SCIENTIFIC COMMITTEE
ELEVENTH REGULAR SESSION
Pohnpei, Federated States of Micronesia
5–13 August 2015

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

WCPFC-SC11-2015/SA-IP-05

Joel Rice[1], Laura Tremblay-Boyer, and Shelton Harley

[1]Joel Rice Consulting Ltd.

Contents

1 Introduction 3
1.1 Report layout 3

2 Description of Data 4
2.1 Longline Fishery Data 4
2.2 Purse Seine data 6

3 Distribution Indicator Analyses 7
3.1 Introduction 7
3.2 Methods 7
3.3 Results 8
3.3.1 Blue Shark 8
3.3.2 Mako Shark 8
3.3.3 Silky Shark 8
3.3.4 Oceanic Whitetip Shark 9
3.3.5 Thresher Shark 9
3.3.6 Hammerhead Shark 9
3.3.7 Porbeagle Shark 9
3.4 Conclusions 10

4 Observed Species Composition Indicator Analyses 10
4.1 Introduction 10
4.2 Conclusions 11

5 Catch Per Unit Effort indicator analyses 13
5.1 Introduction 13
5.2 Methods 13
5.3 Results 15
5.3.1 Blue Shark 16
5.3.2 Mako Shark 16
5.3.3 Silky Shark 17
5.3.4 Oceanic Whitetip Shark 17
5.3.5 Thresher Shark 17
5.4 Conclusions 17

6 Biological indicator analyses 18
6.1 Introduction 18
6.2 Methods 18
6.3 Results 19
6.4 Results 21
6.5 Conclusions 21

7 Feasibility of Stock Assessments 22

8 Impact of Recent Shark Management Measures 23

9 Conclusions 0

10 Research Recommendations and Management Implications **1**

11 Appendices **2**

11.1 CPUE Indicators. Model diagnostics and extra plots 2

12 Tables **2**

1 Introduction

Sharks are typically caught as bycatch in the Pacific tuna fisheries, though some directed and/or mixed species fisheries also exist. The status of the shark species designated as key shark species in 2011 (blue, mako, thresher, silky oceanic whiteip sharks) in the western and central Pacific Ocean (WCPO) ADD REF underwent a comprehensive review in 2011 (**?**). This review presented a number of indicators to inform on the status of the stock of these shark species and their response to fishing pressure. Given the paucity of data availability for shark species compared to target species, these indicators were developed around the type of information typically available from operational-level data for industrial purse-seine and longline fleets.

The current study updates key indicators and extends previous analyses to include hammerhead, porbeagle and whale sharks .

We present information on the geographic range of catches for each of the species considered; temporal trends in catch composition and catch rates, and key biological indicators of fishing pressure such as mean size and sex ratio by species. Whale sharks are assessed separately due to the unique nature of their interactions with fisheries in the WCPO. The analyses are based on Secretariat of the Pacific Community - Oceanic Fisheries Programme (SPC-OFP) data holdings for sharks taken in longline and purse seine fisheries in the Western and Central Pacific Ocean (WCPO). The framework for the analysis is a series of indicators of fishing pressure and stock status that were first described in the Shark Research Plan presented to the sixth meeting of the Western and Central Pacific Fisheries Commission's (WCPFC) Scientific Committee (SC6; Clarke and Harley 2010). A preliminary indicator-based analysis of SPC data holdings was presented to the Commission in December 2010 (Clarke et al. 2010) with an exhaustive review of the fisheries and data sources presented to SC7 (Clarke et al. 2011). end of this paragraph repeats first paragraph, need to merge

1.1 Report layout

This report is necessarily large. To assist the reader it has been structured along the following lines. Following a brief description of the available data in section 2, each of the four indicator analyses are described and results summarized in section 3. Section 4 presents a consideration of the feasibility of conducting a formal stock assessment for each of the shark species discussed in this report. In Section 5, we review the impact of recent shark management measures and, in section 6, recommend future work to extend and improve the indicator analysis approach. Finally, section 7 discusses the management implications arising from the results of the work presented here.

2 Description of Data

The primary source of catch information regarding sharks is the SPC-held observer database which, despite low coverage in all regions (Table 1 %Observer coverage by region), has a substantial amount of information regarding operational characteristics as well as fate and condition data on captured sharks. Observed hooks set is used here because it is a "common currency" and allows for the standardisation of observer coverage rates when undertaking analyses. In addition to the observer data, SPC holds operational logsheet and aggregate data on shark catches by longline fisheries. The operational data submitted to the SPC are at a higher spatial resolution than the aggregate data, and are useful for catch estimation, but in practice their utility is limited by the lack of data provision by species for shark (Table 2 Logsheet coverage by region % that ID sharks to species), especially in equatorial regions where the majority of the longline effort occurs.

Aggregate coverage rates are on par with the coverage rates of the operational logsheet data sets, although coverage differs greatly by region (Table 3). Historical coverage rates are poor partly because prior to February 2011 sharks were not amongst the species for which data provision was required (WCPFC 2013); since that time, data provision for the 13 species designated by WCPFC as key shark species is mandatory . Under CMM 2007-01, required levels of Regional Observer Programme (ROP) coverage in longline fisheries are set to rise to 5% from June 2012 in most areas, but annual average values have been ¡1% in recent years (for the entire WCPO). With some notable exceptions (e.g. northeast and southwest of Hawaii), most observed sets occurred within Exclusive Economic Zones (EEZs). A thorough examination of the SPC-held fisheries data and its utility for shark related analyses can be found in Clarke et al. (2011).

Building on the work of Clarke et al (2011), this indicator analysis uses the six WCPFC statistical areas as defined in the 2010 WCPFC bigeye tuna stock assessment (Figure 1). As noted in Clarke et al. (2011), these regions are somewhat arbitrarily assigned to the key shark species. However, given the fact that the predominant source of fishing mortality for these species is the longline fishery targeting tropical tunas (as well as billfishes and occasionally sharks), these regions adequately capture the important characteristics of the fisheries. Therefore, for purposes of comprehension and comparison to the previous analysis, we opted to keep the same regions. Mention that current BET stock assessment uses different region and that the current set also captures key pattern like eastern end of Japanese fleet for region 1.

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

2.1 Longline Fishery Data

Put this somewhere: With the exception of 2014 total effort in the longline fleet has increased, througout the study period (1995-2014) to approximately 800 million hooks annually with nearly half occuring in regions 3 and 4.

Ideally, indicator analyses would be based on operational-level data as its higher spatial resolution permits more comprehensive and nuanced analyses, however SPC's operational level data is geographically limited with respect to provision of shark data. Figure 2 illustrates the geographic distribution of sets for which SPC holds operational data (blue dots) and sets with at least one recorded shark are overplotted (in orange). However, this picture is somewhat misleading as only

41% of the operational-level sets plotted recorded any sharks. This is in contrast to the observer data in which 93% of the sets recorded at least one shark (overplotted in red).

This is not necessarily due to misreporting. Prior to February 2011, sharks were not amongst the species for which data provision was required (WCPFC 2011); since that time data provision for the 13 species designated by WCPFC as key shark species has been mandatory. Figure 2 does not distinguish between key shark species and other shark species because only 16% of the reported sets recorded any species-specific shark catches. Clarke et al. (2011b) note that most historical species-specific shark catch data are provided by a small number of flag States.

Given the relatively low level of coverage in the operational-level logsheets, a more complete characterization of the longline fishery requires the use of the SPC-held aggregated (5x5 degree grid) data. Effort and reported shark catch data by flag at the aggregated level have a lower degree of spatial resolution but in most cases are raised to represent the entire WCPO longline fishery. Sets with observers present onboard, are shown for comparison (Figure 3) but have a finer degree of spatial resolution due to observer record keeping. Following CMM 2007-01, required levels of Regional Observer Programme (ROP) coverage in longline fisheries were set to rise to 5% in June 2012 but annual average values have been on the order of 1-2%.

A comparison of longline effort by flag and the number of sharks recorded in logsheets was constructed (Figure 4) by showing the top four fishing nations (in the WCPO as a whole) and aggregating the rest of the flag states to another group. If the fishing practices and reporting practices were more or less consistent across flags the numbers of sharks reported would be proportional, by flag, to the effort.

Comprehensive data on shark catches at high spatial resolution are available from observer data held by the SPC-OFP but, as described above, the overall coverage of these data is low, and less than the required levels of ROP coverage. In addition, a comparison of longline effort and longline observer coverage (Figure 5) reveals that the latter is disproportional by region and flag and thus cannot be considered representative of the fishery as whole.

Another aspect of the low data coverage problem is that of temporal representativeness on a month/year basis of the observed effort. A comparison of the annual proportion observed by month - on a regional basis - shows significant fluctuations in the relative coverage of the observer data compared to the logbook data (Figure 6).

Figure 2: Map of WCPO and observed effort.

Figure 3: Logsheet effort by month.

2.2 Purse Seine data

Similar to the longline fishery, SPC-OFP holds logsheet data on shark catches by purse seine fisheries at both the operational and aggregate levels. However, operational-level coverage for the purse seine fishery (87%) is considerably higher than for the longline fishery (23%). 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 ROP on 1 January 2010, in combination with prior observer coverage commitments by Parties to the Nauru agreement (PNA) members, 100% purse seine observer coverage is now required (except for vessels fishing exclusively in one Exclusive Economic Zone (EEZ)). Historical observer coverage in the purse seine fishery has varied between EEZs. Coverage rates were low, generally less than 10%, for the years 1995-2002, with coverage increasing to 10-18% for the years 2003-2009. Recent (2010-2013) annual averages are between 42-56% in total.

While observer coverage of the purse seine fishery is not uniformly representative (Figure 7, 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 fishery (Lawson 2011). Regions 3 and 4 contain 98% of the operational-level reported purse seine sets, and 99% of observed sets and are thus the only regions for which purse seine analyses will be meaningful. Shark interactions are recorded in just 2.5% of purse-seine operational logsheets (Figure 7, red points), a value far lower than the 41% recorded in longline operational-level logsheet. 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.

A comparison by flag of purse seine effort and the number of purse seine sets reporting at least one shark interaction was constructed for associated (floating object) and unassociated (free-swimming) sets based on aggregated logsheet data (Figure 8). For each panel, flags were ranked by number of sets and the top four flags were plotted separately with all remaining flags aggregated into an "Other" category. Although estimated shark catches in the purse seine fishery are considerably lower than shark catches in the longline fishery (SPC 2008, Lawson 2011), it would still be expected that purse seine shark interactions are proportional to purse seine effort. However, from the discrepancies observed between the left and right panels, it appears that some major fishing nations are not submitting or are under-reporting their shark interactions.

Figure 4: Absolute percent difference in effort between reported (logsheet) effort and observed effort.

3 Distribution Indicator Analyses

3.1 Introduction

Distribution indicators consider patterns in the geographic distribution of species catch. Spatial trends in fisheries data need to be interpreted carefully since they originate from a biased sampling design (?). If assessed carefully, however, they can provide useful insight into spatial and temporal trends in species distribution as well as highlight areas of strong interactions between a species and fisheries. In addition, changes in stock abundance might be reflected in distribution (?), with increases and decreases in abundance resulting in range expansions and contractions, respectively. Such patterns have been reviewed at length in the terrestrial literature (?) but less often for marine applications due to the paucity of historical data (but see ?). FIX. The indicators presented below are based on observer data and thus patterns in fishing effort and/or observer coverage may bias the results. These results should therefore be taken as an initial indication of the location and intensity of interactions between these species and WCPO longline fisheries. They can be updated over time to determine if the spatial patterns change or temporal trends develop. More complex methodologies might also be applied to remove potential sampling biases.

Potentially need to add back some of these. These indicators examine the geographic range of each species and the habitat usage (in terms of geography only; oceanographic variables are not considered) by different life stages (adult/juvenile) and sexes based on fishery interaction data. Spatial analysis of fish occurrences can be useful in identifying range contractions or expansions which may be linked to fishing activities (Worm and Tittensor 2011). In addition, since many pelagic shark species are known to exhibit sex- and age- specific distribution patterns (Camhi et al. 2008, Mucientes et al. 2009) spatial analysis can highlight areas which are important to key life stages (e.g. presence of adult females and juveniles may indicate pupping grounds; presence of juveniles only may indicate nursery grounds).

3.2 Methods

In this study, we calculated four Distribution Indicators:

- Species-occurrence. This indicator summarizes the occurrence of a species in any longline set monitored by an observer. A positive value at any given location simply indicates that the species in question was observed at least once, without regard to annual frequency or fishing effort.

- Proportion-presence. This indicator provides a rough indicator of the frequency of occurrence of each shark species in each region and trends in presence over time. Using observer data, the indictor is computed by dividing the total number of sets with at least one occurrence by the total number of sets in each region/year combination.

- High-CPUE. This indicator is intended to illustrate which regions and years have shown relatively high CPUE values for the different species. The index is constructed, again on the basis of observed longline sets, by computing mean CPUE within each $5° \times 5°$ cell within each of the six regions, and then calculating the proportion of cells within a region that are above a specific threshold. For this analysis, the threshold was set at 1 shark per 1000 hooks for blue shark and at 1 shark per 5000 hooks for the other species.

- Catch-Hotspot. This indicator is an extension of the Species-occurrence and Proportion-presence indicators, and is intended to illustrate the possible presence of variable species catch hotspots. All observed data sets are totalled within 1° × 1° cells over four separate five-year (pentad) periods. The proportion of observed sets containing at least one species occurrence within that cell/pentad cell is then computed and mapped. This Catch-Hotspot indicator provides better temporal resolution than the Species-occurrence indicator and better spatial resolution than the Proportion-presence indicator in helping to identify the distributional patterns of each shark species.

3.3 Results

The four sets of Distribution Indicators are grouped in Appendix A, as follows: Species occurrence (Figures **??** to **??**), Proportion-presence (Figure **??**), High-CPUE (Figure **??**), Hot spot analysis (Figures **??** to **??**). Species-specific results below reference these sets of figures.

3.3.1 Blue Shark

Blue sharks are the most common and widely reported shark bycatch species in the WCPO longline fisheries. They are found to occur through the range of longline fishing and have the highest proportion-presence rate in virtually all years and regions among the shark species analysed in this report. Both the Proportion-presence and High-CPUE time series show distinct downwards trends from the late 1990s to the present in most regions (3, 5, and 6). The Catch-hotspot indicator shows consistently high occurrence of blue shark in longline fishery around the Hawaiian Islands with occurrence generally declining to the south, before again increasing in frequency around 20°S.

3.3.2 Mako Shark

Mako sharks are one of the most commonly captured shark species in the longline fisheries of the WCPO. Mako sharks have been encountered in longline sets in all regions that observers have sampled. The largest, most consistent, hotspots have included waters in Region 5 between Australia and New Zealand. Spatially, there are differing trends over time in the Proportion-presence and High-CPUE indicators. The north and west regions (2 and 3) show stable or slightly increasing rates (though data for region 2 is lacking for years 2012-2014) whereas the south Regions (5 and 6) show steadily declining rates.

3.3.3 Silky Shark

Silky sharks are commonly encountered in Regions 3 through 6 and at a very low rate in Region 2. Neither the Proportion-presence nor High-CPUE indicators illustrate sustained temporal trends in occurrence. The region with the greatest proportion of High-CPUE occurrence is Region 3. The Catch Hotspot indicator also illustrates a consistency in both the temporal and spatial encounter of the LL fishery with silky sharks.

3.3.4 Oceanic Whitetip Shark

Oceanic whitetip sharks also occur with regular frequency in observed longline sets through most of the WCPO longline fisheries. In the five regions where they are commonly encountered (Region 1 contains few observed sets) the trend in both Proportion-presence and High-CPUE has been steadily downward since the mid-1990s, with some of the decline in rates exceeding 80%. Catch-hotspots for oceanic whitetip sharks have been in the central Pacific, particular the region surrounding the junction of Regions 3, 4, 5, and 6.

3.3.5 Thresher Shark

Thresher sharks have been found in observed longline sets in most regions of the WCPO with the possible exception of the area around French Polynesia. Catch-hotspots have been north of the equator, especially in Region 4. Both the Proportion-presence and High-CPUE time series show indistinct temporal trends though Regions 3 and 4 have dropped considerably over the past five years.

3.3.6 Hammerhead Shark

Among the shark species analysed in this report, hammerhead sharks have the lowest encounter rates (measured as Proportion-presence) and appear to be patchily distributed. The regions with the apparent largest presence of hammerhead sharks is the Northeast (Hawaiian Islands) and Southwest (Papua New Guinea, Australia east coast). Due to the low encounter rates, little inference can be made regarding temporal trends in occurrence.

3.3.7 Porbeagle Shark

Porbeagle sharks have historically only been encountered in the southern region of the WCPO, essentially only south of 20 ° S (Regions 5 and 6). A decrease in the spatial and temporal occurrence of porbeagle in observed sets is evident in the three Distribution Indicators other than Species-occurrence. The porbeagle catch-hotspots have shrunk both in size and intensity over the four pentads; the Proportion-presence and High-CPUE time series for Regions 5 and 6 have declined as much as 90% over the past 15 years.

3.4 Conclusions

With the exception of blue shark the high-CPUE indicator more or less steady trends for all species in all regions, however this analysis was hampered by the lack of data throughout the region for species.

Intrepretation of the distribution indicators is complicated by the influence of changes in fishing effort, potential changes in community composition, obsservational coverage and operational factors influencing selectivity and catchability (e.g. depth and leader material). As such, these indicators are best used for identifying the areas in which species-fishery interactions take place, and as supporting information for interpreting other patterns and trends.

4 Observed Species Composition Indicator Analyses

4.1 Introduction

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

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

Longline

With just a few exceptions, blue shark catch dominates the longline shark bycatch. In Regions 2, 4, 5, and 6, blue sharks have average 60-90% of shark bycatch; in Region 4 the proportion of blue shark has dropped from around 60% in the late 1990s to 10-15 in recent years. The second most common observation of shark species, in terms of numbers, is silky shark which have constituted a majority of shark bycatch in Region 3 since the early 2000s and have been on the order of 5-10% in other regions. We note that there appears to be a sudden increase in the proportion of silky shark catch for Region 4 in years 2012-2104. In fact, this reflects the absence of observer data from the U.S. longline fleet operating around Hawaii which constituted the large majority of longline sets in that region dating back to the start of the time series. As evidenced by the small number of observed sets shown for years 2012-2014, the shark composition data for these years in Region 4 are quite likely very unrepresentative. Several of the other shark species constitute up to 10% of the shark bycatch in certain regions and time periods: porbeagle in Regions 5 and 6, oceanic white tip sharks in Regions 3, 4, and 6 and thresher sharks in regions 3 and 4. The estimated proportion of unidentified sharks is quite low in all regions, which may reflect indicate that the composition of shark bycatch in tuna fisheries is composed of the mostly the species listed as key shark species.

Division of the longline shark bycatch into shallow and deep sets revealed several differences in the assemblage of sharks caught at depth. Regions 3, 5, and 6 each have relatively large number of observed sets (Regions 1, 2 and 4 have essentially no observed sets in one or the other depth characterization) so we restrict our comparison to those Regions. In the southern Regions (5 and 6), blue shark and porbeagle comprise as much as 95% of the longline shark catch; the deep water sets contain a much more diverse array of species with silky, thresher, oceanic whitetip and mako sharks occurring in substantial numbers. Differences in shark composition in Region 3 are much more subtle than Regions 5 and 6; hammerhead and oceanic white tip sharks are more common in deep sets while silky sharks are a bit more common in shallow sets.

Purse Seine

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

4.2 Conclusions

The Species Composition indicators reveal that shark bycatch differs substantially between longline and purse seine fishing in the WCPO.

Blue sharks are the most prevalent longline caught shark, but there are substantial regional and depth variations. Several species are commonly caught more frequently in deeper sets; porbeagle form a sizable component of the shallow sets in Regions 5 and 6 and silky shark is the second most common longline caught shark.

urse seine shark bycatch is much less variable and is dominated by silky sharks, particularly over the past decade when the number of observed sets increased greatly and composition data may have become more representative. In virtually all regions and years, silky shark comprises more than 95% of the shark bycatch, with minor numbers of hammerhead and oceanic whitetip sharks occurring. Oceanic white tip sharks appear to have been more common prior to 2000, their percentage contribution to the overall shark cath has not been more than 20% in regions 3 and 4 for over a decade, which is stark contrast to the first ten years of the study period.

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

5 Catch Per Unit Effort indicator analyses

5.1 Introduction

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

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

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

5.2 Methods

This analysis follows the work of Clarke et al., (2011, 2011b), Walsh and Clarke (2011), Rice and Harley (2013) however the regions for this study differ slightly. Because silky sharks are tropical species this led to the analysis being considered for one region, from 25??S to 25??N and bordered on the east and west by the WCPFC Statistical Area. A comprehensive overview of the observer logsheet data and a characterization of the fisheries in which each species is caught is presented in the preious sections, what follows is a summary of the methods used in this analysis.

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

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

Latitude and longitude were truncated to the nearest 1

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

Purse Seine data preparation

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

CPUE standardization methodology

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

Overview of GLM Analyses

The filtered datasets were standardized using generalized linear models (McCullagh and Nelder 1989) using the software package R (www.r-project.org). Multiple assumed error structures were tested including; The delta lognormal approach (DLN) (Lo et al. 1992, Dick 2006, Stefansson 1996, Hoyle and Maunder 2006): this approach is a special case of the more general delta method (Pennington 1996, Ortiz and Arocha 2004), and uses a binomial distribution for the probability w of catch being zero and a probability distribution f(y), where y was log(catch/hooks set), for non-zero catches. An index was estimated for each year, which was the product of the year effects for the two model components, The negative binomial (Lawless 1987): is typically more robust to issues of overdispersion (overdispersion can arise due to excess zeros, clustering of observations, or from correlations between observations) was also used. This model has been advocated as a model that is more robust to overdispersion than the Poisson distribution (McCullagh and Nelder 1991), and is appropriate for count data (Ward and Myers 2005), but does not expressly relate covariates to the occurrence of excess zeros (Minami et al. 2007).

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

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

5.3 Results

5.3.1 Blue Shark

5.3.2 Mako Shark

5.3.3 Silky Shark

5.3.4 Oceanic Whitetip Shark

5.3.5 Thresher Shark

5.4 Conclusions

6 Biological indicator analyses

6.1 Introduction

Previous analysis Clarke et al. (2011) examined trends in median length of the key shark species and found significant declines in most combinations of spatial strata and sex for blue and mako sharks, as well as silky sharks. As the sizes of sharks differ by sex (females typically grow larger and heavier than males), it is important to examine indicators on a sex-specific basis where possible (Clarke et al. 2011).

Length is a better measure of size than weight because the former does not fluctuate with reproductive or other seasonal factors. As noted in Francis et al. (2014), median length is preferred over mean length as the median is less likely to be influenced by outliers.

As the sizes of sharks differ by sex (females typically grow larger and heavier than males), it is important to examine indicators on a sex-specific basis where possible (Clarke et al. 2011). The sex ratio of a shark population may also be a useful indicator of its status. Heavy exploitation could lead to a preferential loss of females because they tend to be larger and older than males. Alternative sentence ending: ... loss of female due to their larger size and longer lifespan. (is this true, would seem so if you say they "tend to be older")

Thus, if the median length in a population declines, the sex ratio may also have been impacted. Additionally, male and female sharks often segregate spatially (Mucientes et al. 2009), and this has been reported in highly migratory ("HMS") sharks in New Zealand waters, e.g. in the South region, females dominate the blue shark catch while males domiate the mako shark catch (Francis 2013). If fishing activity is concentrated in areas favoured by one sex, then an imbalance in the sex ratio could be created. In this section we analyse trends in median length and the proportion of females over time.

6.2 Methods

Sex specific length data from the longline observer data was was plotted by region for all key species the length plots, ANNEX :length. Need a brief method description of the sex ratio data Observed length data from the purse seine fishery was limited to silky and oceanic whitetip sharks in regions 3 and 4. In those instances that data was recorded in total length, measurements were converted to fork length using conversion factors given in Table **??**. The median lengths, with 5th and 95th quantiles, were plotted along with the length at maturity for each sex (Table **??**). Length data were plotted on a region by region basis. In the purse seine dataset, sexes were not usually recorded and only oceanic whitetip and silky sharks in Regions 3 and 4 had sufficient data for analysis (6).

Those 5° x 5° cells for which the sample size was less than 20 individuals were removed from the analysis. Results of the nominal analysis of size data for the longline fishery are shown in Annex 7.Due to small longline fishery sample sizes for many individual species, results for mako sharks (two species plus unidentified), thresher sharks (three species plus unidentified) and hammerhead sharks (three species plus unidentified) were grouped. Length at maturity data for shortfin mako, bigeye thresher, and scalloped hammerhead were chosen to represent each group, respectively, as both observer data and literature sources were greatest for these species. While length at maturity and conversion factors might be expected to vary by region within the WCPO, insufficient data were available to support regional analysis.

To standardize for effects of space and observer coverage on the observed shark lengths generalized linear models (GLMs) were used to produce standardized annual lengths from longline fishery data; difficulties with standardization precluded the development of GLMS on purse seine length data.

The GLMs were based on a normal distribution with factors year and 5° x 5° cell - THIS SENTENCE NEEDS HELP. The estimated model coefficients were used to predict shark lengths for each year for an arbitrarily chosen cell lying near the centre of each each population. To more adequately capture population trends, this analysis was carried out the stock level (north and south) for blue and mako sharks, at at a regional level for silky, oceanic whitetip, thresher, hammerhead and porbeagle sharks. Models analyzing the purse seine data combined regions 3 and 4 and used the annual median observed length. Standardized annual length estimatess were created by fitting linear models year coefficients from the GLM; the slopes of these linear models were used to identify significant trends in lengths over time.

Models were developed separately for each species, sex, stock (for blue and mako sharks) and fishery. One important caveat when interpreting the results is that linear models generalize the direction and magnitude of the trend over the entire time series. Therefore, a size trend that rises at the start of the time series and decreases in the later part of the time series may be characterized as having no trend through time.

6.3 Results

The proportion of observed females showed no clar trends over the eintier study period for any of the sharks. Fine scale analysis is dificult due to lack of continous data and small annual sample sizes in the most recent years. The sex ratio of blue shark in region 5 has has been skewed in favor of females for the entire data period. With the exception of blue shark in region 5 there is nothing to suggest that incidental catchability (availabilty) is greater for either sex for all species.

Blue shark females showed declining trends in regions 5 and 6, with stable trends in regions 3, 4, adn 5. Male blue sharks exhibited similar trends with nearly all the observed blue sharks in region 5 being immature in recent years.

Male mako sharks showed the same trends as blue sharks with stable trens in regions 2, 3 and 4, with slightly declining trends in regions 5 and 6. Immature males were more commonly observed in regions 5 and 6 throughout the study. Observed female mako sharks were predominantly immature, approximately the same size as the observed males and showed relatively relatively stable trends throughout the the region.

Both male and female silky sharks showed declining trends in length in the core areas (regions 3 and 4) as well as region 5. The majority of the silky sharks observed were immature throughout the study period.T The only area that showed increases in observed median length were regions 6 for males of both species.

The trends in lenght for both female and male oceanic whitetip sharks were relatively stable in teh core area (region 3 an4) with the majority of the observed sharks being immature.

The majority of observed thresher sharks occured in region 4 where the lengths of both male and female sharks were relatively stable throuhout the time preiod. Observed female thresher sharks were predominantly immature while male thresher sharks did not show any clear bias towards maturity.

Length data for hammerhead sharks is largely limited to region 3 during the time period 1998-2008, during this time the majority of the observed sharks were immature. The limited length data in other regios indicates that the hammerhead sharks available to the longline fishery are mainly immature.

Porbeagle sharks were only observed in regions 5 and 6, where nearly every female and the majoity of the male shaks were immature. Increasing median lenght for both sexes were were observedin region 5 since 2007, Region 6 showed no consitent trends.

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

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

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

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

6.4 Results

Figure 5: CPUE indicators, nominal CPUE in the purse seine fishery, Unassociated Sets, Region 3.

Figure 6: Median length (in fork length) for both sexes (combined) of silky sharks in Regions 3 and 4 based on samples taken from the purse seine fishery, 1995-2014. The 5th and 95th percentiles of the data are shown with dashed lines. Size at maturity is represented by the solid horizontal line. The sample size is shown in the inset to each plot.

Figure 7: Median length (in fork length) for both sexes (combined) of oceanic whitetip sharks in Regions 3 and 4 based on samples taken from the purse seine fishery, 1995-2014. The 5th and 95th percentiles of the data are shown with dashed lines. Size at maturity is represented by the solid horizontal line. The sample size is shown in the inset to each plot.

6.5 Conclusions

7 Feasibility of Stock Assessments

Fisheries stock assessments are designed to provide stock status and management information via a population model that is fitted to the available data. Typically, the data required to conduct a stock assessment include landings or catch estimates, indices of abundance (eg. CPUE) and information on the key biological processes of the species to be assessed (growth, fecundity, natural mortality etc.) Some stocks (including many shark stocks) are not traditionally managed and are often considered a bycatch in fisheries targeted at other species. In such instances there are often large data gaps both in space and time and estimates of removals are typically highly uncertain. In these cases data poor methods or other alternative methods may be a more appropriate approach than full stock assessments. Here we consider, for each of the key shark species, the possibility for conducting either a full stock assessment or other population level study that will provide estimates of stock status leading to management advice.

Blue shark (*Prionace glauca*)in the north Pacific This species has been the subject of multiple stock assessments using both basic Bayesian production models as well as length based methods (SS3 and MFCL), there are sufficient data to develop reliable inputs for both total removals and indices of abundance. However, particular challenges exist for estimating catch and indices of abundance in areas where fishing behaviour has shifted towards the targeting of sharks.

Blue shark (*Prionace glauca*) in the south Pacific An analysis of the potential catch and CPUE series to support a stock assessment of blue shark in the south Pacific Ocean was presented at the SC9 (WCPFC-SC9-2013/SA-WP-04). It noted that in general sufficient data exist to complete a stock assessment, but that all available data sets (observer, logsheet, aggregate) share the same characteristics of poor coverage with respect to space, time, or species identification. The study analysed only data from the WCPO convention area in the south Pacific. It is likely that blue shark in the south Pacific are sufficiently well mixed to support a single south Pacific wide stock assessment. Although fisheries data in the south eastern Pacific exist for blue shark, those data have not been included in this study and, at present, it remains unclear whether they would support a south Pacific wide assessment of blue shark.

Mako shark (*Isurus oxyrinchus* and *Isurus paucus*)in the north Pacific The shark working group of the International Statistical Committee is currently working on an indicator-based analysis of the status of shortfin mako in the the north Pacific Ocean. Preliminary results indicate that indices of abundance, length information and size frequency data exist, although the extent to which these data can represent the entire north Pacific is unclear. There are conflicting trends in abundance and problems with both shortfin and longfin mako being recorded as simply 'mako' shark.

Mako shark (*Isurus oxyrinchus* and *Isurus paucus*)in the south Pacific Although no detailed study of the available data for mako sharks in the south Pacific has been undertaken, the information provided in this indicator analysis combined with the fact that mako sharks are often caught in the same fisheries as blue shark might indicate that sufficient data exist for a basic length based stock assessment in the southern portion of the WCPO.

Oceanic whitetip shark (*Carcharhinus longimanus*) Oceanic whitetip sharks in the WCPO were most recently assessed in 2012 (SC8). At that time there were sufficient data to support an assessment for the period 1995- 2009. In recent years longline observer coverage has decreased in the WCPO as observers have moved to purse seine vessels. At the same time reporting by species in the operational level logsheets has increased. It is unclear what effect these changes in data availability would have on the stock assessment.

Silky shark (*Carcharhinus falciformis*) Silky sharks in the WCPO were most recently assessed in 2013 (SC9) and similar to oceanic whitetip, at that time there were sufficient data to support an assessment for the period 1995- 2009. In recent years longline observer coverage has decreased in the WCPO as observers have moved to purse seine vessels. At the same time reporting by species in the operational level logsheets has increased. It is unclear what effect these changes in data availability would have on the stock assessment, however silky sharks continue to be the most commonly observed shark it region 3 for both longline and purse seine, as well as in region 4 for purse seine and this might indicate that a stock assessment of silky sharks remains feasible.

Thresher shark (*Alopias superciliousus, vulpinus, & pelagicus*) Data for thresher sharks are mainly present in the longline observer records in region 4. They are represented by three species but often identified only as 'Thresher'. Catch rate analysis by species is severely constrained by limited species specific data both spatially and temporally. A limited stock assessment for all combined species may be possible, although the results would be difficult to interpret on a species specific level.

Hammerhead Sharks (*Sphyrna mokarran, lewini, zygaena & Eusphyra blochii*) Observations of hammerhead sharks are virtually non existent in the purse seine database and mainly limited to regions 3 and 5 in the longline database. Information on key biological processes are limited and often based on small sample sizes. A further problem for the analysis of the hammerhead shark species complex is that more than half of the observations in the study period (1995-2014) were not to species but rather to a generic 'hammerhead' category. At present, a stock assessment for this species is not feasible given the current data.

Porbeagle Sharks (*Lamna nasus*) Porbeagle sharks are generally considered a wide ranging oceanic species. In the Pacific they are distributed throughout the southern regions in temperate and cold waters. Observed catches of porbeagle sharks are mainly limted to the EEZs of Australia and New Zealand, although additional data exist for regions adjacent to the WCPO, such as operational logsheet data and potentially observer data from the CCSBT. Given the current SPC data holdings only limited analysis for porbeagle sharks in the WCPO is considered to be feasible.

Whale Shark (*Rhincodon typus*) Whale shark interactions are generally reported only by the purse seine fishery. These observations are subject to considerable spatial and temporal heterogeneity and likely to have been affected 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 are limited. Given the current SPC data holdings only limited analysis for whale sharks in the WCPO is considered to be feasible.

8 Impact of Recent Shark Management Measures

A general Conservation and Management Measure aimed at managing sharks within the WCPFC was developed in 2006 (CMM2006-05). This measure was subsequently updated and refined in 2008 (CMM2008-06), 2009 (CMM2009-04) and 2010 (CMM2010-07), in addition specific measure have been developed for oceanic whitetip sharks (CMM2011-04); whale sharks (CMM2012-04) and silky sharks (CMM2013-08). The general shark measure has evolved over the years but currently requires accurate reporting of key sharks, encourages live release of sharks and attempts to address issues of fining through a 5% fin to carcass ratio. In addition, CMM2014-05 was developed to limit the use of wire traces and shark lines in tuna and billfish target longline sets.

The species specific measures all have a retention ban, reporting requirements and the whale sharks measure also prohibits specific targeting of purse seine sets on whale sharks. Notes on specifc CMMs include;

CMM 2010-07 Conservation and Management Measure for Sharks This CMM was originally designed to encourage full utilization of retained sharks, among the components of this measure was the requirement that vessels shall have on board fins that total no more than 5% of the weight of sharks on board up to the first point of landing. This CMM replaced Conservation and Management Measure 2009-04, which was similar and an extension of CMM 2008-06, which was an extension of CMM 2006-05, which originally went into force on January 1st 2008. Observer records indicate a change in the observed practices of dealing with sharks in the purse seine fishery from the year 2008 to 2009 (Figure 8, bottom panel). The proportion of sharks that were finned was significantly reduced and the proprtion discarded increased and has been approximately 80-100% from 2009-2014. During this time the coverage of the purse seine fleet increased significantly, so the dramatic decrease in the proportion finned maybe partly an artifact of a more extensive sample of the the fleet, thought the CMM likely had some impact in the changes of handling sharks. Observer data for the key shark species in the longline fishery indicates that the years preceeding the CMM were similar (with respect to the fate of sharks) as to those after, with an increase in the number of sharks retained (carcass along with fins as per the CMM) evident in recent years.

Figure 8: Observed fate of key shark species in the longline and purse seine fisheries for the WCPFC convention area.

CMM 2011-04 Conservation and Management Measure of Oceanic Whitetip Shark This CMM went into force on January 1, 2013, as such there should be a reduction in the proportion of retained and finned oceanic white tip sharks over the period 2013 and 2014. The measure aimed at the reduction in mortality of oceanic whitetip sharks in part beause It was noted that the 5% fin to carcass requirement doesn't necessarily lead to a reduction in mortality, as a result this measure was designed to prohibit the retention (and finning) of oceanic whitetip. Observations of oceanic white tip sharks in the longline fishery have generally indicated reduction in the proportion finned since the mid 2000's (Figure 9). However, proportionally more oceanic whitetip sharks were retained in 2013 (the first year of the CMM). With respect to the purse seine fishery,the proportion of oceanic whitetip sharks that were either finned or discarded increased, but the proportion retained decredased (Figure 9). It seems that this is only partially working.

Figure 9: Fate of observed oceanic whitetip sharks in the longline and purse seine fisheries.

CMM 2013-08 : Conservation and Management Measure for Silky Shark . This measuer is specifically a no retention measure for silky sharks, and went into effect July 1 2014. We do not expect to see any impact of this measure as the study period runs from 1995-2014.

Conservation and Management Measure 2014-05; Measures for longline fisheries targeting tuna and billfish, states:

CCMs shall ensure that their vessels comply with at least one of the following options:

1. do not use or carry wire trace as branch lines or leaders; or
2. do not use branch lines running directly off the longline floats or drop lines, known as shark lines.

This CMM goes into effect on July 1 2015. do not expect to see impacts of this measure ini the current study. However this is in response to the analysis carried out by SPC OFP (Rice and Harley 2012, Bromhead et al 2013, Canaco & Donovan 2014) in recent years showing the effect of wire trace and shark lines on the catch rate of sharks.

9 Conclusions

This paper examines data held by the SPC-OFP for longline and purse seine fisheries in the WCPO to make infrence regarding the populations of key shark species in the WCPO. The data sets analyzed-observer, operational level and aggregated data - vary in coverage, representativenes and detail, and in general are not oriented at reporting informatoin on bycatch species such as sharks. Logsheet data at the operational level is most useful in assessing shark catches and catch rates in the WCPO as a whole however such data are available in the longline fishery for 41% of the sets in 1995-2014 for the WCPFC Statistical Area as a whole, and there is little or no coverage in the northwest Pacific. Most of the operational-level longline logsheets sets (59%) did not record any sharks, in contrast XX% observer data for longine did, possible explanations for this discrepancy include underreporting of sharks and that the observer data is not representative of the fishing methods/areas/time periods of the longline fleet as a whole.

Operational-level coverage in the purse seine fishery is considerably higher (87%), but only 2.5% of purse seine operational-level logsheet sets reported any shark interactions. In both fisheries, most reported shark interactions are not species-specific given these limitations in operational-level data, aggregated data (5x5 degree square) were used to characterize effort, observer coverage and reported shark catches by flag for both longline and purse seine fisheries. For longlines, this analysis showed clear evidence of non-/under-reporting of sharks by several major longline fishing countries. It also demonstrated that observer coverage is disproportional by region and flag and to an extent month and thus not entirely representative of the fishery.. Although the same non-/under-reporting patterns were observed in the purse seine aggregated data, observer coverage in the purse seine fishery is more representative by region and flag. Nevertheless observer data on purse seine-caught sharks is limited by the physical practicalities of onboard sampling and the lower diversity of sharks encountered relative to the longline fishery.

With the exception of 2014 total effort in the longline fleet has increased, througthe study period (1995-2014) to approximately 800 million hooks annually with nearly half occuring in regions 3 and 4. With the exception of blue shark the high-CPUE indicator more or less steady trends for all species in all regions, however this analysis was hampered by the lack of data throughout the region for species. Notably the proportion of high-CPUE cells for blue shark was decreasing thought the study period for regions 3,5,and 6 with steady or slightly decreasing trends in region 3 and 4, region 1 was data deficient. Interestingly the percentage of positive sets indicator for blue shark showed the opposite trends, increases in regions 3,5, and 6 with steady trends in regions 2 and 5. For silky shark there seems to be a slight downward trend in the core regions of 3 and 4, while oceanic whitetip sharks show stable to slightly increasing trends trends throughout all of the regions. Porbeagle sharks in region 5 and 6 show slightly increasing to stable trends. Mako sharks show slightly increasing trends in region 5 and 6, stable trends in regions 3 & 4 and a slightly decreasing trend in region 2, though data is lacking for years 2012-2014. The proporiton of positive sets for thresher sharks showed steady trends throughout the regions, however region 4 is where the majorty of the observed threshers occured, in recent years an increase in the proportion of positive sets was evident. Hammerhead sharks had consistent, near zero proportion of positive sets.

-The observed longline catch composition plots illustrate that blue shark continue to dominate the observed catch in most regions. An exception to this pattern is Region 3 where silky sharks, primarily from shallow sets, are the most frequently observed species. Although there are some minor differences in species composition between observed shallow and deep sets in other regions (e.g. Regions 2 and 4), these may be related to sampling representativeness. Note that downward trends in the number of sharks observed in all regions (except region 3) are partially a result of the reduction in obeserver coverage since 2010. Proportionally more skilky sharks were observed in region 3 than any year since 2008, while the proportion of blue sharks observed during 2014 in regions 2-5 is one of the lowest on record. Analysis of observed purse seine shark catches reveals that silky sharks predominate with the majority of these found in associated sets. In previous years, oceanic whitetip shark was the second-most commonly identified shark in associated sets but this species has been only rarely observed in recent years. Substantial numbers of sharks caught by purse seines were unidentified until 2002-2003.

10 Research Recommendations and Management Implications

This indicator analysis can make informative statements regarding silky shark, oceanic whtitetip, mako shark, blue shark and porbeagle sharks, but is somewhat limited in the amount of inference possible for hammerhead and thresher sharks largely due to lack of data. These species are not commonly caught in the tuna and tuna like fisheries in the WCPO, and historically not well reported. Increased observer monitoring is vital to the continued understanding of the less common key shark species. Specific research recommendations include:

- Research to analyze the the discrepancy include underreporting of sharks in logbooks and how to uwe observer data may that is not representative of the fishing methods/areas/time periods of the longline fleet as a whole.
- Silky shark and oceanic whitetip sharks have been declining under recent fishing pressure, and likely maintain theAir overfished satus. The last assessment for both of thsese species used data for 1995-2009, at this point we could easily add another 5 years of data to these assessments, though this would be most useful for sikly shark to understand how its stock status has changed in recent years in conjunction with the new CMM's. Another stock assessment of oceanic whitetip would be interesting, however if the population doubled or halved, it would still be overfished.
- The authors recommend that this be undertaken again in 2-3 years with a stock assessment for BSH in the south Pacific, and another silky shark assessment in the intrim.

Acknowledgements

11 Appendices

11.1 CPUE Indicators. Model diagnostics and extra plots

Blue Shark model diagnostics and extra plots

Silky Shark model diagnostics and extra plots

Oceanic Whitetip Shark model diagnostics and extra plots

Thresher Shark model diagnostics and extra plots

12 Tables

Species	Length at Maturity	Reference(s)
Blue	Males: 168 FL (200 TL) Females: 168 FL (200 TL)	Nakano and Stev
Mako (shortfin mako)	Males: 180 FL Females: 275 FL	Francis and Duff
Oceanic whitetip	Males: 138 FL (168 TL) Females: 144 FL (175 TL)	Seki et al. (1998)
Silky	Males: 175 FL (212 TL) Females: 173 FL (210 TL)	Joung et al. (200
Thresher (bigeye thresher)	Males: 168 FL (270 TL) Females: 203 FL (332 TL)	Smith et al. (200
Hammerhead (scalloped hammerhead)	Males: 153 (198 TL) Females: 163 FL (210 TL)	Chen et al. 1990
Porbeagle	Males: 145 FL Females: 175 FL	Francis and Duff

Table 1: Sources of information used in defining length at maturity and converting between total length (TL) and fork length (FL) measurement standards. TL measurements which fell outside the range of data used to construct the FL-TL conversion equations were excluded from the analysis.

	1	2	3	4	5	6
1995	0.00	0.01	0.00	0.00	0.03	0.00
1996	0.00	0.02	0.00	0.00	0.03	0.00
1997		0.02	0.00	0.00	0.03	0.01
1998		0.02	0.00	0.00	0.02	0.01
1999	0.00	0.02	0.00	0.00	0.02	0.00
2000		0.04	0.00	0.01	0.02	0.00
2001		0.15	0.00	0.02	0.02	0.00
2002		0.13	0.00	0.02	0.03	0.00
2003		0.11	0.00	0.01	0.02	0.01
2004		0.06	0.00	0.02	0.03	0.01
2005		0.13	0.00	0.01	0.02	0.01
2006		0.10	0.00	0.03	0.02	0.02
2007		0.14	0.00	0.03	0.02	0.01
2008		0.16	0.00	0.01	0.02	0.01
2009		0.16	0.00	0.02	0.03	0.01
2010	0.00	0.16	0.00	0.01	0.02	0.01
2011		0.12	0.00	0.01	0.02	0.01
2012			0.00	0.00	0.01	0.01
2013			0.00	0.00	0.02	0.02
2014			0.00	0.00	0.02	0.00

Table 2: Percent of effort observed in the longline fishery by region.

	Log%Report_Reg1	Log%Report_Reg2	Log%Report_Reg3	Log%Report_Reg4	Log%Report_Reg5
1995			0.30	0.08	0.49
1996			0.26	0.14	0.47
1997			0.30	0.24	0.49
1998	0.00	0.00	0.27	0.13	0.33
1999		0.00	0.25	0.05	0.36
2000		0.00	0.28	0.07	0.37
2001		0.19	0.28	0.10	0.38
2002	0.00	0.31	0.48	0.10	0.39
2003	0.14	0.30	0.50	0.19	0.41
2004	0.24	0.31	0.47	0.24	0.45
2005	0.11	0.30	0.33	0.29	0.49
2006	0.26	0.55	0.37	0.18	0.49
2007	0.41	0.71	0.38	0.40	0.50
2008	0.23	0.75	0.41	0.45	0.45
2009	0.37	0.69	0.43	0.45	0.45
2010	0.24	0.74	0.50	0.61	0.46
2011	0.37	0.74	0.58	0.59	0.45
2012	0.55	0.71	0.35	0.42	0.35
2013	0.63	0.70	0.50	0.49	0.29
2014	0.90	0.76	0.57	0.58	0.19

Table 3: Percent of Logsheets reporting sharks to species, longline fishery by region.

	Hks_Reg1	Hks_Reg2	Hks_Reg3	Hks_Reg4	Hks_Reg5	Hks_Reg6
1995	97.10	24.10	240.00	127.00	46.50	49.50
1996	107.30	15.90	227.70	110.40	38.70	51.00
1997	102.50	16.30	220.30	100.40	46.10	55.40
1998	96.00	18.60	238.20	140.30	50.70	75.10
1999	102.00	21.10	305.10	148.50	51.20	81.10
2000	102.00	19.10	299.10	170.80	50.20	84.50
2001	190.80	14.70	345.40	160.30	49.80	124.10
2002	102.50	22.70	360.10	215.40	67.90	161.50
2003	107.60	31.10	323.10	195.70	78.20	190.30
2004	142.60	43.90	298.10	244.10	68.80	177.80
2005	130.80	40.90	176.30	202.90	65.90	144.50
2006	154.20	40.90	201.50	170.60	61.10	141.90
2007	204.80	34.80	256.20	184.50	52.40	125.50
2008	203.80	36.90	228.10	190.30	73.50	143.30
2009	181.40	34.70	326.00	163.60	60.00	203.50
2010	158.50	27.10	228.70	186.60	86.80	184.30
2011	167.30	38.20	274.50	221.50	90.30	186.70
2012	147.10	36.90	313.30	246.70	103.90	221.40
2013	154.80	31.10	290.30	205.50	89.10	224.20
2014	119.10	35.10	251.50	171.00	60.40	153.80

Table 4: Millions of hooks fished in longline fishery by region.