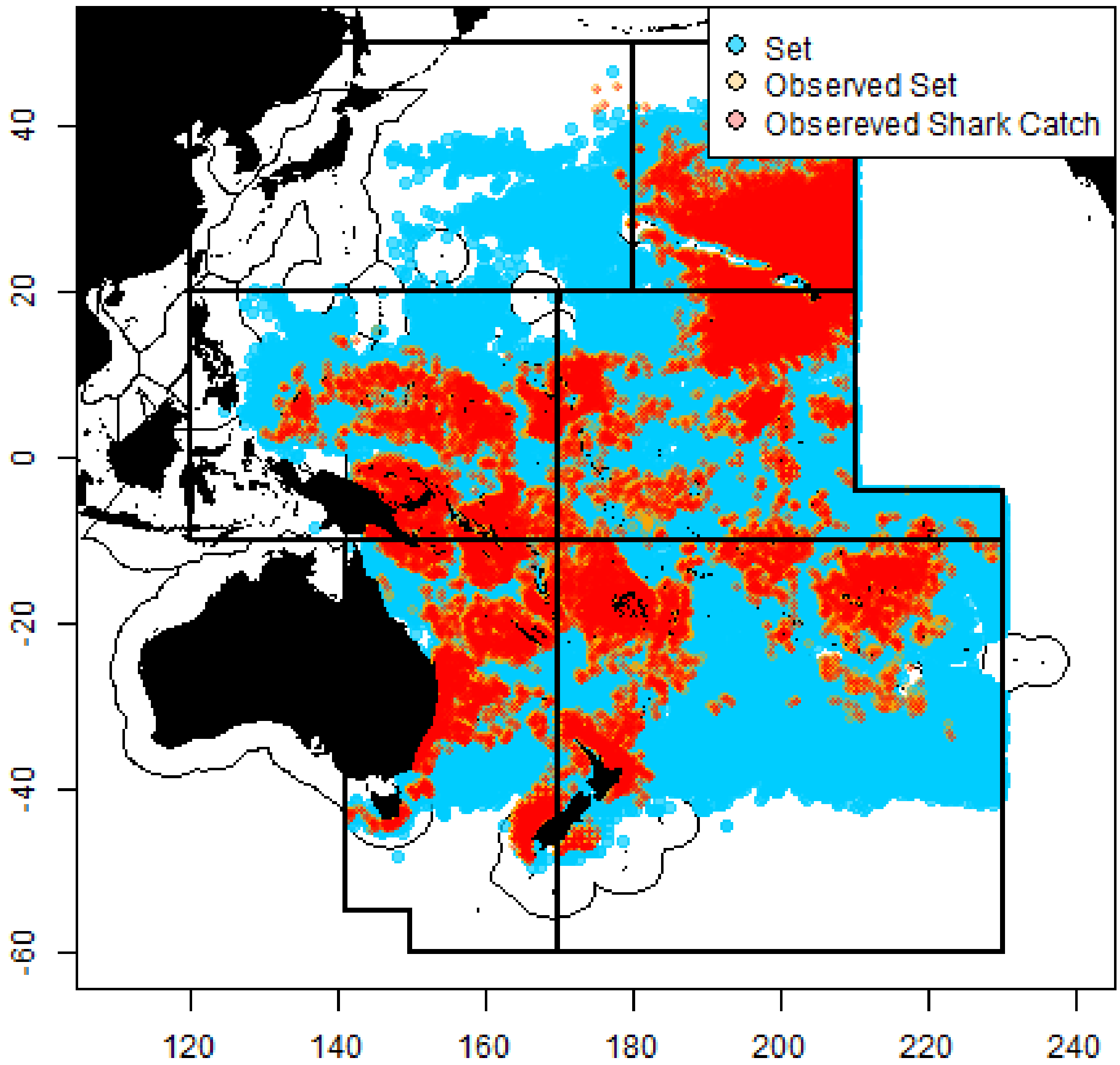

Figure 2: Map of WCPO and observed effort.

data held by the SPC-OFP but, as described above, the overall coverage of these data is low, and less than the required levels of ROP coverage. In addition, a comparison of longline effort and longline observer coverage reveals that the latter is disproportional by region and flag and thus cannot be considered representative of the fishery as whole.

Another aspect of the low data coverage problem is that a temporal representativeness on a month/year basis of the the observed effort A comparison of the annual proportion observed by month - on a regional basis - shows significant fluctuations in the relative coverage of the observer data compared to the logbook data

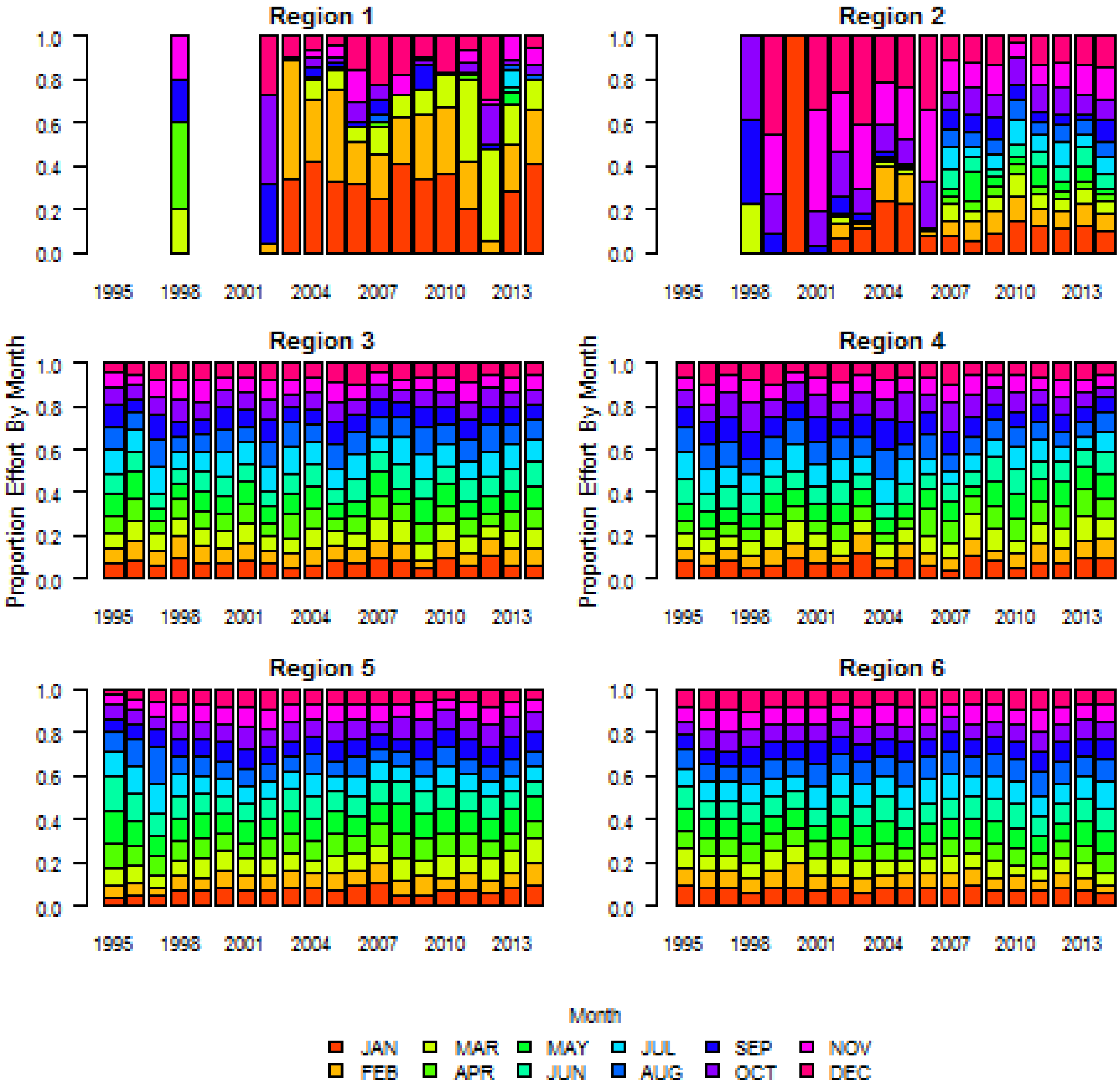

Figure 3: Logsheet effort by month.

Fishing Effort- Purse Seine

As for the longline fishery, SPC-OFP holds logsheet data on shark catches by purse seine fisheries at the operational and aggregate levels, but operational-level coverage for the purse seine fishery (¿80%) is considerably higher than for the longline fishery (???35%). This factor, in combination with the more limited geographic range of the purse seine fishery, contributes to more representative operation-level coverage in the purse seine fishery (Figure 5, green points) than in the longline fishery.

With implementation of the WCPFC ROP on 1 January 2010, in combination with prior observer coverage commitments by Parties to the Nauru Agreement (PNA) members, 100% purse seine observer coverage is now required (except for vessels fishing exclusively in one exclusive economic zone (EEZ). Historical observer coverage in the purse seine fishery has varied between EEZs. Coverage has exceeded 20% in Papua New Guinea but has been generally less than 10% in most other areas (Hampton 2009) with annual averages of 13-16% in 2005-2009. Although observer coverage of the purse seine fishery is not perfectly representative (Figure 2, orange points), the higher coverage levels and the more limited geographic range of the fishery result in more representative observer coverage for purse seines than for longlines (Lawson 2011 (Appendix Figure A2)). Regions 3 and 4 contain 98% of the operational-level reported purse seine sets, and 99% of observed sets and are thus the only regions for which purse seine analyses will be meaningful. In contrast to the longline operational-level logsheet data in which 37% of recorded sets reported at least one shark, only 2% of purse seine operational-level logsheet sets reported any shark interactions6 (Figure 5, pink points). Due to inconsistent recording practices it is not possible to assess the number of shark interactions by set or the species involved using purse seine logsheet data.

A comparison by flag of purse seine effort and the number of purse seine sets reporting at least one shark interaction was constructed for associated (floating object) and unassociated (free-swimming) sets based on aggregated logsheet data (Figure 6). For each panel, flags were ranked by number of sets and the top ten flags were plotted separately with all remaining flags aggregated into an "Other" category. Although estimated shark catches in the purse seine fishery are considerably lower than shark catches in the longline fishery (SPC 2008, Lawson 2011), it would still be expected that purse seine shark interactions are proportional to purse seine effort. However, from the discrepancies observed between the left and right panels in Figure 6, it appears that some major fishing nations are not submitting or are under-reporting their shark interactions. For example, the majority of the shark interactions in the right panels are reported by the US which only comprises about 12% of the effort in the left panels. This comparison also indicates that according to logsheets, shark interactions occur at a lower frequency in unassociated sets.

3 Distribution Indicator Analyses

3.1 Introduction

These indicators examine the geographic range of each species and the habitat usage (in terms of geography only; oceanographic variables are not considered) by different life stages (adult/juvenile) and sexes based on fishery interaction data. Spatial analysis of fish occurrences can be useful in identifying range contractions or expansions which may be linked to fishing activities (Worm and Tittensor 2011). In addition, since many pelagic shark species are known to exhibit sex- and age- specific distribution patterns (Camhi et al. 2008, Mucientes et al. 2009) spatial analysis can highlight areas which are important to key life stages (e.g. presence of adult females and juveniles may indicate pupping grounds; presence of juveniles only may indicate nursery grounds). Both indicators presented below are based on observer data and thus patterns in fishing effort and/or observer coverage may bias the results. These results should therefore be taken as an initial indication of the locations of interactions between these species, sexes and life history stages and the WCPO longline and purse seine fisheries. They can be updated over time to determine if patterns change, and can perhaps be subject to further development to remove sampling biases.

3.2 Methods

Using a subset of the longline observer data (i.e. those records containing length and sex data), patterns of occurrence by life history stage and sex were explored (Annex 2). Data for each shark in each cell where it was observed were partitioned into four subsets: adult females, adult males, juvenile females and juvenile males. The lengths at maturity in fork length, and any conversion factors applied to convert measurements given in total length or pre-caudal length, are shown in Table 1. The number of occurrences of each sex-life history stage combination were then tallied for each 5x5 degree cell and screened to remove cells for which the sample size was less than 20 individuals. Due to small sample sizes for longfin makos, and for bigeye, common and pelagic threshers, results for makos (two species plus unidentified) and threshers (three species plus unidentified) were grouped. Length at maturity data for shortfin mako and bigeye thresher were chosen to represent each group, respectively, as both observer data and literature sources were greatest for these species. While length at maturity and conversion factors might be expected to vary by sub-region within the WCPO, insufficient data were available to support sub-regional analysis.

The maps in Annex 2 were produced by shading each cell based on the proportion of individuals observed in each of the four subsets with darker colours indicating higher proportions. For example, if all of the silky sharks observed in a given cell were adult females the adult female panel would show a darkly shaded cell whereas the other three panels would show only the lightest shading (i.e. even zero proportions receive the lightest colour shading). In order to account for seasonal changes, four-panel plots are presented separately for mid-year (May-July) and year-end (November-January); sharks sampled in other months were excluded from the analysis.

3.3 Results

The following points were noted from the life stage and sex distribution plots: - Adult blue sharks were more common than juveniles in the waters off Hawaii and at latitudes of 20o S this corresponds to the blue shark mating ground proposed by Nakano (1994); the highest proportion of juvenile blue sharks was found in mid-year (May-July) samples in the southern extremities of the WCPO. - Juvenile makos of both sexes were most frequently observed in mid-year (May-July) samples in the southern extremities of the WCPO. - The observed distributions of adult and juvenile oceanic whitetip and silky sharks are similar but samples of silky sharks were particularly skewed toward juveniles in tropical waters. - Thresher sample sizes were small but were mainly comprised of juveniles in tropical areas.

3.3.1 Blue Shark

3.3.2 Mako Shark

3.3.3 Silky Shark

3.3.4 Oceanic Whitetip Shark

3.3.5 Thresher Shark

3.4 Conclusions

Interpretation of fishery interaction indicators is complicated by the influence of changes in fishing effort, and perhaps other operational factors influencing selectivity and catchability (e.g. depth and leader material). Furthermore, samples sizes for length and sex information are quite limited for some species. As such, these indicators are best used for identifying the areas in which species-fishery interactions take place and as supporting information for interpreting other patterns and trends.

4 Observed Species Composition Indicator Analyses

4.1 Introduction

The species composition of the catch, as recorded by longline and purse seine observers, was examined to identify any apparent changes over time. This type of analysis reinforces the species-specific fishery interaction information above, but supplies more detail on interactions by separating longline sets by depth and purse seine sets by type of school association. Another important reason for examining catch composition indicators is to assess changes in the percentage of unidentified shark species over time. Improvements in the observers' ability to identify sharks could contribute to increasing occurrences of species-specific records in the observer database and could bias temporal trends.

While this analysis provides information on the relative proportions of the key species within the observer samples, estimation of total catch composition and quantity is complicated by issues of observer sample coverage and representativeness (see Section 2) and is the subject of a separate analysis (Lawson 2011). Regardless of whether catch composition indicators are based on observer samples or the entire catch, changes in species composition over time can suggest relative population increases or depletions. However, species-specific catch rate analyses should be performed to directly assess whether actual abundances for individual species have changed (see Section 5).

Longline

As expected, blue sharks dominated the shark records from the longline fishery, comprising on average 69-91% of the observed catch in Regions 2, 4, 5 and 6 for 1995-2010 (Figure 14, top panel). In Region 3 silky sharks were the most frequently encountered sharks comprising 64% of the observed catch in 1995-2014. Small numbers of mako and oceanic whitetip sharks were recorded in temperate and tropical areas respectively. Thresher sharks, predominantly bigeye threshers, comprised on average 12% of the observed catch in Region 4 but were rarely recorded in other regions. The non-key species observed in Regions 5 and 6 were primarily composed of porbeagles, roughskin dogfish (Centroscymnus owstoni) and tope shark (Galeorhinus galeus), and in Region 3 were primarily composed of unidentified hammerhead, grey reef (Carcharhinus amblyrhynchos) and blacktip (Carcharhinus limbatus) sharks. Unidentified sharks comprised no more than 1.6% of the recorded sharks in any of the regions.

Species composition is plotted by set depth in the lower panel of Figure 8, using hooks per basket as a proxy variable to separate shallow (¡10 hooks per basket) from deep sets (???10 hooks per basket). This comparison illustrates that although there were more deep sets conducted in Region 3 than shallow sets (n=3,318 versus n=2,181), most of the silky sharks in Region 3 are caught in the shallow sets. The vast majority of sets in Regions 4 and 6 were deep sets and it is these sets which produced the catches of blue and thresher sharks. Shifts in Regions 2 and 5 from shallow to deep sets may reflect changes in fishery regulations in Australia (AFMA 2008) and the US (Walsh et al. 2009), but both types of sets catch primarily blue sharks.

Purse Seine

Plots of the catch composition as recorded by observers in the purse seine fishery indicate that unlike for longlines, a non-negligible portion of the sharks recorded in the first half of the time series (1995-2003) were not identified to species (i.e. UID; Figure 9). As discussed in Section 2, this is probably a function of the practical difficulties in recording purse seine-caught sharks which are not hauled onboard, but the problem appears to have been resolved in recent years. Overall, approximately 70% of the observer-recorded catch was silky shark; the next most abundant species was oceanic whitetip shark which comprised 7% of the records. The numbers of sets shown in the lower panels illustrate that associated sets comprised 67% of the observer samples in Region 3 and 59% of the samples in Region 4, but recorded 88% and 93% of the sharks respectively. It is also noted that oceanic whitetip sharks were observed in substantial numbers only in associated sets and only until 2004-2005.

4.2 Conclusions

The observed longline catch composition plots illustrate that blue shark dominate in most regions. An exception to this pattern is Region 3 where silky sharks, primarily from shallow sets, are the most frequently observed species. Although there are some minor differences in species composition between observed shallow and deep sets in other regions (e.g. Regions 2 and 4), these may be related to sampling representativeness. Analysis of observed purse seine shark catches reveals that silky sharks predominate with the majority of these found in associated sets. In previous years, oceanic whitetip shark was the second-most commonly identified shark in associated sets but this species has been only rarely observed in recent years. Substantial numbers of sharks caught by purse seines were unidentified until 2002-2003.

5 Catch Per Unit Effort indicator analyses

5.1 Introduction

This paper follows from the previous indicator based analysis presented to the Western and Central Pacific Fisheries Commission (WCPFC) Scientific Committee (SC7, Clarke et al. 2011), stock assements (Rice et al. 2014, Rice et al.2013, Rice et al.2012) (cite the standardization papers cite ISC work?). The developments presented here include additional analyses of the Secretariat of the Pacific (SPC) data holdings for silky caught in longline and purse seine fisheries in the Western and Central Pacific Ocean (WCPO), though we note that some previous data (Japan) was not available for this effeort. Standardized catch per unit of effort (CPUE) series are developed for the main shark species.

The framework for the analysis is not to construct inputs for stock assessment or estimate catch, it is designed to illustrate general population trends via catch rate. It is recommended that infrence to develop catch estimates or other stock assessment inputs be conducted independently. The SPC longline observer database contains records from 1985 to recent years, however silky sharks were not routinely identified to species until 1995, hence the dataset used in this analysis spans the years 1995-2014. Recent work by Clarke et al. (2011) noted gaps in observer data in terms of time and space continuity, reporting rate, and identification with respect to sharks. Silky and oceanic white tip sharks are observed mainly in the equatorial waters in the purse seine fishery (Figure 1), and from about -25??S to 25??N in the longline fishery (Figure 1). Silky and oceanic white tip sharks have been assessed (Rice et al 2012, Rice et al 2013) as a single stock in the WCPO, and are presented in this analysis ass one stock (not regionally). Thresher, mako and blue sharks are more common in cold and temperate waters, and generally believed to constitute two seperate stocks, in the north and south. Blue shark in the north pacific have been subject to multiple stock assessments as a single stock. These temperate species stocks will be presented as individual stocks.

CPUE data for species such as sharks often have a large proportion of observations (or sets) with no catch, and also include observations with large catches when areas of higher densities are encountered; this is typical of bycatch species (Ward and Myers 2005). The signals from the nominal CPUE data can be heavily influenced by factors other than abundance and therefore a procedure to standardize CPUE data for changes in factors (e.g. fishing technique, season, bait type) that do not reflect changes in abundance is usually recommended. Nominal CPUE data for bycatch can be more variable than expected (i.e., overdispersed) with many outlying data points from uncommonly high catch rates. These outlying data points can sometimes be a function of shark targeting.

5.2 Methods

This analysis follows the work of Clarke et al., (2011, 2011b), Walsh and Clarke (2011), Rice and Harley (2013) however the regions for this study differ slightly. Because silky sharks are tropical species this led to the analysis being considered for one region, from 25??S to

25??N and bordered on the east and west by the WCPFC Statistical Area. A comprehensive overview of the observer logsheet data and a characterization of the fisheries in which each species is caught is presented in the preious sections, what follows is a summary of the methods used in this analysis.

The data were validated and trimmed (records with missing values for key explanatory variables removed) to include only relevant data from the species 'core' habitat. This was done to reduce the already excessive number of zeros in the data, i.e. zero catch where you would not reasonably expect to catch silky sharks.

Because silky sharks are an epi-pelagic tropical species, all sets that occurred in water colder than 25

Latitude and longitude were truncated to the nearest 1

Although a much smaller proportion of the overall dataset (6.5% of the sets), the targeting sets represent significant shark catch (82% of the total silky shark catch). Therefore the dataset was examined with respect to variables relating to whether sharks were the intentional target of the set. Silky shark CPUE was plotted as a function of the variables sharkline, shark bait, shark target against date of set (Figure 3). Inspection of these covariates led to the separation of shark-targeting sets and non-targeting (bycatch) sets. Shark targeting sets were deemed to be sets where the observer had marked that the set was intentionally targeting sharks of any species, whether shark bait was used, or whether shark lines were used. The results of these filtering rules are in Table XXX.

Purse Seine data preparation

The only restriction placed on the purse seine observer data was that the set occurred within the rectangle defined by

CPUE standardization methodology

CPUE is commonly used as an index of abundance for marine species. However, it is important that raw nominal catch rates be standardized to remove the effects of factors other than abundance. Further, catch data for non-target species (and sharks in particular) often contain large numbers of observed zeros as well as large catch values which need to be explicitly modelled (Bigelow et al. 2002; Campbell 2004, Ward and Myers 2005; Minami et al. 2007). Standardized CPUE series for all fisheries (bycatch and target longline; associated and un-associated purse seine fisheries) were developed using generalized linear models. In the longline analyses the number of hooks in a set was the effort measure, whereas for purse seine it was simply the set. It is notoriously difficult to come up with accurate estimates of the true effort that relates to a purse seine set (Punsly, 1987).

Overview of GLM Analyses

The filtered datasets were standardized using generalized linear models (McCullagh and Nelder 1989) using the software package R (www.r-project.org). Multiple assumed error structures were tested including; The delta lognormal approach (DLN) (Lo et al. 1992, Dick 2006, Stefansson 1996, Hoyle and Maunder 2006): this approach is a special case of the more general delta method (Pennington 1996, Ortiz and Arocha 2004), and uses a binomial distribution for the probability w of catch being zero and a probability distribution f(y), where y was log(catch/hooks set), for non-zero catches. An index was estimated for each year, which was the product of the year effects for the two model components,

The negative binomial (Lawless 1987): is typically more robust to issues of overdispersion (overdispersion can arise due to excess zeros, clustering of observations, or from correlations between observations) was also used. This model has been advocated as a model that is more robust to overdispersion than the Poisson distribution (McCullagh and Nelder 1991), and is appropriate for count data (Ward and Myers 2005), but does not expressly relate covariates to the occurrence of excess zeros (Minami et al. 2007).

The main advantage of the zero inflated approach is that these techniques can model the overdispersion in both the zeros and the counts as opposed to just the counts (negative binomial) and deal with overdispersion better than other models (such as the quasi-Poisson). A drawback of the zero inflated approach is that it is data intensive and the models often fail to converge.

Multiple methods of calculating the indices of abundance and confidence intervals exist depending on the model type (Shono H. 2008, Maunder and Punt 2004). In this study estimates were calculated by predicting results based on the fitted model and a training data set that included each year effect and the mean effect for each covariate (Zuur et al 2009). Confidence intervals were calculated as SE, where SE is the standard error associated with the predicted year effect term. Appendices hold the model diagnostics.

5.3 Results

5.3.1 Blue Shark

5.3.2 Mako Shark

5.3.3 Silky Shark

5.3.4 Oceanic Whitetip Shark

5.3.5 Thresher Shark

5.4 Conclusions

6 Biological indicator analyses

6.1 Introduction

Previous analysis Clarke et al. (2011) examined trends in median length of the key shark species and found significant declines in most combinations of spatial strata and sex for blue and mako sharks, as well as . As 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. As noted in Francis et al 2014 the median length is preferred over the mean length as 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 impact on 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. In this section we analyse trends in median length and the proportion of males over time.

6.2 Methods

Trends in a standardized measure of fish size can indicate changes in the age and size composition of the population, in particular, a decrease in size is expected in a population under exploitation (Goodyear 2003). The magnitude of such change can, in theory, provide information on the level of exploitation that a fish stock is experiencing (Francis and Smith 1995). As the size of sharks differs by sex, it is important to examine indicators on a sex-specific basis where possible. Length, rather than weight, is preferred as a standardized measure of size because it is not as likely to fluctuate with reproductive or other seasonal factors. The median is preferred over the mean as it is less likely to be influenced by outliers. In addition to identifying trends in size, length data can be used to assess whether the catch sample is sexually mature by comparing to species-specific lengths at maturity from the literature.

For the nominal analysis, length data from longline andpurse seine fisheries recorded in total length were converted to fork length using conversion factors given in Table 1 (see Section 3.2). Literature-based length at maturity values are also shown in Table 1. Those 5x5 degree cells for which the sample size was less than 20 individuals were removed from the analysis. In the purse seine dataset, sexes were not usually recorded and only oceanic whitetip and silky sharks in Regions 3 and 4 had sufficient data for analysis (Figure 19). Results of the nominal analysis of size data for the longline fishery are shown in Annex 7. Due to small longline fishery sample sizes for longfin makos, and for bigeye, common and pelagic threshers, results for makos (two species plus unidentified) and threshers (three species plus unidentified) were grouped. Length at maturity data for shortfin mako and bigeye thresher were chosen to represent each group, respectively, as both observer data and literature sources were greatest for these species. While length at maturity and conversion factors might be expected to vary by region within the WCPO, insufficient data were available to support regional analysis.

In addition to the nominal analysis, and in order to account for potential influences on shark size due to changes in sampling effort, fork lengths from the longline fishery (only) were standardized. This was accomplished using a generalized linear model based on a normal distribution with factors year and 5x5 degree cell. The estimated model coefficients were used to predict shark lengths for each year for an arbitrarily chosen cell lying near the centre of each region. As the model was unable to estimate coefficients for those species, sex, region and year combinations which were not adequately supported by the data, results were only produced for Regions 3-6.

In order to the summarise the trends from the length data further, linear models were fit to the year coefficients produced by the standardization models applied to lengths recorded in longline and purse seine samples. The slopes of these linear models were used to identify significant trends in median lengths over time. Models were run separately for each species, sex, region and fishery and a p-value of 0.05 was used to indicate a trend significantly different from zero (Annexes 8 and 9). One important caveat when interpreting the results is that linear models generalize the direction and magnitude of the trend over the entire time series. Therefore, a size trend that rises at the start of the time series and decreases in the later part of the time series may be characterized as having no trend through time. A summary of the results of the linear model fits by species, sex and region is shown in Figure 20.

6.3 Results

6.4 Conclusions

7 Feasibility of Stock Assessments

8 Impact of Recent Shark Management Measures

9 Recommendations for Future Indicator Work

10 Management Implications

Acknowledgements

11 Appendices

11.1 CPUE Indicators. Model diagnostics and extra plots

Blue Shark model diagnostics and extra plots

Silky Shark model diagnostics and extra plots

Oceanic Whitetip Shark model diagnostics and extra plots

Thresher Shark model diagnostics and extra plots

11.2 Longline Fishery Data

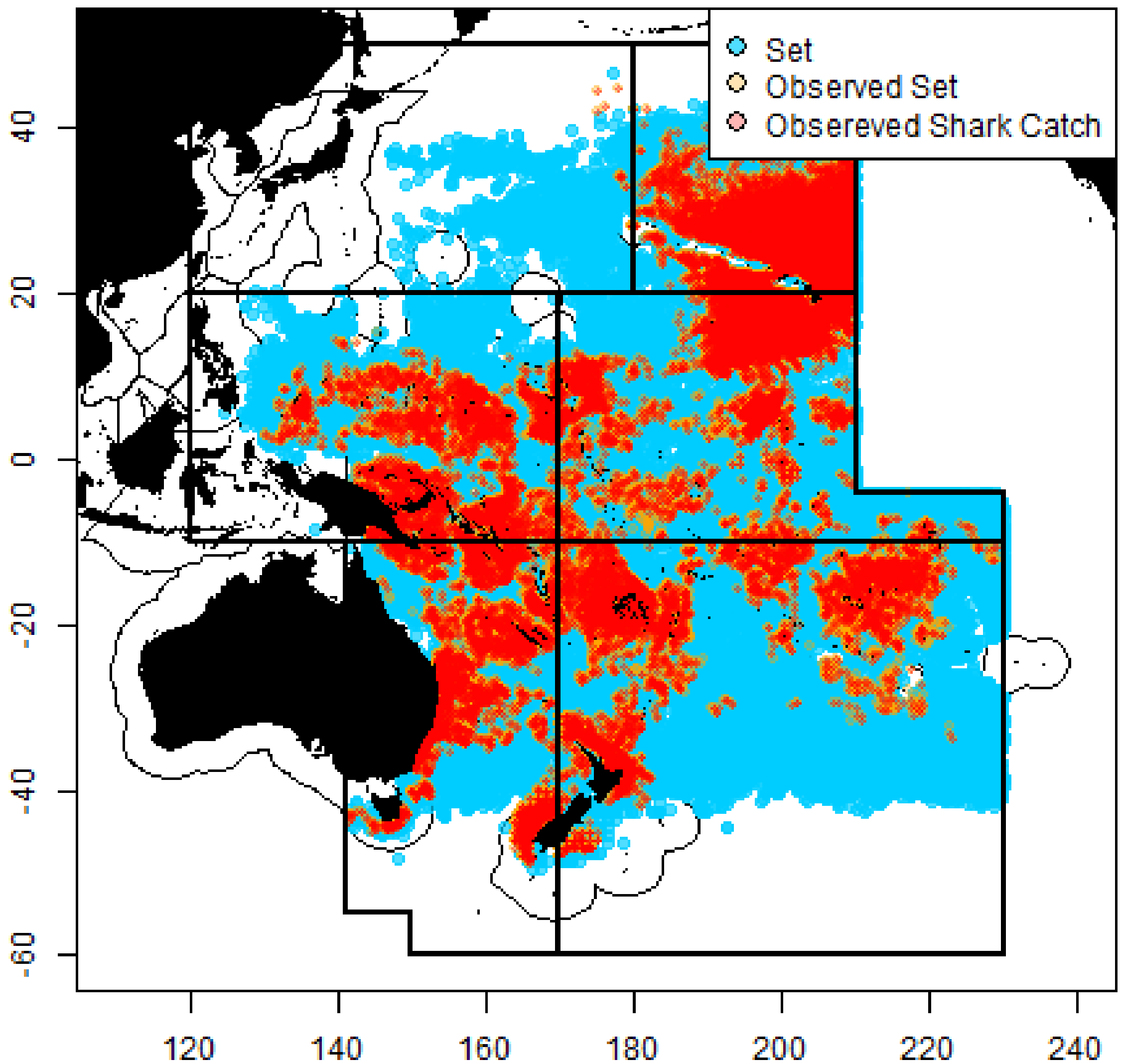

Figure 4: Map of WCPO and observed effort.

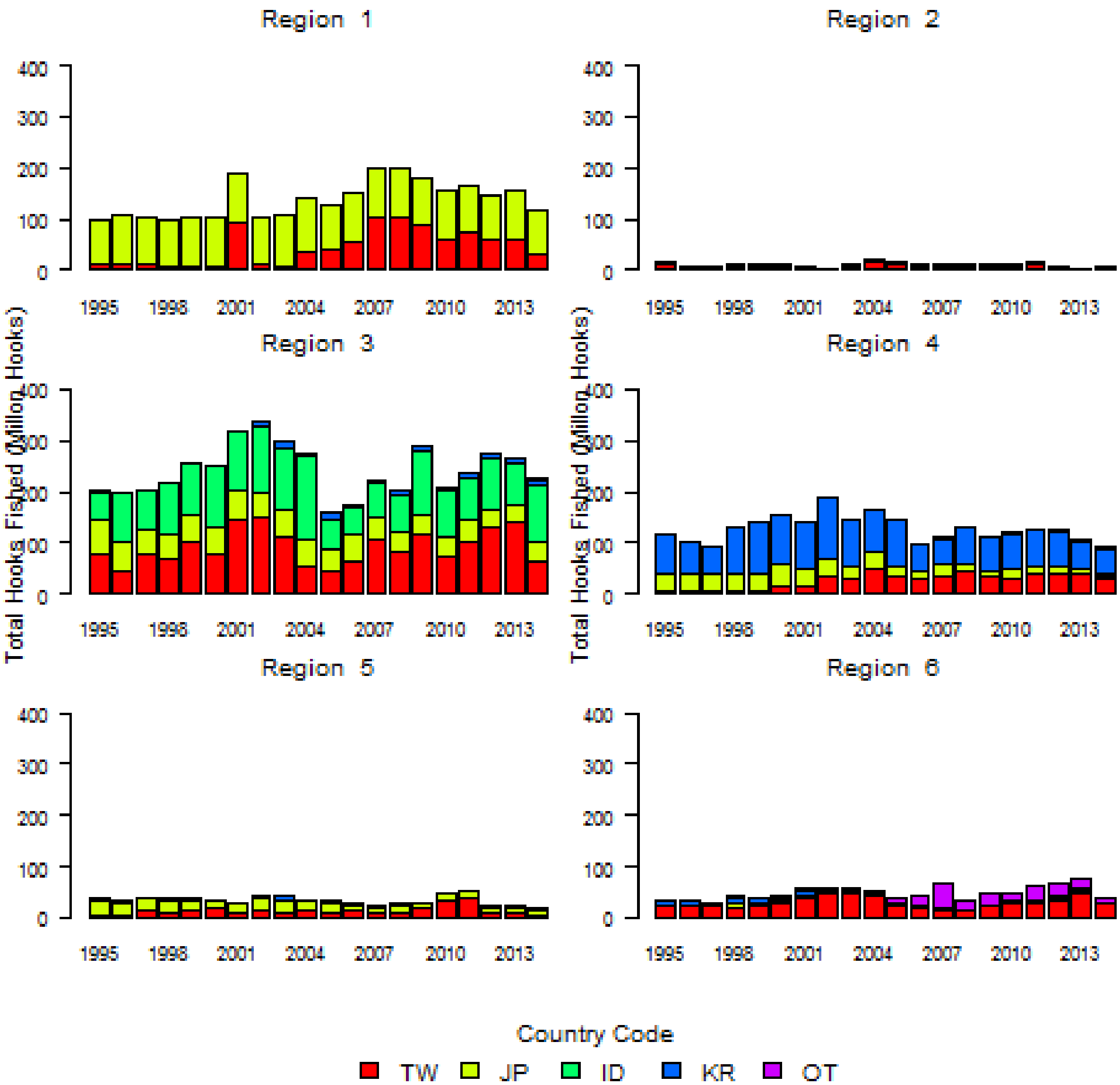

Figure 5: Total number of hooks fished by flag (for the top four fishing nations, and all others combined) based on aggregated (5x5 degree square) data, for six regions of the WCPFC Statistical Area.

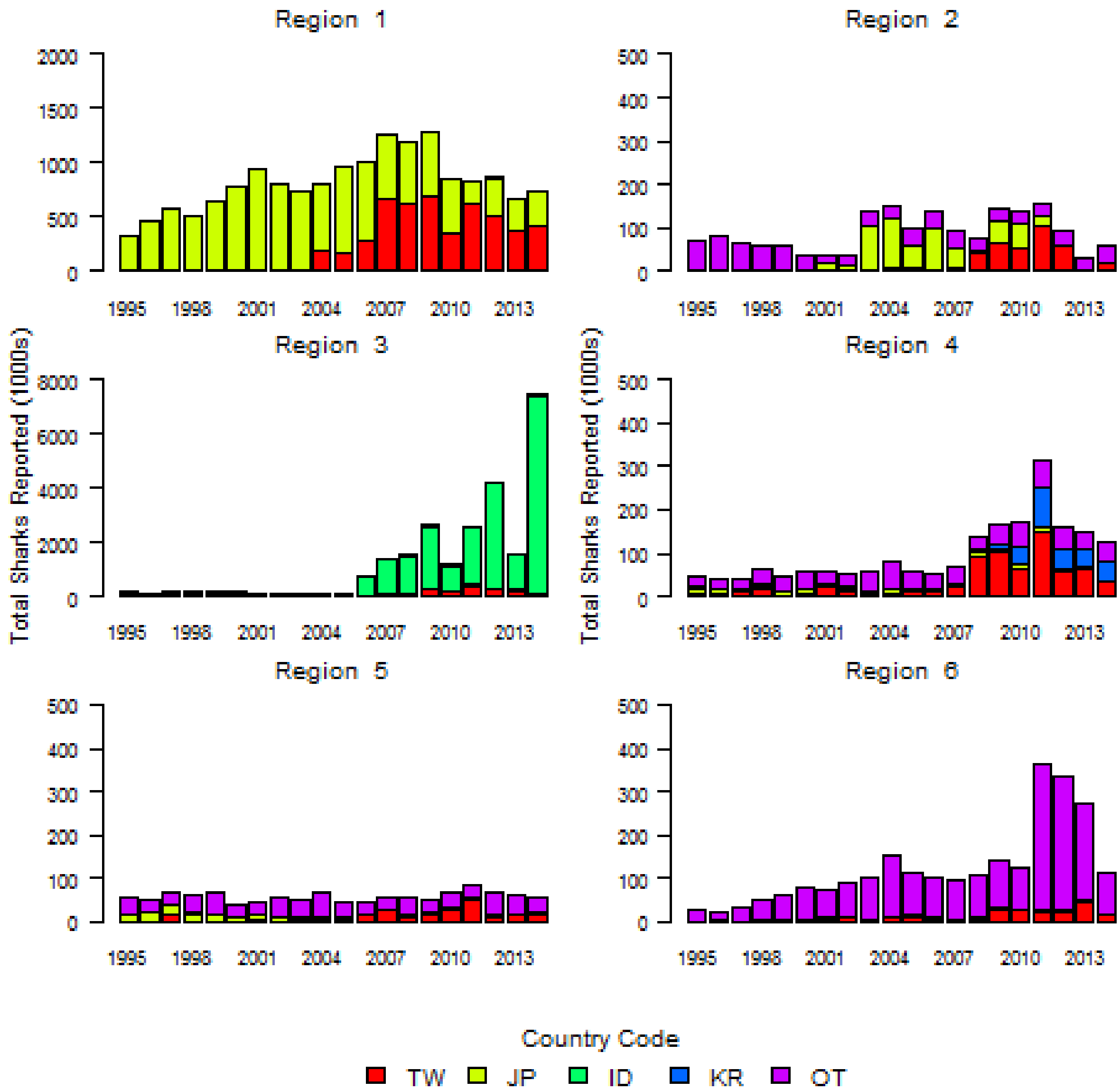

Figure 6: Total number of reported sharks by flag (for the top four fishing nations, and all others combined) based aggregated (5x5 degree square) data, for six regions of the WCPFC Statistical Area.

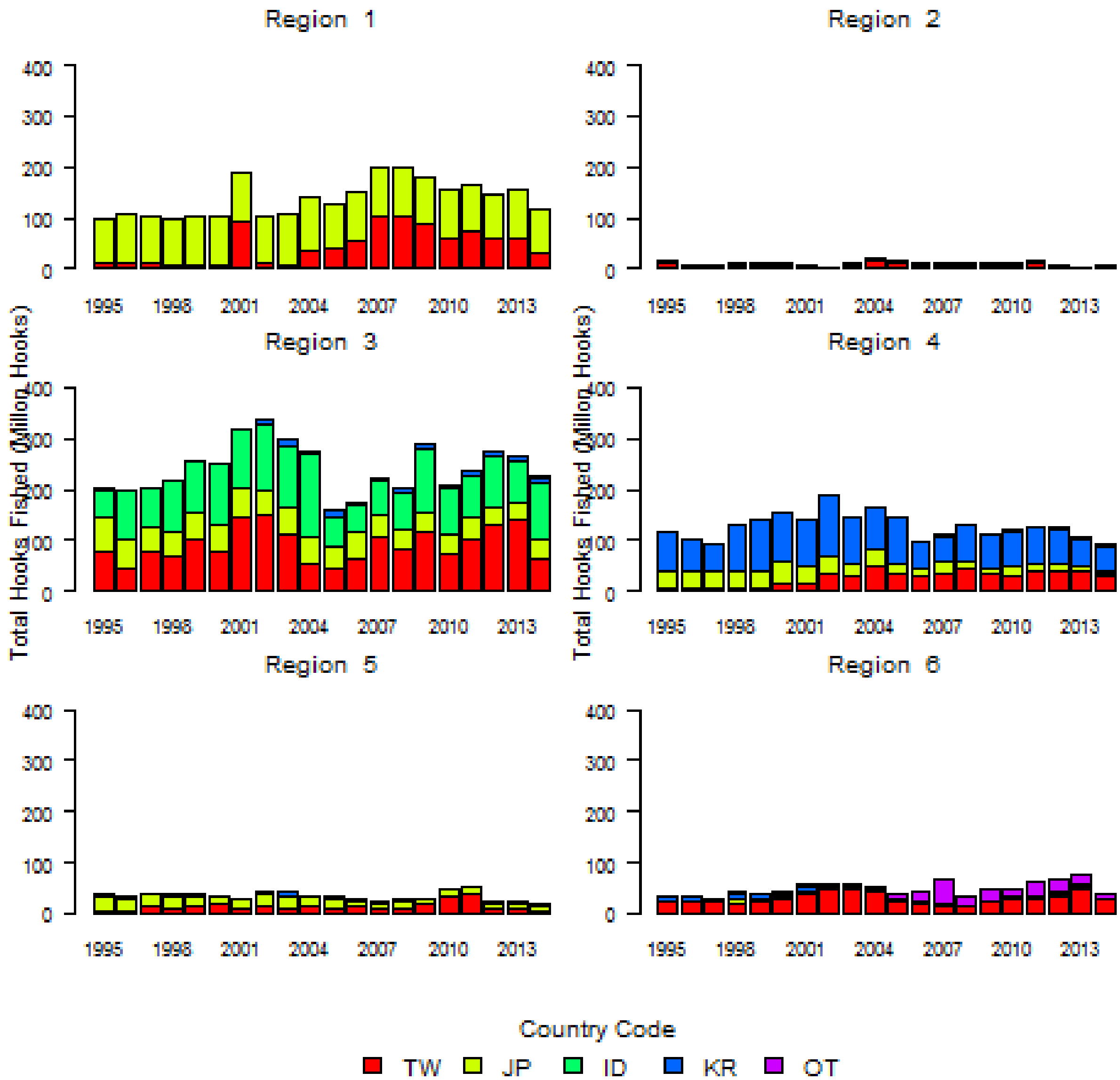

Figure 7: Total number of hooks observed by flag (for the top four fishing nations) based on longline observer records held by the SPC-OFP, for six regions of the WCPFC Statistical Area

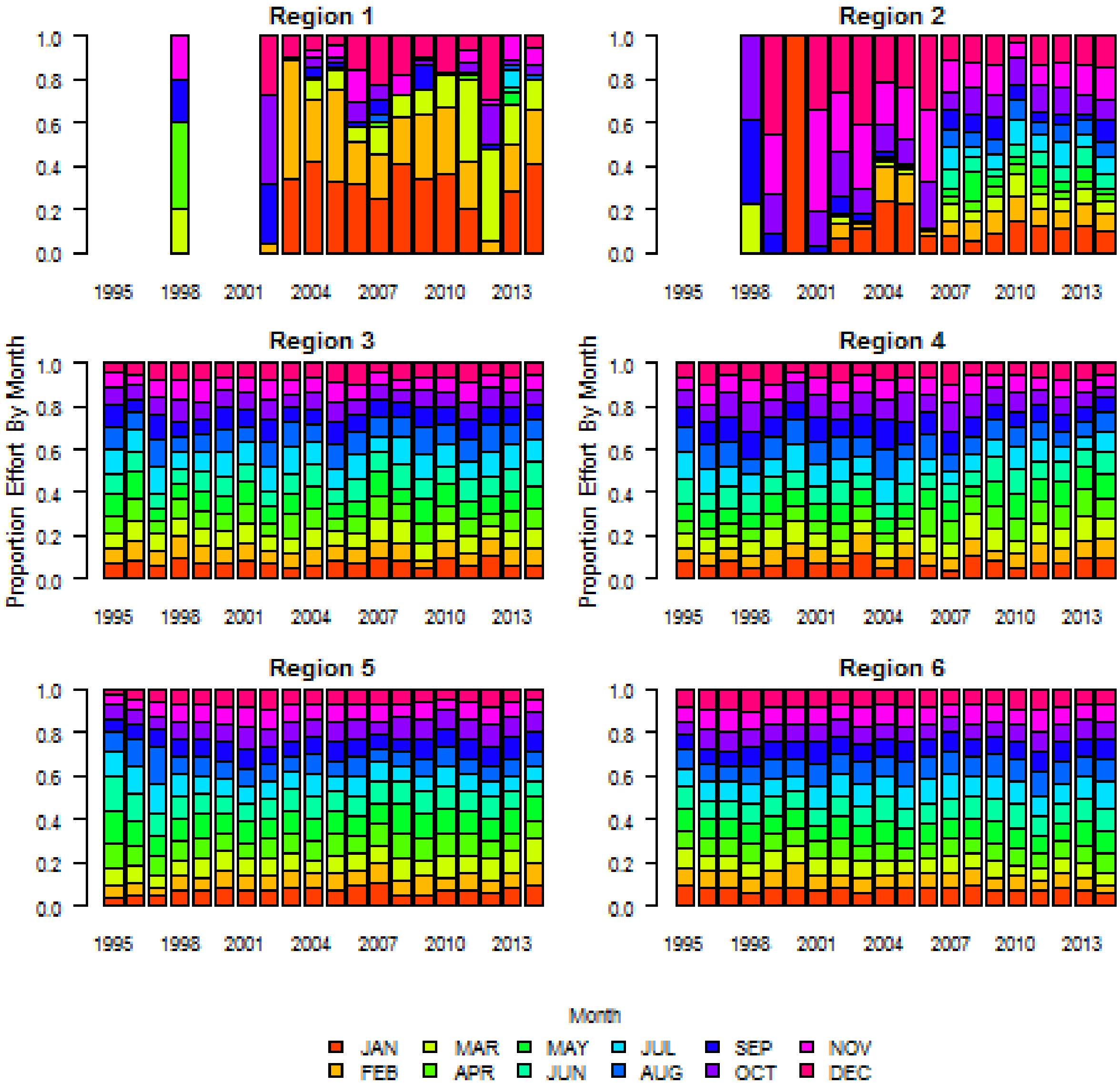

Figure 8: Logsheet effort by month.

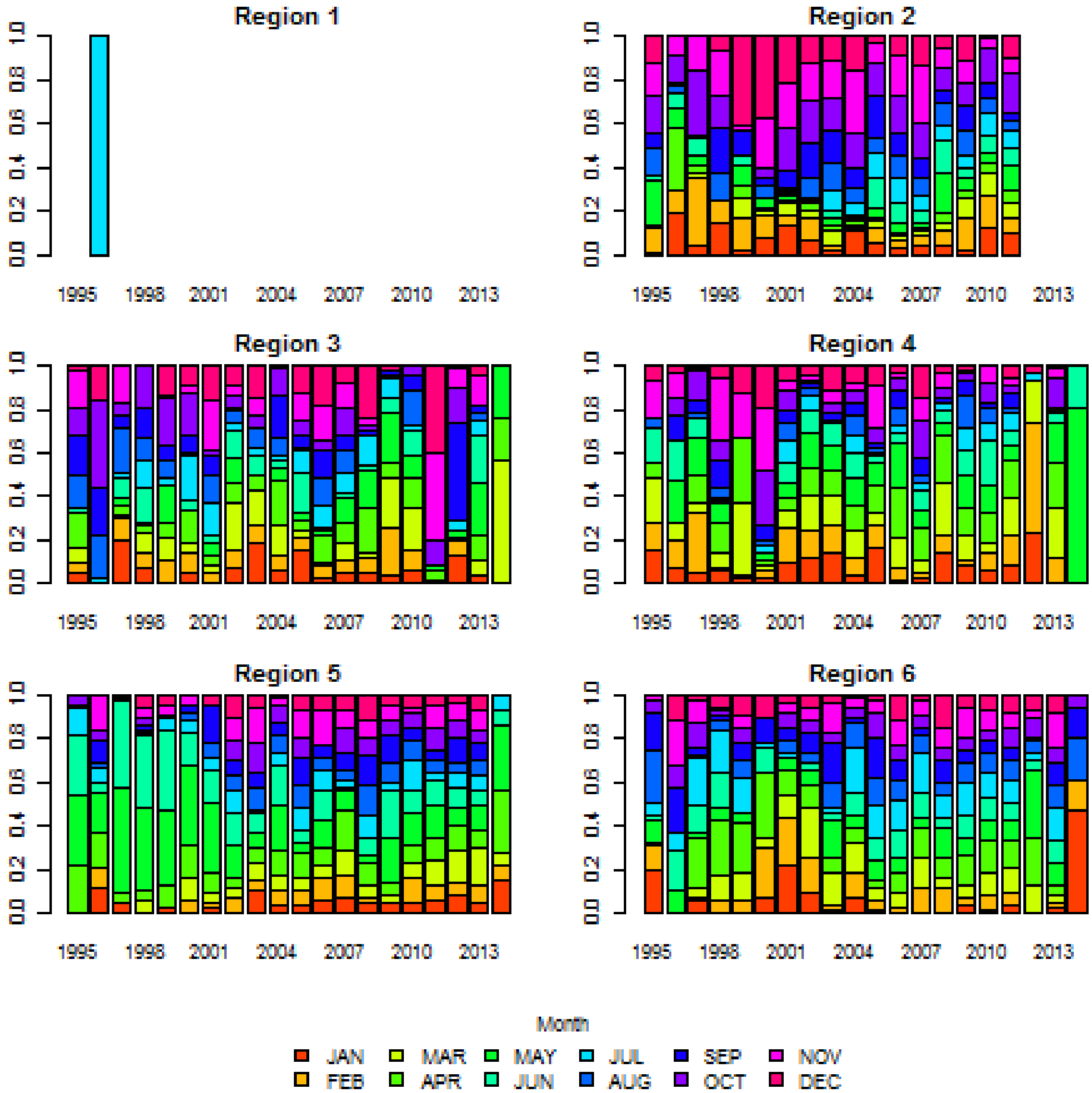

Figure 9: Observed effort by month.

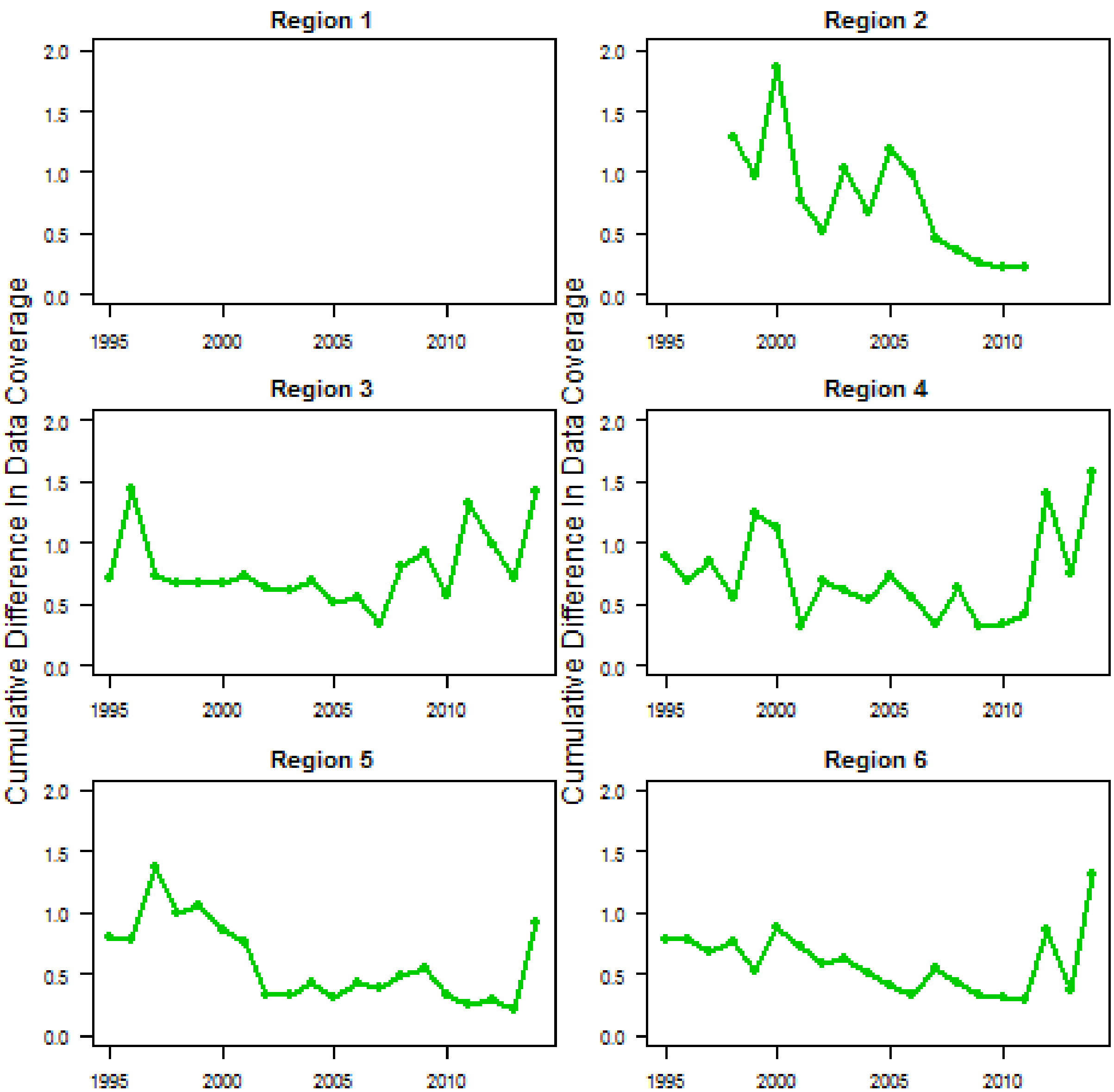

Figure 10: Absolute percent difference in effort between reported (logsheet) effort and observed effort.

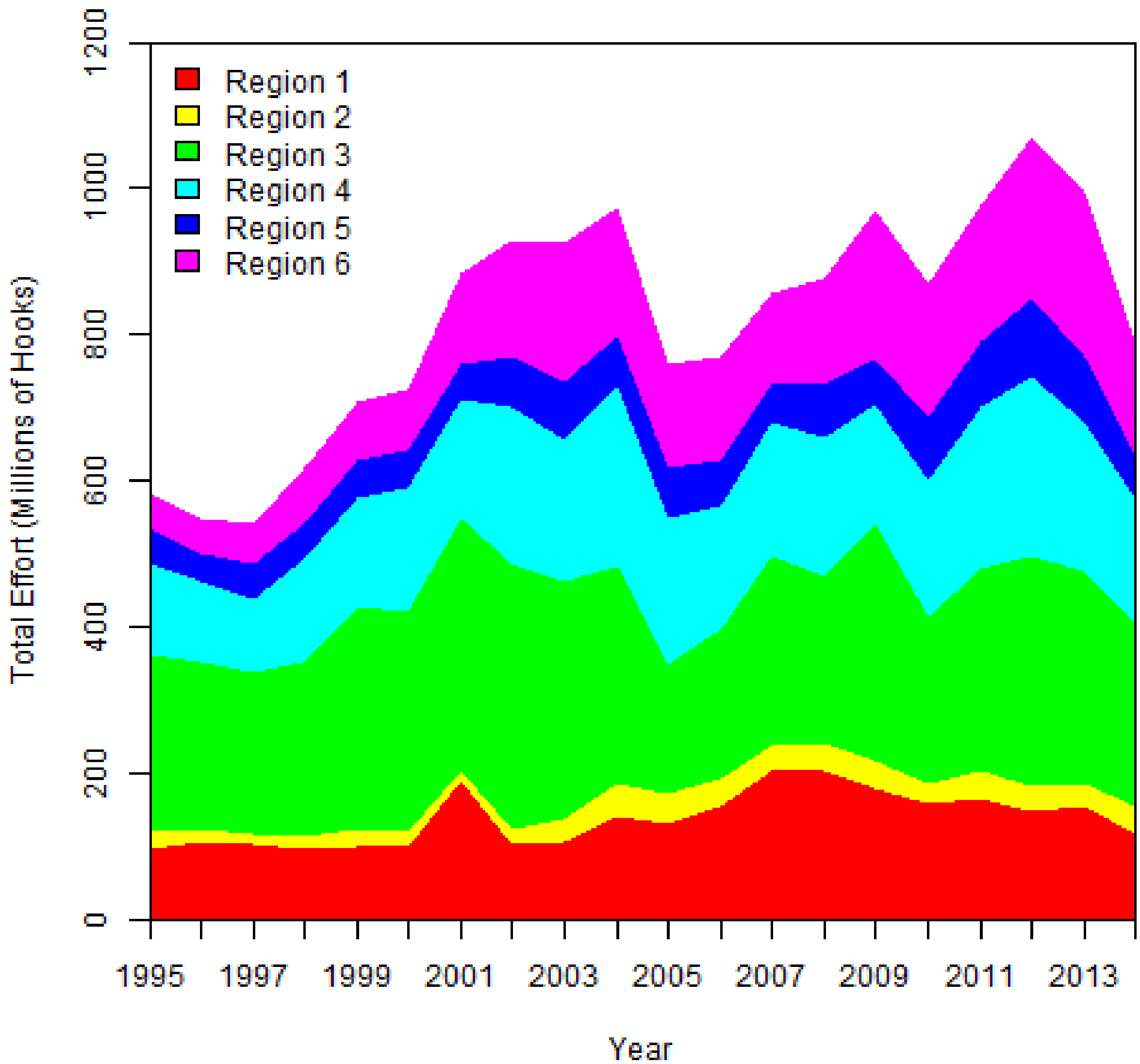

Figure 11: Aggregate effort by region.

Fishing Effort- Purse Seine

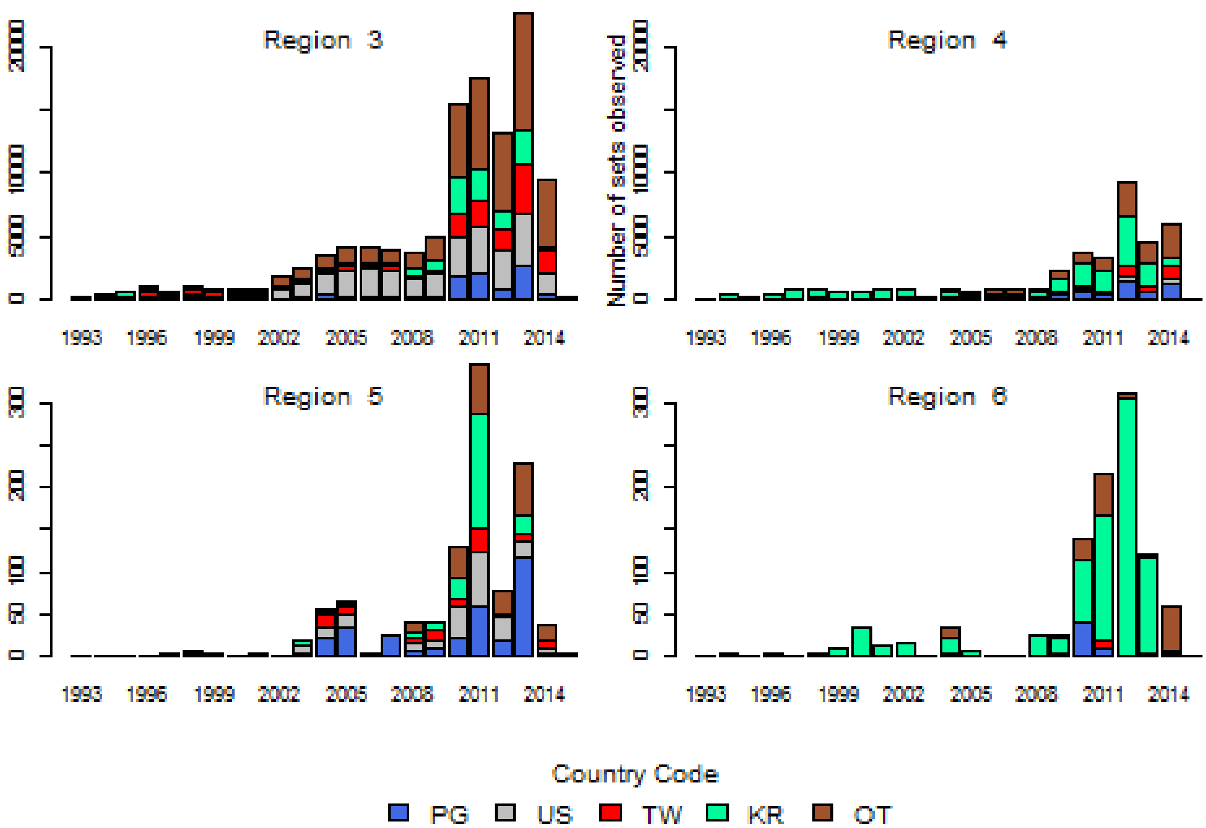

Figure 12: Observed purse seine in the WCPO showing the top four fishing nations and all others combined.

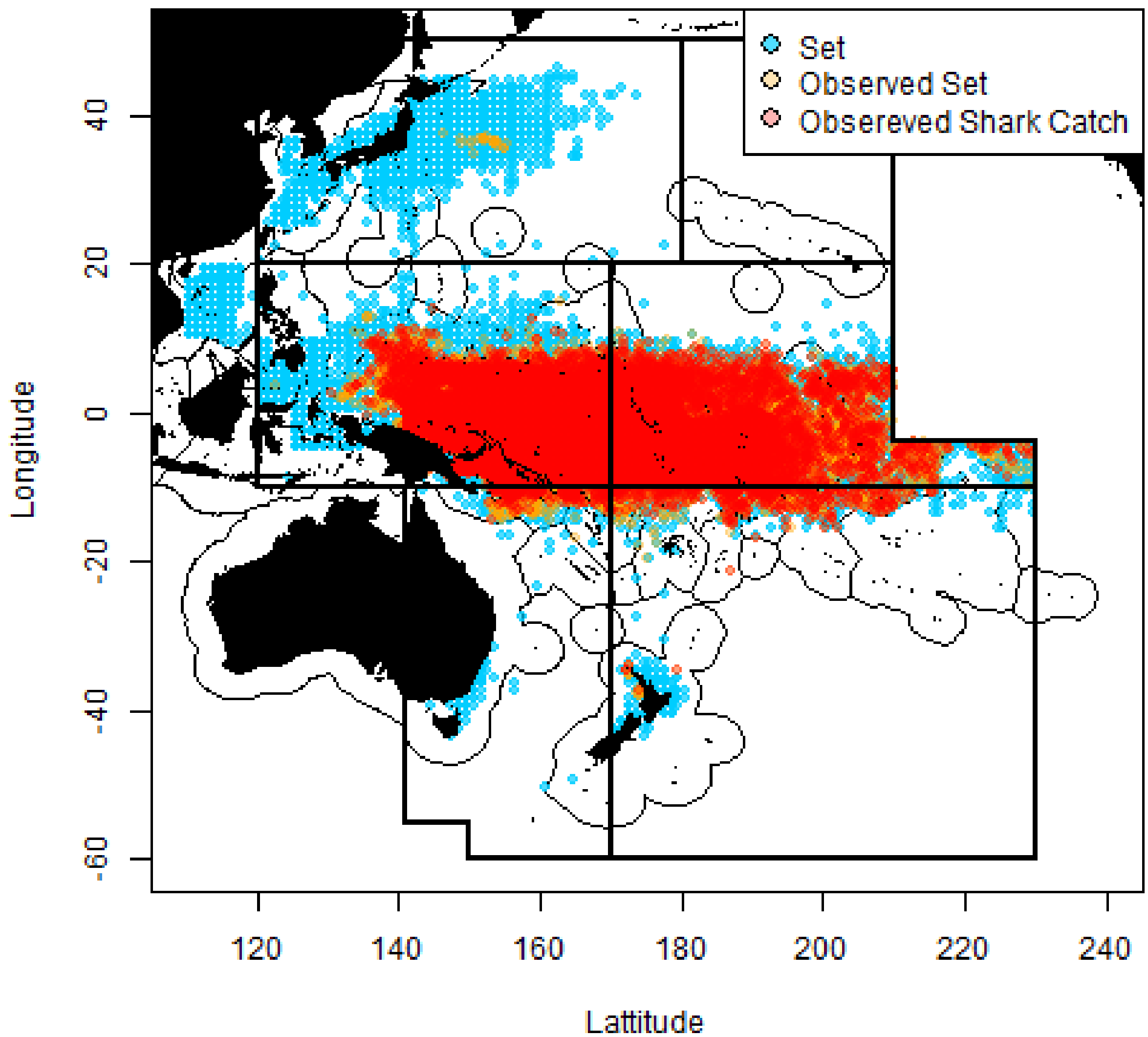

Figure 13: Absolute percent difference in effort between reported (logsheet) effort and observed effort.

12 Distribution Indicator Analyses

12.1 Introduction

12.2 Methods

12.3 Results

12.3.1 Blue Shark

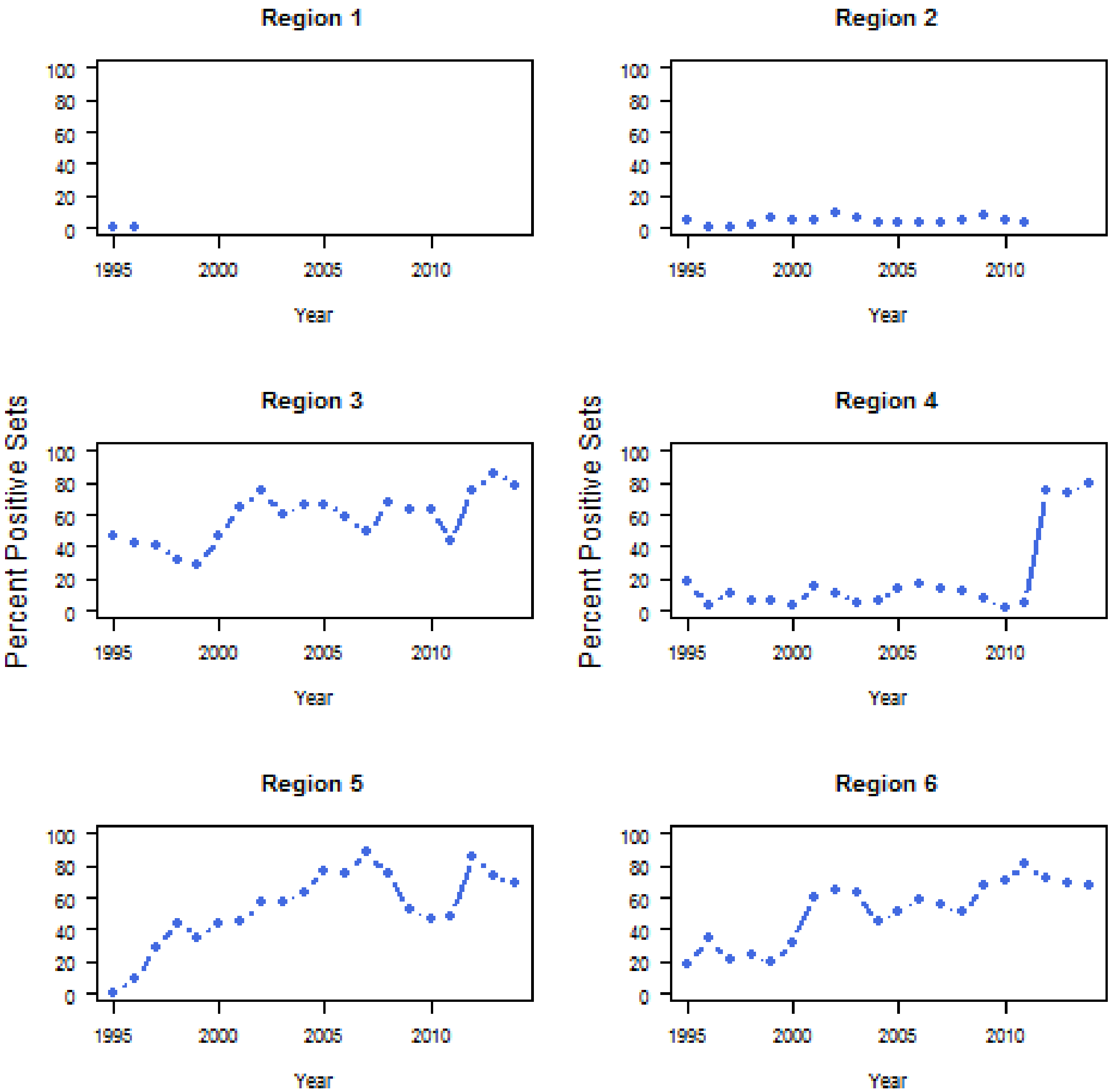

Figure 14: Blue shark distribution indicators. Proportion of positive sets, observer data.

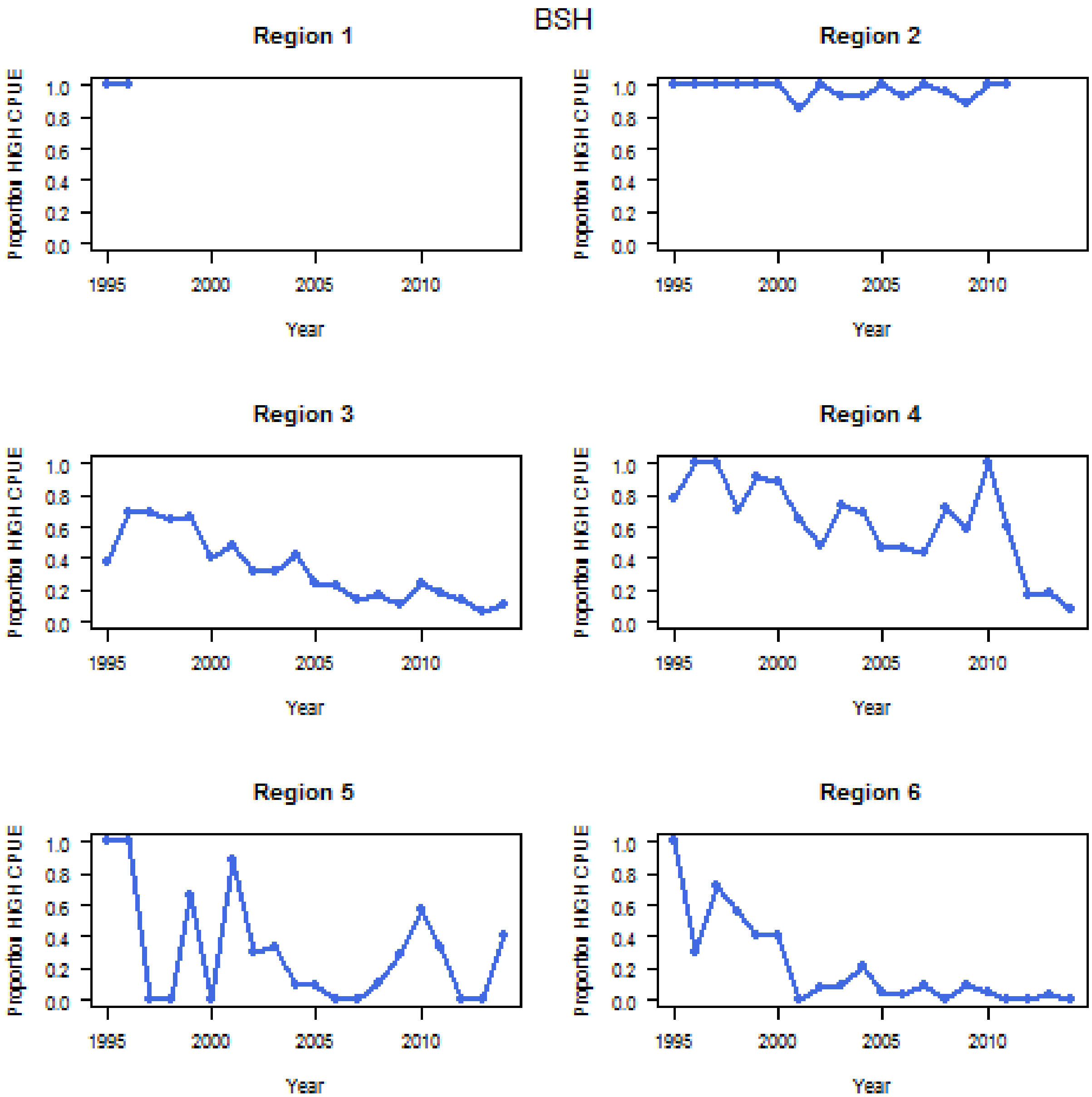

Figure 15: Blue shark distribution indicators. Proportion of 5 degree squares having CPUE greater than 1 per 1000 hooks region, observer data.

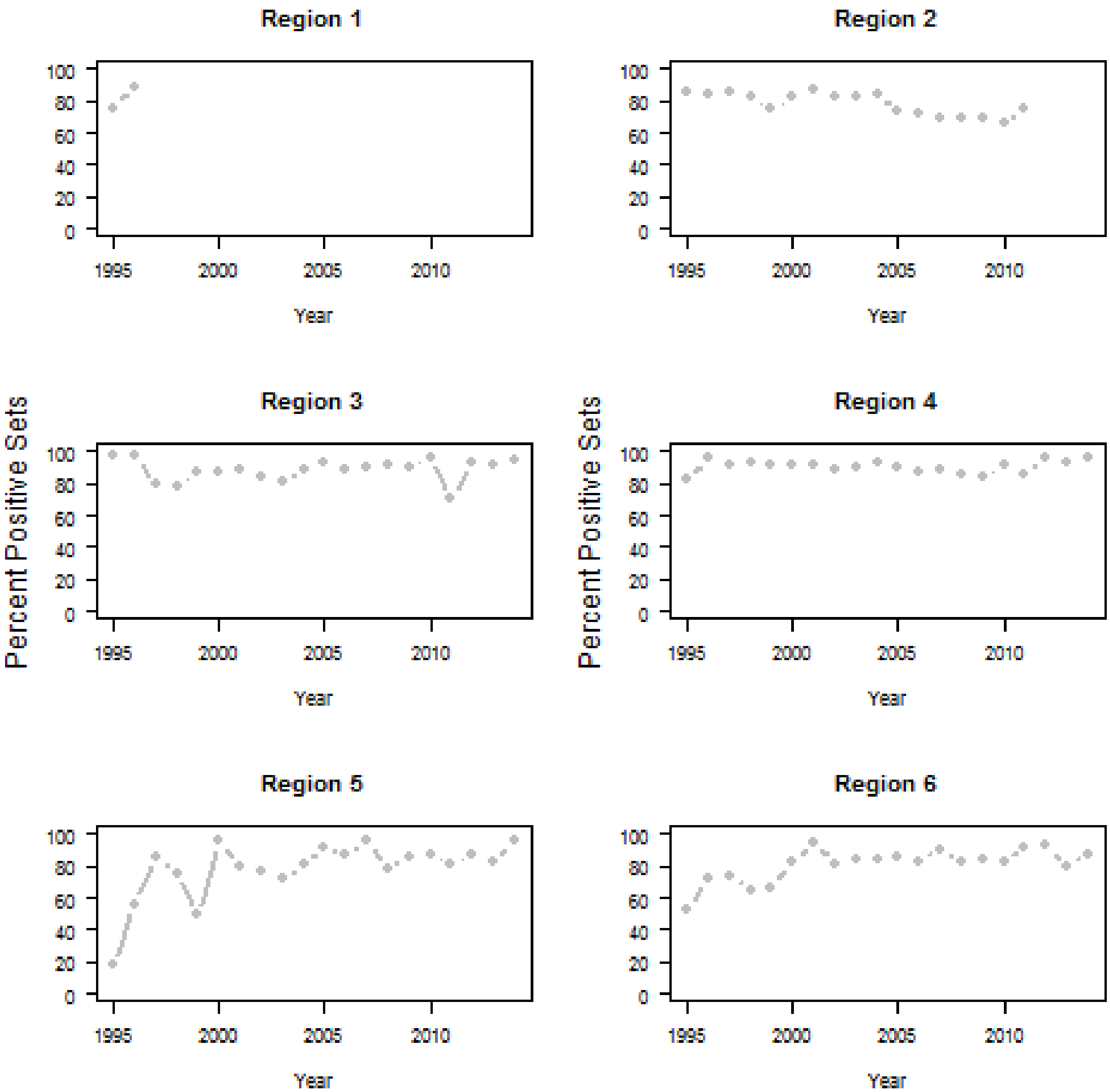

Figure 16: Mako shark distribution indicators. Proportion of positive sets, observer data.

12.3.2 Mako Shark

12.3.3 Silky Shark

12.3.4 Oceanic Whitetip Shark

12.3.5 Thresher Shark

12.4 Conclusions

13 Observed Species Composition Indicator Analyses

13.1 Introduction

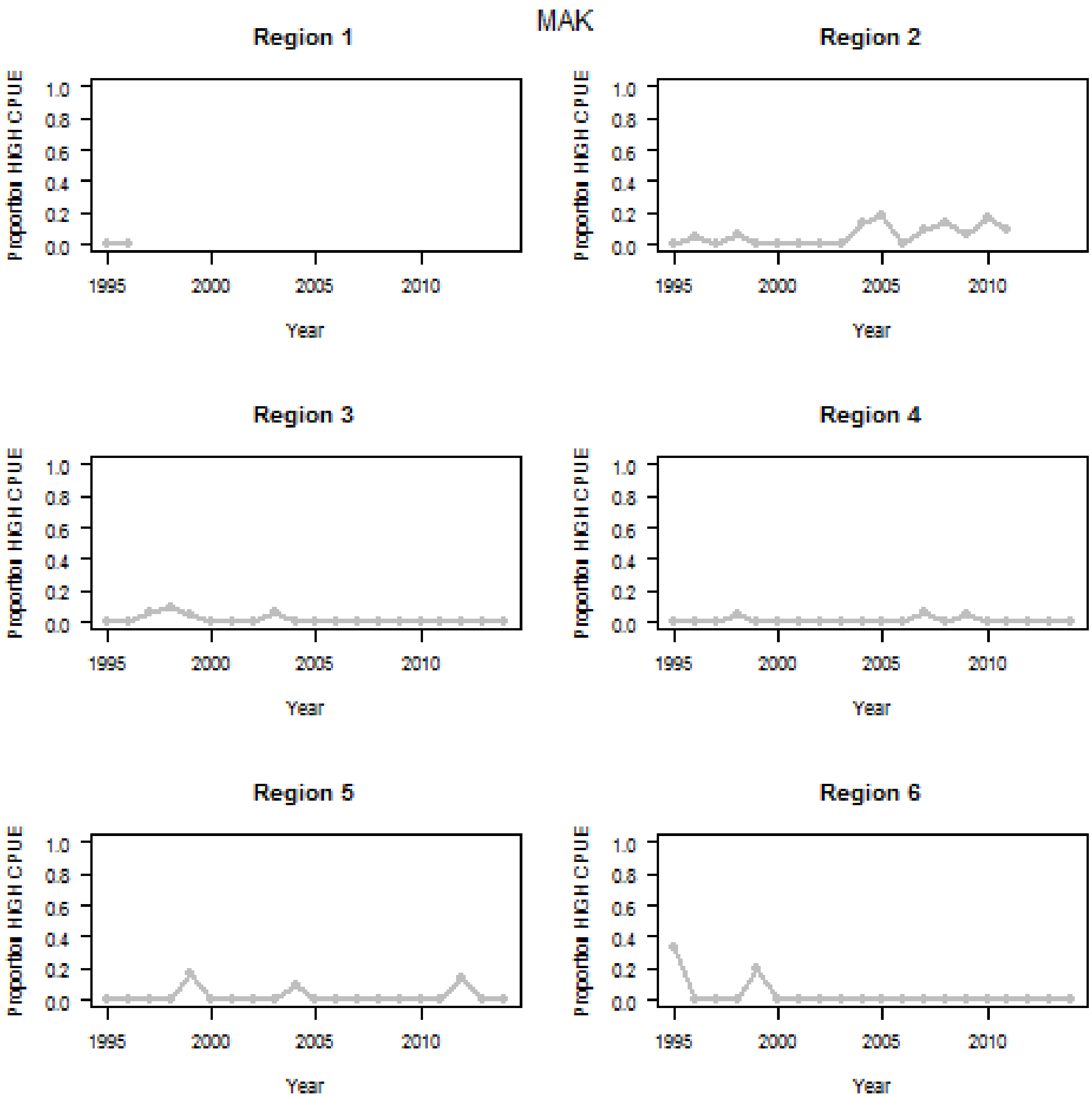

Figure 17: Mako shark distribution indicators. Proportion of 5 degree squares having CPUE greater than 1 per 1000 hooks region, observer data.

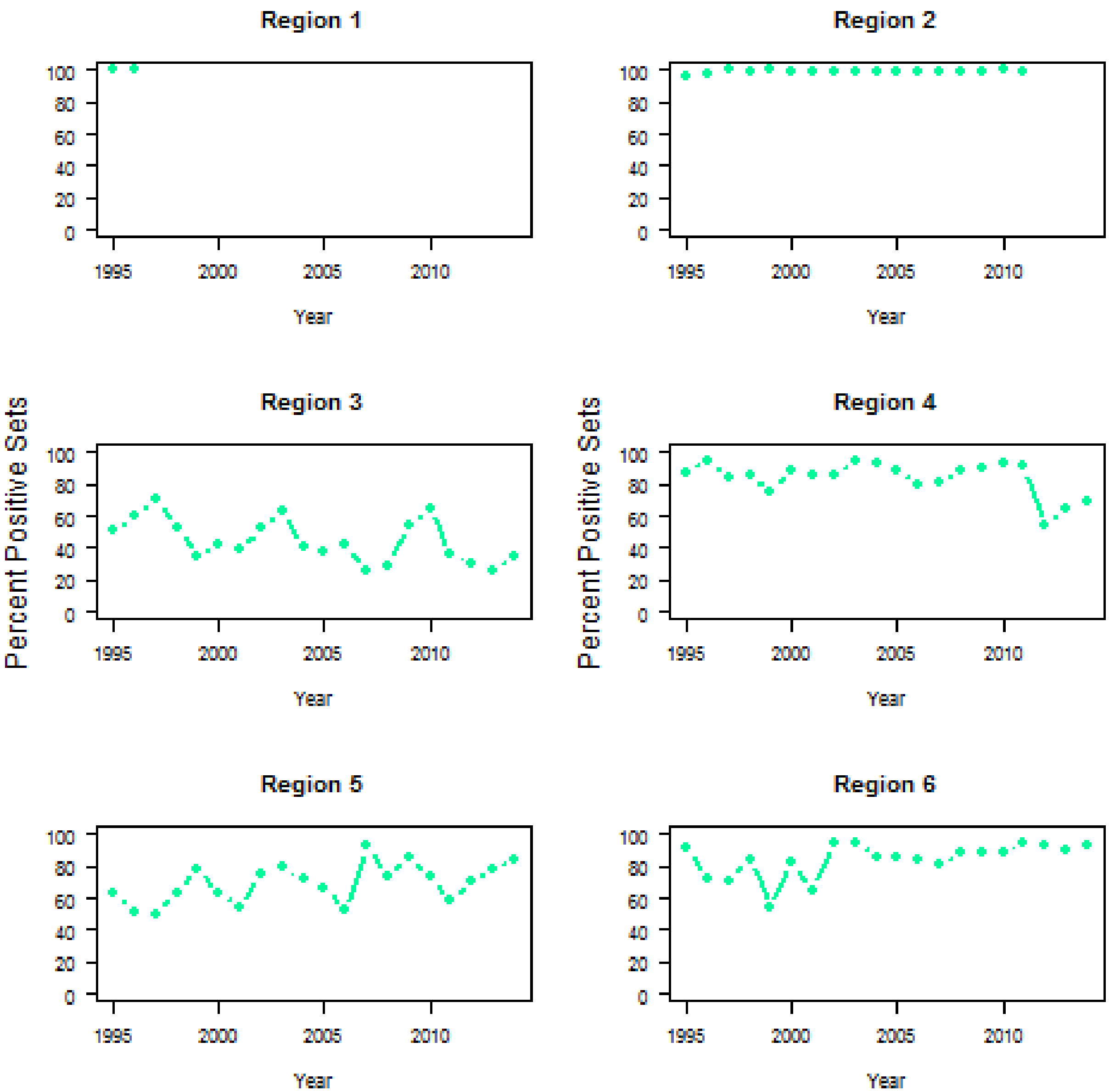

Figure 18: Mako shark distribution indicators. Proportion of positive sets, observer data.

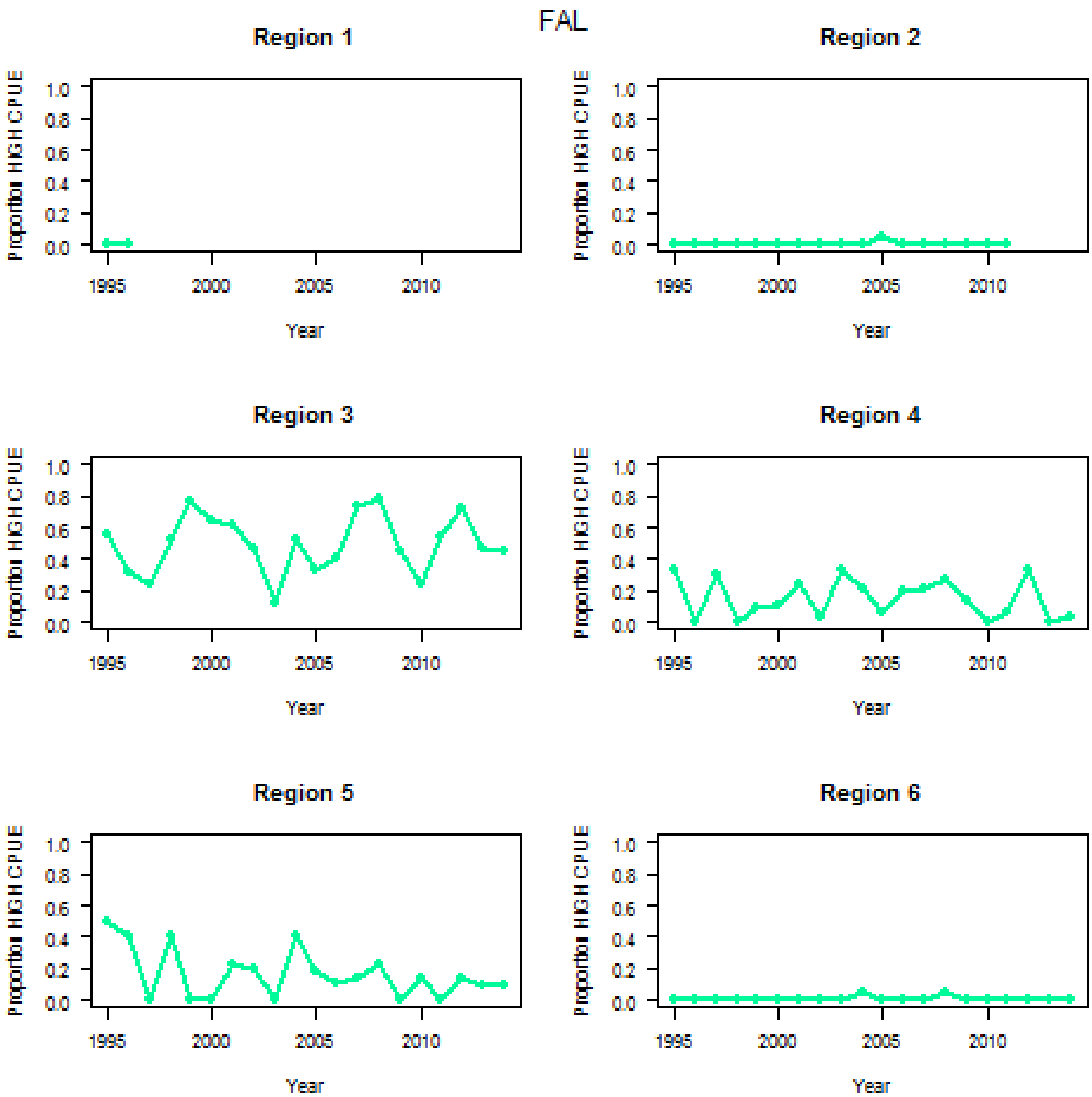

Figure 19: Silky shark distribution indicators. Proportion of 5 degree squares having CPUE greater than 1 per 1000 hooks region, observer data.

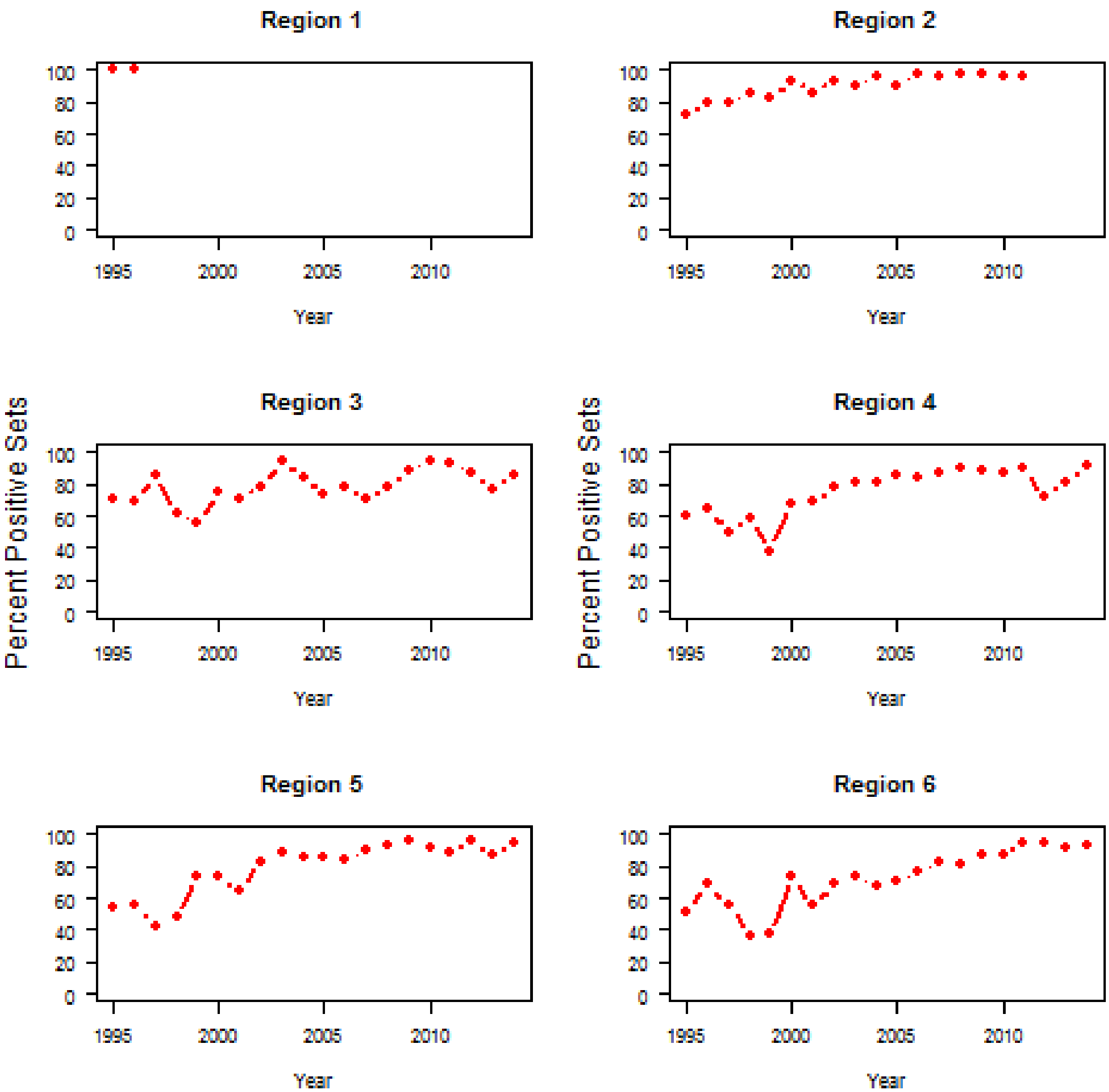

Figure 20: Oceanic whitetip shark distribution indicators. Proportion of positive sets, observer data.

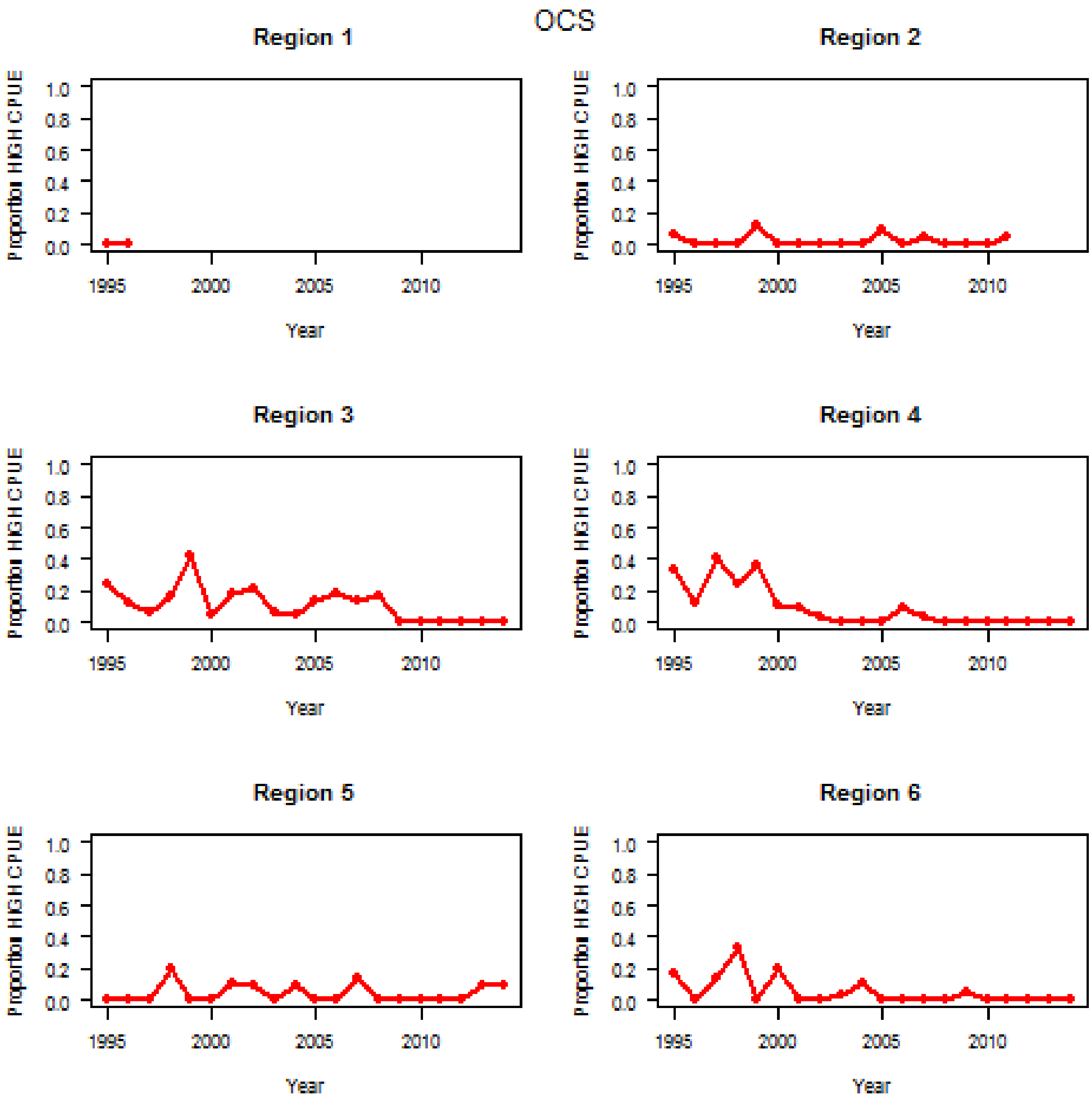

Figure 21: Oceanic whitetip shark distribution indicators. Proportion of 5 degree squares having CPUE greater than 1 per 1000 hooks region, observer data.

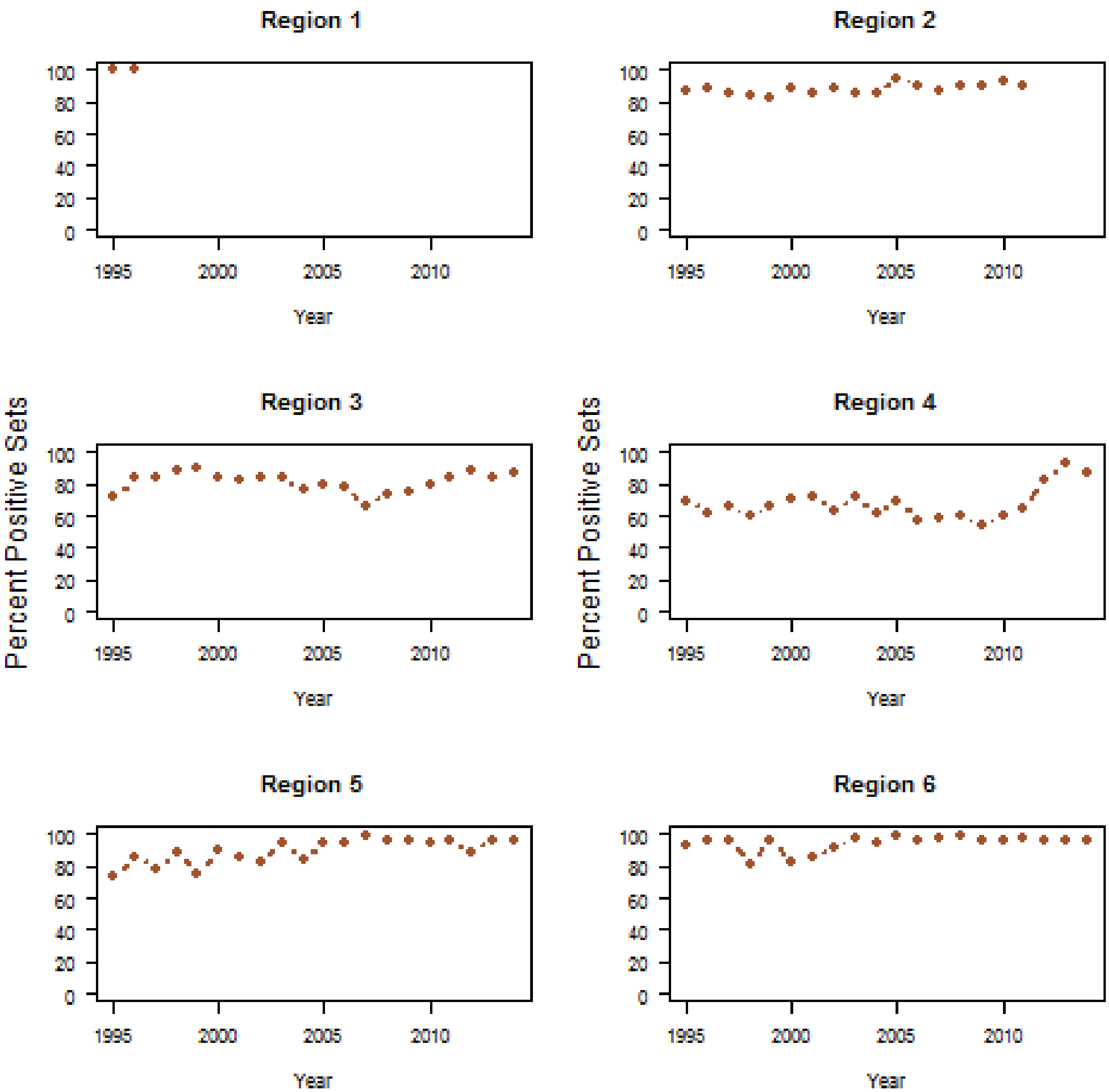

Figure 22: Thresher shark distribution indicators. Proportion of positive sets, observer data.

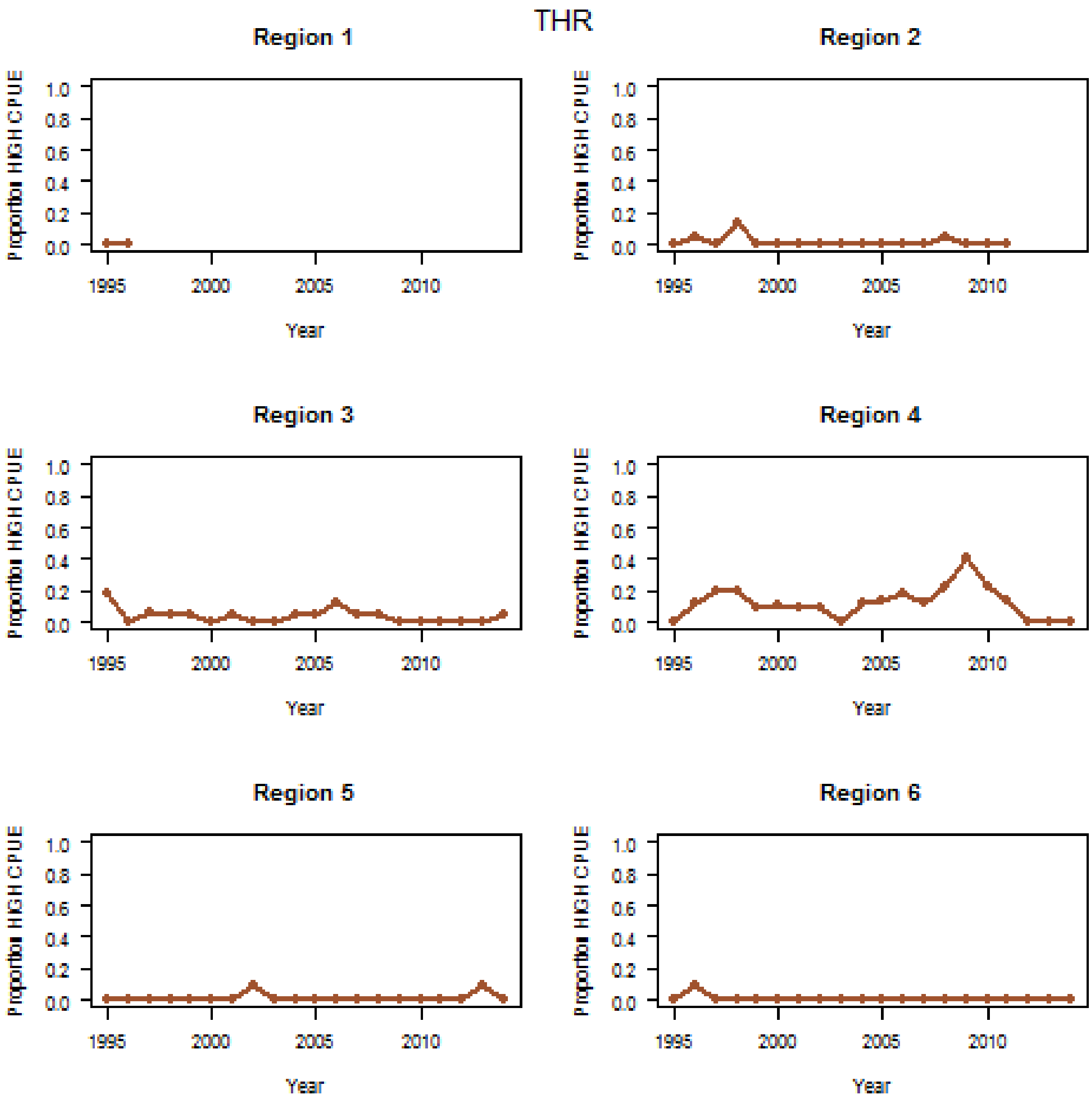

Figure 23: Thresher shark distribution indicators. Proportion of 5 degree squares having CPUE greater than 1 per 1000 hooks region, observer data.

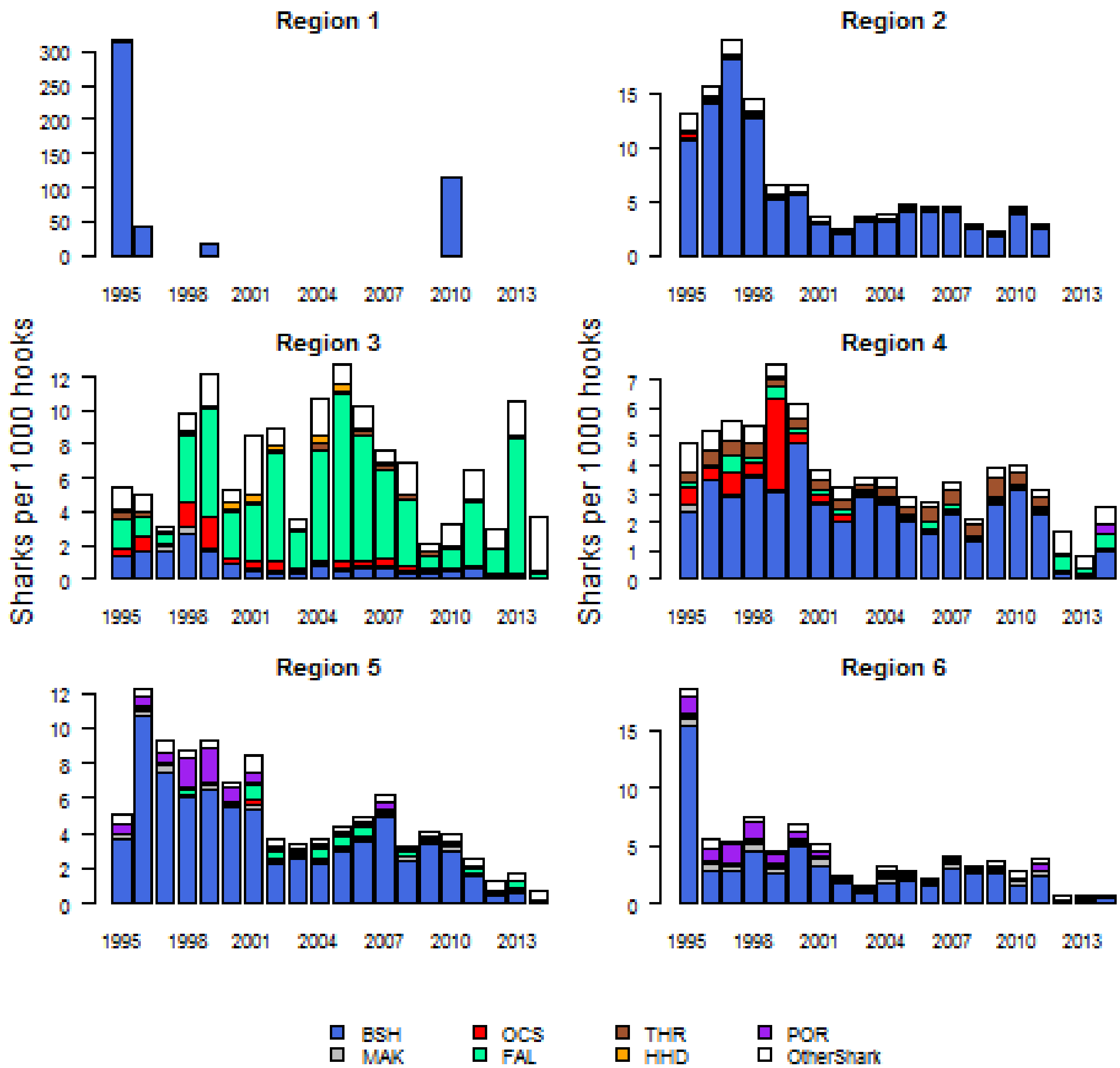

Figure 24: Catch Composition Indicators. Sharks Per. 1000 hooks by region, observer data.

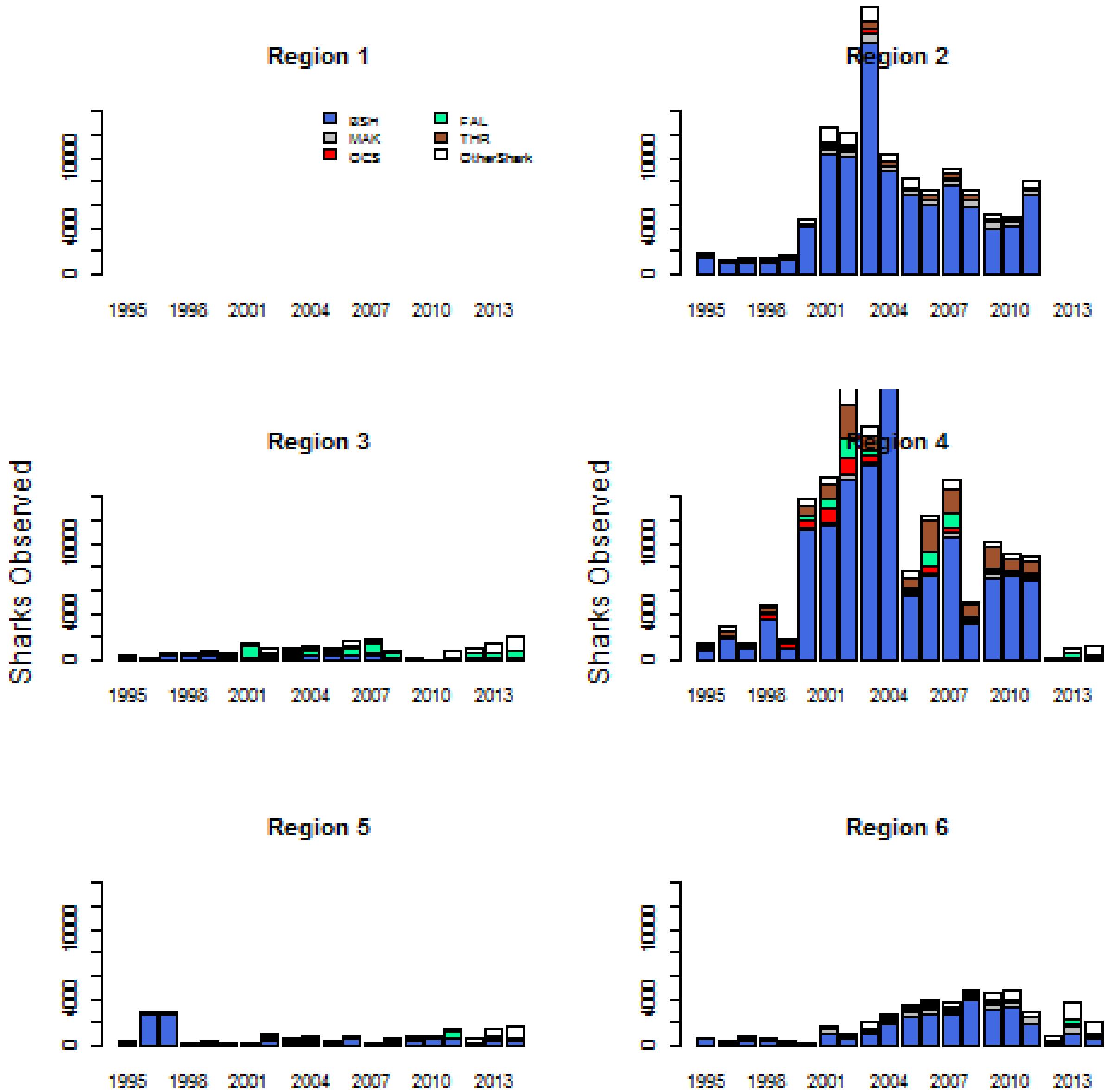

Figure 25: Catch Composition Indicators. Sharks Per. 1000 hooks by region, deep sets observer data.

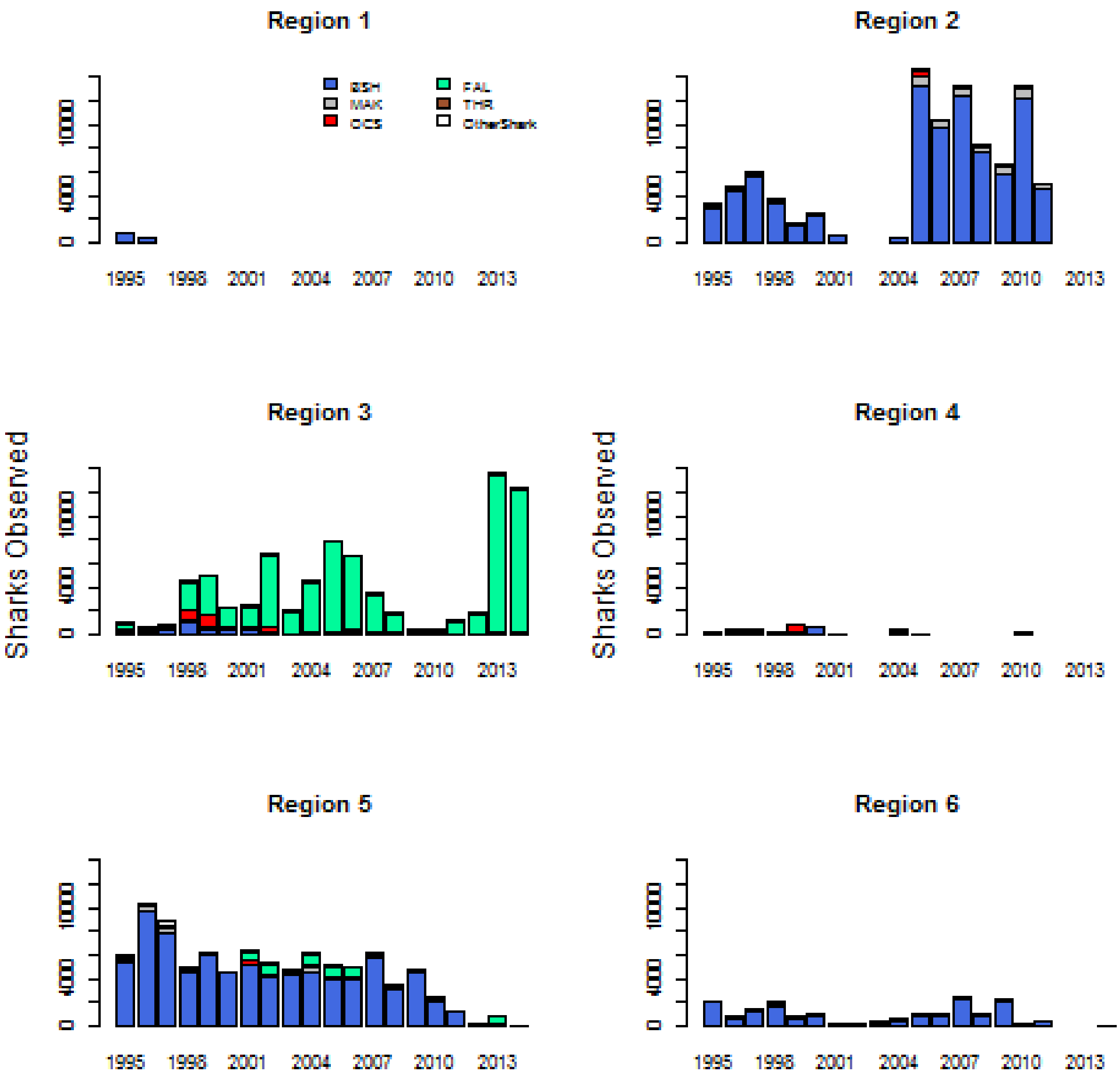

Figure 26: Catch Composition Indicators. Sharks Per. 1000 hooks by region, shallow sets observer data.

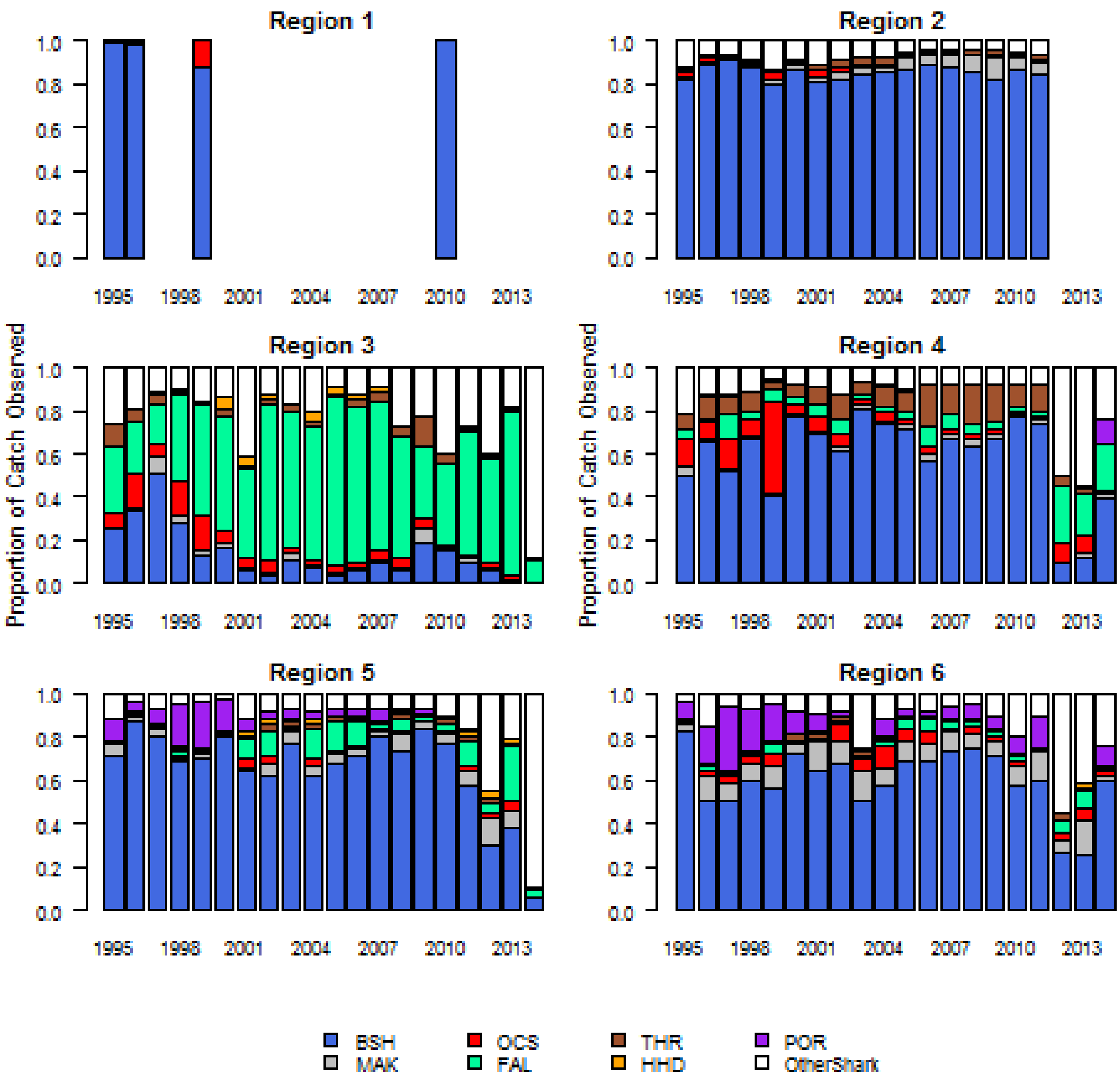

Figure 27: Catch Composition Indicators. Proportional catch of main species and other sharks by retions.

Purse Seine

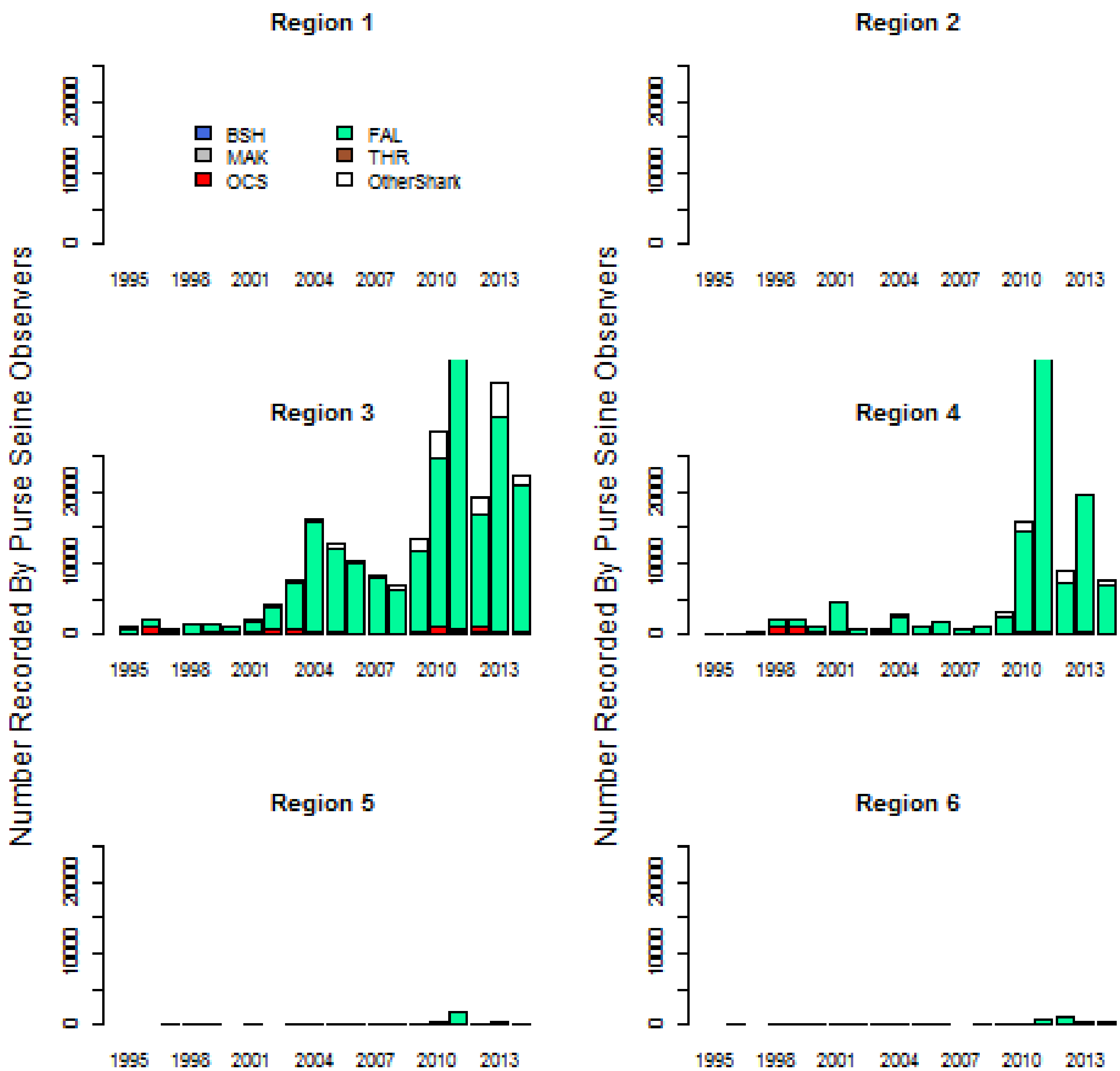

Figure 28: Catch Composition Indicators. Sharks per set, observer data.

13.4 Conclusions

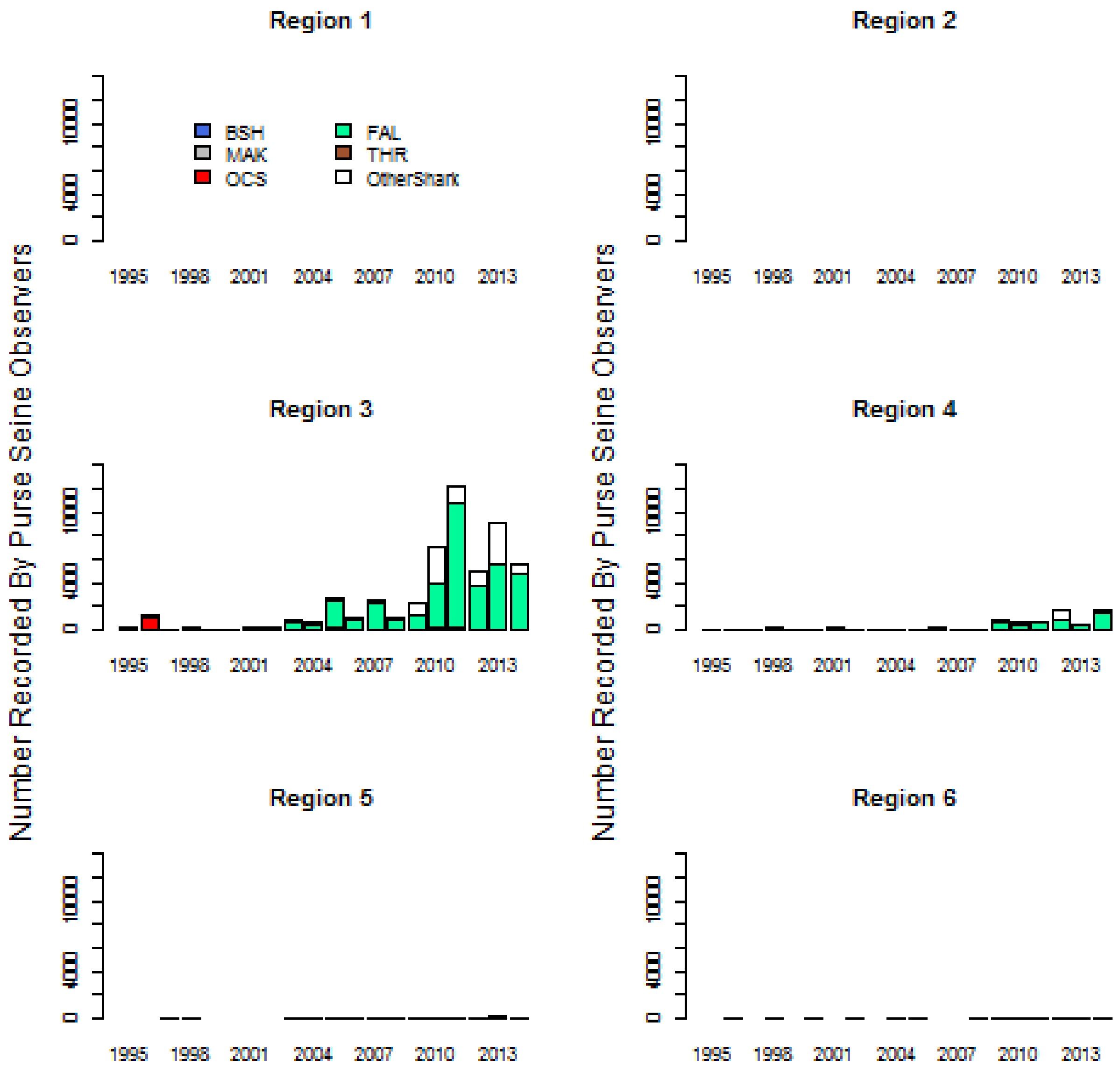

Figure 29: Catch Composition Indicators. Sharks per set, associated sets, observer data

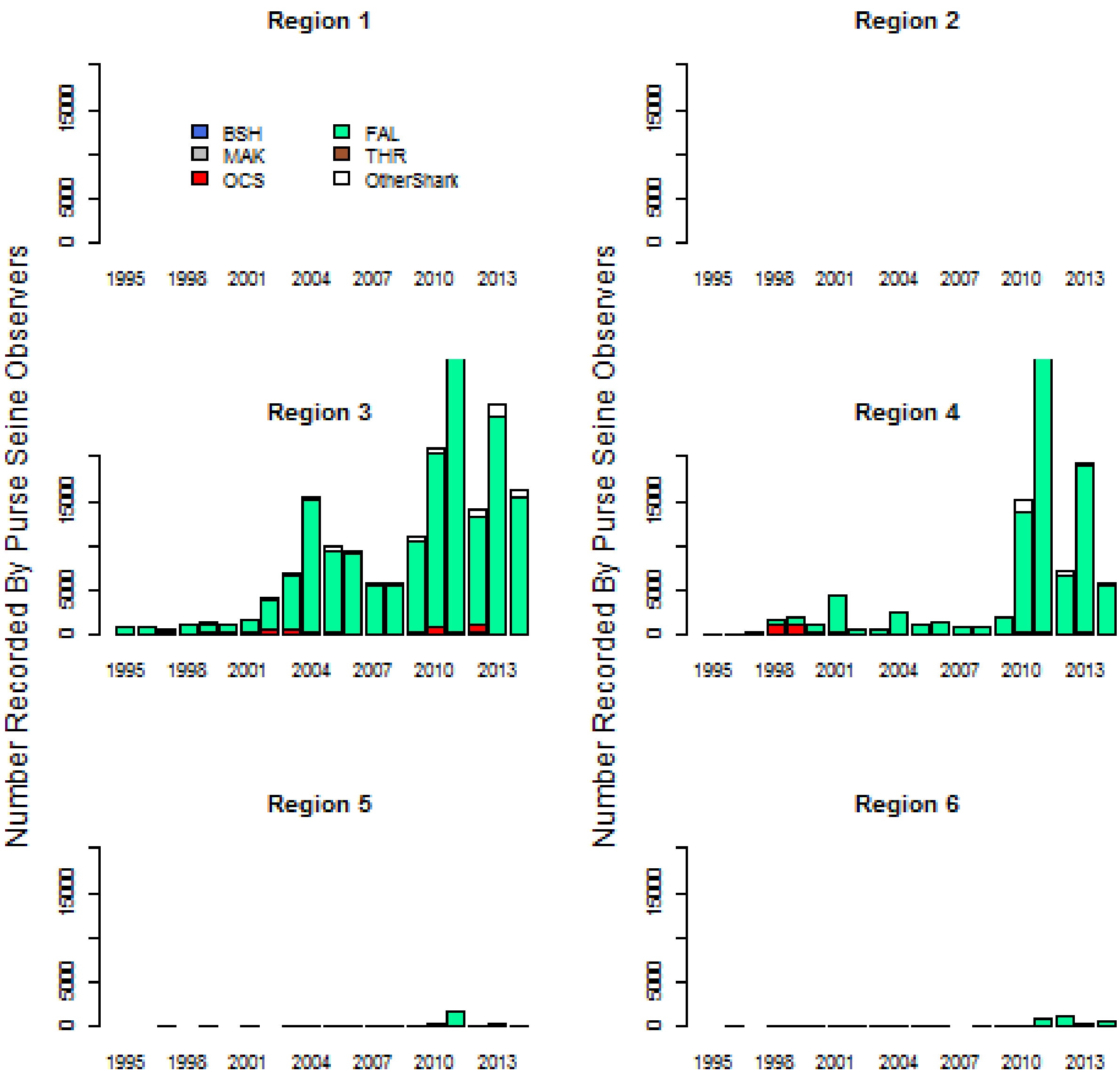

Figure 30: Catch Composition Indicators. Sharks per set, unassociated sets, observer data.

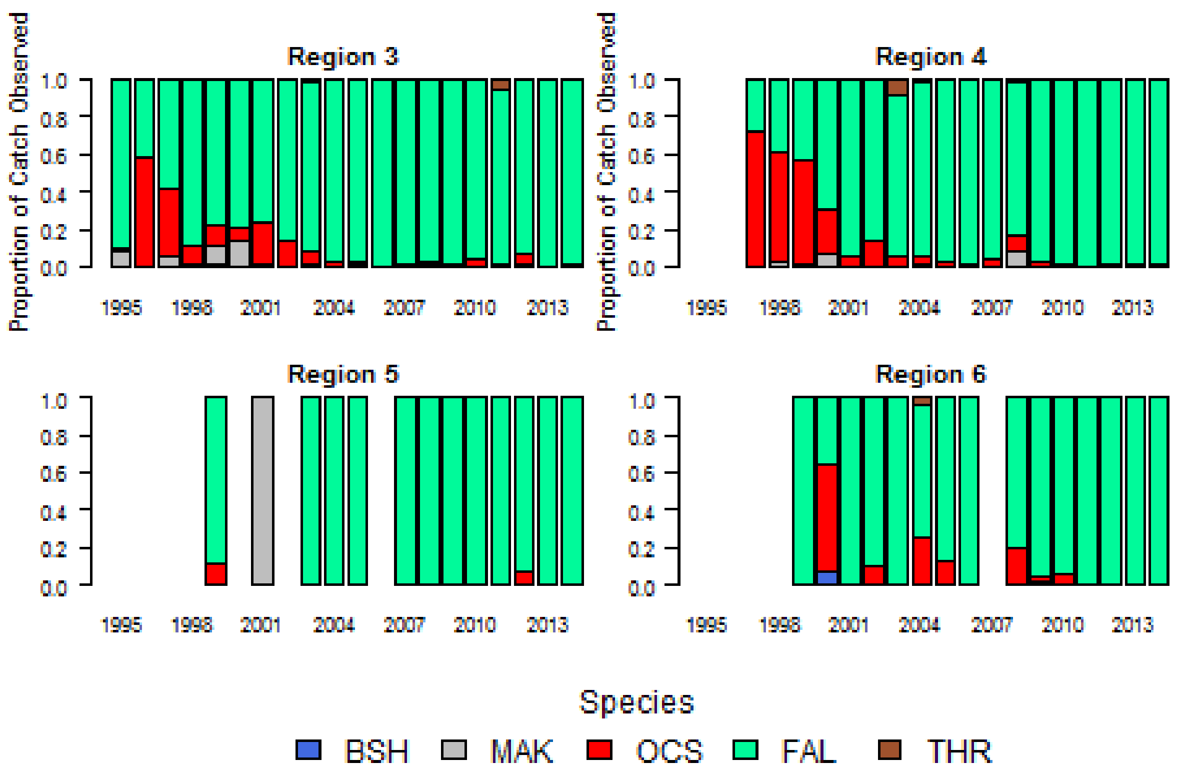

Figure 31: Catch Composition Indicators. Catch composition by proportion , observer data.

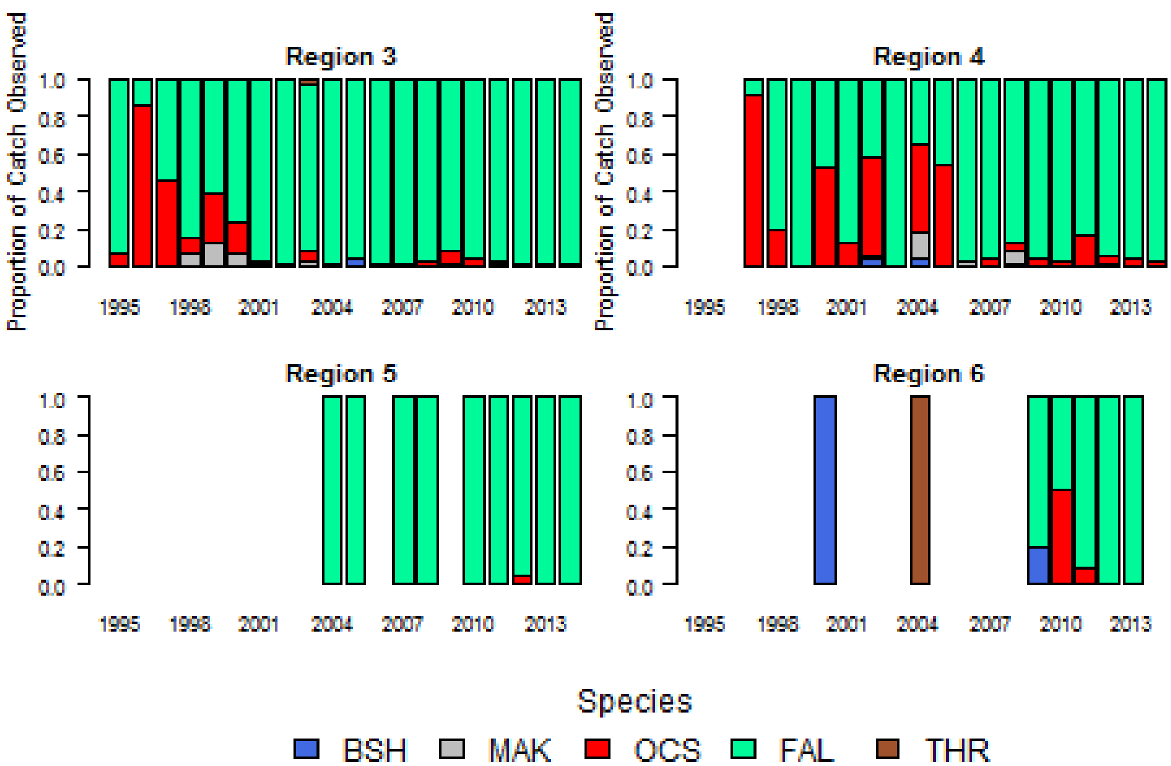

Figure 32: Catch Composition Indicators. Catch composition by proportion, associated sets, observer data

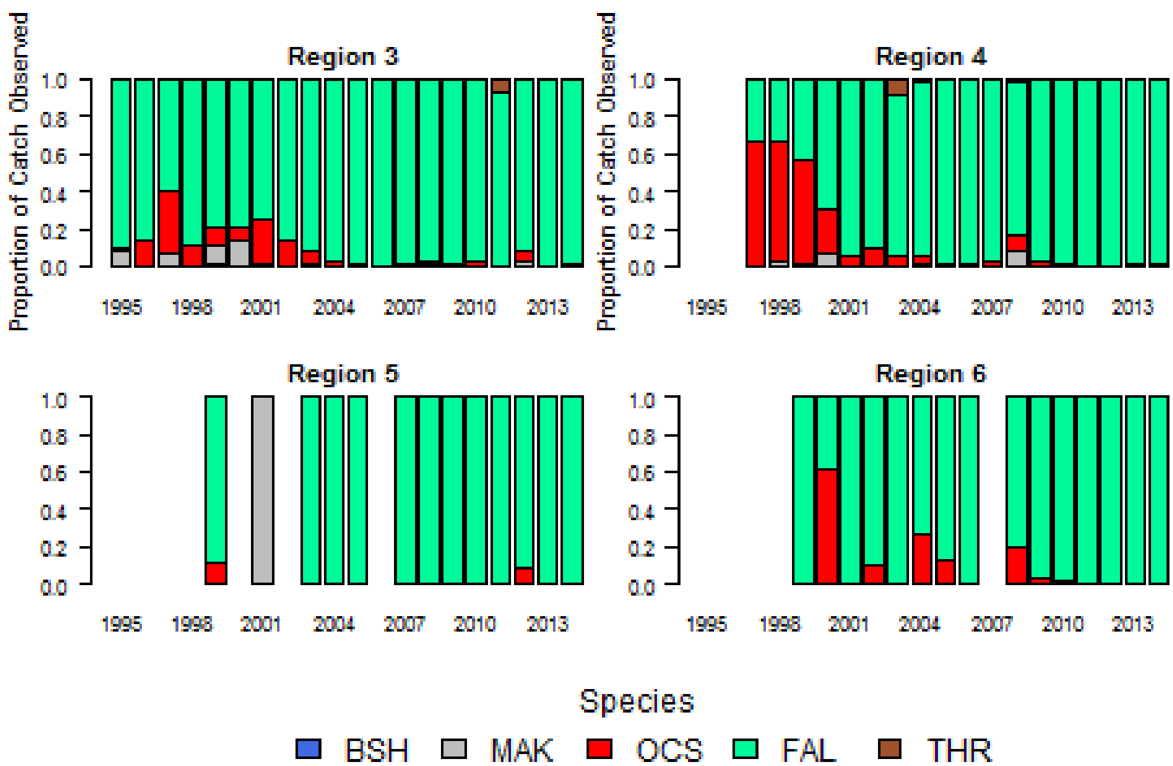

Figure 33: Catch Composition Indicators. Catch composition by proportion, unassociated sets, observer data.

14 Catch Per Unit Effort indicator analyses

Purse Seine data preparation

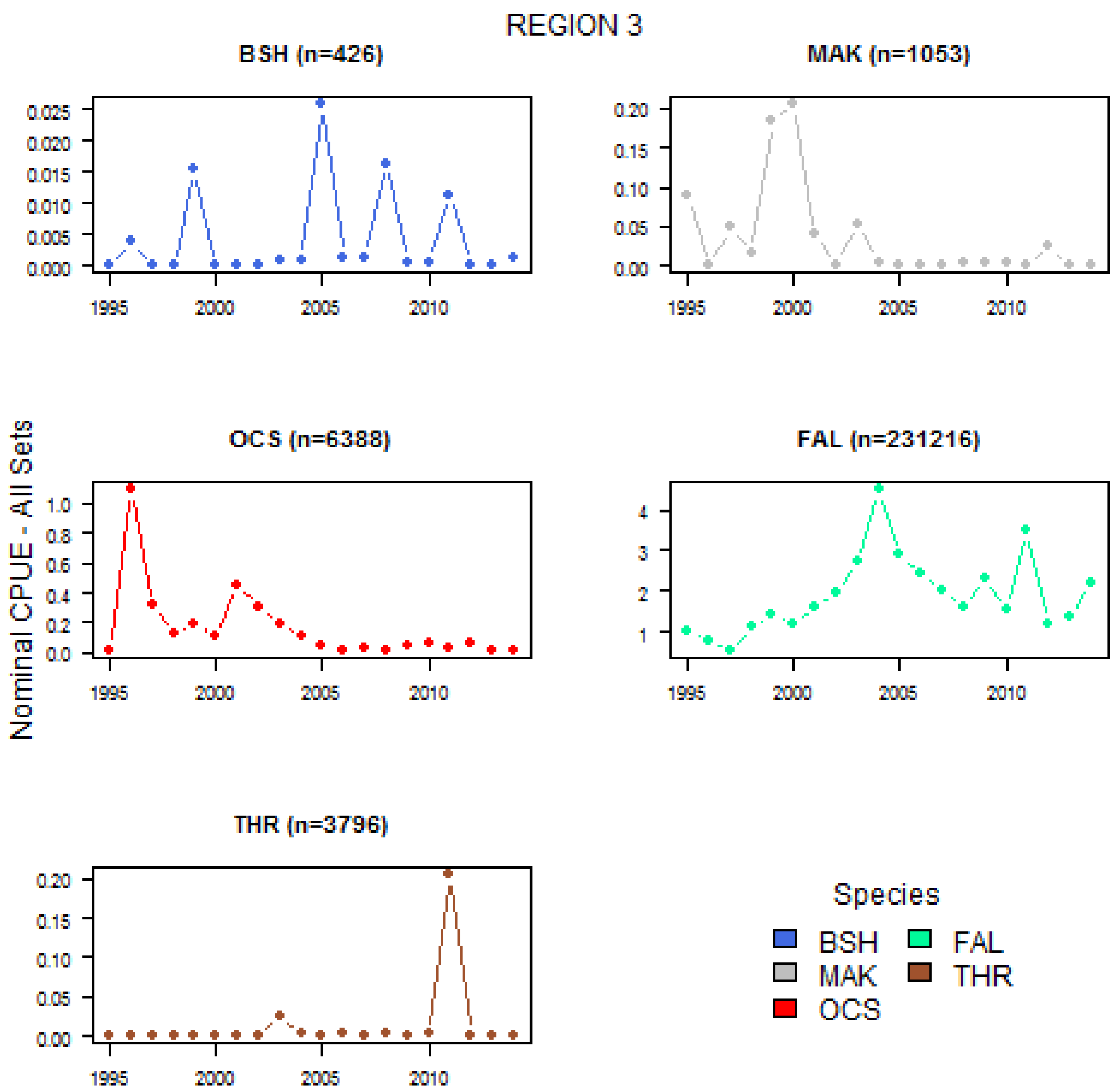

Figure 34: CPUE indicators, nominal CPUE in the purse seine fishery, all sets, Region 3.

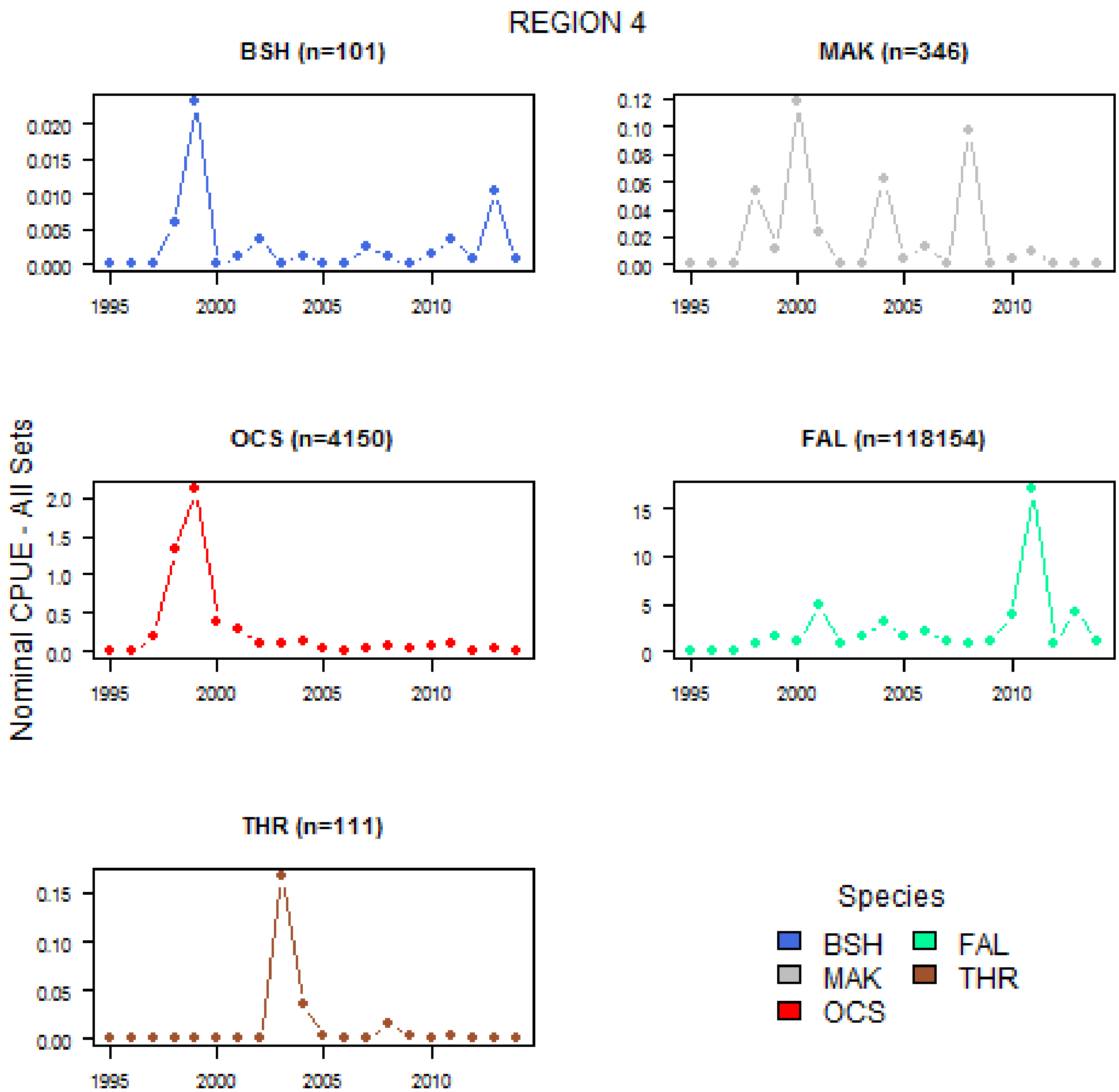

Figure 35: CPUE indicators, nominal CPUE in the purse seine fishery, all sets, Region 4.

14.1 Results

14.1.1 Blue Shark

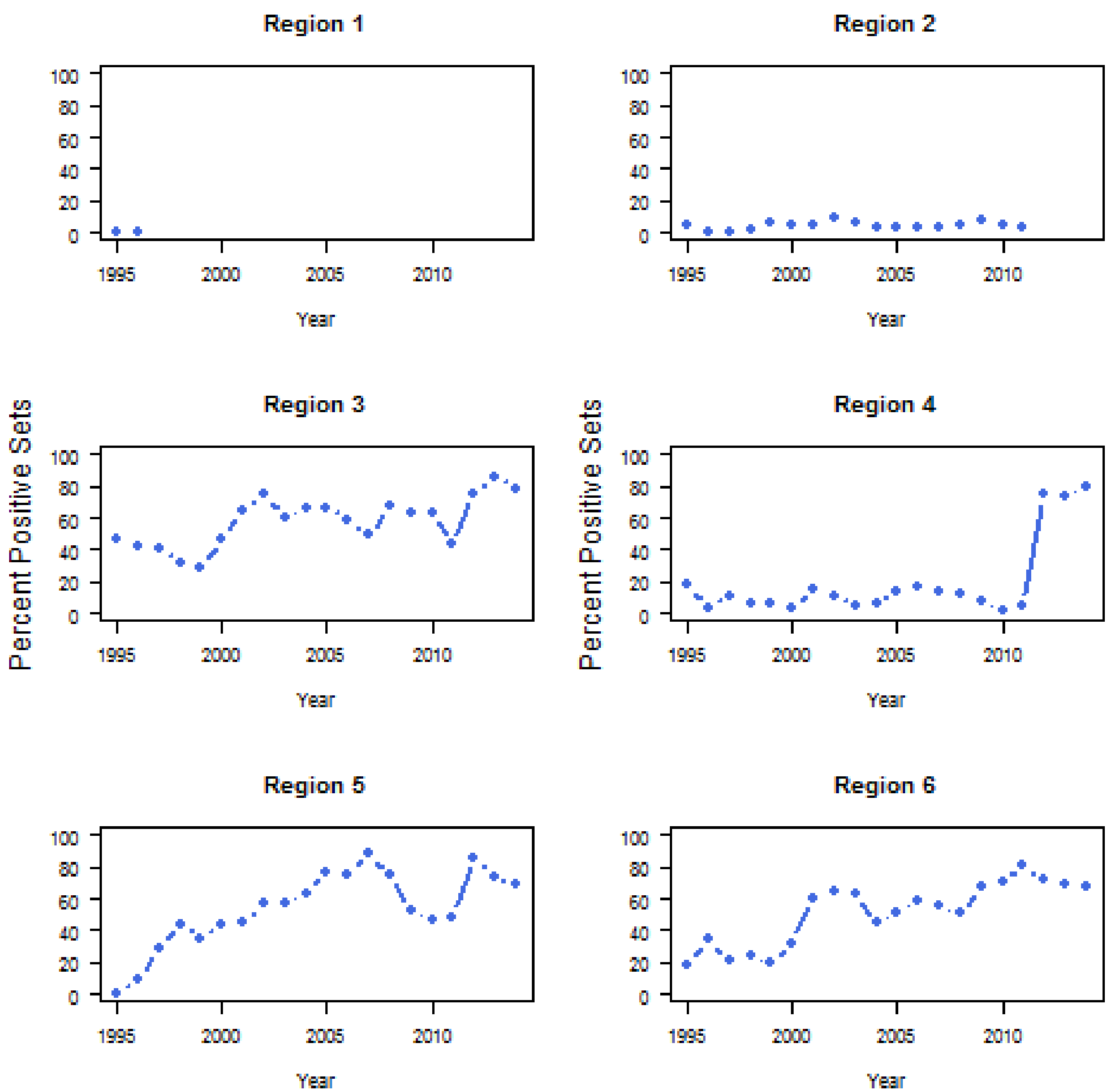

Figure 36: Blue shark CPUE indicators. Proportion of positive sets, observer data.

14.1.2 Mako Shark

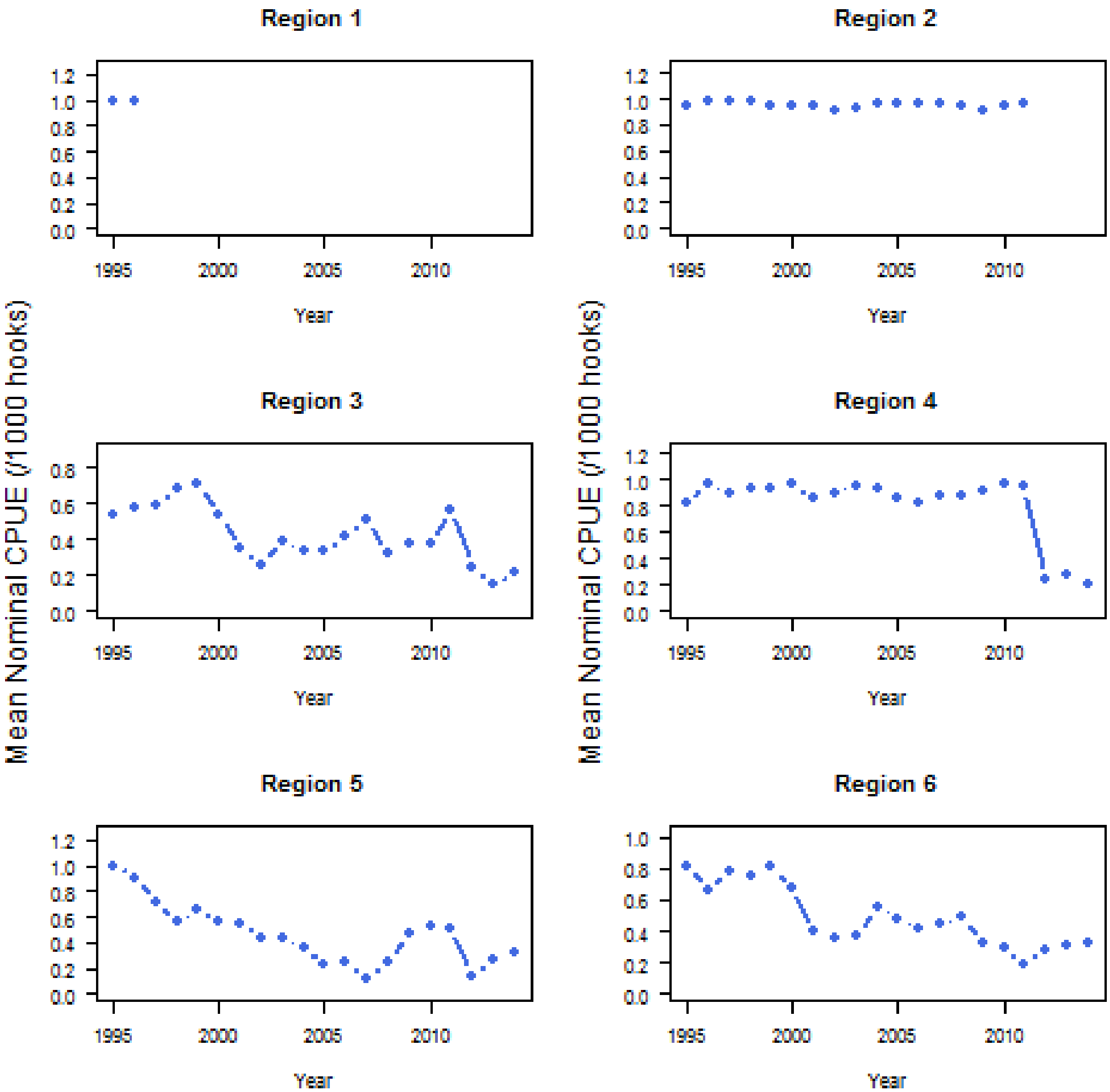

Figure 37: Blue shark CPUE indicators. Nominal CPUE, sharks per 1000 hooks, observer data.

Figure 38: Blue shark CPUE indicators. Standardized blue shark CPUE based on the negative binomial model for observer data in the northern hemisphere.

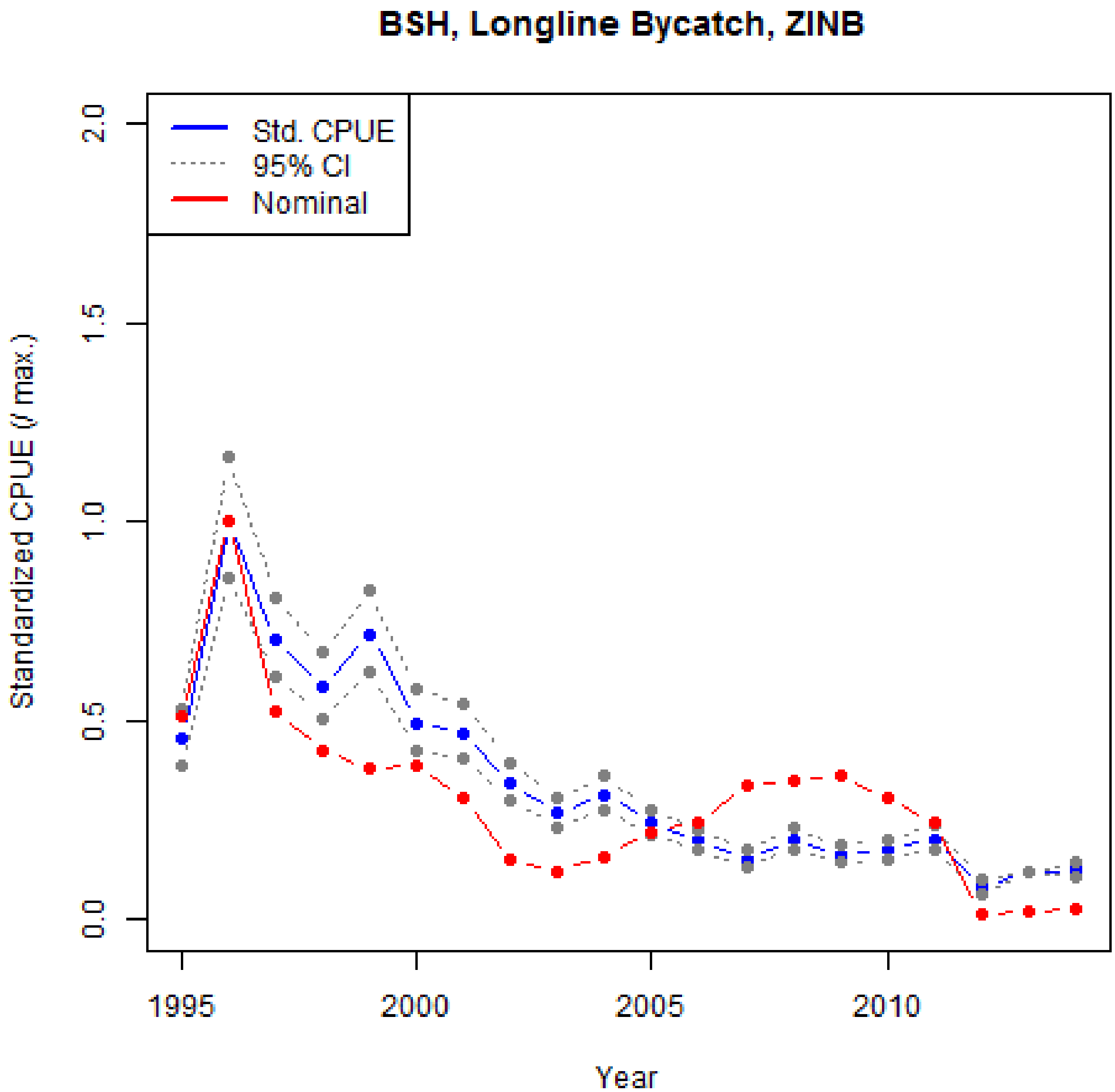

Figure 39: Blue shark CPUE indicators. Standardized CPUE, zero inflated negative binomial Southern Hemisphere, observer data.

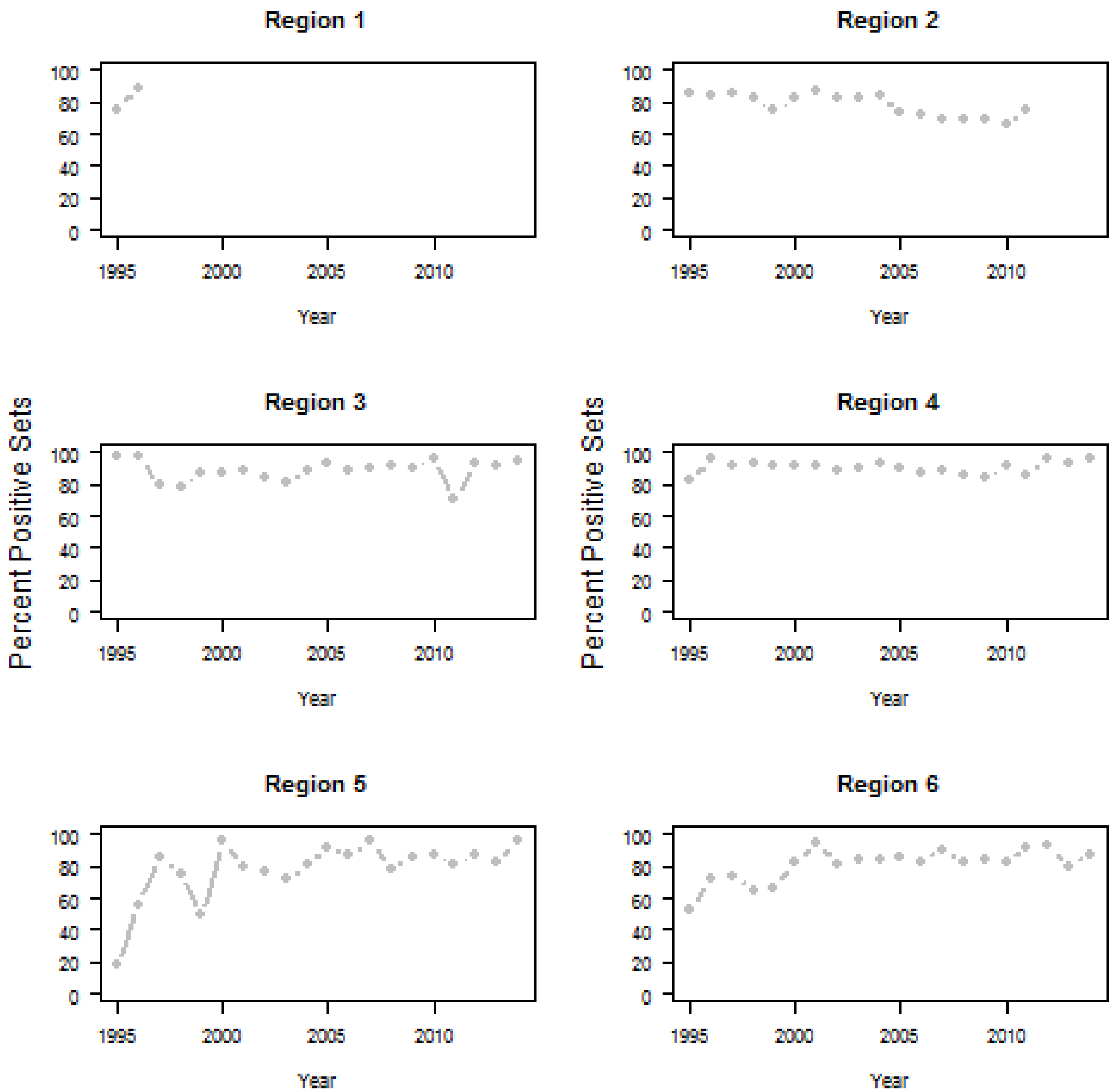

Figure 40: Mako shark CPUE indicators. Proportion of positive sets, observer data.

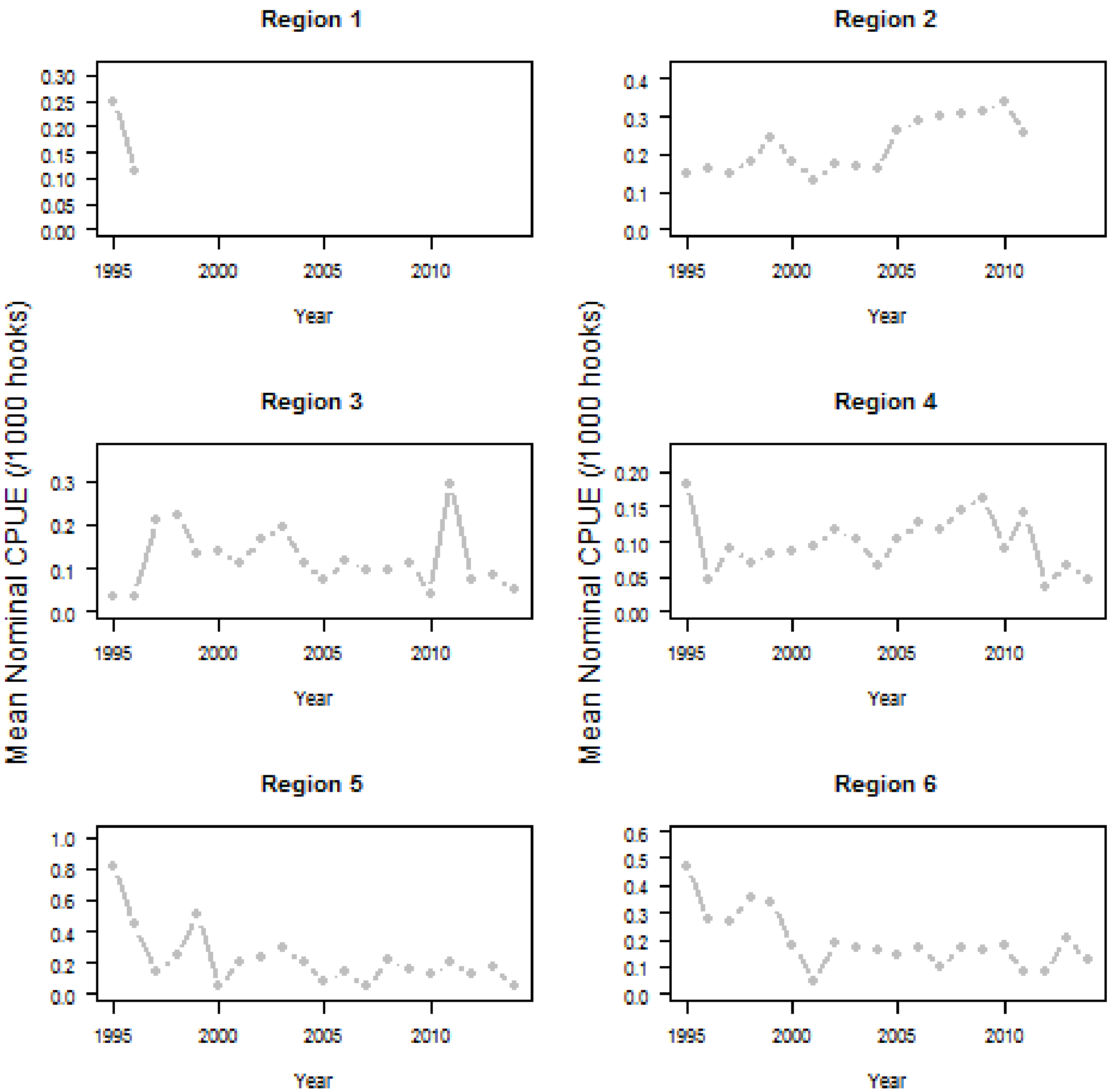

Figure 41: Mako shark CPUE indicators. Nominal CPUE, sharks per 1000 hooks, observer data.

Figure 42: Mako shark CPUE indicators. Standardized CPUE, mako shark in the northern hemisphere.

Figure 43: Mako shark CPUE indicators. Standardized CPUE, mako shark in the southern hemisphere.

14.1.3 Silky Shark

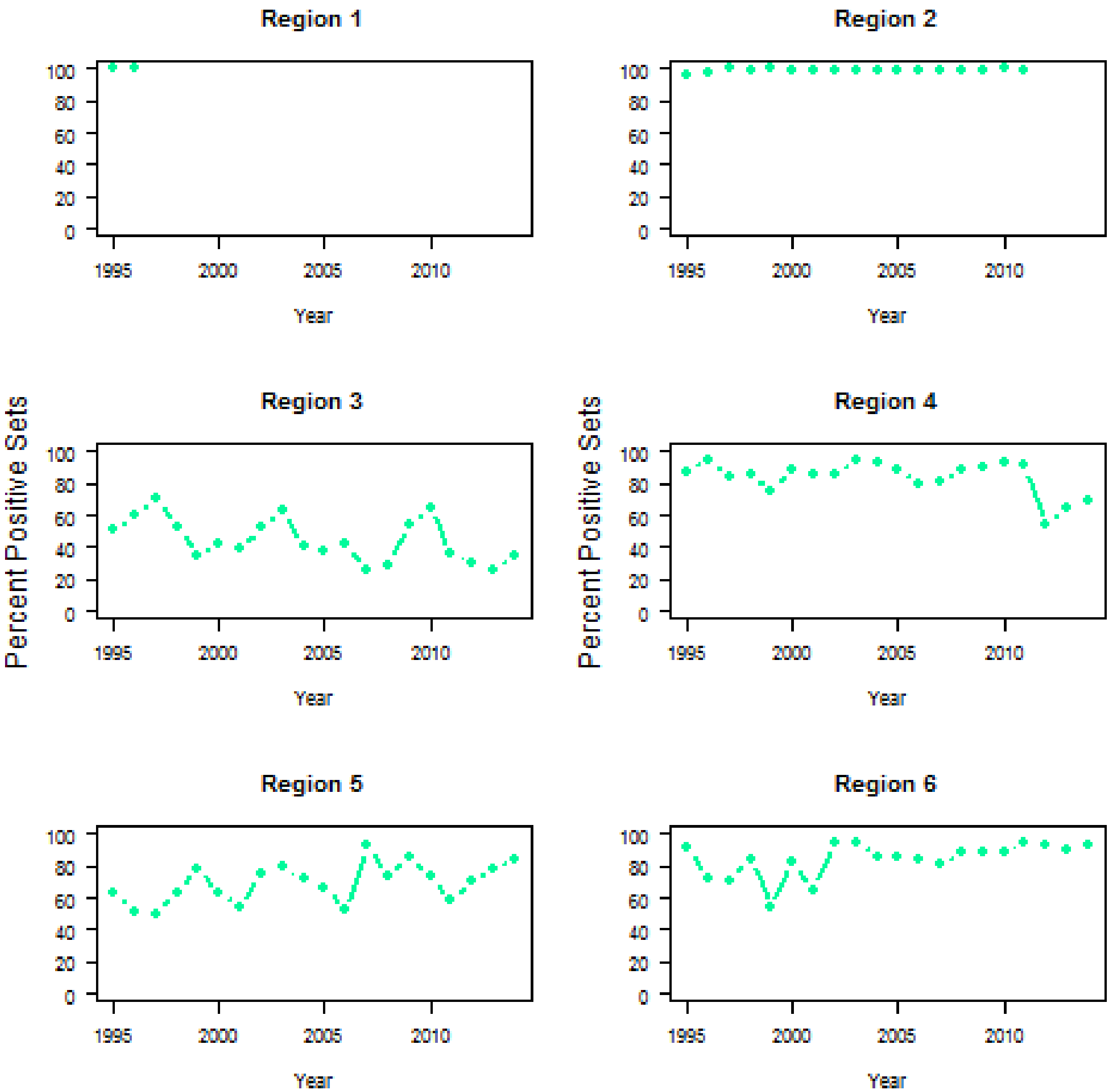

Figure 44: Silky shark CPUE indicators. Proportion of positive sets, observer data.

14.1.4 Oceanic Whitetip Shark

14.1.5 Thresher Shark

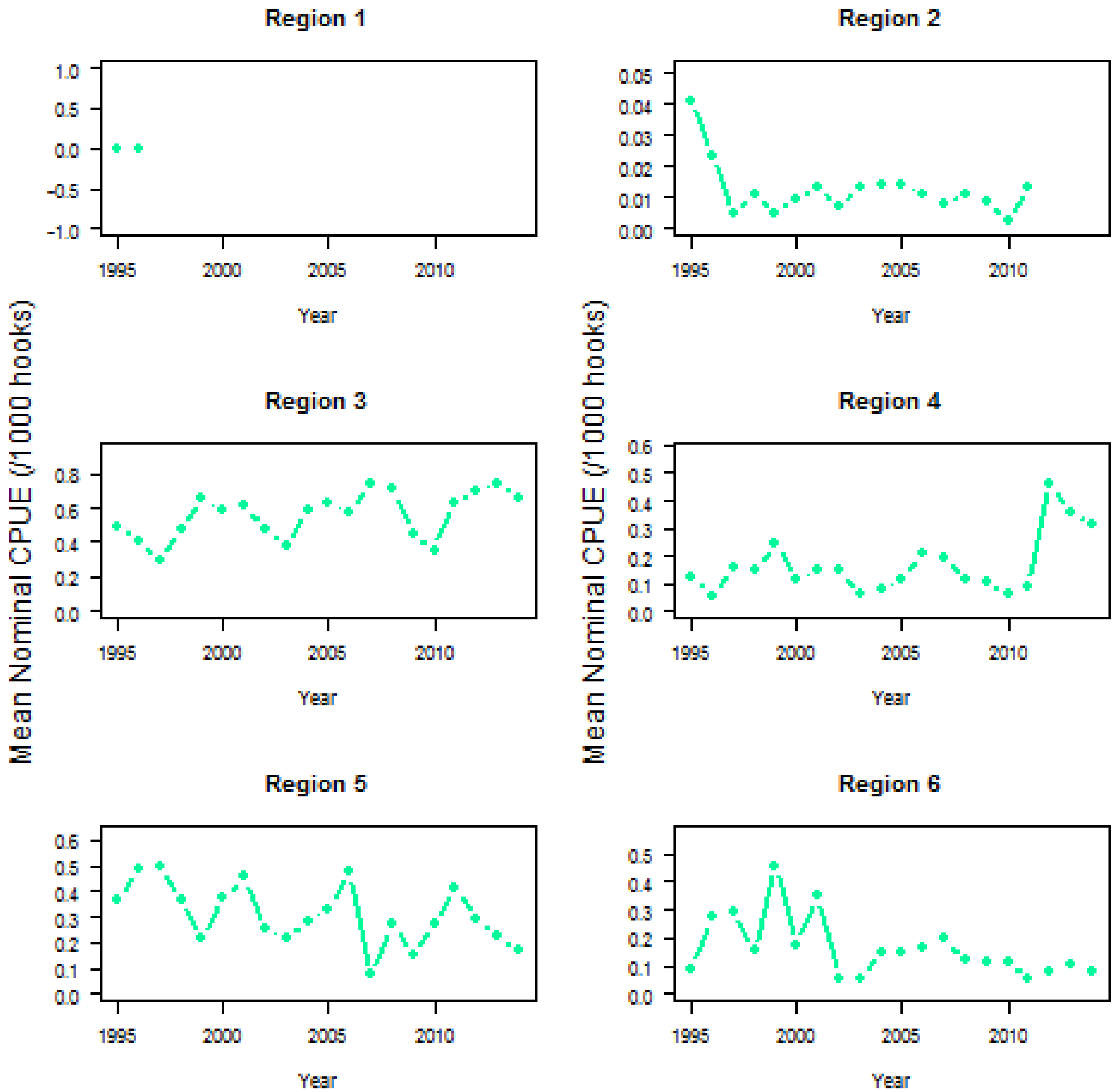

Figure 45: Silky shark CPUE indicators. Nominal CPUE, sharks per 1000 hooks, observer data.

Figure 46: Silky shark CPUE indicators. Standardized CPUE from longline observer data for silky sharks.

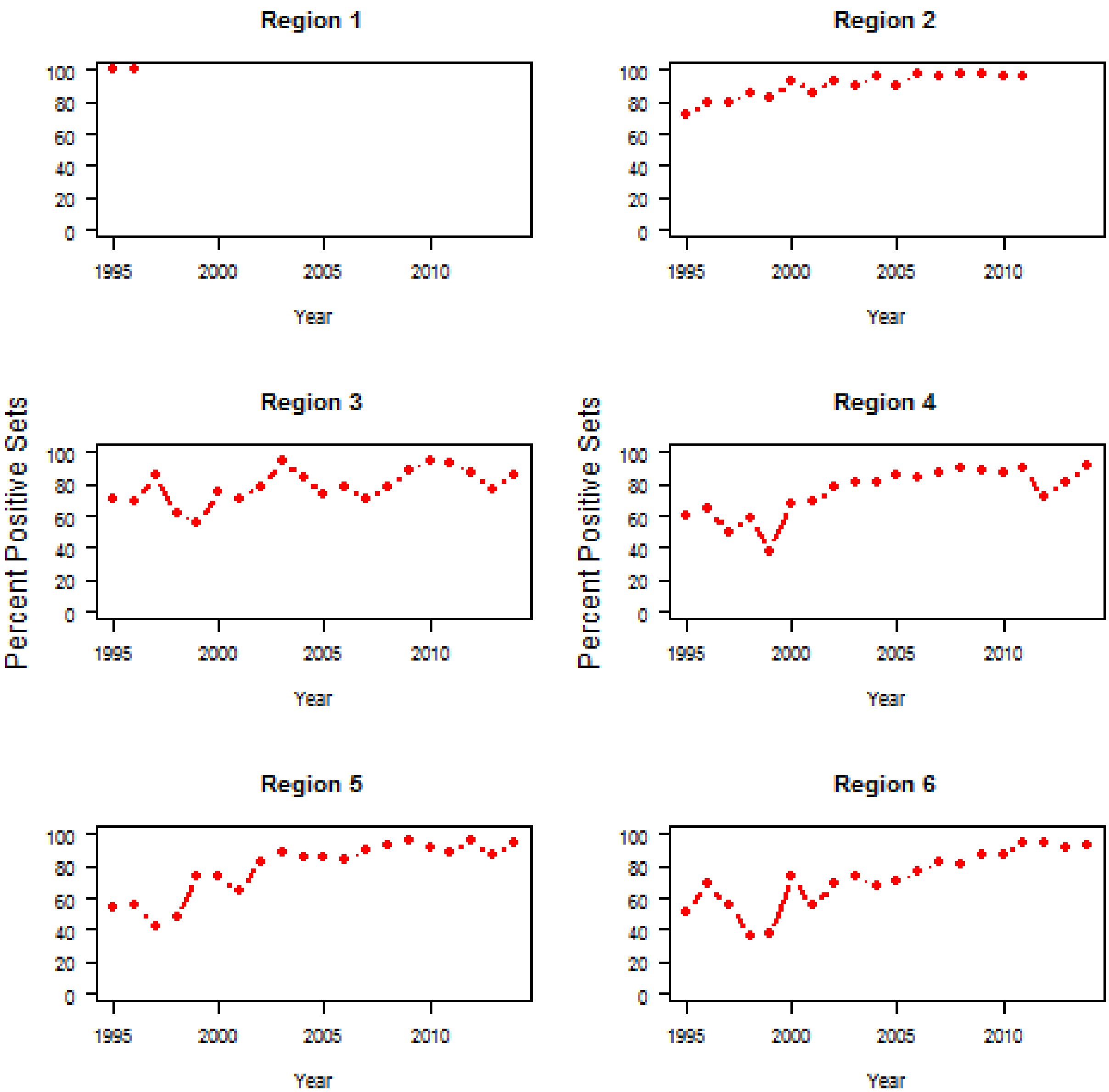

Figure 47: Oceanic whitetip shark CPUE indicators. Proportion of positive sets, observer data.

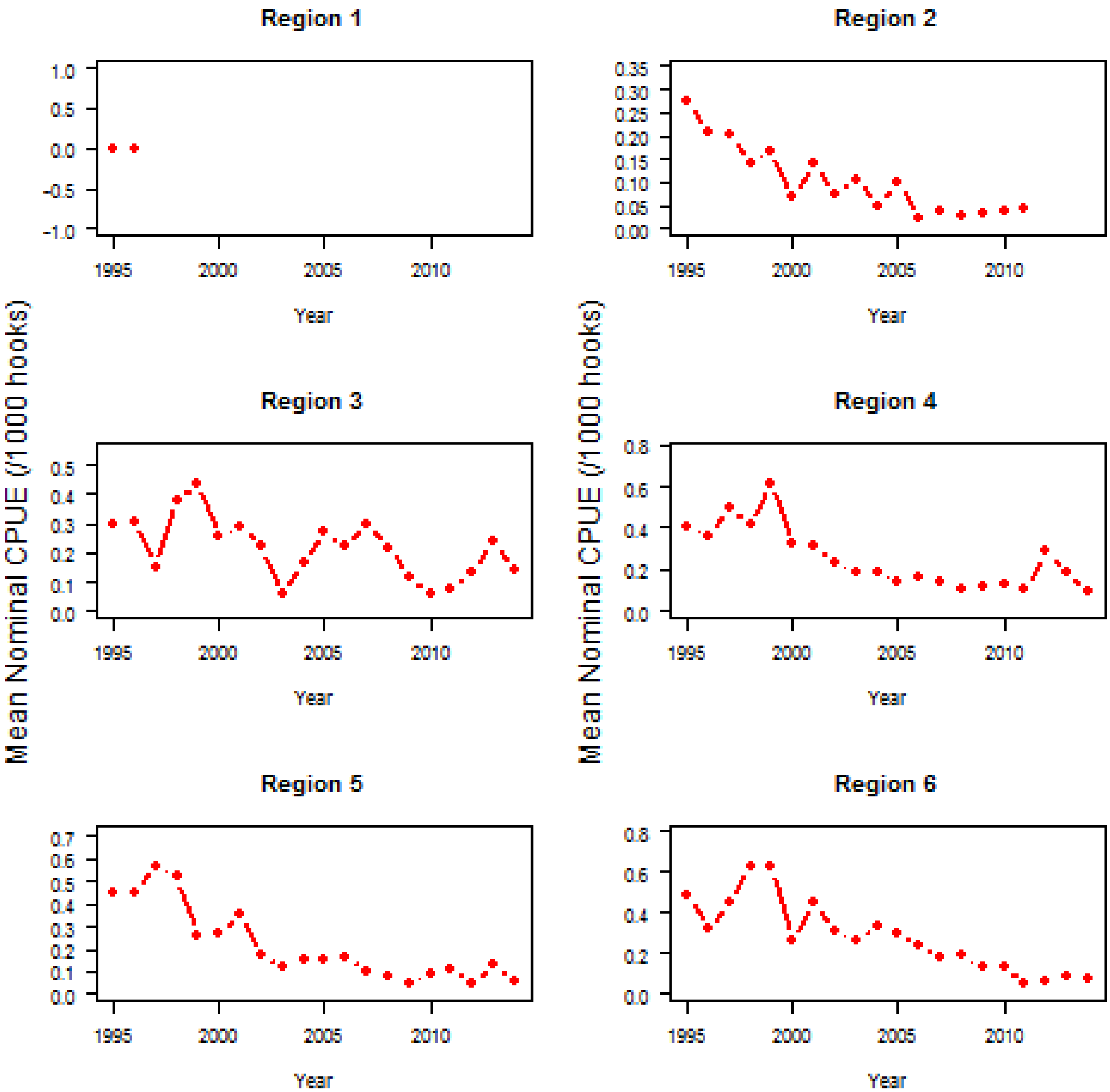

Figure 48: Oceanic whitetip shark CPUE indicators. Nominal CPUE, sharks per 1000 hooks, observer data.

Figure 49: Oceanic whitetip shark CPUE indicators. Standardized CPUE based on negative binomial models applied to observer data.

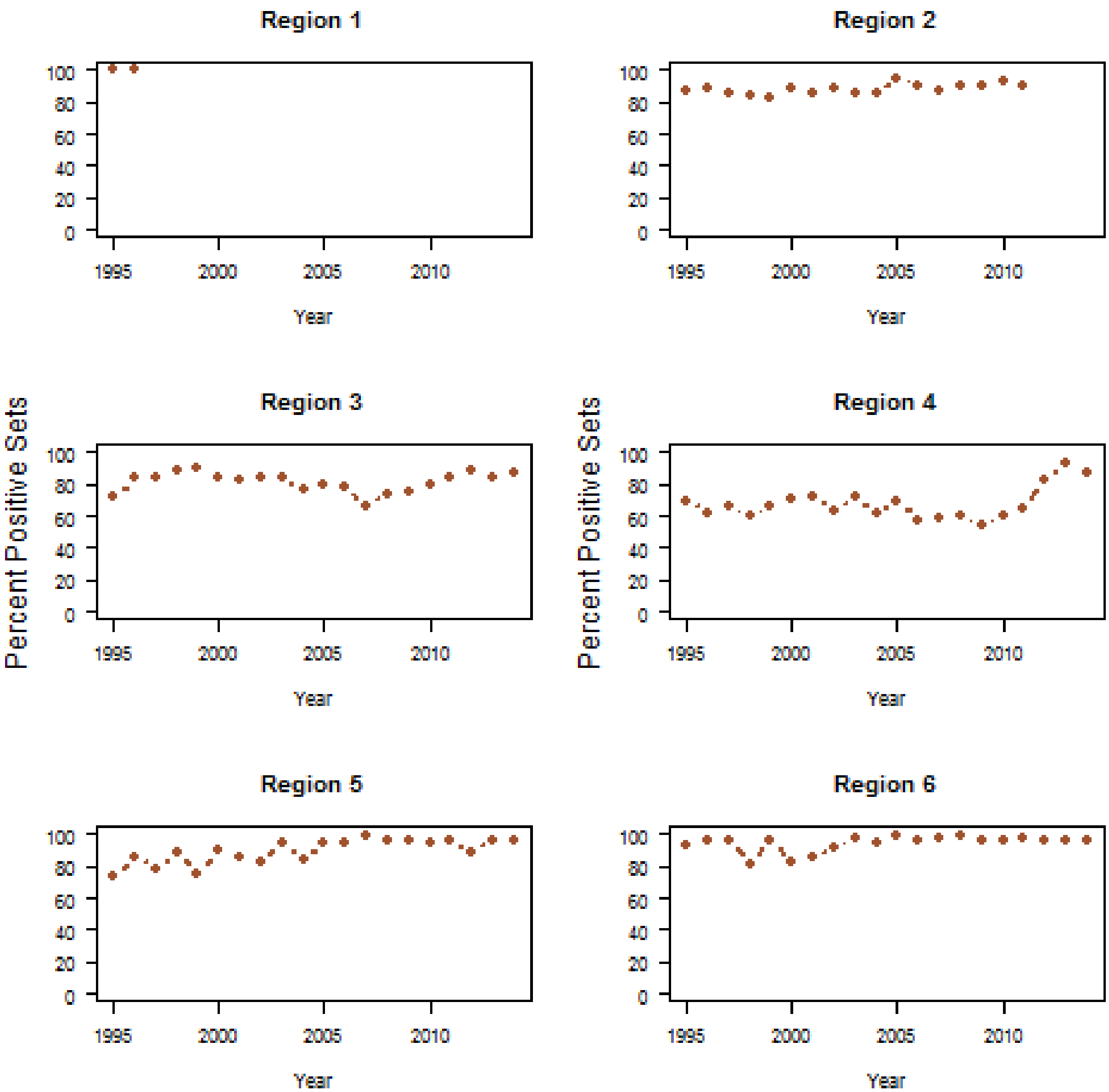

Figure 50: Thresher shark CPUE indicators. Proportion of positive sets, observer data.

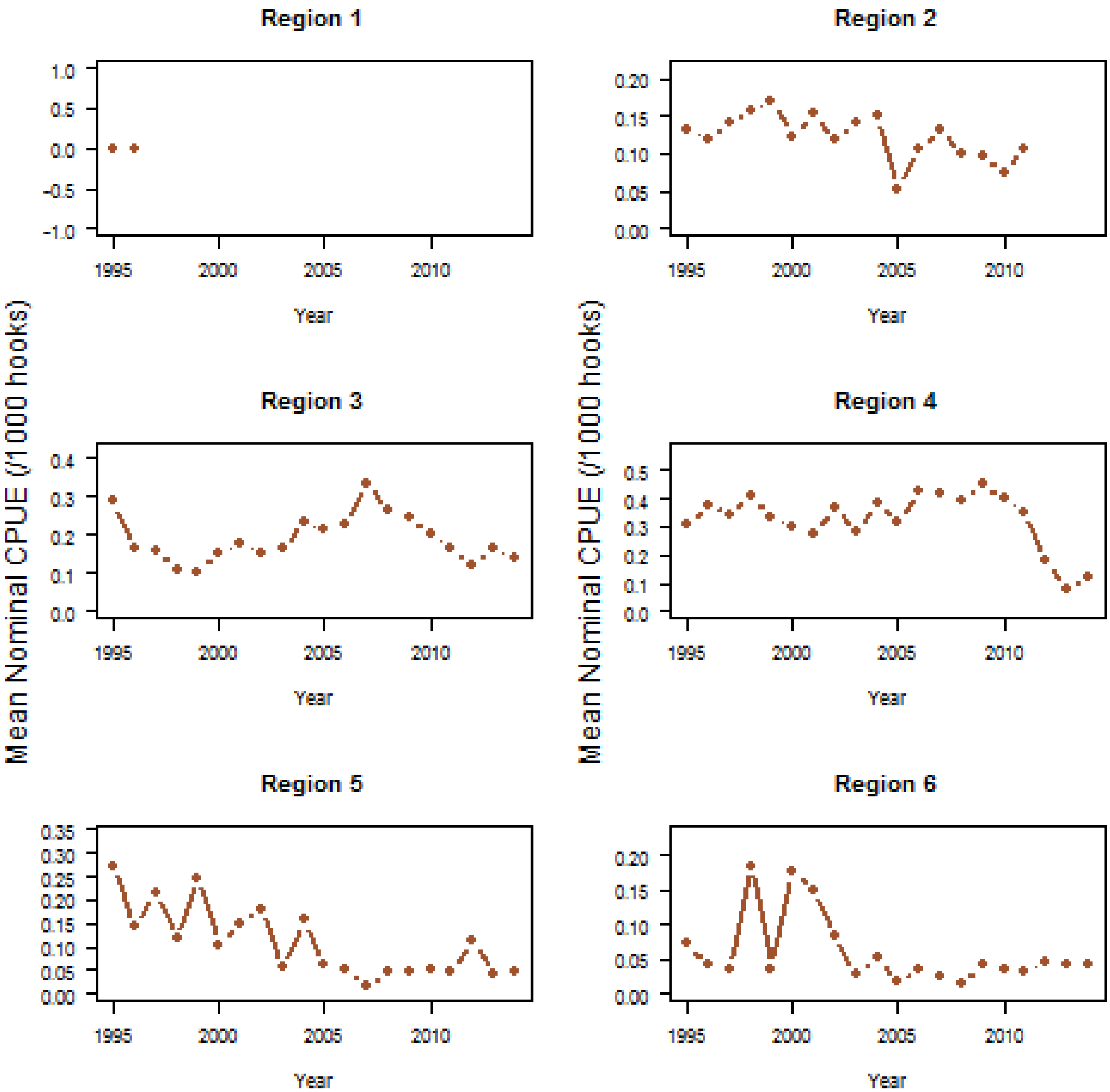

Figure 51: Thresher shark CPUE indicators. Nominal CPUE, sharks per 1000 hooks, observer data.

Figure 52: Thresher shark CPUE indicators. Standardized CPUE of thresher shark based on longline observer data.

15 Biological indicator analyses

16 Feasibility of Stock Assessments

17 Impact of Recent Shark Management Measures

18 Recommendations for Future Indicator Work

19 Management Implications

Acknowledgements

20 Appendices

20.1 CPUE Indicators. Model diagnostics and extra plots

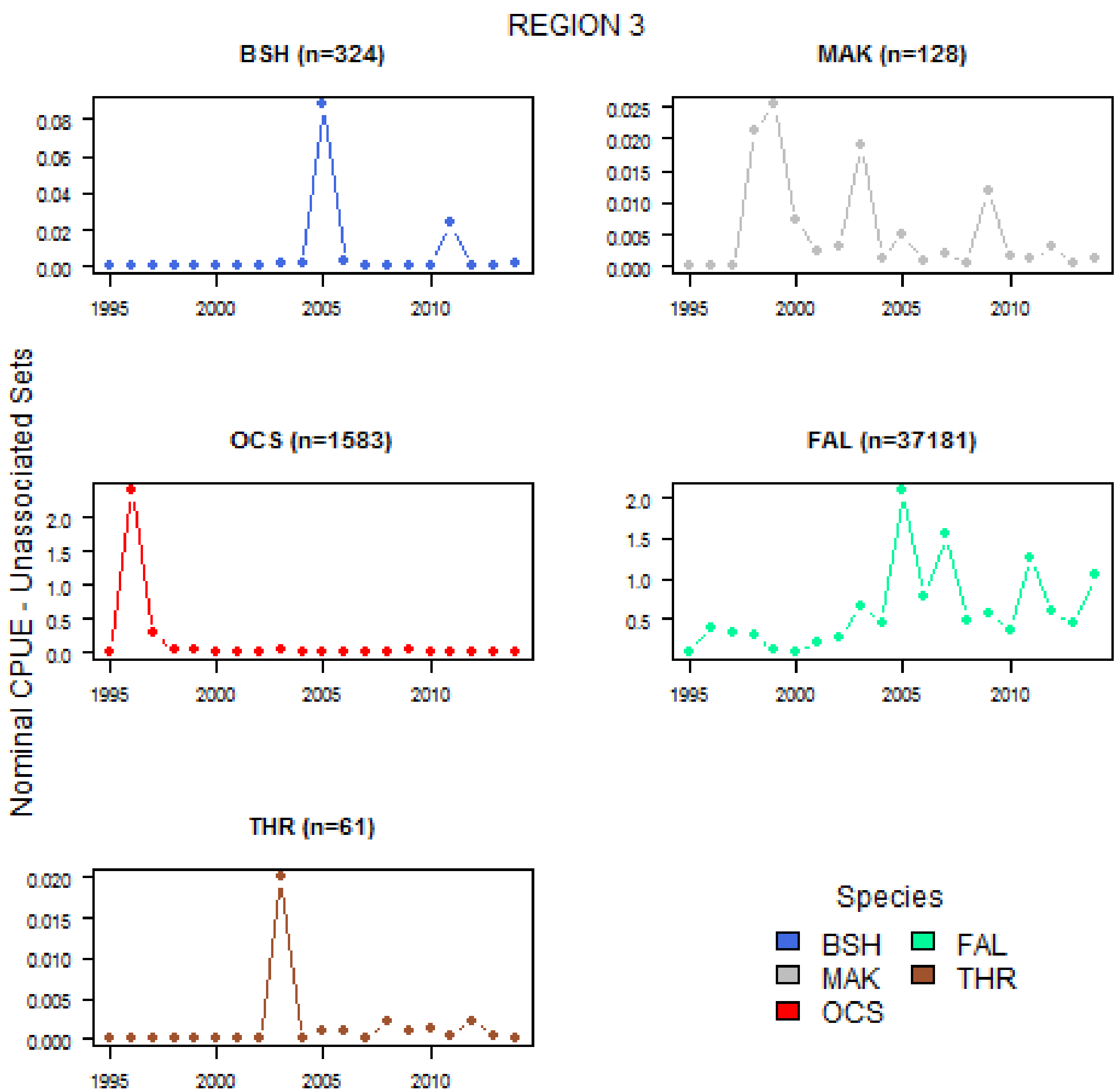

Figure 53: CPUE indicators, nominal CPUE in the purse seine fishery, Unassociated Sets, Region 3.

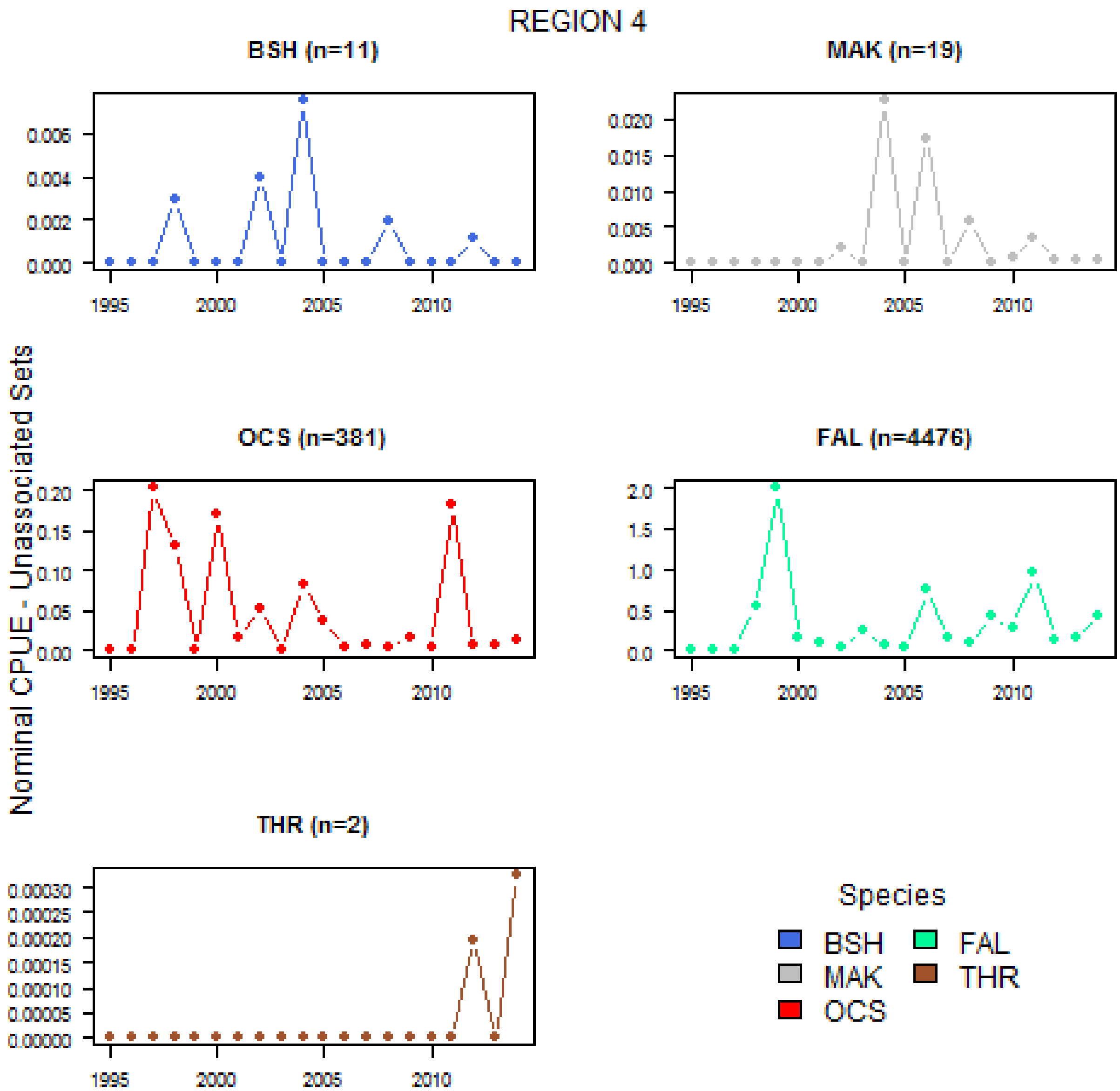

Figure 54: CPUE indicators, nominal CPUE in the purse seine fishery, Unassociated sets, Region 4.

Blue Shark model diagnostics and extra plots

Silky Shark model diagnostics and extra plots

Oceanic Whitetip Shark model diagnostics and extra plots

Thresher Shark model diagnostics and extra plots

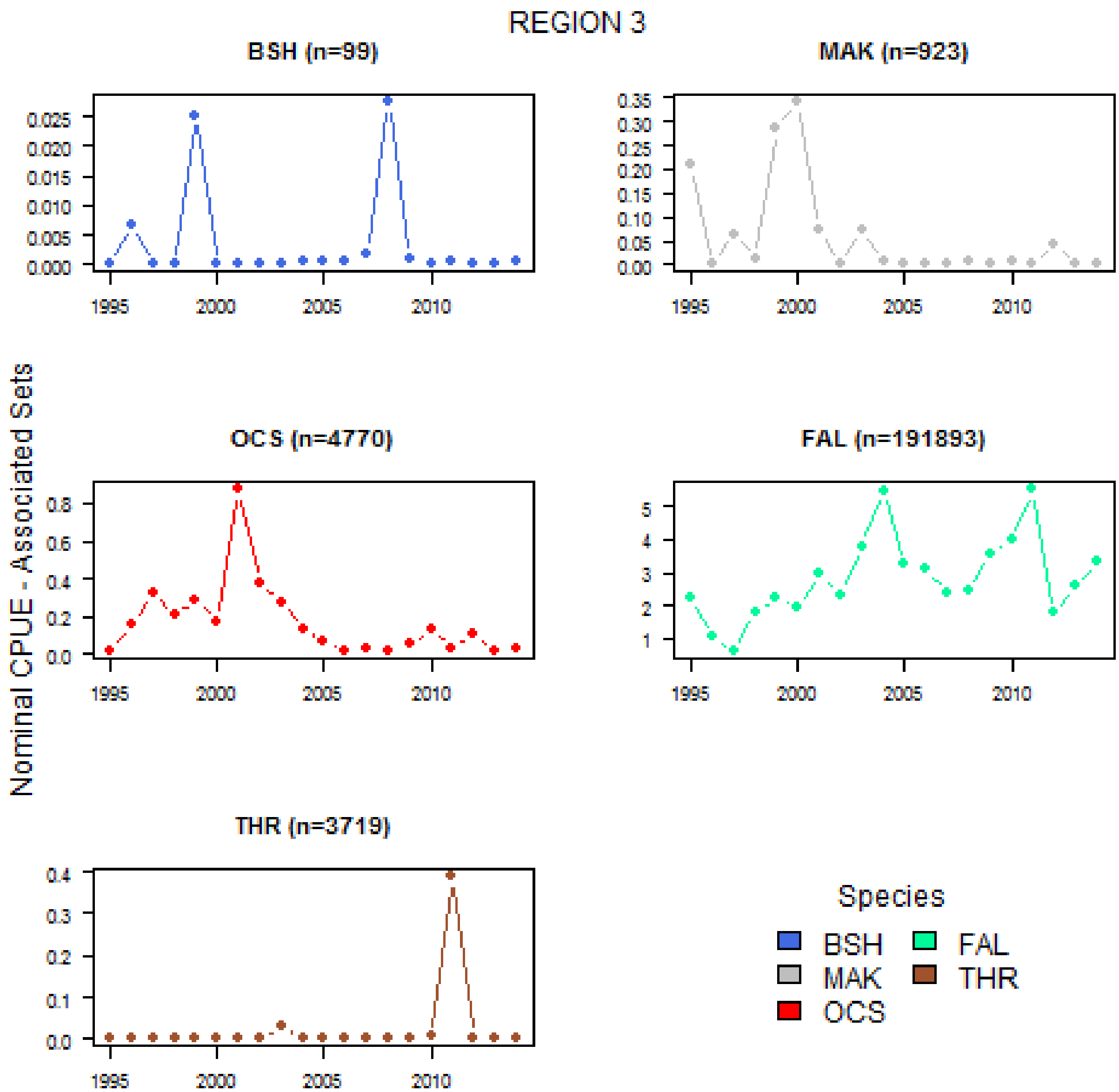

Figure 55: CPUE indicators, nominal CPUE in the purse seine fishery, Associated Sets, Region 3.

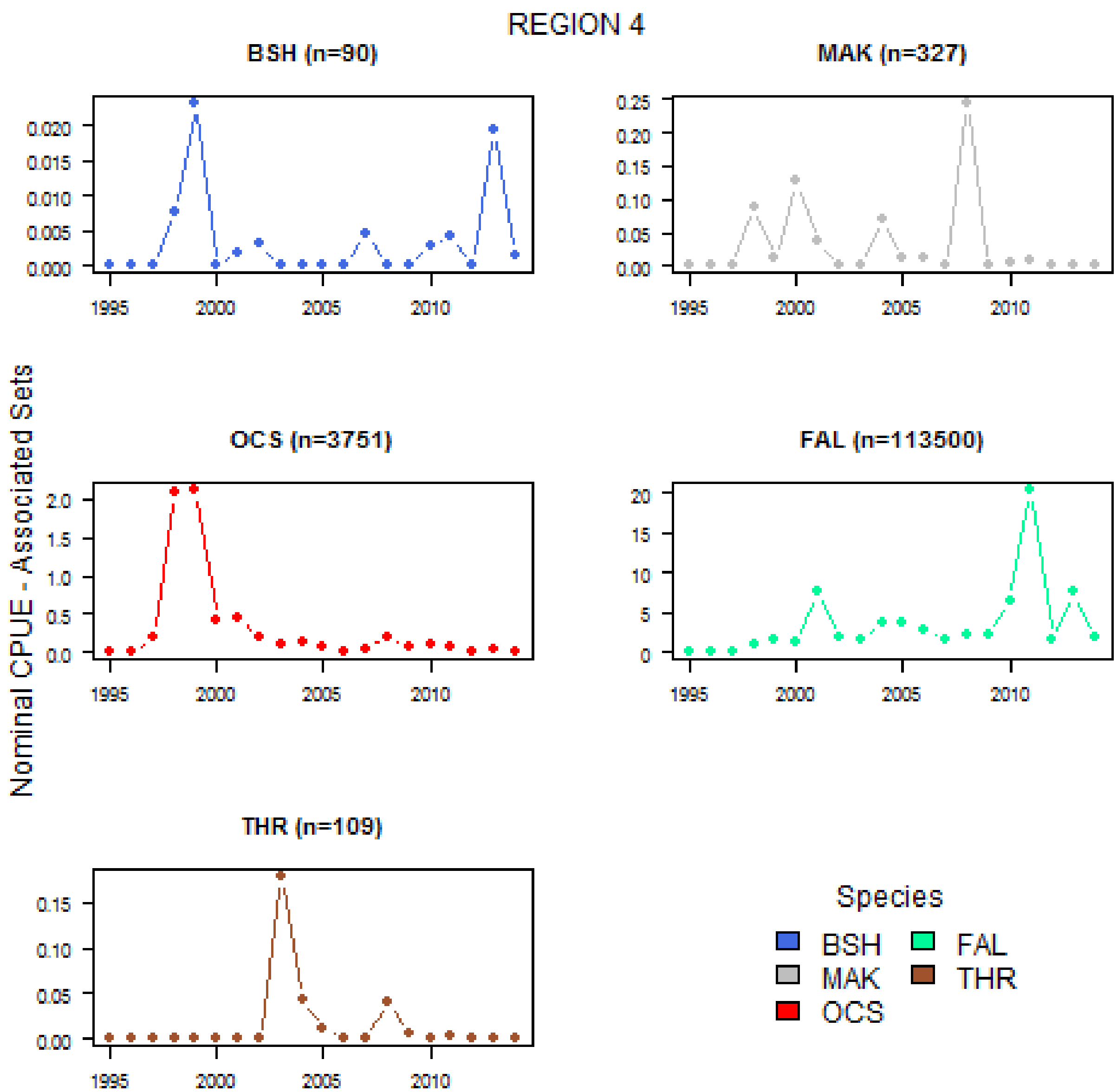

Figure 56: CPUE indicators, nominal CPUE in the purse seine fishery, Associated sets, Region 4.

Figure 57: CPUE indicators, GLM model diagnostics .

Figure 58: CPUE indicators, GLM model diagnostics, BSH in the north Pacific step plot.

Figure 59: CPUE indicators, GLM model diagnostics, BSH in the south Pacific step plot.

Figure 60: CPUE indicators, model diagnostics for mako shark CPUE standardization via negative binomial model, northern hemisphere.

Figure 61: CPUE indicators, model diagnostics for mako shark CPUE standardization via negative binomial model, sourthern hemisphere.

Figure 62: CPUE indicators, GLM model diagnostics, mako shark in the north Pacific step plot.

Figure 63: CPUE indicators, step diagnostics for mako shark CPUE standardization via negative binomial model, sourthern hemisphere.

Figure 64: CPUE indicators, model diagnostics for silky shark CPUE standardization via negative binomial model.

Figure 65: CPUE indicators, step plot for silky shark CPUE standardization via negative binomial model.

Figure 66: CPUE indicators, model diagnostics for oceanic whitetip shark CPUE standardization via negative binomial model.

Figure 67: CPUE indicators, stepplot for oceanic whitetip shark CPUE standardization via negative binomial model.

Figure 68: CPUE indicators, model diagnostics for thresher shark CPUE standardization via negative binomial model.

Figure 69: CPUE indicators, stepplot for thresher shark CPUE standardization via negative binomial model.

Species Distribution Maps

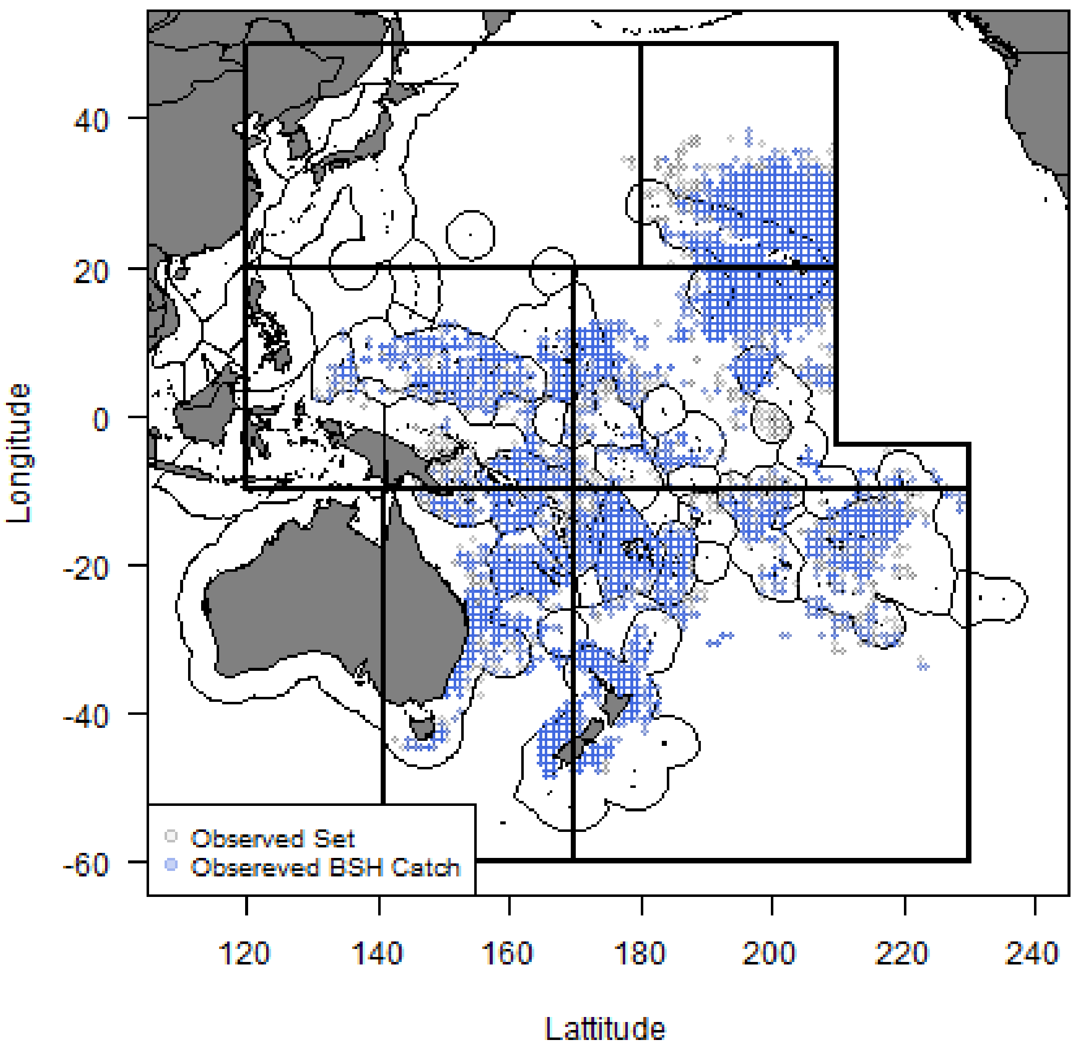

Figure 70: Species distribution, blue shark observed in the longline fishery.

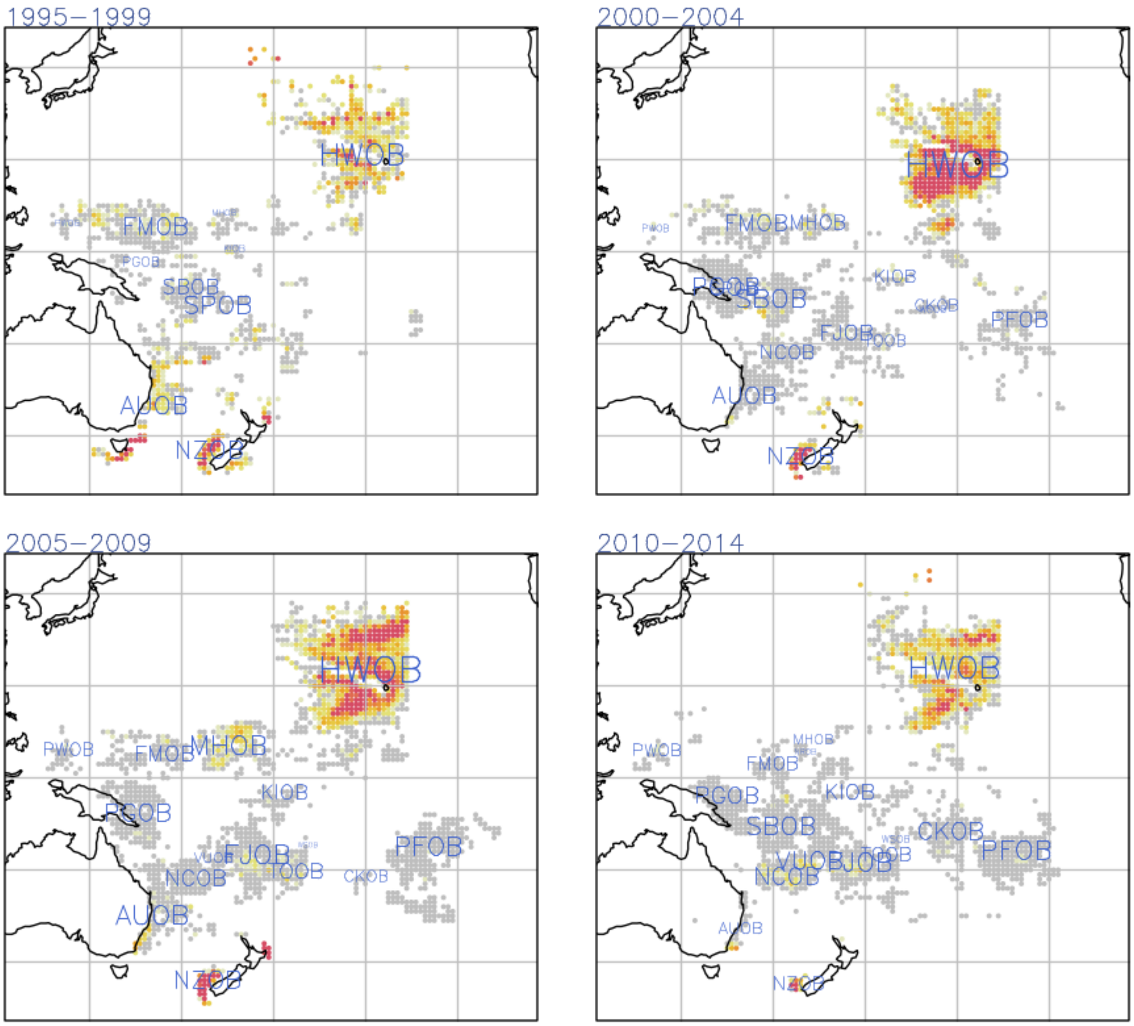

Figure 71: Species distribution, blue shark observed in the longline fishery by observer program.

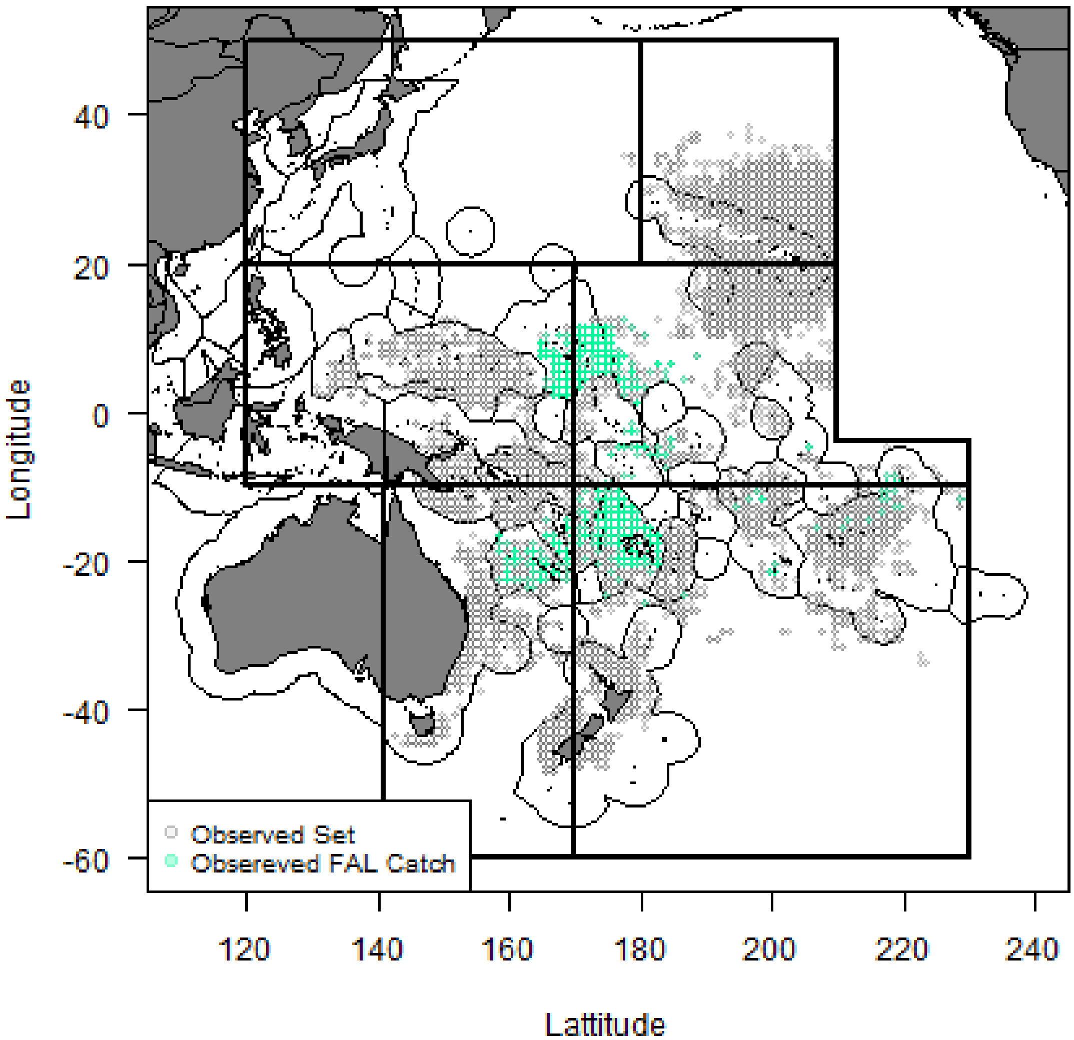

Figure 72: Species distribution, silky shark observed in the longline fishery.

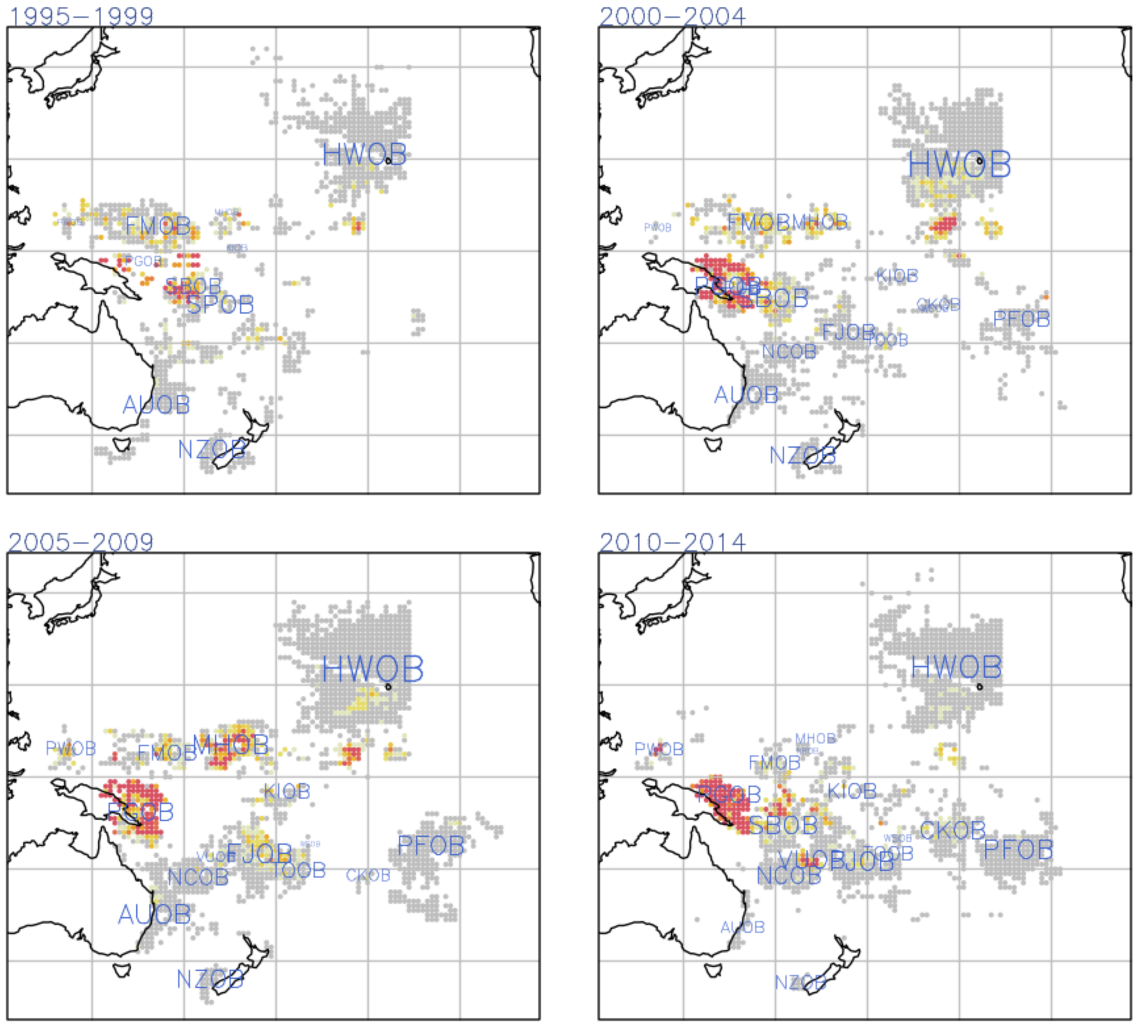

Figure 73: Species distribution, blue shark observed in the longline fishery by observer program.

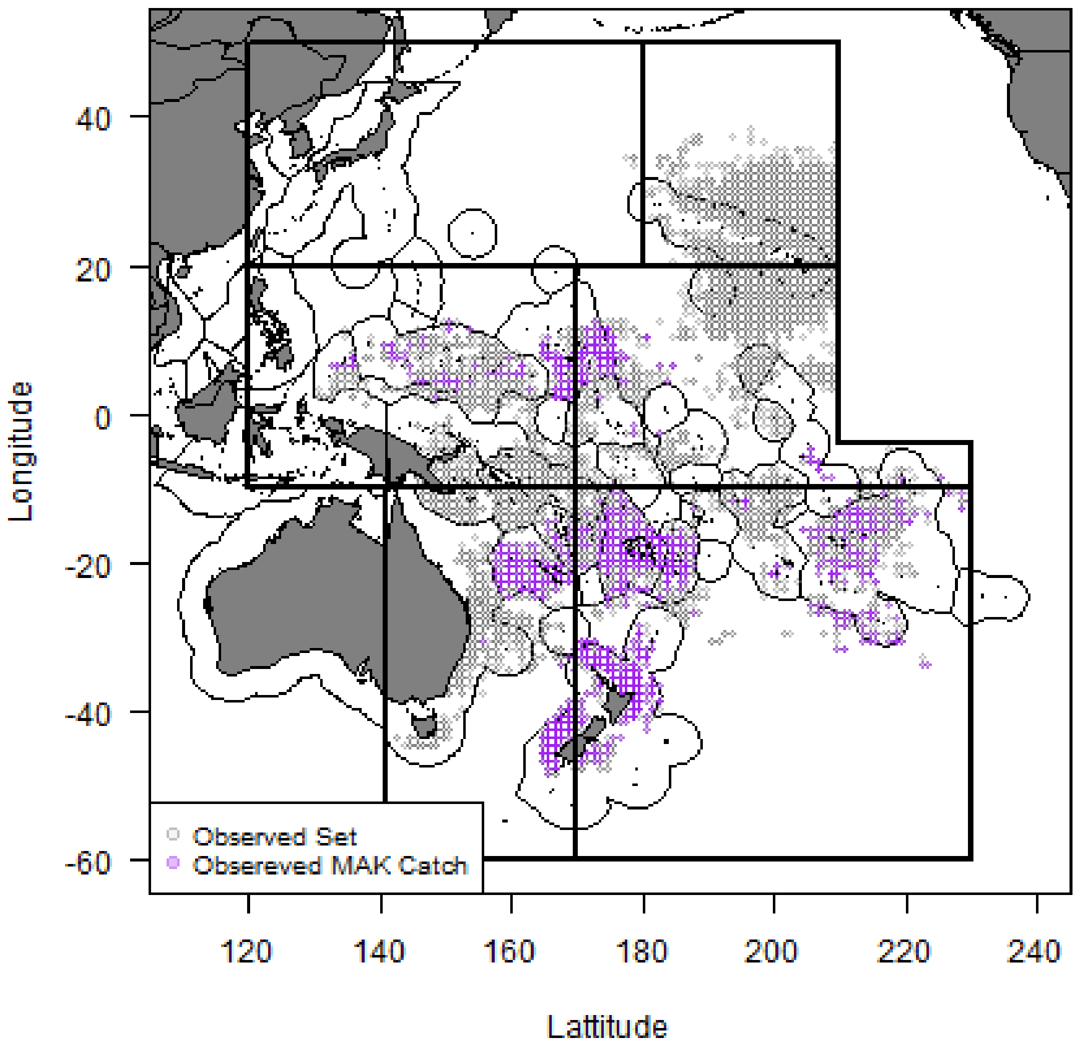

Figure 74: Species distribution, mako shark observed in the longline fishery.

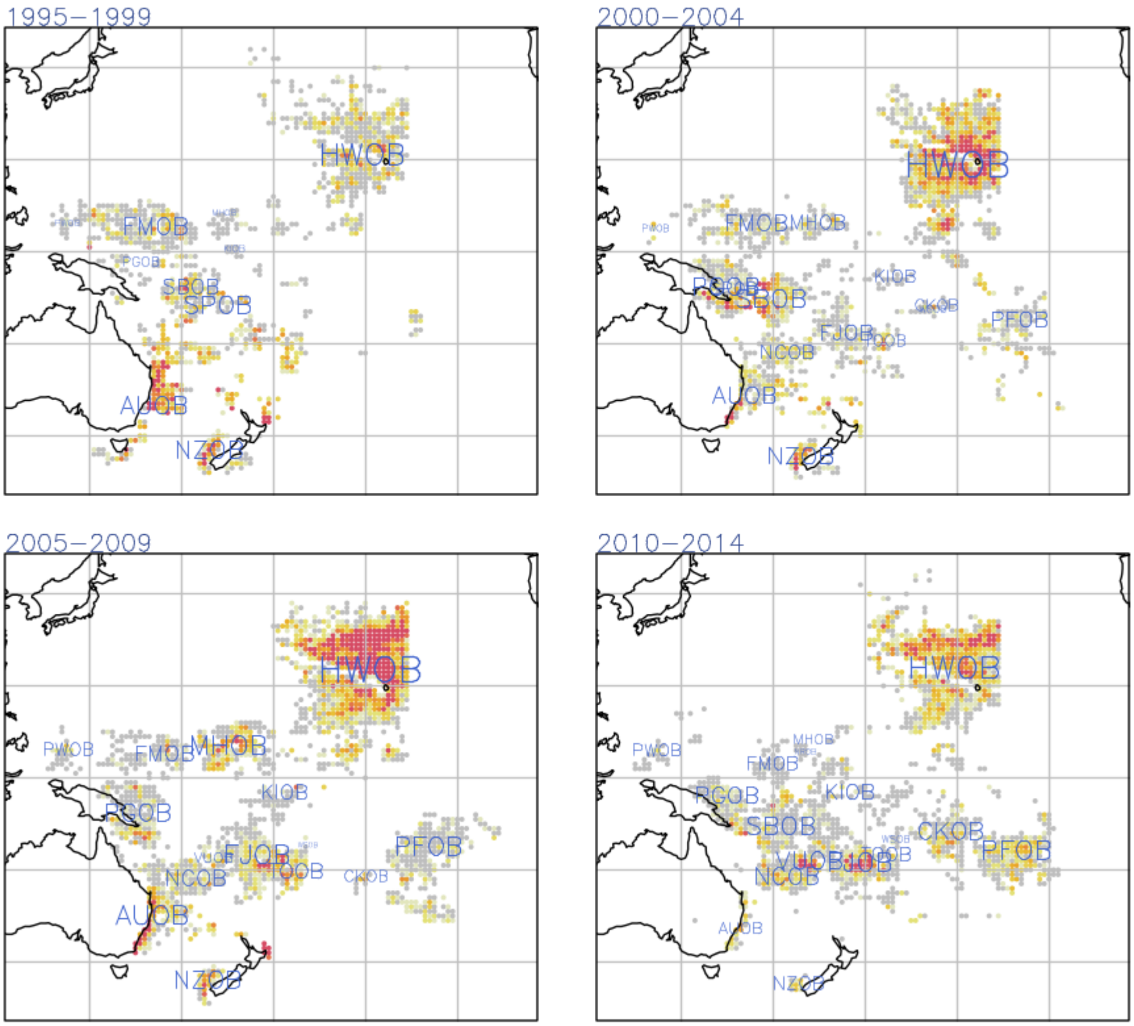

Figure 75: Species distribution, blue shark observed in the longline fishery by observer program.

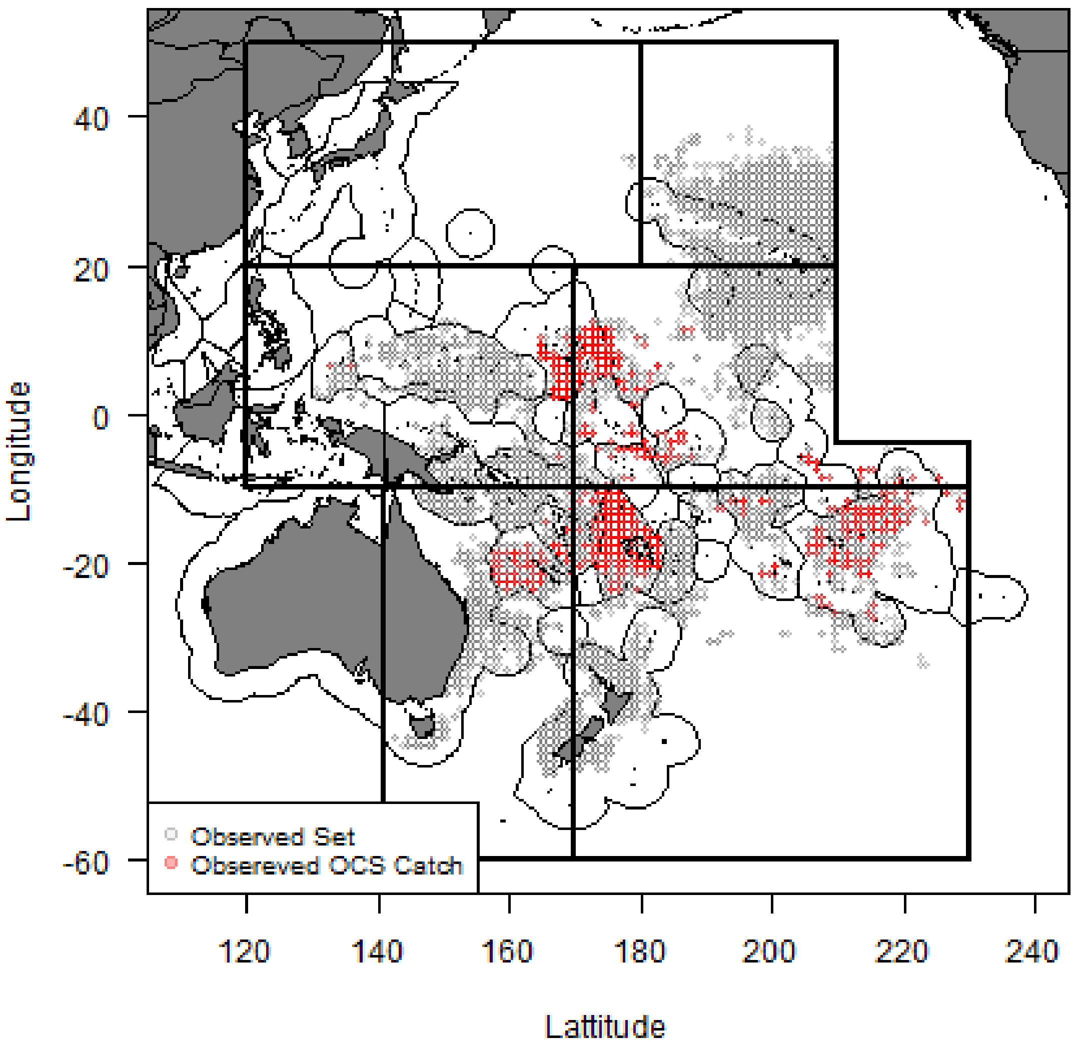

Figure 76: Species distribution, oceanic whitetip shark observed in the longline fishery.

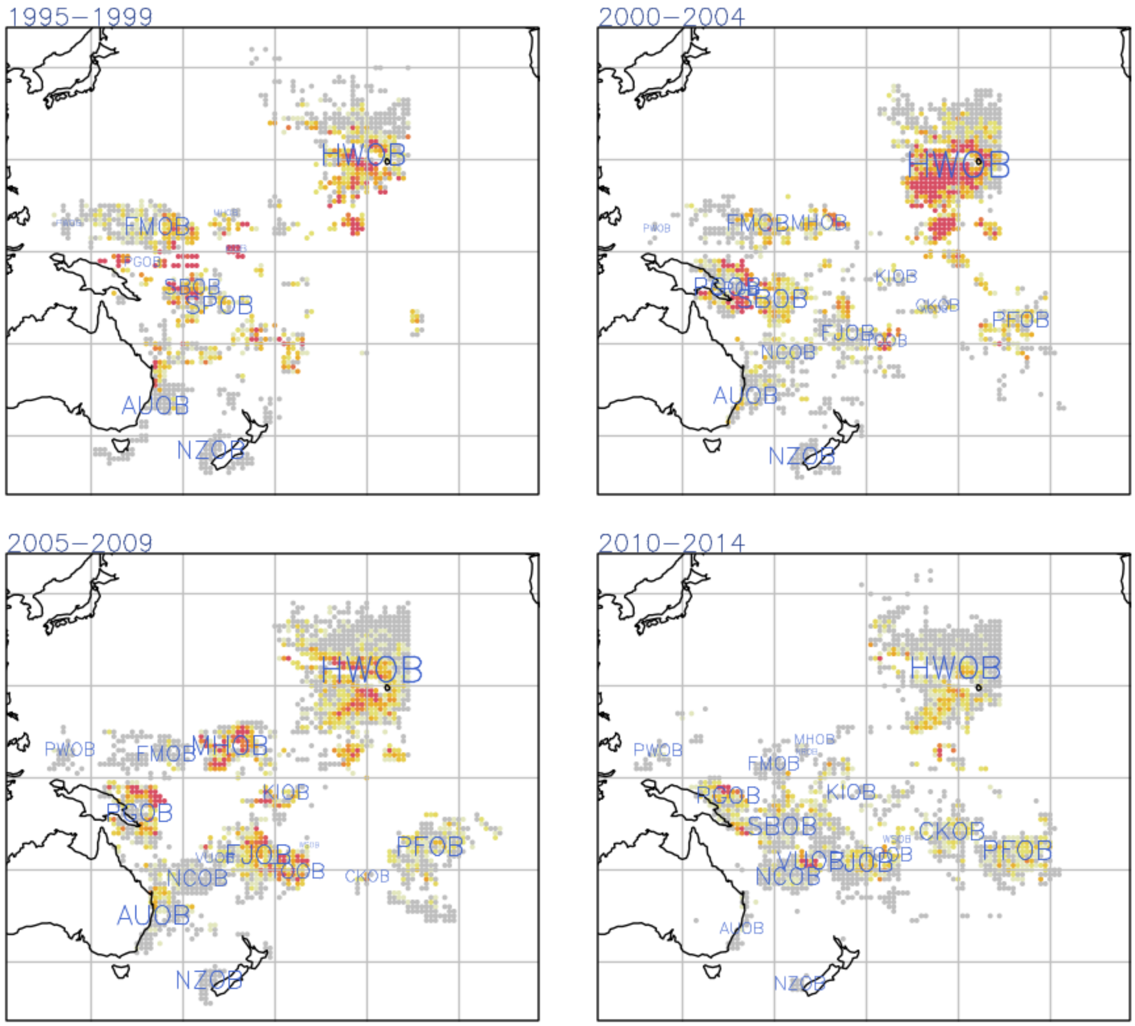

Figure 77: Species distribution, blue shark observed in the longline fishery by observer program.

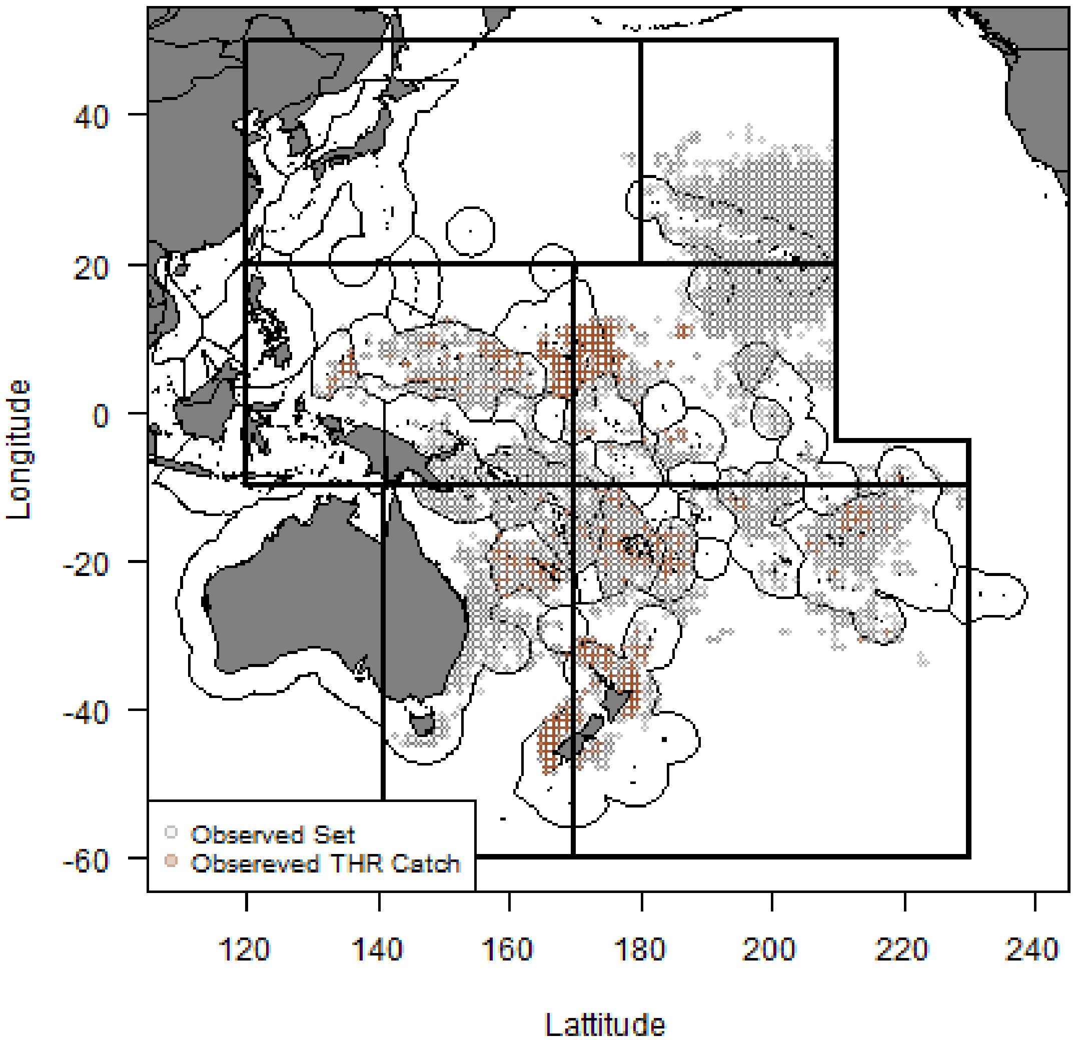

Figure 78: Species distribution, thresher shark observed in the longline fishery.

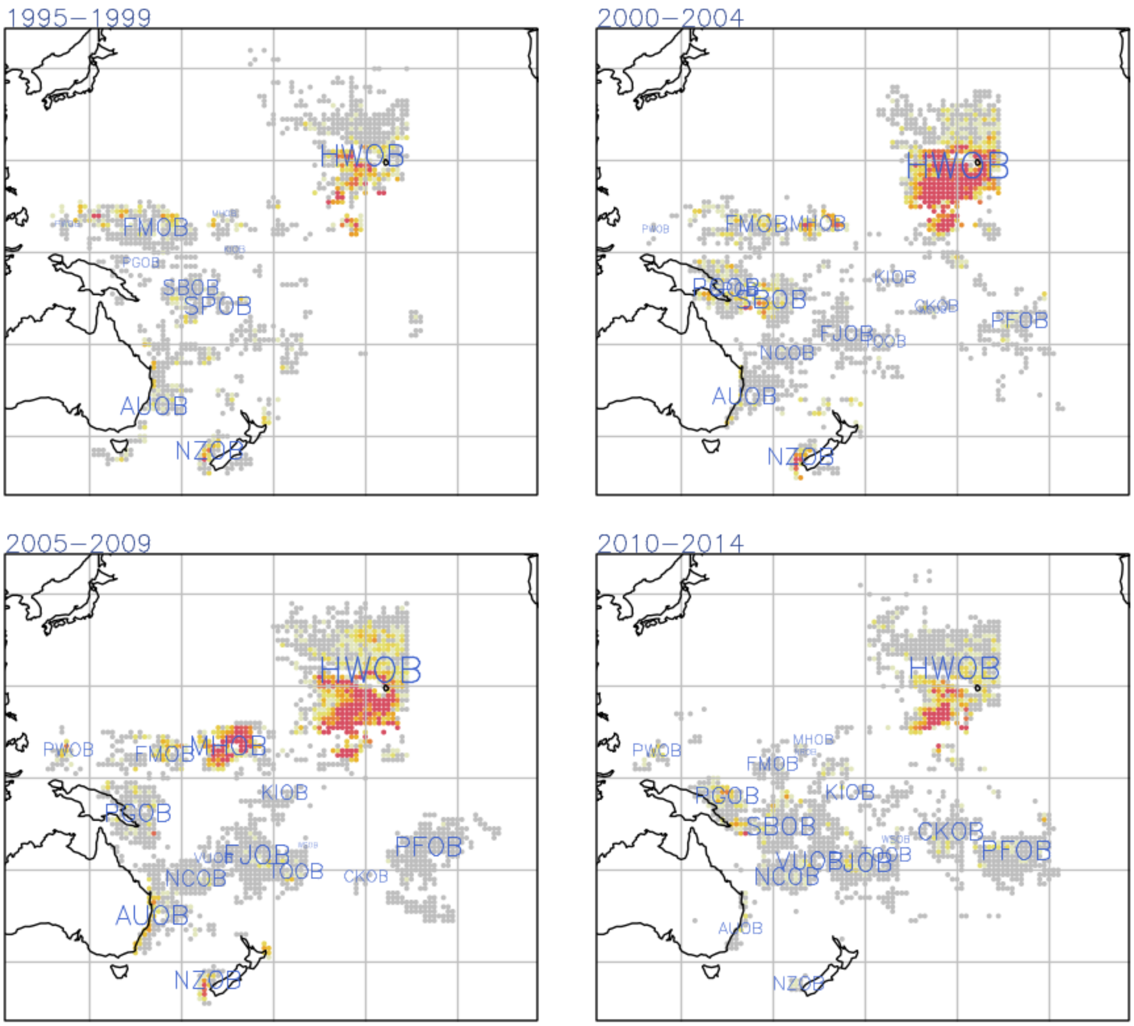

Figure 79: Species distribution, blue shark observed in the longline fishery by observer program.