* Introduction

The status of the many shark species, and in particular those designated as key shark species (blue, mako, thresher, silky and oceanic white tip sharks) in the western and central Pacific Ocean (WCPO) underwent a comprehensive review in 2011 (?). In that review a number of indicators were developed to inform on the status of those shark stocks and their response to fishing pressure. The indicators were developed around information available from operational-level data and included information on the geographic range of catches for each of the species considered; temporal trends in catch composition and catch rates, and in key biological indicators of fishing pressure such as mean size and sex ratio. This study provides an update of many of those indicators and extends the species indicator analyses to include hammer head and porbeagle sharks.

Sharks are often caught as bycatch in the Pacific tuna fisheries (though some directed/mixed species fisheries, sharks and tunas/billfishes, do exist). This paper presents an analysis of Secretariat of the Pacific Community - Oceanic Fisheries Programme (SPC-OFP) data holdings for sharks taken in longline and purse seine fisheries in the Western and Central Pacific Ocean (WCPO). The framework for the analysis is a series of indicators of fishing pressure and stock status that were first described in the Shark Research Plan presented to the sixth meeting of the Western and Central Pacific Fisheries Commission's (WCPFC) Scientific Committee (SC6; Clarke and Harley 2010). A preliminary indicator-based analysis of SPC data holdings was presented to the Commission in December 2010 (Clarke et al. 2010) with an extensive review of the fisheries and data sources presented to SC7 (Clarke et al. 2011).

related to the stocks general trend, whether it has changed from the previous indicator analysis and, in such cases where further analysis is proposed, it provides recommendations on how to undertake that analysis. Uncertainty regarding any species population level mechanisms that drive any individual analysis is qualitatively expressed by species and stock in order to represent the uncertainty in the underlying data. – not sure whether to keep or lose

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,](#page8) 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.

* 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 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.

1. Longline Fishery Data

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 (Clarke et al. 2011b).

Given the relatively low level of coverage in the operational-level logsheets, a more complete characterization of the longline fishery requires the use of 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 observer 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 a 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).

1. 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.

* Distribution Indicator Analysis
  1. Introduction

Distribution indicators provide one means of monitoring spatial and temporal trends in distribution and, potentially, abundance. For example, an increase in overall stock abundance might be signalled by a range expansion which could be picked up in commercial catch records. Similarly, range contraction might portend stock decline (Worm and Tittensor 2011 – maybe this reference applies?). 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.

* 1. 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°x5° 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 100 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°x1° 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.
  1. Results

The four sets of Distribution Indicators are grouped in Appendix A, as follows: Species occurrence (Figures IA\_01 to IA\_07), Proportion-presence (Figure IA\_08), High-CPUE (Figure IA\_09), Hot spot analysis (Figures IA\_10 to IA\_16). Species-specific results below reference these sets of figures.

* + 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. 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.

* + 1. Silky Shark

Silky sharks are commonly encountered in BET 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.

* + 1. 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.

3.3.4 Mako Shark

Mako sharks are one of the most commonly captured shark species in the longline fisheries of the WCPO. Make 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 whereas the south Regions (5 and 6) show steadily declining rates.

3.3.5 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 has been in the central Pacific, particular the region surrounding the junction of Regions 3, 4, 5, and 6.

3.3.6 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.

3.3.7 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 Region4. 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.

3.4 Conclusions

Interpretation of distribution indicators is complicated by the influence of changes in fishing effort, observational coverage operational factors influencing selectivity and catchability (e.g. depth and leader material) and potentially by changes in community composition. 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. With the exception of 2014 total effort in the longline fleet has increased, through the study period (1995-2014) to approximately 800 million hooks annually with nearly half occurring 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 majority 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.

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