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Operational Planning for Shark Biological Data Improvement

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Screening Report

Operational Planning for Shark Biological Data Improvement

Report to the Western and Central Pacific Fisheries Commission

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Contents

Executive summary

The conservation and management of sharks is a growing concern in global fisheries, with mounting evidence of shark population declines, and growing international efforts to improve sustainability and conservation outcomes for sharks and rays. The Western and Central Pacific Ocean (WCPO) supports a range of tuna fisheries that supply over half of the world's tuna, and are a vital economic activity for Pacific countries and territories. However, these fisheries also interact with sharks and rays, and some shark species are experiencing significant declines in Pacific waters.

The Western and Central Pacific Fisheries Commission (WCPFC) manages WCPO tuna fisheries, and has been increasingly involved in research, conservation and management of sharks and rays in the WCPO. The WCPFC has identified a list of shark and ray species as 'key shark species' that are the focus for assessment and management. The WCPFC has also identified that assessment and management require improved information on shark catch and mortality, and improved biological information to inform species assessments and subsequent management plans.

This study collated and reviewed new information available on the biology of key shark species since the 2015 Pacific Shark Life History Expert Panel workshop, and then applied an integrative process to identify specific data gaps and uncertainties, and prioritise potential studies according to conservation contexts, species and fisheries status, and previously identified management needs. This process was designed to develop and prioritise a 'Long List' of biological research studies that would address key information needs. Seven expert reviewers in shark and ray life history, movement and migration, and fisheries assessments in the WCPO were consulted to collect input on potential projects and to prioritize options and opportunities. The process and reviewers' comments were used do revise and refine the Long List into a set of projects that would be practical, feasible, and have the greatest impact in reducing uncertainties and supporting the future management of sharks and rays in WCPO fisheries. The process identified nine potential studies to be considered for addressing key knowledge gaps and informing management of key sharks species in the WCPO.

1. Introduction

The Western and Central Pacific Ocean (WCPO) is a major global supplier of tuna, and the fishery is extremely important to the economies and development of many Pacific Island Countries and Territories (PICTS). In addition to the capture of tunas and billfishes, this fishery also takes a significant amount of shark, mostly as incidental catch (Clarke *et al.* 2014; Rice *et al.* 2015).

In recent years, the Western and Central Pacific Fisheries Commission (WCPFC) has made concerted efforts to identify and refine the status and trends of ‘key shark species’, and has produced assessments for many of these species. There are also efforts to improve catch reporting and document interactions between sharks and WCPFC fisheries, as well as efforts to develop research plans to address key information gaps (e.g. Clarke and Harley 2010). The WCPFC has also introduced Conservation Management Measures (CMMs) to reduce fishing-related mortality of species that are of special conservation interest (WCPFC 2018).

With the status of some shark populations taken in the fishery appearing to be in decline , and growing global conservation concerns for a suite of species (Dulvy *et al.* 2014), research to understand the life history of the species captured is an important part of improving management arrangements that will address these concerns. Life history parameters such as age and growth, and fecundity, and other biological and population factors such as movement and migration, population structuring, natural mortality, and recruitment, are key pieces of information that inform species assessments and subsequent management responses (Cortés 2004).

This report to the WCPFC details a study to assess existing information, identify knowledge gaps, and prioritize future research on key shark species in the Western and Central Pacific Ocean (WCPO). The ultimate objective is to produce a ‘short list’ of candidate research studies, each with a technical specification that outlines the study objectives, approach, expected benefits. This initial report will produce a prospectus of potential research studies (the study “Long List”) by considering existing documentation for identified information gaps, new literature since a WCPFC-run Expert Panel shark life history workshop in 2015, and factors such as practicality.

2. Methods and Approach

This study is a desktop study that used an integrative approach to consider multiple information sources for developing and prioritising candidate research studies that would help operationalise the WCPFC Shark Research Plan. The scope of these potential studies only concerned biological studies, and other potential studies such as management strategy evaluation were out of scope.

This integrative approach considered four main types of information: (1) the data available for each of the key shark species; (2) conservation concerns for each species, (3) assessments of the species' status in WCPO fisheries, and (4) specific research needs identified in management and policy documents (Fig. 1).

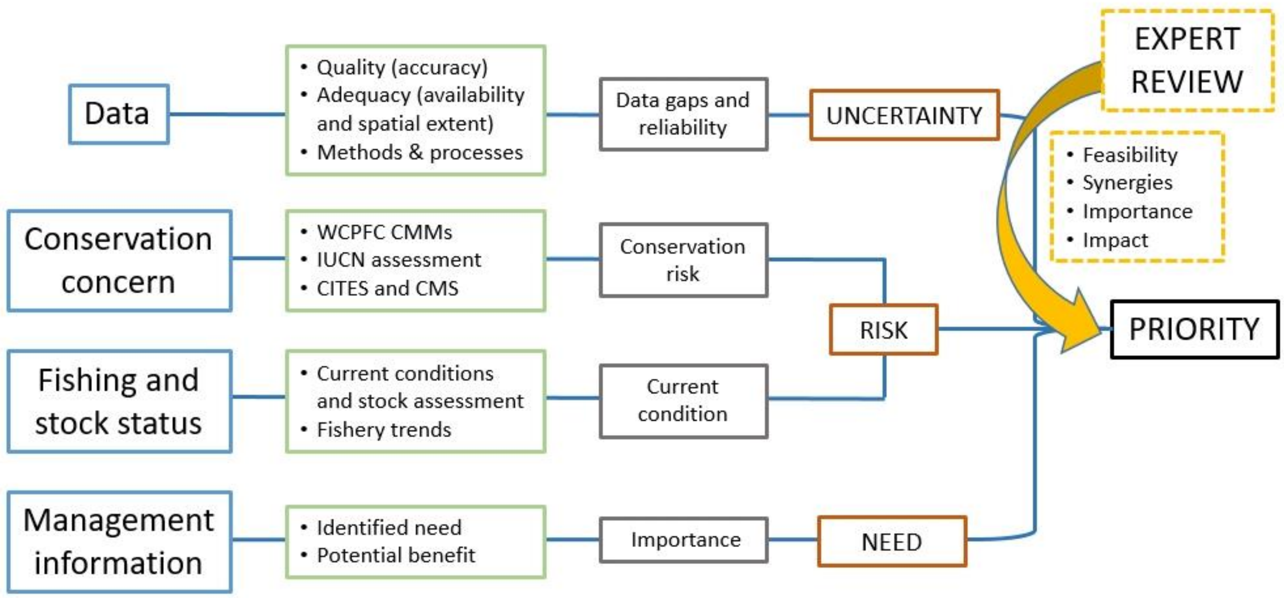

Fig 1. The information and process used to develop and prioritise the list of candidate studies that would address key management needs and information gaps.

Consideration of "Conservation concern", "Fishing and stock status", and "Management information" (Fig. 1) provide indications of about a study's ***importance to conservation and management***. Meanwhile, the consideration of "Data" relates to the ***likelihood that the study would reduce scientific uncertainty***.

Each study was then qualitatively assessed using a review of recent literature and expert knowledge to reassess information gaps, and examine study ***feasibility***. Potential links and ***synergies*** between proposed studies, as well as with existing programs operating in the WCPO, were also identified. A key factor in feasibility was data on catch levels that indicate whether sufficient samples would be acquired to conduct a rigorous study. These factors (feasibility, potential synergies, importance, impacts) were also ground-truthed with expert reviewers who have experience in the region, as well as an assessment of the availability of capacity in the region to conduct the study. Of the criteria specified, feasibility (***the ability to collect required samples within a reasonable timeframe and budget***) was considered a key element in prioritising studies.

2.1 Data and information

A general literature review was conducted to determine what new information (data) on the biology of key shark and ray species had become available since the 2015 Shark Life History Panel report (Clarke *et al.* 2015). A species by species review was conducted by searching the species specific bibliography curated by Shark References (https://shark-references.com/). A wider search of the scientific literature was also conducted using Google Scholar[1] to locate additional literature. The Google Scholar search was conducted using the scientific name of each of the key species as a search term and examined the first 100 papers returned using this search. The search was refined to focus on papers published since the 2015 Shark Life History Panel Report, and all papers were included that examined the species' age, growth, and/or reproductive biology, and for papers within the WCPO region, studies on key shark species movement and migration or fisheries interactions.

2.2 Conservation concern

The level of conservation interest for each species was based on its IUCN status, and whether the species was listed by the Convention on the International Trade in Endangered Species (CITES), the Convention on the Conservation of Migratory Species of Wild Animals (CMS), or listed in a WCPFC Conservation and Management Measure (CMM). Conservation information is presented at Table 1.

A species' relative priority was determined according to their existing listings and management concerns (Table 1). Species that were listed in WCPFC CMMs were considered to have the most pressing conservation and management need, followed (in descending order) by those listed in CITES,

[1] Google Scholar was used as this search engine returns more comprehensive results, especially for recently published studies that are not yet listed in other literature databases such as Scopus and ISI Web of Science, and searches a wider range of literature from across all databases including grey literature.

Species	Common name	WCPFC-CMM	CITES	CMS	IUCN Status	*Overall Priority*
Prionace glauca	blue shark			✓	**NT**	**Low**
Isurus oxyrinchus	shortfin mako			✓	**EN**	**Moderate**
Isurus paucus	longfin mako			✓	**EN**	**Moderate**
Carcharhinus falciformis	silky shark	✓	✓	✓	**VU**	**High**
Carcharhinus longimanus	oceanic white tip	✓	✓	✓	**VU**	**High**
Alopias superciliosus	bigeye thresher		✓	✓	**VU**	**Moderate**
Alopias pelagicus	pelagic thresher		✓	✓	**VU**	**Moderate**
Alopias vulpinus	common thresher		✓	✓	**VU**	**Moderate**
Lamna nasus	porbeagle		✓	✓	**VU**	**Moderate**
Sphyrna zygaena	smooth hammerhead		✓	✓	**VU**	**Moderate**
Sphyrna lewini	scalloped hammerhead		✓	✓	**EN**	**High**
Sphyrna mokarran	great hammerhead		✓	✓	**EN**	**High**
Eusphyra blochii	winghead				**EN**	**Low**
Rhincodon typus	whale shark	✓	✓	✓	**EN**	**High**
Mobulids	Manta rays and devil rays		✓	✓	**NT-EN**	**Moderate**

Table 1: Key elasmobranch species in the Western and Central Pacific Ocean (WCPO) and their respective priority in this study based on (in descending order of importance) (1) existing, WCPFC CMMs, and the combination of CITES and CMS listings, and the global IUCN status. Species with WCPFC CMM's were ranked high, as were species that are listed on CITES *and* CMS *and* listed as VU or EN.

CMS, and then threatened species listed by the IUCN Red List. This order reflects the conservation concern for these species and for fisheries management in the WCPO.

2.3 Fishing and stock status | Management information

There are existing resources that provide information about the four main types of information (Fig. 1): data availability and certainty; conservation need; fishing information and stock status; and management need. Some of these documents also provided useful information on the biological aspects of the key shark species (especially Clarke *et al.* 2015).

These existing resources included:

- Stock assessments prepared for the WCPFC;
- WCPFC scientific reports and research policy documents, especially the Reports of the Pacific Shark Life History Panel (Clarke *et al.* 2015), the current WCPFC Shark Research Plan (WCPFC-SC11-2015/EB-WP-01 rev1), and updates to that Plan (e.g. Progress on the WCPFC stock assessments and shark research plan 2018 (WCPFC-SC14-2018/EB-WP-04);
- Other WCPFC policy documents and meeting reports relating to sharks and bycatch.

These WCPFC scientific reports and policy documents were examined to identify specific listed research and information needs, and to identify priority species among the key shark species to identify Key Information Gaps. These specific information needs were identified and used to guide development of the Candidate List of potential studies – the 'Long List' of studies.

2.4 Expert review

Once the candidate studies were identified, seven independent reviewers were engaged to provide feedback on candidate studies. Experts were selected based on their demonstrated expertise in the areas of elasmobranch age and growth, fisheries management, and movement and tagging studies, and availability to participate. Experts with direct experience in the WCPO were prioritised.

The following experts were contacted to provide independent advice and comment on the 'Long List'. (Table 2).

Expert reviewer	Institution	Expertise
Rui Coelho	Instituto Português do Mar e da Amosfera (Portugal)	Age and growth, fisheries management
Yasuko Semba	National Research Institute of Far Seas Fisheries (Japan)	Age and growth, fisheries management
Kwang-Ming Liu	National Taiwan Ocean University (Taiwan)	Age and growth, stock assessment
Jon Smart	South Australian Research and Development Institute (Australia)	Age and growth
Melanie Hutchinson	National Oceanic and Atmospheric Administration (Hawaii)	Shark tagging, fisheries management
Neville Smith	Secretariat of the Pacific Community (New Caledonia)	Observer program, fisheries management
Caroline Sanchez	Secretariat of the Pacific Community (New Caledonia)	Observer program, fisheries management

Table 2: Expert reviewers who provided input and advice to refine the Long List.

The expert reviewers were specifically asked to comment on the following:

- Which of the studies are the most important in supporting the conservation and management of key WCPFC shark species
- The extent to which these studies would reduce current scientific uncertainty
- The relative feasibility of the different studies
- Opportunities for collaborations or synergies between proposed and existing studies
- Comments or suggestions about other studies that could be considered
- Any other comments or advice

Reviewers were also asked to comment on studies they felt were the least valuable, and also to provide their views on a 'blue sky' study, that is, if any study could be made a reality, what study did they feel would be most beneficial to the management of key shark species in the WCPO.

2.5 Developing the Long List

The study Long List was intentionally devised to produce a portfolio of candidate studies that range across different scopes and scales. These candidate studies were developed by considering data and information, conservation concerns, fishery information and status, and management need (Fig. 1). The Study Long List also reflects specific studies identified by WCPFC documents, especially the Shark Research Plan (Clarke and Harley 2010), the Pacific Shark Life History Expert Panel report (Clarke *et al.* 2015), and associated WCPFC papers reporting on progress of the Shark Research Plan.

The resulting Long List includes targeted studies focused on specific species or regions, as well as some projects that could be applied across multiple species. Multi-species studies are more complex and likely more costly, but would return significantly greater benefits. The smaller scale single species studies may be less costly, but benefits will likely be more restricted. By including this mix of studies, the Study Long List presents WCPFC with a range of investment options.

3. New information

A wealth of new data and information on key shark species has become available since the 2015 Pacific Shark Life History Expert Panel Report (Clarke *et al.* 2015). Unsurprisingly, most of the new biological and Pacific fisheries relevant studies were published on species that are more commonly encountered in global fisheries (e.g. the blue shark and shortfin mako), or that have specific conservation and management concerns (e.g. silky shark). This new information is extensive and is summarised at Appendix A.

4. Key information gaps

Numerous documents were assessed to identify key knowledge and information gaps and research priorities for managing elasmobranchs in the WCPFC (see Methods 2.3). The knowledge gaps identified in this study only cover biological studies. Other potential studies such as management strategy evaluation were outside the scope of this review and are not included here.

Emerging research needs and data gaps are identified in the following four sections.

4.1 Research priorities from the Shark Research Plan (Clarke and Harley 2014)

- Biology of the longfin mako (*Isurus paucus*)
- Region-specific life history for thresher sharks (*Alopias* spp.)
- The Plan notes the need for a coordinated region-wide tagging (both conventional tags and satellite tags) program.

4.2 Research priorities from WCPFC shark research plan progress reports and updates

- Assessment of southwest Pacific mako sharks
- Hammerhead shark biology (species-and region-specific age, growth, and reproductive parameters)
- Whale shark stock discrimination
- Reliable length-at-age estimates and maturity schedule, improved understanding of stock structure, and reliable mortality estimates for the shortfin mako (southern hemisphere), whale shark, and hammerhead sharks.

4.3 Research priorities from the Pacific Shark Life History Expert Panel report (Clarke *et al.* 2015)

- Blue shark: resolve reproductive biology and reproductive schedule and conversion factors for weight-length relationships. Life history information for the South Pacific[2].
- Shortfin mako: resolve periodicity of band pair deposition (potential ontogenetic shift), reproductive parameters and schedule; more life history information on south Pacific mako and stock structure.
- Longfin mako: very little is known about the longfin mako and there is considerable uncertainty about all of its life history parameters.
- Silky shark: Some life history uncertainties remain including reproductive periodicity and longevity. Age validation is required, and stock structure remains uncertain. Need to understand better the difference in life history parameters between east and west Pacific.
- Oceanic whitetip shark: Information is needed on reproductive biology including gestation periods, reproductive periodicity, longevity, and stock structure.
- Thresher sharks: more information needed on reproductive periodicity
    - Bigeye thresher: limited life history data from South Pacific, but wide ranging species.
    - Pelagic thresher: limited life history data from South Pacific, potential differences between eastern and western populations.
    - Common thresher: limited life history data from the South Pacific
- Porbeagle shark: information needed about southern hemisphere stock structure (possibly through genetics), and reproductive characters such as gestation and periodicity.

[2] Life history information has since been published – see Joung, S.-J., Lyu, G.-T., Hsu, H.-H., Liu, K.-M., and Wang, S.-B. (2018). Age and growth estimates of the blue shark *Prionace glauca* in the central South Pacific Ocean. *Marine and Freshwater Research* **69**(9), 1346-1354.

- Whale shark: no information on reproductive periodicity and seasonality.
- Hammerhead sharks: a vulnerable species due to fishery overlaps and low capture survival; contradictory information about periodicity of band pair formation, and inter-region variability in life history traits.
    - Smooth hammerhead: stock structure and movements are unknown, more information needed on reproductive biology.
    - Scalloped hammerhead: more information needed on movement and stock structure, periodicity of vertebral band pair formation (age validation), large differences in growth curves (possibly due to interpretation of band pair periodicity).
    - Great hammerhead: more information needed on stock structure, movement, and periodicity of growth band formation, central Pacific-specific life history parameters.
    - Winghead shark – This species was not considered further as it is a coastal species that at best occurs as a vagrant in pelagic habitats

The Expert Panel also noted that existing length-weight and length-length conversion factors for all species should be reviewed to improve accuracy in a range of fisheries analyses. The expert panel also noted a general need for a review of the potential causes of variations in age estimation between regions, and the need for age validation studies and reproductive biology for several key species (e.g. blue shark, shortfin mako).

4.4 Research priorities arising from assessments

Shark stock assessments were examined to identify specific research priorities pertaining to biological information gaps, listed below.

Silky shark (Clarke *et al.* 2018)

- Tagging studies of movement, stock structure as well as post-release mortality

Oceanic whitetip shark (Rice and Harley 2012)

- Age and growth, and reproductive biology (especially female maturity)
- Tagging studies for stock discrimination and post-release survival

Bigeye thresher shark (Clarke 2017a)

- Refine information on post release survival
- Tagging and tracking of neonates, juveniles, and females

Blue shark (2015)

- Improved information on catch size and sex composition from all fleets
- Verify blue shark reproductive schedule

- Large scale tagging to estimate age-specific mortality rates, and identify movement
- Meta-analysis of biological parameters to improve accuracy of biological parameter estimations.

Blue shark (2017)

- Need further data on age and growth from large blue sharks (both sexes)
- Litter size and reproductive schedule from large blue sharks
- Large scale tagging to estimate age-specific mortality rates, and identify movement
- Meta-analysis of biological parameters to improve accuracy of biological parameter estimations.

Shortfin mako shark (2018)

- Sex specific length-at-age
- Reproductive schedules
- Fecundity

Whale shark (2018)

- Quantify post release mortality from the purse seine fishery
- Reproductive schedules
- Fecundity

Non key species (2016)

- Quantify post release mortality of mobulids from both longline and purse seine fishery
- Review of length-length and length-weight conversion factors

4.5 Assigning study priority

Each candidate study in the Long List was prioritised following the process outlined at Fig. 1. Each study was qualitatively ranked against each criterion as Low, Moderate or High priority depending on the extent to which that study would meet each criterion. The final priority rank represents the mode of the criteria ranks. However, study *feasibility* and *conservation and management importance* were considered the most important criteria.

5. Candidate studies (the ‘Long List’)

The review process produced a list of nine candidate studies.

5.1 | Study 1: resolving blue shark reproductive biology and reproductive schedule

Study objective

Resolve uncertainties in blue shark reproductive schedule and periodicity to refine population models and assessments, especially in the South Pacific Ocean.

Rationale

- Blue sharks are the most commonly encountered and captured shark in the WCPO
- As the most commonly captured shark in the WCPO, the blue shark requires regular assessment, and declining catch rates have been reported (Clarke *et al.* 2013).
- Reproductive biology has been studied (Fujinami *et al.* 2017), but more information is needed.
- The Shark Life History Expert panel (WCPFC-SC11-2015/EB-IP-13) and the latest blue shark assessment (WCPFC-SC13-2017/ SA-WP-10) cite the need for improved data on reproductive schedule, particularly from larger individuals, especially for the South Pacific.

Study methods

- Collect 200 reproductive samples from each sex including testes, clasper length and calcification status for males, ovary condition, follicle development and embryo development in females.
- Will require retention of whole specimens and reproductive staging by trained onboard fisheries observers.
- Samples especially required from large adults and from South Pacific waters.
- Reproductive biology analysis would follow routine protocols of reproductive staging commonly employed in shark life history studies (Walker 2004; Walker 2005b)

Priority – MODERATE to HIGH

Conservation and management importance	***Low to Moderate*** *– the species has relatively low conservation importance and is highly productive. However, the high volume of blue sharks caught warrants moderate management attention.*

Level of uncertainty resolved	***High*** *– blue sharks are well studied. However, the reproductive schedule has a large effect on population modelling and small errors could be significant. This study would resolve ongoing uncertainty about reproductive parameters in particular, and provide better data from the South Pacific.*
Feasibility and costs	***High*** *– blue sharks are captured in large numbers, although captures of larger individuals are less frequent. Project would need to explore options to increase sampling in the South Pacific. The species is not subject to WCPFC CMMs or listed on CITES so acquiring and transferring samples to laboratories will not require special documentation.*
Availability of analytical services	***High*** *– this work is routine, and fisheries laboratories in the North and South Pacific would be able to conduct the work. This study would also be an ideal university based Masters student project which could be a cost effective means for completing the study.*
Synergies	***High*** *– collection of blue sharks could be coordinated with WCPFC's observer program and draw upon data collected by the ISC[3] in the North Pacific. In the South pacific, blue sharks could be sampled in conjunction with New Zealand fisheries research programs.*

Additional comments

This project should build upon the information and data collected by the ISC on North Pacific blue sharks. North Pacific blue sharks are segregated by sex and size, and potential mating grounds have been identified. There is extensive information on size and age at maturity, litter size, gestation time, and reproductive periodicity. In contrast, information is needed on the reproductive schedule and size at birth for South Pacific blue shark (Clarke *et al.* 2015).

[3] International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

5.2 | Study 2: biology of the longfin mako shark

Study objective

Resolve uncertainties in the biology of the longfin mako including age, growth, and reproductive parameters.

Rationale

- While the longfin mako is infrequently encountered better information is needed on its reproductive biology and age and growth parameters.
- These needs are raised the Shark Research Plan (WCPFC-SC10-2014/ EB-IP-06) and the Shark Life History Expert panel (WCPFC-SC11-2015/EB-IP-13).

Study methods

- Vertebrae and reproductive material (testes, ovaries, uteri, ova, and embryos) recovered from longfin mako sharks on board, length and sex data recorded by onboard observers as per WCPFC ROP Minimum Standard Data.
- Participating observers trained in extracting, labelling, and storing shark vertebrae and reproductive material onboard.
- If reproductive material cannot be extracted and retained (it is a lengthy process that requires animals to be dissected and uteri, ova, and embryos removed, frozen, and then fixed for histological analysis – see Walker 2005b), observers can be trained to assess the reproductive stage of males and females using standard protocols (e.g. Walker 2005b, 2005a).
- For age and growth, vertebrae would be sent to laboratories in the Pacific and aged using standard protocols for sharks described by Cailliet et al. (2006).

Priority – MODERATE

Conservation and management importance	***Low***– *the species has moderate conservation importance and is relatively infrequently caught in the WCPO.*
Level of uncertainty resolved	***High*** – *very little is known about the biology and life history of the species so this information would be valuable throughout the Pacific and even globally.*
Feasibility and costs	***Low to moderate*** – *low encounter rates reduce feasibility. However, the species is encountered and observers could begin collecting the required material. The species is not listed on CITES so transferring samples will not require special documentation. SPC catch data would need to be explored to identify key capture times and locations*

Availability of analytical services	***High*** *– this work is routine, and labs in the North and South Pacific would be able to conduct the work.*
Synergies	***Moderate*** *– collection of longfin mako could be coordinated with WCPFC observer programs, the SPC tuna tagging program, and US and New Zealand and Australian fisheries research programs.*

Additional comments

There is the potential for confusing shortfin and longfin mako sharks. Observers may need refresher training to specifically distinguish between the two species. Species identification can also be validated using observer photographs and DNA (see Smart *et al.* 2016).

5.3 | Study 3: life history of thresher sharks

Study objective

Collect region-specific life history parameters for thresher sharks (especially the pelagic thresher and bigeye thresher sharks) from the South Pacific.

Rationale

- Thresher sharks, specifically the bigeye thresher shark, may currently be subjected to overfishing in the WCPO (Clarke 2017a).
- Relatively little life history information is available from the South Pacific with potential life history variations between regions and studies. Variations may also exist between eastern and western Pacific pelagic thresher sharks (Clarke *et al.* 2015).
- There are limited data for all three species (bigeye, common, and pelagic thresher sharks) on age and growth parameters, and reproductive biology (Clarke *et al.* 2015).
- The need for better information on thresher shark life history has been documented in the Shark Research Plan (WCPFC-SC10-2014/ EB-IP-06) and the report of the Shark Life History Expert panel (WCPFC-SC11-2015/EB-IP-13), and at SC13 discussions about the thresher shark assessment.

Study methods

- Thresher shark vertebrae would need to be recovered from thresher sharks with corresponding length and sex data recorded by onboard observers.
- >100 vertebrae would be collected from each species and across a range of size classes.
- Participating observers would need to be trained in extracting, labelling, and storing thresher shark vertebrae onboard until they could be collected and stored in a centralized location.

- Vertebrae would be sent to age and growth laboratories in the Pacific and aged using standard protocols (Cailliet *et al.* 2006).
- Thresher shark vertebrae can be very difficult to section and read as the vertebrae are very light and thin, and often have indistinct band patterns. This study would need to pay special attention to protocols for sectioning, staining, and reading growth band pairs. A reference set of vertebrae should be established with readings also performed by a second lab.

Priority – MODERATE

Conservation and management importance	***Moderate*** *– thresher sharks are of moderate conservation importance and are relatively infrequently caught in the WCPO. However, the species' low fecundity elevates its risk from low to moderate.*
Level of uncertainty resolved	***Moderate*** *– region specific life history information is needed about the biology and life history of thresher sharks to refine assessments.*
Feasibility and costs	***Low to moderate*** *– low encounter rates of thresher sharks reduce feasibility and will extend the time needed to collect sufficient samples. However, observers could begin collecting the required material. The species is not subject to any WCPFC CMMs, however it listed on CITES thus permissions will be required to transfer samples to laboratories for analysis. Observer data would need to be explored to identify key capture times and locations*
Availability of analytical services	***Moderate*** *– while age and growth studies are routine, thresher shark vertebrae are more difficult to process and interpret. While labs are available in the north and south Pacific, scrutiny would be needed to ensure care in processing and interpreting vertebrae. Second readings by a qualified lab could be required.*
Synergies	***Moderate*** *– collection of thresher shark samples could be coordinated with WCPFC observer programs, the SPC tuna tagging program, and US national fisheries research programs.*

Additional comments

The 2017 thresher shark assessment (WCPFC-SC13-2017/SA-WP-11) specifically lists the need for better information on post release mortality, and movement data to resolve stock structure. However, the US has begun studies on post release mortality, which could be an opportunity to collaborate. The three thresher shark species (common, pelagic, and bigeye thresher) may be confused so species identification may require specific training and preparation.

5.4 | Study 4: biology and life history of hammerhead sharks

Study objective

Clarify the stock structure and life history traits of the scalloped, smooth, and great hammerhead sharks in the WCPO, particularly for the great hammerhead shark which has limited life history data.

Rationale

- The three large WCPO hammerhead species (smooth hammerhead, scalloped hammerhead, and great hammerhead) are all species of conservation concern. These species also typically suffer high post release mortality (Ellis *et al.* 2017).
- Hammerhead sharks are highly migratory and exhibit strong stock structuring (Chin *et al.* 2017). Currently, most life history information exists for the scalloped hammerhead shark, and for all species, Pacific region life history is restricted to the north Pacific (e.g. Taiwan) and Australia (Clarke *et al.* 2015).
- There is little information from the central and southern Pacific, and even species ranges and distributions require further verification, especially for the smooth hammerhead. There is also conflicting information about the periodicity of band pair formation.
- The need for region-specific age, growth, and reproductive data, age validation, and stock structure was identified in the Shark Life History Expert panel (Clarke et al. 2015) and the Shark Research Plan ((give formal reference)).

Study methods

- Onboard observers or scientists would need to collect species-specific data and biological samples.
- Ideally >100 vertebrae would be collected from each of the hammerhead species from a range of size classes, especially larger animals.
- Vertebrae would be sent to age and growth laboratories in the Pacific and aged using standard protocols as described by Cailliet et al. (2006).
- Observers would also need to be trained in identifying reproductive stages of males and female hammerhead sharks (e.g. Walker 2005b).
- Distinguishing band pairs in hammerhead sharks can be challenging as the bands can be difficult to clearly identify and interpret. Thus a reference set of vertebrae should be established with readings also performed by a second lab.

Priority – MODERATE to HIGH

Conservation and management importance	***Moderate to High*** *– hammerhead sharks are of global conservation concern (listed on CITES and CMS). However, they are caught in relatively low numbers*

	in the WCPO. Hammerheads have very high post release mortality which elevates management importance.
Level of uncertainty resolved	***Moderate to High*** *– hammerhead age, growth, and biological studies have conflicting results, and there is a lack of data from the south and central Pacific. Data are particularly needed for the smooth hammerhead. Information about stock structure is also needed (see additional comments).*
Feasibility and costs	***Low to moderate*** *– low encounter rates of hammerhead sharks reduce feasibility and will extend the time needed to collect sufficient samples. However, their high at vessel mortality may make sample retention easier. The three hammerhead species have no WCPFC CMMs, however they are listed on CITES thus permissions may be required to transfer samples to laboratories for analysis. Observer data would need to be explored to identify key capture times and locations*
Availability of analytical services	***Moderate*** *– while age and growth studies are routine, hammerhead shark vertebrae can be more difficult to interpret. Need to ensure care in processing and interpreting vertebrae with second readings by another lab recommended.*
Synergies	***Moderate*** *– collection of hammerhead shark samples could be coordinated with WCPFC observer programs, and perhaps national fisheries research programs and port sampling.*

Additional comments

Hammerhead sharks are a relatively infrequent catch and as such the challenge will be to secure sufficient samples to provide statistically rigorous results. The risk can be mitigated by taking a long-term approach to sample collection and by reviewing available data to identify areas and times when hammerheads are more frequently encountered.

A key information gap is also stock structure. Sampling hammerheads would provide the opportunity to collect and store tissue for future genetic studies that use higher resolution techniques (e.g. single nucleotide polymorphisms) to distinguish stock units.

5.5 | Study 5: silky shark and oceanic whitetip shark reproductive biology and longevity

Study objective

Conduct lethal biological sampling to resolve key uncertainties in silky shark and oceanic whitetip shark reproductive biology such as reproductive schedule and periodicity.

Rationale

- The oceanic whitetip shark and silky shark are the subjects of WCPFC CMMs specifically introduced to halt and reverse declines in these species (CMM 2013-08 and CMM 2011-04).
- They are also listed on CITES and CMS indicating broader conservation interest and concern.
- Better information is needed on the reproductive periodicity and gestation period, longevity for both species, and age and growth for the oceanic whitetip shark (see the Shark Life History Expert panel report - WCPFC-SC11-2015/EB-IP-13; and stock assessments for silky shark (SC14-SA-WP-08) and oceanic whitetip sharks (WCPFC-SC8-2012/SA-WP-06 Rev 1)).

Study methods

- Participating observers would need to be trained in identifying reproductive stages of male and female oceanic whitetip sharks using standard methods described by Walker (e.g. 2005b).
- Larger specimens (2.5 m TL) should be retained and vertebrae extracted and frozen on board. Ideally >50 vertebrae would be collected from large animals of each species to establish longevity and maximum sizes and ages.
- Vertebrae would be sent to age and growth laboratories in the Pacific and aged using standard protocols (Cailliet *et al.* 2006).

Priority – HIGH

Conservation and management importance	***High*** *– both silky sharks and oceanic whitetip sharks are management priorities in the WCPO with existing CMMs in place. They are also listed on CITES and CMS.*
Level of uncertainty resolved	***High*** *– the reproductive schedule has a large effect on population modelling and small errors could have significant effects on population projections. Resolving the longevity of the oceanic whitetip could affect population growth and recovery estimates.*
Feasibility and costs	***Moderate*** *– moderate numbers of silky sharks and oceanic whitetip sharks are captured, however observer data would need to be explored to identify key capture times and locations. Retention of both species is prohibited by WCPFC CMMs, and both species are listed on CITES. Therefore, specific permissions would need to be secured to retain specimens, and to transfer samples to laboratories for analysis.*
Availability of analytical services	***High*** *– the reproductive and age and growth analyses needed for this study are routine and could be conducted by numerous labs in the north and south Pacific.*

Synergies	***Moderate to High** – collection of silky shark and oceanic whitetip shark samples could be coordinated with WCPFC observer program and national fisheries research programs.*

Additional comments

This study combines both species as they are both non-retention species and are currently the focus of ongoing research. Combining both species into one project could lead to a single solution for sampling both non-retention species as well as capitalize on potential synergies with ongoing research interests.

There is also an identified need for age validation in these species. This is a very different study that requires animals to be chemically tagged, released, and then recaptured after a period at liberty. As such, that study is considered here as a separate study (see 5.6)

5.6 | Study 6: age validation and stock structure of the silky shark and oceanic whitetip shark

Study objective

Use chemical tag and recapture methods to resolve discrepancies in interpretation of vertebral bands in the age and growth of the silky shark and oceanic whitetip shark to produce more accurate age and growth models, and subsequently, better quality assessments. Clarify the stock structure of both species.

Rationale

- Both the silky shark and the oceanic whitetip shark are subject to WCPFC CMMs (CMM 2013-08 and CMM 2011-04). They are also of broader conservation and are listed on CITES and CMS.
- More information is needed on the longevity for both species, and for age validation as there are disagreements in the interpretation of vertebral band pair patterns. These issues have been identified in the Shark Life History Expert panel report (WCPFC-SC11-2015/EB-IP-13), and stock assessments for silky shark (SC14-SA-WP-08) and oceanic whitetip sharks (WCPFC-SC8-2012/SA-WP-06 Rev 1).
- Stock assessments for both species (SC14-SA-WP-08; WCPFC-SC8-2012/SA-WP-06 Rev 1) and the Shark Life History Expert Panel report also highlighted the need for information on stock structure.

- Given that both age validation and stock discrimination are informed by at-sea tag and release of animals, both objectives could be delivered through the same at-sea effort.

Study methods

- Onboard observers or scientists would tag and release silky and oceanic whitetip sharks. For age validation, sharks are injected with either calcein or oxytetracycline (OTC), both chemical dyes which mark the vertebrae at a known time.
- Sharks will also be tagged with an external fin-mouthed roto-tag so that fishers and observers can recognize chemically tagged sharks to be retained upon recapture.
- Ideally, 5 vertebrae from each species would be recovered from chemically tagged sharks to confirm periodicity of band-pair deposition as described by Goldman (2005).
- An incentive program may be needed to ensure recovery of chemically tagged sharks.
- Sharks can also be tagged with archival satellite tags to track long-term movements over 12 months and thus, provide information on movements and migration to inform stock discrimination. Ideally, at least 12 sharks from each sex of each species would be tagged.

Priority – LOW (see 'additional comments')

Conservation and management importance	***High*** *– both silky sharks and oceanic whitetip sharks are management priorities in the WCPO with existing CMMs in place. They are also listed on CITES and CMS.*
Level of uncertainty resolved	***High*** *– age validation is crucial to correct interpretation of vertebral bands and subsequently, producing accurate growth models that inform population assessments. Resolving stock structure would provide detail about the appropriate application and scaling of data to population assessments.*
Feasibility and costs	***Low*** *– moderate numbers of silky sharks and oceanic whitetip sharks are captured, however observer data would need to be explored to identify key capture times and locations. Retention of both species is prohibited by WCPFC CMMs, and both species are listed on CITES, so specific permissions would need to be secured to retain tagged specimens upon re-capture, and to transfer samples to laboratories for analysis.* *However, the need to recover chemically tagged animals and high cost of satellite tags reduce study feasibility. The main issues are (1) at vessel handling and tagging of sharks to ensure crew safety and shark post release survival; (2) recapture of chemically tagged animals is likely to be low; and (3) the likely high cost of satellite tags (if satellite tagging is included).*
Availability of analytical services	***High*** *–due to the injection of dye the age and growth analyses, and tagging and movement analysis capacity needed for this study are routine and could be conducted by numerous labs in the North and South Pacific.*

Synergies	***Moderate** – This study could be integrated with national fisheries tagging programs, the SPC tuna tagging program, and ongoing efforts to tag sharks for post release mortality studies in Hawaii.*

Additional comments

Even though this would be an important study on species of particular interest (resulting in rankings of moderate to high for most criteria), the low feasibility and potential costs involved reduce this study's priority relative to other studies.

5.7 | Study 7: stock structure and life history of southern hemisphere porbeagle shark

Study objective

Resolve life history, reproductive biology, and stock structure of the porbeagle shark in the southern hemisphere.

Rationale

- Currently biological data on Pacific porbeagle sharks is concentrated around New Zealand.
- The Shark Life History Expert Panel report noted that more data are needed on the life history from the rest of the Pacific (Clarke *et al.* 2015).
- Reproductive data would improve region-specific understanding of gestation period and reproductive periodicity.
- While the 2017 assessment of porbeagle sharks found that they are of low risk of overfishing (Clarke 2017b), the assessment also highlighted the limited knowledge about its life history parameters in the region.
- There are global conservation concerns about the species, based on the northern stock, and it is listed on both CITES and CMS.

Study methods

- Data and samples collected by observers working on vessels fishing at higher latitudes within the South Pacific.
- Porbeagle sharks caught in good condition would be tagged with conventional tags, and (funding dependent) with archival satellite tags. Tagging would provide information on movements and migration, and hence help improve stock discrimination.
- Porbeagle sharks that are dead or unlikely to survive release would be sampled, with vertebrae and reproductive samples stored in frozen form.

- Ideally >100 vertebrae and reproductive samples would be recovered from both sexes from a range of size classes. Observers should also be trained in reproductive staging of both males and females using development categories of testes and claspers for males, and ova, embryos, and uterine condition for females (e.g. Walker 2005b).
- Tissue attached to vertebrae could be stored for future DNA-based stock structure analyses.
- Vertebrae and reproductive samples would be analysed according to standard protocols as described by Cailliet et al. (2005) and Walker (2005b).

Priority – LOW

Conservation and management importance	***Low*** *– the species encounters relatively low levels of fishing in the WCPO (mainly around New Zealand) which reduces the management importance.*
Level of uncertainty resolved	***Moderate to High*** *– regionally specific life history data are required to refine the growth models that underpin population assessments. Reproductive data are especially important to population assessments. Resolving stock structure would provide detail about the appropriate application and scaling of data to population assessments.*
Feasibility and costs	***Low to Moderate*** *– moderate numbers porbeagle are captured particularly in New Zealand waters. If sampling and analyses were completed within New Zealand, CITES permissions would not be required.* *Resolving stock structure could be accomplished by conventional and satellite tagging. The main feasibility issues are (1) at vessel handling and tagging of sharks to ensure crew safety and shark post release survival; (2) cost of satellite tags.*
Availability of analytical services	***High*** *– the age and growth analyses, and tagging and movement analysis capacity needed for this study are routine and could be conducted by numerous labs in the south Pacific (particularly NIWA in New Zealand).*
Synergies	***Moderate*** *– This study could be integrated with national fisheries tagging programs (e.g. in New Zealand and Australia), and opportunistically through WCPFC observer programs.*

Additional comments

Tagging and sampling of porbeagle sharks would provide the opportunity to collect and bank genetic material for future genetic studies that use higher resolution techniques (e.g. single nucleotide polymorphisms) to distinguish stock units.

5.8 | Study 8: validated life history, biology, and stock structure of the shortfin mako in the South Pacific

Study objective

Clarify the life history parameters and stock structure of the shortfin mako in the South Pacific.

Rationale

- Shortfin mako are of global conservation concern (to be considered at the CITES CoP in August 2019) and are listed on Appendix II of the CMS.
- North Pacific shortfin mako were assessed in 2018 (noting that many uncertainties were identified in the assessment), but there is no assessment for the South and West Pacific.
- The species' life history and biology are complex and growth estimates vary considerably, with evidence for an ontogenetic shifts in growth band periodicity (Barreto *et al.* 2016; Kinney *et al.* 2016).
- The need for more data on the life history and stock structure in the South and West Pacific has been raised in scientific reports (e.g. Bruce *et al.* 2013) (Clarke *et al.* 2015) as well as the 2018 stock assessment (WCPFC-SC14-2018/ SA-WP-11).

Study methods

This study could be modular with three distinct activities that could be mobilised or demobilised depending on the resources available.

Life history and biology

- Appropriately trained observers collect vertebral samples with corresponding length and sex data.
- Shortfin mako sharks in good condition tagged and released by observers.
- Shortfin mako sharks that are dead or unlikely to survive release would be retained and vertebrae and reproductive material extracted.
- Ideally, for life history studies, at least 100 vertebrae would be recovered from both sexes and from across a range of size classes, and stored frozen for delivery to the laboratory.
- Ideally, all sharks retained (>100 of both sexes) would be examined on board for reproductive staging using standard categories and protocols (e.g. Walker 2005b).

For age validation,

- Shortfin mako sharks captured in good condition would be injected with either calcein or OTC, both chemical dyes which mark the vertebrae at a known time. Sharks also tagged with an external fin-mouthed roto-tag so that fishers and observers can recognize sharks to be retained upon recapture. Vertebrae recovered from chemically tagged sharks should display a mark that allows the periodicity of band-pair deposition to be determined (Goldman 2005).

Stock Structure

- Tissue attached to vertebrae and recovered from tagged and released animals could be stored and used in future DNA based stock structure analyses.
- Animals in good condition (and tagged and injected for age validation) could also be tagged with conventional dart tags and archival satellite tags to provide information on long-term movements.

Priority – MODERATE to HIGH

Conservation and management importance	***Moderate*** *– the species is relatively frequently captured, is listed on CMS, and is proposed for listing under CITES.*
Level of uncertainty resolved	***High*** *– uncertainty and contradicting data about the species' life history mean that age validation and resolved reproductive data would be very informative. These data are required to refine the growth models that underpin population assessments. Accurate reproductive data are especially important to population assessments. Resolving stock structure would provide detail about the appropriate application and scaling of data to population assessments.*
Feasibility and costs	***Low to High (depending on project scope activated)*** *Life history and reproductive biology components of this study are highly feasible. Short fin mako are relatively frequently encountered so sample feasibility is relatively high.* *Age validation would rely upon recovering sufficient numbers of chemically tagged mako sharks after sufficient times at liberty. Low recapture and recovery rates are likely which reduces the feasibility of this part of the study.* *Resolving stock structure could be accomplished by conventional and satellite tagging. The main feasibility issues are (1) at vessel handling and tagging of sharks to ensure crew safety and shark post release survival; (2) cost of satellite tags. The species also appears somewhat robust to capture and handling (French et al. 2015) which could aid tagging success.*
Availability of analytical services	***High*** *– the age and growth analyses, and tagging and movement analysis capacity needed for this study are routine and could be conducted by numerous labs in the north and south Pacific.*

Synergies	***High*** *– This study could be integrated with national fisheries tagging programs (e.g. in conjunction with ISF programs), and the SPC observer program. Potential synergies could also be explored with national research programs (e.g. New Caledonia), the SPC tuna tagging program, and ongoing studies to examine post release mortality of silky sharks and oceanic whitetip sharks.*

Additional comments

The modular nature of this study means that it could initially begin with simpler, less costly activities (observer training, vertebrae recovery and reproductive staging), and then progress to the more complex task of tagging and recovering tagged individuals. Alternatively, this study could also be separated into two distinct studies (1) age and growth, and reproductive biology that uses deceased individuals; and (2) age validation and stock structure that focuses on tagging, releasing and recapturing individuals.

5.9 | Study 9: whale post release survival from WCPO purse seine fisheries

Study objective

Quantify the post release survival of whale sharks encountered in the WCPO purse seine fishery.

Rationale

- Whale sharks are a high priority conservation concern (Table 1)
- Whale sharks sometimes encircled by nets during purse seine operations, posing the risk of injury or mortality, and their safe release is a priority in the WCPO (WCPFC CMM 2012-04)
- The Shark Life History Expert Panel report (Clarke et al. 2015) and the risk assessment for whale sharks in WCPO purse seine fisheries (WCPFC-SC14-2018/SA-WP-12 (rev. 2) highlight the need for data on whale shark biology and life history, and in particular the need to quantify post release mortality.
- Practices have been developed with the fishing industry to release whale sharks from purse seine nets (Poisson *et al.* 2014), and post release mortality has been studied in the Atlantic (Escalle *et al.* 2016) using archival satellite tags.

Study methods

- WCPFC observer data (e.g. Harley *et al.* 2013) would need to be examined to identify potential times and locations where whale sharks are more commonly encountered.

- Purse seine vessel captains and crews from higher encounter areas invited to participate in the study. Participating vessels engaged to adopt and adapt safe release methods as per Poisson et al. (2014).
- Apply the tagging and release methods detailed by Escalle et al. (2016) by tagging sharks with pop-up archival satellite tags from the deck of the purse seine vessel using a 4 m tagging pole while they were still enclosed in the sack, but after fishing operations had concluded. The study would aim to deploy 12 tags as a minimum (see pg 10 Shark Research Plan WCPFC-SC11-2015/EB-WP-01 rev1). A plan to deploy tags on whale sharks in the WCPO has been previously developed (NOAA Fisheries USA *et al.* 2015)
- Once tagged, safe release procedures would be implemented (Poisson *et al.* 2014; Escalle *et al.* 2016) and post release mortality and behaviour retrieved from archival tags after the 12 month tag deployment period.

Priority – HIGH

Conservation and management importance	***High*** *– although whale shark captures are relatively infrequent, whale sharks are species of special interest to the WCPFC, and are listed on both CITES and CMS.*
Level of uncertainty resolved	***High*** *– while post release survival of whale sharks has been studied in the Atlantic, no such data for post release survival related to different release techniques exists for Pacific fisheries.*
Feasibility and costs	***Moderate*** *– archival satellite tags have been successfully deployed on whale sharks in many locations. While the technique would need to be trialed and potentially adapted to suit purse seine operations in the WCPO, successful studies in the Atlantic demonstrate the potential.* *Archival satellite tags are costly, but co-funding could be sought. The use of survival archival tags to monitor movements over a shorter 60 days would reduce tag costs.*
Availability of analytical services	***High*** *– the tagging and movement analysis capacity needed for this study are routine and could be conducted by numerous labs in the north and south Pacific.*
Synergies	***Low*** *– This study could be integrated with national fisheries tagging programs and WCPFC observer programs.*

5.10 Additional sampling considerations

Many of the age and growth, and reproductive biology studies use standard methods to sample, process, and analyse vertebrae (Goldman 2005; Cailliet *et al.* 2006) or reproductive material (Walker 2005b). These standard techniques are widely used and thus represent repeatable and reputable scientific protocols that would be relevant to studies for any of the key shark species. Additionally, studies using these methods should generate results that are comparable with previous biological studies as well as findings from other regions.

This standardisation provides a capacity building opportunity. Training observers in the WCPO to be proficient in species identification (particularly for similar looking shark species), extraction and storage of vertebrae and reproductive material, and 'on-deck' reproductive staging by examining uterine condition, ova, and embryos, could provide the opportunity to collect valuable samples to support future shark studies in the WCPO.

6. Expert review of the Long List

Expert comments were collected during May 2019 and included a series of Skype meetings and receipt of written comments. These comments resulted in a revised 'Long List" of projects (detailed above). Reviewers expressed a variety of views, but several consistent comments emerged from amongst all reviewers. These broader comments are outlined below.

6.1 Practical and logistical issues

Several reviewers raised concerns about the logistical challenges of collecting samples, especially whole sharks for age, growth, and reproductive studies, as well as potential for post release mortality in tagging studies and age validation studies. Reviewers agreed with the risks identified in age, growth, and reproductive biology studies that collecting sufficient samples (in terms of sample abundance, spread across life stages, and spatial distribution), could be very difficult to achieve for less commonly encountered species such as thresher sharks and hammerhead sharks. Gear and fleet selectivity issues may also reduce the ability to sample individuals across size classes, and across sexes as many pelagic shark species have size and sex-structured populations (e.g. hammerhead sharks, blue sharks).

Reviewers also identified potential challenges in securing whole sharks on board, citing concerns that fishers prefer to cut sharks free, often at distance from the vessel, and may often retrieve gear at night, factors that would reduce the ability of observers or crew to identify target sharks or tagged sharks to make the effort to retain them. Even if target sharks were identified, crews and observers may be unwilling to handle and kill large specimens. Additionally, the CMM banning retention of silky sharks and oceanic whitetip sharks will complicate efforts to secure whole specimens from fishing vessels. These issues could also greatly reduce tag retrieval rates, thus compromising age validation and tagging studies. A similar issue exists for countries that are shark sanctuaries who may prohibit the retention of sharks for any purpose within their EEZs. Reviewers also agreed with the risks identified for studies involving CITES listed species that sample certification and tracing will be required to export samples to a suitable laboratory for analysis.

6.2 Other comments

The expert reviewers commented that smaller scale, species-specific studies could be aggregated into larger scale studies. The other comment raised was that securing samples, especially recovering tagged animals, would require broad scale effort. However, once a wider system was developed, it could be mobilised across the WCPO to collect samples from, and/or tag all species of interest. As such, this wider system would deliver economies of scale.

It was mentioned that the SPC Oceanic Fisheries Program could provide opportunities, if adequately resourced, to provide the platform for coordinating tagging, sample collection, and data curation. This could be operationalised though the Pacific Islands Regional Fisheries Observer (PIRFO) program as well as fishery independent sampling through research cruises, such as the SPC tuna tagging program. However, reviewers also noted that many other programs are also conducting tagging and sampling (e.g. NOAA Fisheries, NIWA and DOC tagging in New Zealand; fisheries research programs in the North Pacific; recreational angler tagging of mako sharks in New South Wales, Australia. Reviewers advised exploring potential integration and collaboration with existing efforts as a much more cost effective and practical approach as opposed to trying to initiate a new program. While reviewers indicated that a Pacific-wide coordinated tagging and sampling program would be beneficial to parties across the WCPO, coordination and data curation will require close cooperation and ‘buy in’ from stakeholders and would be a significant undertaking. The cost of such a program is likely to be significantly more than what is currently available from WCPFC resources, but the potential benefits from such a program would be considerable.

Reviewers also raised suggestions and ideas for further work which fall outside the scope of the current study but are captured in **Appendix B.**

7. Projects shortlist

The original plan under the terms of reference for this study was to move on to a Short List of three priority research projects, including technical specifications but this could not be accomplished in the time available so the contract was modified and this deliverable produced for SC15.

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Appendix A – relevant literature published since 2015 on the biology of key shark species in the WCPO.

Blue shark (*Prionace glauca*) – relevant references since 2015 Expert Panel meeting

Age and growth of the blue shark in the Indian Ocean (Andrade *et al.* 2019)

- Age and growth from animals ranging between 82 and 301 cm FL.
- L_∞ = 283.8 cm FL, k = 0.13 $year^{-1}$ for males; and L_∞ = 290.6 cm LF, k = 0.12 $year^{-1}$,
- max age 25 years.

Post release mortality in Palauan longline fisheries (Musyl and Gilman 2018)

- Mean Fr (released mortality rate) was 0.17 [95% CI 0.09–0.30] for blue shark.

Age and growth of blue sharks from the central south Pacific Ocean (Joung *et al.* 2018)

- von Bertalanffy growth function (VBGF) best fitted the observed total length (TL)-at-age data.
- for females, theoretical maximum length (L_∞) mean ± s.d. = 330.4 ± 46.6 cm TL, growth coefficient k = 0.164 ± 0.057 year–1 and theoretical age at length 0 (t0) = –1.29 ± 0.78 years.
- for males, L_∞ = 376.6 ± 32.6 cm TL, k = 0.128 ± 0.022 year–1 and t0 = –1.48 ± 0.54 years.
- Longevities were estimated to be at least 16.8 and 21.6 years for females and males respectively.

Species composition of the international shark fin trade (Fields *et al.* 2018)

- Blue shark majority of fin trade 2014-2015.

Genetic analysis of global blue shark populations (Bailleul *et al.* 2018)

- Genetic analysis from samples from the Pacific, Atlantic, and Mediterranean
- Blue shark genetics (mtDNA) and microsatellites show homogeneity across regions.
- However genetic time lags mean genetic studies probably unable to differentiate discrete blue shark stocks.

Biology and growth models for blue sharks (Yokoi *et al.* 2017)

- New two sex age structured population model for blue shark populations.
- Blue shark estimated median population growth rate was 0.384 with a range of minimum and maximum values of 0.195–0.533.

From: Impact of biology knowledge on the conservation and management of large pelagic sharks

Species	Value	Covered area	Model/Method	Reference
Blue shark	median = 0.384 (0.195–0.533)[a]	Global	Two-sex age-structured matrix population model	**This study**
	0.28–0.41[b]	North Pacific	Bayesian surplus production model	25
	mean = *0.337 (0.250–0.428)[c]	North Atlantic	Age-structured matrix population model	39
	median = 0.286 (0.237–0.334)[c]	North Atlantic	Age-structured matrix population model	51
	mean = 0.30, sd = 0.045	North Pacific	Bayesian surplus production model	80
	0.169–0.599[b]	North Pacific	Euler-Lotka equation	46
	mean = *0.297 (0.214–0.373)[d]	North West Pacific	Euler-Lotka equation	47
	mean = *0.259 (0.198–0.317)[d]	North East Pacific	Euler-Lotka equation	47

Blue shark catches in the Fiji longline fishery (Piovano and Gilman 2017)

- Blue sharks 51% of shark catch (sharks were 2.4% of the total catch by number).
- J hooks landed more sharks.

Biodiversity and life history parameters for blue shark from the northeastern Atlantic (Ebert *et al.* 2017)

- TL_{max} (cm) = 380 | Female l_{mat} (cm TL) = 173-221 | Female age at maturity 5-7 yrs
- Litter size -35
- Longevity = 20 yrs
- Population growth metric (r_{max}) = 0.577147 | VBF growth rate k = 0.18-0.25

Genetic traits of blue shark populations from the central Pacific Ocean (Li *et al.* 2017)

- Blue sharks in the CPO (n=78), mtDNA, suggests single panmictic population.

Blue shark reproductive biology in the western North Pacific Ocean (Fujinami *et al.* 2017)

- Size at 50% maturity was estimated to be 160.9 cm for males and 156.6 cm PCL for females.
- Litter size varied from 15 to 112 (mean 35.5) and was positively correlated with maternal PCL.
- Parturition, ovulation and mating occurred sequentially from spring to summer, with an eleven-month gestation period. Embryo growth suggests annual reproduction.
- Productivity of North Pacific blue sharks is higher than previously thought, based on larger fecundity and a shorter reproductive cycle.

Potential blue shark nursery in shallow waters in the Atlantic (Bañón *et al.* 2016)

- Size at first sexual maturity of about 184.8 cm TL for females and 178.5 cm TL for males.
- Reports on the anomalous presence of numerous blue shark neonates and juveniles in shallow inshore waters of Galicia, north-west Spain, during the summers of 2014 and 2015.

- Changes in oceanographic conditions, high recruitment events or changes in the pupping area are discussed as possible causes of this unusual behaviour.

Discard and hooking mortality in Canadian longline fishery (Campana *et al.* 2015)

- 37 blue sharks tagged with PSATs
- Healthy at capture blue sharks survived, while injured blue sharks suffered 30% mortality
- Total blue shark mortality was 24%
- Results indicate that the conservation benefits of mandatory release regulations for pelagic longline gear are not nearly as great as is now assumed, especially for shortfin mako and porbeagle sharks (see sections on the shortfin mako and porbeagle shark).

Distribution, abundance, and size of blue sharks from northeastern Japan (Ohshimo *et al.* 2016)

- Longline surveys conducted in the Northwest Pacific Ocean from 2000 to 2014 using chartered commercial longline vessels.
- Most catches of blue sharks and shortfin mako were juveniles, and the nominal catch rate of blue shark was more than 10 times that of shortfin mako.
- The standardized CPUE for blue shark in the second quarter of the year peaked in the mid-2000s and then decreased, but it has been increasing since 2012.

Age validation of blue shark from the eastern Pacific Ocean (Wells *et al.* 2017)

- 26 blue sharks marked with oxytetracycline (OTC) were obtained from tag–recapture activities.
- Results from band counts distal to the OTC mark on each vertebra indicated that a single band pair (1 translucent and 1 opaque) is formed per year for blue sharks ranging from 1 to 8 years of age.
- Length–frequency modal analysis was also used to obtain growth estimates from a dataset spanning 26 years of research and commercial catch data.
- Results provide support for annual band-pair deposition in blue shark.

Shortfin mako (*Isurus oxyrinchus*) – relevant references since 2015 Expert Panel meeting

Population connectivity of the shortfin mako (Corrigan *et al.* 2018)

- Shortfin mako tagged in Australia with PSATs, genetics also examined.
- mtDNA suggest matrilineal substructure across hemispheres, but nuclear DNA indicate global panmictic population.
- Telemetry data indicate the species is highly migratory with frequent long distance movements, but some site fidelity.
- Oceanic transit phases link Australia to the northeastern Indian Ocean, and to New Zealand and New Caledonia.

Distribution, abundance, and size of blue sharks and shortfin mako sharks from northeastern Japan (Ohshimo *et al.* 2016)

- Longline surveys conducted in the Northwest Pacific Ocean from 2000 to 2014 using chartered commercial longline vessels.
- Most catches of blue sharks and shortfin mako were juveniles, and the nominal catch rate of blue shark was more than 10 times that of shortfin mako.

Spatio-temporal distribution of shortfin mako in the Pacific Ocean (Kai *et al.* 2017)

- Size at first sexual maturity of about 184.8 cm TL for females and 178.5 cm TL for males.
- Best-fitting model showed that most hotspots for "immature" shortfin mako occurred in the coastal waters of Japan.
- Meanwhile, hotspots for "subadult and adult" occurred in the offshore or coastal waters of Japan
- size-specific catch rates provide an indication that there has been a recent increasing trend in stock abundance since 2008.

Discard and hooking mortality in Canadian longline fishery (Campana *et al.* 2015)

- 26 shortfin mako sharks tagged with PSATs
- 30% of healthy at capture SFM died, while 33% of injured SFM died
- Total SFM mortality was 30%
- Results indicate that the conservation benefits of mandatory release regulations for pelagic longline gear are not nearly as great as is now assumed, especially for shortfin mako and porbeagle sharks.

Age validation for adult shortfin mako shark (Kinney *et al.* 2016)

- An oxytetracycline injected adult male shortfin was recaptured in waters off of southern California after 6 years at liberty.
- from a time at or near sexual maturity, male I. oxyrinchus in the north-east Pacific Ocean exhibit a band-pair deposition rate of one band pair per year.
- Meanwhile deposition rates for juveniles in the area have been validated at two band pairs per year.

High survivorship after catch-and-release fishing suggests physiological resilience of shortfin mako shark (French *et al.* 2015)

- size at first sexual maturity of about 184.8 cm TL for females and 178.5 cm TL for males
- This study assessed the post-release survival of 30 recreationally caught shortfin mako sharks using Survivorship Pop-up Archival Transmitting (sPAT) tags in Australia.
- Study also examined physiological indicators of capture stress from blood samples and injuries that may be caused by hook selection
- Overall survival rate was 90%
- Longer fight times and higher SST elevated plasma lactate.
- Circle hooks significantly reduced foul hooking compared to J hooks.

- high aerobic scope associated with the species' endothermy probably enabled it to cope with long fight times and the associated physiological responses to capture

Movement and behaviour switching of shortfin mako sharks (Francis *et al.* 2018)

- Electronic tags were deployed on 14 mostly juvenile New Zealand mako sharks to investigate their habitat use, and the spatial and temporal scale of their movements.
- Movement behaviour was classified as Resident or Travel, with the former focused in New Zealand coastal waters, and the latter in oceanic waters around New Zealand and along oceanic ridges running north towards the tropical islands of Fiji, Vanuatu and New Caledonia
- Sharks regularly switched between Resident and Travel behavioural states, but their residency periods sometimes lasted for several months.
- Sharks spent most of their time in the New Zealand Exclusive Economic Zone (median 77%, five sharks > 90%), presumably because of the high coastal productivity and access to abundant prey.
- Results indicate that fishing mortality should be managed at a local as well as a regional scale.

Age, growth, and distribution of shortfin mako in the western and central Atlantic (Barreto *et al.* 2016)

- SFM has conflicting life history parameters, the main discrepancies regard the interpretation of the periodicity of the deposition of band pairs (BPs) on vertebrae and the possibility of ontogenetic variations in growth.
- The von Bertalanffy growth function was used to calculate growth rates for the species through the interpretation of BPs in different scenarios: one BP per year (s1), two BPs per year (s2) and two BPs per year until five years of life (s3).
- Growth parameters varied for both females (Linf = 309.7[s3] to 441.6[s1]; k = 0.04[s1] to 0.13[s3]; t0 = -7.08[s1] and -3.27[s3]) and males (Linf = 291.5[s3] to 340.2[s1]; k = 0.04[s1] to 0.13[s3]; t0 = -7.08[s1] and -3.27[s3]).
- the spatial distribution of the life stages of the shortfin mako sharks caught by commercial longline fishing operations in the South Atlantic was performed with findings indicating that the portion of the population exploited by the fleets is predominantly juvenile.

Long term movements of shortfin mako in the western North Atlantic (Vaudo *et al.* 2017)

- 26 SFM were tagged, and showed wide ranging and variable movements.
- 22% were recaptured in the fishery suggesting fishery mortality is higher than reported.
- Identifying high-use areas could be important for quantifying fisheries interactions.

Size and age on shortfin mako in the Mexican Pacific Ocean (Carreón‐Zapiain *et al.* 2018)

- size at first sexual maturity of about 184.8 cm TL for females and 178.5 cm TL for males.
- Data were collected by scientific observers on board medium-size fishing vessels during 2006–2013, size as TL was obtained for 5,740 individual SFM.
- The range of TL was 70–362 cm for females and 71–296 cm for males.
- The weight-to-TL ratio was best fitted by the equation W = 4 × 10−5 (TL)2.59 (r2 = 0.6532).

- Using length at age data from other studies, the age of captured animals ranged from 0 to 39 years in females and from 0 to 21 years in males.
- Mean length at sexual maturity was obtained for 2,532 males (TL = 190 cm).

Life history parameters for the shortfin mako shark from the northeastern Atlantic (Ebert *et al.* 2017)

- TL_{max} (cm) = 400 | Female l_{mat} (cm TL) = 275-293 | Female age at maturity 19-21 yrs
- Litter size 10-18
- Longevity = 29-32 yrs
- Population growth metric (r_{max}) = 0.116395 | VBF growth rate k = 0.17-0.19

Distribution, body length, and abundance of blue shark and shortfin mako offshore of northeastern Japan (Ohshimo *et al.* 2016)

- Longline surveys have been conducted in the Northwest Pacific Ocean from 2000 to 2014 using chartered commercial longline vessels
- The nominal catch rate of blue shark was more than 10 times that of shortfin mako.
- The CPUE for shortfin mako in the second quarter generally increased, with fluctuations.

Shortfin mako habitat use and migration in the Atlantic (Santos *et al.* 2018)

- Data from 32 tags/specimens is available and a total of 1260 tracking days have been recorded.
- shortfin makos moved in multiple directions, travelling considerable distances. Shortfin mako sharks spent most of their time above the thermocline (0-90 m), between 18 and 22 °C.

Longfin mako (*Isurus paucus*) – relevant references since 2015 Expert Panel meeting

Length weight relationships recorded in pelagic longline fisheries in Hawaii and American Samoa (Curran and Bigelow 2016)

- Min length = 60 cm; max length = 162 cm; average length = 161 cm
- Average weight = 42.1 kg
- W=a*((L/0.91) ^b)
- size at first sexual maturity of about 184.8 cm TL for females and 178.5 cm TL for males
- In the 52 gravid females examined, the average number of embryos per female was seven; with a range of 3-14 embryos.
- Results obtained showed that C. falciformis gives birth most of the year, with the highest proportion of births during the rainy season (May to October).

Life history parameters from the northeastern Atlantic (Ebert *et al.* 2017)

- TL_{max} (cm) = 426.7 | Female l_{mat} (cm TL) = >245
- Litter size 2-8

Catch rate and survival rate in the Palauan longline fishery (Gilman *et al.* 2016)

- Long fin mako shark are very rarely caught, only 10 caapture = 0.22% of catch by number
- Average mortality in NW Atlantic long line was 51%; average mortality in the Pacific Ocean longline was 40%.

Silky shark (*Carcharhinus falciformis*) – relevant references since 2015 Expert Panel meeting

Post release survival of silky sharks from long line fisheries in Costa Rica and Ecuador (Schaefer *et al.* 2019).

- 36 of 38 tagged silky sharks tagged with PSAT tags survived for an average of 100 days.
- Handling methods developed by fishers were used.

Life history of silky sharks from the western Pacific (Papua new Guinea) (Grant *et al.* 2018)

- Females ranged from 65 to 253 sm (TL), oldest female was 28 years.
- Males ranged from 68 to 271 cm (TL), oldest male was 23 years.
- Logistic growth model suggest length at birth L_0 = 82.7 cm TL, growth coefficient g = 0.14 year^{-1} and asymptotic length L_∞ = 261.3 cm TL for the sexes combined.
- Females reached sexual maturity at 204 cm TL and 14.0 years, whereas males reached maturity at 183 cm TL and 11.6 years.
- Average litter size was 8 (ranging from 3-13 pups).
- Late age at maturity suggests high sensitivity to fisheries exploitation.

Behaviour of silky sharks around FADs (Filmalter *et al.* 2015)

- Behaviour of twenty juvenile silky sharks (69 to 116 cm total length; TL) was examined with acoustic tags at 9 drifting FADs equipped with satellite-linked acoustic receivers in the western Indian Ocean
- Sharks remained associated with FADs for extended periods (mean = 15 days)
- Sharks moved away from FADs after sunset and returned later that night and remained until the following evening. Long residence times and close association highlights vulnerability of the species to FAD fishing.

Reproductive biology of silky sharks in the southern Mexican Pacific (Galvan-Tirado *et al.* 2015)

- Reproductive biology studied from 117 female and 145 male silky sharks.
- Males mature at 180 cm, and females at 190 cm.
- Uterine fecundity was 2-14 embryos, with mating inferred between May and June.
- Size at birth was between 60 and 69 cm TL.

Biology of the silky shark in the Arabian Sea (Varghese *et al.* 2016)

- 473 sharks examined from longline and gill net fisheries.
- The von Bertalanffy growth parameters estimated using length-based models were asymptotic length (L_∞) = 309.80 cm, growth coefficient (K) = 0.10 year−1 and age at zero length (t_0) = −2.398 year. Females reached sexual maturity at 204 cm TL and 14.0 years, whereas males reached maturity at 183 cm TL and 11.6 years.
- In males, sexual maturity was attained at 201–223 cm total length (L T) with the size at maturity (L T50) occurring at 217.0 cm, whereas in females, sexual maturity was attained at 224–231 cm L T and L T50 occurs at 226.5 cm.
- Average litter size was 7.6 (ranging from 3-13 pups).

Population structure and reproductive biology of silky sharks in Mexico (del Carmen Alejo-Plata *et al.* 2016)

- Size at first sexual maturity of about 184.8 cm TL for females and 178.5 cm TL for males
- In the 52 gravid females examined, the average number of embryos per female was seven; with a range of 3-14 embryos.
- Results obtained showed that C. falciformis gives birth most of the year, with the highest proportion of births during the rainy season (May to October).

At vessel mortality and post release survival of sharks in the eastern Pacific associated with purse seine fisheries using FADs (Eddy *et al.* 2016)

- At vessel silky shark mortality ranged from 23%-70%
- Total silky shark mortality ranged from between 80-95%

Post-release survival of juvenile silky sharks in FAD associate purse seine sets in the Western Pacific (Hutchinson *et al.* 2015)

- Total mortality exceeded 84%
- Survival rates dramatically declined one the sharks were confined in the sack portion of the net prior to loading.
- Science observed interaction rates were higher than those reported by vessel officers and observers

At sea tests for releasing sharks from purse seine gear (Hutchinson *et al.* 2019b)

- Sharks have high survival rates if released from nets while the nets are still open enough for them to swim.
- Mobulid rays (*M. tarapacana*) suffer high mortality once landed on deck
- In the 52 gravid females examined, the average number of embryos per female was seven; with a range of 3-14 embryos.
- Results obtained showed that C. falciformis gives birth most of the year, with the highest proportion of births during the rainy season (May to October).

Catchability of sharks in Hawaiian and American Samoan longline fisheries (Bigelow and Swimmer 2018)

- Silky shark catches were not affected by changes in hook sizes.

Post release mortality of silky sharks from Palauan long line fisheries (Musyl and Gilman 2018)

- 35 silky sharks were tagged with PSATs.
- 20% of silky sharks died after released, but gear haul back was the main factor influencing survival with only 1 out of 27 of the ‘excellent/green’ condition sharks dying.

Movements of juvenile silky sharks in the Pacific (Hutchinson *et al.* 2019a)

- Juvenile silky sharks were tagged with PSATs from around FADs.
- Sharks spent almost 100% of their time in shallow warm waters of the mixed layer, the same preferred environmental conditions of tuna. This behaviour makes them especially vulnerable to capture in shallow set purse seine gear.

Oceanic whitetip shark (*Carcharhinus longimanus*) – relevant references since 2015 Expert Panel meeting

Age and growth of oceanic whitetip sharks from Papua New Guinea (D’Alberto *et al.* 2017)

- Samples from 103 individuals (70 males and 33 females; 76.0–240- and 128–235-cm total length (TL) respectively) were used to estimate age, growth and maturity parameters.
- The von Bertalanffy growth model provided the best fitting growth model for both sexes.gravid females examined, the average number of embryos per female was seven; with a range of 3-14 embryos.
- Parameter estimates for males were: asymptotic length (L_∞) = 315.6 cm TL; growth coefficient (k) = 0.059 year^{-1}; and length at birth (L0) = 75.1 cm TL.
- For females, the parameter estimates were: L_∞ = 316.7 cm TL; k = 0.057 year^{-1}; and L0 = 74.7 cm TL.
- Maximum age was estimated to be 18 years for males and 17 years for females, with a calculated longevity of 24.6 and 24.9 years respectively.
- Males matured at 10.0 years and 193 cm TL, whereas females matured at 15.8 years and 224 cm TL.
- C. longimanus is a slow-growing, late-maturity species, with regional variation in life history parameters, highlighting increased vulnerability to fishing pressure in this region.

Life history parameters for the oceanic whitetip shark from the northeastern Atlantic (Ebert *et al.* 2017)

- TL_{max} (cm) = 400 | Female l_{mat} (cm TL) = 170-190 | Female age at maturity 3-5 yrs
- Litter size up to 15
- Population growth metric (r_{max}) = 0.212198 | VBF growth rate k = 0.103

Structure and genetic variability in the oceanic whitetip shark in the Atlantic and Indian oceans (Camargo *et al.* 2016)

- Partial sequences of mitochondrial DNA (mtDNA) control region were used to determine the population genetic structure of oceanic whitetip sharks across the Atlantic and Indian Oceans
- 724 base pairs were obtained from 215 individuals that identifed nine polymorphic sites and defined 12 distinct haplotypes.
- The Analysis of Molecular Variance (AMOVA) evidenced moderate levels of population structure ($\phi ST = 0.1039$) with restricted gene flow between the western and eastern Atlantic Ocean, and a strong relationship between the latter region and the Indian Ocean.
- Although the oceanic whitetip is a highly migratory, their genetic variability is slightly below the average of other pelagic sharks.
- At least two populations in the Atlantic Ocean should be considered distinct (eastern and western Atlantic

Age and growth of oceanic whitetip sharks in the western north Pacific Ocean (Joung *et al.* 2016)

- 188 specimens (89 females and 99 males) were collected from November 2002 to January 2006 at the Nanfanao fish market in north-eastern Taiwan before the prohibition of retaining on board for commercial use by the Western and Central Pacific Fisheries Commission.
- The relationship between TL and the pre-caudal vertebral centrum radius (R) for sexes-combined data was described using the following equation: $TL = 29.98 + 20.99R$ ($n = 112$, $P < 0.05$).
- The opaque bands in pre-caudal vertebrae are formed once annually between June and September based on a marginal increment ratio analysis.
- The maximum number of growth band pairs was 12 for both sexes in this study.
- The two-parameter von Bertalanffy growth function best fits the length-at-age data, and the growth parameters (sexes combined) were estimated as follows: asymptotic length ($L\infty$) = 309.4 cm TL and growth coefficient (k) = 0.085/yr with the size at birth set as 64 cm TL ($n = 112$, $P < 0.01$).
- The litter size was 10–11, and the size at birth was at least 64 cm TL.
- The sizes at first and 50% maturity were 190 cm and 193.4 ± 0.97 cm TL for females and 172 cm and 194.4 ± 6.57 cm TL for males. These corresponded to 8.5 yr and 8.8 yr for females and 6.8 yr and 8.9 yr for males.

Shark catches in Fijian longline fisheries 2011-2013 (Piovano and Gilman 2017)

- Oceanic whitetip sharks were mostly finned and discarded

Catchability of sharks in Hawaiian and American Samoan longline fisheries (Bigelow and Swimmer 2018)

- Oceanic whitetip shark catches were not affected by changes in hook sizes

Bigeye thresher shark (*Alopias superciliosus*) – relevant references since 2015 Expert Panel meeting

Distribution and reproductive biology of bigeye thresher in the Atlantic (Fernandez-Carvalho *et al.* 2015b)

- Median sizes at maturity were estimated at 208.6 cm FL for females and 159.2 cm FL for males.
- Pregnant females were recorded in the tropical northeast and southwest Atlantic, with these regions possibly serving as nursery areas.

Age and growth of the bigeye thresher in the Atlantic Ocean (Fernandez-Carvalho *et al.* 2015a)

- 546 vertebrae collected by fishery observers between 2007 and 2009 were used to estimate age and growth parameters for this species in the Atlantic Ocean
- the 3-parameter von Bertalanffy growth model, reparameterized to estimate length at birth (L0), estimated asymptotic maximum length (Linf)=284 cm FL, growth coefficient (k)=0.06/year, and L0=109 cm FL for females; and Linf=246 cm FL, k=0.09/year, and L0=108 cm FL for males
- Although differences between hemispheres indicate slower growth rates in the South Atlantic Ocean, these differences may also have been caused by the lower sample size and larger specimen sizes for the Southern Hemisphere.
- The species is highly vulnerable to fishing pressure.

Habitat use and vertical migrations of the bigeye thresher in the Atlantic (Coelho *et al.* 2015)

- Fifteen bigeye threshers were tagged with PSATs.
- Animals spent the day in cooler deeper waters, and the night in warmer shallower waters.
- Overlap with pelagic longline gear is occurring at night and is higher for juveniles.

Catchability of target and non-target species by circle hook size (Bigelow and Swimmer 2018)

- Use of size 15/0 and larger circle hooks could reduce catch of bigeye thresher sharks in Pacific longline fisheries.

Life history parameters for the bigeye thresher shark from the northeastern Atlantic (Ebert *et al.* 2017)

- TL_{max} (cm) = 461 | Female l_{mat} (cm TL) = 332-355 | Female age at maturity 12-13 yrs
- Litter size 2-3
- Longevity = 20 yrs
- Population growth metric (r_{max}) = 0.0929036 | VBF growth rate k = 0.06-0.18

Pelagic thresher shark (*Alopias pelagicus*) – relevant references since 2015 Expert Panel meeting

Movements around a tropical seamount in the Philippines (Oliver *et al.* 2019)

- The pelagic thresher shark (Alopias pelagicus) is one such species that visits a seamount in the Philippines.
- Fourteen pelagic thresher sharks were fitted with acoustic tags to monitor fine scale movements for 66 days (June to mid-August 2014). Individuals were present at the seamount for 32% of their days at liberty, and 42% of the tagged sharks were still being detected there at the end of the study.
- These movements demonstrated that they have access to the jurisdictional waters of five provincial territories when dispersing from and returning to the seamount on a diurnal basis.

Life history parameters for the pelagic thresher shark from the northeastern Atlantic (Ebert *et al.* 2017)

- TL_{max} (cm) = 330 | Female l_{mat} (cm TL) = 282-292 | Female age at maturity 8-9 yrs
- Litter size 2
- Longevity = 16-30 yrs
- Population growth metric (r_{max}) = 0.14516 | VBF growth rate k = 0.085-0.118

Common thresher shark (*Alopias vulpinus*) – relevant references since 2015 Expert Panel meeting

Bomb radio carbon data and revised growth curves in the Atlantic (Natanson *et al.* 2016)

- Bomb radiocarbon dating was used to determine the periodicity of band pair formation
- The traditional interpretation of band pairs (i.e. annual) is accurate up to approximately 14 years of age. A new maximum validated age was estimated to be 38 years (an increase of 18 years over the band count estimates).
- Revised growth curves were generated using the Schnute general model (sexes combined)
- Updated estimates of age at maturity remained the same for males (8 years) and increased by one year to 13 years for females.
- The primary finding was the increase in longevity for this species from a band pair count estimate of 24 years to a bomb radiocarbon validated estimate of 38 years, indicating this species lives much longer than previously thought

Age validation for the common thresher shark in the northeastern tropical Pacific (Spear 2017)

- Vertebrae of 37 common thresher sharks marked with oxytetracycline (OTC) were collected from tag-recapture efforts.

- Time at liberty of the 37 sharks ranged from 0.53 to 3.81 years with an average of 1.27 years
- Shark size at time of injection with OTC ranged from 63 to 128 cm fork length (FL) and from 83 to 168 cm FL at recapture.
- Vertebral band pair counts distal to the OTC marks indicate one band pair (1 translucent and 1 opaque) form annually for common threshers of the size range examined in the NEPO.

Life history parameters for the bigeye thresher shark from the northeastern Atlantic (Ebert *et al.* 2017)

- TL_{max} (cm) = 573 | Female l_{mat} (cm TL) = 260-465 | Female age at maturity 3-9 yrs
- Litter size 3-4
- Longevity = 24-50 yrs
- Population growth metric (Lambda) = 1.125 | VBF growth rate k = 0.158-0.215

Porbeagle shark (*Lamna nasus*) – relevant references since 2015 Expert Panel meeting

Porbeagle shark migration in the Atlantic (Biais *et al.* 2017)

- PSATs deployed on sub adult and adult porbeagle sharks.
- Mean duration of each deployment was 292 d, with four reaching 365 d.
- Reconstructions show that, after migrations that extended up to 2000 km away from the point of release, the tagged porbeagles returned to their location of tagging.
- The observed site fidelity to the Bay of Biscay and the common migration pattern of all females provide evidence of complex spatial structure and dynamics that encompasses both the open ocean and heavily fished coastal areas, and highlights the challenge of assessing and managing the porbeagle stocks.

Discard and hooking mortality in Canadian longline fishery (Campana *et al.* 2015)

- 33 porbeagle sharks tagged with PSATs
- 10% of healthy at capture porbeagle sharks died, while 75% of injured porbeagle sharks died
- Total SFM mortality was 30%
- Results indicate that the conservation benefits of mandatory release regulations for pelagic longline gear are not nearly as great as is now assumed, especially for shortfin mako and porbeagle sharks.

Trans-Atlantic movement of porbeagle shark (Cameron *et al.* 2018)

- A female porbeagle shark tagged off Ireland moved to newfoundland.
- First record of trans-Atlantic movement for the species, support genetic evidence for panmictic stock.

Abundance indicators for New Zealand porbeagle sharks (Francis and Large 2017)

- CPUE based indices suggest porbeagle sharks are increasing in abundance or availability in southern NZ waters, and stable in northern NZ waters
- While CPUE trends are variable in space and time, overall there appears to have been an increase in abundance or availability in NZ waters.

Smooth hammerhead shark (*Sphyrna zygaena*) – relevant references since 2015 Expert Panel meeting

Distribution and movement of smooth hammerheads in northern New Zealand (Francis 2016)

- Highest catch rates were recorded in relatively sheltered bays and coastlines along the northeast coast of North Island. Neonate and juvenile sharks use shallow coastal waters and large harbours and estuaries as nursery areas up to an age of two years and total length of 150 cm.
- Five sharks electronically tagged. Two tagged sharks remained in or near the Bay of islands for 6–55 days after tagging, moving extensively through the bay. A third shark moved about 155 km southeast in 250 days. That shark spent 70 days mostly shallower than 10 m (94% of time) with occasional dives to 40 m.

Age and growth of smooth hammerhead in the Atlantic (Rosa *et al.* 2017)

- Data from 304 specimens, caught between October 2009 and September 2014, ranging in size from 126 to 253 cm fork length (FL)
- The model fit to the quadratic modified Dahl-Lea back-calculated data seems to be the most appropriate to describe growth in this species, with resulting growth parameters of Linf = 285 cm FL, k = 0.09 year−1 for males and Linf = 293 cm FL, k = 0.09 year−1 for females.

Life history parameters for the smooth hammerhead shark from the northeastern Atlantic (Ebert *et al.* 2017)

- TL_{max} (cm) = 440 | Female l_{mat} (cm TL) = 265
- Litter size 20-49
- Longevity = >20 yrs
- VBF growth rate k = 0.06-0.07

Scalloped hammerhead shark (*Sphyrna lewini*) – relevant references since 2015 Expert Panel meeting

Life history parameters for the scalloped hammerhead shark from the northeastern Atlantic (Ebert *et al.* 2017)

- TL_{max} (cm) = 346 | Female l_{mat} (cm TL) = 210-250 | Female age at maturity 5.8-15 yrs
- Litter size -12.9

- Longevity = 30.5 yrs
- Population growth metric (r_{max}) = 0.464941 | VBF growth rate k = 0.073-0.013

Scalloped hammerhead nursery in Fiji (Marie *et al.* 2017)

- 1054 SHS (including 796 tagged individuals; 101 of which were recaptured) were captured from September 2014 to March 2016
- A majority of the captures in this area were neonates and young-of-the-year (YOY) (99.8%)
- Significant seasonality in patterns of occurrence of both neonates and YOY individuals suggests a defined parturition period during the austral summer.
- Between the seven sampling sites in the RD we also found significant differences in SHS neonate catch per unit of effort, and average total length of individuals. According to the data, the RD is likely to represent an important nursery area for SHS up to one year of age.

Scalloped hammerhead movement in the Eastern Tropical Pacific (Nalesso *et al.* 2019)

- Eighty-four scalloped hammerhead sharks (*Sphyrna lewini* Griffith & Smith), were tagged with acoustic transmitters at Cocos Island between 2005–2013.
- Residency was significantly greater at Alcyone, a shallow seamount located 3.6 km offshore from the main island, than at the other sites.
- Timing of presence at the receiver locations was mostly during daytime hours
- Timing of presence at the receiver locations was mostly during daytime hours. Although only a single individual from Cocos was detected on a region-wide array, nine hammerheads tagged at Galapagos and Malpelo travelled to Cocos. The hammerheads tagged at Cocos were more resident than those visiting from elsewhere.

Artisanal shark fishing in Milne Bay, Papua New Guinea (Appleyard *et al.* 2018)

- Over 20 species of elasmobranchs were identifed from 623 fns from the artisanal fshery in Milne Bay Province of PNG,
- Of concern, 21% of fns examined were from IUCN listed threatened species (Vulnerable or Endangered) with 8% of fns from the Endangered scalloped hammerhead (Sphyrna lewini).

Multiple paternity of scalloped hammerhead sharks (Rossouw *et al.* 2016)

- 54 S. lewini individuals from 13 litters.
- Multiple paternities were observed in 67, 35 and 46% of the litters of M. mustelus, C. obscurus and S. lewini, with corresponding average sire size of 1·6, 1·4 and 2·0, respectively.

Variability of multiple paternity in scalloped hammerhead sharks (Green *et al.* 2017)

- 17.2 pups per litter for scalloped hammerhead.
- Using 14 and 10 microsatellite loci respectively, multiple paternity identified in 66% of grey reef sharks (4 out of 6 litters) and 100% MP in scalloped hammerheads (5 litters).

- positive correlation between female adult size and litter size in scalloped hammerheads

Aggregation site for juvenile scalloped hammerheads in Fiji (Brown *et al.* 2016)

- Research findings indicated that the average length of both males (60.6 ± 6.78 cm, n = 31) and females (60.4 ± 6.85 cm, n = 51) was well within published size limits of juvenile S. lewini studied in other locations (range = 38.0–89.5 cm).

Length-weight relationships and reproductive size of scalloped hammerhead in Indonesia (Wahyudin *et al.* 2019)

- During March-May 2018 period, there were 1,753 *C. falciformis* and 219 *S. lewini* landed at Tanjung Luar. Respectively, length varied between 670 and 2,650 mm and 490-3,040 mm, while weight was between 1,200 and 73,000 g and 500-168,000 g, for C. falciformis and S. lewini.
- Meanwhile, for S. lewini, based on data analysis of length-weight relationship, the estimation value of the length-weight coefficient is 2.8.
- As for S. lewini, out of 140 shark samples measured during March-May 2018, more than 50% belong to the sexually mature category. For male S. lewini from 20 sharks measured, around 70% belong to the sexually mature category. As for the female sharks from 140 samples measured, around 54% were included in the sexually mature category.

Scalloped hammerhead catch, and age and growth from Indonesia (Jaliadi and Hendri 2017)

- 311 hammerhead sharks caught were dominated by male (111 sharks) at length ranging from 70.5 to 91.5 cm and female (57 sharks) at length ranging from 70.5 to 91.5 cm. TL.
- Von Bertalanffy growth rate was K=0.20 for males, and K=0.25 for females
- Asymptote length L_∞ for both sexes was 262.50 cm.

Great hammerhead shark (*Sphyrna mokarran*) – relevant references since 2015 Expert Panel meeting

Great hammerheads in a shark aggregation and parturition site in Fiji (Vierus *et al.* 2018)

- A total of 103 juvenile sharks identified as blacktip Carcharhinus limbatus (n = 57), scalloped hammerhead Sphyrna lewini (n = 35), and great hammerhead Sphyrna mokarran (n = 11) sharks were captured, tagged, and released. The condition of umbilical scars (68% open or semihealed), mean sizes of individuals (±SD) (C. limbatus: 66.5 ± 3.8 cm, S. lewini: 51.8 ± 4.8 cm, S. mokarran77.4 ± 2.8 cm)

Whale shark (*Rhincodon typus*) – relevant references since 2015 Expert Panel meeting

Longest recorded trans-Pacific movement of a whale shark (Guzman *et al.* 2018)

- Satellite tag shows a trans-Pacific migration of a female whale shark tagged at Coiba Island (Panama), and which travelled over 20,000 km from the Tropical Eastern Pacific (Panama) to the western Indo-Pacific (Mariana Trench) in 841.

Estimates of whale shark growth (Perry *et al.* 2018)

- Growth measured by repeat measurements of whale sharks at Ari Atoll, Maldives.
- The Maldives aggregation consisted of primarily male (91%) juvenile (total length ¼ 3.16–8.00 m) sharks and sharks new to the area were significantly smaller than were returning sharks
- Estimates of von Bertalanffy (VBG) growth parameters for combined sexes (L_∞ = 19.6 m, k = 0.021 year1) were calculated from 186 encounters with 44 sharks.
- For males, VBG parameters (L_∞ = 18.1 m, k = 0.023 year^1) were calculated from 177 encounters with 40 sharks and correspond to a male age at maturity of 25 years and longevity of 130 years.

Post release survival of whale sharks in Atlantic purse seine fisheries (Escalle *et al.* 2016)

- Details methods developed with the fishery to tag whale sharks encircles in purse seine nets, and development of release procedures.
- Six whale sharks were tagged with five tags transmitting data.
- All five tagged sharks survived at least 21 days after release, with the longest deployment lasting 71 days.

Mobulids (*Mobula spp.*) – relevant references since 2015 Expert Panel meeting

Reproductive biology and range extension for *Mobula kuhlii* cf. eregoodootenkee (Broadhurst *et al.* 2018)

- Females (disc width [DW]: 92.5 to 130.0 cm, mean ± SD 112.8 ± 7.8 cm) were significantly larger than males (99.0 to 123.0 cm, 109.4 ± 6.3 cm). Of those caught, 45 died (71% mortality), of which 20 females and 11 males were assessed for reproduction.
- Nine females were pre-ovulatory and non-gravid with 7 to 23 oocytes in their left ovary, while 11 had 14 to 40 ovarian oocytes and 1 embryo (DW: 7.0 to 21.2 cm) in their left uterus.
- The development of the largest embryo (DW: 21 cm) suggests parturition occurs well above this size.
- The maximum DW for this species is now recorded as 130 cm.

Movement, depth distribution and survival of spinetail devilrays (*Mobula japanica*) tagged and released from purse-seine catches in New Zealand (Francis and Jones 2017)

- Nine rays were tagged with popup archival tags.
- Seven of the nine tags reported data, and four of those rays died within 2–4 days of release. All four rays that died had been brought aboard entangled in the bunt.
- One surviving ray remained near New Zealand for 2.7 months during summer, and the other t wo 1400800 km northward to tropical waters near Vanuatu and Fiji at minimum speeds of 47 and 63 km day^{-1}
- The ray made regular vertical movements of 25–100 m and spent most of its time in shallow water <50 m depth
- All three surviving rays typically moved between the surface and 200 to 300 m depth.

Gestation and size at parturition for *Mobula kuhlii* cf. eregoodootenkee (Broadhurst *et al.* 2019)

- Twelve adult specimens were necropsied: two were males (99.5 and 106.3 cm disc width–DW); five were pre-ovulatory (112.4–122.0 cm DW) non-gravid females with 15–25 oocytes in their functional left ovary; and five were gravid (112.6–121.0 cm DW), each with a single embryo (24.0–42.3 cm DW)
- At 43.2 cm DW or 36% of its mother's DW, the largest embryo was almost full term. Considering previous data describing early pregnancies, reproduction appears seasonal (but not consecutive) and involves protracted mating and a gestation probably >12 mo.

Growth, productivity, and relative extinction risk of a data-sparse devil ray (Pardo *et al.* 2016)

- Maximum lifespan of *Mobula japanica* was between 15 and 20 years.
- The median estimates of average lifespan for the Spinetail Devil Ray was 11.5 years, and therefore the median natural mortality M estimate was 0.087 year−1(95th percentile = 0.079–0.097).
- Have at most a single pup annually or even biennially

Appendix B - Additional opportunities raised by expert reviewers that fall outside the scope of the current study

Reviewers also noted that some of these challenges could be overcome through fishery independent sampling, such as research tagging cruises carried out by the SPC Ocean Fisheries Program, specifically the blue fin tuna tagging program, and other programs such as SPC bycatch mitigation studies. Integrating shark tagging and sampling components into this existing program could be very cost effective. There could also be opportunities to collaborate with research programs run by NOAA, New Zealand and Australia, and collaborate with specific fishing vessels and even recreational fishers. One reviewer also mentioned the use existing smartphone or tablet Apps to enhance data collection. This reviewer also highlighted the importance of a reward or incentive program to increase the return of tags and data.

Reviewers also raised the potential for close kin mark-recapture using genetic analysis to estimate population parameters such as abundance and survival. These newer techniques have been used for sharks (Hillary *et al.* 2018) and for southern bluefin tuna (Bravington *et al.* 2016). While many genetic samples would be required to complete such analysis, genetic samples are potentially easy to collect and store, and thus a widespread genetic sampling effort could deliver long term benefits. This potential study could be integrated with the SPC tissue bank study. Costs for close kin mark recapture are also reducing as techniques improve. However, one limiting factor could be securing available expertise for data analysis.

Reviewers widely commented on the need for improved at vessel catch and landings data, and several reviewers also mentioned the potential of electronic monitoring studies. While out of scope for the biological research focus of this study, electronic monitoring could provide valuable information for documenting catch, validating logbook data, and could improve monitoring coverage and compliance with catch reporting requirements. Reviewers suggested that electronic monitoring could be tested on both long-line and purse seine vessels, but some also noted that it may require fishing practices to be changed, i.e. sharks on longlines hauled to within the field of view of the cameras. Reviewers noted that some trials have been conducted in the Pacific, and in other regions by other RFMOs, but that further work in this area is needed.

Another reviewer also suggested the expansion of satellite tagging using longer term deployments of pop-up satellite tags. Long-term tag deployments (1 to 2 years) would provide better data on shark movement and connectivity of mako and silky sharks, as well as habitat (depth, temperature, light) data.

Reviewers also mentioned very specific potential research areas including:

- Identification of nursery, pupping, and mating grounds;
- Better information on spawner-recruitment relationships;
- Estimation of intrinsic rate of natural increase and natural morality; and
- Review of modelling frameworks for data-poor species