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Report for Project 78: Analysis of Observer and Logbook Data Pertaining to Key Shark Species in the Western and Central Pacific Ocean

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Joel Rice[1]

[1] JoelRice@UW.edu

Executive Summary

This paper presents an analysis of data for sharks caught in longline and purse seine fisheries in the Western and Central Pacific Ocean (WCPO) held by The Pacific Community – Oceanic Fisheries Programme (SPC-OFP). It represents the final report of WCPFC Project 78 (Review of shark data and modelling framework to support stock assessments).

Overall the quality, with respect to the key shark species, of logbook data currently held by SPC has been improving over time. The logbook data has increasing levels of spatial coverage and higher levels of reporting sharks to species. For both the longline and purse seine fisheries the logbook data is useful to support analytical and indicator assessments.

Similarly, the quality of the observer data currently held by SPC is better in recent years than the historical data. Observer data coverage has required to be 100% in the purse seine fishery since 2010, but the data available do not represent 100% coverage, similarly the available data do not reach the required 5% coverage level in the longline fishery. Coverage, as a percent of total effort, has been increasing over time and has also increased in spatial coverage. In general, these data can support analytical (or indicator) assessments for the more commonly caught species but would require significant extrapolation to assess the less common species.

Reporting of logsheet data by fleet is highly variable, with many fleets reporting significantly less than 100%. It is difficult to identify whether logsheet data are provided for all key species given that non-reporting may be a result of a zero catch event (e.g. whale sharks in the longline fishery) or a lack of reporting. The relationship between the observer and logsheet reporting and the logsheet and aggregate reporting affect the precision in estimation of catch and potentially other stock related metrics such as distribution. Comparison of observer and logsheet data highlights that there is a large discrepancy in the rate of non-species-specific recording in the longline fishery logbook data pertaining to sharks. It is important to note that historic logbook recording did not have the provision for reporting the key shark species as there was no obligation to report to species level. There are historical logbook data that SPC does not hold and may have been useful for this study, noting that historic operational logbook data may be subject to similar non-reporting of sharks.

The general recommendation is for fishers to receive further identification training to improve the provision of shark interaction information to the species level. This is especially important for manta and mobulid rays which are commonly recorded only to the generic level. Recently the Western and Central Pacific Fishery Commission listed manta and mobulid rays as key sharks . In adopting manta and mobulid rays as key sharks the Commission also noted that data gaps would likely preclude traditional assessment methods and that revision of the minimum reporting standards should be undertaken due to the lack of data for these species. Correspondingly, this report does not generate new results for manta and mobulid rays, but refers to the SC 12 document on non-key sharks including manta and mobulid rays.

The largest gap in the data is within the longline fishery. The observer data covers a fraction of the overall effort, is biased towards those fleets which have strong observer programs and is

spatially concentrated within the EEZs, with little coverage on the high seas. The key mechanism to address the current data gaps would be an increase in observer coverage to at least the mandated 5% coverage level, potentially supplemented by electronic monitoring approaches. Without representative coverage any reconstruction of shark catch and CPUE estimation will likely be biased. One of the difficulties with the data analysis is that there is no readily identifiable mechanism to link logbook and observer data to the same set.

Initial conclusions (based on data from 2010 – 20115) regarding the impact of WCPFC shark related CMMs on data quality is that the lack of reporting specifications within these CMMs have resulted in non-reporting of shark catch within the purse seine fishery logsheets, despite observed of shark catch by observers and high levels of observer coverage. Within the longline fishery the reported catch of silky and oceanic whitetip sharks is similar to that before and after the CMMs banning retention came into force, however recent data from 2016 and 2017 indicate that the retention of silky sharks has decreased.

This project's Terms of Reference (ToR) are listed below with an interpretation of the results provided under each heading in italics. The Terms of reference for this project included:

1. Assess the quality of logbook and observer data currently held by SPC including their spatial and temporal coverage and the potential for their use to support analytical or indicator assessments.

Overall the quality, with respect to the key shark species, of logbook data currently held by SPC has been improving over time. The logbook data has increasing levels of spatial coverage and higher levels reporting sharks to species. Longline logbook data in 2015 accounted for approximately 38% of the overall longline effort (by hooks), and has been near that level since 2013, up from values of 30-35% over the years 2005-2012. Logbook data continues to lack the specificity in species-specific reporting for mako, hammerhead and thresher sharks, and is in general of poor quality for the infrequently caught species. There are substantial logbook data (e.g. historic logbook data from DWFN fleets) that SPC does not hold and may have been useful for this study, noting that historic operational logbook data may be subject to similar non reporting of sharks that is in the available data.

The observer data from both the purse seine and longline fleet is useful for conducting indicator analyses of catch at length and computing sex ratio. Observer data from the purse seine fleet is limited in its utility as an index of abundance due to the difficulties with computing a standardized CPUE. For species which are more prevalent in the longline fisheries (i.e. blue shark, silky shark, oceanic whitetip shark, and to an extent mako shark) the observer data is useful for calculating nominal and standardized CPUE time series. These CPUE time series are important to analytic and indicator assessments because they can be interpreted as indices of abundance in population dynamics models and are often used to calculate total catch (see TOR #4).

In 2015, Rice et al. carried out indicator analyses for all the key shark species. Recently more detailed indicator analyses using maximum impact sustainable threshold (MIST) and indicator analyses have been carried out for porbeagle, bigeye thresher and shortfin mako in the north Pacific. Integrated assessments have been carried out for silky, oceanic whitetip, blue shark (in *the north and south Pacific). Information regarding the data reporting patterns is covered in Section 3. Misidentification is common for many species including hammerhead, thresher and mobula rays. Misidentification or identification only to generic species, results in unreliable catch rates, and overall poor data quality, which is the case for the manta and mobulid rays, the hammerhead sharks, the longfin mako, common and pelagic thresher and also whale sharks.*

1.a. Investigate data reporting patterns by fleet including whether i) annual catches and discards are reported for all key species; ii) whether operational or aggregated logsheet data are provided for all key species; and iii) the extent to which the provided data are estimated and how that might affect their precision;

Data reporting patterns are investigated in Section 3. In comparing reported catch and discards it should be noted that not all key shark species are caught by every fleet, as some species and fisheries occupy non-overlapping habitat (i.e. temperate vs tropical). Furthermore reports of zero catch events for the shark species that are not usually associated with the target catch should be expected. Catch and discards are reported at the species level for blue shark, oceanic whitetip, silky, and porbeagle shark (though only from New Zealand and Spain). Reports of mako, thresher and hammerhead sharks exist, though they are often reported to the generic species level and not identified to the individual species. The logbook reported effort accounted for between 20% and 40% of the total aggregate longline effort (Table 7, Figure 23). Catch is similarly underreported on an annual basis with respect to the logsheet and the annual aggregate catch (Figure 24). Reporting by flag is highly variable with some countries averaging nearly 100% reporting and others reporting less than 5% (Table 7), overall. Reported effort in the purse seine fishery from the logbook data set ranges between 87% and 91% over the years 2010-2015, and between 83% and 96% over 1995-2009 (Table 4, Figure 27). The reported target catch (skipjack, bigeye, and yellowfin) to aggregate catch ranged between 81% and 93% of the aggregate catch by year (Table 8 shows the year/fleet coverage).

1.b. Compare observer and logsheet data with a view to identifying and adjusting for under-reporting, discarding, non-species-specific recording and other missing data;

Observer and logsheet data often come from different spatial areas even for the same fleet. Note that direct comparison of observer and logsheet data was attempted but due to differences in the reporting, a set by set comparison was not feasible. A solution to this would be for the Commission to mandate that logbook sets be somehow uniquely identifiable for sets when observers are present. The key fields that would allow a link between logbook and observer data at the set level is the 'SET START DATE' and 'TIME (UTC)'. These are required in observer data however are not currently a mandatory WCPFC requirement for logbook data. By making the logbook requirements on data provision for these two fields congruent with the observer data requirements direct comparison between observer and logbook data would be possible. Reported catch and discard rates by fleet for the key species are listed in Annex 2.

1.c. Provide advice on what types of analyses the data might support, including advice on appropriate modelling approaches (e.g. CPUE standardisation) where data are considered sufficient.

Section 8.1 and Table 14 summarize the species level analysis, and Appendix 4 shows the species assessment decision trees (SADTs) for each of the key shark species. Of the 15 species and 17 stocks (including north and south for blue and mako sharks) of key shark species, 7 have been assessed. Of the remaining 10 all but the shortfin mako in the South Pacific is considered data poor. These data poor shark stocks should be the focus of a new productivity susceptibility analysis, as well as enhanced data gathering (e.g. CPUE and sex ratio) along with species-specific identification for thresher, mako and hammerhead sharks. Where data supports the calculation of catch estimates these should be undertaken. Note that the tables referenced here reflect the sources and time series of information available, but cannot readily reflect whether that information will allow successful analytical assessments to be performed.

2. Identify significant data gaps and the uncertainties which these gaps imply,

The significant data gaps are summarized in Section 7.1 and 7.2. The current gaps in catch rate and catch data, low observer coverage, lack of reporting to species and misidentification of species, imply uncertainty with respect to fishery impacts on the population and the overall trajectory of the stock. Stock status determinations based on highly uncertain or largely extrapolated data would be unreliable.

3. Identify mechanisms to addressing the current data gaps including potential new sources of historical data,

The uncertainties can be remedied by expanding observer coverage, for observer programs to be structured so that they match the spatial / temporal distribution of fishing effort, for observers to receive further identification training for these species, and for logbooks to report sharks to species level where these sharks are WCPFC key shark species. Additionally, it is recommended that reporting of logbook or observer data be done in such a way that direct comparison of observer and logbook data on a set by set basis can be made (such as a unique identifier for sets when observers are present). As noted above making the logbook requirements on data provision for set start date and time congruent with the observer data requirements direct comparison between observer and logbook data would be possible.

4. Review the main data assumptions for re-constructing shark catch data time-series and propose methods (e.g. weighting, extrapolation, etc.) to adjust for potential biases,

In Section 2.3 the main methods for estimating undocumented shark catch time series are reviewed. In practice, the choice of estimation methodology is often dictated by the data that are available. Given the data currently available in the WCPO, methods that relate species specific catch rates by fleet, area and time to the overall effort appear to make the best use of the available data. Model-based methods that can account for gaps in the operational or observer data are appropriate for species with low catch rates. If possible, catch rates should be based on survey or observer data from fisheries similar to the main fisheries. When possible, alternative *catch histories should be developed using different methodologies and sources of data*. *At a minimum, estimates of catch should be carried out based on a standardized CPUE (from observer data that is proportioned by fleet, area and target species catch) raised to total effort that is stratified by the same factors as the CPUE.*

5. Examine the potential impact of key WCPFC shark related CMMs on data quality.

In general there has been an increase in logsheet reporting of sharks to species (Figures 31 and 33). While the increase may be in part attributable to impact of CMM 2010-07, species specific reporting also increased in the 2000's relative to the 1990s. The impact of the non-retention CMMs (CMM 2011-04 and 2013-08) has been an absence of reporting in the purse seine fishery for the years 2014 and 2015 (Table 13) despite observed catch rates that are similar to the years 2012-2013 (Table 12). Reporting of silky shark and oceanic whitetip in the longline fishery occurred in 2014 and 2015 at a similar rate to 2013, indicating that the CMM is not adopted over the entire fleet. CMM 2014-05 entered into force on July 1st 2015 and as such there is not enough data to quantify the effect of the bycatch mitigation via the implementation of this CMM (either no wire trace use or no shark line use). As the CMMs that specify non-retention for oceanic whitetip and silky shark continue to be implemented the importance of the observer data in both purse seine and longline fisheries will increase.

1. Introduction

This paper presents an analysis of data for sharks caught in longline and purse seine fisheries in the Western and Central Pacific Ocean (WCPO) held by The Pacific Community – Oceanic Fisheries Programme (SPC-OFP).

The framework for this study is an analysis of the potential for the available data to support indicators of fishing pressure and stock status for the designated WCPFC key shark species that are assessed and evaluated by SPC-OFP. Despite the lack of traditional fisheries statistics associated with target species (observed catch, effort, distribution, reported landings) indicator based assessments (Clarke and Harley 2010, Rice et al. 2015) and directed assessments (Rice and Harley 2012, Rice and Harley 2013, Fu et al. 2012) have been undertaken for many of the key shark species. However different data reporting patterns exist by fleet, and often the data provided are estimates of the true catch. This introduces uncertainty and potential bias to the results.

The majority of the shark catch in the pelagic fisheries of the Pacific Ocean is considered bycatch, though some directed and/or mixed species fisheries also exist. Although coastal artisanal and semi industrial fisheries often target sharks for local consumption and trade, the main sources of catch and effort are the pelagic fisheries targeting tuna and tuna like species. Summaries of stock status are available in the Shark Research Plan (Brouwer and Harley 2015) which notes;

> "The shark data holdings by SPC and WCPFC are reviewed annually through the WCPFC Data Catalogue (http://www.wcpfc.int/wcpfc-data-catalogue). Relevant statistics are highlighted below. The provision of annual catch estimates for key sharks has been a WCPFC requirement since 2007. The annual coverage of shark catch data across the raised aggregate longline data set, that includes actual and estimated effort for all fleets operating in the Convention Area include sets with no reported shark catch, which will include both true zeros and non-reporting of sharks. Note that changes between zero, generic shark and key sharks reported are assumed to be changes in reporting rates and not changes in species composition of the catch. Prior to 1990 there was very little information on shark catch and what was available was not species-specific, as almost all sharks that were reported were reported to the generic shark code. Since then there has been a sustained and continuing increase in the reporting of sharks, both to generic and species-specific codes. Despite this, over the past ten years less than a third of the reporting is species-specific and it is not clear whether these reports include discards. This indicates that reporting is improving but challenges remain in assessing sharks and generating plausible catch and CPUE time series. Since 2010, however, species-specific reporting of key sharks jumped and now averages just over 50% of reported sharks, this may reflect a change in logsheet form use to the SPC extended format longline logsheet and/or WCPFC members developing their own logsheets that require species specific reporting. However,

some fleets, while reporting key sharks to species level, may report all other sharks as SHK."

Given the nature of the catch (possibly underreported, largely estimated) and variable reporting rates of shark catch, this project aims to assess the quality of logbook and observer data currently held by SPC to identify the gaps in those data, significant implications that those data gaps imply, and to identify the mechanisms to addressing these data gaps in order to support future indicator and analytical assessments of WCPO shark stocks. Much of this work has been done in the past either through assessments (Rice and Harley 2012, Rice and Harley 2013, Rice et al. 2015), estimates of catch and catch per unit effort (CPUE, Tremblay-Boyer and Takeuchi 2016), indicator analyses (Clarke et al. 2011, Rice et al. 2015) or via shark specific reports (Brower and Harley 2015, Tremblay-Boyer and Brouwer 2016). This study synthesizes the previous work where applicable and expands upon it, to identify the potential of the data to support analyses for designated WCPFC key shark species (Table 1). The time frame of this analysis covers data for the years 1995- 2015, unless otherwise stated.

2. Description of the data holdings and review of methods for estimating catch

Most fisheries are managed by using a catch limit related to the stock's abundance at the maximum sustainable fishing mortality rate (F_{MSY}). For target fisheries the F_{MSY} is usually estimated via a stock assessment which typically uses time series of catch and index of abundance, to estimate current stock size and productivity. Even for populations that have insufficient catch data, indices of abundance or information about life-history to conduct conventional stock assessments, data-limited methods are generally designed to use a single time series of annual catches. Estimates of catch are therefore critical to the understanding of the impact of fisheries on target and bycatch species and their management. Two key sources of data are available within the WCPO to assess shark catches:

- SPC-held observer data from both purse seine and longline operations;
- Reported operational (logsheet) and aggregate shark catch data.

The primary source of shark catch data is the SPC-held observer database which, despite low coverage in all regions (Table 2) has substantial information regarding fleet operational characteristics as well as fate and condition data of captured sharks. The SPC held logsheet data on shark catches by longline fisheries does have high spatial resolution, but the geographic coverage is limited due to lack of total data provision, and the data does not have detailed operational characteristics on shark catches at the high spatial resolution that is available from observer data.

2.1 Longline Fishery Data

Longline fishing effort in the WCPO has increased steadily over the study period (1995-2014) to approximately 1.1 billion hooks (Table 2), with nearly half of the effort occurring in the equatorial waters between 20˚S and 20˚N. The measure of observer coverage is defined by "observed hooks set" and is used here because it is a common currency and allows for the standardization of observer coverage rates when undertaking analyses. In addition to the observer data, SPC holds longline logsheet (operational) and aggregated shark catch data. The operational data submitted to the SPC are at a higher spatial resolution than the aggregate data, and are useful for catch estimation, but their utility is limited by the lack of data provision by species for sharks (Table 3), especially in equatorial regions where the majority of the longline effort occurs. Aggregate data coverage is on par with the logsheet data, although coverage differs greatly throughout the region. Historical coverage rates with respect to sharks 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 the 14 species designated by WCPFC as key shark species is mandatory however, 'thresher' and 'hammerhead' sharks are each considered as a species complex for reporting purposes. A thorough examination of the SPC-held fisheries data and its utility for shark related analyses and resulting indicators of stock status can be found in Clarke et al. (2011) and Rice et al. (2015). Under CMM 2007-01, 5% observer coverage by the Regional Observer Programme (ROP) has been required since June 2012 in longline fisheries, 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). Ideally, stock assessments, indicator analyses, and calculation of indices of abundance would be based on operational-level data as its higher spatial resolution permits more comprehensive and nuanced analyses, however SPC's operational level data are geographically limited and not consistent with the spatio-temporal distribution of the fleet. In addition the operational-level coverage for the longline fishery is approximately 28% (by hooks fished for the period 1995 - 2015), which indicates the overall limitation of the utility of the operational data. Figure 1 illustrates the geographic distribution of longline logsheet data held by SPC (grey points). However, this picture is somewhat misleading as only 31% (15% over the entire time series) of the sets plotted recorded sharks. This is in contrast to the observer data (yellow points) in which 93% of the sets recorded at least one shark (red points). This discrepancy is not necessarily due to misreporting. Figure 1 does not distinguish between key shark species and other shark species because only 36% of the reported sets recorded any species-specific shark catches (1950-2015). Clarke (2011) note that most historical species-specific shark catch data are provided by a small number of flag States. Given the relatively low level of coverage in the operational data, a more complete characterization of the longline fishery requires the use of the aggregated (5◦ × 5◦ grid) data. Effort and reported shark catch 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. Sets with observers present onboard are shown for comparison (Figure 1) but have a finer degree of spatial resolution due to observer record keeping. Although shark interactions (reports of generic or species level catch) are recorded in 36% of the effort (by hooks) reported in longline logsheets (Figure 1, grey points), from 1950-2015, the level of reporting in for 1995-2015 is 61%. As a result, it is possible to use the logbook data in conjunction with the observer data to assess the number of shark interactions by fishery and the bycatch species involved in the longline fishery. However there are large differences in coverage levels by fleet and EEZ which are discussed in section 3. Operational-level coverage for the longline fishery was 28% (hooks reported/aggregate hooks) over the time period 1995-2015. This along with the variable level of reporting by species complicates the use of the operational data for analyses such as estimation of total catch and catch rate over time.

2.2 Purse Seine data

Similar to the longline fishery, SPC-OFP holds logsheet data on shark catch by purse seine fisheries at both the operational and aggregate levels. However, operational-level coverage for the purse seine fishery (average of 90% coverage, by set, 1995 - 2015) is considerably higher than for the longline fishery (average of 28% coverage based on hooks observed to hooks fished). 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 than in the longline fishery.

Following implementation of the WCPFC Regional Observer Programme (ROP) on 1 January 2010, in combination with prior observer coverage commitments by the Parties to the Nauru Agreement (PNA), 100% purse seine observer coverage is now required. Historical observer coverage in the purse seine fishery has varied between EEZs. Observer coverage rates were low, generally less than 12%, for the years 1995-2002, with coverage increasing to 18%-30% for the years 2003-2009. Recent (2010-2013) annual observer coverage rates are between 73-90% for observed sets / aggregate sets (Table 4), but see Williams et al. (2017) for a more detailed analysis of purse seine observer coverage. While observer coverage of the purse seine fishery is not uniformly representative (Figure 3, orange points), it is more representative than observer coverage of the longline fishery, owing to both higher coverage levels and the more limited geographic range of the purse seine fishery (Lawson, 2011). Shark interactions are recorded in just 3.7% of purse-seine logsheets (Figure 3, grey points), a value far lower than the 36% recorded in longline logsheets. In the observer database sharks were recorded (both general shark and to species) in 31% of the observed sets of between 2011 and 2015. As a result, it is not possible to assess the number of shark interactions by set or the species involved using purse seine logsheet data. Although estimated shark catch in the purse seine fishery are considerably lower than the longline fishery (Lawson, 2011; SPC, 2008), it would still be expected that purse seine shark interactions are proportional to purse seine effort. However, from the discrepancies between observed and reported (logbook) catch, it appears that some major fishing nations are not submitting or are under-reporting shark interactions, however this finding is complicated by the fact that historically there was no provision for reporting catches of some key WCPFC shark by species. This could be due in part to a spatial mis-match from observer and logbook data, though theoretically with 100% observer coverage the overlap between the observer data and purse seine observer coverage is highest around the western equatorial area near Papua New Guinea and the Solomon Islands, with little coverage extending to the central Pacific (Figure 4).

2.3 Methods for re-constructing historical shark catch

The majority of global fish stocks lack adequate data to evaluate stock status using conventional stock assessment methods; this applies especially to sharks and is certainly the case for the key shark species in the WCPO. Not all stocks can, or need to be assessed by traditional stock assessment models, and indicator-based analyses have been used for the key shark species within the WCPO (Clark et al. 2011, Rice et al. 2015). While the number of fleets reporting shark catch to species level has increased over time (Table 3) catch estimates for sharks in purse seine and longline fisheries continue to require some level of adjustment or partial/full estimation. Estimation of unobserved shark bycatch by pelagic longline and purse seine fisheries is difficult for multiple reasons, including: 1) data are generally limited in quantity and quality; 2) sharks are usually taken as bycatch or incidental catch which may be reported as 'total sharks', if reported at all (Camhi et al. 2008; Pikitch et al. 2008); and 3) when reported, catch data are likely to be biased by underreporting, and non-reporting of discards (Camhi 2008). For example, significant under-and non-reporting of blue shark (*Prionace glauca*) in the Hawaii longline fishery has been documented (Walsh et al. 2002) despite some of the best monitoring circumstances (Walsh et al. 2005, 2007).

Multiple methods for estimating bycatch rates exist. For example, design-based or ratio-based estimators are often used for bycatch of co-occurring non-target species with similar distributions and relative catch rates as the target species (e.g., Pikitch et al. 1998; Stratoudakis et al. 1999; Rochet et al. 2002) while model-based estimators are more commonly used for predicting less frequent bycatch events (e.g., Walsh et al. 2002; Perkins and Edwards 1996). In their simplest form ratio-based estimators calculate a ratio of bycatch to catch or effort from a smaller data rich data set and extrapolate to a larger data set (e.g. the annual observed shark /tuna ratio raised by total tuna catch to estimate total shark catch). Model based methods vary but typically use a data rich period or strata to parameterize one or more models and then predict through to the data poor periods or stratum. Methods that use both design and model based approaches (Miller and Skalski 2006; Kaiser 2006) have been developed for select fisheries. There are trade-offs between model based and ratio based estimates depending on the data sources, model chosen and fishery (Allen et al. 2001, Diamond 2003). The following are general descriptions of methods used for the estimation of shark catches.

Target Species Ratio based estimates. In situations where reported effort is unknown or thought to be unreliable, shark catch can be estimated based on the ratio of sharks to target catch. This ratio would be calculated at the finest scale possible (area, fleet, target species) and applied to the catch in that same stratum. In practice, this method assumes that the abundance of the particular shark species is proportional to the target catch at the strata level, and that ratio is applicable to the larger data set. This also assumes that targeting does not change the ratio of shark to target species and that all sharks are correctly identified and enumerated. The resulting estimates would then be a product of the annual target species catch and the ratio of shark to target catch (Murua et al. 2013).

Effort and CPUE based Estimates. Estimates of catches are commonly derived from the relationship between catch per unit of effort (CPUE) and total effort, with the assumption that

*CATCH = CPUE *EFFORT.* This method has been applied to sharks in the WCPO (Lawson 2011; Rice 2012). Typically, the catches are estimated as the product of effort (hooks fished for longline or sets for purse seine) in the region and catch rates for those fisheries based on observer data. At a basic level the catch rates would be stratified by timeframe, fleet, area, target species, or other factors as the data sets pertaining to the effort and catch rates. Model based approaches, typically using generalized linear models (GLMs) or some variant such as generalized additive models (GAM), or generalized linear mixed models (GLMM), to calculating a CPUE can be used to remove the effects of one or more covariates (season, area, etc.). With model based approaches the CPUE data are typically predicted based on models fit to observer data, on a proxy data set that has the same structure (year, fishery, fleet, area etc.) as the reported effort data.

Model based approaches using reported landings. Total shark landings can be estimated directly from reported fishery data, provided that some records of shark landings do exist. This method utilizes the reported species specific shark catch to parameterize a model (typically a GLM or GAM), and then uses that model to predict the catch for those records that contain no reports of shark catch. The main assumption for this process is that fishing operations in the same area/time/gear strata would, on a sufficiently broad scale, catch a similar combination of species; hence the lack of shark catch in some records reflects lack of reporting. This method is useful in situations where non-reporting or underreporting is common in sectors of the fishery, but is inherently biased towards the catch that is reported.

Dis-aggregated shark estimates. Often shark catches are reported as aggregate 'sharks', i.e. not species specific. Estimates of the species composition of reported aggregate shark catches (SKH) can be developed based using ratios from proxy fleets, time periods and regions (or other available data). This method uses substitution rules to define the species composition based on the most similar record of species specific shark catch (Fiorellato et al. 2016). This method makes many assumptions, chiefly that fleets or vessels operating in similar areas with the same gear would have similar catch rates across target and bycatch species. Further, when no directly comparable records exist, ratios of shark to target species or the species specific breakdown of the shark species may be borrowed from adjacent years, making the assumption that species composition is static across years.

Trade Based Estimates. Estimates of shark catch based on shark fin trade data have been produced for use in assessments in the Atlantic (Clarke 2008), Indian Ocean (Clarke 2015) and WCPO (Clarke 2009). This methodology produces estimates of catches of sharks utilized in the shark fin trade but may capture only a portion of the potential shark mortality (i.e. only those sharks' whose fins are traded). Estimates by species (in number and biomass based on Hong Kong shark fin auction data and extrapolated to the global trade) in 2000 were reconstructed using triangular distributions in a Bayesian model and Markov chain Monte Carlo (MCMC) methods. These estimates were then adjusted using annual imports into Hong Kong for 1980-2011. Figures were then further adjusted based on the diminishing share of Hong Kong's shark fin trade as compared to the total global trade over the later part of the time series. Finally, these adjusted global estimates were scaled in a number of ways (by ocean area (km^2), by target species catch, by longline effort and by import country of origin statistics) to represent potential shark catches in the specific ocean and fishery. It is important to note that among the assumptions used in this method the following particularly strong assumptions are highlighted by the author (Clarke 2014);

- The species composition of the sampled portion of the Hong Kong shark fin trade in Clarke et al. (2006a) is representative of global species composition.
- The species composition of the fin trade observed in 2000, and the relationships between fin sizes/weights and whole shark weights observed at that time, are constant throughout the time series.

Integrated model based estimates are also possible using statistical catch at age models (i.e. Fournier and Archibald 1982) these models combine population biology, indices of abundance and information on selectivity to estimate what the 'true' catch would have been, given the model fit to the observed plus reported landings, and indices of abundance (Aarts and Poos 2009). This approach has been developed to estimate unreported discards and uses either a fixed or flexible selectivity to reconstruct historical unreported discards in addition to the stock status. In this approach the model is fitted to the survey or observer data in combination with the known population biology, the most appropriate model is selected via likelihood or other information theoretic methods. Estimates of current and historical biomass are obtained along with estimates of discards or unreported (Casey 1996, Punt et al. 2006). These models often assume that natural mortality is constant in time, and that the survey or observer based discard information is broadly applicable to the fishery as a whole. The assumption that natural mortality is invariant over time is common in stock assessment models but may not hold if changes in predation pressure, community composition, habitat, or species distribution occur.

2.4 Biases associated with these methods and potential solutions

Bias in the estimation of catch can arise if the observed trips within a stratum (such as year, quarter, area, gear, target species) are not representative of the other vessels within the stratum. Such bias could arise if the vessels with observers on board consistently catch more or less than other vessels, if the average trip durations change, if the vessels with observers fish in different areas (i.e. in an EEZ vs outside of the EEZ), or if fishing behaviour changes with an observer on board. These types of biases can be tested for by comparing observable properties in strata having data from vessels with and without observers. This requires adequate data from observed vessels and a distribution of observer data that is representative of the fishery as a whole.

When calculating catch there is often a data rich period that is used to extrapolate to the data poor period. This implicitly assumes that the conditions in the data rich period are similar enough to the data poor period that the predictions are valid. Simulation studies that use different statistical techniques such as boosted regression trees, cross validation and machine learning could be useful in these situations. Methods that account for patterns of bycatch through time and space (i.e. integrated nested Laplace algorithms) have been applied to shark and other species bycatch (Cosandey-Godin et al. 2014) to account for the spatio-temporal correlation for species that are clustered in space and time, and where bycatch varies significantly from year to year. Long-term solutions include greater observer coverage and better quality data. In turn, the developing use of electronic monitoring could provide the type of data that would lead to greater precision in the estimation of bycatch.

In practice, the choice of estimation methodology is often dictated by the data that are available. Given the data currently available in the WCPO, methods that relate species specific catch rates by fleet, area and time to the overall effort appear to make the best use of the available data. Model based methods that can account for gaps in the operational or observer data are appropriate for species with low catch rates. If possible catch rates should be based on survey or observer data from fisheries similar to the main fisheries. When possible, alternative catch histories should be developed using different methodologies and sources of data. This is one of the main advantages of the trade based catch estimate methodology. As this method starts at the global level and works down to the species level it is not subject to the patterns in reporting, through space and time that the logbook and observer data contain.

3. Data Reporting Patterns

This section investigates the spatial and temporal quality of the logbook and observer data held by SPC, and their potential to support indicator or assessment based analyses of the key shark species. The coverage of observer data, in terms of the effort in WCPO purse seine and longline fisheries is examined along with the spatial coverage of the fishing activity to examine potential biases in raised data due to unrepresentative fleet-level coverage. In turn, a comparison of logsheet coverage in comparison to aggregate (annual catch) estimates is performed to identify the potential issues and uncertainties that may be encountered when raising.

3.1 Observer Coverage Calculation

CMMs 2007-01 and 2012-03 require that "…CCMs shall achieve 5% coverage of the effort of each fishery [fishing for fresh fish…]". Observer coverage can be calculated in many different ways, with Commission decisions allowing coverage to be achieved based on the number of hooks fished, number of trips, days at sea, or days fished. This analysis defines observer coverage as the number of hooks observed divided by the number of hooks fished for longline fisheries. For purse seiners, the observer coverage is calculated as the number of set hauls observed over the total number of fished sets. It should be noted that as CCMs can choose the method for calculating the observer coverage, the CCM-reported observer coverage and the levels calculated in this report may differ.

3.2 Observer coverage in purse seine fisheries

The number of sets reported in the logsheet data is compared to the number of sets within the observer data to quantify the percent coverage (observer/logsheet) by flag, year and area (5˚x 5˚ cell). The time frame for the analysis is 2010-2015 unless otherwise specified. The relative distribution of effort (both observed and reported) at the 5˚x 5˚ cell was calculated by summing the annual effort in each cell and dividing by the corresponding annual maximum effort.

The overall observer coverage has ranged between 73.5 and 89.8 percent from the years 2010 to 2015. Prior to 2010 the overall coverage (observed sets / aggregate sets) was approximately 30% or less (Table 4). During 2010-2015 the majority of countries observed more that 50% of the sets, with the exception of New Zealand, the Solomon Islands and Indonesia. The same data shows that the fleets of Papua New Guinea and the Philippines reported higher numbers of observed sets than logbook sets indicating that not all logbook data have been submitted (Table 5, observed sets /aggregate sets; see bolded entries), this could also be due to zero catch event sets that were recorded by observers but not in the logbook. Coverage by year and by fleet (Table 5) indicates that the coverage level is variable by flag and year, and sometimes shows pronounced fluctuations.

The spatial distribution of the observer data (Figure 6) is similar to that of the reported sets (Figure 7), and is centered in the equatorial waters between 20˚N and 20˚S. Analysis of the spatial distribution of the observer coverage indicate that the western equatorial area (near Papua New Guinea and the Solomon Islands) has the highest rate of coverage, while the central Pacific (the eastern part of the WCPO convention area) has a lower (less than 50%) rate of coverage (Figures 8-11). Although the observer coverage is biased towards the western WCPO both the spatial extent and coverage rates have been increasing over time (Figures 8-11).

The distribution of the relative effort of the observer data by 5˚ cell shows the unevenness of the distribution of effort, actual and observed. Of the 109 cells fished, 20 cells (18%) account for the top 85% of the total observed effort (Figure 12). This pattern is similar for the logbook data where 21 of the 114 cells with effort accounted for 90.3% of the total reported logsheet effort (Figure 13).

3.3 Observer coverage in longline fisheries

Similar to the previous section, this section assesses the quality of the longline logbook and observer data held by SPC by measuring spatial and temporal trends in the overall observed effort. The number of hooks reported in the logsheet data is compared to the number of hooks observed within observer data to quantify the percent coverage (observed hooks/reported hooks) by flag, year and area (5˚x 5˚cell). The relative distribution of effort (both observed and reported) at the 5˚ cell was calculated by summing the annual effort in each cell and dividing by the maximum effort.

The overall observer coverage ranged between 2.23% and 4.49%from the years 2010 to 2015 (Table 2). Prior to 2010 the overall coverage ranged from approximately 1% to 3.5% across the entire longline fleet. The range of variation at the fleet (flag) level was highly variable (Figure 14), with all countries except the US having less than 10% coverage between 2010 and 2015 (Table 6). Annual coverage values for the US range between 18.9 and 48.7% over that period.

The spatial distribution of the observer data (Figure 15) is similar to that of the reported logbook data (Figure 16), and is largely clustered in EEZs with little coverage in the high seas. This relationship between the observer data to the logbook data in not necessarily reflective of overall fishing patterns, due to the low coverage of the logsheet to aggregate data, but reflective of logsheet returns. Analysis of the spatial distribution of the observer coverage indicates that the areas near Hawaii, French Polynesia and the Solomon Islands/Papua New Guinea have the highest rates of coverage (Figures 17-20). Spatial coverage of the observer data has been increasing over time, however there continue to be low amounts of coverage outside of EEZs and in the areas further from the coasts. Fleet specific reporting rates indicate that there are only 4 countries (US, New Caledonia, Solomon Islands, and Papua New Guinea) reporting both observer data and logbook data where the average annual (from 2010-2015) observer coverage rate is in excess of 5% (Table 6). Many nations including Australia, the Cook Islands, the Federated States of Micronesia and French Polynesia have average annual (from 2010-2015) coverage rates in excess of 4%. Although average coverage rates are helpful to characterize overall coverages, they do obscure trends in the annual rate that may be indicative of an expansion of a program (note Fiji's recent expansion of observer growth), or where coverage levels have remained consistently low.

By looking at the relative breakdown of the observed data, by-cell comparisons can be made on the distribution of reported and observed effort. Twenty-four cells receive relatively high levels of observer effort (defined here as 90% or more of the maximum observed effort by cell, i.e. right most bin in Figure 21). This accounts for 36% of the total observed effort, whereas 17% of the reported effort occurs in the top 28 cells (Figures 21 and 22). This means that the observer effort is more concentrated than the effort reported in logsheets. Another way of interpreting these data is that between 2010 and 2015 6 cells received 25% of the total observer effort even though 10 cells made up the 25% of the logbook effort in the same time period meaning that the observer effort is more concentrated than the logsheet data.

3.4 Logsheet vs Annual Reports

Longline logbook data informs the annual catch estimates of sharks. In many cases catch of the key shark species is estimated based in part based on catch rates raised to the overall catch of the target species or overall effort. There is a need for representative data across the major strata, (i.e. fleets, areas, time, target species etc.), so that any extrapolation could be completed via representative time frames. This section compares the logbook data to the aggregate data, in terms of target catch and effort to assess the extent to which the data are provided. Target catch was computed as the sum of yellowfin, bigeye and albacore tuna. Data were compared on an annual basis, by year and flag, and by 5˚ by 5 ˚ spatial cell, over the time frame of 2010-2015.

The logbook reported effort accounted for between 20% and 40% of the total aggregate longline effort (Table 7, Figure 23). Catch is similarly underreported on an annual basis with respect to the logsheet and the annual aggregate catch (Figure 24). Reporting by flag is highly variable with some countries averaging nearly 100% reporting and others reporting less than 5% (Table 7) overall.

Analysis of the longline effort and catch on a 5˚ x 5˚ spatial scale (Figure 25 and Figure 26) show that the majority of the cells for which both logsheet and aggregate data exist have a ratio less than one. Conversely, there are areas around the Solomon Islands, Fiji, New Zealand and Tasmania where the reported logsheet data is much higher than the aggregate data both for the target catch and reported effort.

The reported effort in the purse seine fishery from the logbook data set ranges between 87% and 91% over the years 2010-2015, and between 83 and 97% over all fleets for the years 1995-2009 (Table 4, Figure 27). The reported target catch (skipjack, bigeye, and yellowfin) to aggregate catch by year ranged between 81% and 93% of the aggregate catch (Table 8 presents a breakdown by fleet). By looking at the data spatially we can see that there are areas in which the logsheet data report higher effort than the aggregate data centered near the Solomon Islands and Papua New Guinea. This same area shows higher logbook effort than aggregate effort (Figure 29 and Figure 30). Reported catch and discards by flag are included in Annex 3.

The difference in coverage between longline and purse seine should give some good indications of which species may be amenable to indicator analyses (noting that the length of the data set, in combination with the life history, may not easily support some analytical assessments). Section 7 of this report covers data gaps and the appropriate methodologies for analysis on a species specific basis.

3.5 Taxonomic reporting

The provision of annual catch estimates for key sharks has been a WCPFC requirement since 2007. Prior to that time the majority of the reported effort was associated with generic shark landings or no reports of sharks at all.

The annual reported composition of effort that included information on generic shark and key shark species was separately calculated across the logbook and observer data for the longline and purse seine fishery data sets (Figure 31 and Figure 32). These include sets with no reported shark catch, which will include both true zeros and non-reporting of sharks. Note that changes between zero, generic shark and key sharks reported are assumed to be changes in reporting rates and not changes in species composition of the catch. Records based on observed catch rates indicate that the proportion of effort (sets) that reporting generic sharks is much smaller, likely reflecting the training and resources that observers have available. The majority of the logbook data from longline fisheries between 1995 and 2015 included either data on generic shark or species specific reporting (for key shark). This is in contrast to the observer data where the majority of the observed longline effort contained records of key shark species. The majority of the reported (in logbook) purse seine sets report no shark catch (Figure 33), which is supported by the observer data from the same fishery (Figure 34).

The vulnerability of sharks is often assessed in part by examining fisheries catch trends, however the reported trends are not generally recorded on a species level. Shark catch trends aggregated at the family or genus level tend to be more stable than those trends at the species level. Simple estimates of catch were calculated by family, genus and species for the key shark species, for the longline and purse seine fisheries, with the exception of whale sharks for the longline fishery. Catch was estimated by calculating the observed CPUE by year and flag and then multiplying the observed CPUE by the aggregated effort data (by flag and year). This was to assess whether the apparent stability of the aggregated catch trends was contrary to the species level assessment. These catch trends by family, genus and species highlight which species are identified well at the species levels (e.g. blue shark) and which are still reported at the genus level (e.g. threshers, hammerheads). The general recommendation is for observers to receive further identification training for these species. Additionally, these estimated catch trends show that catch-based indicators may be reliable for only the most commonly occurring species within a genus.

The total reported catch (catch and discards) by key species was summarized for 2010-2015 in the purse seine and longline fishery. These data are reported as the sum total by year and by flag. Reported discards and catch for the longline fishery and reported catch rates for key shark species for the purse seine fishery were calculated by flag and year by dividing the number of sets that reported either catch or discards by the total number of sets reported by flag on an annual basis. The purse seine logbook data did not contain information on the discards of key shark species.

The aggregated catch trends for Carcharinids (Figure 35) show that blue shark is well identified, as it is the only member of the genus *Prionace*, and the trends are the same. The genus *Carcharinus* is nearly equal to the sum of the two key shark species in that family, silky shark and oceanic whitetip. The calculated catch by family and species for the longline fishery shows the change in the key species reporting over time. The catch of key shark species in the Carcharinidae family (blue shark, silky shark and oceanic whitetip) changed in 2012 to be dominated by catches of blue shark. The longline catch of Alopiidae and Sphyrnidae are dominated by the thresher and hammerhead complexes. Catch by genus and family for the longline fisheries are presented in Figures 35-38 for the longline fishery and 39 -42 for the purse seine fishery.

The reported catch rate and discard rate of blue shark in the longline fishery has increased from 2010 to 2015. Along with blue shark the reported catch and discards of oceanic whitetip and thresher sharks has increased over the same time period. The reported rate of mako sharks has stayed constant while the discard rate has increased. The reported total catch (catch + discards) of key shark species is dominated by blue shark for all flags and lowest for porbeagle (Figure 43 and Figure 44).

The reporting rate (number of sets with key sharks /number of sets) of key shark species in the purse seine fishery shows non-zero catch rates for all key shark species except porbeagle. The sharks that have the highest catch rates are whale shark and silky shark. Reporting rates existed for silky shark prior to 2014, after which there exist no records of silky shark catch in the purse seine logbook data, likely due to the retention ban. In addition to silky shark, both oceanic whitetip and whale shark are reported in 2010 and from 2010-2014 respectively. The reported total catch by country is dominated by silky shark, with lower levels of catch in each of the other species.

Previous analyses (Clarke et al. 2011, Rice et al. 2015) have utilized observer and logbook data to estimate indicative trends (based on CPUE) for silky shark, oceanic whitetip, mako shark, blue shark, whale sharks and porbeagle sharks. Rice et al. (2015) noted that limited inferences were possible for hammerhead and thresher shark species complexes, largely due to lack of data. These species are not commonly caught in the primary fisheries in the WCPO, and are historically not well reported. A recent study by Fu et al. (2017) estimated whether the current rates of fishing mortality on bigeye thresher in the Pacific are sustainable. This was undertaken by evaluating whether current impacts from fisheries exceed a maximum impact sustainable threshold (MIST) defined based on population productivity. It is relevant to note that this study was able to evaluate the question of whether overfishing is occurring but not whether the stock is depleted. This study was done in a data poor framework and was able to account for uncertainty in species distribution, initial population status, maximum density and post-capture survival, the resulting analysis characterized the risk of exceeding the defined MIST value for bigeye thresher shark.

3.6 Ratio of Key Shark Species to Target Tuna Species

The total reported catch of the individual key shark species was calculated by year, flag and by 5° cell and compared to the corresponding total target tuna catch. These values were averaged by year (for logbook and observer data) for annual comparison, and 5° cell for spatial comparison for the observer data only. This analysis was completed for the observer data and logsheet data. The metric used was the number of sharks/50,000 tuna individuals, or sharks/5000 MT of tuna for longline and purse seine data respectively. Mako and blue shark were each assessed as two separate stocks (northern and southern hemisphere) and the porbeagle considered only data south of 30°S for the longline data. Target species for the longline analysis were considered to be the sum of yellowfin, bigeye and albacore, while target species for purse seine was yellowfin, bigeye and skipjack.

The ratios of observed silky shark and oceanic whitetip to target tuna in the longline fishery have been declining since 2012 (Tables 9 and 10). In almost all cases the observed ratios of sharks to tuna in the longline fishery are higher than the ratios of sharks to tuna reported in the logbook data (Tables 9 and 10 for longline, Tables 11 and 12 for purse seine). The sharks observed most frequently in the purse seine fishery are silky shark and oceanic whitetip (Table 11). These sharks are present in the purse seine observer data for the years 2014 and 2015, but not in the reported data. This is likely a result of the retention ban on these species. Observed catch rates of oceanic whitetip and silky shark in the purse seine fishery for the years 2014 and 2015 are higher than for the two previous years.

Spatial analysis for both the purse seine and longline fleets indicate areas of high shark-to-tuna catch rates for silky shark near the Solomon Islands and Papua New Guinea (Figure 48, and 55). Higher catch rates for the more temperate sharks (blue shark and mako) are similar between the purse seine and observer data with higher catch rates in the temperate latitudes (Figures 51, 53, 57, and 58).

3.7 Comments Regarding the Data Reporting Patterns and shark related CMMs

Four main CMMs govern the catch of sharks in the WCPO:

- CMM 2010-07. Reporting of key shark species and '5% rule'.
- CMM 2011-04, non-retention for oceanic whitetip sharks, entered into force on January 1, 2013.
- CMM 2013-08, non-retention for CMM for silky sharks - effective from 1 July 2014.
- CMM 2014-05 bycatch mitigation via no wire trace or no shark lines, effective from 1 July 2015.

In general there has been an increase in logsheet reporting of sharks to species (Figures 31 and 33). While the increase may be in part attributable to the impact of CMM 2010-07, species-specific reporting also increased in the 2000's relative to the 1990s. The impact of the retention bans (CMM 2011-04 and 2013-08) has been an absence of reporting in the purse seine fishery for the years 2014 and 2015 (Table 12) despite observed catch rates that are similar to the years 2012-2013 (Table 11). Reporting of silky and oceanic whitetip shark in the longline fishery occurred in 2014 and 2015 at a similar rate to 2013 (Table 10), indicating that the CMM is not implemented over the entire fleet. CMM 2014-05 entered into force on July 1st 2015 and as such there is not enough data to quantify the effect of the bycatch mitigation via the implementation of this CMM (either no wire trace use or no shark line use). As the implementation of the CMMs that specify non-retention for oceanic whitetip and silky shark proceeds, the value of observer data for both purse seine and longline fisheries will increase for these species.

4. Evaluation of the relative spatial distribution of fishing effort and observer coverage and the effect on catch estimation and CPUE trends.

Observer coverage rates are usually less than 100% of fishing effort. Total estimates of bycatch are often calculated using ratios of observed bycatch to target species, raised via the total annual target species catch. This simulation study investigates the relationship between observer coverage and the ability to reliably estimate parameters of interest, specifically total bycatch and catch per unit of effort (CPUE) through time.

The model investigates the influence of the match or mismatch of the spatial coverage of the observer effort in relation to the actual fishing effort on the estimation of catch and CPUE for each of the key shark species in longline and purse seine fisheries. Previous studies have looked at the relationship between observer coverage and the error (or bias) associated with various levels of observer coverage (Babcock et al. 2003, Amande et al. 2012, Diaz et al. 2011, Komoroske 2015). Here we use the approach set out by Babcock et al. (2003) and Amande et al. (2012).

The techniques used in Amande et al. (2012) are updated to include spatial information regarding effort distribution and the distribution of observer coverage. These are the main inputs to the simulations, and can (in general) represent a random process or one informed by reported fisheries and or observer data. The reader is referred to Amande et al. (2012) for details on the methods, in summation the following steps were followed for each simulation exercise:

1. Simulate a fishery (the sampling universe) and the observer sampling process, repeat many times and sample at various levels of observer coverage

The simulator uses 420 individual 5°x 5° grids nominally corresponding to the WCPO from area from -55° to 45° within the east and west borders of the WCPFC convention area (Figure 60). The model is set up with an annual time step. The distribution of effort (*sets*) is the same among year for each simulation but varies randomly between simulations. Effort can be randomly distributed or distributed according to the relative average over the years 2010-2015 (Figure 60).

Each spatial cell is assigned an abundance based on an arbitrary 'true' population density. Each cell is then either fished or not within a time period, with 70% of the cells in the model receiving 'effort'. Each cell receives the relative amount of effort for each year where it gets assigned a 'fished' status. The relative distribution of the observed sets and the longline effort is drawn from either a uniform distribution or based on observer data (Figure 61) The relative abundance is scaled to an overall abundance that can vary in each time step to mimic a decreasing population.

2. Calculate the CPUE, and estimate the total bycatch for each sample at each level of coverage

Annual catch and annual mean CPUE are calculated at various levels of observer coverage based on either uniform, or observer coverage throughout the simulation area. The observer distribution is based on the relative average observed effort, where each cell is sampled with a probability equal to that of its relative average observer coverage. Within that observer coverage design, coverage can be set from 0 to 100%. Coverage levels included observer coverage rates of 1%, 5%, 10%, 20%, 50% and 100% (full coverage must be included so that the bias and error in catch can be calculated).

Catch calculation was performed by sampling the CPUE (at the specified coverage rates) to calculate an average annual CPUE and then multiply by the total effort. This value is compared to the 'total catch' obtained through the 100% sampling coverage to calculate the RMSE and bias, which can be expressed in relative terms. Following the Amande et al. 2013 the relative root mean square (RRMSE) is calculated as $[\sqrt{(\sum_{i=1}^{n}(x_i - x)^2/n]})/x$and the relative bias is calculated as $RBias_{i,j} = \sum_{i,j} \frac{X_{i,j} - X_i}{X_i}$.

Where $X_{i,j}$ is the expectation of the estimates, (the true value for the simulated data or the median of 1000 samples from the observer data for the actual observer data). The X_i is the sampled shark species CPUE or bycatch number for purse-seine.

Simulations were run over 15 years with a set (but arbitrary) level of decline over that time frame. The estimated catch was then compared to the 'true' value from the 100% coverage scenario at the specified levels of observer coverage.

Results

Similar to previous studies the results indicated that the RRMSE was highest for low levels of observer coverage (Figure 62) and the relative bias was slightly negative at low levels of observer coverage and converging on zero rather quickly (Figure 63). The RRMSE represents the relative sample standard deviation of the differences between estimated values and true catch values, these values are negatively correlated to the higher the sampling coverage. The lower the level of observer coverage the higher the error, with current levels of observer coverage resulting in approximately a 10% difference the annual estimates of catch.

The effect of using the spatial distribution of the longline effort on the RRMSE was to increase it (Figure 64) on average. The effect of using the spatial sampling of the observer coverage decreased the amount of error, more substantially for lower levels of coverage than for higher levels. The combination of including observed sampling coverage and reported effort showed an increase in the RRMSE that was higher at lower levels of observer coverage.

5. Manta and Mobula Rays

At SC12, research on non-key shark species (NKS) was presented (WCPFC SC 12- EB-WP-08), the result of which was that the Commission at WCPFC 13 adopted the following:

> 1. CCMs shall record where possible, through observer programs, the number of discards and releases of Manta and Mobula rays with indication of species (to the best extent possible), length, sex, status (dead or alive) and location caught.
> 2. Manta and Mobula rays shall be considered WCPFC key shark species for assessment and thus listed under the Shark Research Plan, noting that data gaps may preclude a traditional stock assessment approach.

3. SC13 shall review, as appropriate, a revision of the ROP minimum standards data fields and develop safe release guidelines for Manta and Mobula rays, with a view to their adoption by WCPFC14.

As noted in EB-WP 08, large gaps in the longline coverage exist which are particularly noticeable in the high seas to the northwest and southeast of the WCPO. Furthermore, the observer coverage throughout is not representative of the spatial distribution of the fishing effort. This report also noted that while many records of Mobula are reported as landed, this may represent either of the two species whose distributions appear to overlap, and that attributing the records to specific species would be complicated. Further EP-WP-08 concludes that "It would be uninformative to attempt to interpret CPUE trends for this group as we have no way to separate the records to species level and have no information on how different the productivities are for each species."

6. Whale Sharks

For the purposes of this report, information on whale sharks has been retained in a separate section. Information on whale sharks is limited almost exclusively to the purse seine fishing fleet where tuna schools associated with whale sharks are either specially targeted or whale sharks are discovered to be associated with schools that were previously thought to be free school tuna aggregations. Observations of whale sharks are subject to considerable spatial and temporal heterogeneity and likely to have been effected by changes in observer coverage and reporting practices in recent years. The fate of whale sharks following interactions is also uncertain and information on key biological processes is limited. Given the current SPC data holdings only limited analysis for whale sharks in the WCPO is considered to be feasible. The background to the original work by Harley et al. (2013) (for a full description of the analysis) was initiated from a request at WCPFC 9 to add whale sharks to the list of key shark species and subsequently a conservation and management measure was adopted (CMM-2012-04). Additional analyses of the spatial and temporal distribution of whale sharks in the western and central Pacific Ocean based on observer data collected from purse seine vessels was presented at SC 9 (SPC, 2011). As part of the Common Oceans program a Pacific wide study of whale sharks is scheduled for 2018.

7. Data gaps

7.1 Gaps in catch rate information and estimates of catch

Over the last decade species specific reporting has increased from 20%-30% (2005-2010), to between 30% and 45% (2011-2015, Table 2) in the longline fishery. While this represents an improvement in the last five years, there remains a significant amount of sets (36%-55%) that still report catches of generic shark. This indicates that reporting is improving but challenges remain in assessing sharks and generating plausible catch and CPUE time series. As noted in the shark research plan (Brouwer and Harley 2015) this improvement likely reflects a change in logsheet form use to the SPC 'extended format' longline logsheet and/or WCPFC members developing their own logsheets that require species specific reporting. When catch is not recorded or not recorded to species, catch needs to be estimated with some combination of effort and catch rate. Catch rate information also underpins the estimation of indices of abundance, in the WCPO the most reliable catch rate information is from the observer programs. Limited inferences are possible for some species (shortfin mako, hammerhead and thresher shark species complexes), largely due to a lack of records in the observer data, mis-identification and identification to species complex only. Additionally, where there are data it is often not spatially representative of the overall fishery, or range of the species. The uncertainties that these gaps imply are that any inference of stock status will also be uncertain. These current gaps in catch rate and catch data, low observer coverage, lack of reporting to species and misidentification of species, can be remedied by expanding observer coverage (supplemented through electronic means), for observers to receive further identification training for these species, and for logbooks to report sharks to species where these sharks are WCPFC key shark species. Additionally, reporting of logbook data in such a way that direct comparison of observer data and logbook data on a set by set basis can be made is necessary.

7.2 Gaps in biological knowledge and stock structure.

Catch and catch rate information provide key indicator trends for sharks, and are important inputs into analytical and indicator assessments. For both of these assessment types some understanding of the life history of the shark species of interest is required as well. Recent WCPO assessments of silky, oceanic white tip and blue shark (Rice and Harley 2012, Rice and Harley 2013, Rice et al 2014.) have noted that improvements in biological knowledge, including on growth, mortality, reproduction and movement (e.g. Takeuchi et al., 2016) are required to facilitate stock assessments and reduce uncertainty in assessment outputs.

Clarke et al. (2015) reviewed a worldwide database of key life history parameters from over 270 studies on blue, mako, silky, oceanic whitetip, thresher, porbeagle, hammerhead and whale shark species, detailing their associated uncertainties and prioritizing further studies. This analysis provides the basis for the development of priors for some assessment approaches, as well as sensitivity analyses for others. Overall stock structure for many key shark species (especially hammerhead and thresher shark species) remain a key gap in biological knowledge for these species in the Pacific.

7.3 Species Level Data Summaries and Analysis of Appropriate Methodologies for Analysis

There are a range of methods that might be used to monitor levels of shark bycatch, or fishery impacts ranging from simple to more complex. Examples of a tiered approach (loosely adapted from the ICES tiered assessment approach ICES 2012) are shown in Table 13.

A decision on the most appropriate method will be guided by factors such as data availability, available capacity and resources to undertake the review and review objectives. The data availability, and the representativeness of those data with respect to the fishery and distribution of the species, is species-specific. Species-specific summaries, here termed Species Assessment Decision Trees (SADTs), are provided in Annex 4. These species assessment decision trees indicate the available data, and types of analyses the data might support. Where data are considered sufficient, the potential analysis is listed (e.g. CPUE standardization). The SADTs refer to and ecological risk assessment (Kirby and Hobday 2007) which carried out productivity susceptibility analyses (PSA) for the majority of the commonly caught species in the longline fisheries in the WCPO. The PSA are used with three different formulations, for both the shallow and the deep longline fisheries in the WCPO to assign a risk (Low, Medium or High) for the effects of longline fishing. It is important to note that each PSA is relative to the formulations used, which were for 1) all species, 2) all fish, and 3) for all species of special interest (birds, mammals, reptiles, sharks), and referred to as PSA1, PSA2, and PSA3. A final general recommendation is that a PSA be completed for just the sharks and rays commonly found in the WCPO to help prioritize and inform future research efforts.

The SADTs show a stepwise approach to the development of a working stock status determination based on the quality of the data. Data poor species should be subject to a revised productivity-susceptibility analysis (or similar analysis). Medium data quality species should be assessed by an indicator analysis (Rice et al. 2015) or stock reduction analysis (Fu et al. 2015). Data rich species should be assessed via one or more analytic population dynamics model (though not necessarily a fully integrated model) that examines the structural assumptions in the estimated catch, representative indices of abundance and other key parameters. The recent assessments of bigeye thresher and porbeagle sharks using the MIST framework are a good example of integrating uncertainty into the assessment when dealing with species for which there may be significant data, but there is also uncertainty in key inputs such as species distribution, population trends, and total catch.

8. Conclusions and Recommendations

The overall quality, of logbook data currently held by SPC with respect to key shark species has been improving over time. The logbook data has increasing levels of spatial coverage and higher levels of taxonomic reporting to the species level. For both the longline and purse seine fisheries the logbook data are useful to support analytical and indicator assessments. The quality of the observer data currently held by SPC has also improved in recent years. Observer data coverage is not 100% of sets in the purse seine fishery nor does it reach the required 5% coverage level (calculated by hooks) in the longline fishery overall, but it has been increasing over time and has also increased in spatial coverage. In general, these data can support analytical (or indicator) assessments for the more commonly caught species, but would require significant extrapolation to assess the less common species.

Reporting of logsheet data by fleet is highly variable, with many fleets reporting significantly less than 100% (Table 8 and Table 10). It is difficult to identify whether logsheet data are provided for all key species given that perceived non-reporting may be a result of a zero catch event (i.e. whale sharks in the longline fishery) or an actual lack of reporting. The relationship between the observer and logsheet reporting and the logsheet and aggregate data reporting affect the precision in estimation of catch and potentially other stock related metrics such as spatial distribution. Comparison of observer and logsheet data highlights that there is a large discrepancy of the rate of non-species-specific recording in the longline fishery logbook data. The general recommendation is for the fishing crew to receive further training in the identification of sharks to the species level.

The largest gap in the data currently held is within the longline datasets, as the observer data covers a fraction of the overall effort, is biased towards those fleets with strong observer programmes and is also spatially concentrated within the EEZs with little coverage on the high seas. The key mechanism for addressing the current data gaps would be an increase in observer coverage to at least the mandated 5% coverage level. Without representative coverage, any reconstruction of shark catch and CPUE estimation will likely be biased; note that the results of section 4 highlight the reduction in error associated with catch estimation that occurs with higher levels of observer coverage. One of the difficulties with the data analysis is that there is no readily identifiable mechanism to specifically link sets recorded within logbooks with those directly observed by observers.

This project's Terms of Reference (ToR) are listed below with an interpretation of the results provided under each heading in italics. The Terms of reference for this project included: provided under each heading in italics.

1. Assess the quality of logbook and observer data currently held by SPC including their spatial and temporal coverage and the potential for their use to support analytical or indicator assessments.

Overall the quality, with respect to the key shark species, of logbook data currently held by SPC has been improving over time. The logbook data has increasing levels of spatial coverage and higher levels reporting sharks to species. Longline logbook data in 2015 accounted for approximately 38% of the overall longline effort (by hooks), and has been near that level since 2013, up from values of 30-35% over the years 2005-2012. Logbook data continues to lack the specificity in species-specific reporting for mako, hammerhead and thresher sharks, and is in general of poor quality for the infrequently caught species. There are substantial logbook data (e.g. historic logbook data from DWFN fleets) that SPC does not hold and may have been useful for this study, noting that historic operational logbook data may be subject to similar non reporting of sharks that is in the available data.

The observer data from both the purse seine and longline fleet is useful for conducting indicator analyses of catch at length and computing sex ratio. Observer data from the purse seine fleet is limited in its utility as an index of abundance due to the difficulties with computing a standardized CPUE. For species which are more prevalent in the longline fisheries (i.e. blue shark, silky shark, oceanic whitetip shark, and to an extent mako shark) the observer data is useful for calculating nominal and standardized CPUE time series. These CPUE time series are important to analytic and indicator assessments because they can be interpreted as indices of abundance in population dynamics models and are often used to calculate total catch (see TOR #4).

In 2015, Rice et al. carried out indicator analyses for all the key shark species. Recently more detailed indicator analyses using maximum impact sustainable threshold (MIST) and indicator analyses have been carried out for porbeagle, bigeye thresher and shortfin mako in the north Pacific. Integrated assessments have been carried out for silky, oceanic whitetip, blue shark (in the north and south Pacific). Information regarding the data reporting patterns is covered in Section 3. Misidentification is common for many species including hammerhead, thresher and mobula rays. Misidentification or identification only to generic species, results in unreliable catch rates, and overall poor data quality, which is the case for the manta and mobulid rays, the hammerhead sharks, the longfin mako, common and pelagic thresher and also whale sharks.

1.a. Investigate data reporting patterns by fleet including whether i) annual catches and discards are reported for all key species; ii) whether operational or aggregated logsheet data are provided for all key species; and iii) the extent to which the provided data are estimated and how that might affect their precision;

Data reporting patterns are investigated in Section 3. In comparing reported catch and discards it should be noted that not all key shark species are caught by every fleet, as some species and fisheries occupy non-overlapping habitat (i.e. temperate vs tropical). Furthermore reports of zero catch events for the shark species that are not usually associated with the target catch should be expected. Catch and discards are reported at the species level for blue shark, oceanic whitetip, silky, and porbeagle shark (though only from New Zealand and Spain). Reports of mako, thresher and hammerhead sharks exist, though they are often reported to the generic species level and not identified to the individual species. The logbook reported effort accounted for between 20% and 40% of the total aggregate longline effort (Table 7, Figure 23). Catch is similarly underreported on an annual basis with respect to the logsheet and the annual aggregate catch (Figure 24). Reporting by flag is highly variable with some countries averaging nearly 100% reporting and others reporting less than 5% (Table 7), overall. Reported effort in the purse seine fishery from the logbook data set ranges between 87% and 91% over the years 2010-2015, and between 83% and 96% over 1995-2009 (Table 4, Figure 27). The reported target catch (skipjack, bigeye, and yellowfin) to aggregate catch ranged by year between 81% and 93% of the aggregate catch (Table 8 presents coverage by fleet and year.

1.b. Compare observer and logsheet data with a view to identifying and adjusting for under-reporting, discarding, non-species-specific recording and other missing data;

Observer and logsheet data often come from different spatial areas even for the same fleet. Note that direct comparison of observer and logsheet data was attempted but due to differences in the reporting, a set by set comparison was not feasible. A solution to this would be for the Commission to mandate that logbook sets be somehow uniquely identifiable for sets when observers are present. The key fields that would allow a link between logbook and observer data at the set level is the 'SET START DATE' and 'TIME (UTC)'. These are required in observer data however are not currently a mandatory WCPFC requirement for logbook data. By making the logbook requirements on data provision for these two fields congruent with the observer data requirements direct comparison between observer and logbook data would be possible. Reported catch and discard rates by fleet for the key species are listed in Annex 2.

1.c. Provide advice on what types of analyses the data might support, including advice on appropriate modelling approaches (e.g. CPUE standardisation) where data are considered sufficient.

Section 8.1 and Table 14 summarize the species level analysis, and Appendix 4 shows the species assessment decision trees (SADTs) for each of the key shark species. Of the 15 species and 17 stocks (including north and south for blue and mako sharks) of key shark species, 7 have been assessed. Of the remaining 10 all but the shortfin mako in the South Pacific is considered data poor. These data poor shark stocks should be the focus of a new productivity susceptibility analysis, as well as enhanced data gathering (e.g. CPUE and sex ratio) along with species-specific identification for thresher, mako and hammerhead sharks. Where data supports the calculation of catch estimates these should be undertaken. Note that the tables referenced here reflect the sources and time series of information available, but cannot readily reflect whether that information will allow successful analytical assessments to be performed.

2. Identify significant data gaps and the uncertainties which these gaps imply,

The significant data gaps are summarized in Section 7.1 and 7.2. The current gaps in catch rate and catch data, low observer coverage, lack of reporting to species and misidentification of species, imply uncertainty with respect to fishery impacts on the population and the overall trajectory of the stock. Stock status determinations based on highly uncertain or largely extrapolated data would be unreliable.

3. Identify mechanisms to addressing the current data gaps including potential new sources of historical data,

The uncertainties can be remedied by expanding observer coverage, for observer programs to be structured so that they match the spatial / temporal distribution of fishing effort, for observers to receive further identification training for these species, and for logbooks to report sharks to species level where these sharks are WCPFC key shark species. Additionally, it is recommended that reporting of logbook or observer data be done in such a way that direct comparison of observer and logbook data on a set by set basis can be made (such as a unique identifier for sets when observers are present). As noted above making the logbook requirements on data *provision for set start date and time congruent with the observer data requirements direct comparison between observer and logbook data would be possible.*

4. Review the main data assumptions for re-constructing shark catch data time-series and propose methods (e.g. weighting, extrapolation, etc.) to adjust for potential biases,

In Section 2.3 the main methods for estimating undocumented shark catch time series are reviewed. In practice, the choice of estimation methodology is often dictated by the data that are available. Given the data currently available in the WCPO, methods that relate species specific catch rates by fleet, area and time to the overall effort appear to make the best use of the available data. Model-based methods that can account for gaps in the operational or observer data are appropriate for species with low catch rates. If possible, catch rates should be based on survey or observer data from fisheries similar to the main fisheries. When possible, alternative catch histories should be developed using different methodologies and sources of data. At a minimum, estimates of catch should be carried out based on a standardized CPUE (from observer data that is proportioned by fleet, area and target species catch) raised to total effort that is stratified by the same factors as the CPUE.

5 Examine the potential impact of key WCPFC shark related CMMs on data quality,

In general there has been an increase in logsheet reporting of sharks to species (Figures 31 and 33). While the increase may be in part attributable to impact of CMM 2010-07, species specific reporting also increased in the 2000's relative to the 1990s. The impact of the non-retention CMMs (CMM 2011-04 and 2013-08) has been an absence of reporting in the purse seine fishery for the years 2014 and 2015 (Table 13) despite observed catch rates that are similar to the years 2012-2013 (Table 12). Reporting of silky shark and oceanic whitetip in the longline fishery occurred in 2014 and 2015 at a similar rate to 2013, indicating that the CMM is not adopted over the entire fleet. CMM 2014-05 entered into force on July 1st 2015 and as such there is not enough data to quantify the effect of the bycatch mitigation via the implementation of this CMM (either no wire trace use or no shark line use). As the CMMs that specify non-retention for oceanic whitetip and silky shark continue to be implemented the importance of the observer data in both purse seine and longline fisheries will increase.

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10. Tables

Table 1

Table 1: Species and species groupings included in the analysis

Species Label	Species Code	Scientific Name
Blue Shark	BSH	*Prionace glauca*
Hammerhead Sharks	SPN	*Sphyrna mokarran, S. lewini, S. zygaena, and Eusphyra blochii*
Mako Sharks	MAK	*Isurus oxyrinchus, I. paucus*
Oceanic Whitetip Sharl	OCS	*Carcharhinus longimanus*
Porbeagle Shark	POR	*Lamna nasus*
Thresher Sharks	THR	*Alopias supercilious, A. vulpinus and A. pelagicus*
Silky Shark	FAL	*Carcharhinus falciformis*
Whale Shark	RHN	*Rhincodon typus*

Table 2

Table 2. Observer effort (in hooks fished), reported effort and total effort in the longline fishery by year

Year	Observed Hooks (Millions)	Reported Hooks (Millions)	Total Hooks Fished (Millions)	% Observer Coverage	% Logbook Coverage
1995	2.58	182.99	599.18	0.43%	30.54%
1996	2.40	129.10	569.30	0.42%	22.68%
1997	3.15	115.41	571.33	0.55%	20.20%
1998	2.78	123.47	642.30	0.43%	19.22%
1999	2.54	172.59	732.73	0.35%	23.55%
2000	4.00	182.09	785.55	0.51%	23.18%
2001	7.25	179.63	965.40	0.75%	18.61%
2002	11.10	219.40	1,006.03	1.10%	21.81%
2003	11.67	250.98	994.32	1.17%	25.24%
2004	12.73	287.71	1,064.85	1.20%	27.02%
2005	15.81	255.34	871.62	1.81%	29.30%
2006	15.84	275.96	898.58	1.76%	30.71%
2007	15.03	334.84	1,013.16	1.48%	33.05%
2008	15.46	300.51	1,030.07	1.50%	29.17%
2009	14.94	334.06	1,112.96	1.34%	30.02%
2010	16.45	354.06	1,082.29	1.52%	32.71%
2011	20.50	396.74	1,165.69	1.76%	34.04%
2012	25.07	433.30	1,219.86	2.06%	35.52%
2013	30.00	410.12	1,007.73	2.98%	40.70%
2014	27.66	408.49	1,041.82	2.66%	39.21%
2015	20.07	421.24	1,108.67	1.81%	37.99%

Table 3

Table 3. Longline logbook reporting of sharks by species, generic shark or none.

Year	None	Sharks	Species
1950	0%	100%	0%
1951	0%	100%	0%
1952	100%	0%	0%
1953	100%	0%	0%

1954	100%	0%	0%
1955	100%	0%	0%
1956	100%	0%	0%
1957	100%	0%	0%
1958	95%	5%	0%
1959	96%	4%	0%
1960	96%	4%	0%
1961	95%	5%	0%
1962	93%	7%	0%
1963	93%	7%	0%
1964	95%	5%	0%
1965	96%	4%	0%
1966	95%	5%	0%
1967	95%	5%	0%
1968	91%	9%	0%
1969	93%	7%	0%
1970	93%	7%	0%
1971	94%	6%	0%
1972	96%	4%	0%
1973	93%	7%	0%
1974	95%	5%	0%
1975	90%	10%	0%
1976	94%	6%	0%
1977	92%	8%	0%
1978	91%	9%	0%
1979	81%	19%	0%
1980	73%	27%	0%
1981	67%	33%	0%
1982	71%	29%	0%
1983	85%	15%	0%
1984	81%	19%	0%
1985	67%	33%	0%
1986	83%	17%	0%
1987	59%	40%	0%
1988	61%	39%	0%
1989	66%	34%	0%
1990	71%	29%	0%
1991	67%	31%	2%
1992	66%	31%	3%
1993	62%	35%	3%
1994	25%	46%	28%

1995	23%	52%	25%
1996	27%	48%	25%
1997	28%	50%	22%
1998	27%	47%	26%
1999	28%	49%	23%
2000	28%	50%	22%
2001	48%	35%	17%
2002	37%	43%	20%
2003	36%	40%	24%
2004	25%	47%	28%
2005	24%	49%	27%
2006	25%	47%	28%
2007	20%	54%	26%
2008	10%	62%	28%
2009	7%	66%	27%
2010	8%	53%	39%
2011	11%	55%	34%
2012	13%	44%	43%
2013	18%	37%	45%
2014	22%	38%	39%
2015	23%	36%	40%

Table 4

Table 4: Observer and Operational coverage for the purse seine fishery

Year	Observed Sets	Logbook Sets	Aggregate Sets	% Observer Coverage (Obs./Agg.)	% Operational coverage (Log./Agg.)
1995	1,785	21,334	25,833	7%	83%
1996	3,032	24,534	27,291	11%	90%
1997	2,460	24,552	27,327	9%	90%
1998	2,608	25,980	28,221	9%	92%
1999	1,677	22,243	23,926	7%	93%
2000	2,000	23,610	26,937	7%	88%
2001	2,354	26,701	27,439	9%	97%
2002	3,533	29,277	30,490	12%	96%
2003	3,673	28,006	30,013	12%	93%
2004	5,348	29,572	31,446	17%	94%
2005	6,273	31,912	35,478	18%	90%
2006	6,128	30,068	33,249	18%	90%
2007	6,032	32,470	35,709	17%	91%
2008	6,323	35,269	40,124	16%	88%
2009	11,117	38,340	43,495	26%	88%
2010	34,068	46,163	50,825	67%	91%
2011	33,251	45,258	51,165	65%	89%
2012	39,165	50,282	56,604	69%	89%
2013	44,660	49,002	55,141	81%	89%
2014	40,065	48,659	56,067	72%	87%
2015	33,792	41,750	46,959	72%	89%

Table 5 Observer coverage by year and fleet (100 observed purse seine sets / aggregate sets)*

Year	CN	EC	ES	FM	JP	KI	KR	MH	NZ	PG	PH	SB	SV	TV	TW	US	VU
1995				9.9	2.7	36.1	2.6			16.1					4.1	16.4	11.5
1996				2.8	2.2	18.5	4.9			10.5	1.7				8.7	32.4	
1997					1.5	19.3	4.1			8.9	6.9				5.2	26.5	5.6
1998				17.2	1.2	23.4	5.5			7.7		5.6			12.5	20.8	3.6
1999				7.3	0.7	21.2	6.2			4.3	1.5	10.5			8.0	17.5	1.9
2000				14.3	2.6	5.2	4.2		24.5	4.3	2.4	25.1			7.4	22.2	
2001				10.2	3.2	5.9	2.8	4.1	15.7	5.1	17.0	8.7			7.2	26.7	
2002	13.5			20.6	2.4	62.2	1.1	10.9		25.4	43.2	54.5			4.2	22.8	
2003				14.4	3.0	51.8	2.4	16.9	2.5	35.4	32.8	37.1			1.4	20.9	2.7
2004				20.5	3.4	25.9	8.7	22.9	4.0	32.6	39.1	35.3			8.1	31.5	14.0
2005	5.8			17.3	2.7	15.0	5.6	31.0	9.3	36.0	47.8	12.1			10.5	22.1	17.8
2006	4.0			25.9	3.0	48.7	5.6	60.6	4.0	43.9	58.3				5.4	25.1	14.0
2007	6.9			19.6	2.3	18.9	5.1	57.5	0.7	40.0	37.6	12.0			8.6	20.0	17.7
2008	1.7		6.8	23.4	2.0	30.5	6.7	59.2	6.0	25.2	41.7	29.8			8.2	22.9	12.3
2009	13.3		1.1	21.7	13.0	30.2	10.2	57.2	22.8	38.8	49.0		34.0	21.9	15.7	34.9	37.5
2010	66.5	186.5	69.8	59.6	58.5	72.7	60.2	69.9	33.0	65.9	63.6	10.1	**110.4**	96.1	51.4	92.1	**105.5**
2011	39.6	105.4	27.5	74.1	60.5	47.9	59.4	51.4	56.9	72.9	71.9	14.1	81.7	67.1	54.0	97.8	**113.3**
2012	62.9	64.4	55.5	69.2	73.9	60.4	55.9	73.6	82.1	74.9	61.7	32.1	17.1	69.4	60.8	89.9	84.2
2013	71.8	**139.3**	**126.7**	11.7	85.8	58.5	74.2	93.1	81.0	82.6	**108.2**	16.0	80.8	56.5	71.1	96.5	65.1
2014	69.5	**128.3**	**114.2**	70.5	68.0	57.1	48.2	84.6	50.0	53.0	**102.5**	37.9	110.9	47.2	65.4	99.7	60.6
2015	**130.4**	90.0	53.3	83.8	51.0	50.1	76.3	72.2	30.5	73.3	80.3	41.3	51.9	67.1	63.6	84.3	72.9

Table 6. Observer coverage percent by year and flag for the longline fishery. Coverage was calculated as the ratio of observed hooks to hooks fished. The US flag comprises fleets based in Hawaii and American Samoa for the years 2003-2015. The information presented herein represents coverage of all observer available to SPC, including non-ROP defined trips, which are not available to the WCPFC without authorization from the CCM providing the data. Data from 2015 is provisional for some countries.

Observer coverage percent by year and flag for the longline fishery.

Year	AS	AU	CK	CN	FJ	FM	GU	JP	KI	KR	MH
1995			1.4%	0.2%	0.9%	0.3%	9.0%	0.7%			
1996			6.7%	0.2%	0.4%	0.9%	4.0%	0.5%			
1997		0.5%		0.6%	0.5%	1.5%	10.5%	0.8%			
1998	0.0%			0.5%		0.7%	8.0%	0.5%		0.1%	
1999		0.0%		0.2%	1.1%	0.5%		0.5%		0.1%	
2000				0.2%		1.0%	0.0%	0.4%			
2001		0.7%		0.9%		0.9%		0.3%			
2002	1.1%	5.6%	0.7%	0.0%	0.3%	0.7%		0.4%		0.3%	
2003		4.9%	0.0%	0.5%	1.2%	0.8%		0.4%		0.1%	
2004		7.3%		0.5%	0.6%	2.3%		0.0%		0.0%	
2005		11.2%		0.8%	2.6%	4.4%		0.5%		0.3%	
2006		10.3%		2.0%	2.5%	11.4%		0.3%		1.0%	
2007		6.0%	0.2%	1.5%	1.9%	1.2%		0.5%		0.5%	
2008		9.5%	0.9%	0.3%	2.6%	1.0%		0.2%	9.1%		1.8%
2009		6.3%	1.8%	0.4%	1.3%			0.4%			0.5%
2010		3.6%	1.6%	0.1%	0.8%			0.2%			
2011		6.4%	1.7%	0.1%	1.2%			0.1%	0.6%	0.3%	
2012		6.0%		1.1%	0.7%			0.3%		1.0%	
2013		6.6%	7.7%	2.0%	3.6%	1.9%		0.3%		2.7%	3.7%
2014		2.9%	4.6%	2.4%	6.5%	8.4%		0.4%		1.3%	
2015		1.3%	6.4%	0.6%	9.3%	2.0%		0.7%	3.8%	2.8%	

Year	NC	NZ	PF	PG	PW	SB	TO	TW	US	VU	WS
1995		2.7%						0.0%	3.6%	0.4%	
1996	4.0%	4.8%		1.9%			5.2%	0.2%	4.5%		
1997		5.0%	2.2%					0.2%	3.3%		
1998	1.1%	3.6%					3.6%	0.2%	3.7%		0.0%
1999	0.7%	0.5%		1.0%			0.8%	0.1%	3.2%		0.0%
2000		0.5%		1.5%	3.9%		1.1%	0.2%	11.6%		3.4%
2001	0.7%	3.5%		4.5%				0.0%	23.4%		0.5%
2002	2.3%	1.4%	1.0%	3.3%				0.2%	25.3%		
2003	2.4%	6.0%	2.5%	2.9%				0.1%	22.6%		
2004	2.4%	11.9%	1.7%	2.7%			7.0%	0.1%	26.2%		
2005	1.2%	2.7%	1.6%	5.6%			0.7%		33.5%		
2006	2.6%	2.5%	3.6%	4.5%			8.0%	0.0%	25.8%		0.3%
2007	2.6%	4.2%	1.6%	1.6%			3.4%	0.0%	28.3%		
2008	3.1%	4.2%	2.6%	5.9%			8.7%	0.1%	32.7%		
2009	7.8%	4.6%	6.0%				4.9%	0.1%	32.1%	0.2%	
2010	8.4%	4.7%	6.0%	0.9%			2.6%	0.1%	48.7%	0.5%	
2011	6.7%	3.3%	3.9%	4.1%		1.7%		1.0%	48.4%	1.9%	0.2%
2012	4.3%	3.3%	4.9%	7.5%		9.1%	0.8%	2.3%	41.5%	0.0%	
2013	4.2%	2.4%	5.0%	8.2%		7.7%		2.9%	36.5%	2.6%	0.6%
2014	6.0%	3.0%	4.5%	6.1%			3.2%	2.4%	32.2%	1.0%	
2015	4.2%	4.1%	3.2%				8.1%	1.1%	18.9%	1.4%	0.8%

Table 7 Longline logbook coverage (logbook/aggregate) effort, based on hooks fished.

Year	AU	BZ	CK	CN	ES	FJ	FM	ID	JP	KI	KR	MH	NC	NU
1995	0.90	1.00	1.00	0.77		0.71	0.64	0.00	0.31	0.83	0.49	0.64	0.38	
1996	0.95	1.00	1.00	0.72		0.38	0.57		0.21	1.00	0.39		0.40	
1997	1.00	1.00	1.00	0.76		0.79	0.64		0.17		0.36		0.50	
1998	0.95	1.00		0.58		1.00	0.57		0.13		0.30		0.72	
1999	0.96	0.93		0.30		0.86	0.57		0.19		0.47		0.65	
2000	0.93	0.86		0.37		0.62	0.50		0.16		0.47		0.77	
2001	0.88	0.91	1.00	0.55		0.73	0.63		0.12		0.41		0.70	
2002	0.89	0.32	1.00	0.42		0.94	0.44		0.09		0.31		0.68	
2003	0.85	0.12	1.00	0.25		0.90	0.62		0.14	1.00	0.28		0.68	
2004	0.86	0.31	0.89	0.27	0.97	0.79	1.00	0.00	0.11	1.00	0.41	1.00	0.94	
2005	1.00	0.55	1.00	0.41	1.00	1.00	1.00	0.01	0.15		0.22		0.99	0.97
2006	0.93	0.77	1.00	0.33	1.00	1.00	1.00	0.01	0.18		0.45		0.89	0.72
2007	1.00	0.29	1.00	0.45	1.00	1.00	0.21	0.00	0.18		0.66	0.60	0.92	1.00
2008	1.00	0.41	1.00	0.27	0.98	0.98	0.76	0.00	0.16	1.00	0.37	0.77	0.94	1.00
2009	1.00	0.36	1.00	0.40	0.99	1.00	0.77		0.15		0.45	0.50	0.94	0.16
2010	1.00		0.94	0.43	0.96	1.00	1.00		0.20		0.37	0.66	0.90	1.00
2011	1.00		0.85	0.57	0.99	0.98	0.56	0.01	0.18	0.46	0.32	0.74	0.99	
2012	1.00	0.24	0.56	0.43	0.99	0.99	0.67	0.02	0.17	1.00	0.33	0.70	0.98	
2013	1.00	0.05	0.96	0.62	1.00	1.00	0.73	0.01	0.15	1.00	0.34	1.00	0.92	
2014	1.00	1.00	1.00	0.82	0.95	1.00	0.85	0.02	0.15	1.00	0.89		1.00	
2015	1.00		0.90	0.82	1.00	1.00	1.00	0.00	0.11	0.22	0.92	1.00	0.96	

Year	NZ	PF	PG	PH	PT	PW	SB	SN	TO	TV	TW	US	VN	VU	WS
1995	0.65	0.64	0.26								0.13	0.03		1.00	
1996	0.57	0.65	0.64						1.00		0.16	0.02		1.00	
1997	0.73	0.76	0.99	0.03					0.26		0.12	0.03		1.00	
1998	0.70	0.85	0.66	0.01					0.19		0.12	0.04		1.00	0.15
1999	0.78	0.83	0.70						0.24		0.11	0.05			0.21
2000	0.82	0.83	0.72			0.49			0.62		0.15	0.07		1.00	1.00
2001	0.75	0.73	0.82			0.24			0.69		0.07	0.21		0.91	0.13
2002	0.77	0.78	0.96	0.03					0.85		0.12	0.33		0.53	0.21
2003	0.71	0.85	1.00	0.02					1.00		0.17	0.33		0.50	0.40
2004	0.62	0.76	0.86			0.14			1.00		0.17	0.28	0.00	0.99	0.51
2005	0.73	0.76	0.91						0.73	1.00	0.18	0.03	0.00	0.99	0.41
2006	0.75	0.80	1.00					1.00	0.83		0.19			0.98	0.30
2007	0.91	0.77	0.85					1.00	0.87		0.15	0.98		0.94	0.24
2008	0.62	0.79	0.83						0.91		0.14	1.00		0.97	0.22
2009	0.84	0.78	0.48						0.89		0.15	1.00		0.98	0.37
2010	0.82	0.72	0.95	0.02			0.01		0.77	1.00	0.20	1.00		0.97	0.53
2011	0.68	0.69	0.39	0.06			0.14		0.65	1.00	0.22	1.00		0.90	0.55
2012	0.78	0.76	0.56	0.05			1.00		0.42	0.87	0.22	1.00		0.87	0.81
2013	0.83	0.86	0.77	0.04			1.00		0.50	1.00	0.30	1.00		0.68	0.72
2014	0.70	0.78	0.70		1.00		0.05		0.70	1.00	0.28	0.87		0.87	0.95
2015	1.00	0.89	0.93		0.10		0.06		0.89	1.00	0.22	0.82		0.78	0.98

Table 8. Ratio of reported target catch to aggregate target catch for the purse seine fishery by flag

Year	AU	CN	EC	ES	FM	FR	JP	KI	KR	MH
1995	0.26				1.00		0.58	1.00	0.91	
1996	0.90				1.00	1.00	0.62	1.00	0.95	
1997	0.81				1.00		0.40	0.73	0.95	
1998	0.70			1.00	1.00		0.35	0.84	1.00	
1999	1.00			1.00	1.00		0.46	1.00	0.98	
2000	1.00			1.00	1.00		0.42	1.00	0.89	1.00
2001	0.73	0.14		0.31	1.00		0.78	1.00	0.96	1.00
2002	1.00	1.00		0.97	1.00		0.80	0.97	0.94	0.98
2003	1.00	0.65		0.91	1.00		0.72	1.00	0.84	0.99
2004	1.00	0.55		0.98	1.00		0.80	0.99	0.91	1.00
2005		0.67		1.00	1.00		0.42	0.91	0.98	1.00
2006	1.00	0.52		0.98	1.00		0.48	1.00	0.98	1.00
2007		0.74	0.75	1.00	0.97		0.47	1.00	1.00	1.01
2008		0.45	0.60	0.97	1.02		0.35	1.12	0.98	1.02
2009		0.79	1.16	0.96	0.99		0.36	0.97	1.00	0.97
2010		0.78	1.00	1.00	1.00		0.71	0.89	0.94	1.00
2011		0.58	1.00	1.00	0.87		0.80	0.73	1.00	0.83
2012		0.80	0.88	0.98	0.94		0.74	0.89	0.95	1.00
2013		0.80	0.89	1.00	1.00		0.31	0.86	0.97	0.96
2014		1.00	1.00	0.99	0.95		0.48	0.86	0.93	0.99
2015		0.97	1.00	0.99	0.92		0.72	0.94	1.00	0.97
2016		1.00	0.94	0.98	0.98		0.79	0.90	0.97	1.00

Year	NZ	PG	PH	SB	SV	TV	TW	US	VU
1995	0.84	1.00	0.30	1.00			0.90	0.96	1.00
1996	0.91	1.00	0.36	1.00			0.98	1.00	1.00
1997	0.92	0.72	0.83	1.00			1.00	1.00	0.90
1998	0.87	0.94	0.78	0.99			0.99	0.99	1.00
1999	0.98	1.00	1.00	1.00			0.98	1.00	0.98
2000	0.96	1.00	1.00	0.83			0.92	0.98	1.00
2001	0.91	1.00	1.00	0.75	1.00		0.98	0.98	0.99
2002	0.70	1.00	1.00	0.95	0.84		0.98	0.95	0.99
2003	0.97	1.00	0.64	0.76	1.00		1.00	1.00	0.99
2004	0.71	0.92	1.00	0.87			0.98	1.00	0.95
2005	0.98	1.00	0.64	0.48			0.98	0.96	0.85
2006	1.00	1.00	0.90	0.79			0.94	0.95	0.97
2007	0.89	1.00	0.84	0.94	0.91		0.92	0.92	0.84
2008	1.00	0.99	0.93	1.00	0.87		0.93	0.94	0.93
2009	0.96	0.99	0.70	1.00	0.85	0.84	0.88	0.93	1.09
2010	1.00	0.90	0.99	1.00	1.00	0.90	0.79	0.98	0.92
2011	0.91	1.00	0.73	0.97	1.00	0.95	0.83	0.96	0.74
2012	1.00	0.93	0.85	0.85	1.00	0.92	0.70	0.95	1.00
2013	0.96	1.00	0.99	0.94	1.00	0.95	0.91	0.97	1.00
2014	0.96	0.72	0.90	0.77	0.40	0.98	0.90	0.94	1.00
2015	1.00	0.88	0.86	0.85	1.00	1.00	0.97	0.83	0.95
2016	1.21	0.64	0.74	0.72	1.00	1.00	0.91	0.96	1.00

Table 9. Ratio of observed key shark to target species in the longine fishery by year.

Year	FAL_ratio	OCS_ratio	THR_ratio	SPN_ratio	BSH_N_ratio	MAK_N_ratio	BSH_S_ratio	MAK_S_ratio	POR_ratio
2010	0.0352	0.0064	0.0107	6.00E-04	0.7389	0.0407	0.0608	0.007	0.0883
2011	0.058	0.0057	0.0157	9.00E-04	0.4026	0.0232	0.0593	0.0114	0.093
2012	0.1105	0.0077	0.0124	0.0025	0.3121	0.0209	0.0655	0.0089	0.043
2013	0.0654	0.0045	0.01	0.0016	0.2895	0.0218	0.0682	0.0071	0.0131
2014	0.0488	0.0033	0.0146	9.00E-04	0.3154	0.0204	0.0753	0.005	0.0253
2015	0.0185	0.0027	0.0023	2.00E-04	0.0113	0.0032	0.0783	0.0059	0.3264

Table 10: Ratio of reported (logbook) key shark species to target species in the longline fleet aggregated by year.

Ratio of reported (logbook) key shark species to target species in the longline fleet aggregated by year									
Year	FAL_ratio	OCS_ratio	THR_ratio	SPN_ratio	BSH_N_ratio	MAK_N_ratio	BSH_S_ratio	MAK_S_ratio	POR_ratio
2010	0.003	0	0.001	0	0.062	0.004	0.035	0.005	0.028
2011	0	0	0.001	0	0.05	0.003	0.071	0.008	0.079
2012	0	0	0.001	0	0.05	0.002	0.055	0.006	0.106
2013	0.002	0.001	0.001	0	0.049	0.003	0.031	0.02	0.034
2014	0.005	0.001	0.003	0	0.058	0.004	0.033	0.005	0.018
2015	0.001	0.002	0.003	0	0.062	0.004	0.015	0.002	0

Table 11:

Ratio of observed key shark species to target species in the purse seine fleet aggregated by year								
Year	FAL_ratio	OCS_ratio	BSH_ratio	MAK_ratio	POR_ratio	THR_ratio	SPN_ratio	RHN_ratio
2010	0.5815	0.0108	2.00E-04	0.001	NA	7.00E-04	0.004	0.0049
2011	1.393	0.0118	0.003	8.00E-04	NA	0.052	0.0017	0.0027
2012	0.2799	0.0109	1.00E-04	0.0032	NA	3.00E-04	3.00E-04	0.0038
2013	0.474	0.0032	5.00E-04	1.00E-04	NA	2.00E-04	3.00E-04	0.0028
2014	0.4148	0.0038	3.00E-04	2.00E-04	NA	9.00E-04	3.00E-04	0.0017
2015	0.4827	0.0045	6.00E-04	6.00E-04	2.00E-04	3.00E-04	5.00E-04	0.0022

Table 12:

Ratio of reported key shark species to target species in the purse seine fleet aggregated by year								
Year	FAL_ratio	OCS_ratio	BSH_ratio	MAK_ratio	POR_ratio	THR_ratio	SPN_ratio	RHN_ratio
2010	0.2263	0.0019	1.00E-04	5.00E-04	NA	0.0046	0.001	0.7052
2011	1.176	0.0014	0.0048	3.00E-04	NA	5.00E-04	0	0.436
2012	0.3483	0.0026	0.0024	NA	NA	0.0029	4.00E-04	0.7143
2013	0.3483	0.0018	2.00E-04	8.00E-04	NA	0.0079	1.00E-04	0.4389
2014	NA	NA	0.0679	0.0022	NA	0.001	5.00E-04	0.1938
2015	NA	NA	NA	NA	NA	NA	NA	NA

Table 13. Examples of a tiered data assessment system with a description of the available data and analysis methods.

Tier #	Description of data and analysis methods
1	Data rich - full analytical assessment and forecast used for advice
2	Quantitative assessment and forecast available but they are only considered indicative of trends in fishing mortality, recruitment and biomass
3	Survey-based trends assessment - surveys are reliable indicators of trends in stock metrics such as mortality, recruitment and biomass but no quantitative assessment is available Sufficient information to determine a target biomass level, which would be obtained at equilibrium when fishing according to the control rule with recruitment at the average historical level.
4	Catch data available over a short time series - a time-series of catch can be used to approximate MSY Catch-only methods - have biomass level Reasonable biomass level, catch or landings data available and approximation of FMSY/M and M possible.
5	Data-poor - compile all available information. Limited landings data available, no indication of F relative to proxies.
6	Bycatch or negligible landings - stocks with landings that are negligible in comparison to discards. Also stocks that are part of stock complexes and primarily caught as bycatch species in other targeted fisheries. Bycatch methods - compile all available information. Limited landings data available, no indication of F relative to proxies.

Table 14. Summary of the species assessment decision trees.

Species	Species Code	Scientific Name	Stock	Last assessment, assessment type	Data Quality/assessment type possible	Proximate analysis if NOT assessed.
Silky shark	FAL	*Carcharhinus falciformis*	WCPO	2013 (Integrated)	Data rich	Analytic assessment, possibly Pacific wide
Blue Shark	BSH	*Prionace glauca*	Southwest Pacific	2016 (Integrated)	Data rich	Analytic assessment
			North Pacific	2017 (Integrated)	Data rich	Analytic assessment
Thresher Sharks						
Pelagic thresher	ALP	*Alopias pelagicus*	WCPO	Not Assessed	Data poor	Update PSA, Possibly estimate catch
Common thresher	ALV	*Alopias vulpinus*	WCPO	Not Assessed	Data poor	Update PSA, Possibly estimate catch
Bigeye thresher	BTH	*Alopias supercillious*	WCPO	2017 (MIST Analysis)	Data Medium	Update of the recent (MIST) analysis in 3-4 years
Oceanic Whitetip Shark	OCS	*Carcharhinus longimanus*	WCPO	2012 (Integrated Assessment)	Data Medium	Analytic assessment, possibly integrated
Porbeagle Shark	POR	*Lamna nasus*	Pacific-wide (southern hemisphere)	2017 (MIST analysis)	Data Medium	Update of the recent (MIST) analysis in 3-4 years
Mako Sharks						
Longfin mako	LMA	*Isurus paucus*	WCPO	Not Assessed	Data poor	Update PSA, Possibly estimate catch
Shortfin mako	SMA	*Isurus oxyrinchus*	North Pacific	2015 (Indicator Analysis)	Medium data	Estimate Catch, develop indices of abundance
			Southwest Pacific	Not assessed	Medium data	Estimate Catch, develop indices of abundance
Hammerhead Sharks						
Great hammerhead	SPK	*Sphyrna mokarran*	WCPO	Not Assessed	Data poor	Update PSA, Possibly estimate catch
Scalloped hammerhead	SPL	*Sphyrna lewini*	WCPO	Not Assessed	Data poor	Update PSA, Possibly estimate catch
Smooth hammerhead	SPZ	*Sphyrna zygaena*	WCPO	Not Assessed	Data poor	Update PSA, Possibly estimate catch
Winghead shark	EUS	*Eusphyra blochii*	WCPO	Not Assessed	Data poor	Update PSA, Possibly estimate catch
Whale shark	RHN	*Rhincodon typus*	WCPO/Pacific-wide	Not Assessed	Data poor	Update PSA, characterize PS interactions. Stock structure research.
Manta and Mobulid Rays	MOB	*Mobulidae*	WPCO	Not Assessed	Data poor	Update PSA, Gather more data

11. Figures

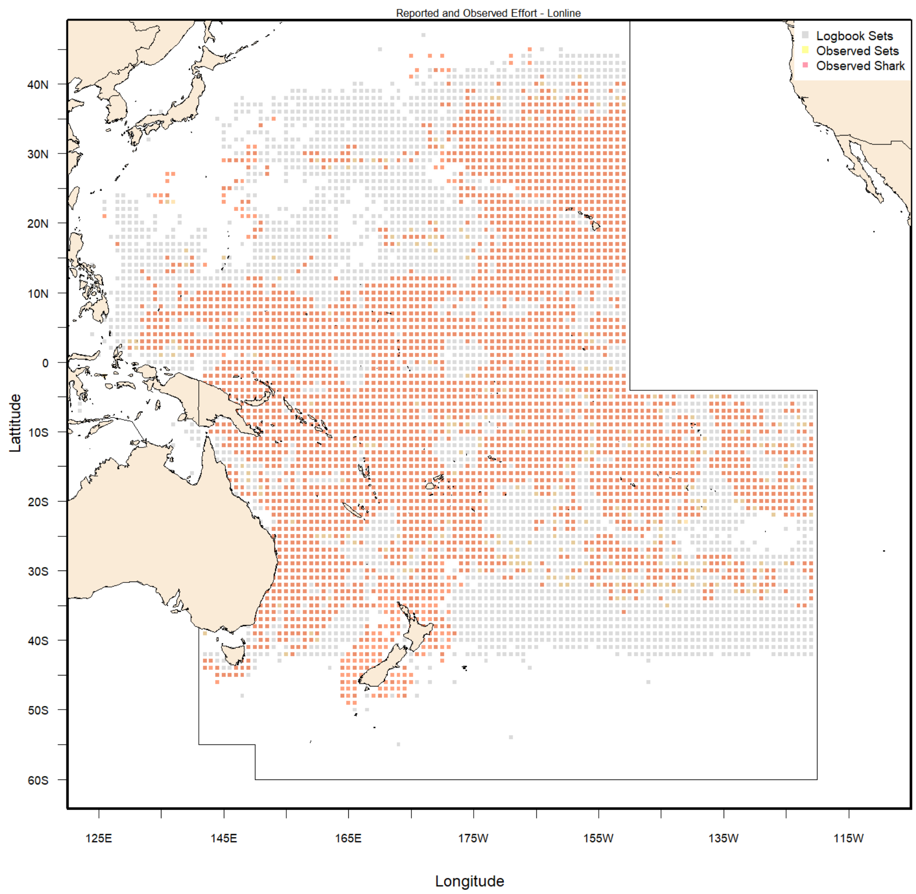

Figure 1. Reported and observed longline sets, with observed sharks for the longline fishery 1995:2015. Light grey squares indicate reported sets, yellow squares indicate observed sets, red squares indicate sets where sharks were observed.

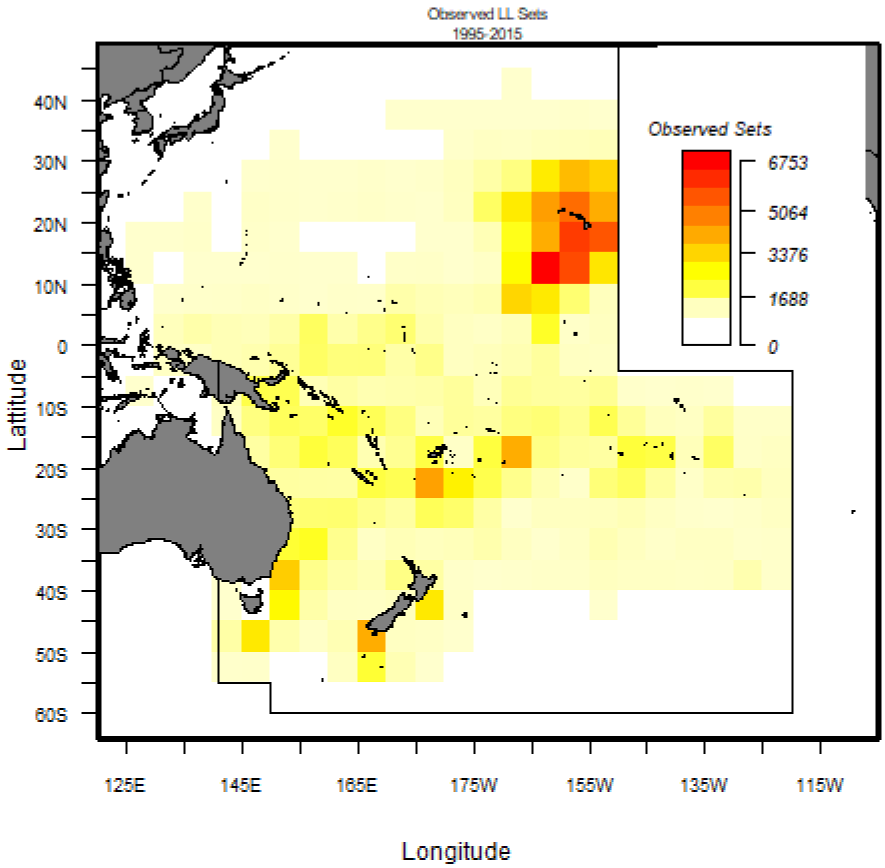

Figure 2. Total observed sets by 5 degree square for the longline fishery, 1995-2015. Darker colors indicate higher amounts of observer effort.

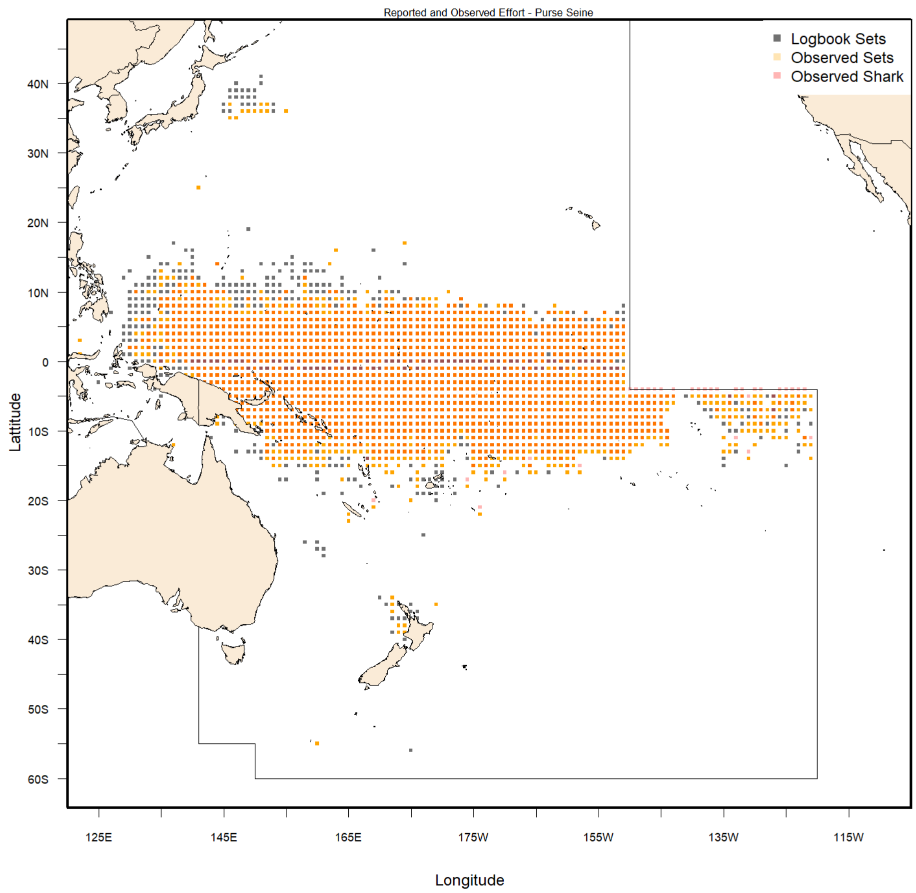

Figure 3. Logbook reported, observed sets and observed shark sets for the purse seine fishery, 1995-2015. Grey points indicate logbook sets, yellow points indicate observed sets and red points indicate sets where sharks were observed.

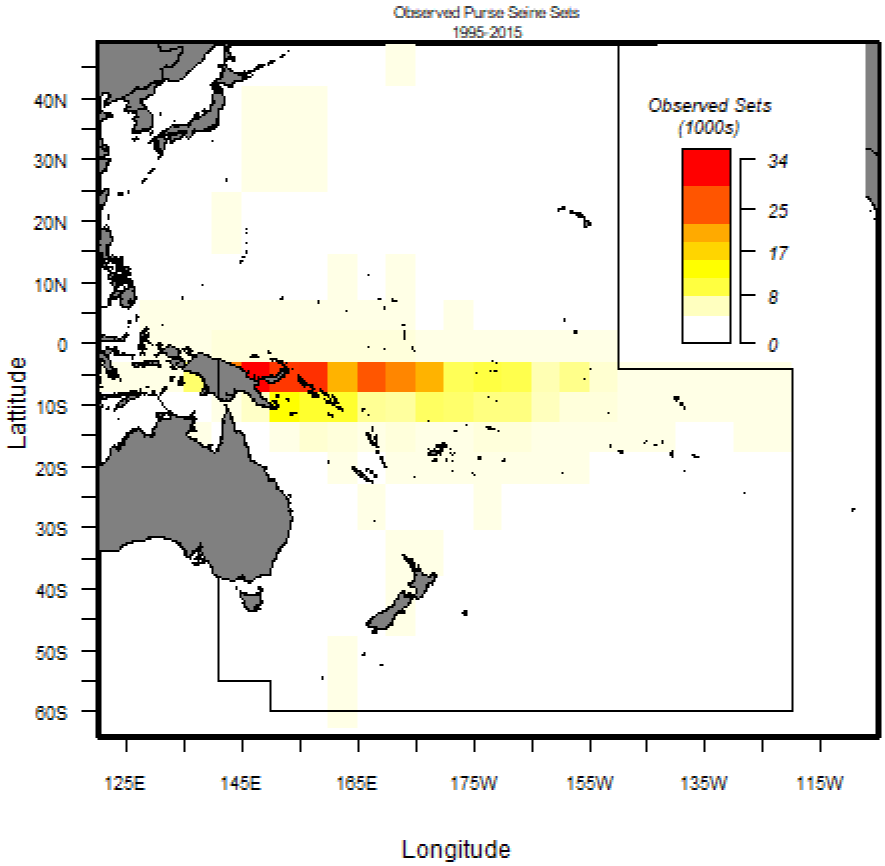

Figure 4. Observed sets ('000s) in the purse seine fishery 1995 2015.

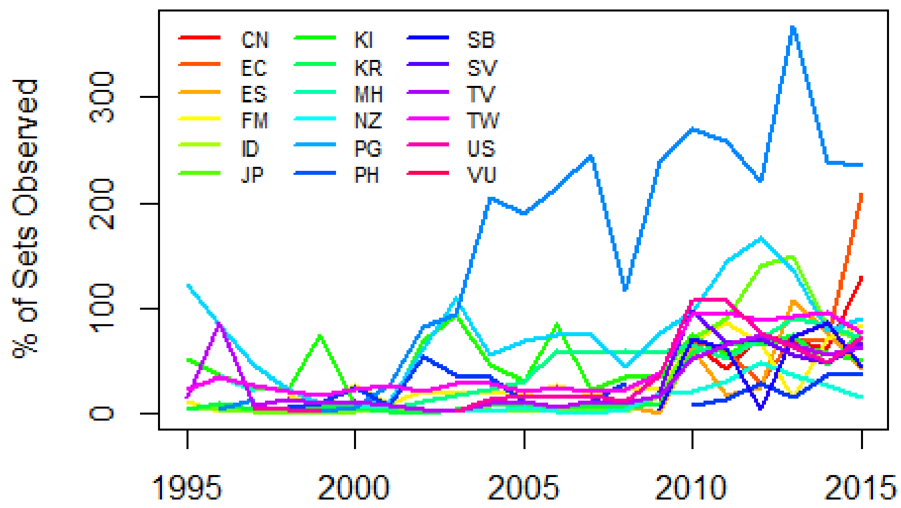

Figure 5. Percent observer coverage by flag (observer data / operational data).

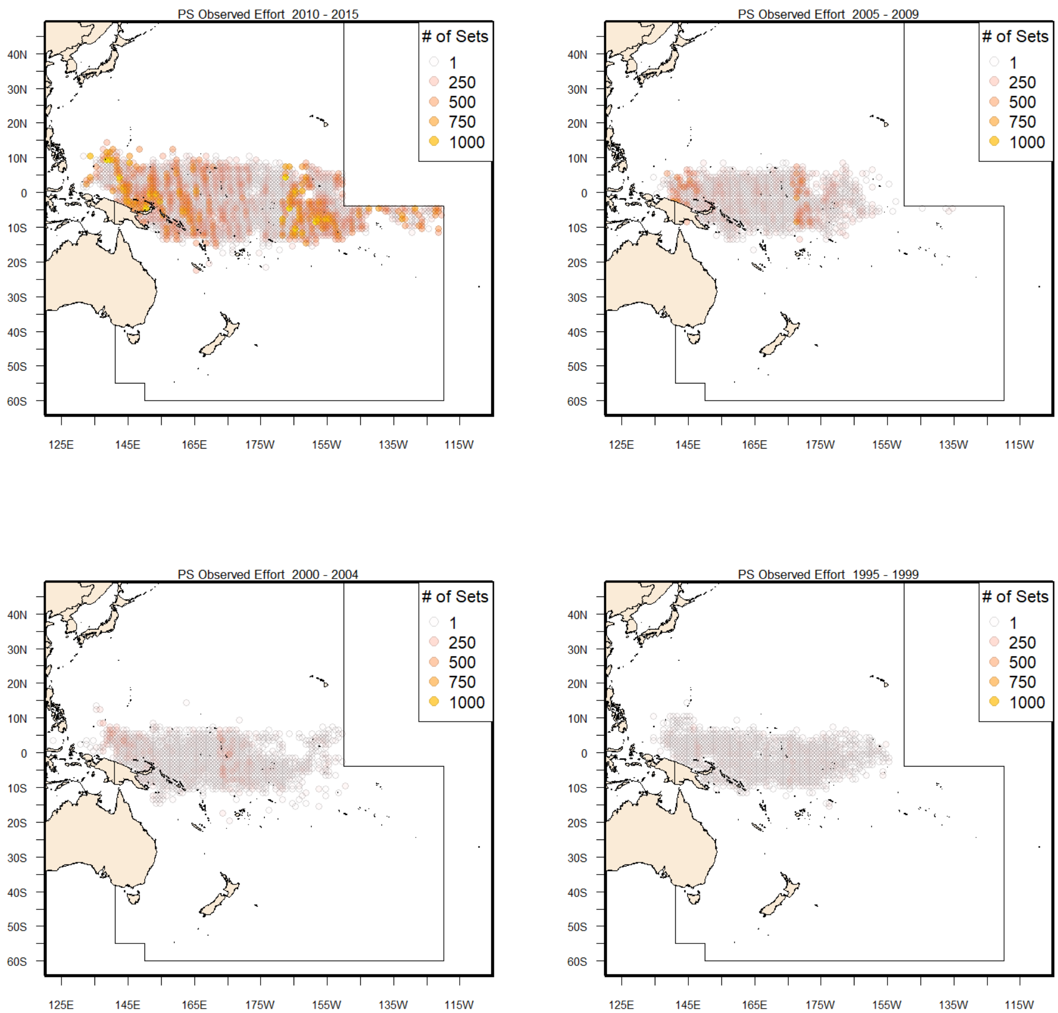

Figure 6. Spatial distribution of the observed purse seine sets by 5 year time frame.

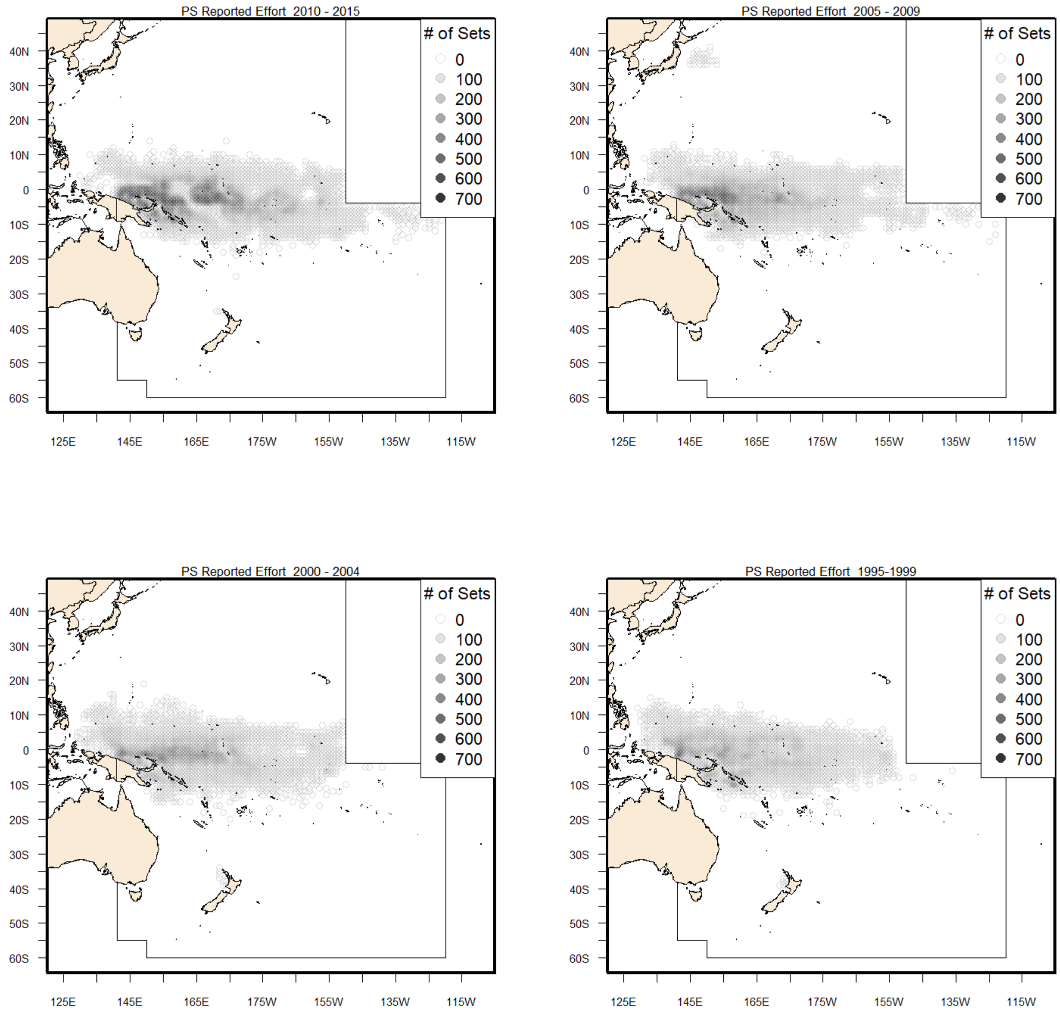

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Figure 7. Reported purse seine effort by 5 year time frame.

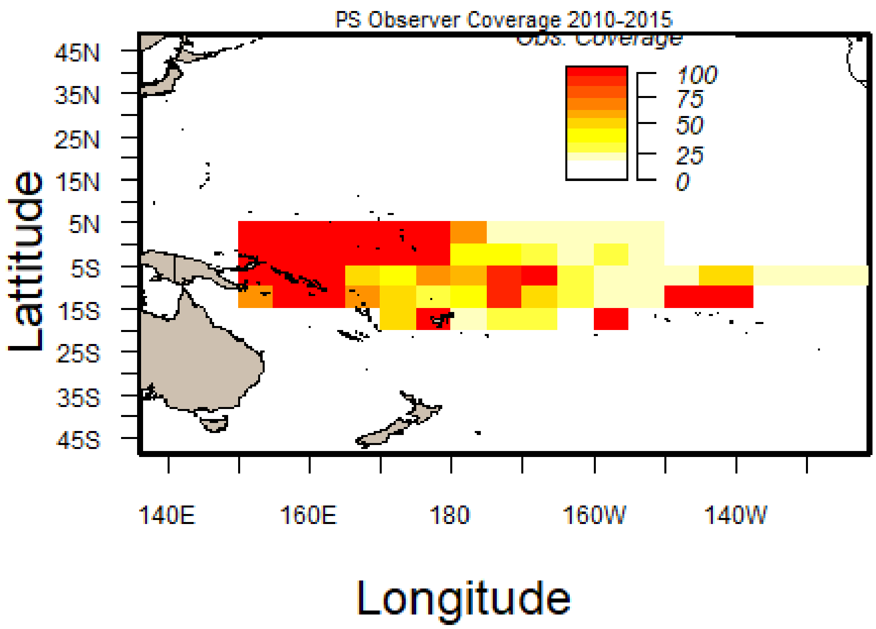

Figure 8. Spatial distribution of the observer coverage for the purse seine fishery 2010-2015.

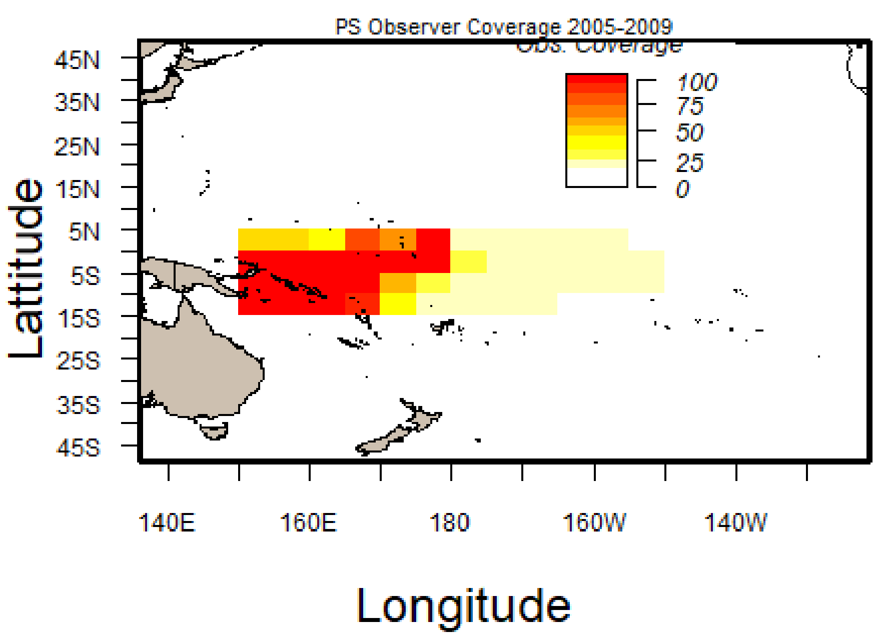

Figure 9. Spatial distribution of the observer coverage for the purse seine fishery 2005-2009

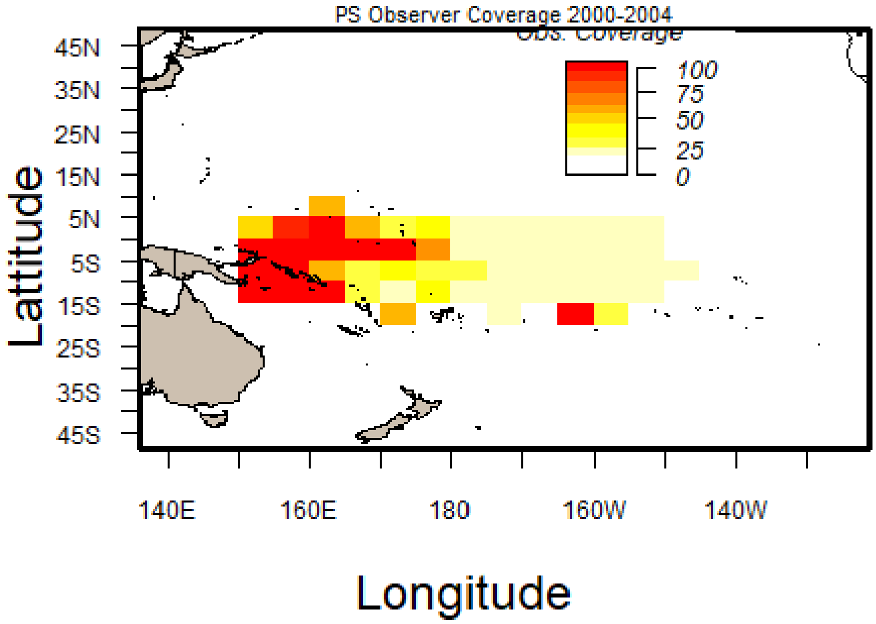

Figure 10. Spatial distribution of the observer coverage for the purse seine fishery 2000-2004.

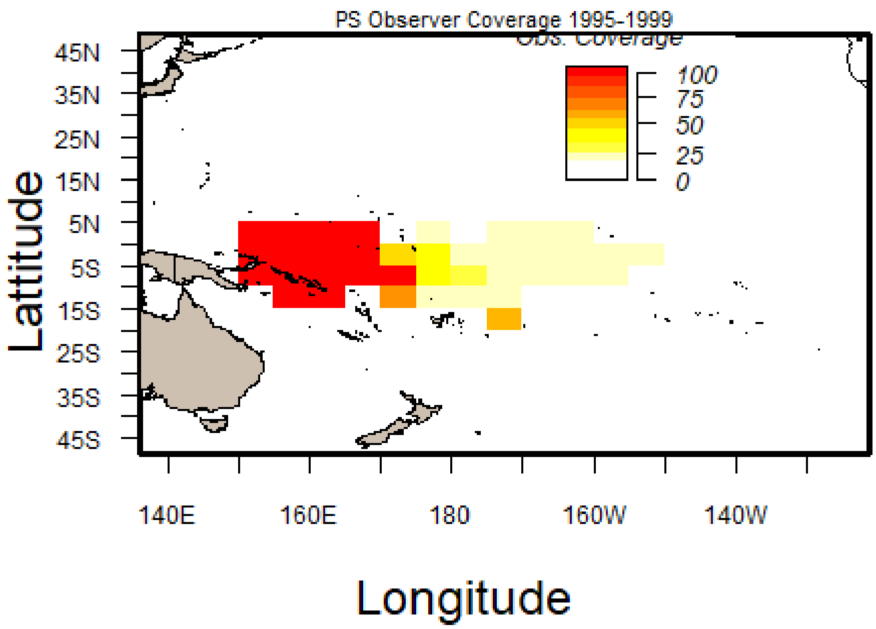

Figure 11. Spatial distribution of the observer coverage for the purse seine fishery 1995-2009.

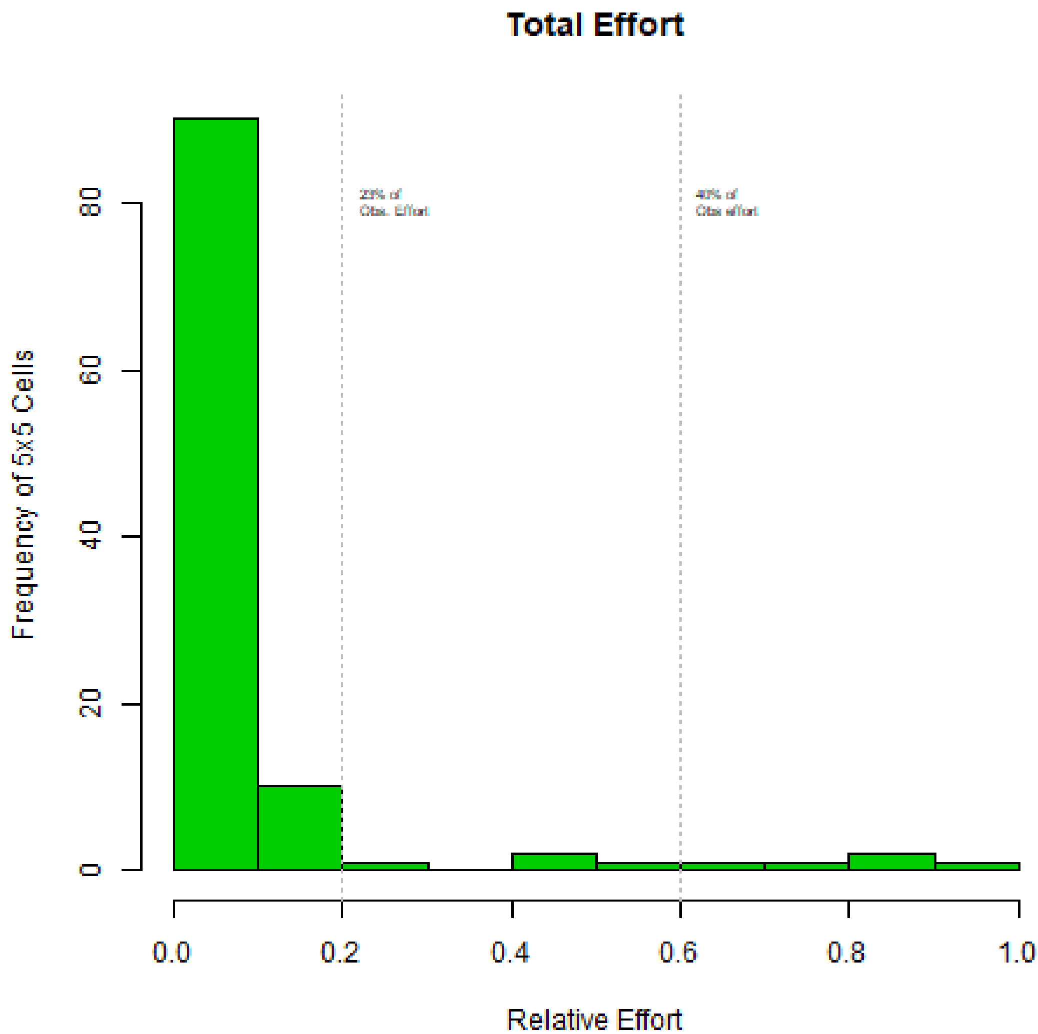

Figure 12. Distribution of the relative effort of purse seine observer data.

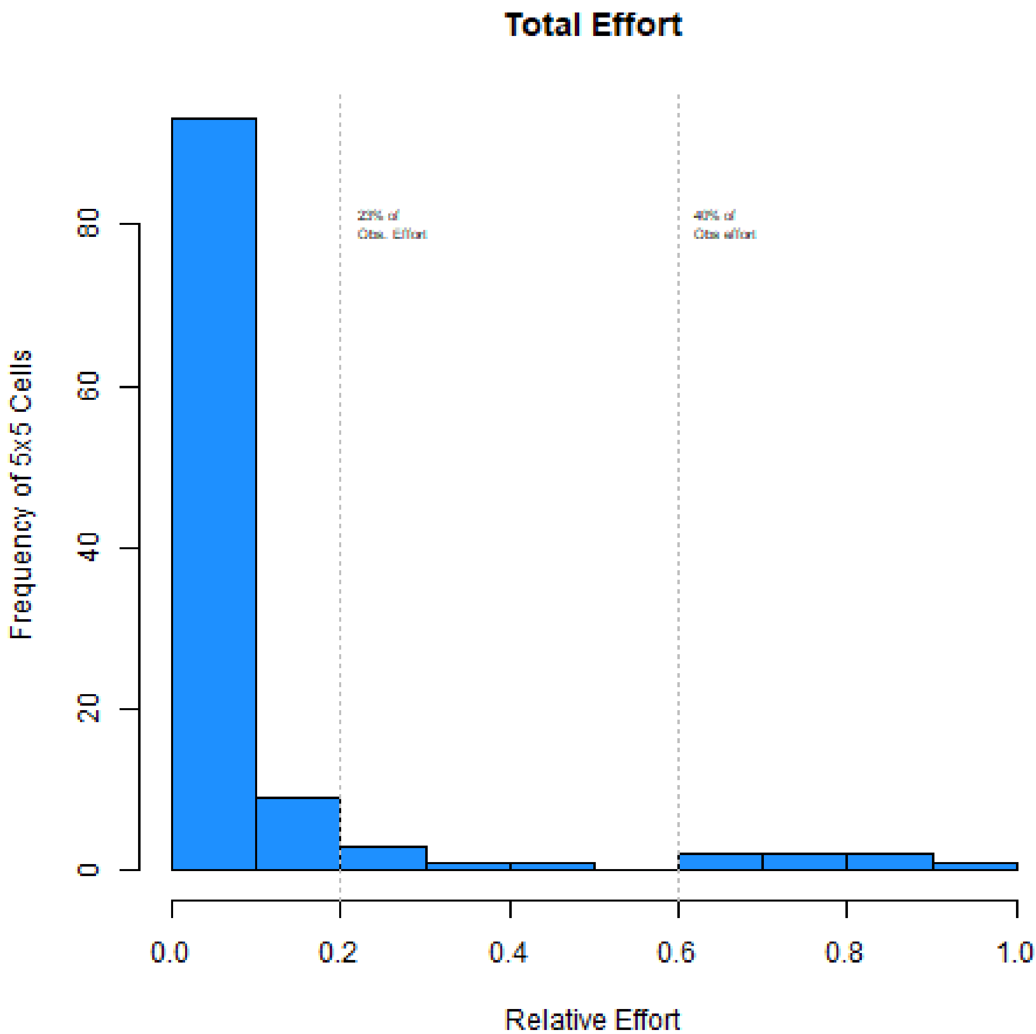

Figure 13. Relative distribution of purse seine logsheet effort.

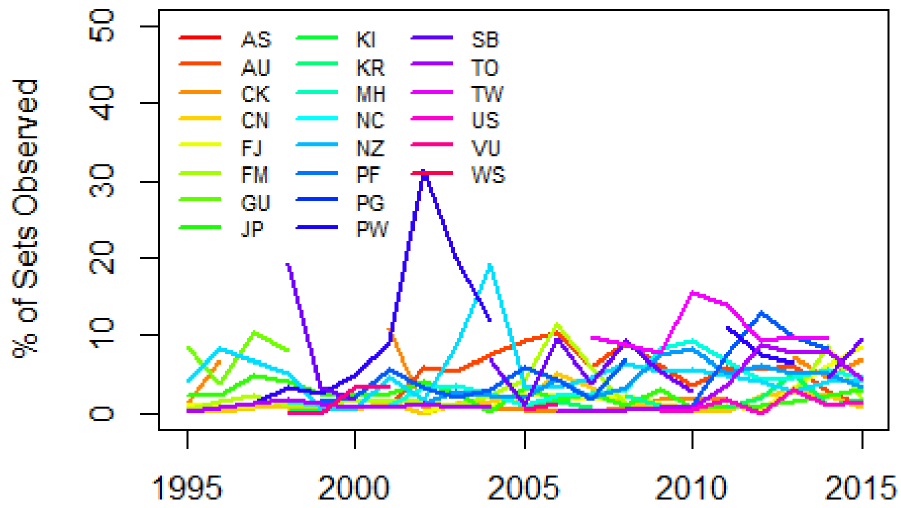

Figure 14. Percent observer coverage by year and flag, longline fishery. For the years 1995-2015.

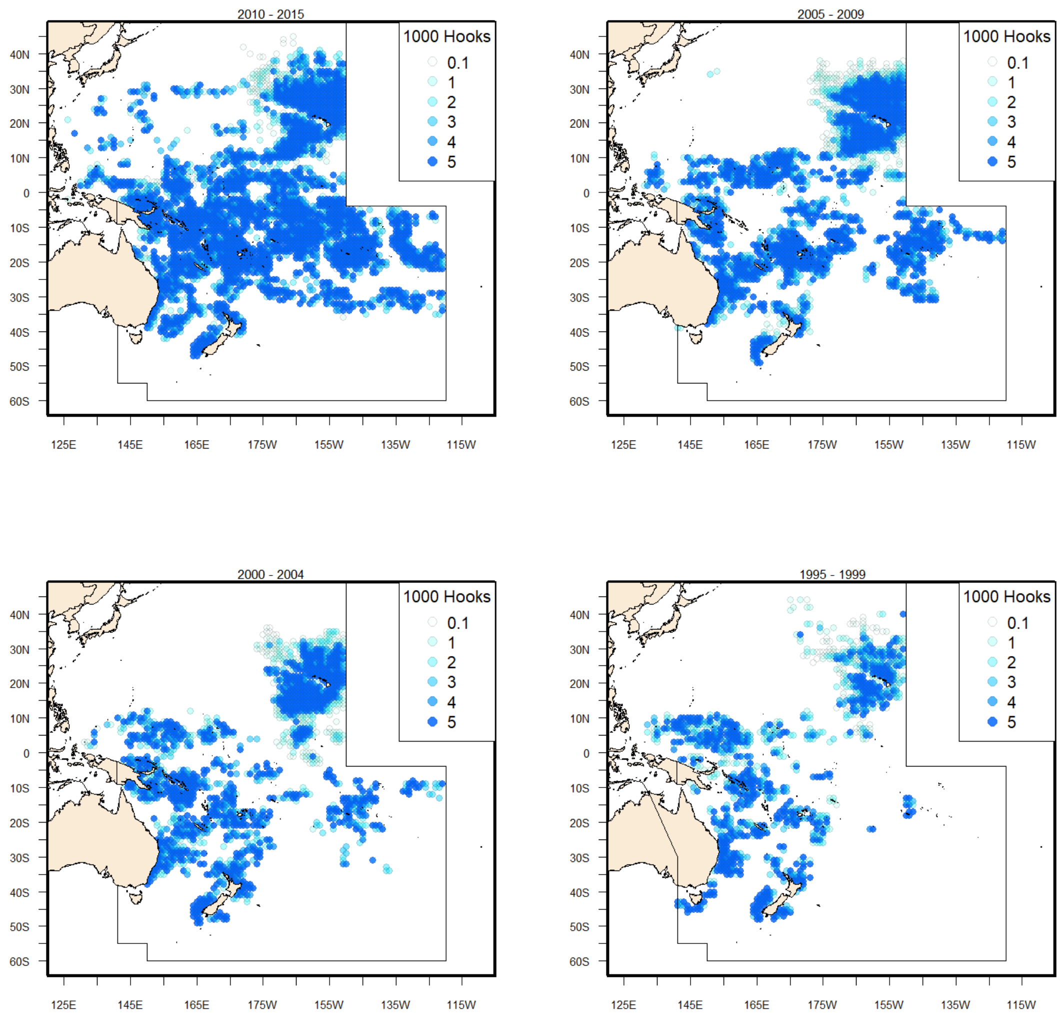

Figure 15. Observed longline ('000s of hooks) effort by 5 year time block, points indicate individual observed sets, darker areas indicate higher observed effort, based on available and processed observer data.

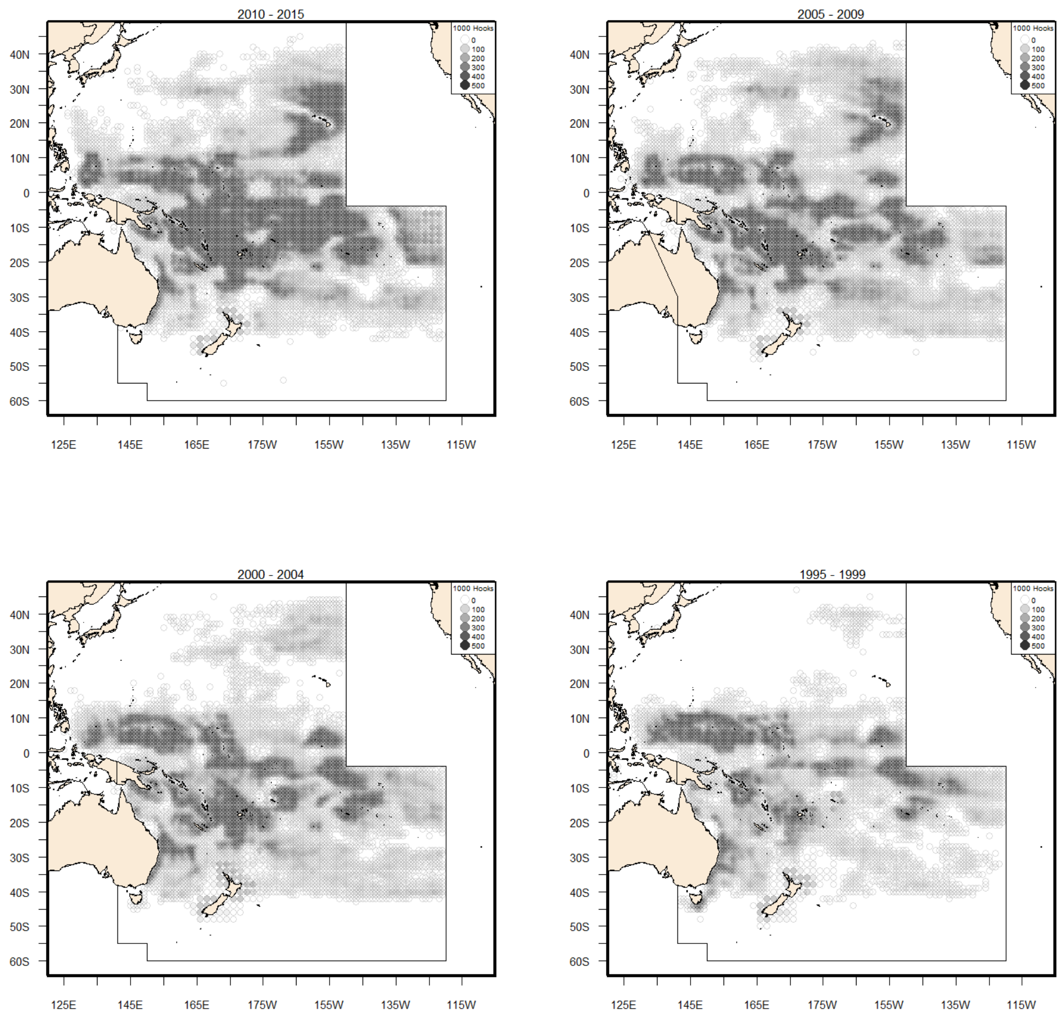

Figure 16. Reported longline (1000s' of hooks) effort by 5 year time block, points indicate individual reported sets, darker areas indicate higher reported effort.

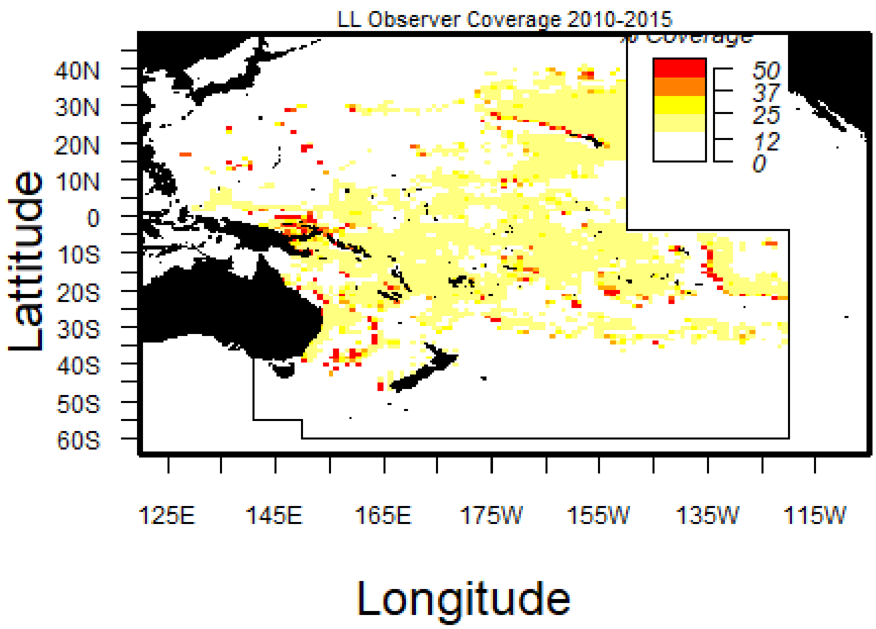

Figure 17. Longline observer coverage at the 1 degree square spatial resolution, 2010-2015.

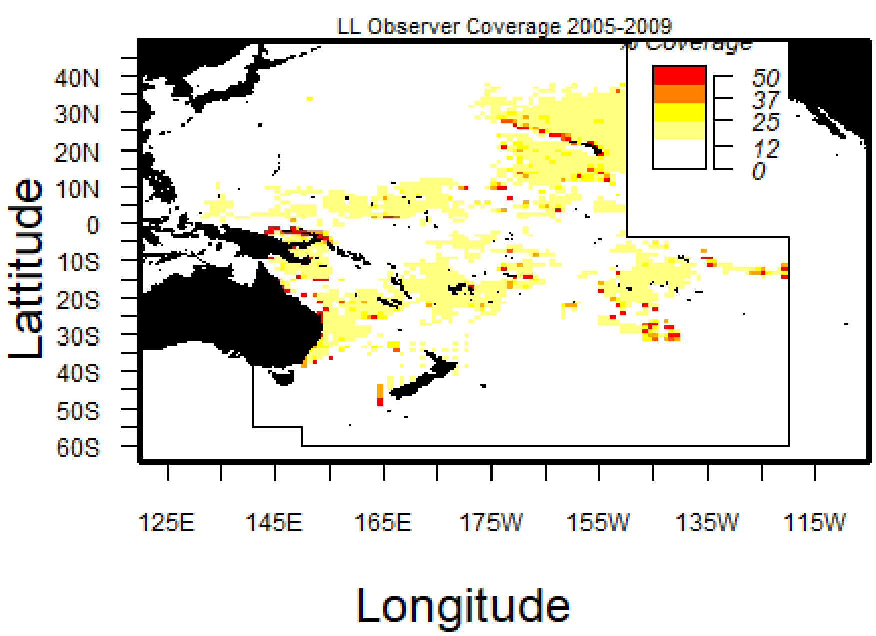

Figure 18. Longline observer coverage at the 1 degree square spatial resolution, 2005-2009.

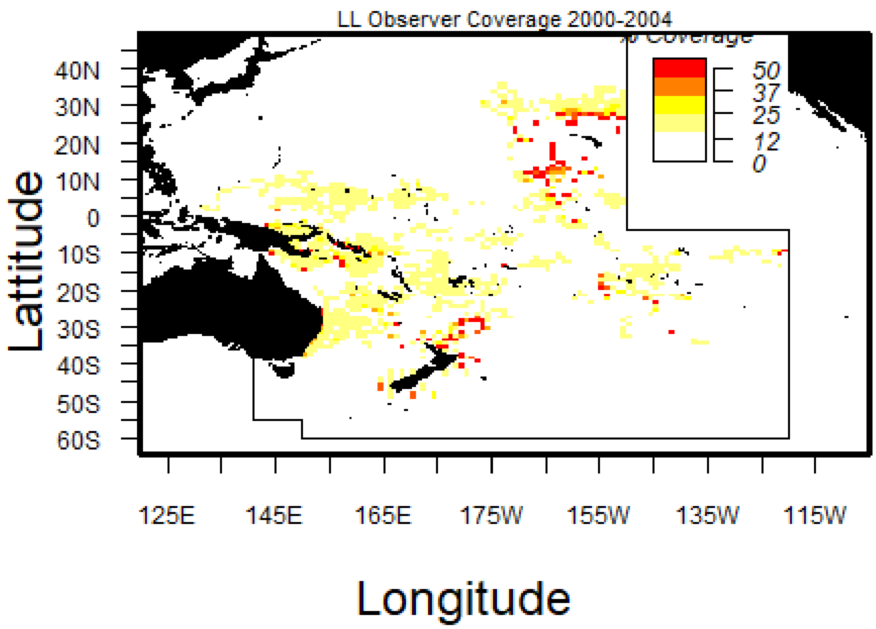

Figure 19. Longline observer coverage at the 1 degree square spatial resolution, 2000-2004.

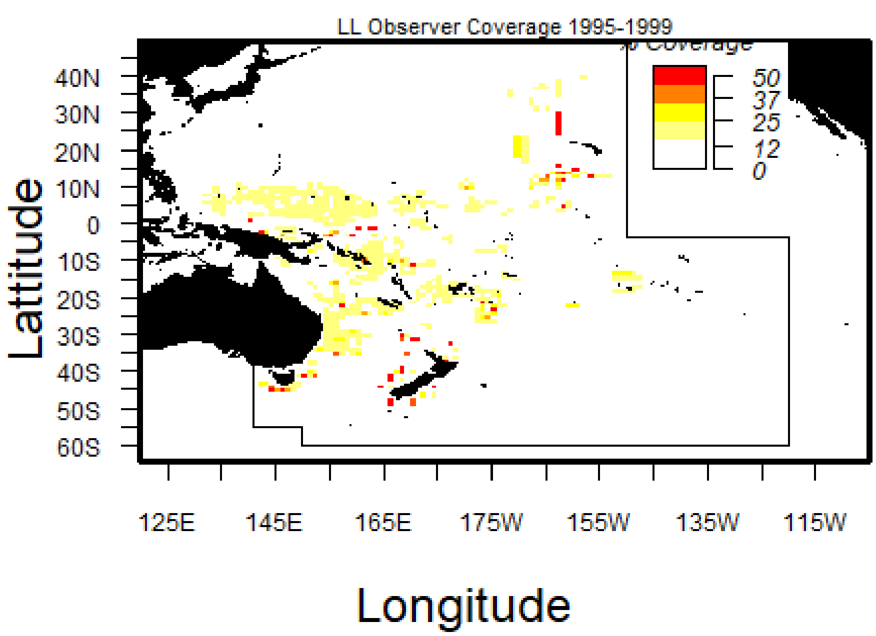

Figure 20. Longline observer coverage at the 1 degree square spatial resolution, 1995-1999.

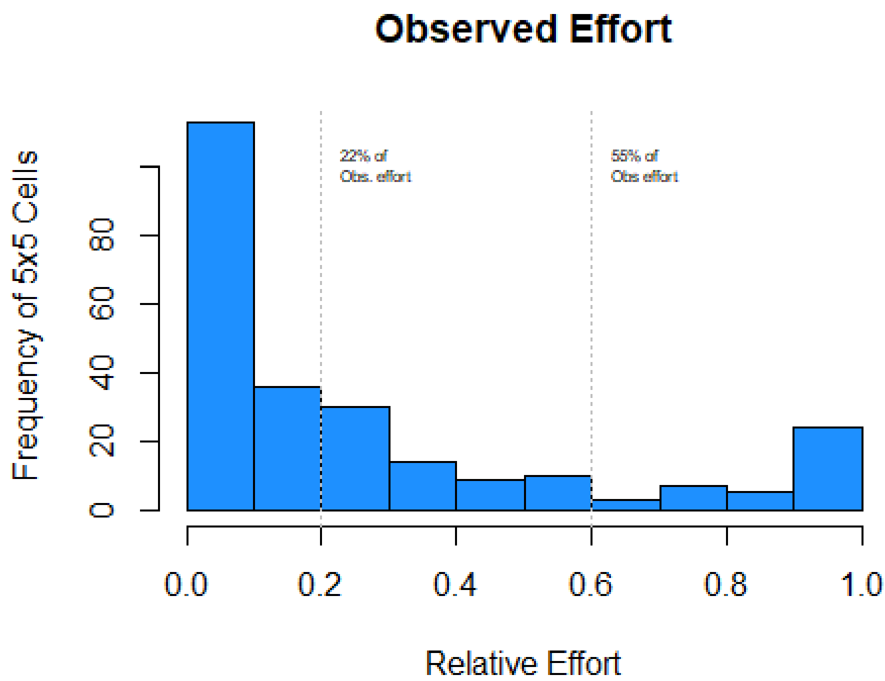

Figure 21 Relationship between the relative (to the maximum effort in a cell over the years 2010-2015) fishing effort, binned in deciles on the x axis and the frequency (number of cells) in each decile of relative effort (y-axis). Based on logbook data for the years 2010-2015.

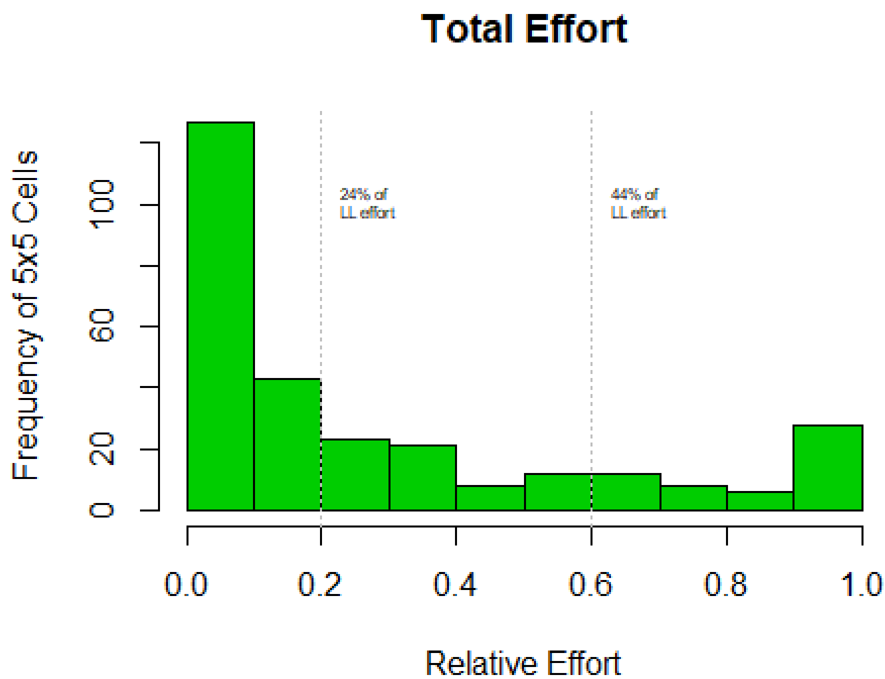

Figure 22. Relationship between the relative (to the maximum effort in a cell over the years 2010-2015) fishing effort, binned in deciles on the x axis and the frequency (number of cells) in each decile of relative effort (y-axis). Based on logbook data for the years 2010-2015.

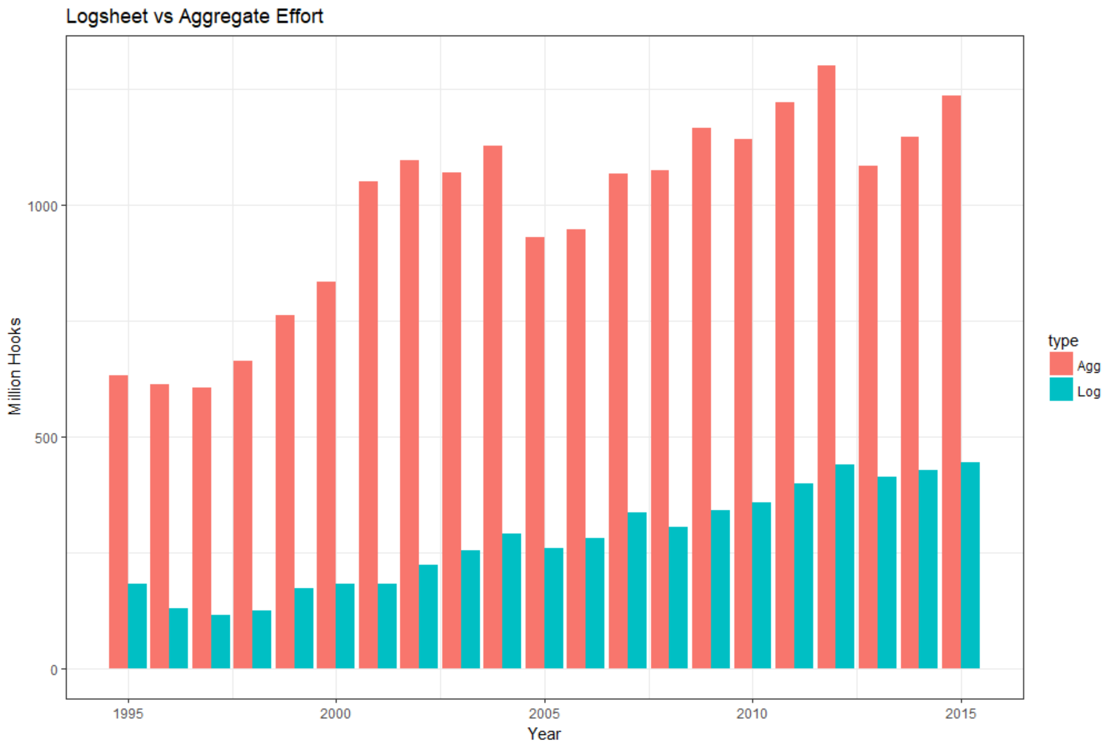

Figure 23. Comparison of logsheet vs aggregate effort for the longline fishery for all fleets operating in the WCPO, 1990-2015.

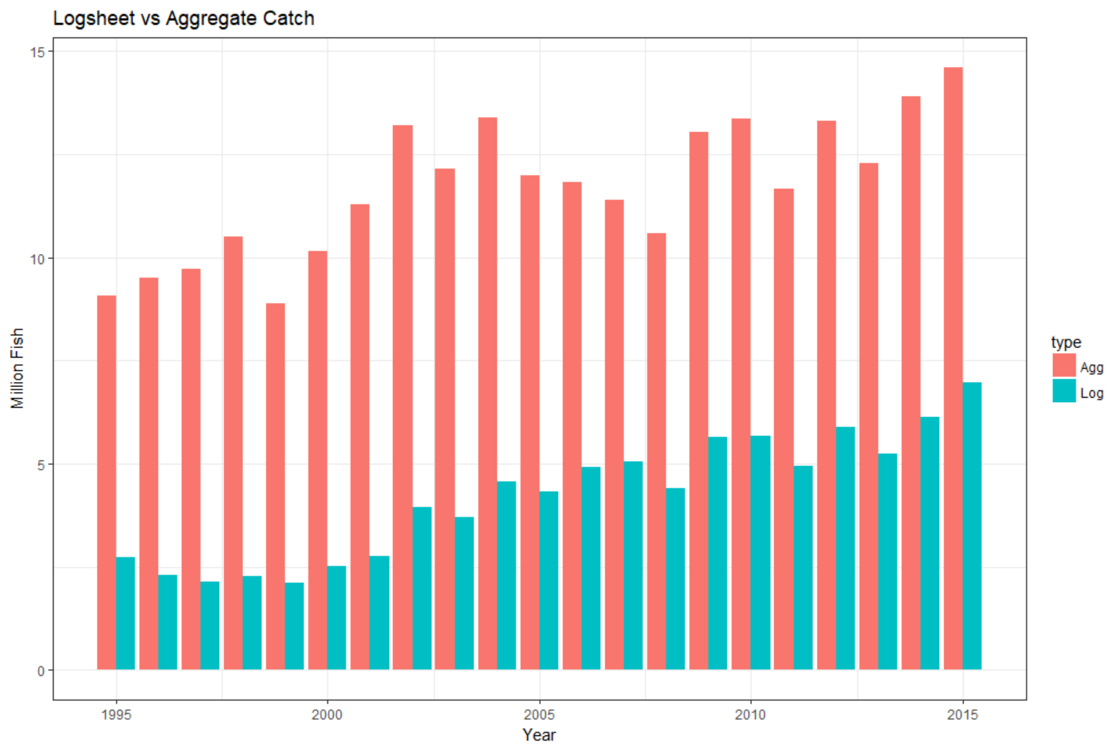

Figure 24. Comparison of logsheet vs aggregate catch of target species (YFT, BET, & ALB) for the longline fishery for all fleets operating in the WCPO, 1990-2015.

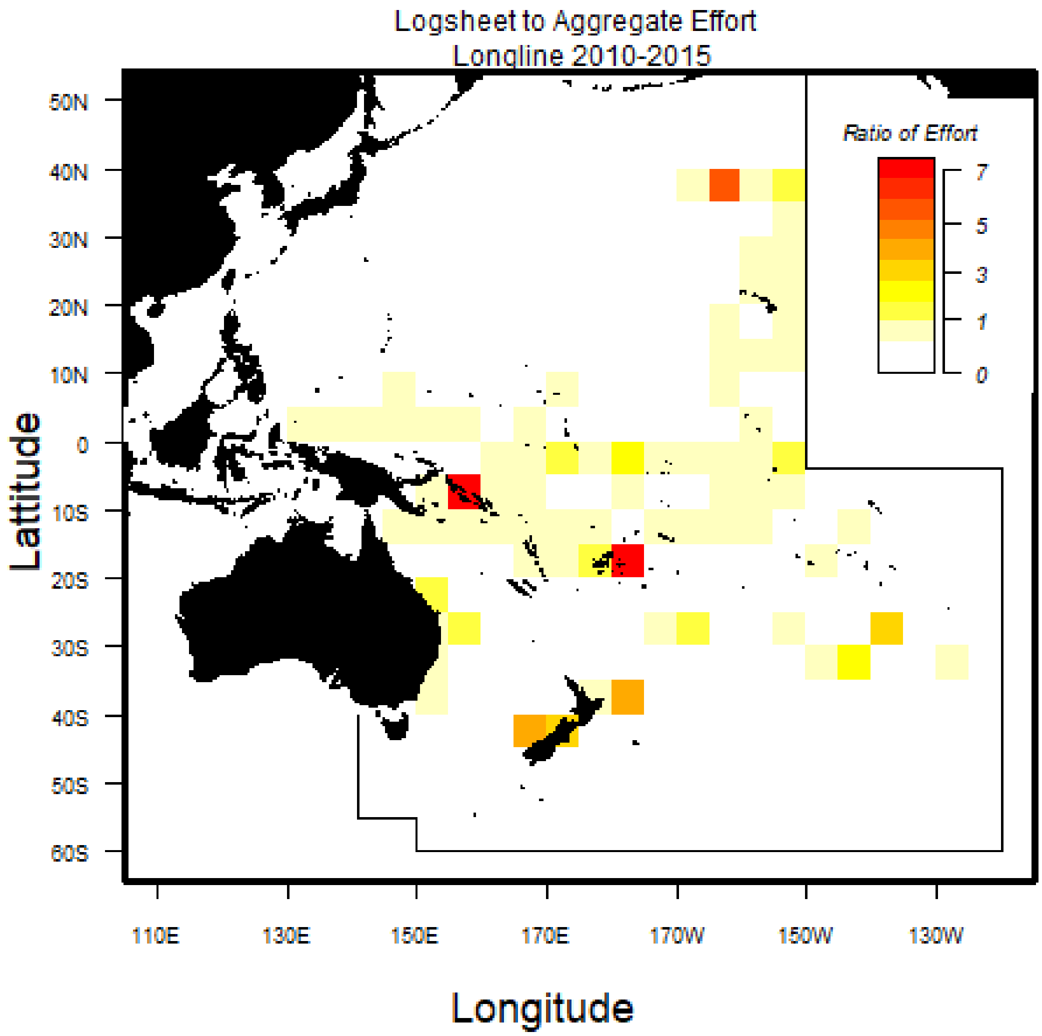

Figure 25. Comparison of logsheet vs aggregate effort for the longline fishery for all fleets operating in the WCPO 2010-2015.

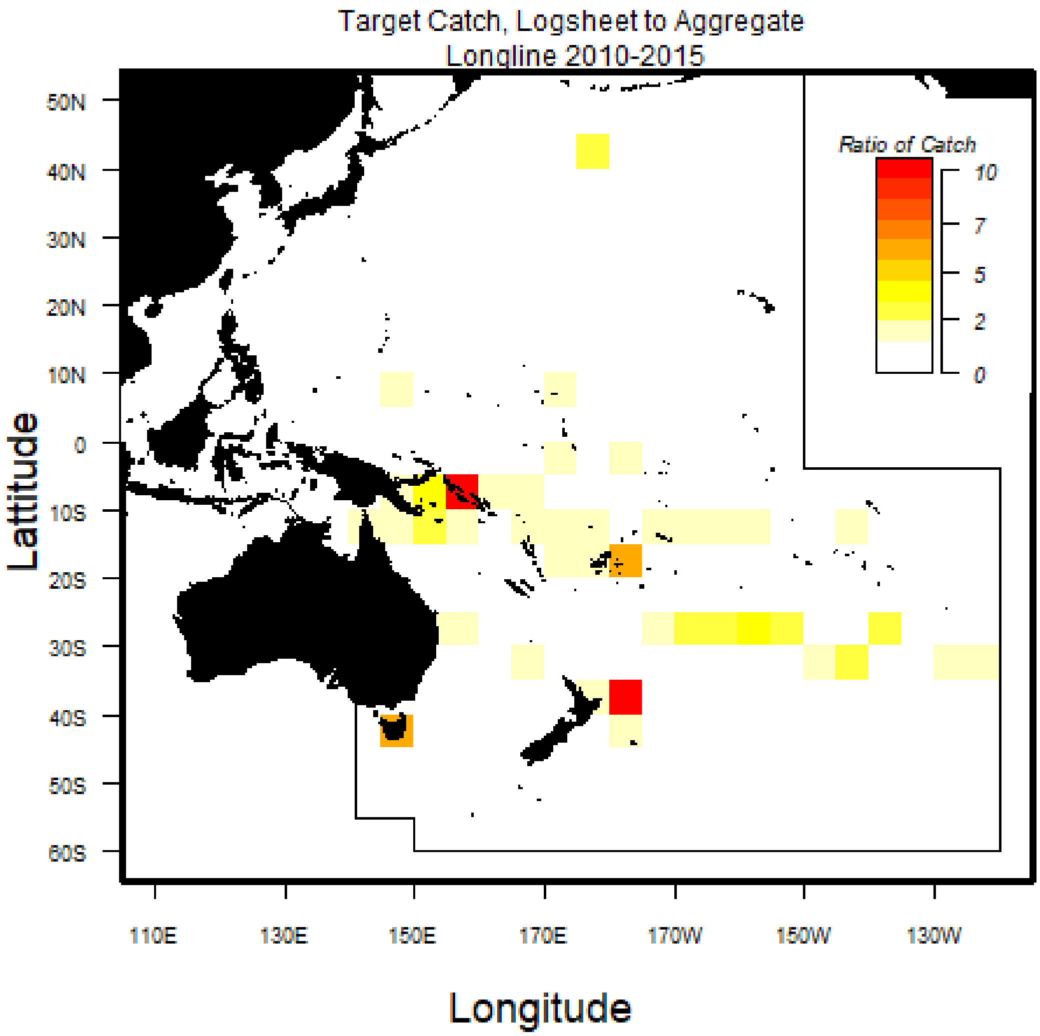

Figure 26. Comparison of logsheet vs aggregate catch of target species (YFT, BET, & ALB) by 5˚x5˚ cell for the longline fishery for all fleets operating in the WCPO 2010-2015.

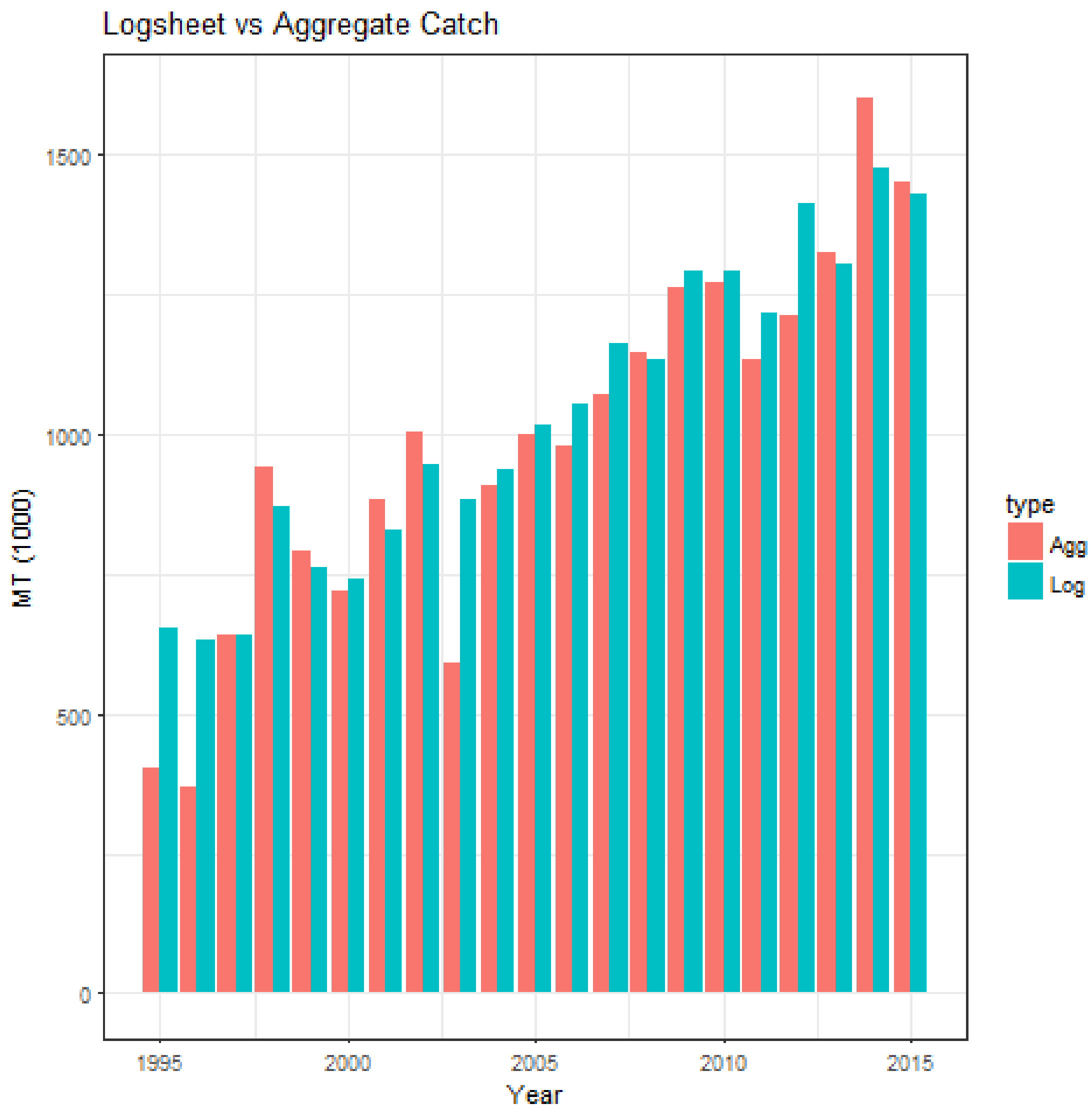

Figure 27. Comparison of reported and aggregate target catch (YFT, SKJ & BET), purse seine vessels opperating in the WCPO region.

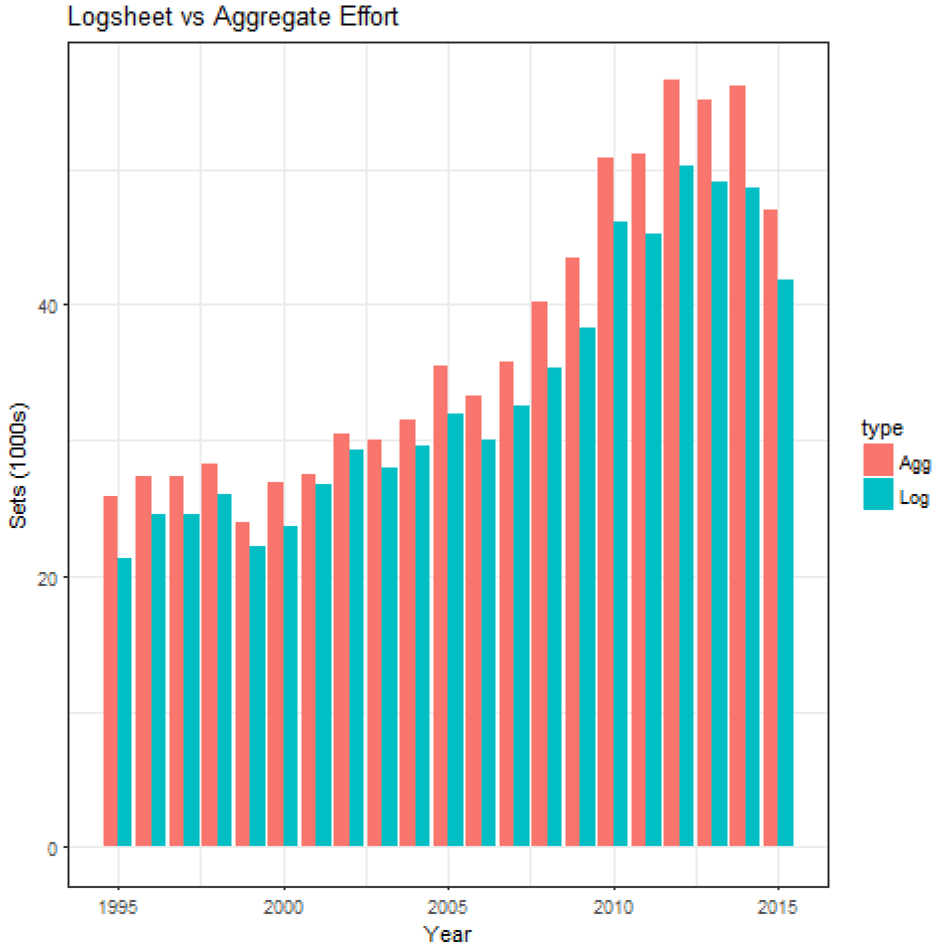

Figure 28. Comparison of reported and aggregate effort (100s of sets), purse seine vessels operating in the WCPO region.

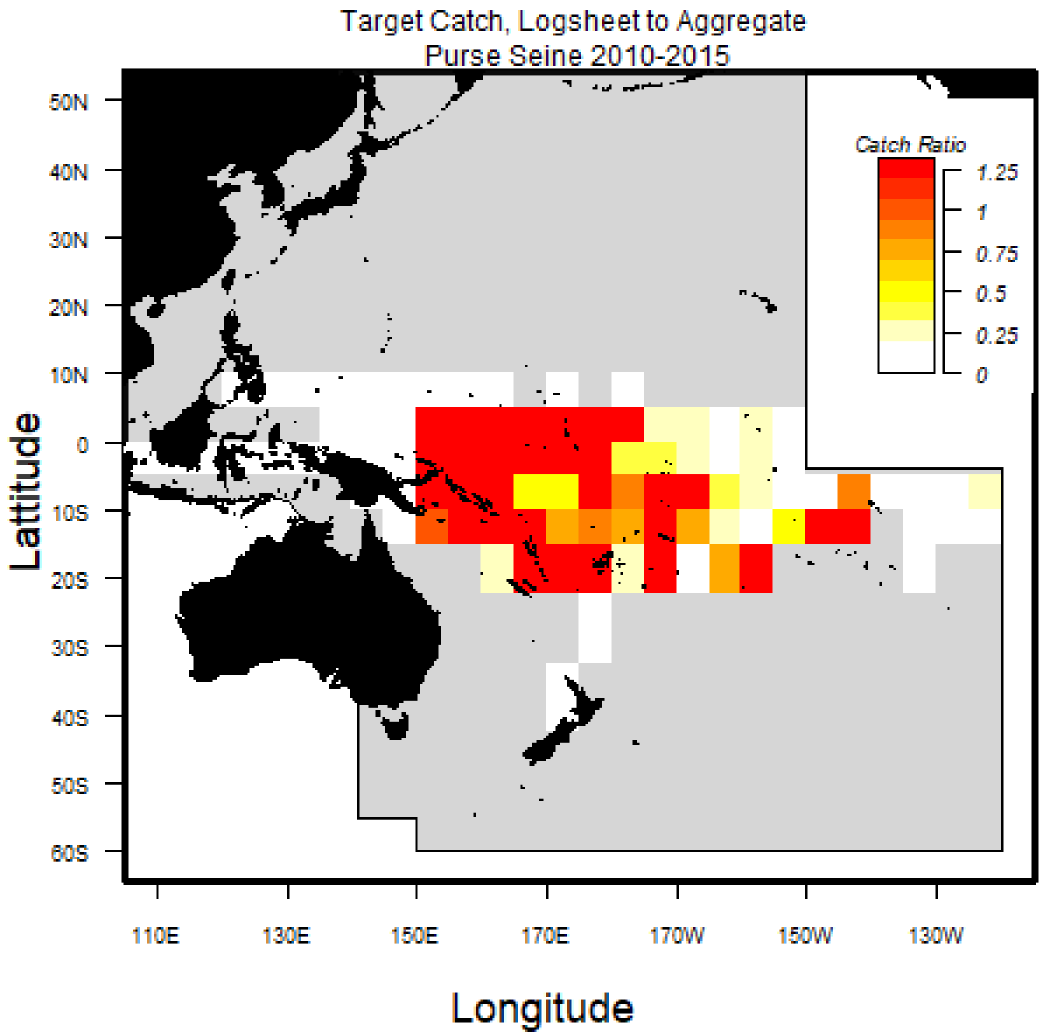

Figure 29. Comparison of reported and aggregate target catch (YFT, SKJ & BET), by 5 degree cell for vessels in the purse seine fishery, 2010-2015.

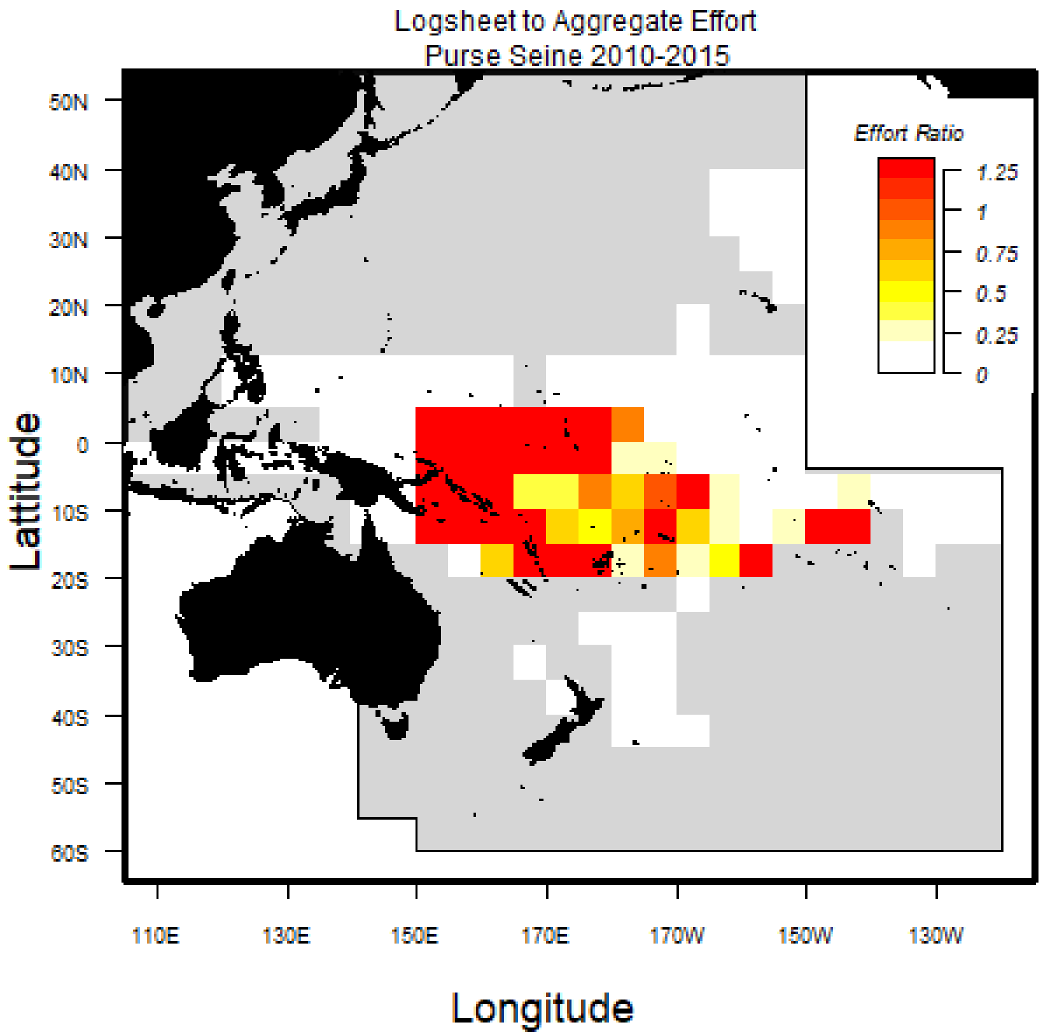

Figure 30. Comparison of reported and aggregate effort, by 5 degree cell for vessels in the purse seine fishery, 2010-2015.

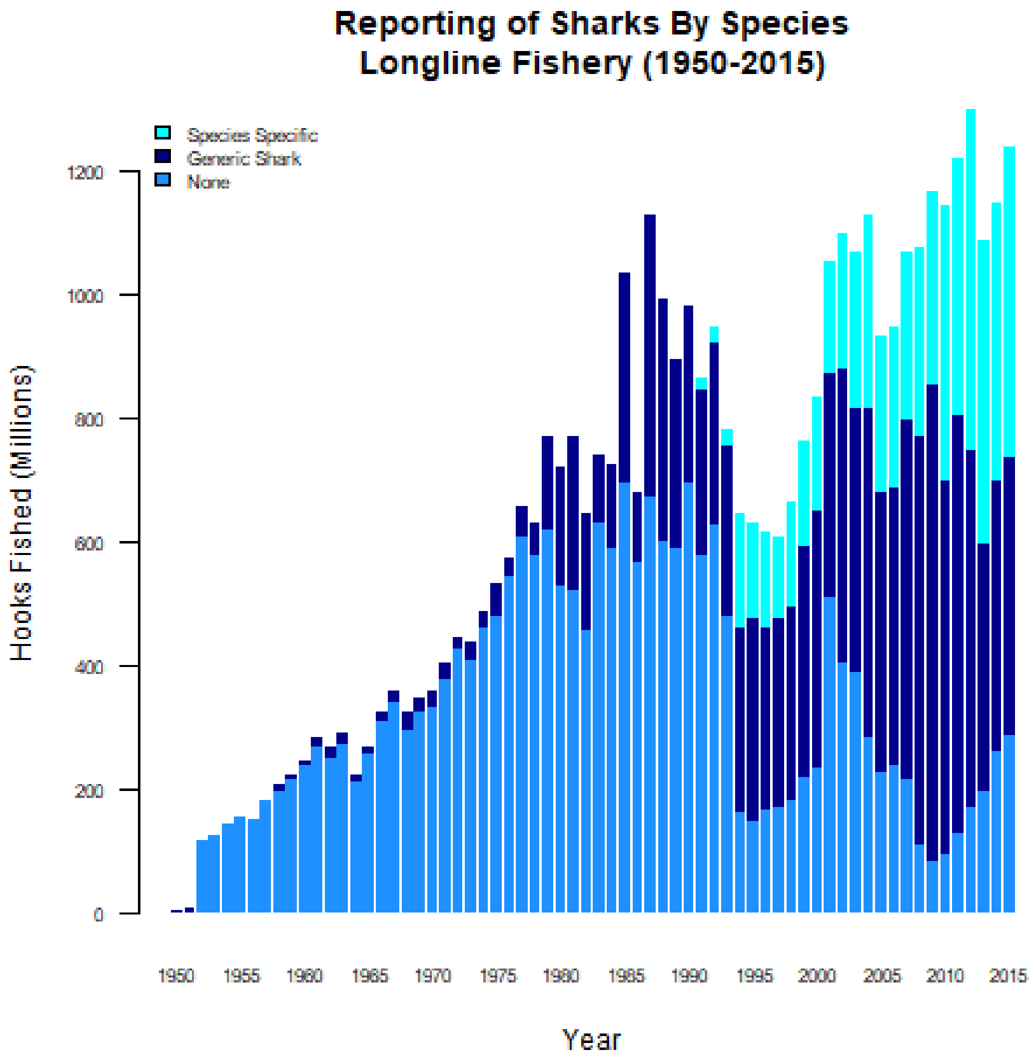

Figure 31. Reporting of sharks; by species, generically, or not at all. Longline vessels operating in the WCPO region, 1950-2015.

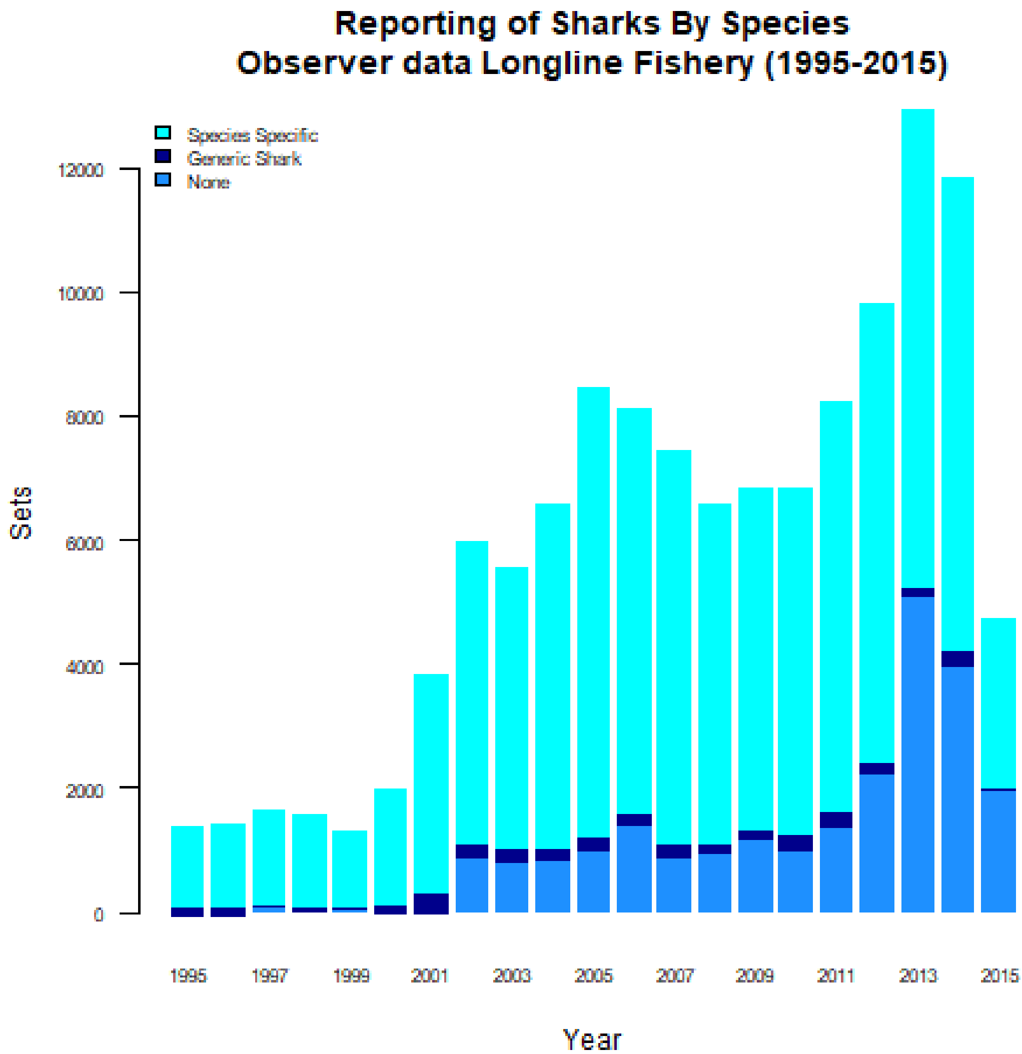

Figure 32. Recording of sharks based on observer data; by species, generically, or not at all. Longline vessels operating in the WCPO region, 1995 - 2015.

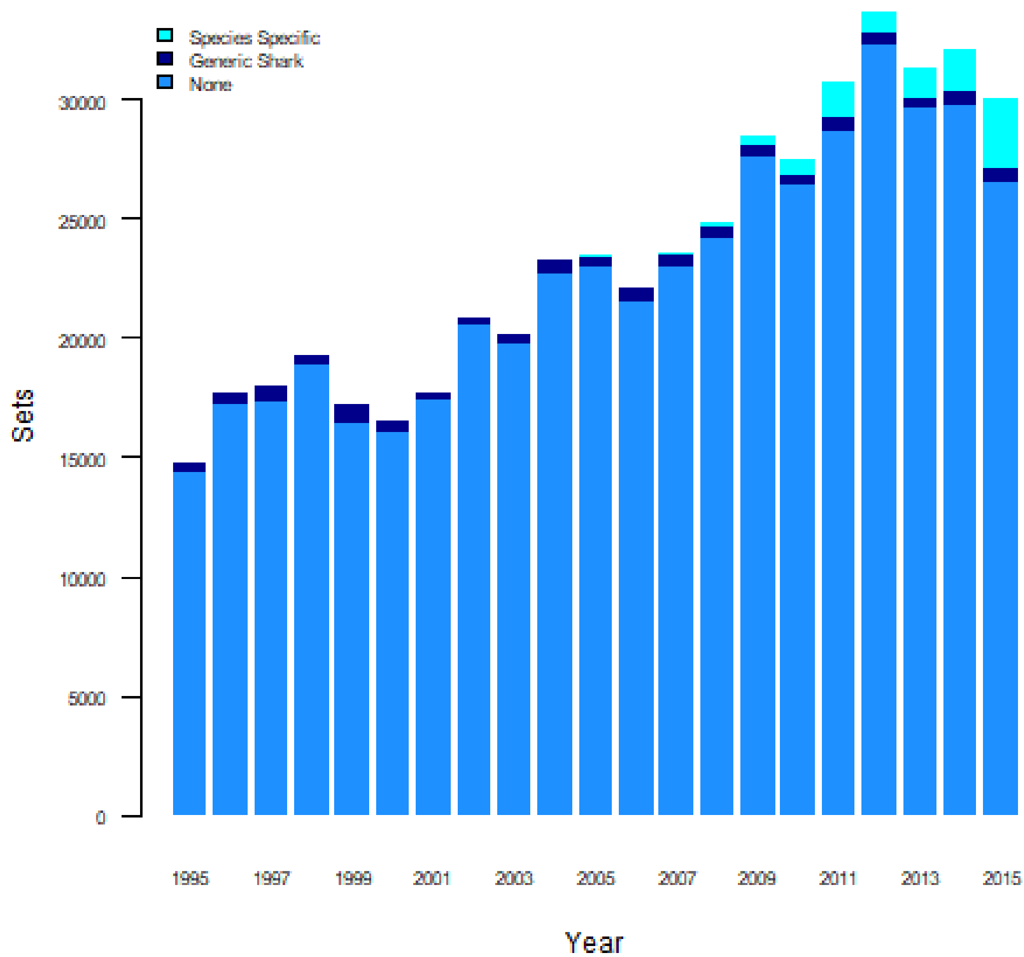

Figure 33. Reporting of sharks by species, generically or non-reporting from logbook data in the purse seine fishery, 1995-2015.

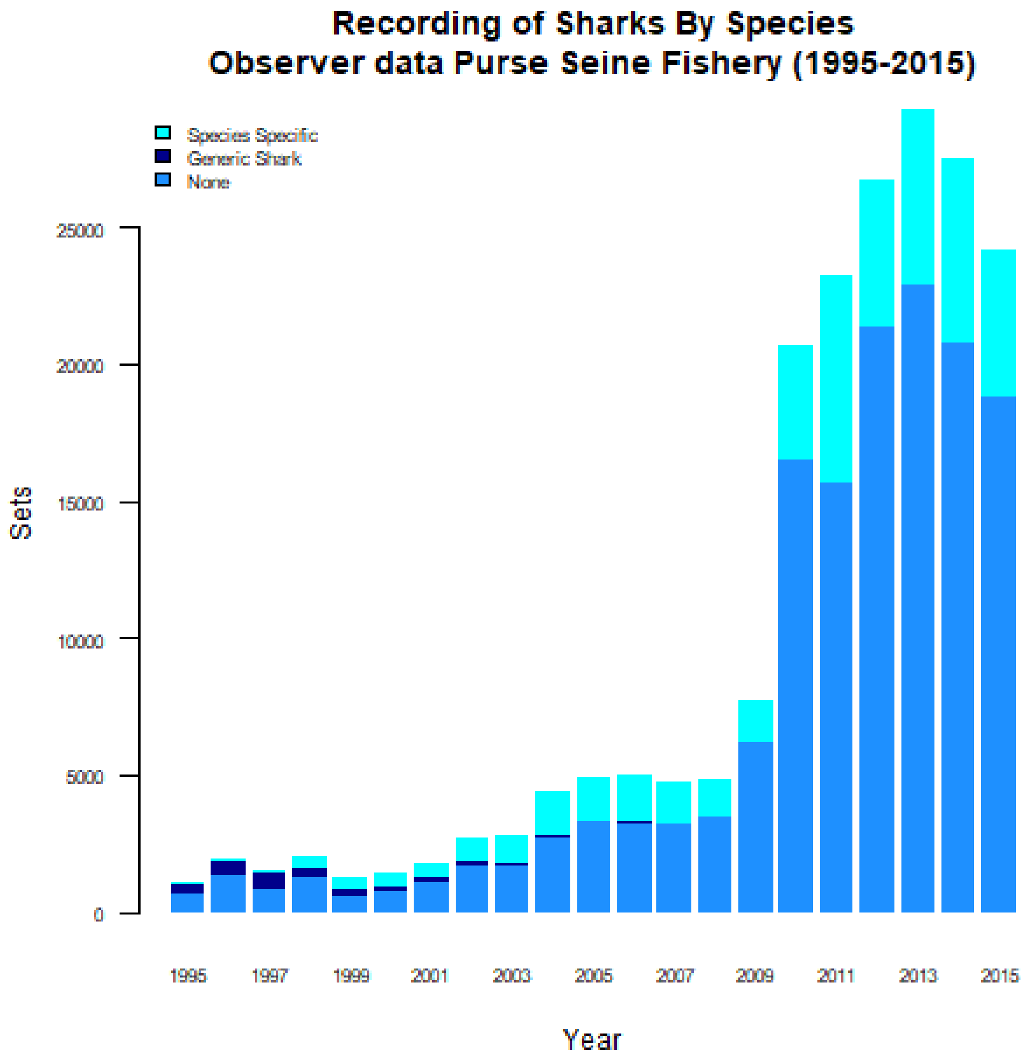

Figure 34. Recording of sharks by species, generically or non-reporting from observer data in the purse seine fishery, 1995-2015.

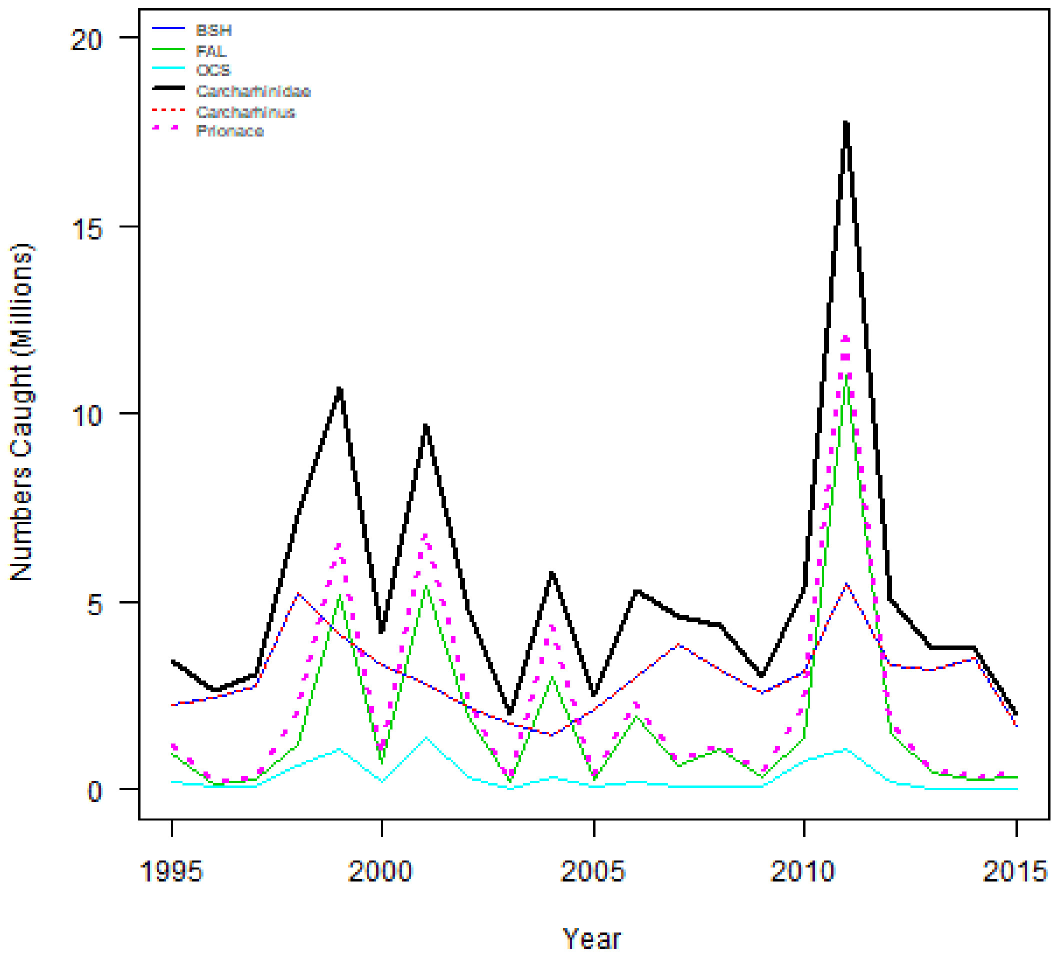

Figure 35. Reported catch by Family Genus and Species- longline fishery, Carcharinidae family, which consists of blue shark (BSH, also Prionace), oceanic whitetip shark (OCS), and silky shark (FAL). Both oceanic whitetip and silky shark are part of the Carcharhinus genus.

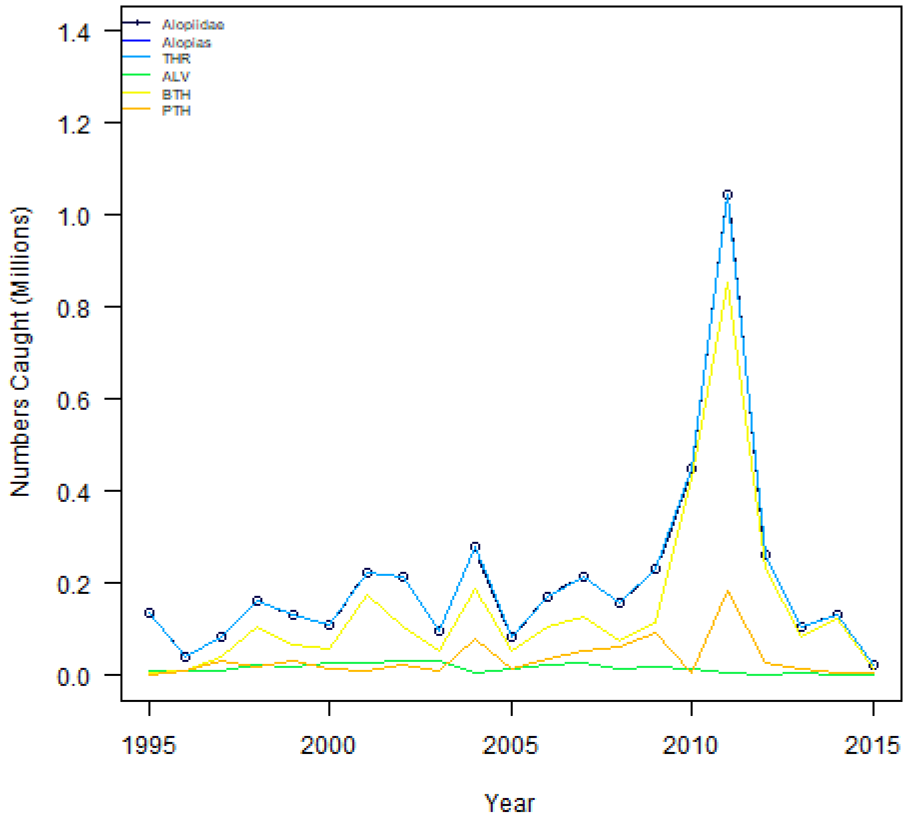

Figure 36 Estimates of catch by Family Genus and Species- longline fishery, Alopiidae family, which consists of the bigeye thresher shark (BTH), the pelagic thresher (PTH), and common thresher (ALV), all of which are often reported at the generic genus level thresher (THR) or Alopias.

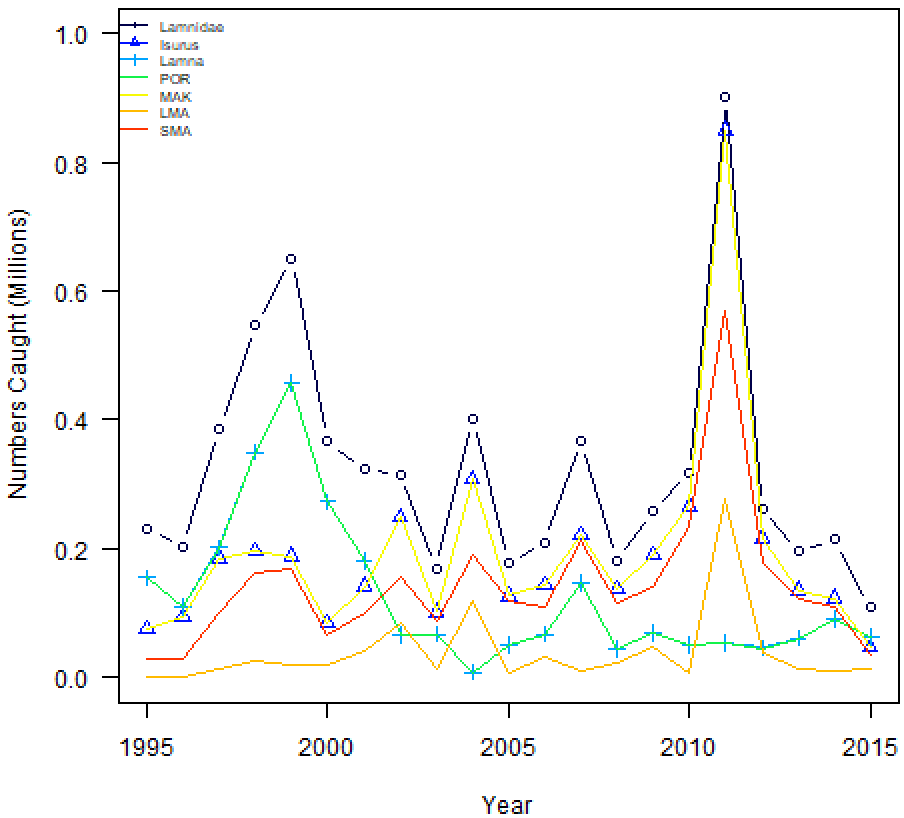

Figure 37. Estimated catch by family, genus and species, Lamnidae family, longline fishery, which consists of shortfin mako sharks (SMA), longfin mako sharks (LMA) and porbeagle sharks (POR). Shortfin and longfin mako sharks are often reported at the generic genus level, MAK, or Isurus. Porbeagle sharks are well identified and not usually referred to by their genus (Lamna).

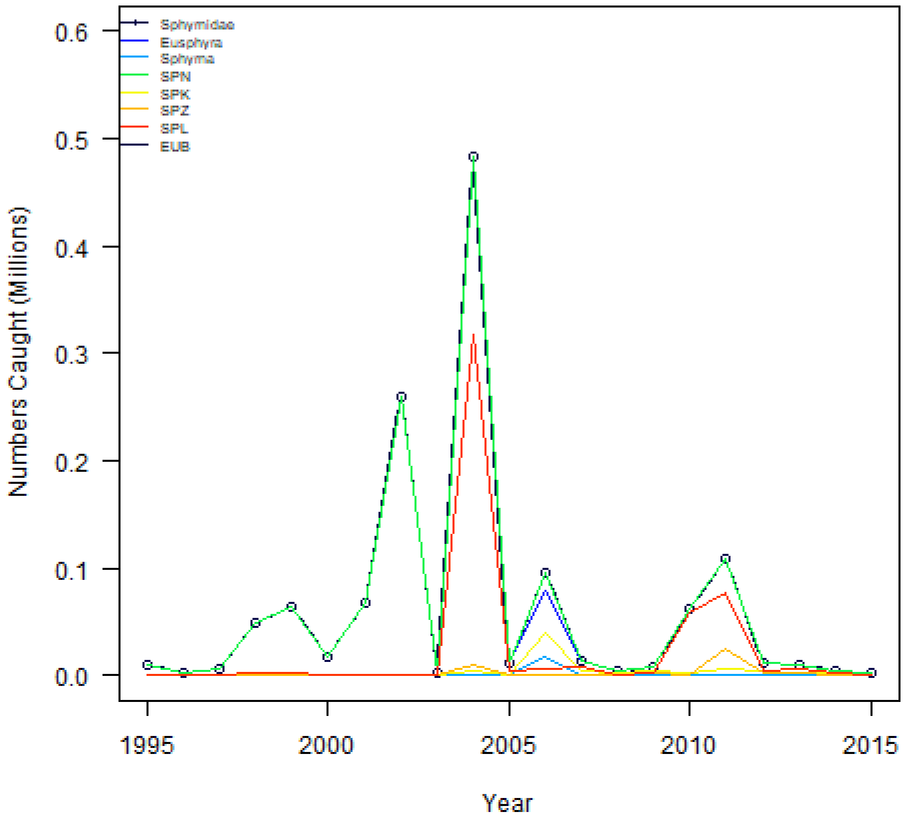

Figure 38. Estimated catch by family genus and species, Sphyrnidae family, longline fishery, which consists of winghead sharks (EUS), a member of the Eusphyra genus, smooth hammerhead (SPZ), scalloped hammerhead (SPL), and great hammerhead (SPK). Hammerhead sharks are often reported at the generic genus level (SPN)

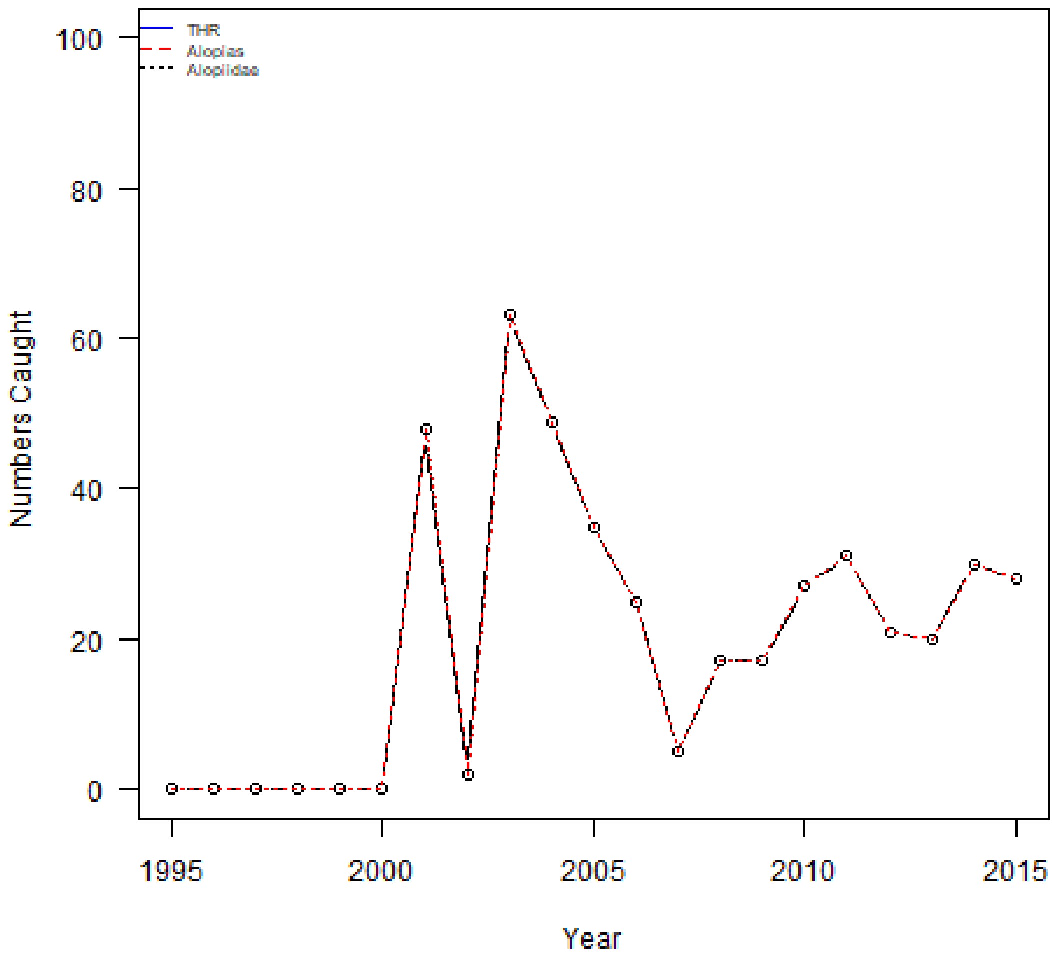

Figure 39. Estimated catch by family genus and species, Alopiidae family, purse seine fishery, species specific identification is rare in the purse seine fishery, with most thresher shark catch reported at the generic genus level (THR) or Alopias.

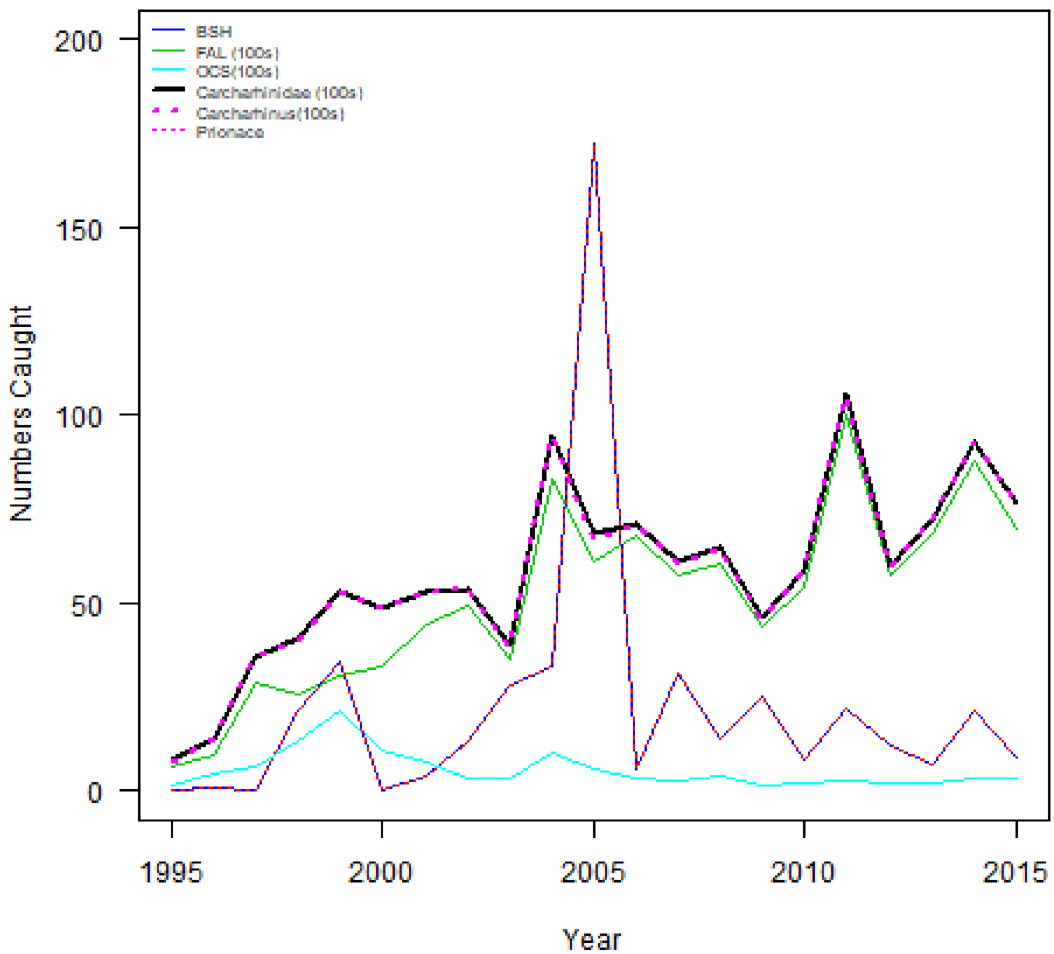

Figure 40. Estimated catch by family genus and species, Carcharinidae family, purse seine fishery, which consists of blue shark (BSH, also Prionace), oceanic whitetip shark (OCS), and silky shark (FAL). Both oceanic whitetip and silky shark are part of the Carcharhinus genus.

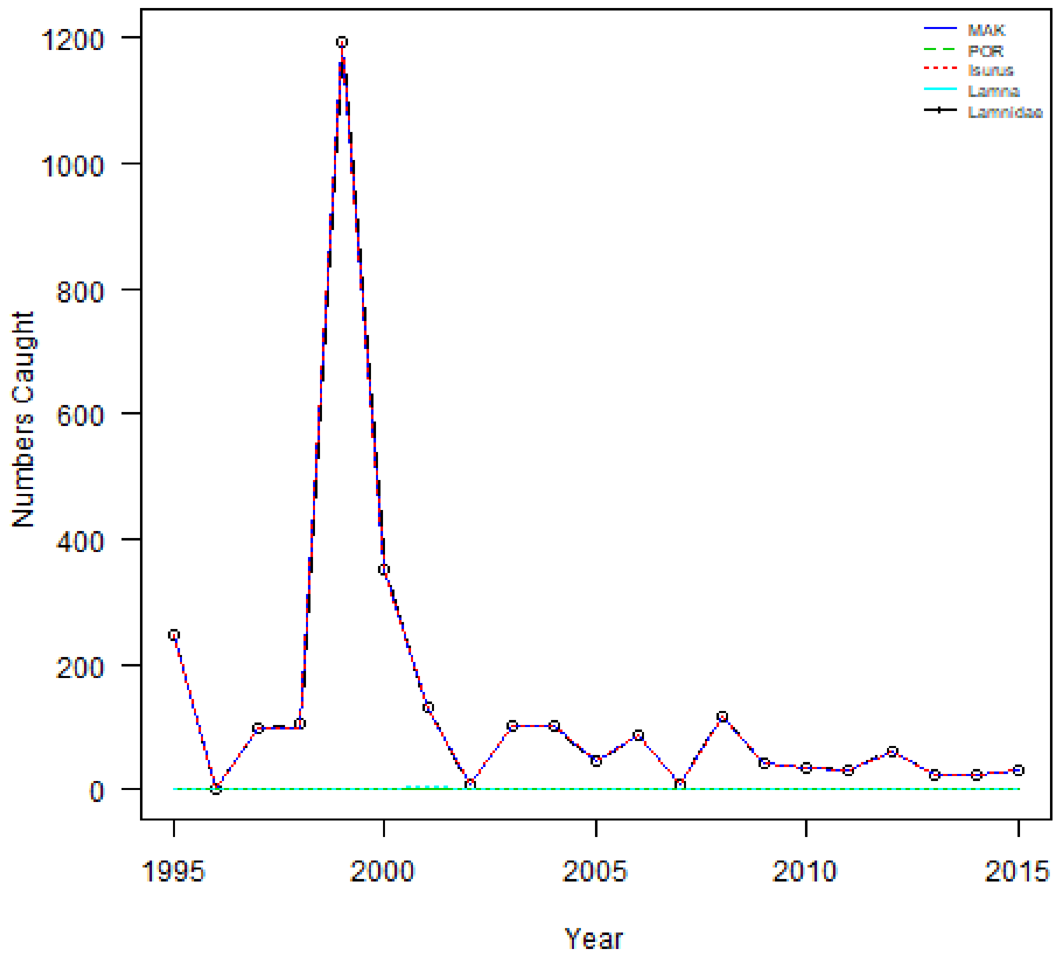

Figure 41. Estimated catch by family genus and species, Lamnidae family, purse seine fishery. Catch of Lamnids (porbeagle sharks (POR) and mako sharks (MAK) are often reported at the generic genus level or(Lamna or Isurus respectively).

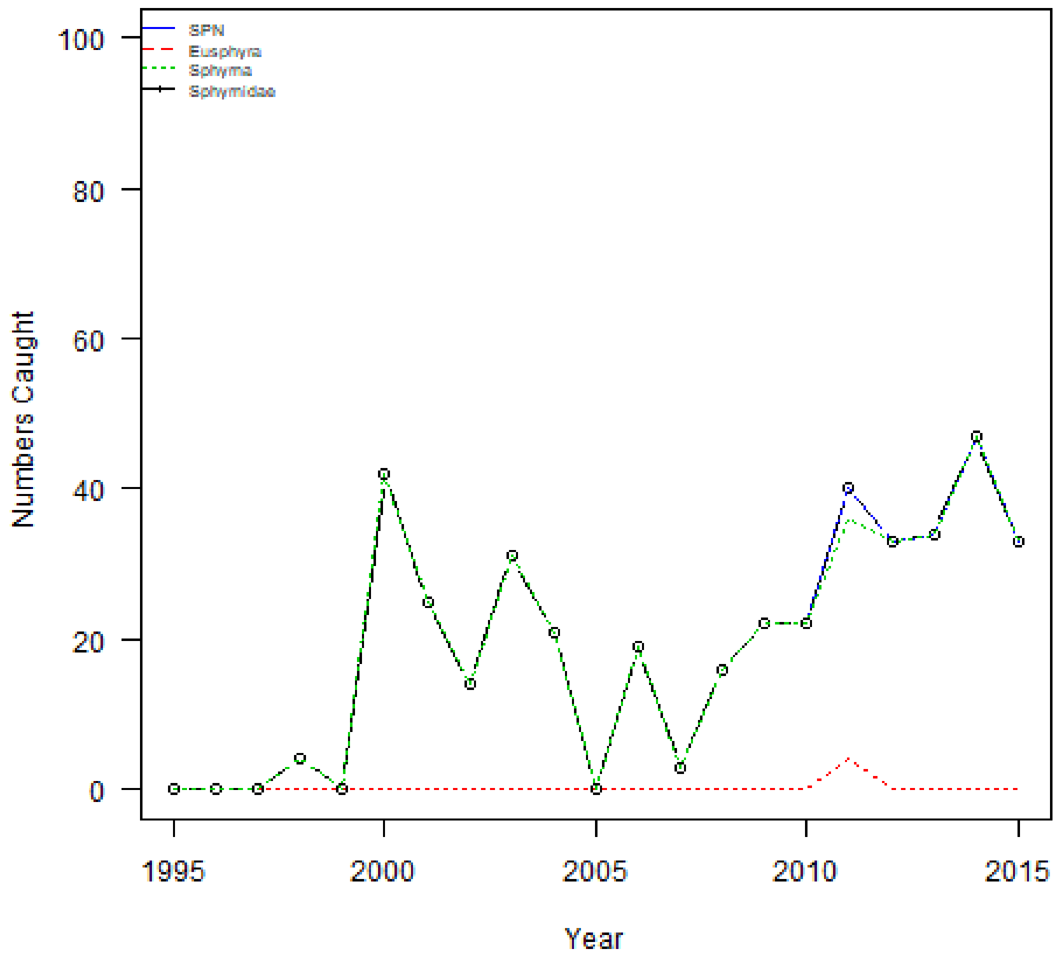

Figure 42. Estimated catch by family genus and species, Sphyrnidae family, purse seine fishery. Catch of the Sphyrnidae family, in the purse seine fishery are usually reported at the generic species level (SPN) with relatively little identification at the two genus that compose the family (Sphyrna and Eusphrya).

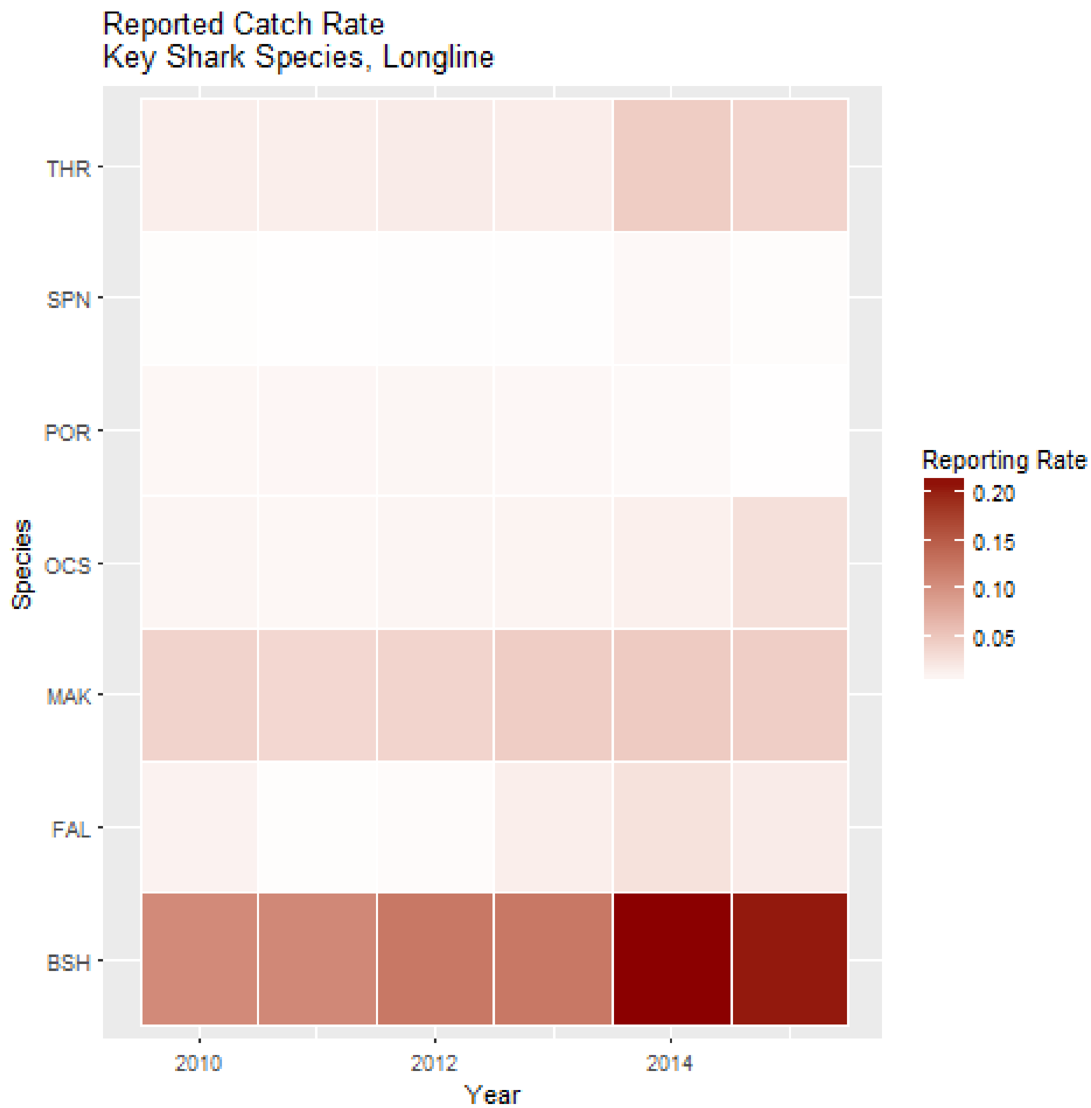

Figure 43. Reported Catch Rate of Key Shark Species by Year, longline vessels. The species codes are listed in Table 1.

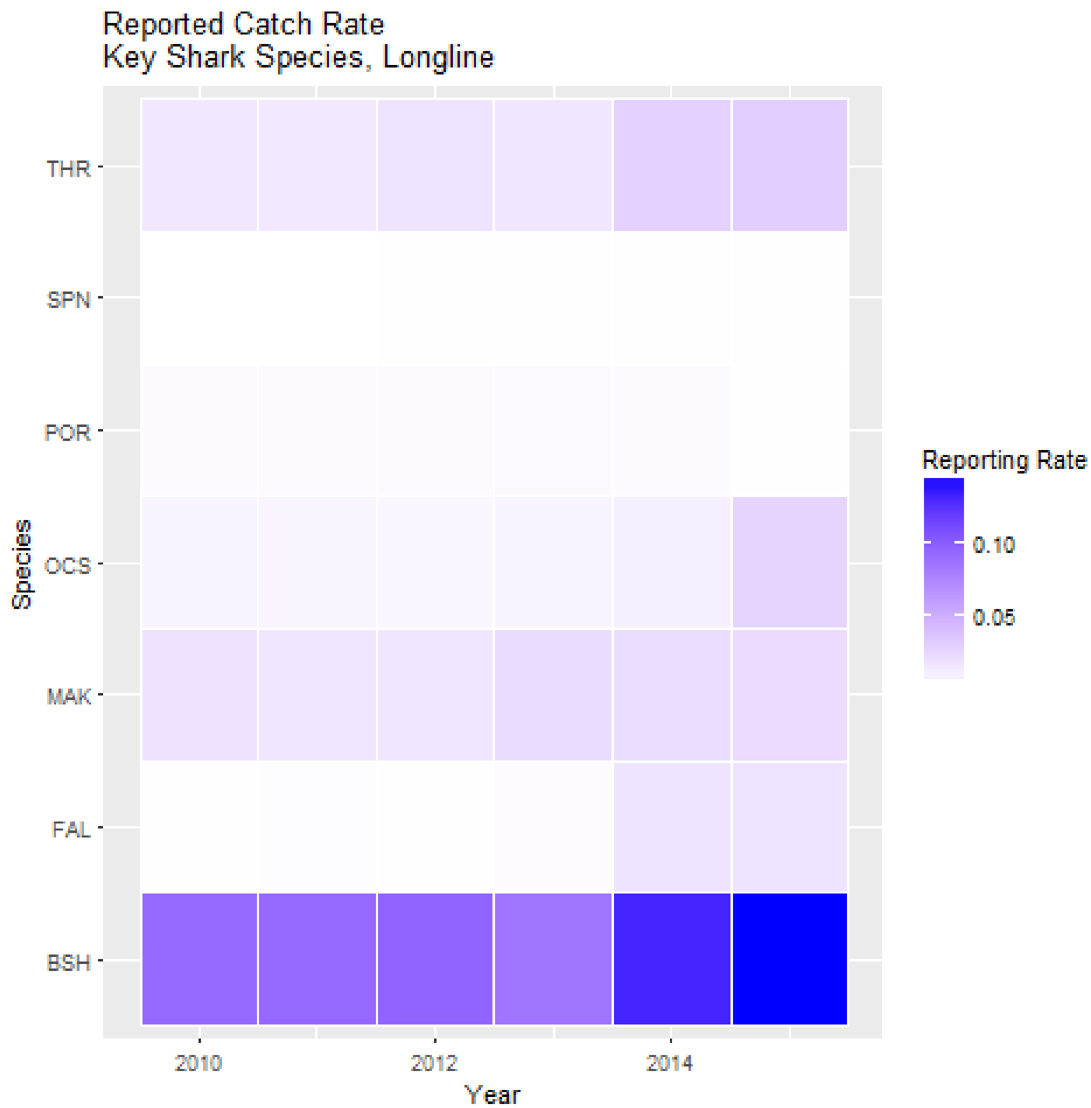

Figure 44 Reported Discard Rate of Key Shark Species by Year, the species codes are listed in Table 1.

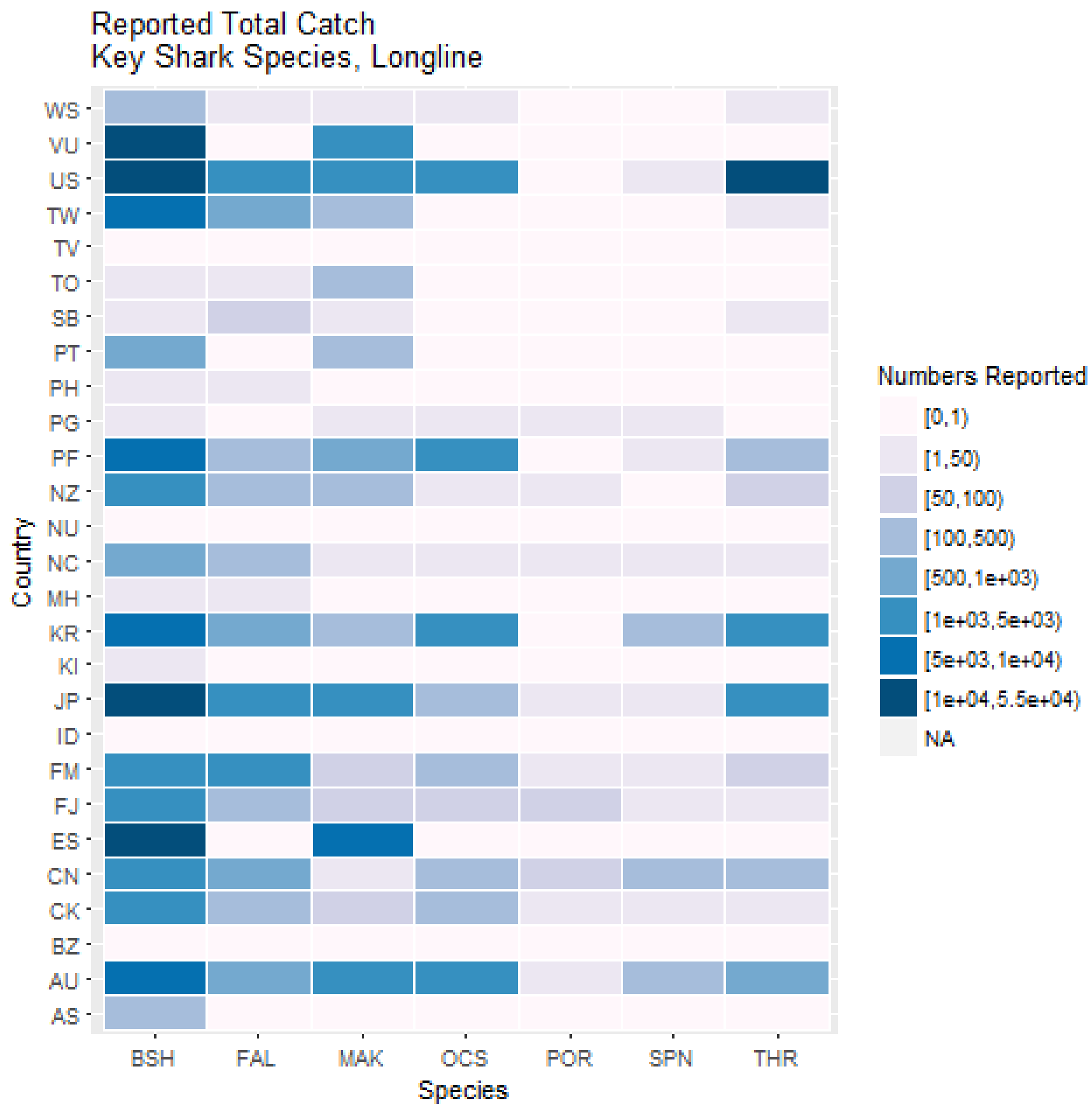

Figure 45. Reported Total Catch of Key Shark Species By Year, the species codes are listed in Table 1.

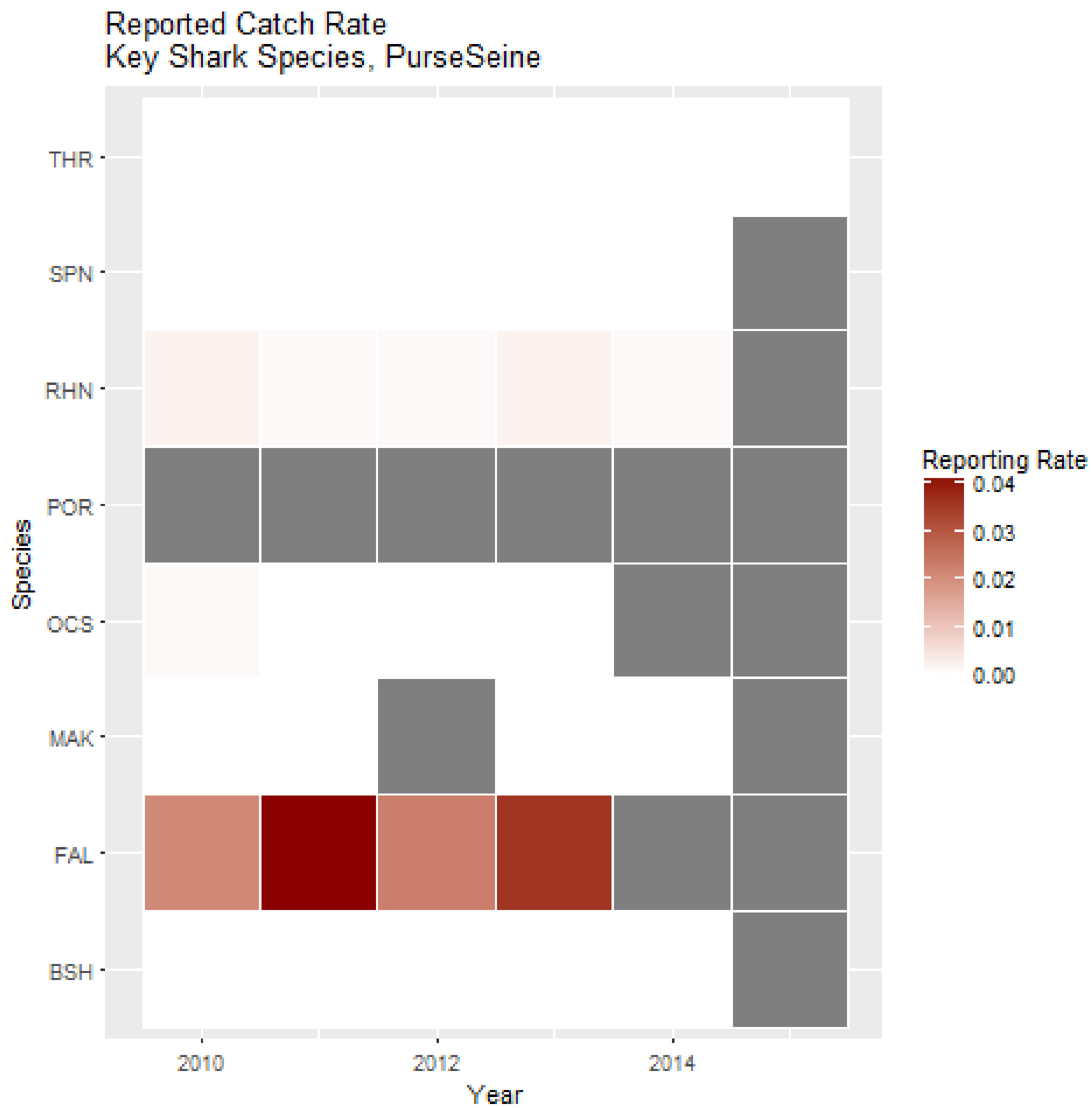

Figure 46. Reported Catch Rate of Key Shark Species by Year, purse seine vessels, the species codes are listed in Table 1.

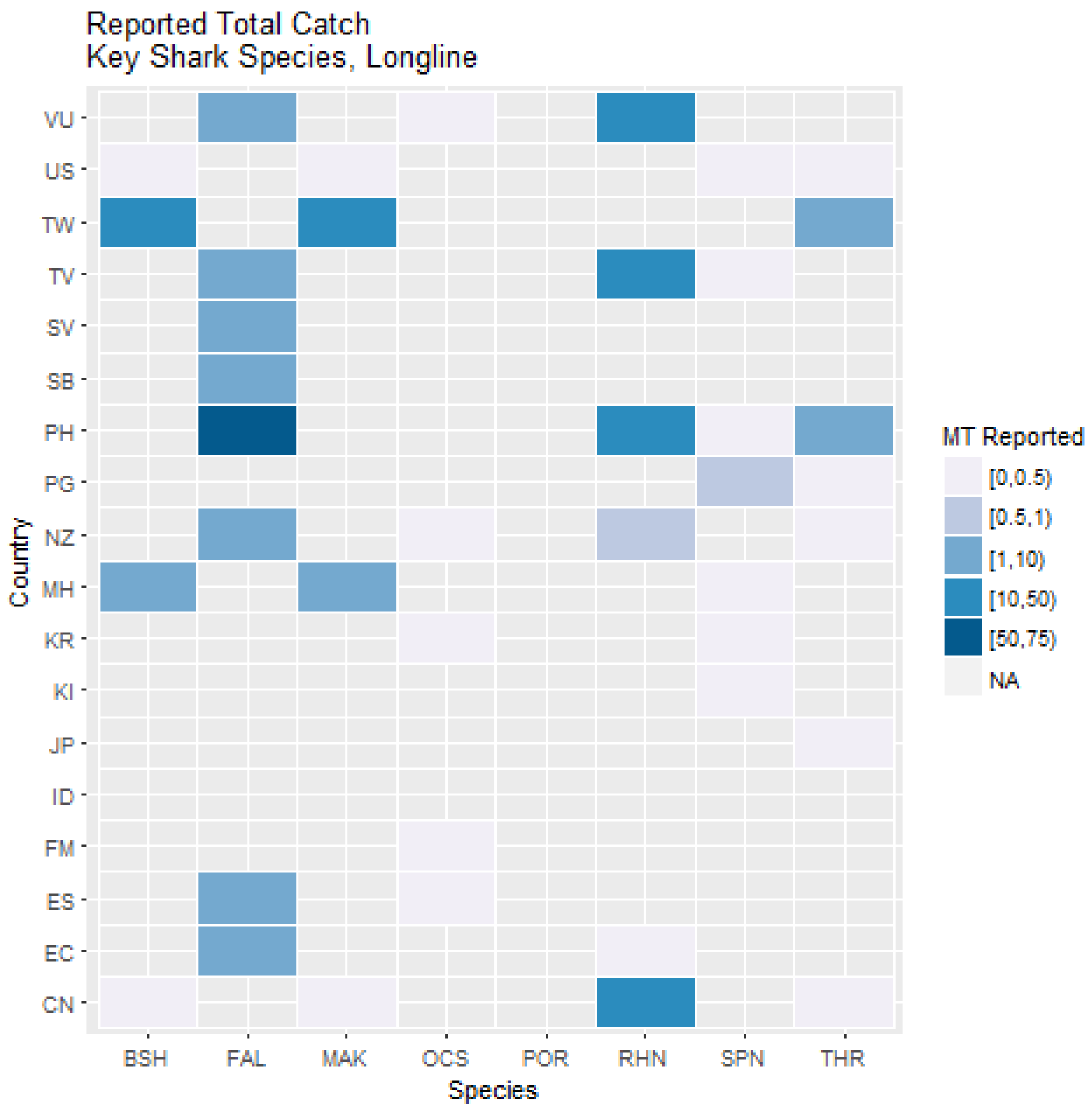

Figure 47. Reported total catch (retained + discarded) for the period 2010-2015, longline vessels, the species codes are listed in Table 1.

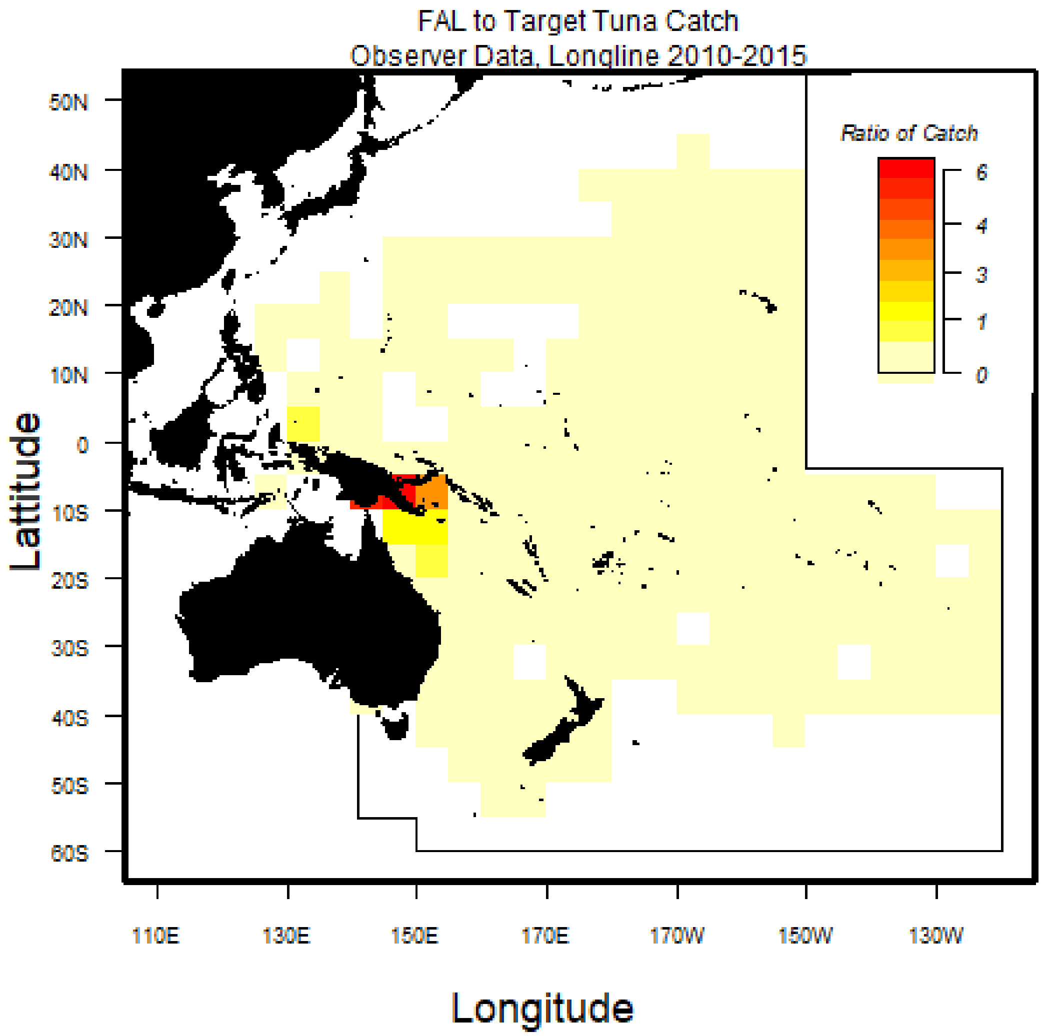

Figure 48. Maps of silky shark (FAL) to target tuna catch, longline vessels 2010-2015 (in units of 50,000 tuna).

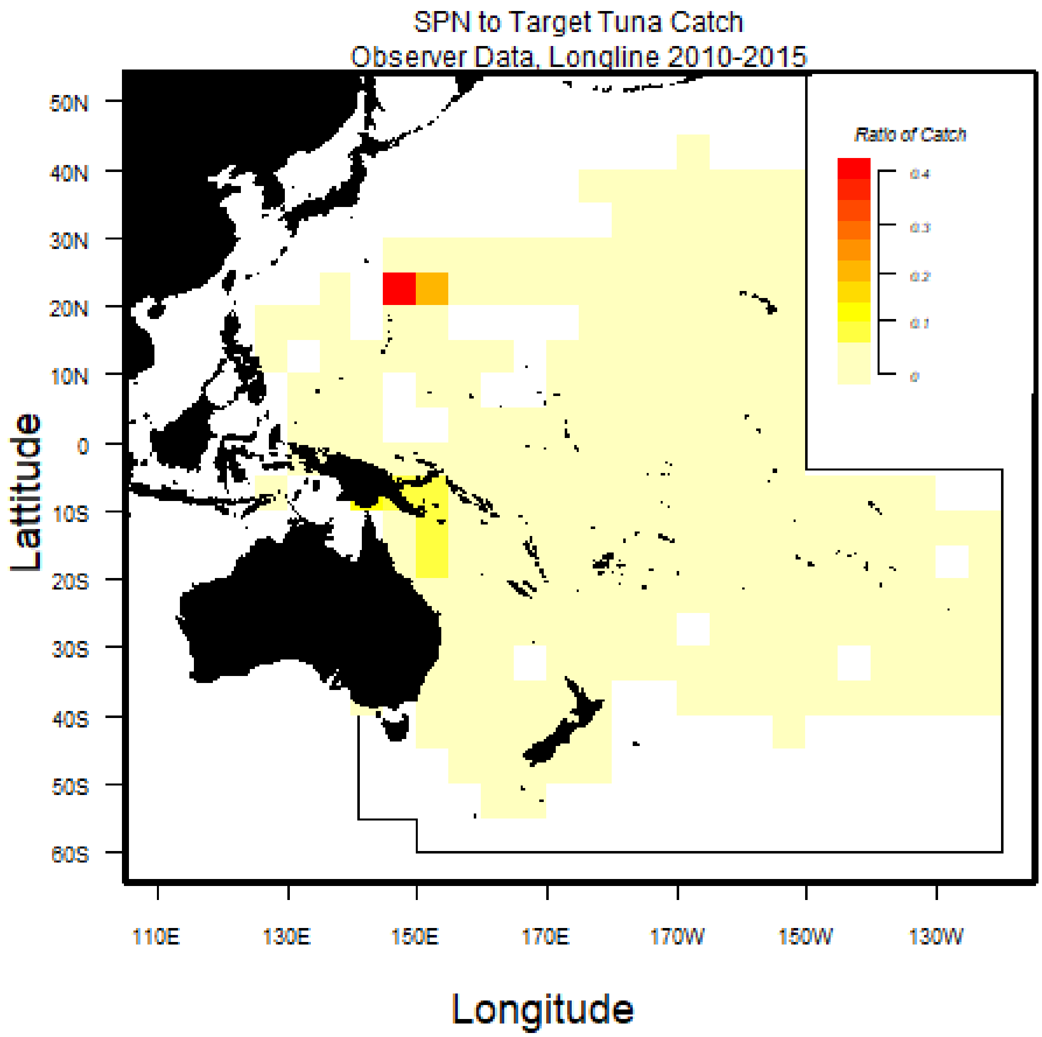

Figure 49.Maps of hammerhead sharks (SPN) to target tuna catch, longline vessels 2010-2015 (in units of 50,000 tuna).

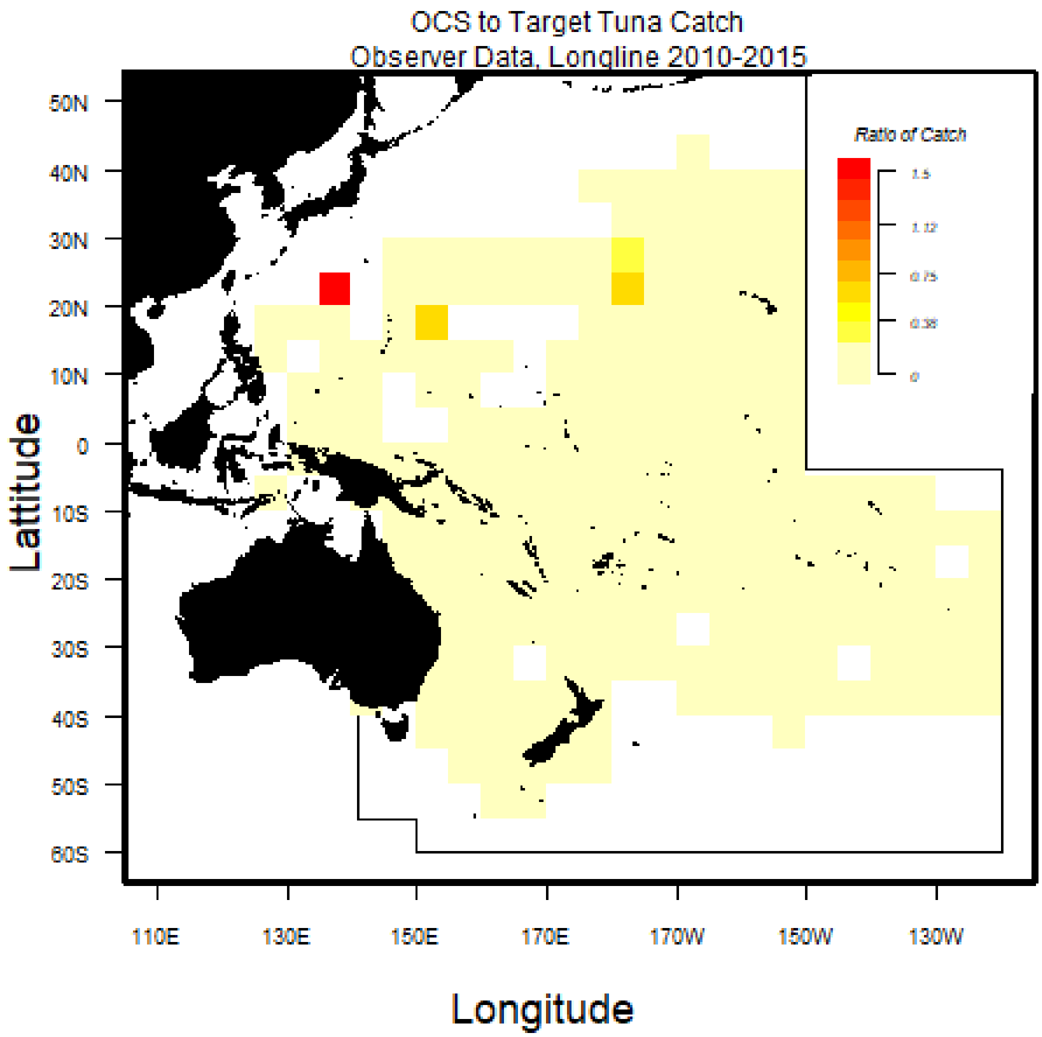

Figure 50. Maps of oceanic whitetip shark (OCS) to target tuna catch, longline vessels 2010-2015 (in units of 50,000 tuna).

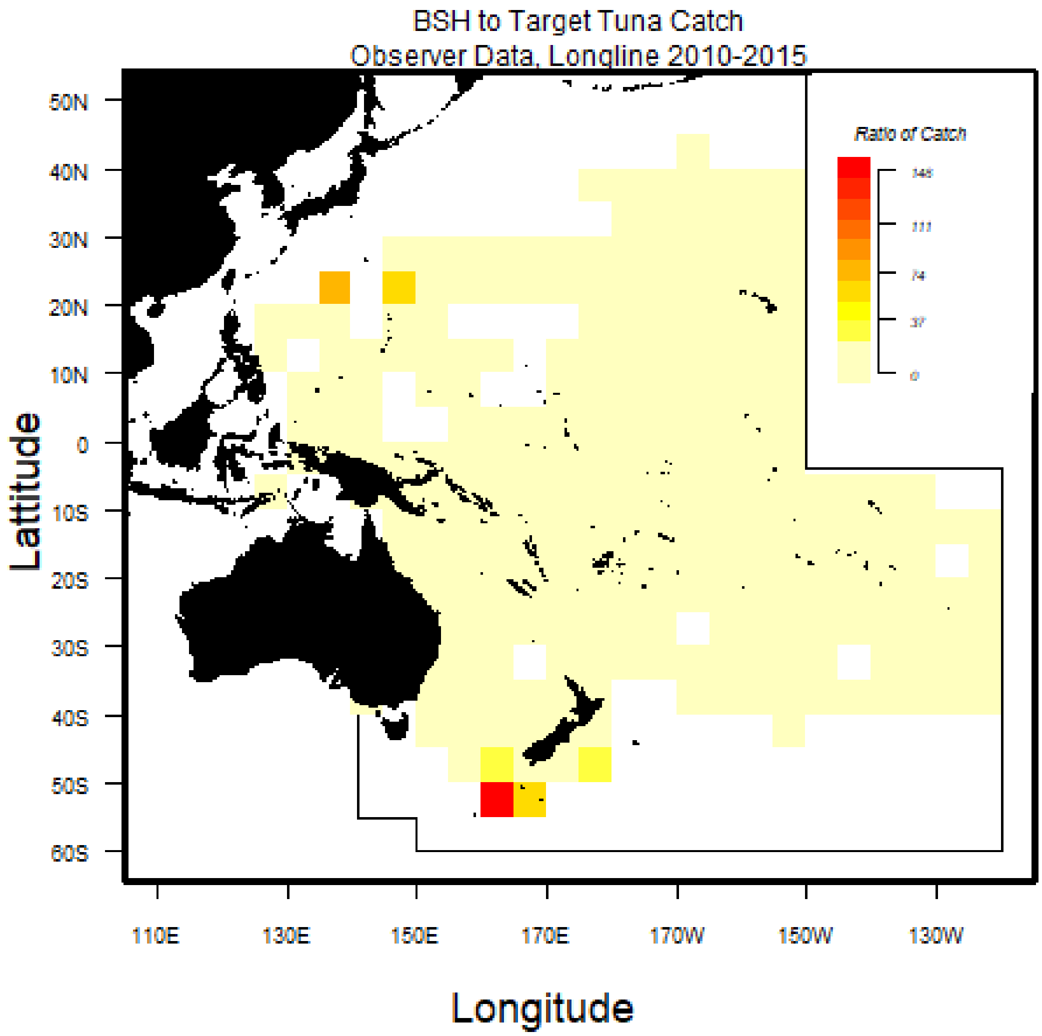

Figure 51. Maps of blues shark (BSH) to target tuna catch, longline vessels 2010-2015 (in units of 50,000 tuna).

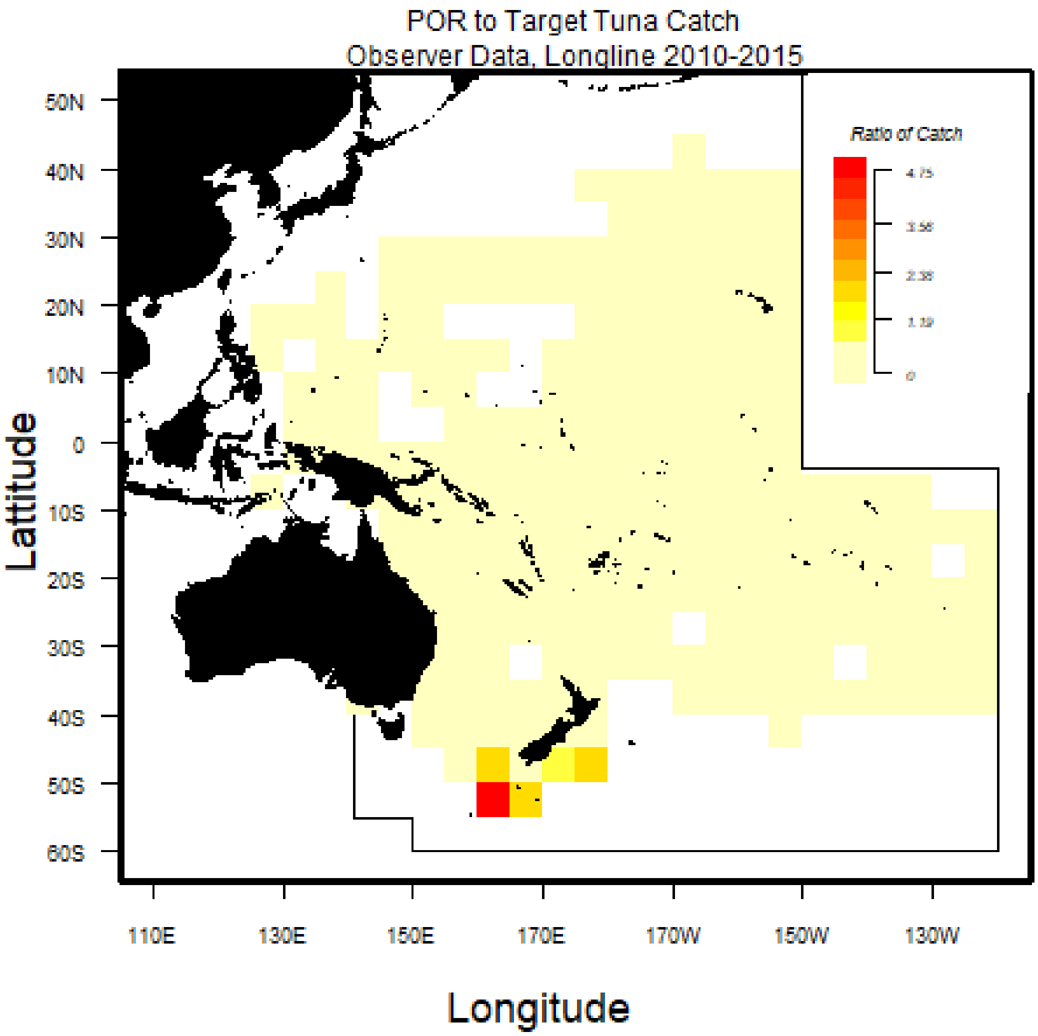

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Figure 52. Observed catch of porbeagle (POR) to target tuna (in units of 50,000).

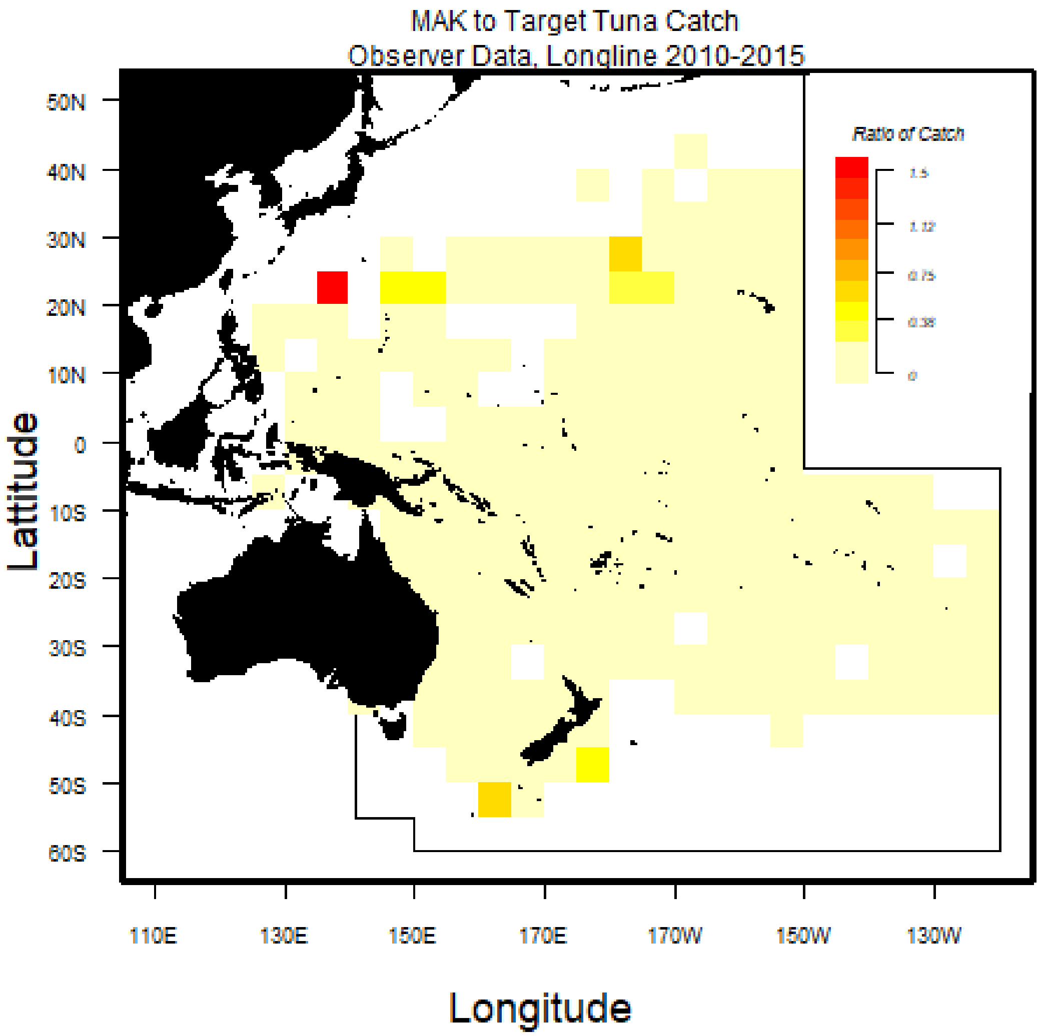

Figure 53. Maps of mako shark (MAK) to target tuna catch, longline vessels 2010-2015 (in units of 50,000 tuna).

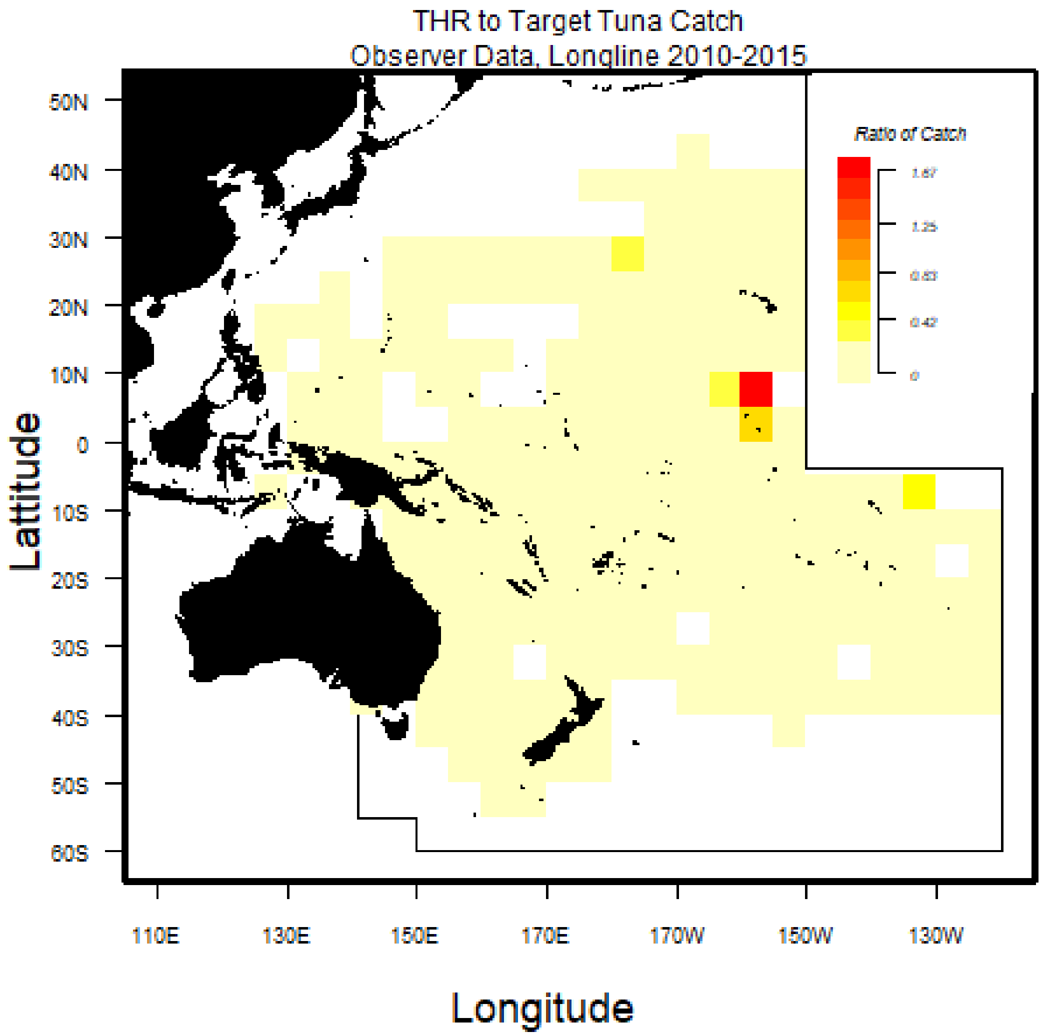

Figure 54. Maps of thresher shark (THR) to target tuna catch, longline vessels 2010-2015 (in units of 50,000 tuna).

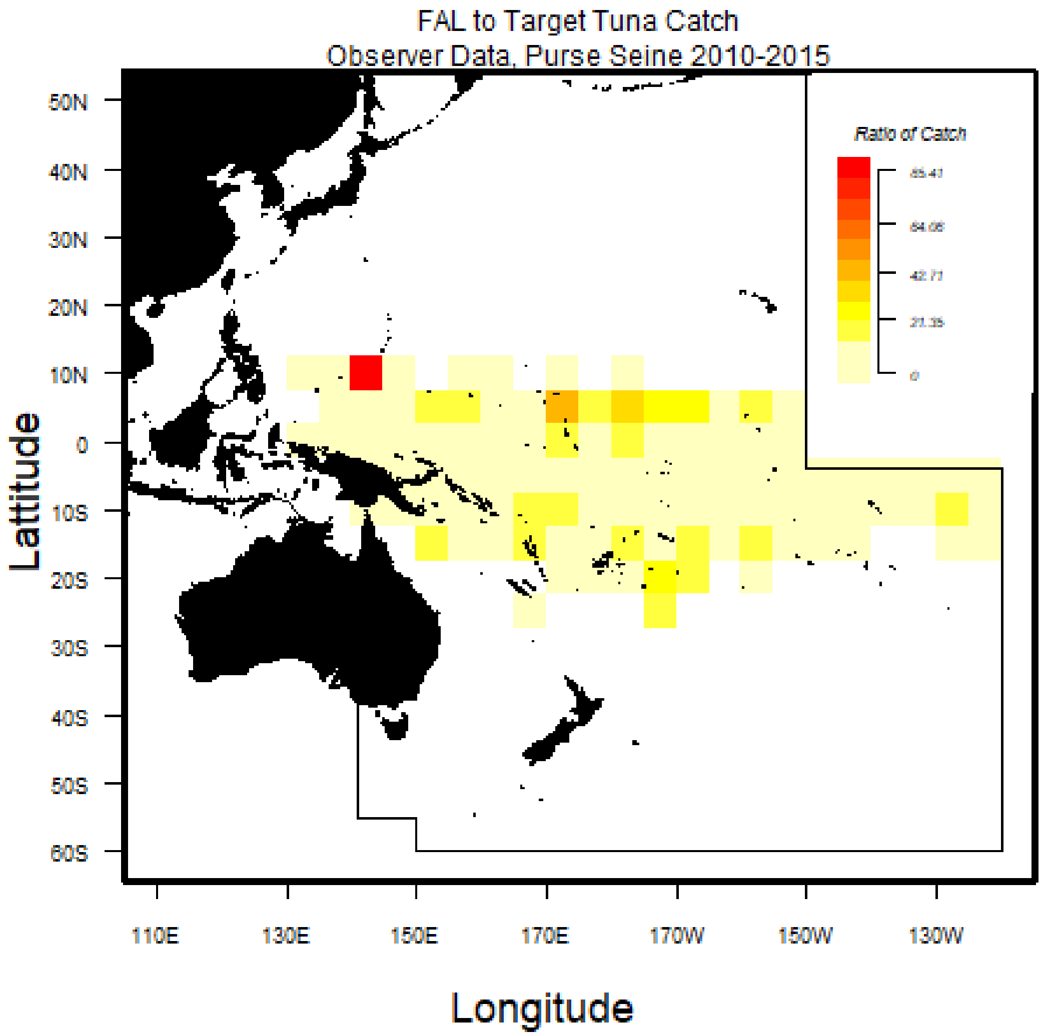

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Figure 55. Maps of silky shark (FAL) to target tuna catch, purse seine, 2010-2015 (in units of 50,000 tuna).

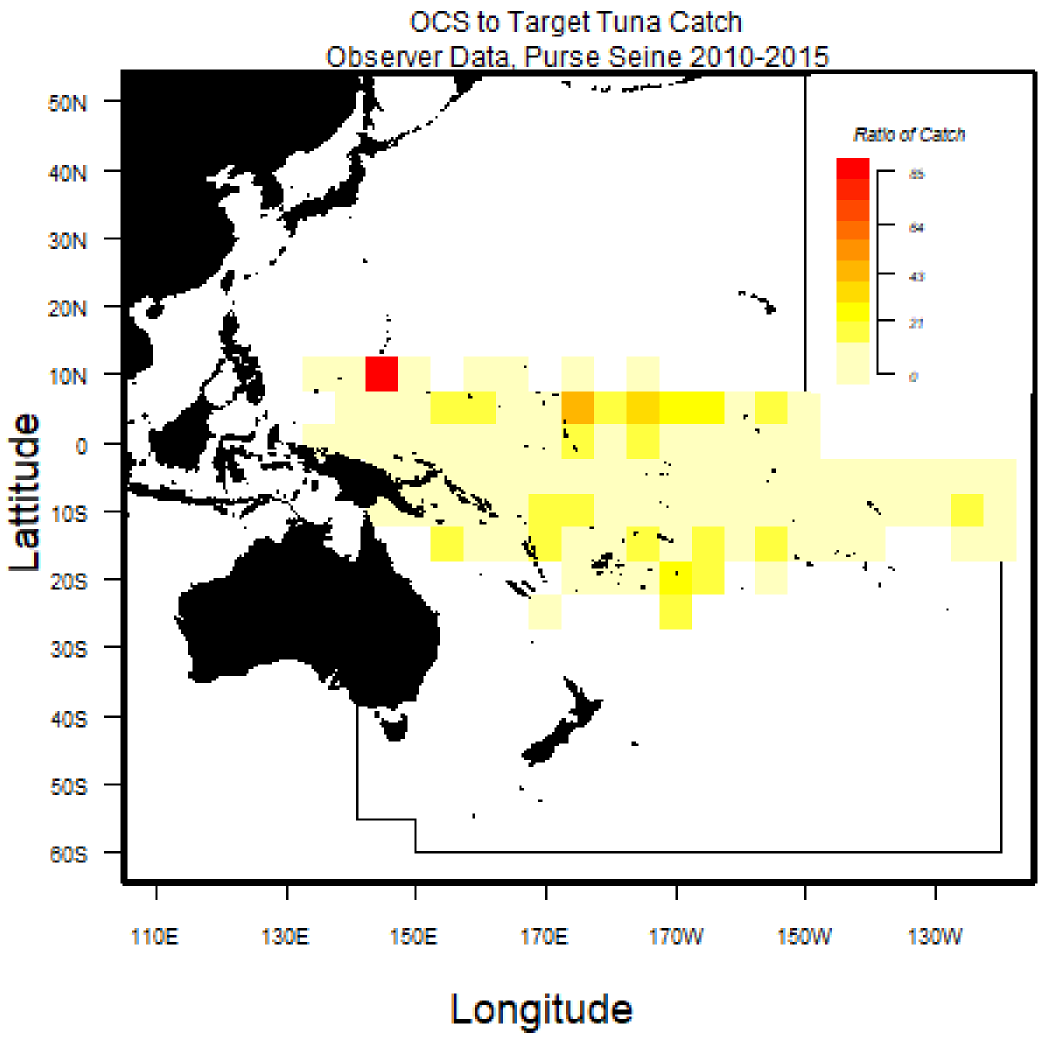

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Figure 56. Maps of oceanic whitetip to target tuna catch, purse seine, 2010-2015 (in units of 5000 MT tuna).

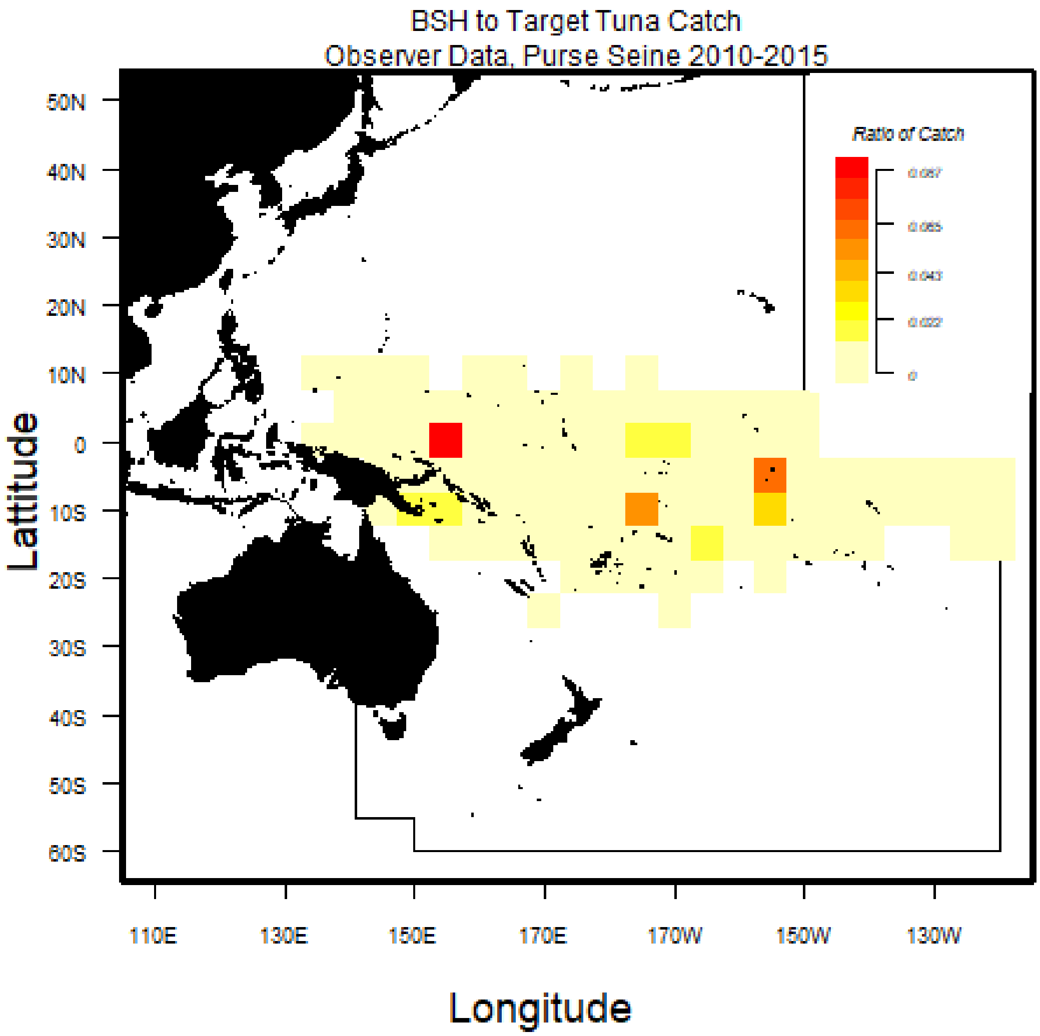


Figure 57. Maps of blue shark (BSH) to target tuna catch, purse seine, 2010-2015 (in units of 5000 MT of tuna).

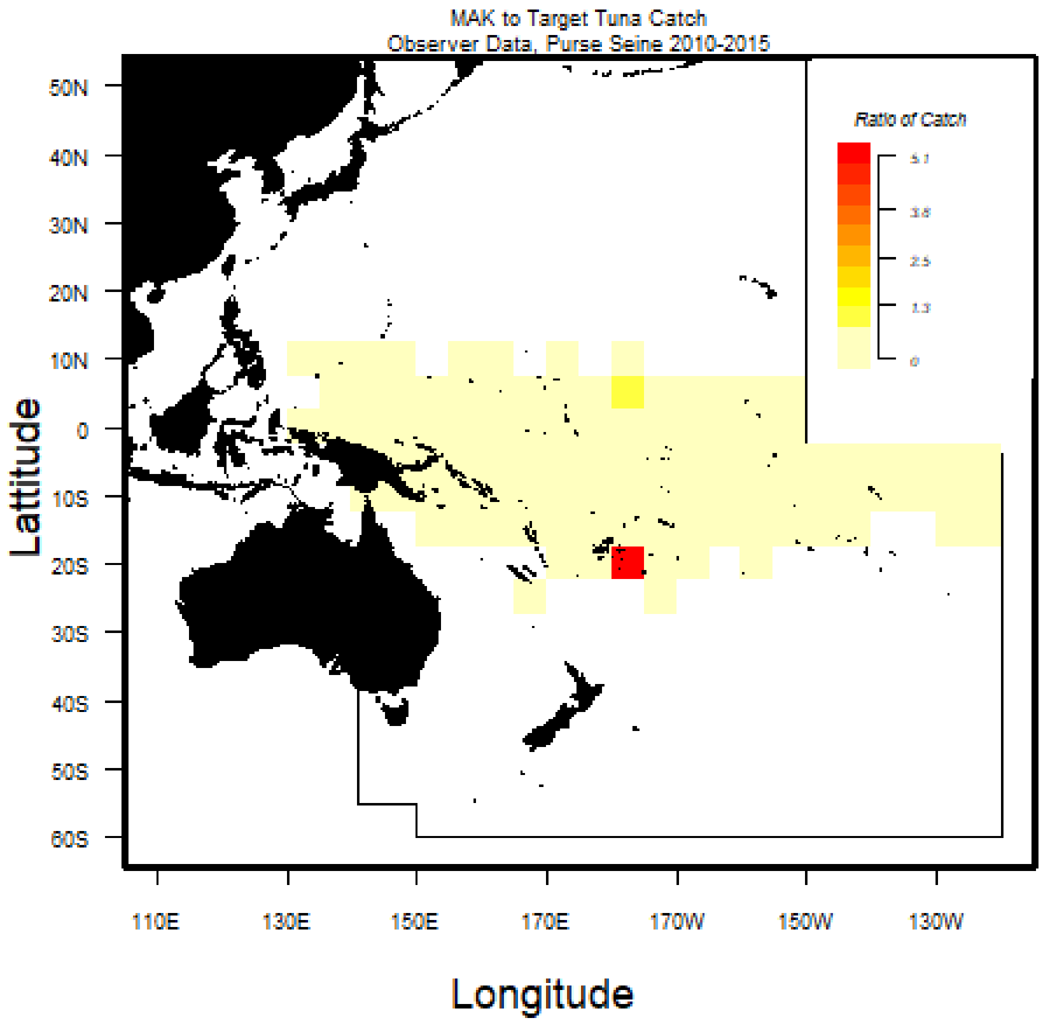


Figure 58. Maps of mako shark (MAK) to target tuna catch, purse seine, 2010-2015 (in units of 5000 MT tuna).

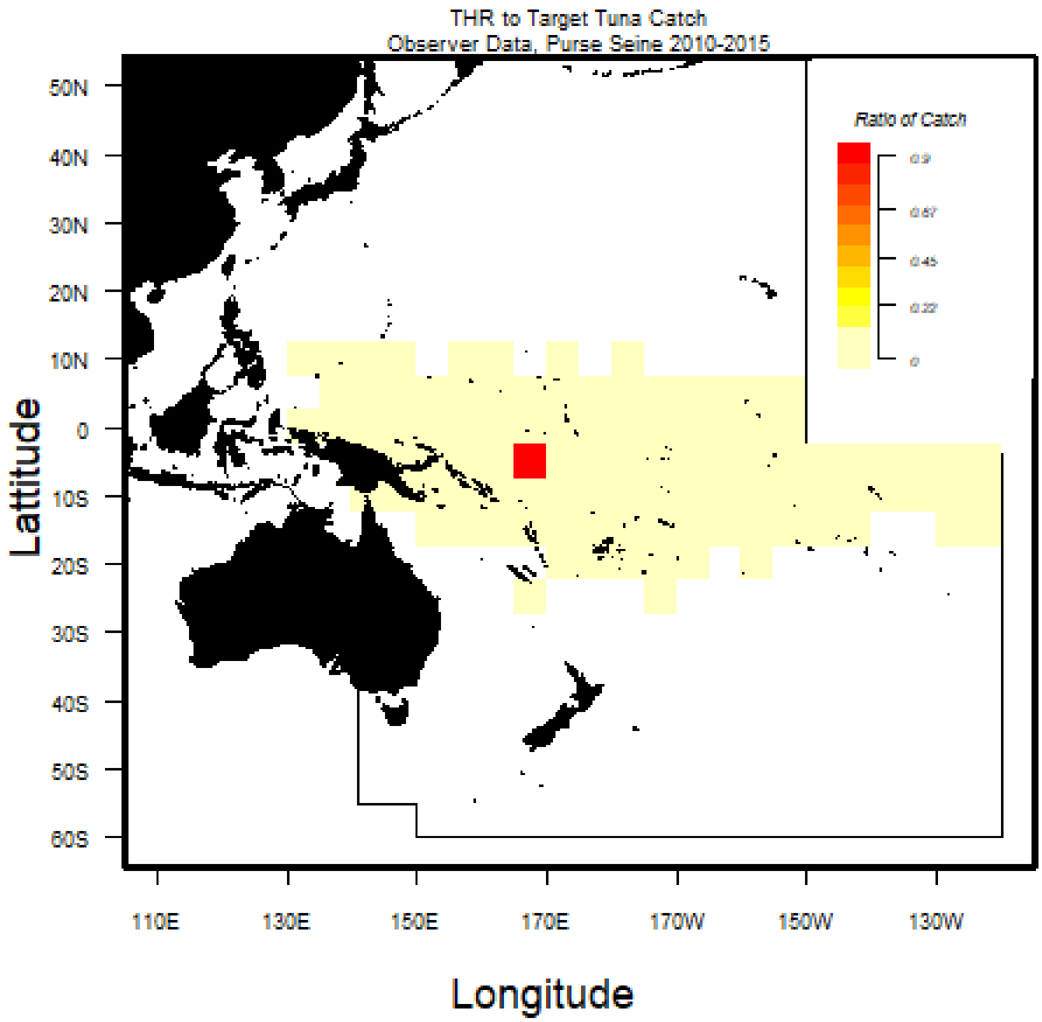


Figure 59. Maps of thresher shark (THR) to target tuna catch, purse seine, 2010-2015 (in units of 5000 MT tuna).

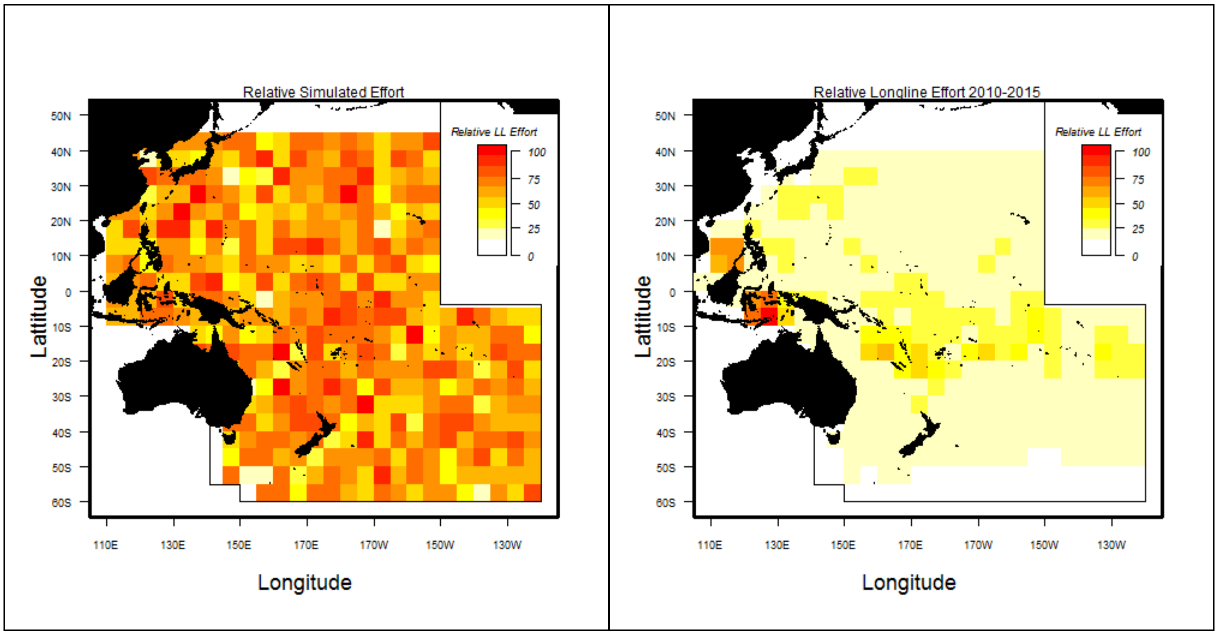


Figure 60. Random relative effort distribution (left panel) and average (for 2010-2015) relative distribution of effort based on aggregated data reporting. Darker colored cells indicate higher relative effort.

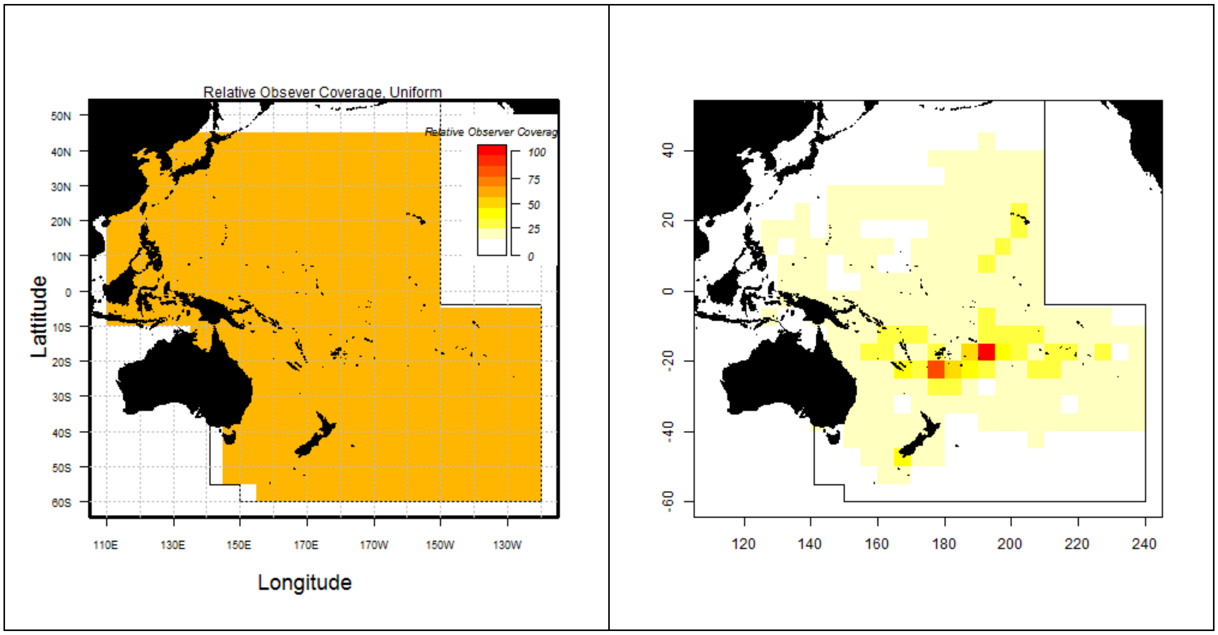


Figure 61. Simulated uniform observer coverage where all cells receive experience the same amount of observer coverage (left panel) and average (for 2010-2015) relative distribution of observer effort based data reporting. Darker colored cells indicate higher relative effort.

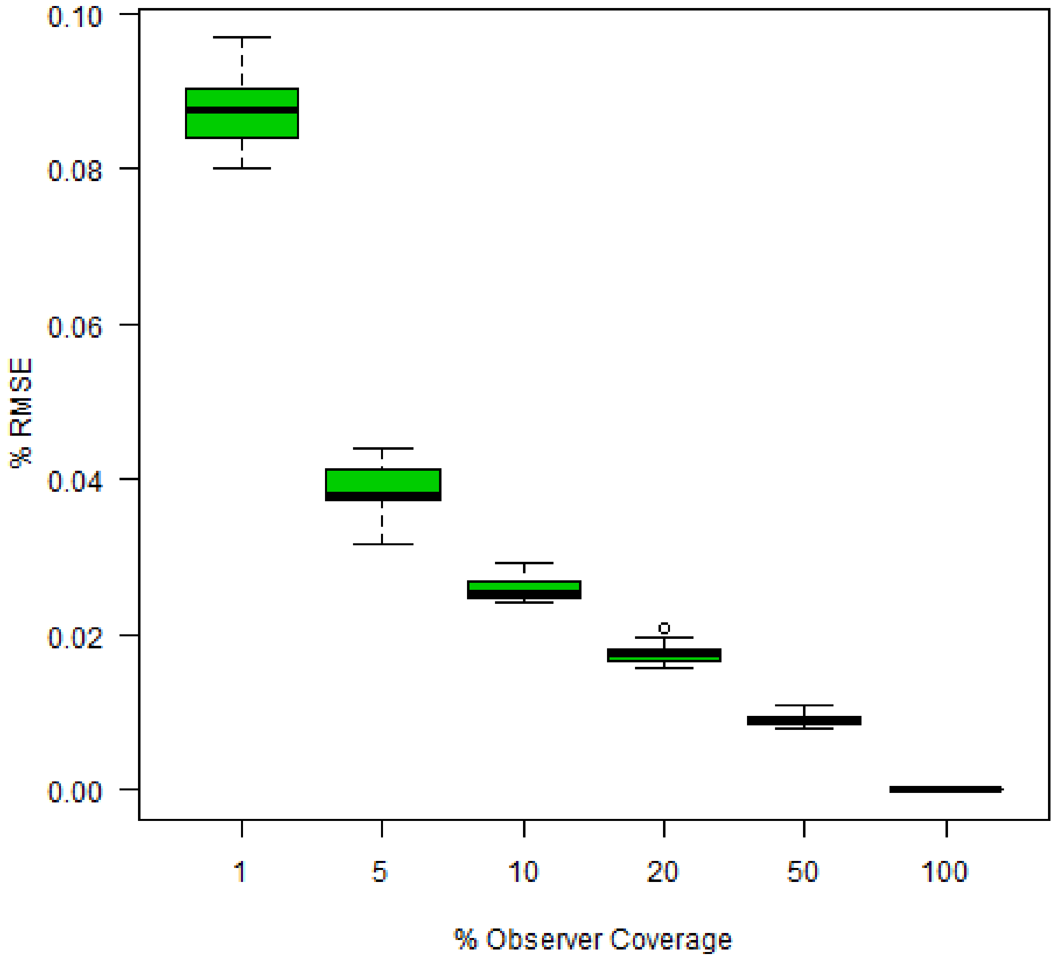


Figure 62. Relative root mean square error (RRMSE) as a function of observer coverage for the scenario assuming uniform distribution of species, effort and sampling.

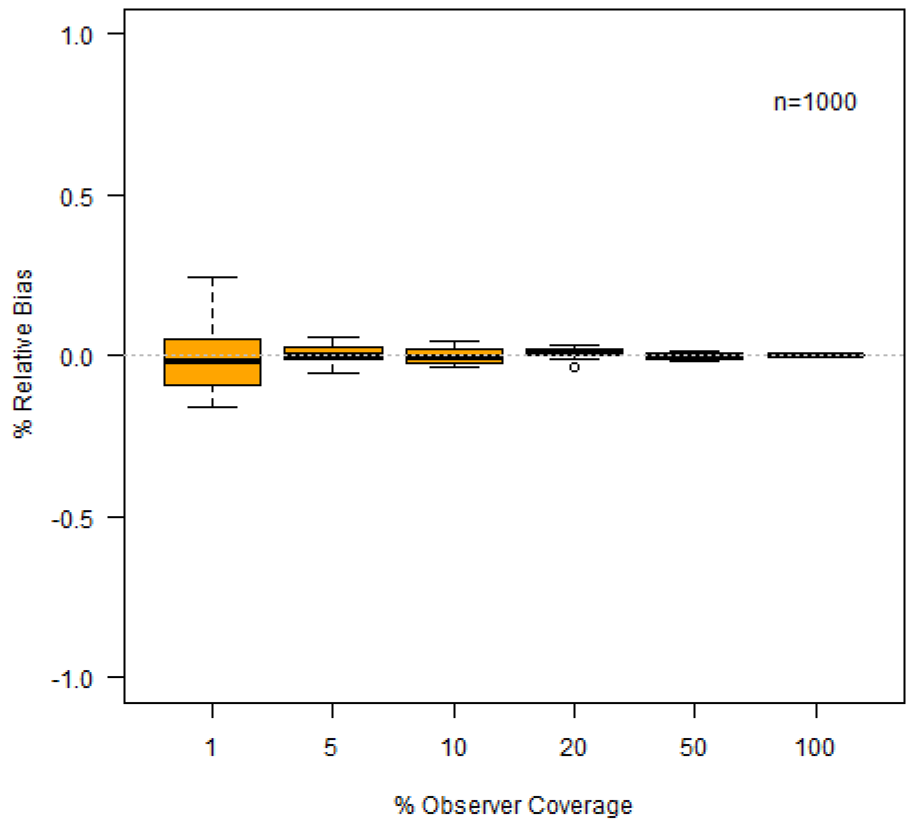


Figure 63 Relative bias as a function of observer coverage for the scenario assuming uniform distribution of species, effort and sampling.

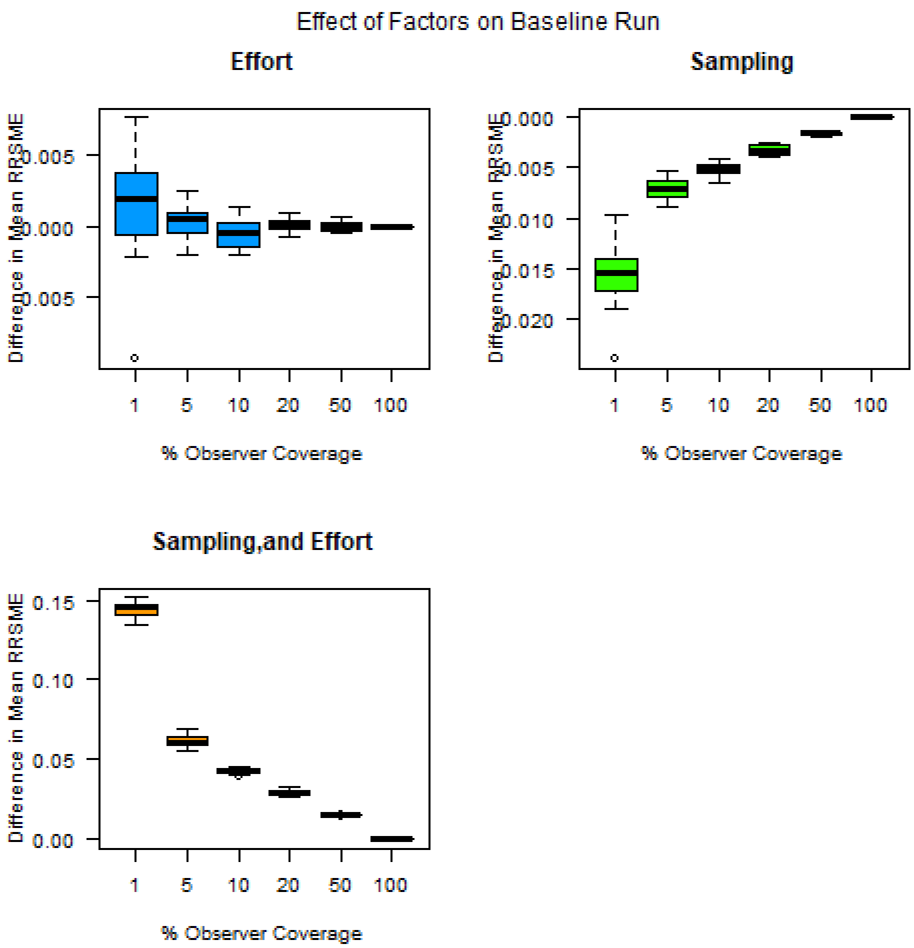


Figure 64. Effect of using the observed distribution of effort for the observer sampling, and the relative distribution of fishing effort on the relative root mean square error (RMSE, vertical axis) across various coverage rates (horizontal axis).

Annexes

Annex 1 Detailed Taxonomic Reporting for the longline fleet.

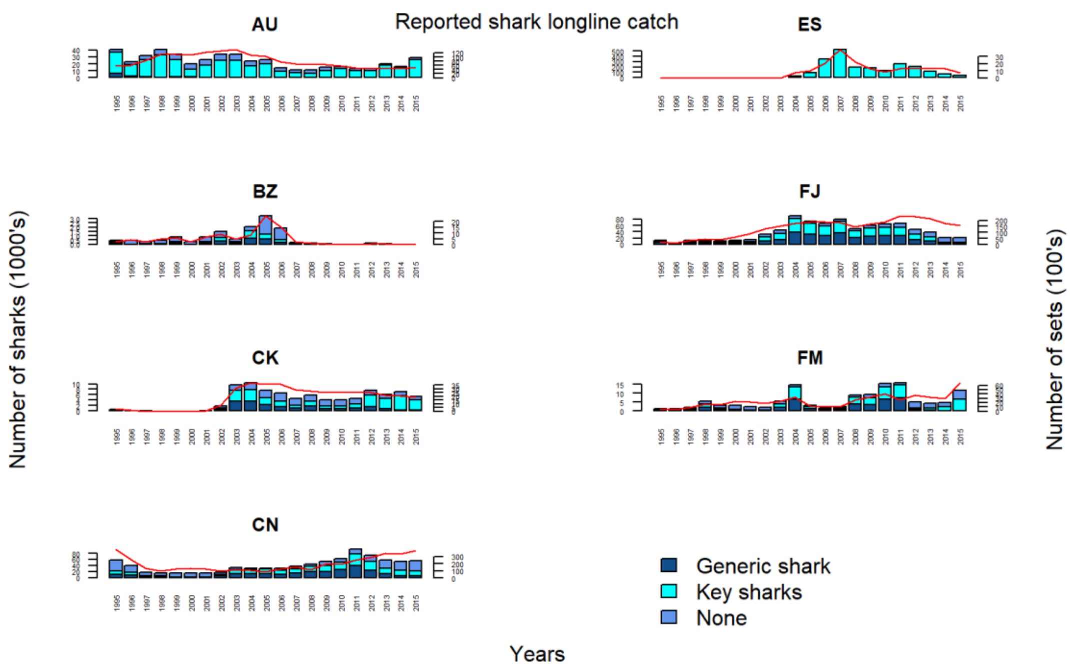


Figure ANNEX1.1 Reported taxonomic catch from the longline fishery by country.

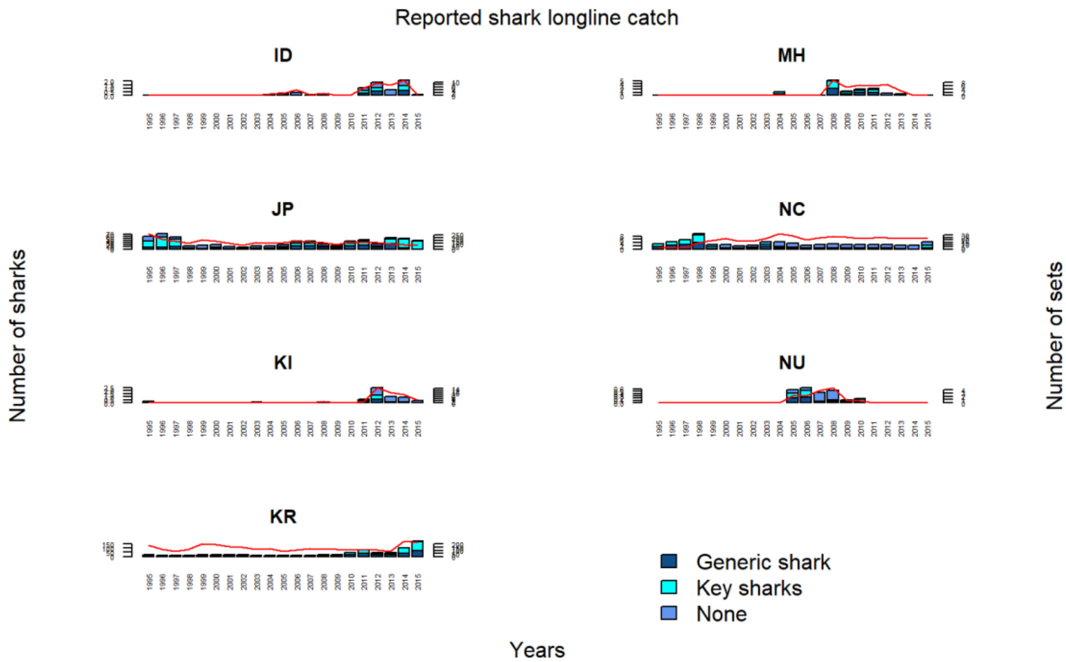


Figure ANNEX1.2 Reported taxonomic catch from the longline fishery by country.

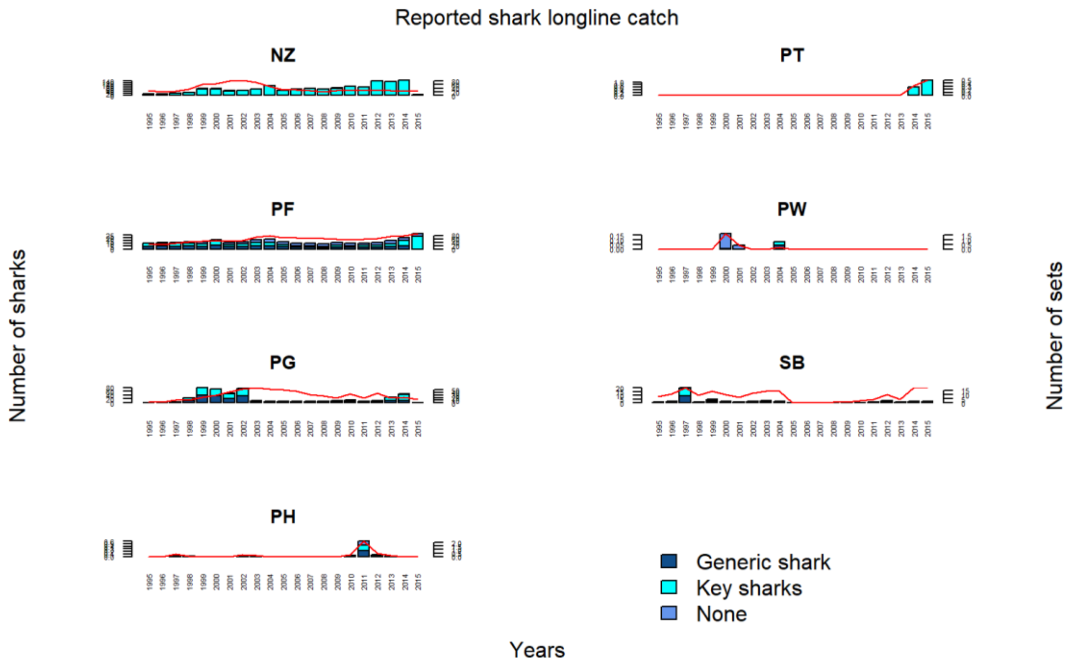


Figure ANNEX1.3 Reported taxonomic catch from the longline fishery by country.

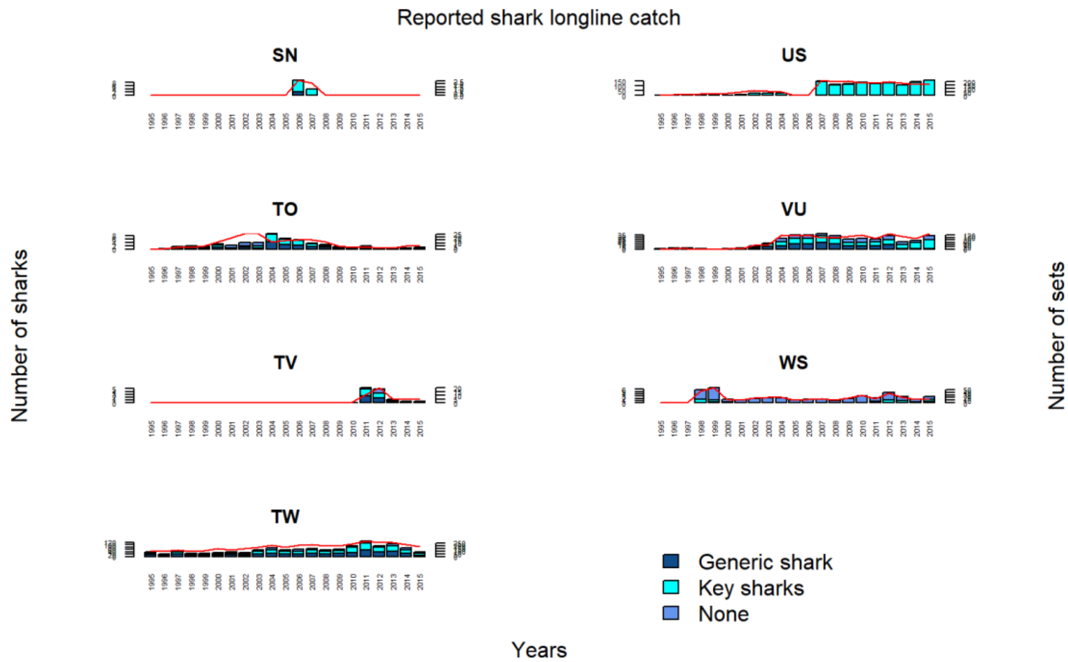
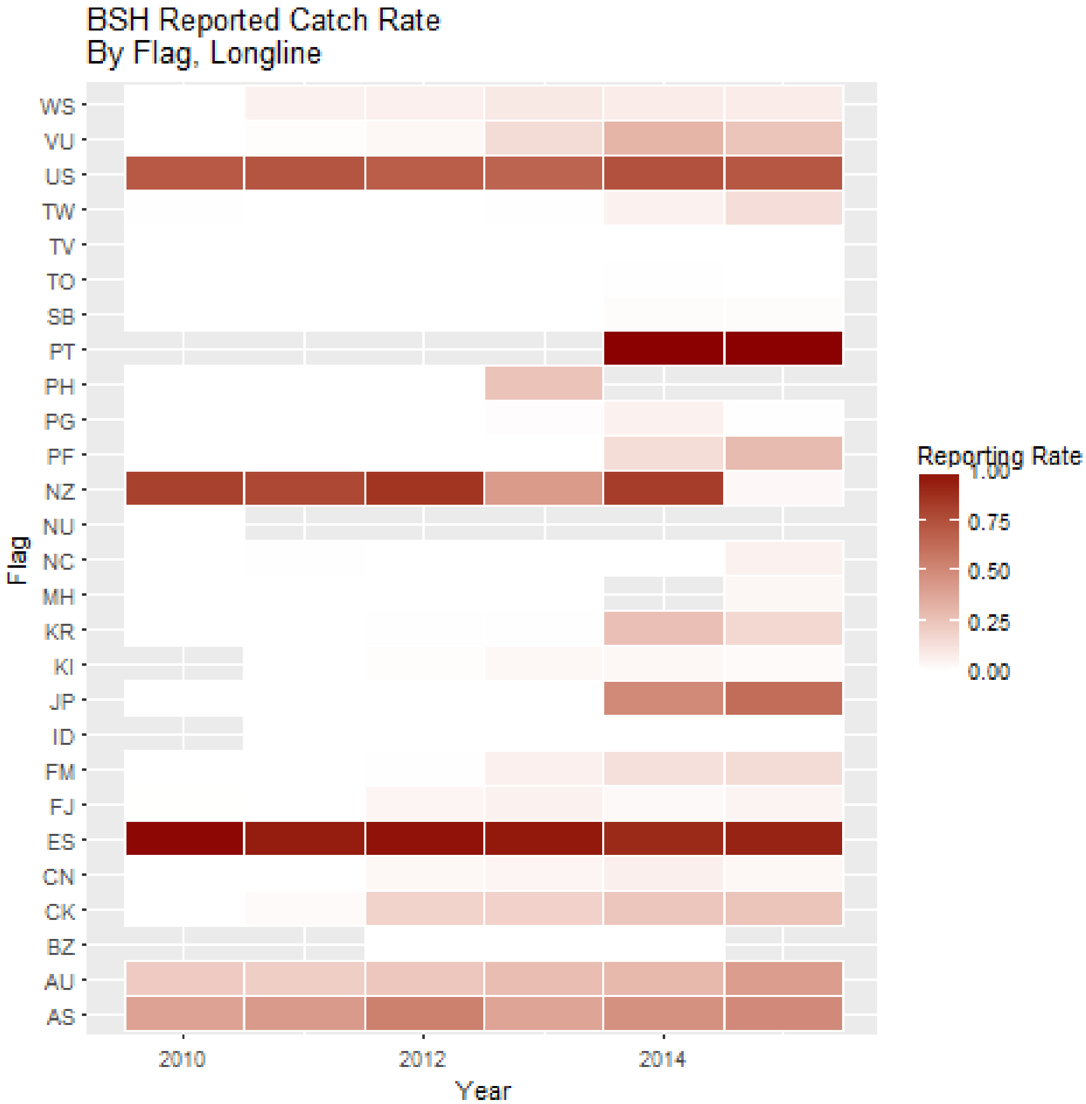


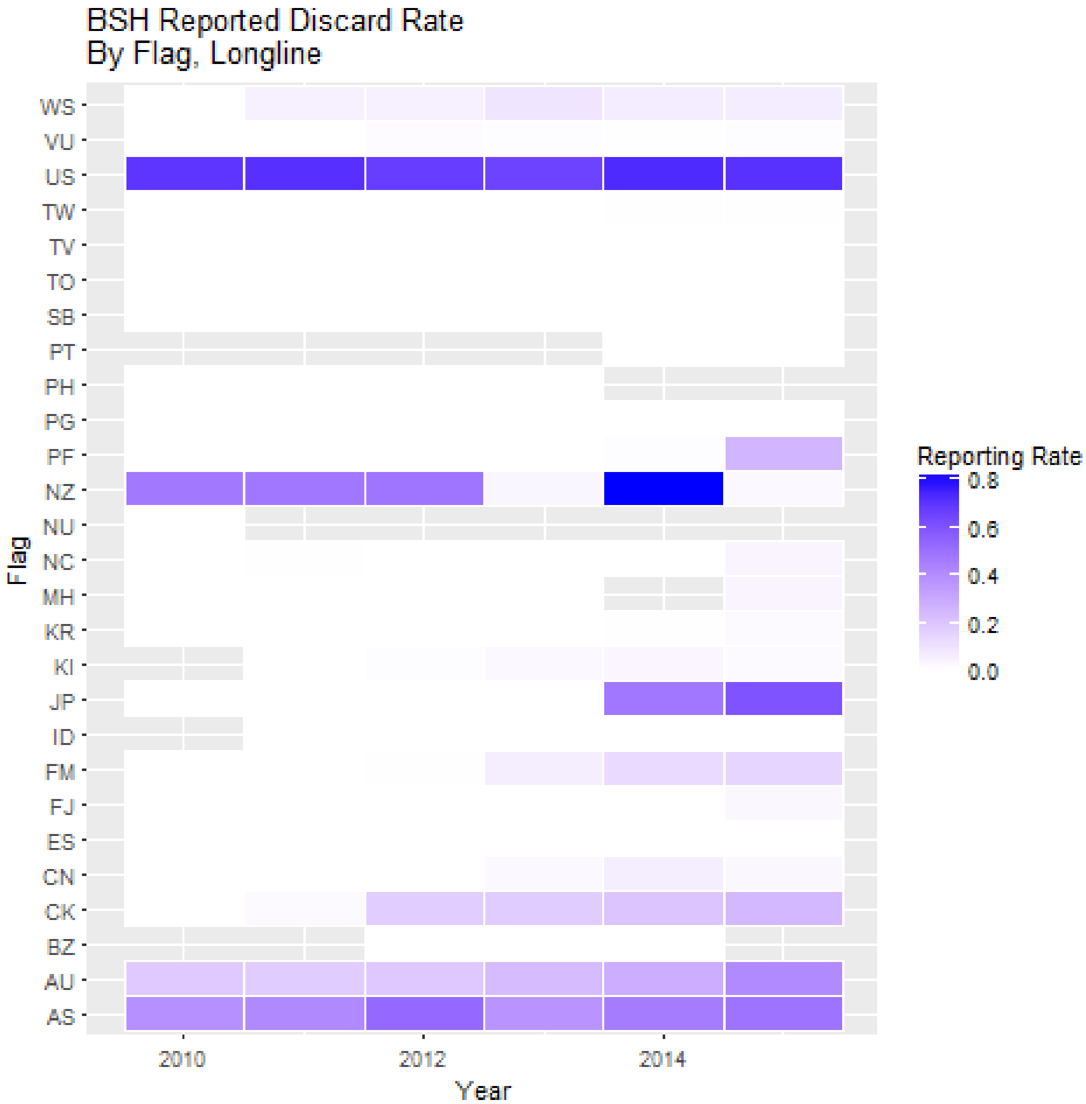
Figure ANNEX1.4 Reported taxonomic catch from the longline fishery by country.

Annex 2 Reported Catch and discard rate by species and flag, longline.

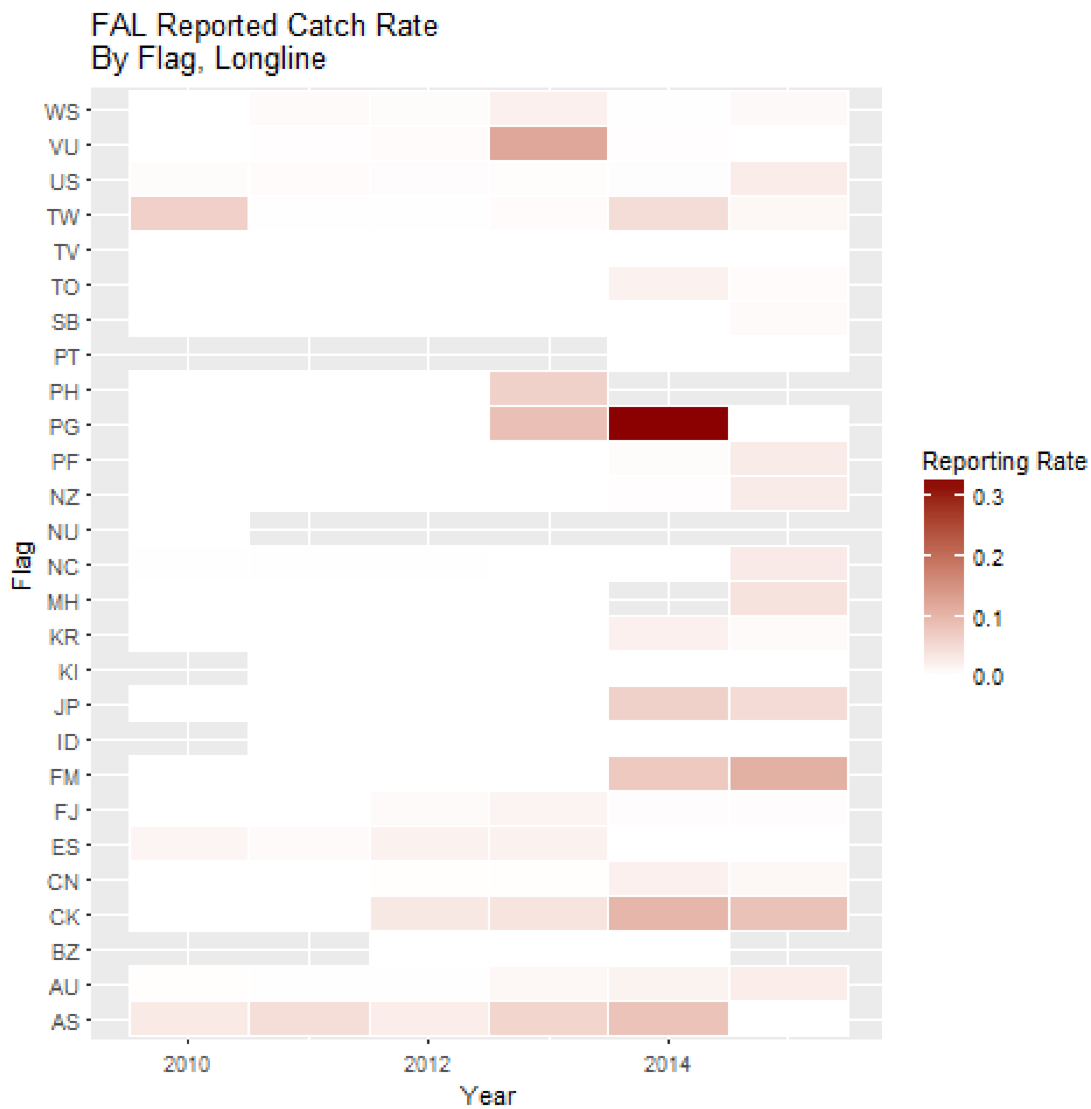
Blue shark reported catch rate:



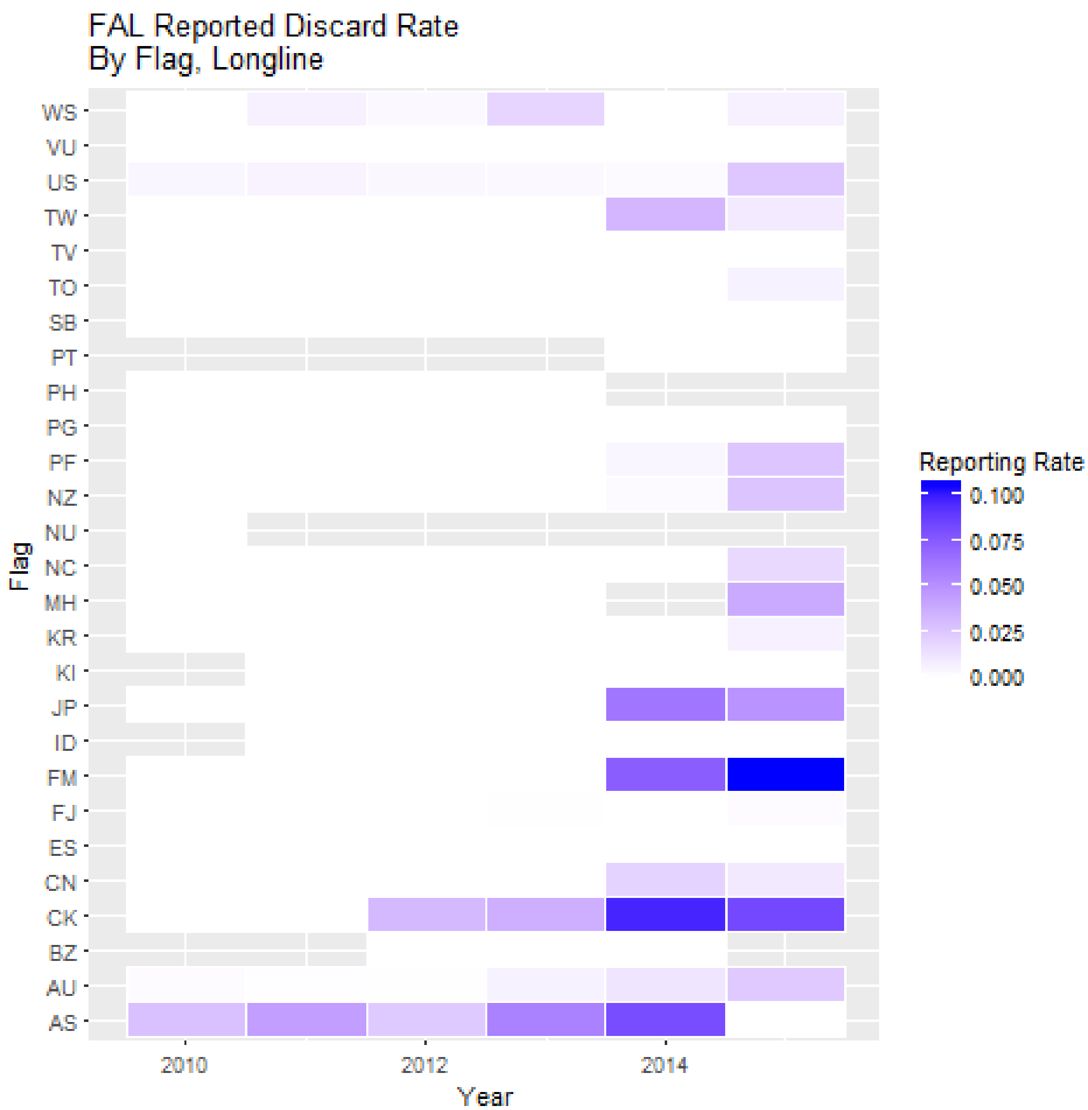
Blue shark reported discard rate:



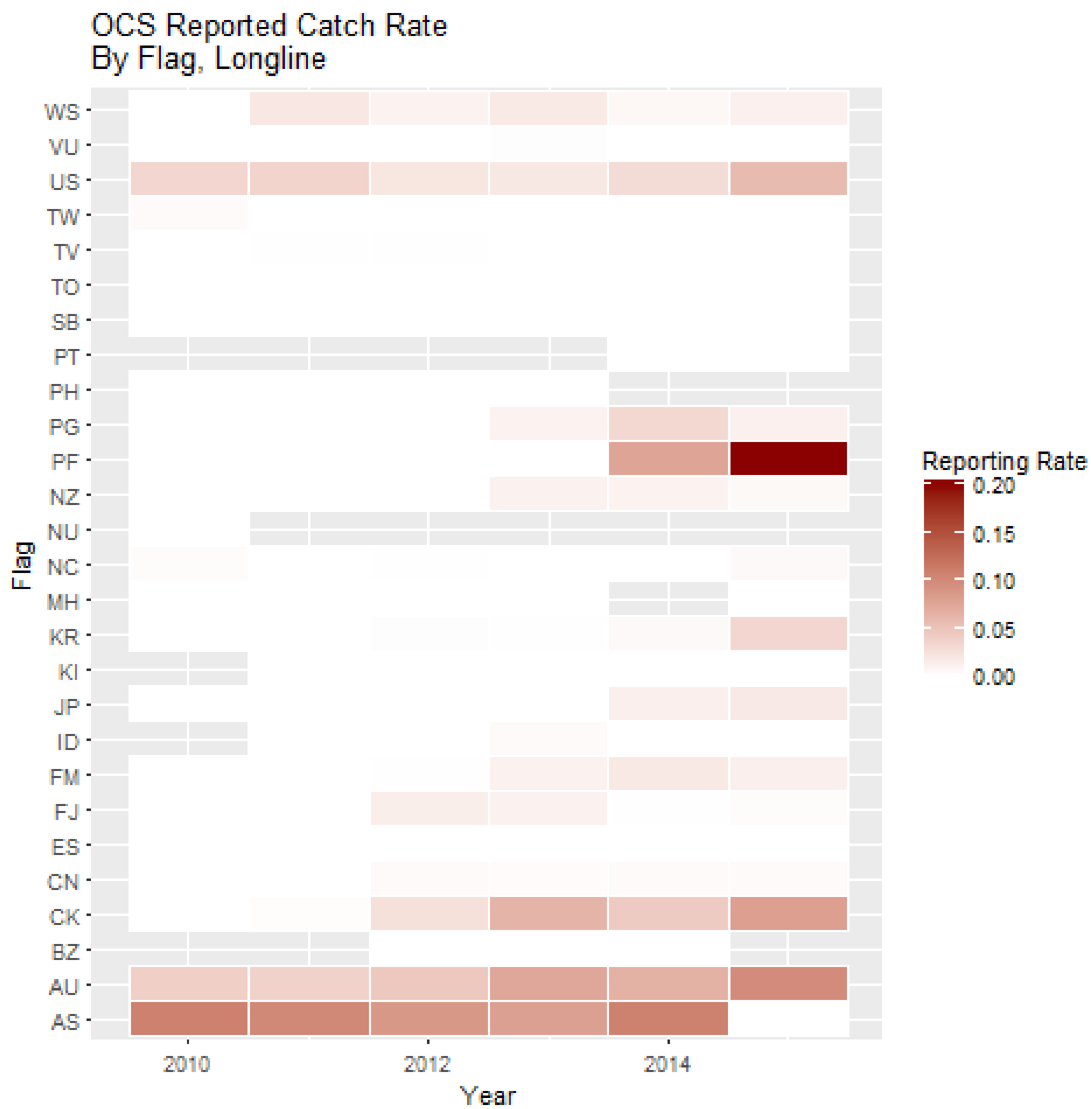
Silky shark reported catch rate:



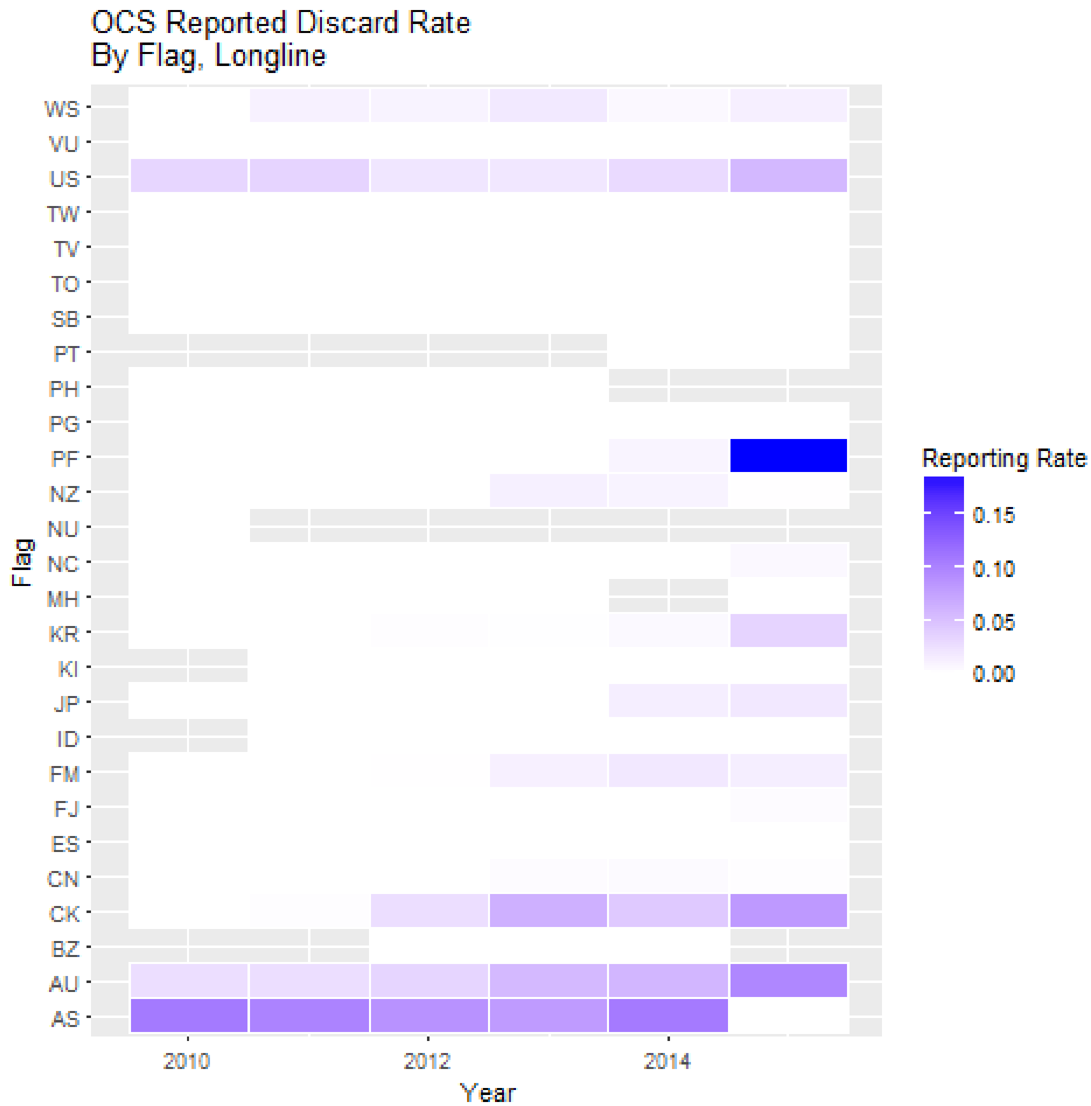
Silky shark reported discard rate:



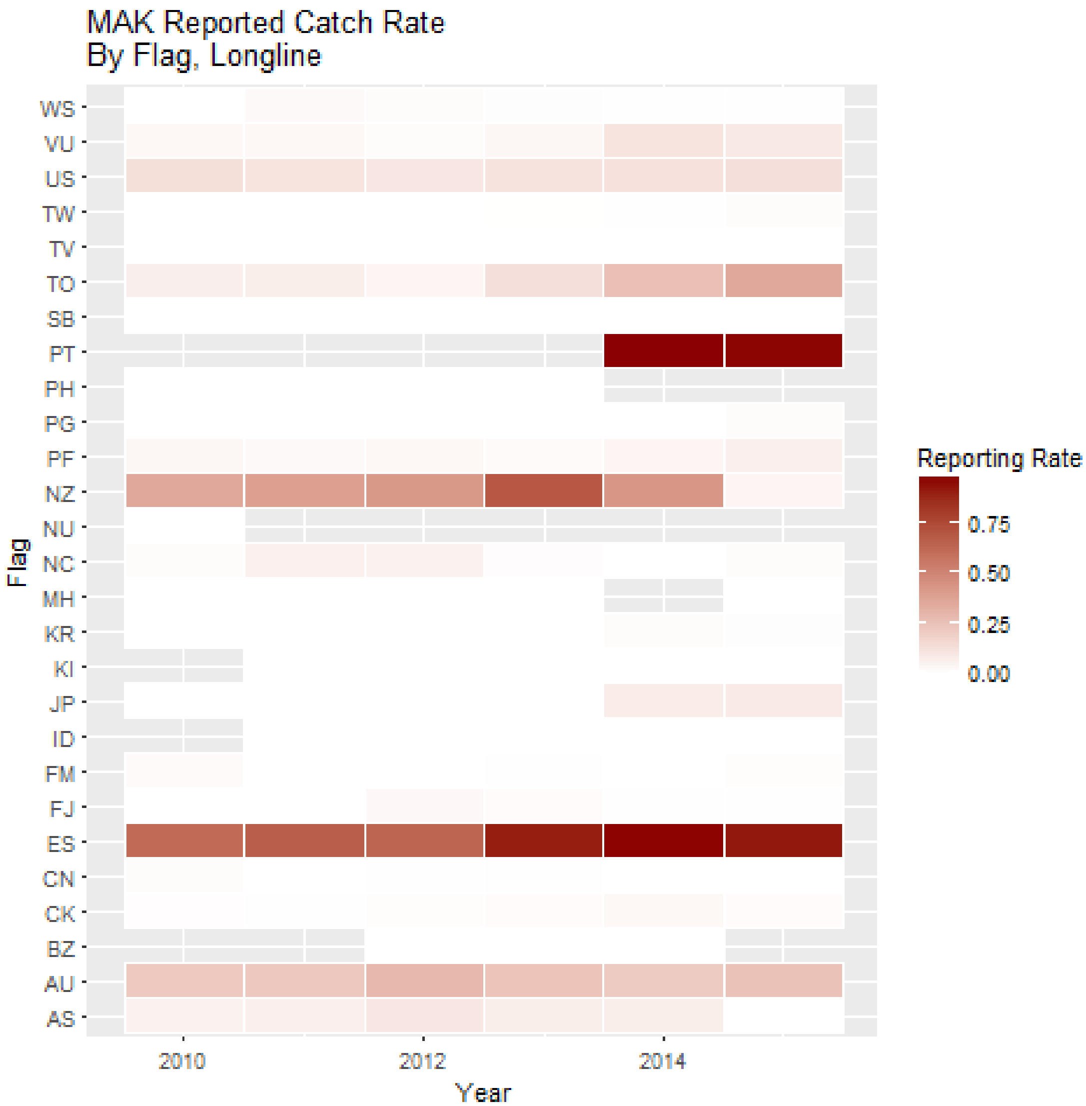
Oceanic whitetip reported catch rate:



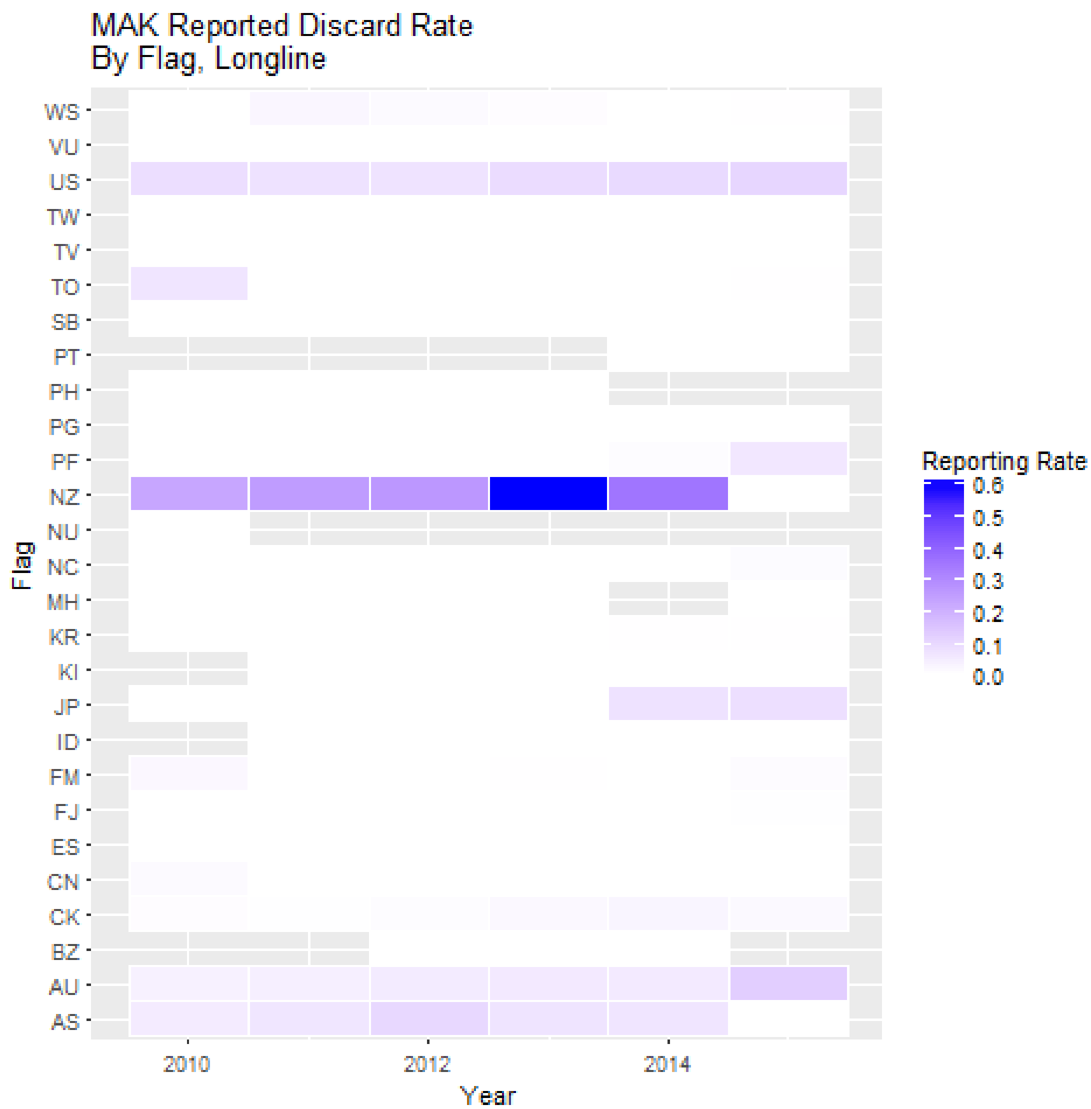
Oceanic whitetip reported discard rate:



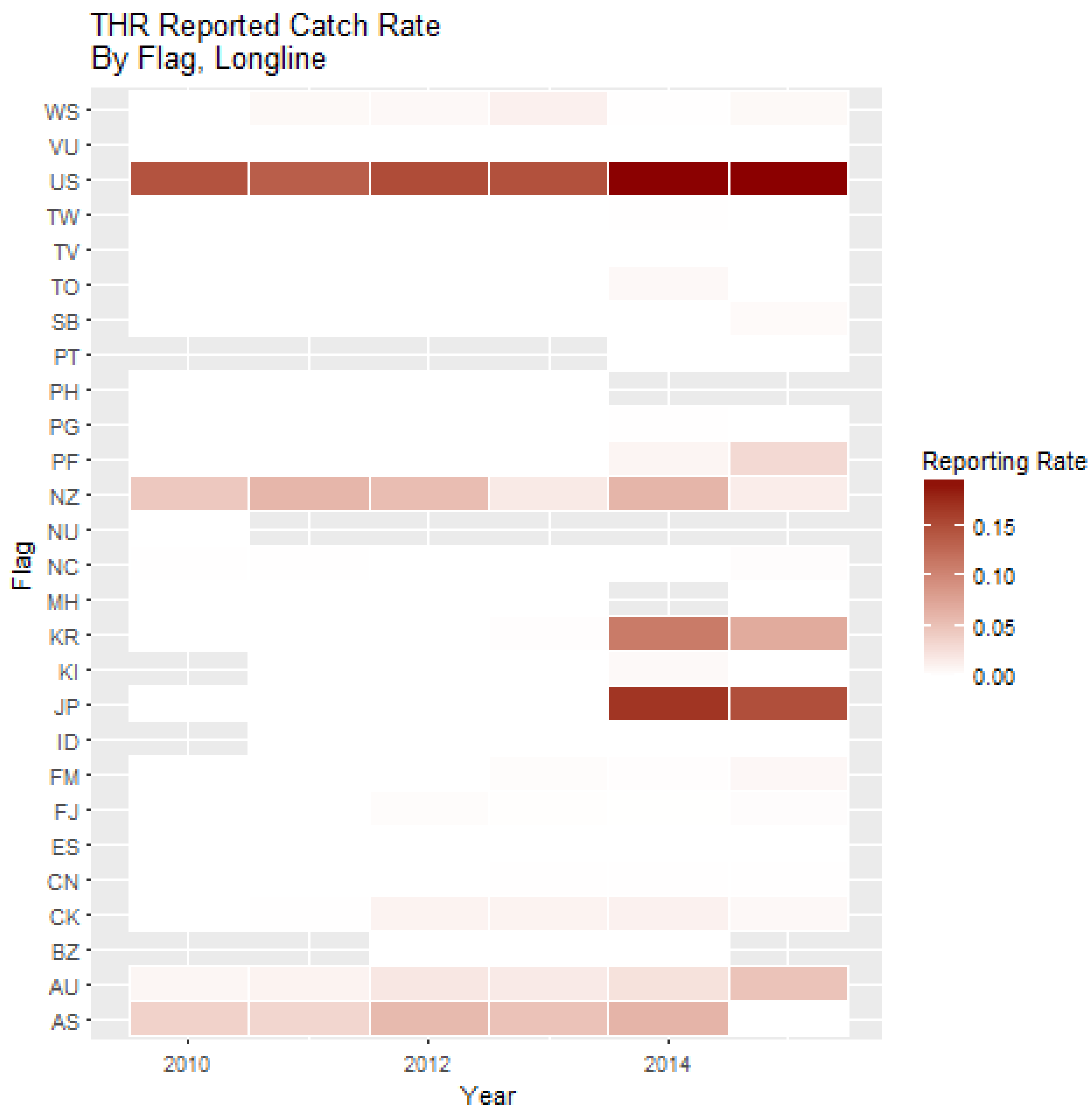
Mako shark reported catch rate:



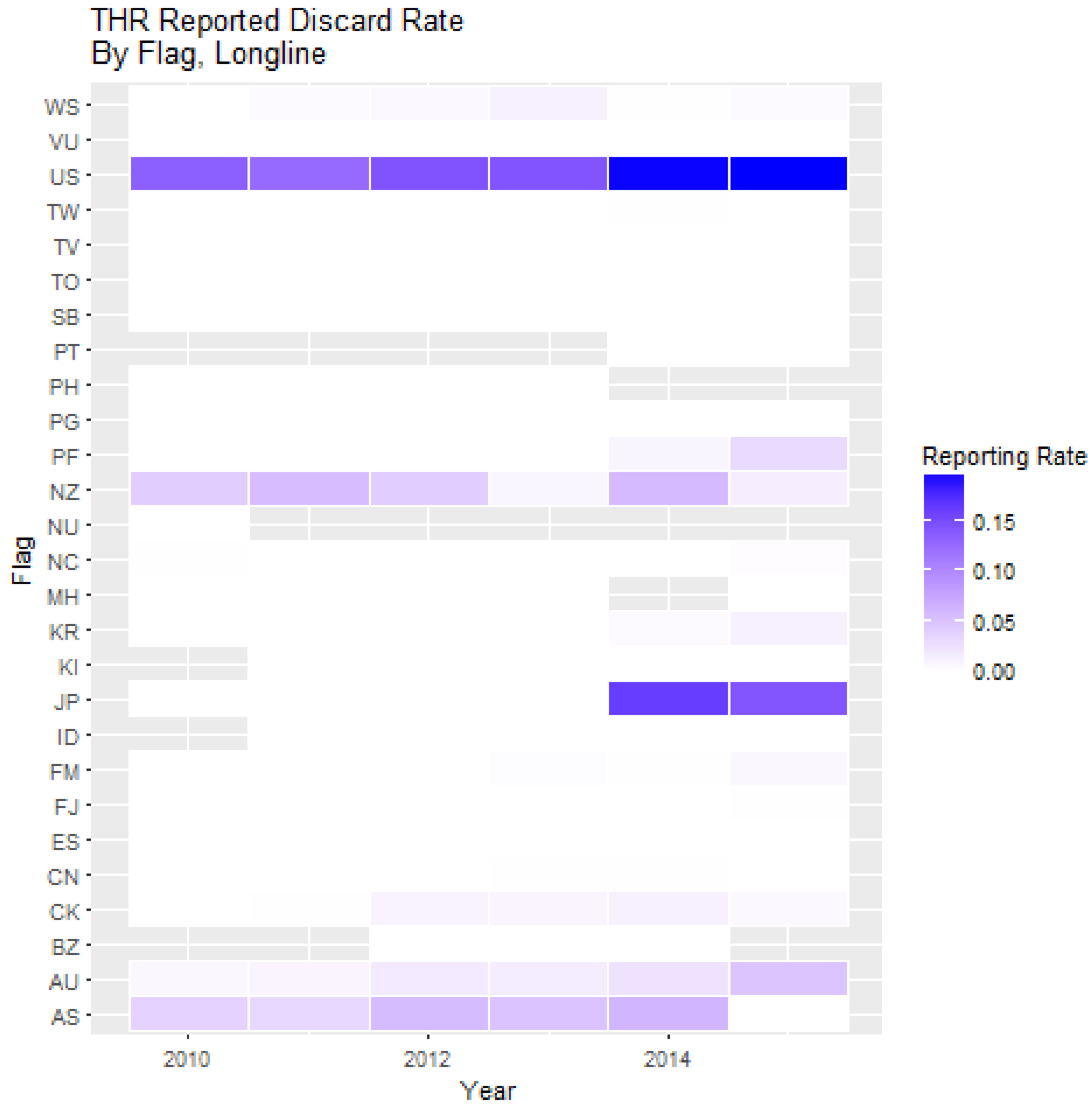
Mako shark reported discard rate:



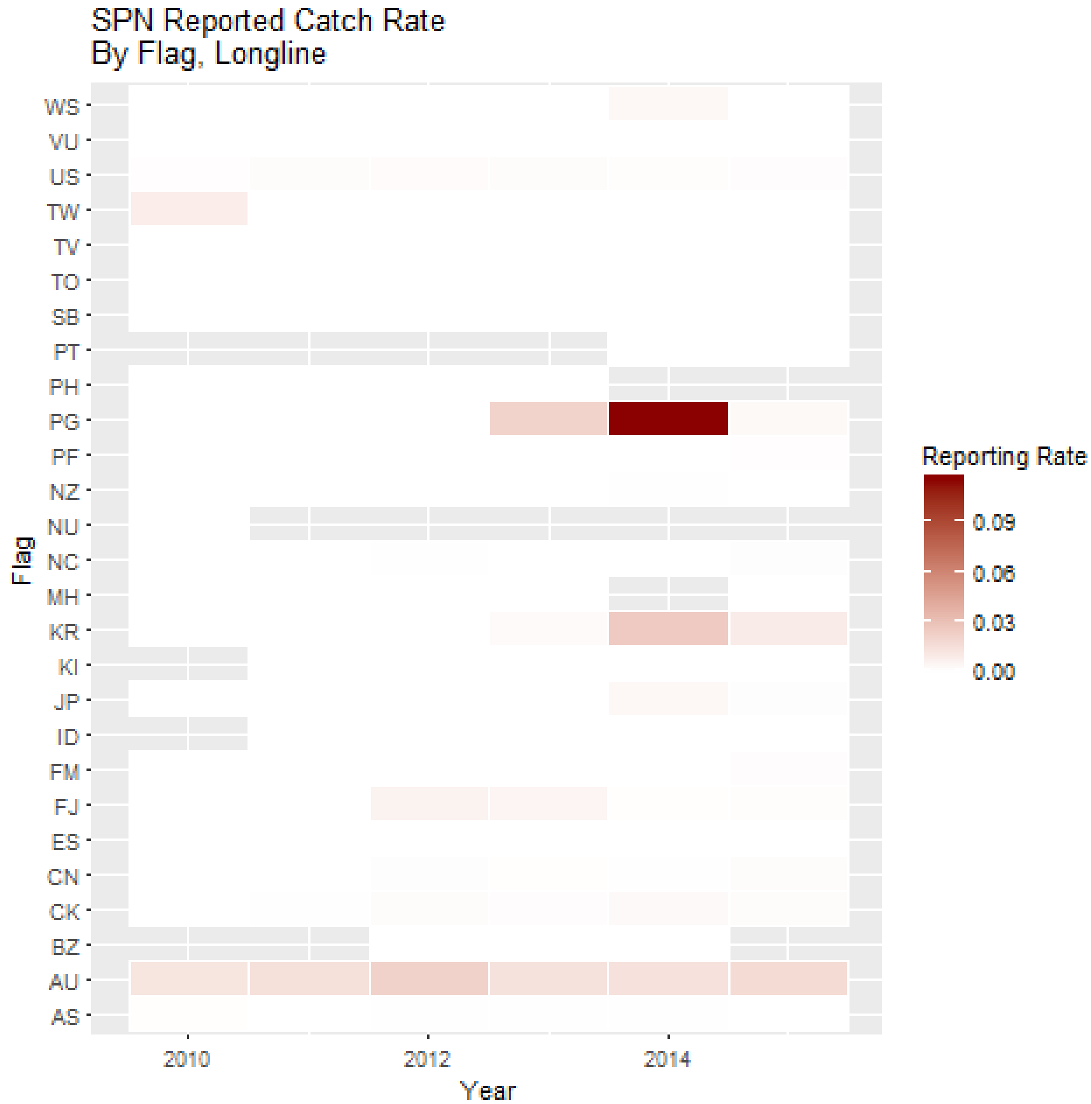
Thresher shark reported catch rate:



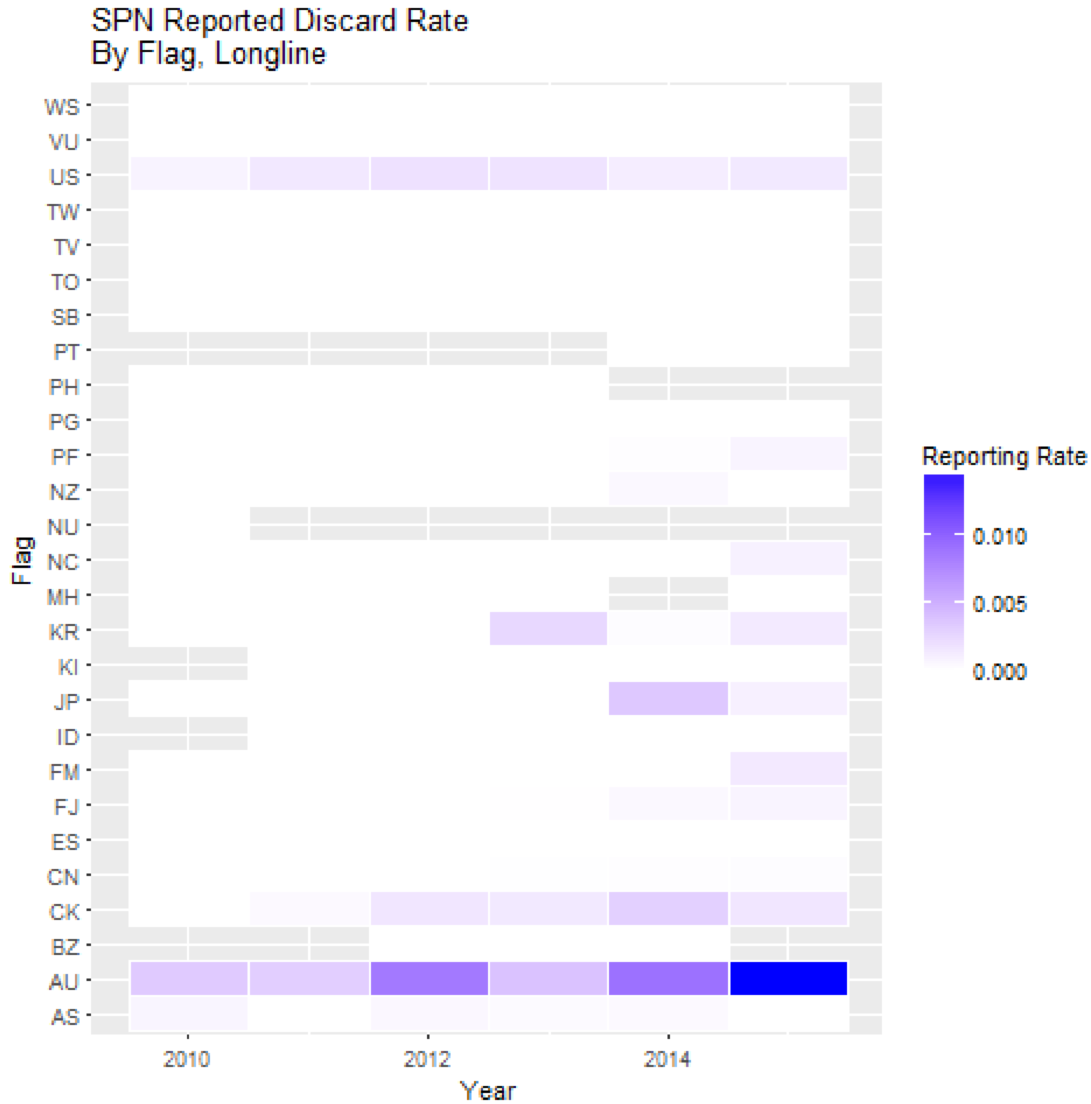
Thresher shark reported discard rate:



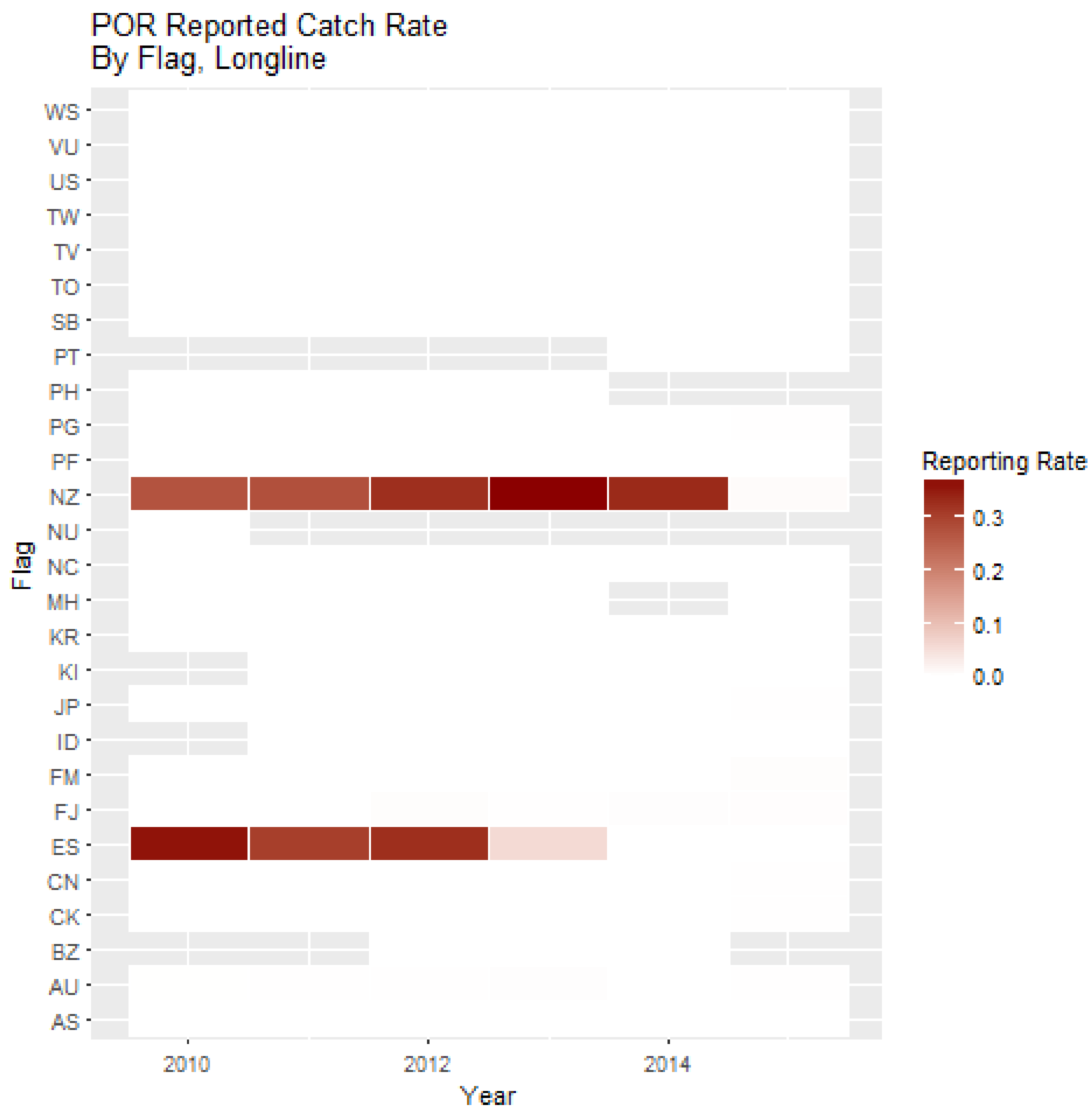
Hammerhead shark reported catch rate:



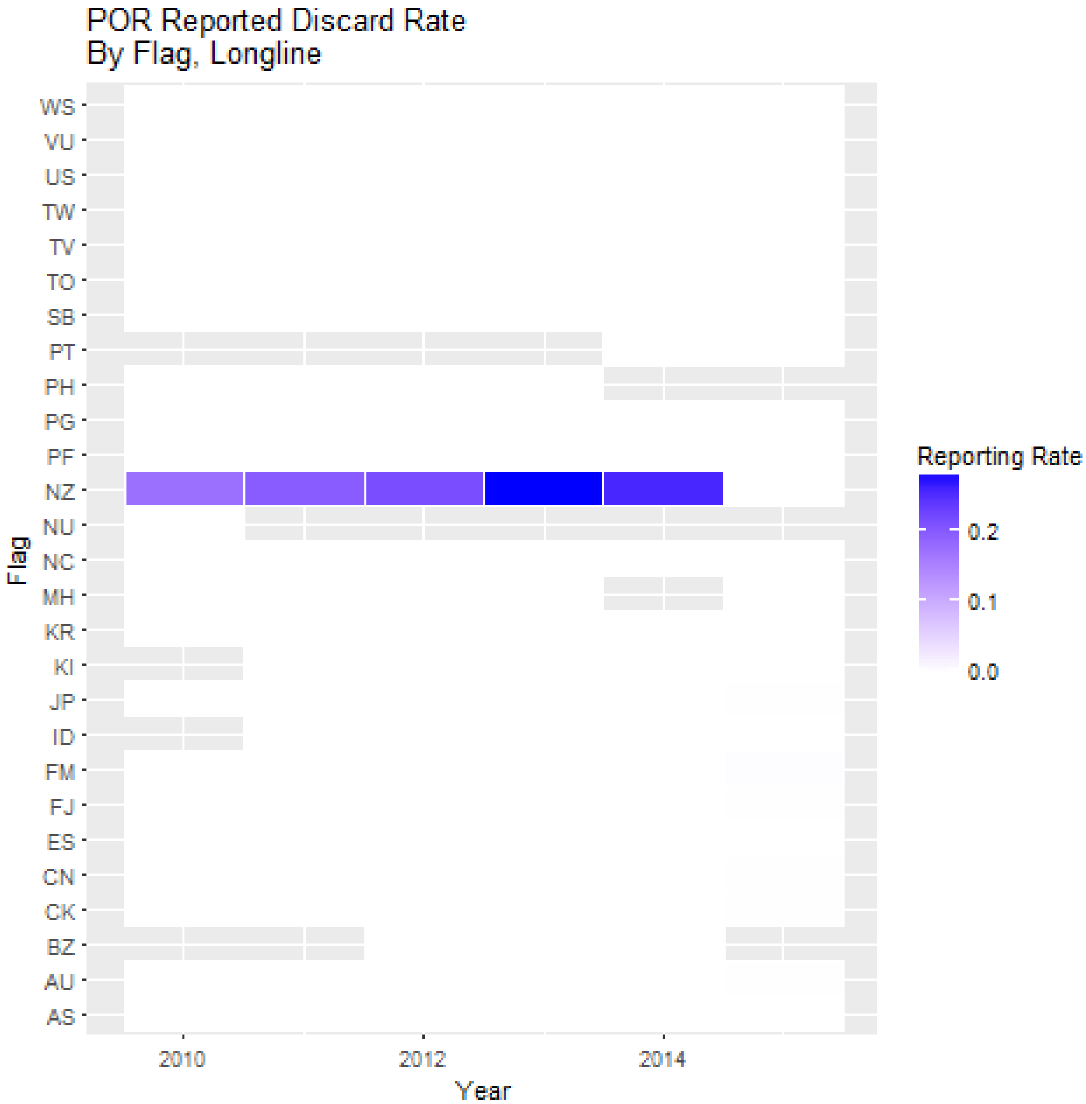
Hammerhead shark reported discard rate:



Porbeagle shark reported catch rate:

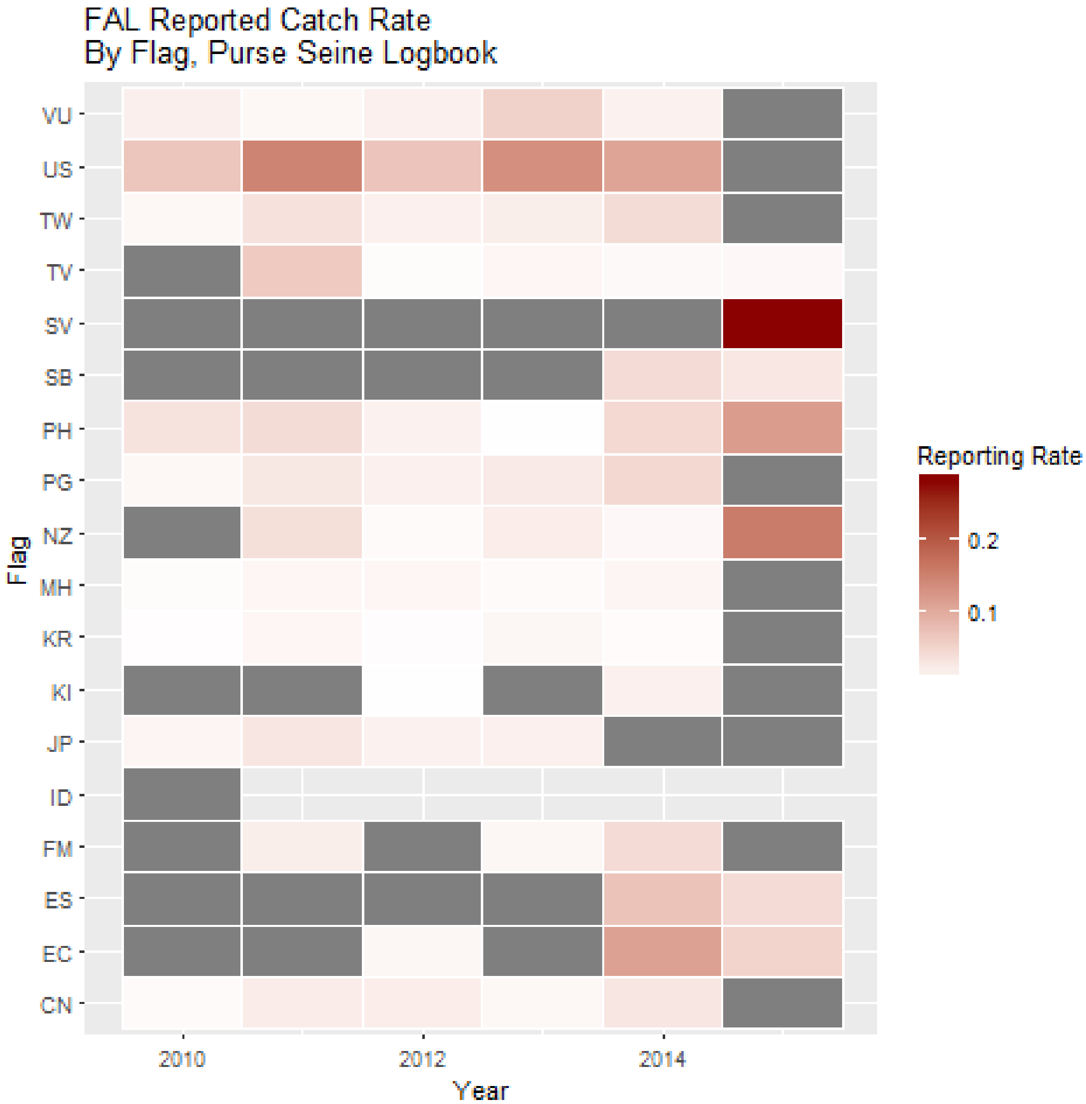


Porbeagle shark reported discard rate:

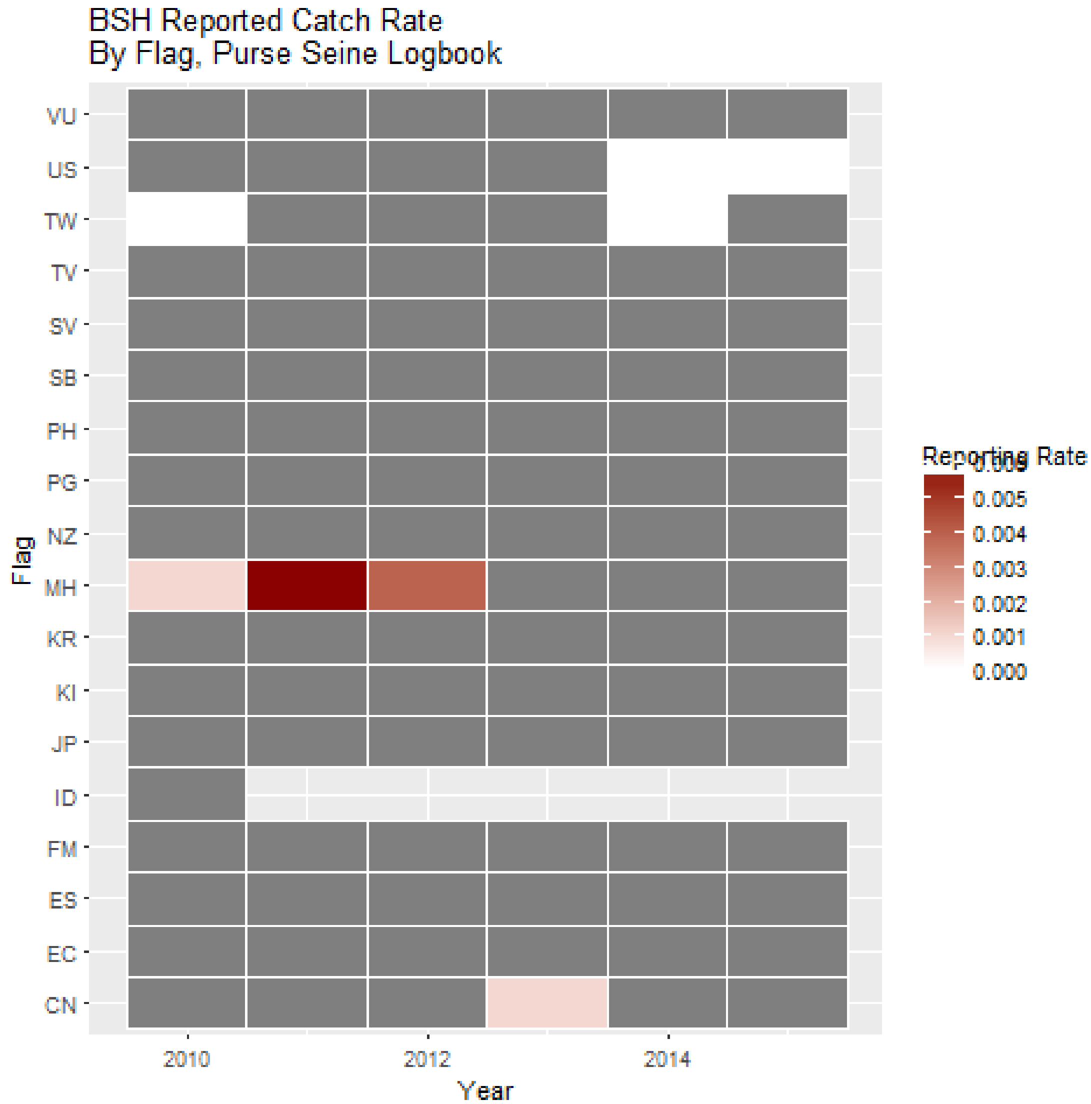


Annex 3 Reported Catch rate by species and flag, Purse Seine

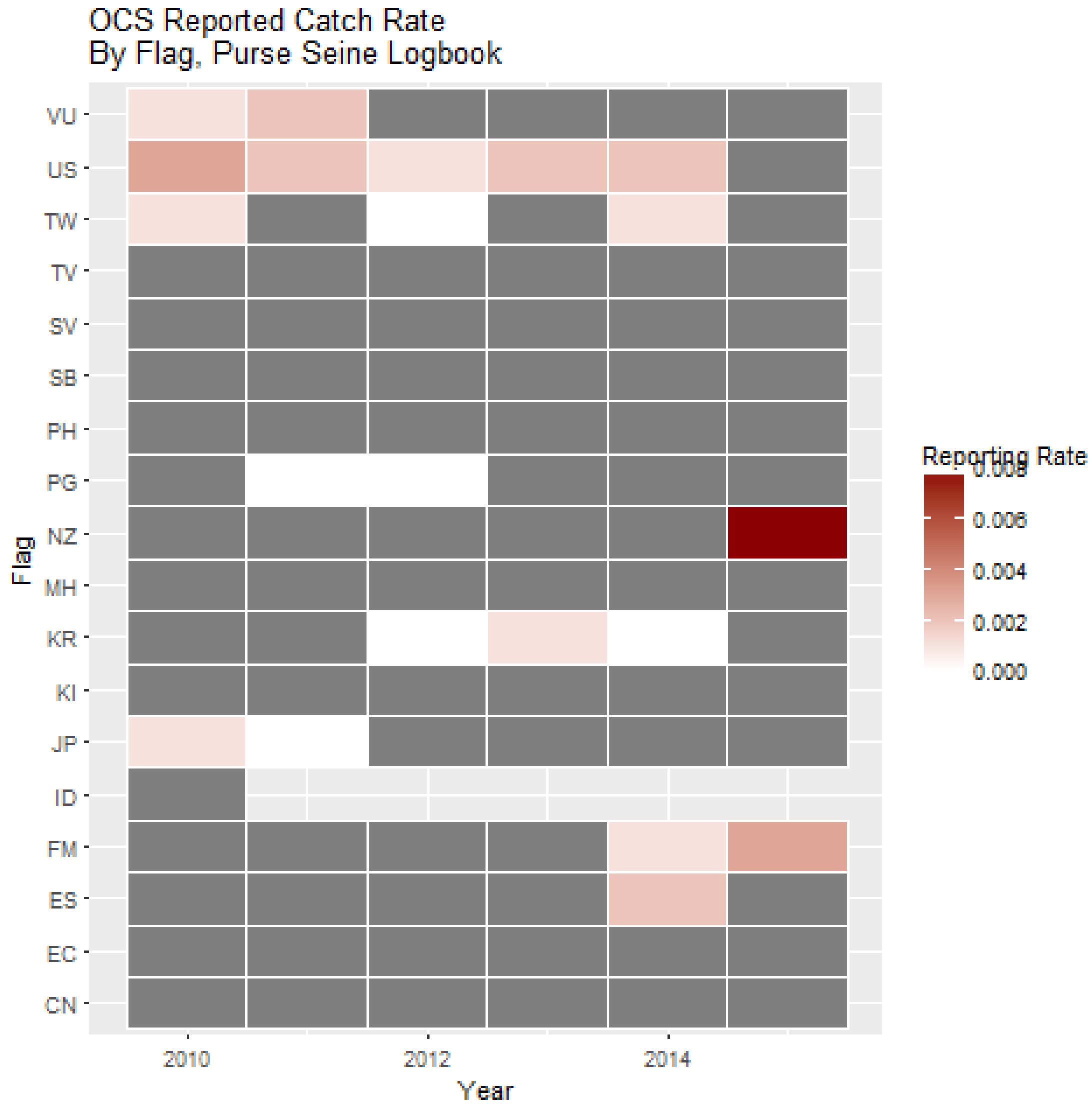
Silky shark reported catch rate:



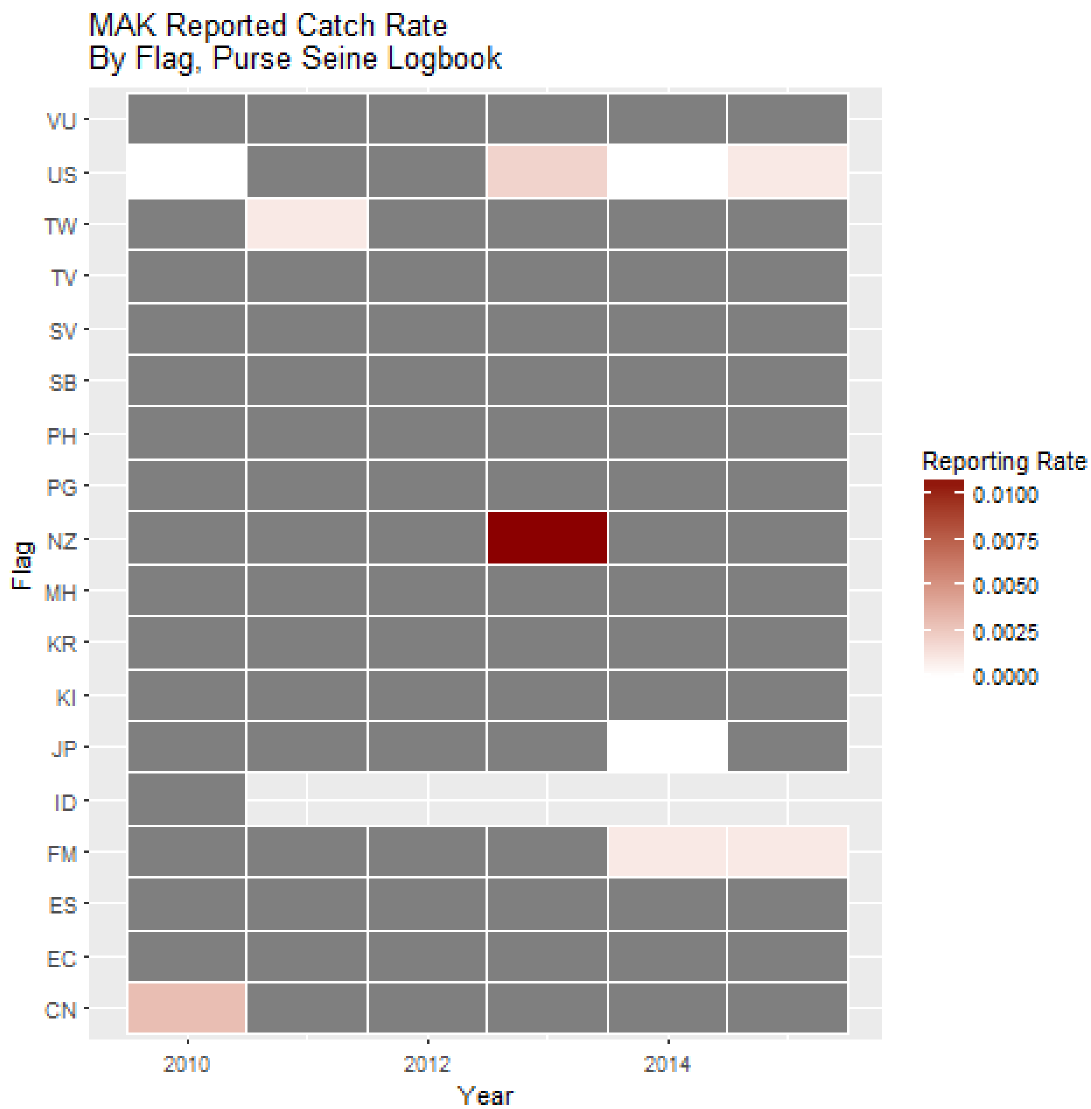
Blue shark reported catch rate:



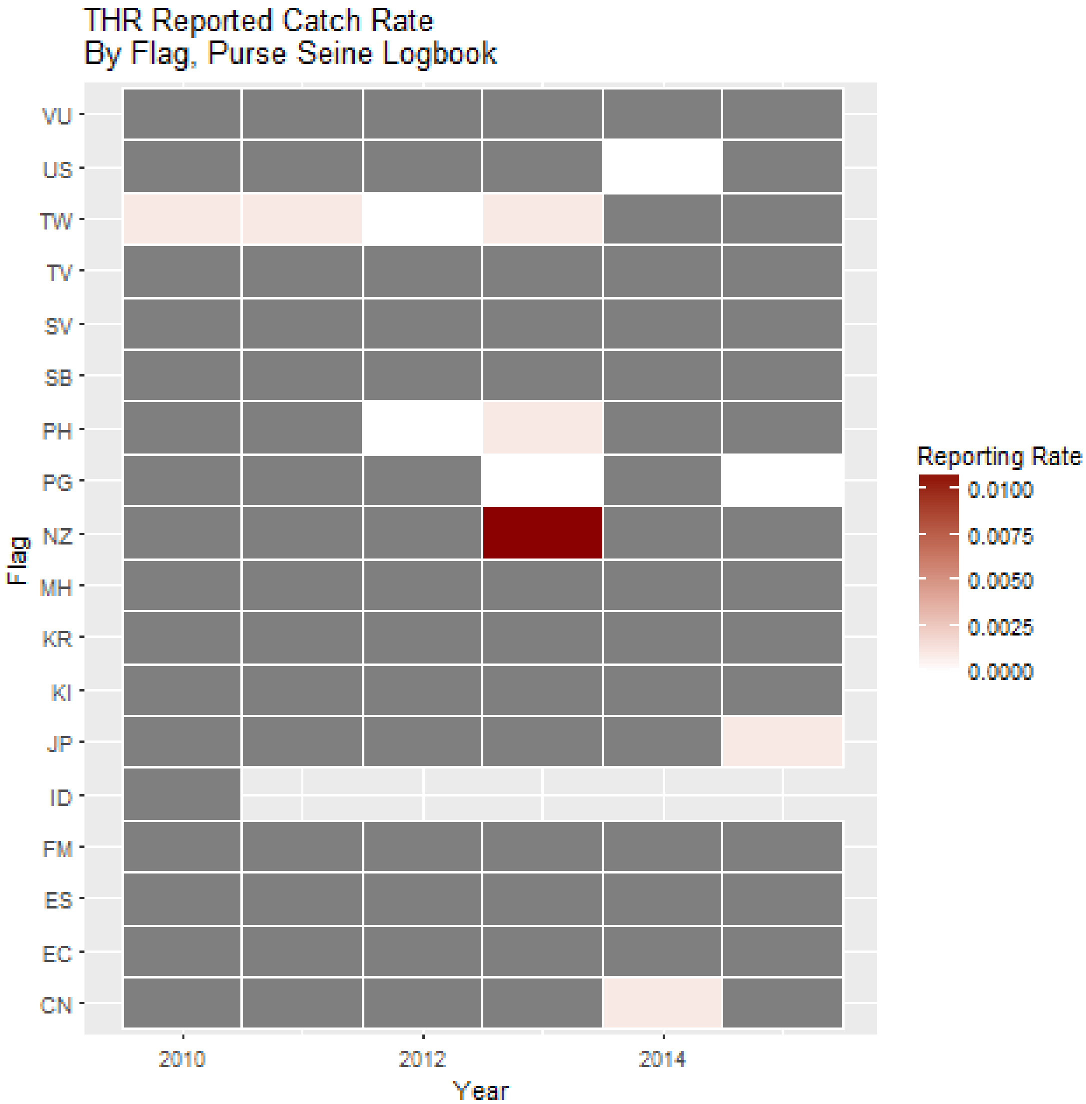
Oceanic whitetip shark reported catch rate:



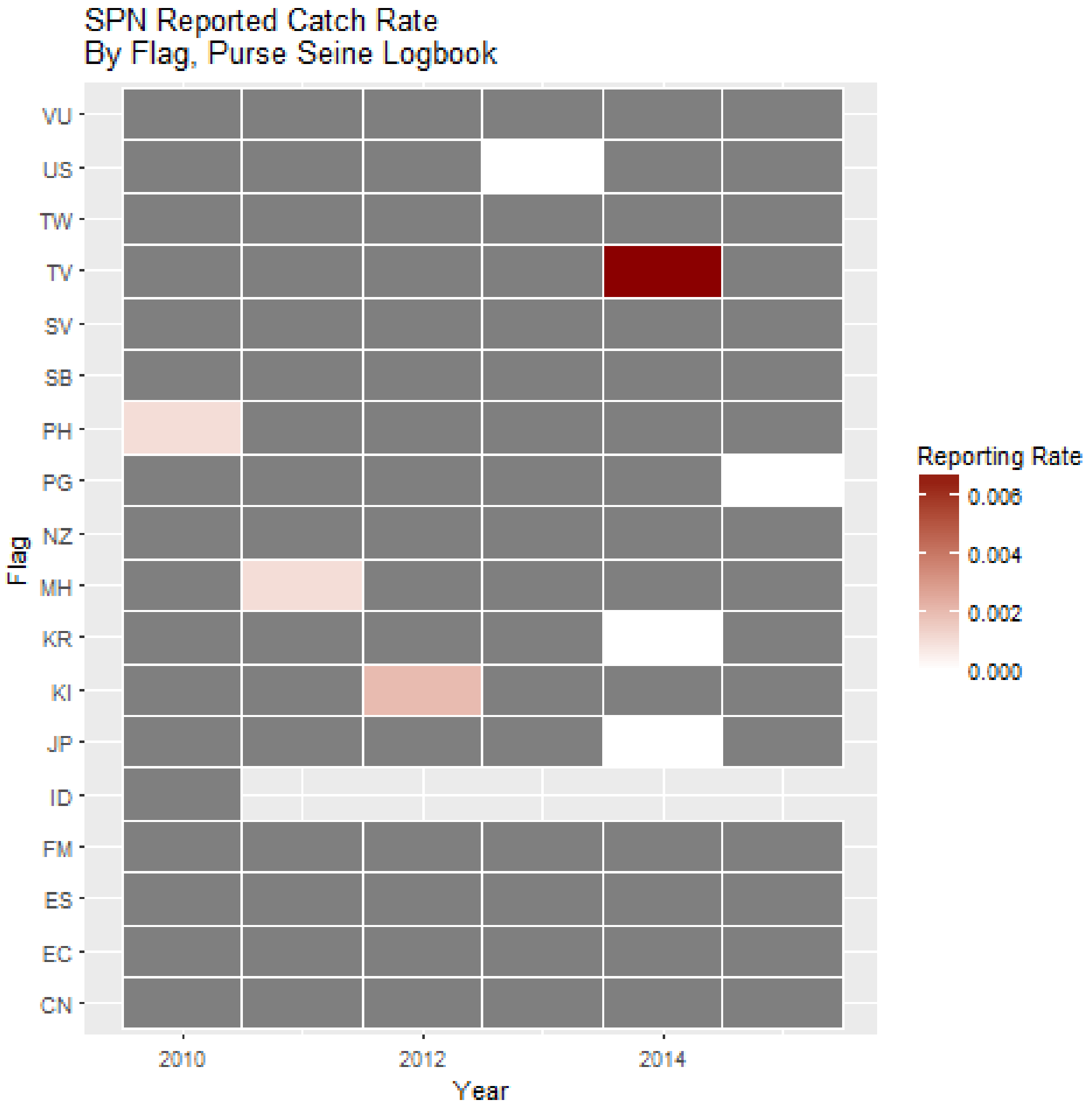
Mako shark reported catch rate:



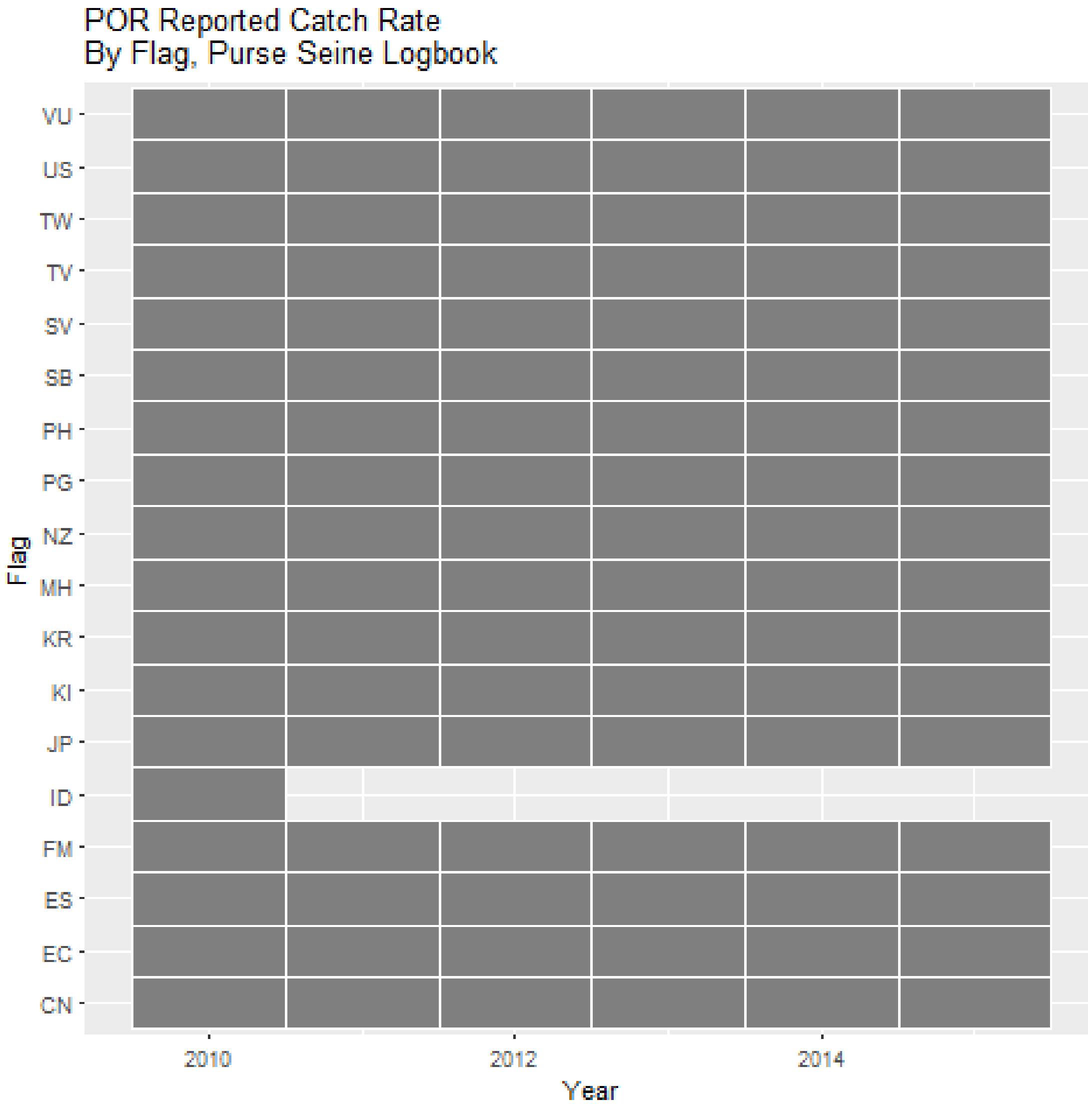
Thresher shark reported catch rate:



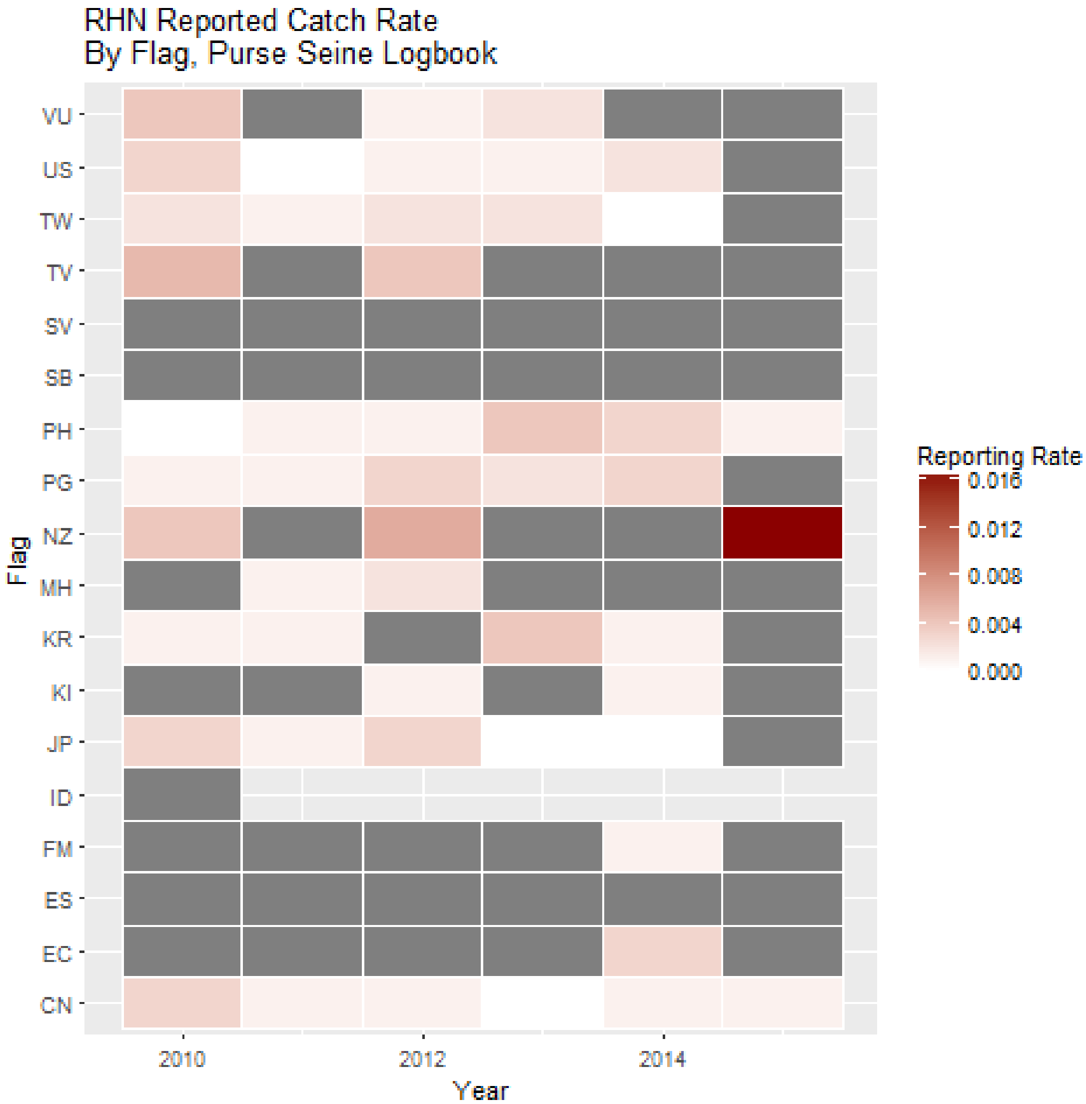
Hammerhead shark reported catch rate:



Porbeagle shark reported catch rate:



Whale shark reported catch rate:



Annex 4 Species Specific Assessment Decision Trees

Species Assessment Decision Tree (*Silky Shark -Carcharhinus falciformis*)

Silky Shark (Carcharhinus falciformis)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	Yes		Yes. WCPO assessment has been completed, a Pacific wide assessment is planned as part of the Common Oceans Program.
		Maturity	Reliable maturity schedule	Yes		
		Stock structure	Some understanding of stock structure	Yes		
		M	Reliable M estimate	Yes		
	Fisheries	Catch	Catch history (more than 20 years)	No	Yes	
		Effort	Effort data	Yes		
		Length	Length samples from some fisheries	Yes		
		Weight	Weight samples from some fisheries	Yes		
Medium Data Assessment Indicator based assessment (e.g. Rice et	Biology	Age and growth				
		Maturity				
		Stock structure				

al) or SRA - e.g. MIST (Fu *et al*.) Ref Pt F based	Fisheries	Catch				
		Effort				
		Length				
		Weight				
Data Poor Assessment, SPR or ERA- eg PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	PSA score	**PSA1**	**PSA2**	**PSA3**		Kirby and Hobday 2007. WCPFC-SC3-EB SWG/WP-1
	Deep Risk	MEDIUM	MEDIUM	MEDIUM		
	Shallow Risk	MEDIUM	MEDIUM	MEDIUM		

** Research should take into account the utility of any assessment*

Species Assessment Decision Tree (*Blue Shark – Prionace glauca*)

Blue Shark (Prionace glauca)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	Yes		**North Pacific:** Yes, most recent assessment was through 2015 (N. Pacific WCPFC-SC13-2017/ SA-WP-10. **South Pacific:** Possibly but large gaps in observer coverage exist, while data provided limited contrast for
		Maturity	Reliable maturity schedule	Yes		
		Stock structure	Some understanding of stock structure	Yes, evidence for Pacific wide North and South populations		
		M	Reliable M estimate	Yes		
	Fisheries	Catch	Catch history (more than 20 years)	No official landings	Yes in N. Pacific, has been done in the S. Pacific but inconsistencies exist	
		Effort	Effort data	Total aggregate effort for Purse Seine and Longline		
		Length	Length samples from some fisheries	Yes		
		Weight	Weight samples from some fisheries	Yes		

						assessment model
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth				
		Maturity				
		Stock structure				
	Fisheries	Catch				
		Effort				
		Length				
		Weight				
Data Poor Assessment, SPR or ERA- eg PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	PSA score	**PSA1**	**PSA2**	**PSA3**		
	Deep Risk	MEDIUM	MEDIUM	MEDIUM		
	Shallow Risk	MEDIUM	MEDIUM	LOW		

** Research should take into account the utility of any assessment.*

Species Assessment Decision Tree (*Pelagic thresher - Alopias pelagicus*)

Pelagic thresher (Alopias pelagicus)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	Yes	Drew et al. 2015	No
		Maturity	Reliable maturity schedule	Yes	Drew et al. 2015	
		Stock structure	Some understanding of stock structure	Yes		
		M	Reliable M estimate	No		
	Fisheries	Catch	Catch history (more than 20 years)	No		
		Effort	Effort data			
		Length	Length samples from some fisheries	Limited		
		Weight	Weight samples from some fisheries	Limited		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth		Yes	Drew et al. 2015	No, but catch estimates could be attempted
		Maturity		Yes	Drew et al. 2015	
		Stock structure		Yes		
	Fisheries	Catch		No	With High uncertainty	
		Effort		Reported Effort		
		Length		Limited		
		Weight		Limited		
Data Poor Assessment, SPR or ERA- e.g PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	PSA score	**PSA1**	**PSA2**	**PSA3**		Risk analysis should be updated.
	Deep Risk	MEDIUM	MEDIUM	MEDIUM		
	Shallow Risk	MEDIUM	MEDIUM	MEDIUM		

* *Research should take into account the utility of any assessment.*

Species assessment decision tree (*Common thresher - Alopias vulpinas*)

Common Thresher (Alopias vulpinas)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	Yes		No, not enough data
		Maturity	Reliable maturity schedule	No		
		Stock structure	Some understanding of stock structure	Yes		
		M	Reliable M estimate			
	Fisheries	Catch	Catch history (more than 20 years)	No	With high uncertainty	
		Effort	Effort data	Reported Effort		
		Length	Length samples from some fisheries	Limited information		
		Weight	Weight samples from some fisheries	Limited information		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth		Yes		Estimates of total catch and CPUE trends should be a priority.
		Maturity		Yes		
		Stock structure		No, assumed one		
	Fisheries	Catch		No	With high uncertainty	
		Effort		Reported Effort		
		Length		Limited information		
		Weight		Limited information		
Data Poor Assessment, SPR or ERA- eg PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	PSA score	**PSA1**	**PSA2**	**PSA3**		Risk assessments should be updated
	Deep Risk	MEDIUM	High	MEDIUM		
	Shallow Risk	MEDIUM	HIGH	MEDIUM		

* *Research should take into account the utility of any assessment.*

SRP Assessment decision tree (*Bigeye thresher - Alopias superciliosus*)

Bigeye Thresher (Alopias superciliosus)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	Yes		No, not enough data
		Maturity	Reliable maturity schedule	No		
		Stock structure	Some understanding of stock structure	Yes		
		M	Reliable M estimate			
	Fisheries	Catch	Catch history (more than 20 years)	No	With high uncertainty	
		Effort	Effort data	Reported Effort		
		Length	Length samples from some fisheries	Limited		
		Weight	Weight samples from some fisheries	Limited		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth		Yes		Recent (2017) sustainability risk assessment (MIST)
		Maturity		Yes		
		Stock structure		No, assumed one		
	Fisheries	Catch		No	With high uncertainty	
		Effort		Reported Effort		
		Length		Limited information		
		Weight		Limited information		
Data Poor Assessment, SPR or ERA- eg PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	PSA score	**PSA1**	**PSA2**	**PSA3**		
	Deep Risk	MEDIUM	MEDIUM	MEDIUM		
	Shallow Risk	MEDIUM	MEDIUM	MEDIUM		

** Research should take into account the utility of any assessment.*

Species Assessment Decision Tree (*Oceanic Whitetip, Carcharhinus longimanus*)

Oceanic Whitetip (Carcharhinus longimanus)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	Yes		Yes. Most recent assessment was in 2012. Note that changes in retention (CMM 11-04) may result in more uncertain CPUE trends and catch estimates in recent years.
		Maturity	Reliable maturity schedule	Yes		
		Stock structure	Some understanding of stock structure	Yes		
		M	Reliable M estimate	Yes		
	Fisheries	Catch	Catch history (more than 20 years)	No	Yes	
		Effort	Effort data	Yes	Purse Seine and	
		Length	Length samples from some fisheries	Yes		
		Weight	Weight samples from some fisheries	Yes		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth				
		Maturity				
		Stock structure				
	Fisheries	Catch				
		Effort				
		Length				
		Weight				
	PSA score	**PSA1**	**PSA2**	**PSA3**		
	Deep Risk	MEDIUM	MEDIUM	MEDIUM		

Data Poor Assessment, SPR or ERA- eg PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	Shallow Risk	MEDIUM	MEDIUM	MEDIUM		

** Research should take into account the utility of any assessment*

Species Assessment Decision Tree (*Porbeagle shark- Lamna nasus*)

Porbeagle shark (Lamna nasus)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	Yes (Francis et al 2015)		No the recent stock status assessment that used a spatially-explicit risk assessment methodology determined that estimated that fishing mortality on porbeagle shark stock is very low.
		Maturity	Reliable maturity schedule	Yes (Francis et al 2015)		
		Stock structure	Some understanding of stock structure	Yes		
		M	Reliable M estimate	Yes		
	Fisheries	Catch	Catch history (more than 20 years)	No	Can be estimated	
		Effort	Effort data	Reported Effort		
		Length	Length samples from some fisheries	Limited		
		Weight	Weight samples from some fisheries	Limited		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth		Yes (Francis et al 2015)		Yes
		Maturity		Yes (Francis et al 2015)		
		Stock structure		Yes		
	Fisheries	Catch		Yes		
		Effort		Yes		
		Length		Yes		
		Weight		Yes		
	PSA score	**PSA1**	**PSA2**	**PSA3**		

Data Poor Assessment, SPR or ERA- eg PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	Deep Risk	MEDIUM	MEDIUM	MEDIUM		
	Shallow Risk	MEDIUM	MEDIUM	MEDIUM		

** Research should take into account the utility of any assessment.*

Species Assessment Decision Tree (*Shortfin mako - Isurus oxyrinchus*)

Shortfin-mako (Isurus oxyrinchus) Northern Hemisphere						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	Yes		Next stock assessment scheduled for 2018 through the ISC Shark Working Group.
		Maturity	Reliable maturity schedule	No	Uncertainty with the reproductive cycle timing and the gestation period (9-25 mo.)	
		Stock structure	Some understanding of stock structure	Yes		
		M	Reliable M estimate			
	Fisheries	Catch	Catch history (more than 20 years)	No	Yes	
		Effort	Effort data	Yes, mostly longline effort		
		Length	Length samples from some fisheries	Yes for some		
		Weight	Weight samples from some fisheries	Yes for some.		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al*.) Ref Pt F based	Biology	Age and growth				
		Maturity				
		Stock structure				
	Fisheries	Catch				
		Effort				
		Length				
		Weight				
Data Poor Assessment, SPR or ERA- eg PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	PSA score	**PSA1**	**PSA2**	**PSA3**		Kirby and Hobday 2007. WCPFC-
	Deep Risk	MEDIUM	MEDIUM	MEDIUM		

						SC3-EB SWG/WP-1

** Research should take into account the utility of any assessment.*

Species Assessment Decision Tree (*Shortfin mako - Isurus oxyrinchus*)

Short finned mako (Isurus oxyrinchus) – Southern Hemisphere						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	Yes		Yes – noting catch uncertainty
		Maturity	Reliable maturity schedule	No	Uncertainty with the reproductive cycle timing and the gestation period (9-25 mo.)	
		Stock structure	Some understanding of stock structure	Yes		
		M	Reliable M estimate	Yes	Approximate estimates 0.1-0.15	
	Fisheries	Catch	Catch history (more than 20 years)	No	Yes	
		Effort	Effort data	Yes, mostly longline effort		
		Length	Length samples from some fisheries	Yes for some fleets		
		Weight	Weight samples from some fisheries	Yes for some fleets		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth				Yes estimates of catch and indices of abundance should be produced and checked for reliability
		Maturity				
		Stock structure				
	Fisheries	Catch				
		Effort				
		Length				
		Weight				

Data Poor Assessment, SPR or ERA- eg PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	PSA score	**PSA1**	**PSA2**	**PSA3**		Kirby and Hobday 2007. WCPFC-SC3-EB SWG/WP-1
	Deep Risk	MEDIUM	MEDIUM	MEDIUM		
	Shallow Risk	MEDIUM	MEDIUM	MEDIUM		

** Research should take into account the utility of any assessment*

Species Assessment Decision Tree (*Great hammerhead shark - Sphyrna mokarran*)

Great hammerhead (Sphyrna mokarran)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	No		No
		Maturity	Reliable maturity schedule	No	Yes- based on studies from other areas	
		Stock structure	Some understanding of stock structure	Limited	HHD sharks are often misidentified	
		M	Reliable M estimate			
	Fisheries	Catch	Catch history (more than 20 years)	No	With high uncertainty	
		Effort	Effort data			
		Length	Length samples from some fisheries	Very Limited		
		Weight	Weight samples from some fisheries	Very Limited		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth		No	Eastern Pacific estimates exist	Estimates of overall catches would be the first step towards an SRA type analysis.
		Maturity		No	Regional information	
		Stock structure		No	General information only.	
	Fisheries	Catch		No	With high uncertainty	
		Effort		Reported		
		Length		Minimal observed species specific data		
		Weight		Minimal observed species specific data		
	PSA score	**PSA1**	**PSA2**	**PSA3**		
	Deep Risk	MEDIUM	MEDIUM	MEDIUM		

Data Poor Assessment, SPR or ERA- eg PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	Shallow Risk	MEDIUM	MEDIUM	MEDIUM		Yes, should be updated

**Research should take into account the utility of any assessment.*

Species Assessment Decision Tree (*Scalloped hammerhead - Sphyrna lewini*)

Scalloped hammerhead (*Sphyrna lewini)*						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	Yes		No
		Maturity	Reliable maturity schedule	No	Yes- based on studies from other areas	
		Stock structure	Some understanding of stock structure	Limited	HHD sharks are often misidentified	
		M	Reliable M estimate			
	Fisheries	Catch	Catch history (more than 20 years)	No	With high uncertainty	
		Effort	Effort data			
		Length	Length samples from some fisheries	Very Limited		
		Weight	Weight samples from some fisheries	Very Limited		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth		No	Eastern Pacific estimates exist	Estimates of overall catches would be the first step towards an SRA type analysis.
		Maturity		No	Regional information	
		Stock structure		No	General information only.	
	Fisheries	Catch		No	With high uncertainty	
		Effort		Reported		
		Length		Minimal observed species specific data		
		Weight		Minimal observed species specific data		
Data Poor Assessment, SPR or ERA- eg PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	PSA score	**PSA1**	**PSA2**	**PSA3**		Yes, should be updated
	Deep Risk	MEDIUM	HIGH	MEDIUM		
	Shallow Risk	MEDIUM	HIGH	MEDIUM		

** Research should take into account the utility of any assessment*

Species Assessment Decision Tree (*Smooth hammerhead shark - Sphyrna zygaena*)

Smooth hammerhead (Sphyrna zygaena)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	No		No
		Maturity	Reliable maturity schedule	No	Yes- based on studies from other areas	
		Stock structure	Some understanding of stock structure	Limited	HHD sharks are often not misidentified	
		M	Reliable M estimate			
	Fisheries	Catch	Catch history (more than 20 years)	No	With high uncertainty	
		Effort	Effort data			
		Length	Length samples from some fisheries	Very Limited		
		Weight	Weight samples from some fisheries	Very Limited		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth		No	Eastern Pacific estimates exist	Estimates of overall catches would be the first step towards an SRA type analysis.
		Maturity		No	Regional information	
		Stock structure		No	General information only.	
	Fisheries	Catch		No	With high uncertainty	
		Effort		Reported		
		Length		Minimal observed species specific data		
		Weight		Minimal observed species specific data		
	PSA score	**PSA1**	**PSA2**	**PSA3**		

Data Poor Assessment, SPR or ERA- eg PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	Deep Risk	MEDIUM	HIGH	MEDIUM		Yes, should be updated
	Shallow Risk	MEDIUM	HIGH	MEDIUM		

** Research should take into account the utility of any assessment*

Species Assessment Decision Tree (*Winghead Shark - Eusphyra blochii*)

Winghead shark (Eusphyra blochii)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	No		No
		Maturity	Reliable maturity schedule	No	Yes- based on studies from other areas	
		Stock structure	Some understanding of stock structure	Limited	HHD sharks are often misidentified	
		M	Reliable M estimate			
	Fisheries	Catch	Catch history (more than 20 years)	No	With high uncertainty	
		Effort	Effort data			
		Length	Length samples from some fisheries	Very Limited		
		Weight	Weight samples from some fisheries	Very Limited		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth		Yes	Estimates from Australia and Eastern Pacific exist.	Estimates of overall catches would be the first step towards an SRA type analysis.
		Maturity		No	Regional information	
		Stock structure		No	General information only.	
	Fisheries	Catch		No	With high uncertainty	
		Effort		Reported		
		Length		Minimal observed species specific data		
		Weight		Minimal observed species specific data		
	PSA score	**PSA1**	**PSA2**	**PSA1**		Not Assessed in
	Deep Risk					

Data Poor Assessment, SPR or ERA- e.g. PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	Shallow Risk					Kirby and Hobday 2007. Risk assessments should be updated,

** Research should take into account the utility of any assessment.*

Species Assessment Decision Tree (*Whale Shark - Rhincodon typus*)

Whale Shark (Rhincodon typus)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates	No		No
		Maturity	Reliable maturity schedule	No		
		Stock structure	Some understanding of stock structure	No		
		M	Reliable M estimate	No		
	Fisheries	Catch	Catch history (more than 20 years)	No		
		Effort	Effort data	Yes		
		Length	Length samples from some fisheries for	Limited		
		Weight	Weight samples from some fisheries	Limited		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth		Limited information		As part of the 2018 Common Oceans program a Pacific wide analysis of whale shark purse seine interactions.
		Maturity		Limited information		
		Stock structure		Limited information		
	Fisheries	Catch		No		
		Effort		No		
		Length		Limited		
		Weight		Limited		
Data Poor Assessment, SPR or ERA- e.g. PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	PSA score	**PSA1**	**PSA2**	**PSA3**		Kirby and Hobday 2007. WCPFC-SC3-
	Deep Risk	HIGH	MEDIUM	MEDIUM		
	Shallow Risk	HIGH	MEDIUM	MEDIUM		

						EB SWG/WP-1

** Research should take into account the utility of any assessment*

Species Assessment Decision Tree (Mobulidae, which includes manta rays and mobula rays)

Manta and Mobula rays (Mobulidae)						
Assessment type	Inputs		Data needs	Do we have it (*may need to provide detail*)	Can we get it or estimate it? (*may need to provide detail*)	Can we do it?* (*if NO, should we work towards this, if YES should we do it*)
Data Rich Assessment. Integrated or other analytic assessment - e.g. Rice et al. Ref Pt F&B based	Biology	Age and growth	Reliable length-at-age estimates			No
		Maturity	Reliable maturity schedule			
		Stock structure	Some understanding of stock structure			
		M	Reliable M estimate			
	Fisheries	Catch	Catch history (more than 20 years)			
		CPUE	Effort data	Reported effort, no CPUE		
		Length	Length samples from some fisheries	Extremely limited, many different measurements		
		Weight	Weight samples from some fisheries	No		
Medium Data Assessment Indicator based assessment (e.g. Rice et al) or SRA - e.g. MIST (Fu *et al.*) Ref Pt F based	Biology	Age and growth				No, better data collection should b e a priority.
		Maturity				
		Stock structure				
	Fisheries	Catch Fisheries				
		Effort				
		Length		Extremely limited, many different measurements		
		Weight		No		
	PSA score	**PSA1**	**PSA2**	**PSA3**		Risk assessments
	Deep Risk	MEDIUM	HIGH	MEDIUM		

Data Poor Assessment, SPR or ERA- e.g. PSA (Kirby *and Hobday*) Or Risk indicator Risk H, M, L	Shallow Risk	MEDIUM	HIGH	MEDIUM		should be updated.

** Research should take into account the utility of any assessment.*