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Report of the Pacific Shark Life History Expert Panel Workshop, 28-30 April 2015

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ABSTRACT

Inputs on age, growth and reproduction are often critical determinants of stock assessments, yet such data are lacking or highly uncertain for even the most common of shark species. In recognition of this WCPFC's SC10 recommended that an expert panel be convened to review and advise on appropriate life history parameters for the fourteen WCPFC key shark species. This panel met from 28-30 April in Cairns, Australia and this paper reports the outcomes of the workshop. The panel compiled and reviewed a worldwide database of over 270 studies on blue, mako, silky, oceanic whitetip, thresher, porbeagle, hammerhead and whale shark species. Tables showing over a dozen of the most important life history parameters and their uncertainties and caveats were constructed for each species. The panel then provided guidance on the prioritization of further studies, use of the parameters in stock assessment, and overcoming difficulties in sample collection.

Pacific Shark Life History Expert Panel Workshop

FINAL REPORT

28-30 April 2015

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1 Introduction

Life history information is fundamental in establishing the age structure of the population and its growth and reproductive characteristics. Stock assessment models rely on life history parameters such as age at maturity, natural mortality rate, life span and litter size to properly account for a population's resilience to exploitation. These parameters also inform the population productivity estimates used in ecological risk assessment, and can be used to formulate limit reference points which can serve as benchmarks for fishery management. As life history data thus underpin all of these stock status assessment methods it is critical that the best available information is applied and that residual uncertainties are properly taken into account.

The Tenth Meeting of the Western and Central Pacific Fisheries Commission's Scientific Committee (WCPFC SC10) in August 2014 recommended that an expert panel be convened to review and advise on appropriate life history parameters for the WCPFC key shark species. Fourteen species have been designated as "key" by the WCPFC: blue, mako (two species), silky, oceanic whitetip, thresher (three species), porbeagle, hammerhead (four species) and whale sharks. This initiative in the Pacific Ocean follows similar efforts to compile life history information for sharks in the Atlantic Ocean, the Indian Ocean and the North Pacific (blue and shortfin mako only). After SC10's funding allocation of USD 25,000 was approved by WCPFC11 in December 2014, nominations were sought from WCPFC members and cooperating non-members (CCMs) in January 2015 (WCPFC Circular 2014/106) and a five-person panel was appointed in February 2015 (WCPFC Circular 2015/04).

The panel was convened jointly by the WCPFC and the Areas Beyond National Jurisdiction (ABNJ or 'Common Oceans') Tuna Project, with financial support for participants travel and expenses provided by WCPFC, and organization, chairing and report writing by ABNJ Technical Coordinator-Sharks and Bycatch, Dr Shelley Clarke. The panel comprised Dr Rui Coelho (EU-Portugal), Dr Malcolm Francis (New Zealand), Dr Kwang-Ming Liu (Chinese Taipei), Dr Colin Simpfendorfer (Australia) and Dr Javier Tovar-Avila (Mexico). Dr Suzanne Kohin (United States) and Dr Mikihiko Kai (Japan) participated via a live voice link. Venue and on-site support was provided by James Cook University's Centre for Sustainable Tropical Fisheries and Aquaculture in Cairns, Australia with JCU students Cassandra Rigby and Jonathan Smart providing rapporteuring support and contributing information from their own shark life history research (*Figure 1*).

Figure 1. Participants in the Pacific Shark Life History Expert Panel Workshop, Cairns, Australia, 28-30 April 2015 (photo: Jonathan Smart).

2 Workshop Objectives and Methods

The objectives of the workshop were to advise on appropriate life history parameters for the WCPFC key shark species. In doing so the panel was also tasked with identifying the most important uncertainties in these parameters and recommending further studies to elucidate data deficient parameters or to fill data gaps. It was noted that the results of the workshop, in the form of a report with attached species-specific tables of parameters, would be submitted to WCPFC SC11 for review and comment.

2.1 Experience from Other Relevant Organizations

To provide background for the panel's work, presentations were made on the shark life history parameter compilations that have been undertaken by other organizations. Dr Rui Coelho gave a presentation on efforts to compile shark life history parameters by the Indian Ocean Tuna Commission (IOTC) and the International Commission for the Conservation of Atlantic Tunas (ICCAT). IOTC efforts were focused on seven species (blue, shortfin mako, oceanic whitetip, silky, scalloped hammerhead and bigeye and pelagic thresher sharks). IOTC's experts compiled studies and tallied the number of studies by parameter without identifying specific parameters for use (IOTC 2014). ICCAT discussed this topic at two meetings in 2013 and 2014: the first compiled relevant studies and the second identified preferred parameters for 16 species (ICCAT 2014). In many cases ICCAT experts found there was only one study informing each parameter therefore it was not necessary to develop criteria to choose between parameter estimates. For species that had more than one parameter available the recommendation was based on expert judgement, taking into account study characteristics such as sample size and coverage. Funding from the tuna Regional Fisheries Management Organizations (t-RFMOs) themselves for life history data improvement initiatives is limited but some of the studies identified in these two tuna t-RFMO reports are proceeding as national initiatives or with improved collaboration between member countries.

Dr Suzy Kohin presented the work of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) on blue shark and shortfin mako shark. ISC's decision to focus its life history review on these two species supports its decision to prioritize North Pacific stock assessments for these species. Two dedicated shark age and growth workshops have been held (ISC 2012, 2014) and work plans were developed to reduce uncertainty in ageing blue and shortfin mako sharks. It is appreciated that resolving uncertainties in the selection of growth parameters, and some other life history and demographic parameters for the stock assessments, will require a long-term effort. In the case of North Pacific blue shark, some life history parameters are known with greater certainty and were selected for use in the stock assessments, and other more uncertain parameters were handled through sensitivity testing in the models. The ISC Shark Working Group will use a meta-analysis approach, examining data from prior and ongoing growth and reproductive biology studies, to help select life history parameters for future assessments. For North Pacific shortfin mako, a fishery indicators approach was used to assess the status of the stock in 2015 in part because of life history data gaps.

2.2 Methodological Issues

Before starting their species-specific work, the panel discussed what would be reasonable goals for a three-day workshop attempting to cover 14 shark species. Considerable work had been done prior to commencement of the meeting:

- All experts and the Chair were assigned to research and collect relevant studies on one or more species for loading into a cloud-based folder;
- The contents of the species-specific folders (i.e. over 270 studies) were loaded into bibliographic freeware (Zotero) and tagged with one or more descriptors depending on the species and parameters covered;
- All experts and the Chair were asked to fill in a table showing preferred and alternative parameters, uncertainties and recommendations for further studies for 26 life history parameters; and
- All experts and the Chair were asked to prepare a presentation on their tables which were then discussed and reviewed by the panel as a whole.

Participants considered that, due to lack of time at the workshop for discussion, the priority should be to focus on the six age and growth parameters and the seven reproductive parameters. The other thirteen parameters could be noted in the tables as ancillary information but would not be discussed unless they were of particular interest. Original instructions regarding listing preferred and alterative parameters in different columns, and shading each cell based on the certainty of its value were considered to be too difficult to implement. This was because making such judgements would require delving into details such as sample sizes, methodological comparisons and model fits, and this was not possible due to data availability and time constraints. Furthermore, all studies have their own strengths and weaknesses and decisions about which parameters are "preferred" can be quite subjective. As a result of these considerations, it was agreed to list "Pacific" and "other" parameters in separate columns in each table and to reflect any issues related to uncertainty in a comments column.

The group also discussed some general principles for evaluating studies to populate each table. First, in terms of statistical issues, participants were encouraged to consider, and report wherever possible, the sample size and the range of individuals comprising the sample (e.g. ages, regions, years, etc.). It is not good practice to extrapolate parameters beyond the range of the sample. Second, participants were asked to report the original (untransformed) data or parameter. If, for comparative purposes, it is desirable to convert to a common unit, the conversion factors applied should be annotated. It was acknowledged that the measurement methods for fish length may vary among studies with no clear standard. Furthermore, length measurements can vary by up to 6% based on the alignment of the tail (stretched or natural position) or up to 3% based on curvature of the measurement tape (straight line or over the body), and freezing the fish can cause its length to shrink by 2-5% (Francis 2006). Finally, when reporting age parameters participants were encouraged to report whether the ageing methods have been verified or validated, particularly in terms of band pair periodicity. It was noted that a considerable amount of ageing validation work remains to be done for sharks.

Some details regarding best practice when reporting specific life history parameters were also discussed:

- It is important to distinguish between model-estimated size at birth versus observed size at birth.
- It is also important when summarizing longevity information to distinguish between the oldest observed specimen and the calculated maximum age.
- Rather than focusing on the maximum length of an individual it is better to establish the average of the largest individuals observed.
- Using photos to determine shark length is unreliable due to problems with establishing scale, distortion, etc.
- When summarizing litter size, include the relationship between female size and number of pups where one is known to exist.
- When reporting embryonic sex ratios it is acceptable to calculate a ratio over multiple females but the number of females represented should be reported. Sex ratios of age 0 pups can be used as a proxy if embryonic sex ratios are not available.
- Mortality parameters should be clearly specified as F, M or Z, and the method of calculation should be noted if possible.

Participants also discussed how to compare growth model parameters among studies. As it is important to consider all parameters in the growth model simultaneously, plotting the various growth curves was considered to be a useful exercise. Therefore, for each species and geographic region, growth curves from the literature were plotted to illustrate the growth rates, and the variability among studies, sexes, and/or locations. Growth curves reported by the studies were based on one of three different growth models:

1. The von Bertalanffy growth model with three parameters:

   $$L_t = L_\infty (1 - e^{-K(t-t_0)})$$

   where L_t is the expected length at age t years, L_∞ is the asymptotic maximum length, K is the Brody growth constant, and t_0 is the theoretical age at zero length.

2. The von Bertalanffy growth model with two parameters, forced through the estimated length at birth:

   $$L_t = L_0 + (L_\infty - L_0)(1 - e^{-Kt})$$

   where L_0 is the observed length at birth and the other parameters are the same as above.

3. The Schnute growth model suite. The generalised model (Case 1) has four parameters: L_1 and L_2 which are the estimated lengths at two selected reference ages τ_1 and τ_2, and κ and γ which determine the shape of the curve. Case 1 reduces to four sub-models (Cases 2–5) depending on whether the parameters κ and γ are zero, one, or another value, but only Case 1 and Case 3 models were used by the reviewed studies. Reference ages τ_1 and τ_2 were set at 1 and 10 years respectively (see Bishop et al. (2006) for further details).

   For Case 1, where $\kappa \neq 0$ and $\gamma \neq 0$, the following equation was used:

   $$L_t = \left(L_1^\gamma + \left(L_2^\gamma - L_1^\gamma\right) \frac{1 - e^{-\kappa(t-\tau_1)}}{1 - e^{-\kappa(\tau_2-\tau_1)}} \right)^{\frac{1}{\gamma}}$$

   For Case 3, where $\kappa = 0$ and $\gamma \neq 0$, the following equation was used:

$$L_t = \left(L_1^{\gamma} + \left(L_2^{\gamma} - L_1^{\gamma} \right) \frac{t - \tau_1}{\tau_2 - \tau_1} \right)^{\frac{1}{\gamma}}$$

It was noted that there is an option to fix L_0 rather than letting the model estimate it (von Bertalanffy model with two parameters versus von Bertalanffy model with three parameters above). This may improve the fit for small individuals but could increase residuals for large individuals. The choice should depend on the distribution of size classes represented in the sample. For plotting in this workshop, where studies fitted and compared multiple growth curves, the 'best' growth model identified by the author(s) was plotted. If a study found no difference between the two sexes, or if separate growth parameters were not reported for the two sexes, a combined sexes model was adopted.

3 Species-specific Life History Parameters

3.1 Blue shark (*Prionace glauca*, BSH)

3.1.1 Presenter's Summary

A total of 44 papers on blue shark in the Pacific Ocean were reviewed. The blue sharks in the Pacific can be treated as two stocks (south and north) based on tagging studies because no individuals were found to cross the equator. However, blue sharks were caught near the equator. A recent genetic study showed weak or no differentiation in the Pacific Ocean but the authors supported the two stocks hypothesis for management purposes.

Spatial segregation by size and sex for the North Pacific blue shark has been reported (*Annex A*). Blue sharks were more abundant in temperate regions with water temperatures >15-25^{o}C, and can be found from the sea surface to 300 m. The mating ground in the northern hemisphere is at 20-30^{o}N, the parturition ground is at 35-45^{o}N, and the nursery ground is believed to be at 30-35^{o}N for males, and north of 45^{o}N for females but some studies have found sex ratios close to 1:1 in purported nursery areas. This species is one of most productive shark species, and mean litter size ranges from 25-35. Size at birth ranges from 35 to 60 cm TL and the sex ratio of embryos is 1:1. Age at 50% maturity was 4-6 years for males and 4-7 years for females. Gestation period was estimated to be 9-12 months, but the reproductive cycle is poorly known and one-year or two-year periods have been proposed by different authors. Resolving this uncertainty by collecting more adult females should be considered a priority for future studies of this species. Asymptotic lengths range from 295.3 - 369 cm TL for males and from 241.9 - 304 cm TL for females. The growth coefficient for the von Bertalanffy growth model was estimated to range from 0.094 yr^{-1} to 0.175 yr^{-1} for males and 0.116 yr^{-1} to 0.251 yr^{-1} for females (*Figure 2*). Unlike most pelagic sharks, males reach a larger asymptotic length than females.

Little information on life history parameters was found for blue shark in the South Pacific (*Annex B*). The litter size ranges from 13-68 with a mean of 35. Size at birth information is not available and the sex ratio of embryos is 1:1. Age at 50% maturity was 8 years for males and 7-9 years for females. The gestation period and reproductive cycle is not known. Resolving this uncertainty by collecting more adult females should be considered as a priority for future studies of this species. The asymptotic length ranges from 342.9 - 376.6 cm TL for males and from 267.5 - 330.4 cm TL for females (*Figure 3*). The growth coefficient of the von Bertalanffy growth model was estimated to range from 0.088 yr^{-1} to 0.128 yr^{-1} for males and 0.126 yr^{-1} to 0.164 yr^{-1} for females. As in the North Pacific, blue shark males in the South Pacific grow to larger sizes than females.

3.1.2 Panel Discussion

The panel remarked on the surprising degree of uncertainty in the reproductive pattern for what is one of the most common of pelagic sharks. Japanese data suggest mating all year round, Taiwanese data show there is strong periodicity, and Australian data suggest that young are often born in spring or summer (J. Stevens, pers. comm.). In terms of whether there is a resting period, Japanese data suggest mating every year, Taiwanese data suggest mating every two years and Australian data suggest that at least some females are known to breed each year (J. Stevens, pers. comm.). The panel agreed that clarifying blue shark reproductive parameters is a top priority and noted that Japan is continuing to collect biological data. In the absence of updated estimates the ISC plans to use a meta-analysis approach to further consider both reproductive and growth parameters. The stock-recruit relationship including steepness will also be explored.

The panel also discussed uncertainty in conversion factors for length-weight. The ISC plans to undertake a comparison of conversion factors and if large differences are apparent a meta-analysis may be done. It was noted that although separate growth curves have been explored for the northeast (e.g. Cailliet and Bedford 1983 and Blanco-Parra et al. 2008, see *Annex A*) and northwest (Tanaka 1990, Nakano 1994 and Hsu et al. 2011, see *Annex A*) Pacific, there do not appear to be meaningful differences in the growth curves from these two areas. The panel agreed that if blue shark data are lacking for the South Pacific, the default option should be to fill the gaps with data from blue shark in the North Pacific.

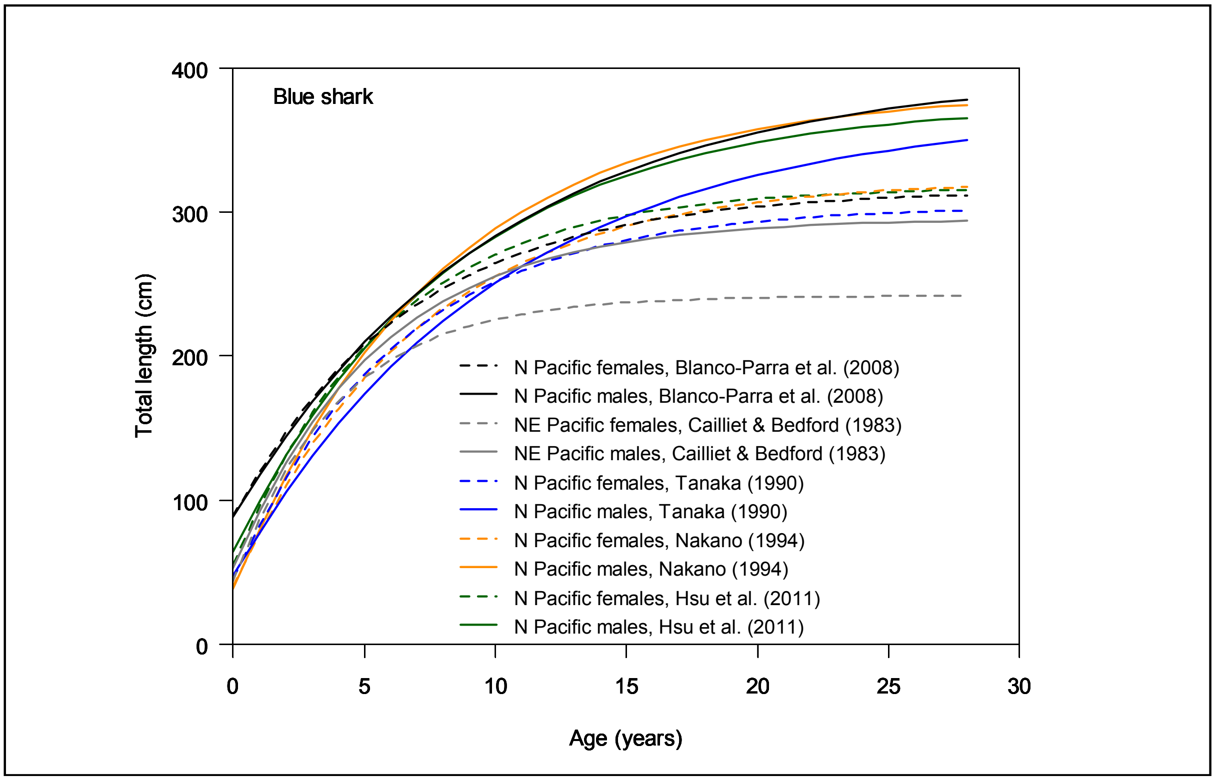

Figure 2. Growth curves for blue shark (*Prionace glauca*) in the North Pacific. Precaudal lengths were converted to total lengths using the formula: TL = (PCL+2.505)/0.762.

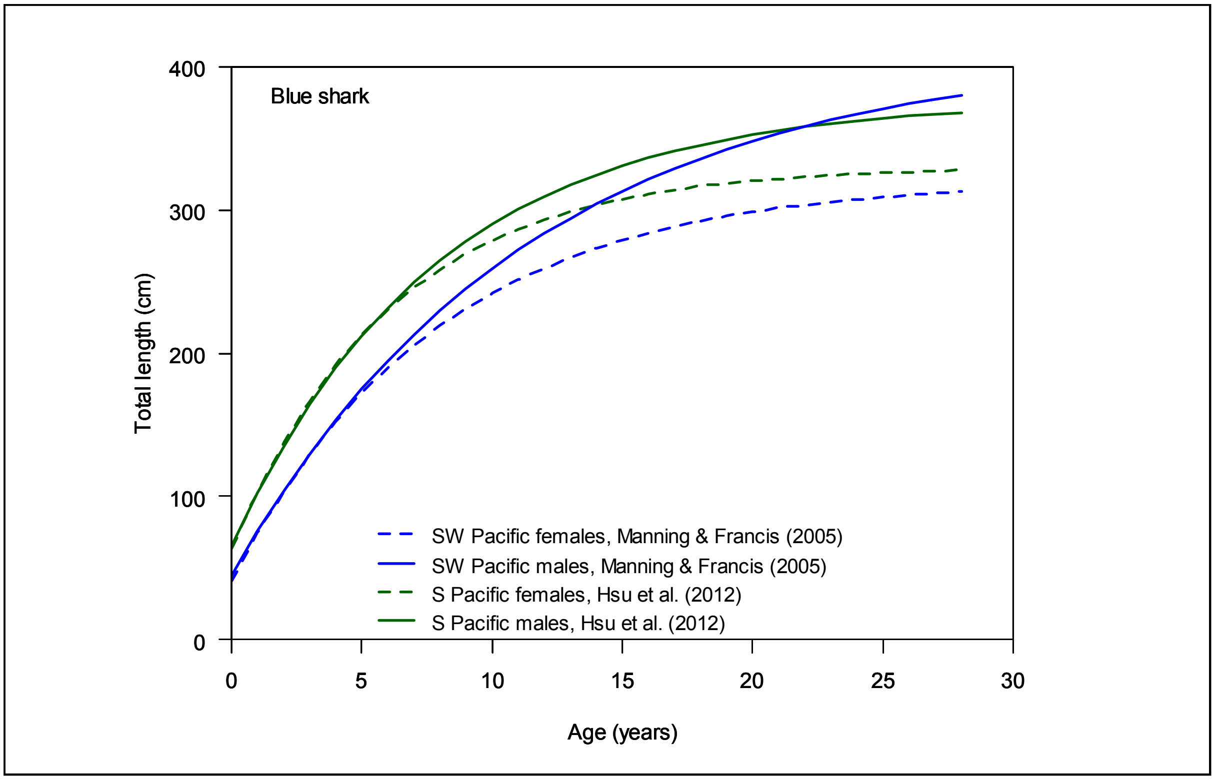

Figure 3. Growth curves for blue shark (*Prionace glauca*) in the South Pacific. Fork lengths were converted to total lengths using the formula: TL = (FL+1.615)/0.838.

3.2 Shortfin mako shark (*Isurus oxyrinchus*, SMA)

3.2.1 Presenter's Summary

Dr Suzy Kohin and Dr Mikihiko Kai presented information regarding the life history of shortfin mako sharks in the North Pacific Ocean. Sixty-eight papers were archived and discussed on shortfin mako sharks, 65 of which contained information on the key life history parameters relating to age and growth and reproductive biology of shortfin mako sharks in the North Pacific Ocean (*Annex C*). Despite the relatively large number of studies, there remains a great amount of uncertainty in the understanding of growth and reproductive biology of this species in the North Pacific. The main challenges are due to the uncertainty about the interpretation of vertebral band pairs and their periodicity to determine ages, and the scarcity of large reproductive female specimens to help reduce uncertainty about mating period and area, pupping period and area, breeding periodicity, gestation time and other reproductive parameters. There is ongoing uncertainty about ageing shortfin mako sharks in the North Pacific and how to assign ages to particular life history events. Age validation studies are typically few and far between, and for shortfin mako sharks worldwide, there remains uncertainty about the rate at which vertebral band pairs are deposited per year. Some parameters are known with relatively high certainty, for example the size at birth, size of male maturity, and litter size. Other parameters which rely on knowledge of the age of sharks, for example, longevity and age at first maturity, are highly uncertain.

While recent age validation studies based on oxytetracycline tagging (OTC) in the northeast Pacific have shown that the vertebral band pair deposition rate is two per year in juvenile shortfin mako sharks, and there appears to be an ontogenetic switch to one band pair per year in male shortfin makos at about age 5, it is not clear if that pattern is true for females or across all regions. Also leading to great uncertainty is the lack of information from reproductive female mako sharks. Shortfin mako sharks exhibit sexual dimorphism in growth and reproduction. Female shortfin mako sharks reach sexual maturity at a much larger size than do male shortfin mako sharks, and the number of mature females caught in the North Pacific is very limited. Information on the gestation period and breeding periodicity of adult female mako sharks and the age of first maturity, because of the uncertainty in ageing, are highly uncertain. Thus, estimates of shortfin mako productivity which rely on knowledge of the growth and fecundity, and the demographic analyses that rely on such estimates, remain uncertain. Studies which aim to address these uncertainties should be prioritized.

In order not to duplicate the information in the table for the North Pacific shortfin mako, the table for the South Pacific shortfin mako highlights information from eleven studies that is specifically relevant to the South Pacific (*Annex D*). Southwest Pacific shortfin mako sharks are genetically distinct from those in the Southeast Pacific and the North Pacific. This stock separation is supported by tagging studies that show regular movement around the Southwest Pacific but only one known movement of a Southwest Pacific shark to the North Pacific, and none to the Southeast Pacific. Juveniles in the Southwest Pacific spend much of their time near continental margins but seasonally move into open ocean waters, a pattern that increases with increasing age. Growth rates and length and age at maturity are reasonably well understood from studies in the Southwest Pacific, assuming that the ageing based on a vertebral band pair deposition rate of one per year is reliable for that population. Other aspects of the reproductive cycle are unknown and are assumed to be similar to those in other populations. Based on an assumption of one band pair per year forming on their vertebrae, shortfin makos grow slowly, maturing at 7-9 years for males and 19-21 years for females. Longevity is estimated to be greater than 29 years. Length-length and length-weight conversion regressions are available.

3.2.2 Panel Discussion

Although the panel did not focus on reviewing genetic and tagging studies, it acknowledged that the literature suggests that Southwest, Southeast and North Pacific shortfin makos are genetically distinct based on mitochondrial DNA analysis, and that most tagging datasets show that North Pacific individuals do not mix with Southwest Pacific individuals. However, a single record of a tagged shortfin mako crossing the equator from Australia to the Philippines was noted. Large individuals have been mapped to areas around 20°N in the North Pacific and there are also reports of large females found at 35°N along the Kuroshio Current and south of Hawaii. Although females are known to come close to coastal nursery areas to drop their pups, overall few large females are caught and there is thus a limited understanding of their distribution.

The panel discussed the possibilities that SMA deposits one vertebral band pair per year, two band pairs per year, or one band pair per year when young with a switch to two band pairs per year at some point in the maturation process. It is also possible that there is regional variation in these patterns. The ISC review of this issue was summarized as follows: early studies suggested that vertebral band pair deposition was either one or two band pairs per year, but more recently several studies suggested one band pair per year in both the Atlantic and Pacific. OTC tagging of juveniles in the Northeast Pacific by the US (n=29) indicated two band pairs are deposited per year up to age 4 or 5. Recent studies of tag-return and length frequency data from the Atlantic show relatively rapid growth that is not inconsistent with the Northeast Pacific studies for younger sharks. A recent recovery of an OTC-tagged adult male from the Northeast Pacific after 6 years shows a shift from deposition of two band pairs per year to one band pair per year after age 5. A number of

North Pacific shortfin mako growth curves, all of which are based on ages assigned by assuming one vertebral growth band pair per year, are plotted in *Figure 4*. As there is high uncertainty around the longevity of North Pacific shortfin mako, there is also high uncertainty in natural mortality and this, among other uncertainties, led to the ISC pursuing an indicators approach rather than a traditional stock assessment earlier this year.

With regard to reproductive parameters there is considerable uncertainty about whether North Pacific shortfin mako has a two or three year reproductive cycle. It was noted that the ISC is re-examining published reproductive parameters by meta-analysis, and residual uncertainty may need to be handled through sensitivity analysis. One particular feature of shortfin mako sharks is that females mature at more than double the age of males; this is a larger-than-usual difference in age at maturity between sexes. The panel acknowledged that there is some evidence of increasing pup number with increasing female size, which seems to be rare in laminid sharks. A key reference for the reproductive biology of this species is Mollet et al. (2000, see *Annex C*) which draws upon data from all over the world, but there are many assumptions and uncertainties inherent in its estimates.

The panel noted that when choosing conversion factors, there are those with little noise but low sample size and those with more noise but a bigger sample size. Participants involved in the ISC stressed that the ISC has not formally agreed upon any particular conversion factors, therefore the listing of conversion factors in *Annex C* does not imply they reflect an official ISC decision regarding their appropriateness.

The panel noted that most of the information on South Pacific shortfin mako derives from New Zealand where juveniles are caught both on the shelf and off the edge of the shelf but only one pregnant female has ever been recorded. Larger females may usually be in open ocean, warmer subtropical waters but come close to shore to give birth.

South Pacific shortfin mako growth curves are unique among the species considered in this workshop because the data were best fit using a Schulte model (*Figure 5*). Deposition of one vertebral band pair per year over the entire range of ages was assumed and it was noted that changing the assumption from one to two band pairs per year would affect the entire curve by shifting it to the left. This source of uncertainty would proportionally affect younger ages more, due to the higher slope. In contrast, older ages are more prone to uncertainty due to under-ageing. It was noted that growth curves from the Southeast and Southwest Pacific (the latter not illustrated here) are moderately similar, however, it appears there is slower growth in the Southeast Pacific up to about 8 years of age.

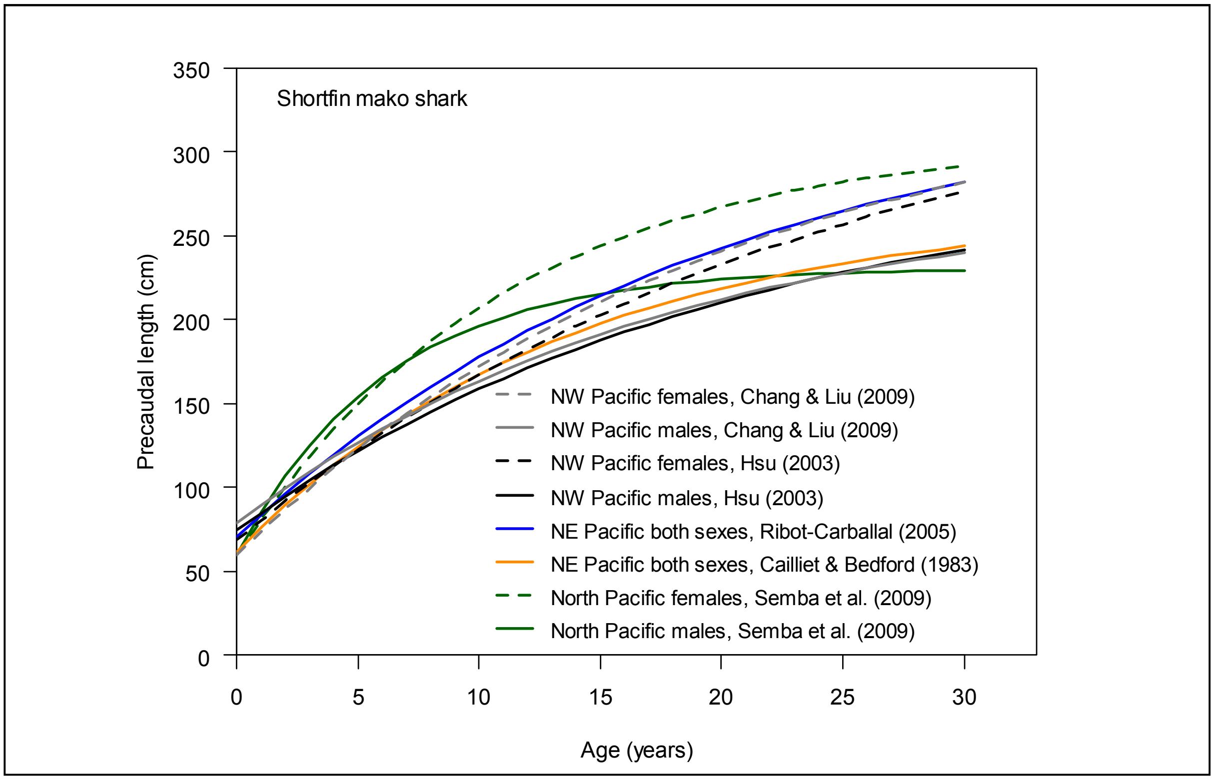

Figure 4. Growth curves for shortfin mako shark (*Isurus oxyrinchus*) in the North Pacific. Total and fork lengths were converted to precaudal lengths using the formulae: PCL = 0.84*TL-2.13 and PCL = 0.91*FL-0.95

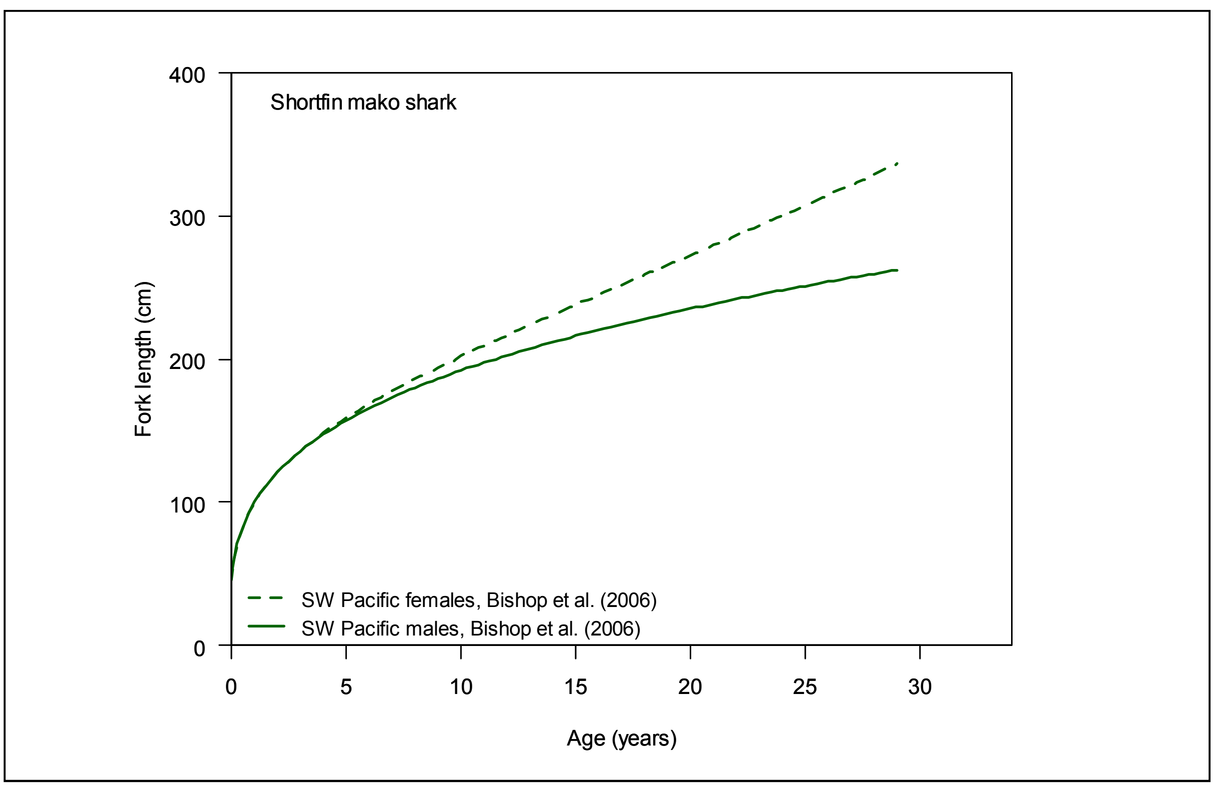

Figure 5. Growth curves for shortfin mako shark (*Isurus oxyrinchus*) in the South Pacific.

3.3 Longfin mako shark (*Isurus paucus*, LMA)

3.3.1 Presenter's Summary

Eleven studies were reviewed for longfin mako shark (*Annex E*). The longfin mako is a very poorly understood shark that occurs worldwide in tropical and warm temperate seas. It is epipelagic, possibly mesopelagic, in deep water. A very small number of tag recaptures indicate it can travel several thousand kilometres. Total length at birth is about 1 m and length at maturity is about 2-2.5 m, but these values are poorly estimated. Litter size is usually two. Other aspects of the biology and behaviour of longfin mako sharks are largely unknown. No growth curves are available for this species.

3.3.2 Panel Discussion

The panel noted that longfin mako sharks undertake large vertical migrations to the surface from depth at night. Dr Rui Coelho shared unpublished satellite archival tag data from the Atlantic of one specimen (a juvenile male of 140 cm FL) that was tracked for 6 months and showed diel vertical movements with dives to 764 m. Conventional tagging from the Atlantic suggests that this species travels large distances.

As this species is rarely caught there is considerable uncertainty associated with all of its life history parameters. It is believed the species is vulnerable to catch by fisheries immediately after birth. Reproductive periodicity has not been established and there are no species-specific data available on age and growth. In the absence of species-specific data it was considered reasonable to assume that longfin mako shark has similar values to shortfin mako shark.

3.4 Silky shark (*Carcharhinus falciformis*, FAL)

3.4.1 Presenter's Summary

Information from 20 studies of life history parameters for the silky shark are summarized in *Annex F*. There is strong evidence of at least two stocks in the Pacific Ocean, thus analysis of life history parameters and population assessments should take this point into consideration (*Figure 6*). A relatively large amount of information exists for this species, although some uncertainties remain, particularly in the longevity estimates. Such uncertainties might be related to the high biological variability of the species, as well as the size range of individuals analyzed in each study. Age has not been validated to date and is a priority for further studies. Biological variability is also reflected in the wide range of some parameters, such as length at birth and fecundity. This biological variability should be incorporated in the population assessments separately from uncertainty (measurement error) from the estimation of the parameters. The lack of seasonality in the reproductive period complicates estimation of the silky shark's reproductive cycle. Although evidence exists for a cycle longer than one year, it is not clear whether the cycle might be two years or less. The periodicity of the reproductive cycle is an important issue for population assessment since considering a biennial cycle would considerably reduce the population growth rates and other demographic parameters.

3.4.2 Panel Discussion

The panel considered that this species is relatively data rich. Nevertheless, there are important uncertainties and the potential for regional variation, particularly as stock structure remains poorly understood. For example, the wide range of published values for birth length and age-at-maturity (e.g. doubles/halves between studies) may reflect real differences due to regional variation. The potential for plasticity in the reproductive traits of this species was noted given that the reproductive periodicity may be one year, two years or something in between.

The panel also raised the possibility that overfishing, if occurring, could lead to a greater number of smaller sharks being sampled. This would bias fecundity estimates downward given the relationship between female size and the number of pups in the litter.

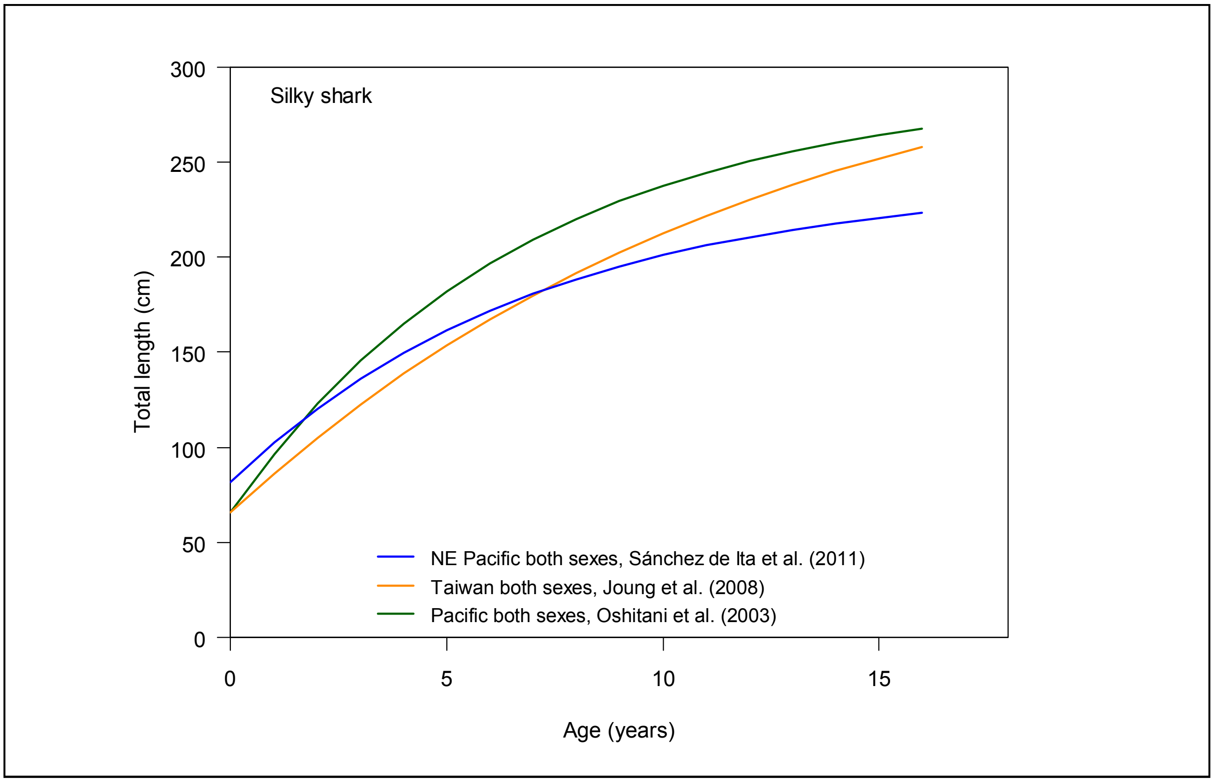

Figure 6. Growth curves for silky shark (*Carcharhinus falciformis*).

3.5 Oceanic whitetip shark (*Carcharhinus longimanus*, OWT)

3.5.1 Presenter's Summary

A review of the shark life history literature identified 22 studies pertaining to oceanic whitetip sharks (*Annex G*). Comprehensive studies have been conducted in the Northwest Pacific and in the Southwest Atlantic and cover both age and growth and reproduction (*Figure 7*). While these studies provide a useful grounding in the basic life history parameters, there is little or no published information on gestation, reproductive periodicity and stock structure. There has been great concern in recent years about the severe declines in oceanic whitetip shark catch rates in many areas including the Pacific. Whether the vulnerability of this species is due to its life history traits or to its catchability by fisheries remains a key question. Early studies suggested that the oceanic whitetip shark is slow growing, but more recent studies have shown faster growth rates comparable to blue and silky sharks. Similarly, the oceanic whitetip shark's litter size is relatively large compared to some other carcharhinid species and some demographic studies estimate the oceanic whitetip shark's productivity to be at levels similar to that of blue shark. One author suggested that the oceanic whitetip shark's vulnerability stems from the fact that its juveniles do not grow fast enough from their small size at birth to escape predation in the oceanic habitat. The listing of this species by CITES, as well as no-retention policies adopted by all of the tuna RFMOs, may make it more difficult to collect and analyse samples of this species for future life history studies.

3.5.2 Panel Discussion

The panel remarked that most oceanic whitetip samples collected in oceanic waters are juveniles. Pregnant females are often found close to shore, particularly around the Caribbean Islands. One pregnant female has been found washed ashore near Auckland, New Zealand. These points suggest that females come close to shore to pup.

It was noted that a study of oceanic whitetip shark age, growth and reproduction by Taiwanese researchers has recently been submitted for publication (*Annex Q*). This study states that oceanic whitetip sharks reproduce every year whereas other studies have found that this species has a one year resting period. Given these conflicting results regarding the reproductive periodicity, the possibility that this species does not have specific mating and pupping seasons, or that these seasons vary by region, should be considered.

Another area of uncertainty is longevity. The panel considered that the estimate of 11 years is probably too low and thus 17 years may be a more appropriate estimate despite being from an Atlantic study. The model-based estimate of maximum age (36 years) was not considered reliable.

The panel also discussed whether or not the oceanic whitetip's litter size of 10-14 pups should be considered "large" compared to other shark species. The panel considered that it would be more accurate to characterize the oceanic whitetip's litter size as average.

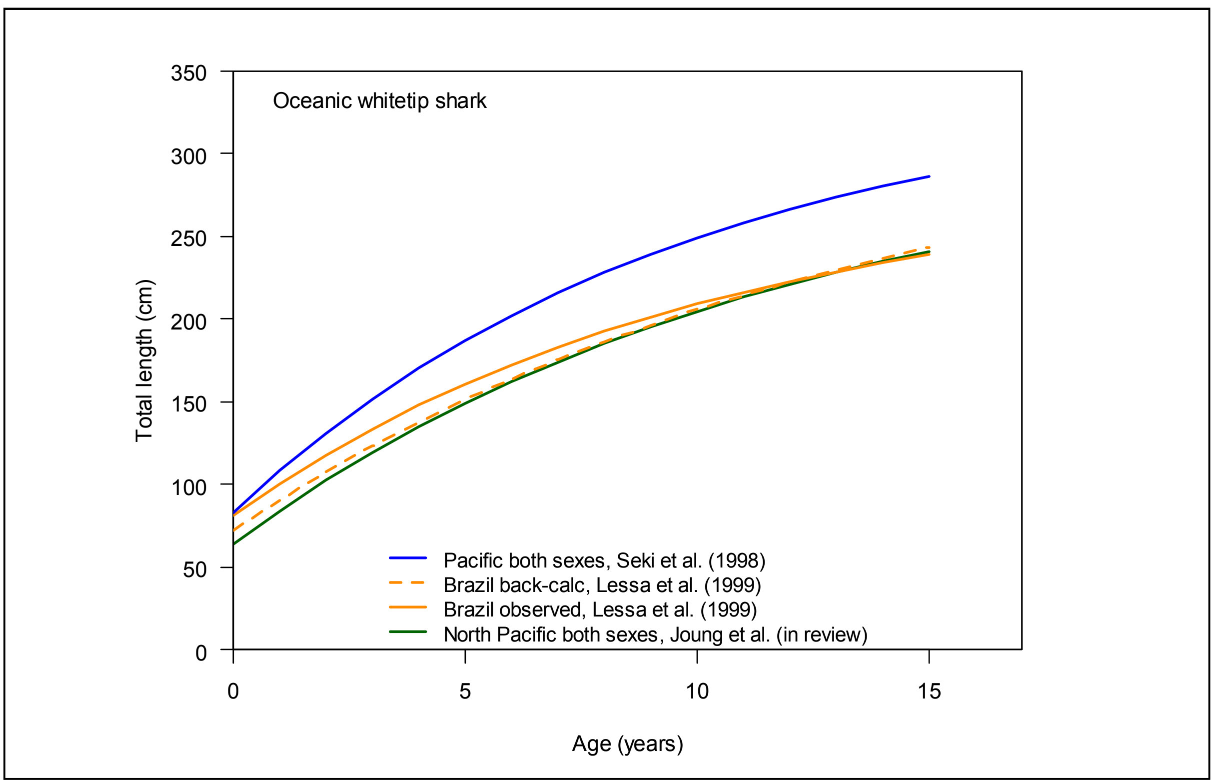

Figure 7. Growth curves for oceanic whitetip shark (*Carcharhinus longimanus*). Precaudal lengths were converted to total lengths using the formula: TL = PCL*1.397. The abstract for Joung et al. (in review) is attached as *Annex Q*.

3.6 Thresher sharks (*Alopias* spp.)

3.6.1 Presenter's Summary

The biological parameters of the three thresher species (bigeye thresher, *Alopias superciliosus*; pelagic thresher, *Alopias pelagicus*; and common thresher, *Alopias vulpinus*) for the Pacific, Indian and Atlantic Oceans were reviewed. Bigeye and common thresher sharks occur in all three oceans whereas the pelagic thresher only occurs in the Pacific and Indian Oceans. A total of 14 studies were reviewed for bigeye thresher shark (six from the Pacific, three from the Atlantic, one from the Indian Ocean and four with information from several regions); ten for pelagic thresher (five from the Pacific, two from the Indian Ocean and three with information from several regions); and twelve for common thresher (four from the Pacific, three from the Atlantic and five with information from several regions).

Overall, there is more information on thresher sharks from the Pacific than from other oceans. There is some information from the Atlantic Ocean but much less from the Indian Ocean. For the major life history parameters considered (age, growth and reproduction) there is specific information available for the Pacific Ocean, particularly the Taiwanese studies in the Northwest Pacific for bigeye and pelagic threshers, and the United States' studies in the Northeast Pacific for common threshers. Information for the South Pacific is more limited.

The available age and growth studies of thresher sharks have assumed a one band pair per year periodicity in the growth bands, and in some cases verification has been accomplished with marginal increment analysis. With regard to reproduction, some parameters such as fecundity and size at maturity are well known, while the periodicity of the reproductive cycle is still uncertain. This last parameter is difficult to estimate but should be prioritized for future research as it has implications for demographic models and estimates of population growth rates.

3.6.2 Bigeye thresher shark (*Alopias superciliosus*, BTH)

Presenter's summary

For bigeye thresher sharks there is one age and growth study in the Pacific (Taiwan) and one in the Atlantic (tropical Northeast Atlantic). The growth parameters found in the two regions were different with the K values higher in the Pacific for the females and higher in the Atlantic for males, while the L_{inf} was higher in the Pacific for females and higher in the Atlantic for males (*Figure 8*). Age at maturity was estimated at 12.3-13.4 years for females and 9-10 years for males. The litter size is 2 pups per cycle with a 1:1 sex ratio and the reproductive cycle duration is unknown (*Annex H*).

Panel Discussion

The panel noted that while this species primarily occurs in tropical waters, its distribution in the Pacific extends at least as far north as Taiwan and the west coast of the United States. Some information suggests that it ranges north to the western coast of British Columbia but after further enquiry with Canadian scientists the panel was informed that these records are erroneous. Population genetics suggest that bigeye thresher migrate between the Atlantic and Southwest Indian Oceans. The species is found near the surface at night and makes deep dives during the day. Information from the Atlantic suggests that pregnant females are distributed away from the equator in the tropical Northeast and Northwest Atlantic, and at the edge of the habitat in temperate waters of the Southern Hemisphere.

Although this species is characterized by high juvenile survival and year-round reproduction (i.e. there is no fixed mating or birthing season), its low fecundity (i.e. it produces only two pups per litter) causes it to have low productivity compared to other pelagic sharks. This reproductive strategy causes the bigeye thresher to be highly vulnerable to fisheries which catch juveniles of the species

The key life history studies for this species were considered to be Liu et al. (1998) for age and growth and Chen et al. (1997) for reproduction. While there are a few gaps in the life history data, these gaps per se would not prevent assessment.

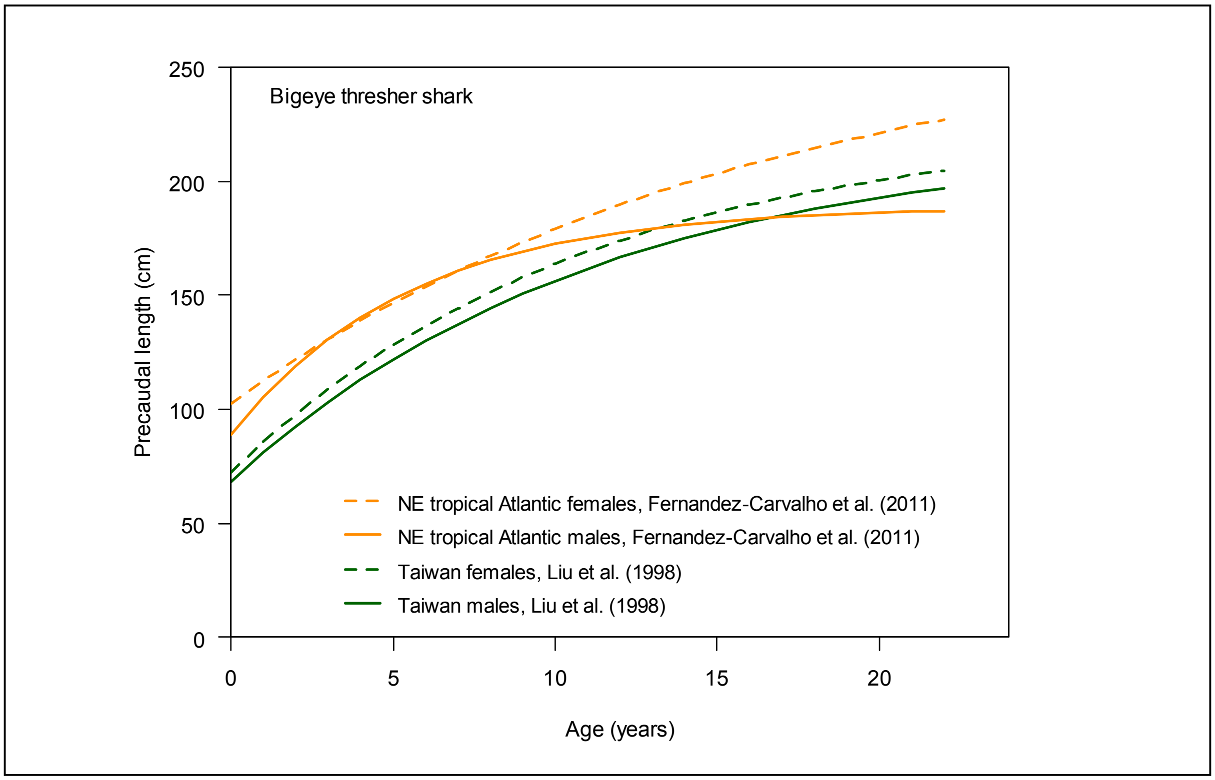

Figure 8. Growth curves for bigeye thresher shark (*Alopias superciliosus*). The following formulae were applied to convert published lengths to precaudal lengths: PCL = (TL - 15.1)/1.76 where TL = 26.3+1.56*FL (for males) and PCL = (TL - 15.3)/1.81 where TL = 13.3+1.69*FL (for females).

3.6.3 Pelagic thresher shark (*Alopias pelagicus*, PTH)

Presenter's summary

For the pelagic thresher shark there is one age and growth study in the Pacific (Taiwan) and one in the Indian Ocean (Indonesia). The growth coefficients (K) found in the Pacific were lower than those in the Indian Ocean and the L_{inf} were higher (*Figure 9*). Age at maturity in the Pacific was estimated at 8.0-9.2 years for females and 7.0-8.0 years for males. The litter size is two pups per cycle with a 1:1 sex ratio (*Annex I*).

Panel Discussion

With regard to the distribution of this species in the Pacific, the panel noted that the pelagic thresher is commonly encountered in the Philippines and its range extends north at least as far as Taiwan. It is also frequently encountered off Northwest Mexico and there may be unpublished data from that region that were not reviewed by the panel. There is some information to suggest that there are genetic differences between eastern and western Pacific populations.

The panel considered that the key studies are Liu et al. (1999) from Taiwan for age and growth; and Liu et al (1999) as well as studies from Ecuador and Indonesia on reproduction. In noting the demographic study of Tsai et al. (2010), the panel concluded that the population growth rate can be characterized as stable.

When considering data gaps for the pelagic thresher the panel noted that it is more productive than the bigeye thresher because it matures earlier (i.e. at 7-8 years of age as compared to 12 years of age). The pelagic thresher is not well-studied in the South Pacific but it appears reasonable to apply North Pacific parameters where there are data gaps. In contrast, differences in eastern and western Pacific populations may be important.

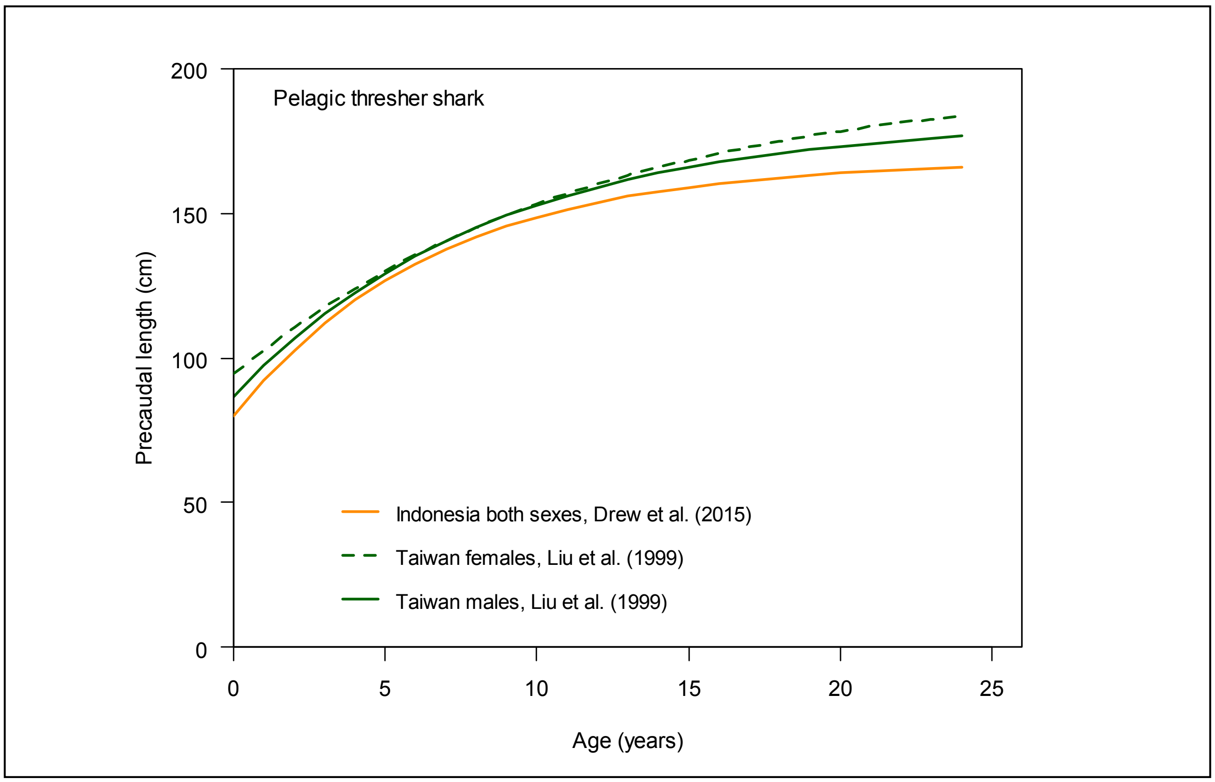

Figure 9. Growth curves for pelagic thresher shark (*Alopias pelagicus*). The following formula was used to convert total lengths to precaudal lengths: PCL = (TL - 2.34)/1.91.

3.6.4 Common thresher shark (*Alopias vulpinus*, ALV)

Presenter's summary

For the common thresher all the age, growth and reproduction studies in the Pacific were carried out in the Northeast Pacific, and there are also studies from the Northwest Atlantic. In the Pacific, the most recent age and growth study by Smith et al. (2008) is an update of previous work by Cailliet and Bedford (1983). The Pacific age and growth study considered specifying sex-specific growth curves, but given the number of samples with undetermined sex it presented a combined sex growth curve (*Figure 10*). In the Atlantic, specific equations for each sex were suggested. The Pacific and Atlantic curves (excluding the preliminary analysis for the Pacific) are relatively similar: the K value for the Pacific (combined sexes) is larger than the K for Atlantic females and smaller than K for the males. The same is observed for L_{inf}, with the Pacific Ocean L_{inf} larger than L_{inf} for Atlantic males and smaller than for the females (*Figure 10*). The common thresher shark is the most fecund of the thresher sharks with usually 2-4, but reportedly up to 7, pups per cycle (Smith et al. 2008). It has a 1:1 embryonic sex ratio and an annual reproductive cycle has been suggested (*Annex J*).

Panel Discussion

The panel noted that the common thresher is the most coastal and temperate of the threshers. This species is common off California (US) and to a lesser extent off Northwest Mexico. The Northeast Pacific population appears to be confined to within 200 nmi of these two countries' coastlines. Unlike the diel vertical migration patterns of bigeye threshers, common threshers remain predominantly in the mixed surface layer and may not dive for long periods. Instead common threshers tend to make short dives during the daylight hours.

Key age and growth and reproduction studies for the Pacific are Cailliet and Bedford (1983), Gilmore (1993) and Smith et al. (2008). NOAA is engaged in ongoing studies of this species off the California coast including electronic tagging as well as OTC marking of 1,187 juvenile common threshers since 1997 (NOAA 2014).

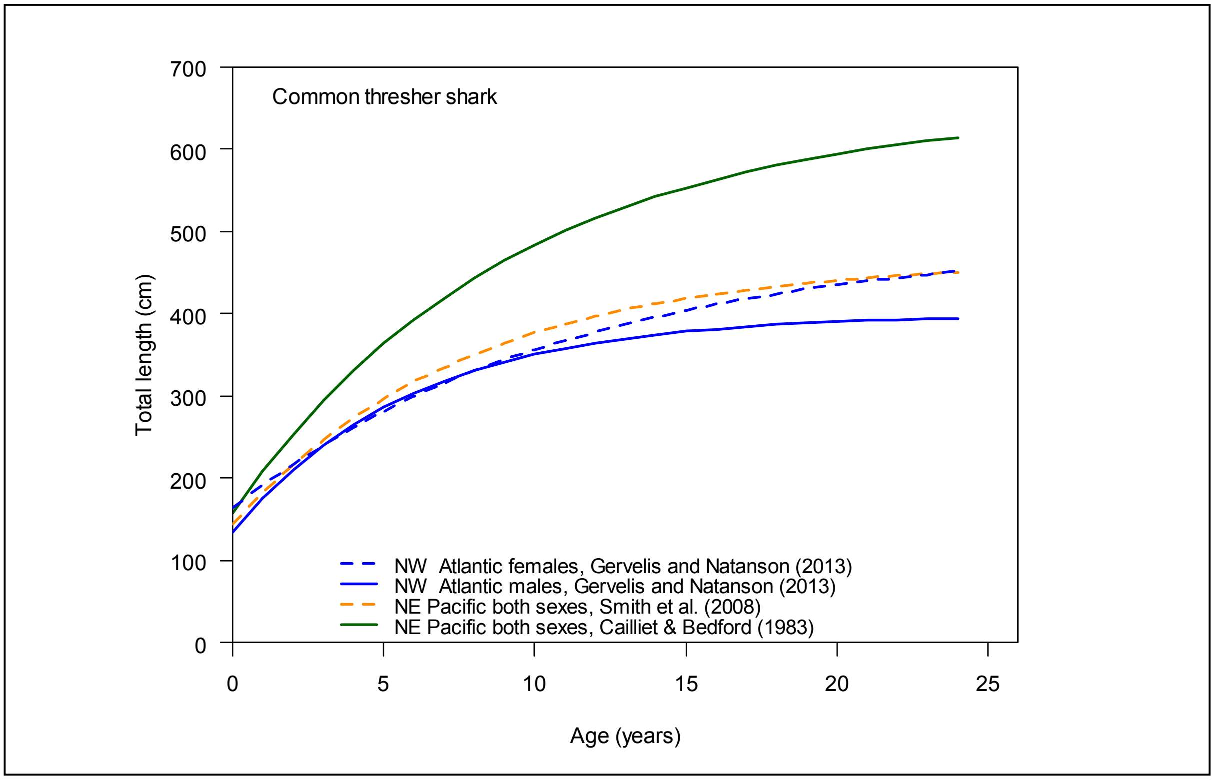

Figure 10. Growth curves for common thresher shark (*Alopias vulpinus*). The following formula was used to convert fork length to total length: TL = (FL-7.0262)/0.5474. Note that the study by Smith et al. (2008) is an update of Cailliet & Bedford (1983).

3.7 Porbeagle shark (*Lamna nasus*, POR)

3.7.1 Presenter's Summary

Eleven studies were reviewed for porbeagle shark (*Annex K*). Southern Hemisphere porbeagle sharks are genetically and biologically distinct, and geographically isolated, from those in the North Atlantic. Stock structure within the circumglobal Southern Hemisphere population is unknown but very limited tagging results indicate they undergo seasonal north-south movements and longitudinal movements of several thousand kilometres. Porbeagles are mainly epipelagic in the open ocean where they make regular diel vertical movements, but they also frequently occur over continental shelves and near shore. Growth rates and reproductive biology are reasonably well understood from studies in the Southwest Pacific. Porbeagles grow slowly, maturing at 6-8 years for males and 13-16 years for females. Longevity is estimated to be about 65 years and possibly older. The gestation period is about 8-9 months but the reproductive cycle length is unknown. Litter size is usually four. The natural mortality rate is estimated to be less than 0.1. Length-length and length-weight conversion factors are available (*Annex K*).

3.7.2 Panel Discussion

The panel noted that the Southern Hemisphere population of porbeagle sharks is not only genetically distinct from the Northern Hemisphere population, it is quite different in terms of its life history characteristics: the Southern Hemisphere porbeagle is a dwarf form that lives twice as long as its northern conspecifics. Stock structure in the Southern Hemisphere is unknown but there is potential for a large amount of mixing. Most data derive from ongoing fisheries in New Zealand and from previous fisheries in Australia; there is no known life history information from other areas. As these fisheries mainly catch juveniles, large females are not well-sampled. Porbeagle shark growth curves are shown in *Figure 11*. A New Zealand growth study (2015) obtained slightly younger ages for a given length than an earlier (2007) study, because of a modified vertebral band pair counting protocol. However, the shape of the growth curves was almost identical between studies for both sexes. Males and females grow at similar rates up to about 10 years of age and diverge thereafter.

The panel considered that a better understanding of stock structure, including genetic (e.g. microsatellite) and tagging studies, is the highest priority. Other important data gaps exist for gestation, reproductive periodicity and other reproductive traits, and this will require greater sampling of early- and late-term pregnant females and small juveniles particularly around the start of the pupping season in April. Noting that North Atlantic porbeagle growth band pairs have been validated to 26 years (Campana et al. 2002), a similar validation study for ages 1-20 in the Southern Hemisphere population is recommended in order to test the accuracy of the two published growth studies.

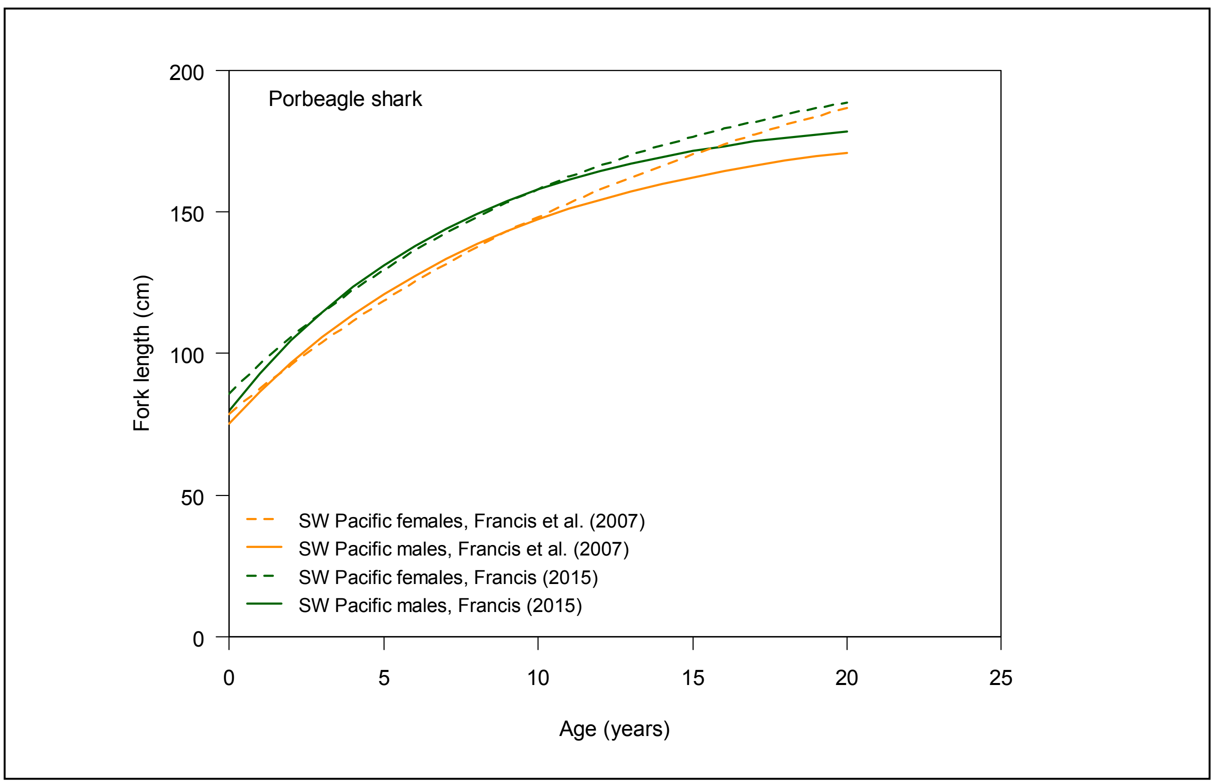

Figure 11. Growth curves for porbeagle shark (*Lamna nasus*).

3.8 Hammerhead sharks (*Sphyrna* spp.)

3.8.1 Presenter's Summary

Over 32 studies of the life history of hammerhead species from all of the major ocean basins were reviewed. Information from all four species of hammerheads that occur in the Pacific were included: winghead (*Eusphyra blochii*), scalloped hammerhead (*Sphyrna lewini*), great hammerhead (*Sphyrna mokarran*) and smooth hammerhead (*Sphryna zygaena*). Unlike most other pelagic shark species, hammerheads spend considerable periods of their lives in coastal waters. For species like winghead this coastal period represents most of their life, but for other species the adults spend much of their time in pelagic habitats. These patterns of habitat use, in combination with limited information on stock structure and connectivity, present a number of challenges for sampling, assessment and management of these species.

For all species, basic life history data are available from the Pacific Ocean but only scalloped hammerhead has been subject to multiple studies in this region. Available studies for scalloped hammerhead shark contain conflicting data on the periodicity of band formation in vertebrae, and thus the inferred ages of sampled individuals are uncertain. This uncertainty has important implications for the outcomes of demographic and population modelling. Therefore, further research on the validation and/or verification of the periodicity of band formation is required.

Hammerhead species all have relatively large litter sizes, but data on reproductive periodicity is limited. This situation further increases uncertainties in assessing the productivity of these species and so should be subject to further study.

3.8.2 Panel Discussion

The panel considered that most hammerhead species have sufficient life history information to support stock status assessment (although in some cases these data are from other oceans). However, it is important not to gloss over conflicting estimates among studies and to properly account for these uncertainties. It was noted that all hammerheads are particularly vulnerable species not necessarily because of their life history but because they are caught by both coastal and oceanic fisheries and because they exhibit high haulback and post-release mortality rates.

3.8.3 Smooth hammerhead (*Sphyrna zygaena*, SPZ)

Panel Discussion

The panel discussed that while the Pacific distribution of the smooth hammerhead is largely unknown, this species is the most oceanic of the hammerheads and leaves the coastal environment at 2-3 years of age. Limited information on stock structure is available, with the only broad scale study showing strong between-basin differences, and the likelihood of within-basin structuring (Testerman 2014).

It was noted that a smaller size at birth has been recorded for this species in New Zealand. A study there documented that individuals of this species can travel large distances (i.e. to Tonga, a distance of some 1200 nmi).

A key uncertainty for the smooth hammerhead is the periodicity of the reproductive cycle, i.e. whether or not females of this species have a resting period. The existence of two unpublished studies from Taiwan (in Chinese) containing information on length-weight relationships, age and growth parameters and reproductive information were noted. One of these (Chow 2004, *Annex R*) provides a growth curve and this was plotted along with the Atlantic growth curve for comparison (*Figure 12*). Differences between the growth curves from the Atlantic and Pacific Oceans may represent different sizes of animals used in the analyses or differences in growth between ocean basins. Information from these or other studies is needed to confirm whether parameters known from Atlantic studies can be appropriately applied to Pacific populations (*Annex L*).

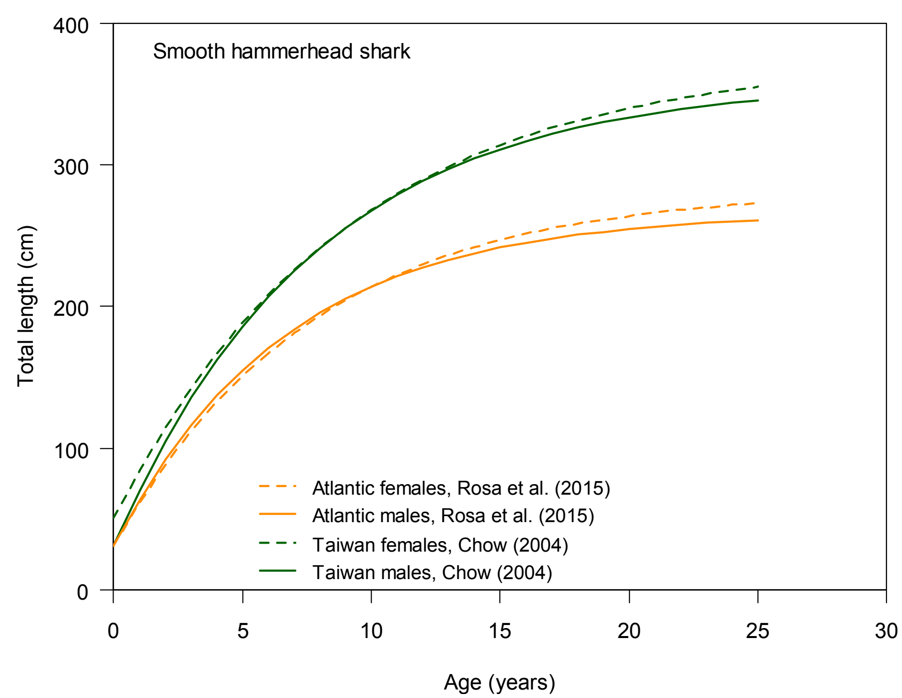

Figure 12. Growth curves for smooth hammerhead shark (*Sphyrna zygaena*). The following formula was applied to convert fork length to total length: TL = (FL -12.72)/0.84.

3.8.4 Scalloped hammerhead (*Sphyrna lewini*, SPL)

Panel Discussion

The panel remarked that this species is found in the Eastern Pacific Ocean despite the fact that some range maps do not reflect this. There may be segregation between eastern and western Pacific populations and there is also some evidence for north-south population structure[1]. Philopatric pupping characteristics of scalloped hammerhead females is likely to play a major role in stock structuring, along with the fact that individuals are known to migrate up to 3000 km. More tagging research was recommended to further elucidate these issues.

The panel considered one of the key uncertainties for scalloped hammerhead life history is associated with the periodicity of vertebral band pair formation (*Annex M*). Some studies report

[1] For example, see the United States' Endangered Species Act listing process for this species for more information: https://federalregister.gov/a/2013-07781

that band pair deposition occurs every year while some studies report deposition twice each year. Whether this is due to differences in methodology, changes in deposition frequency as sharks age, or to regional variation needs to be resolved in order to accurately estimate age and growth parameters. For example, at present size and age at maturity estimates vary between tropical and sub-tropical regions and a systematic review of these data should be undertaken. New approaches to shark ageing such as near infrared spectroscopy and improved marginal increment analysis have promise for new insights on this topic (Okamura et al. 2013, Rigby et al. 2014). Growth curves for scalloped hammerhead sharks are shown in *Figure 13*. The variation in the growth curves reflects the differences in periodicity of growth band formation, with those with two band pairs per year estimated to grow more rapidly. There is also considerable difference in the maximum sizes estimated which may relate to regional differences (Harry et al. 2011).

As for smooth hammerhead, it is not known whether female scalloped hammerheads have a resting period or whether they reproduce annually. Litter sizes are large by shark standards, but annual reproductive rates will depend on the periodicity of the reproductive cycle.

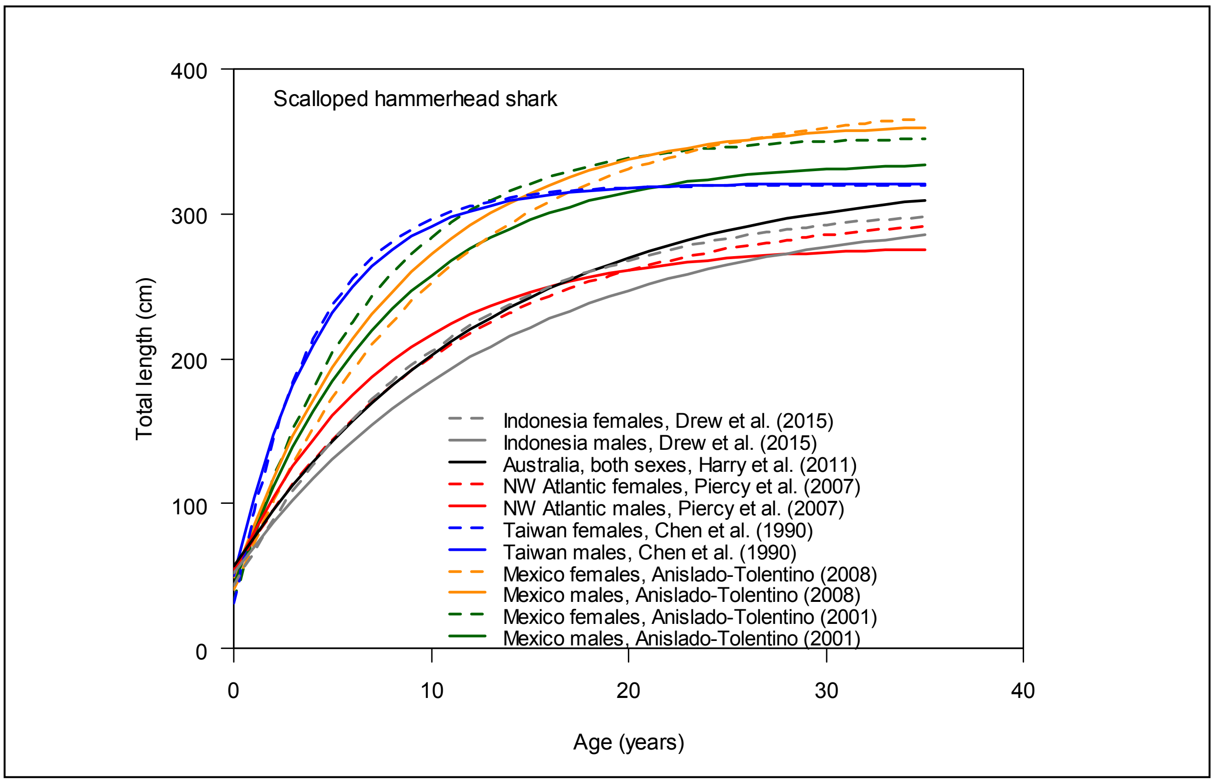

Figure 13. Growth curves for scalloped hammerhead shark (*Sphyrna lewini*).

3.8.5 Great hammerhead (*Sphyrna mokarran*, SPK)

Panel Discussion

The panel noted that the great hammerhead is often captured in similar habitats to the scalloped hammerheads but is less common and more tropically distributed. The key life history studies for this species are Harry et al. (2011) from the east coast of Australia and Piercy et al. (2010) from the Atlantic (*Annex N*). The only validated growth curve derives from the former study (*Figure 14*). The panel considered that the major data gaps for great hammerhead are confirming the reproductive periodicity of two years across a wider range of areas, understanding movement and stock structure through tagging studies and genetics particularly in the Indo-West Pacific, and better estimation of sex-specific growth parameters from the broader Pacific region.

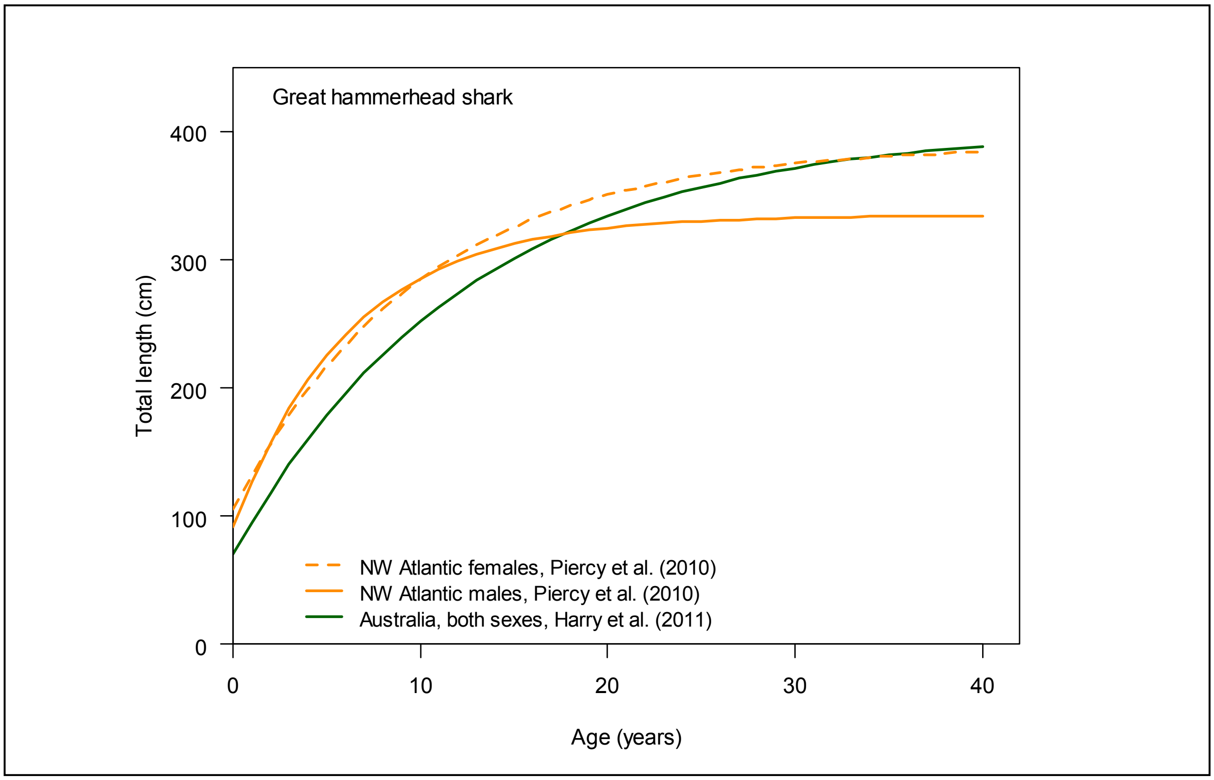

Figure 14. Growth curves for great hammerhead shark (*Sphyrna mokarran*).

3.8.6 Winghead (*Eusphyra blochii*, EUB)

Panel Discussion

The panel noted that the winghead only occurs in large numbers in coastal northern Australia and therefore the key references for its life history are based on studies conducted in that area (Stevens & Lyle 1989 and Smart et al. 2013, see *Annex O*). The winghead is sometimes caught with longline gear but most of the catch is taken in coastal gill nets. The fundamental growth parameters are available (*Figure 15*) but in order to reduce uncertainty a larger sample of age vertebrae should be gathered and analyzed. Where species-specific data are missing for winghead sharks, the panel suggested that data for the scalloped hammerhead could be applied.

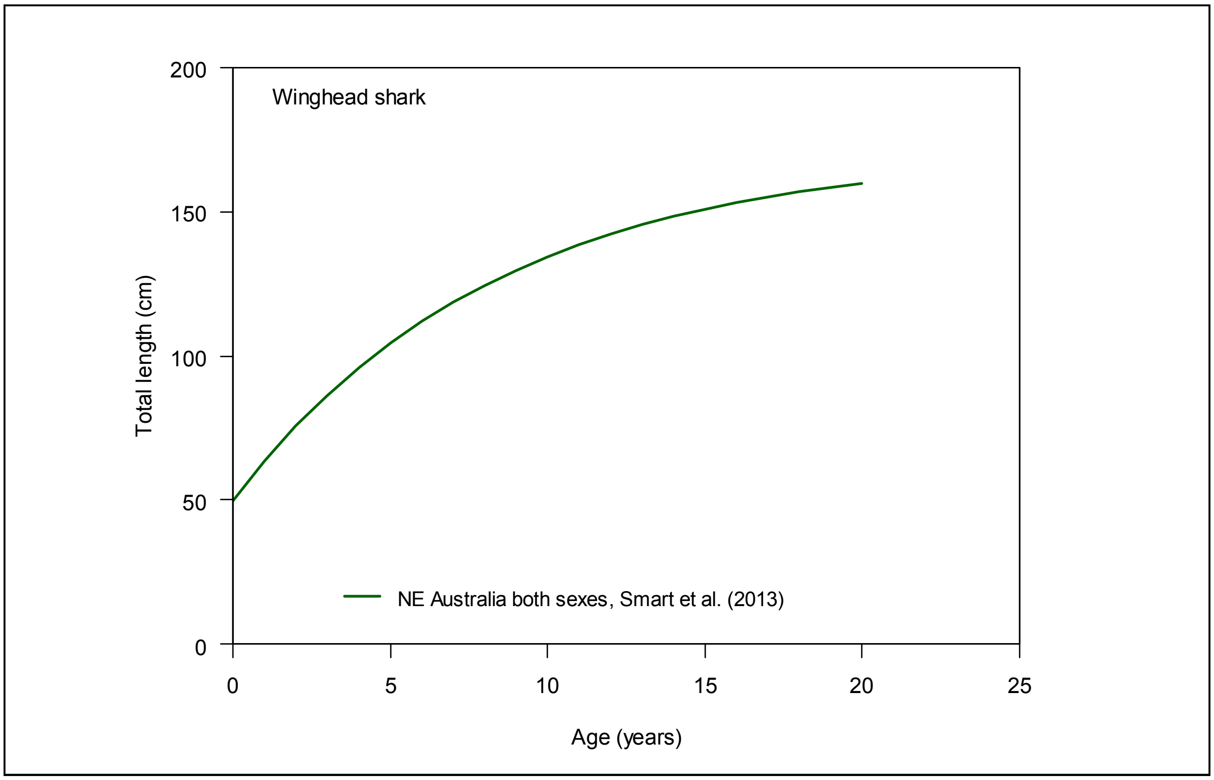

Figure 15. Growth curves for winghead shark (*Eusphyra blochii*).

3.9 Whale shark (*Rhincodon typus*, RHN)

3.9.1 Presenter's Summary

Information from 16 papers on the life history of the whale shark (*Rhincodon typus*) is summarized in *Annex P*. The available information includes recent genetic and migration information providing strong evidence of a single meta-population in the Indo-Pacific. There is limited but consistent information on the length at birth from observed full-term embryos and neonates, length at maturity for males, and fecundity. However, there is an absolute lack of information on the periodicity and seasonality of the reproductive cycle. Vertebral growth band analysis has provided recent estimations of the von Bertalanffy growth function parameters, obviating the need to use extrapolation and theoretical estimations based on other species as was done few years ago. Nevertheless, the limited number of vertebrae of mature individuals (mainly females) may be creating a bias in the growth parameters. Marginal increment analysis indicates biannual formation; however, the possibility of annual periodicity has not been discarded. Direct validation is recommended because growth curves and longevity estimates can be considerably affected by which growth band pair periodicity is assumed (*Figure 16*). Despite the low number of samples, several length-length conversion equations are available for adults and embryos. The whale shark has the highest fecundity of any shark species known to date, but its slow growth rate and high longevity (and consequently low natural mortality) makes the species highly vulnerable.

3.9.2 Panel Discussion

The panel noted that despite evidence for a single meta-population in the Pacific and Indian Oceans, studies of the Caribbean population of whale sharks suggests that that population is genetically distinct. In addition to the studies reviewed by the panel, it was considered that aquarium-based studies, such as those in Japan, might provide further useful information on growth rates.

The most useful age and growth study of whale sharks is by Hsu et al. (2014b) which used marginal increment analysis and centrum analysis to show that there are two band pairs deposited each year. The sample size is quite high (n=73) but only one of the individuals sampled was mature. Therefore, the uncertainty in the growth curve at the older ages is very high. It was noted that an earlier paper by Wintner (2000) showed numbers of growth band pairs at certain sizes that are consistent with the data in Hsu et al. (2014b).

In terms of reproductive parameters, the panel recognized that there is no existing information on reproductive periodicity and seasonality. The size at birth is not known but it can be estimated from the size of the largest near-term embryo (64 cm) and the smallest free-swimming neonate (78 cm).

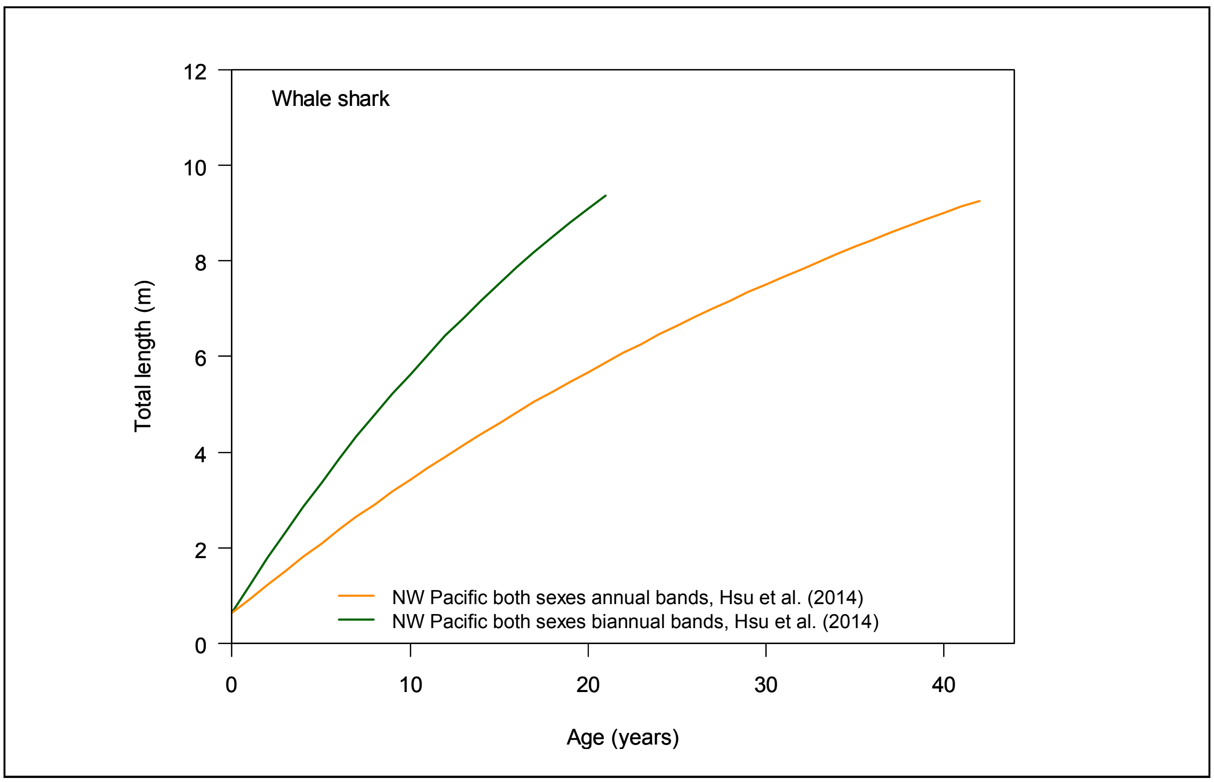

Figure 16. Growth curves for whale shark (*Rhincodon typus*).

4 Key Concerns when Undertaking Stock Assessments

Having reviewed and summarized the available life history for all 14 of the WCPFC key shark species, the panel then considered what guidance it could provide to scientists who will use the data for stock status assessments.

The panel considered that when selecting life history parameters from the available literature careful consideration should be given to *inter alia* sample size, the sizes of individuals sampled, potential selectivity issues in the collection of the sample including representativeness of the sample over age classes and areas, and proper use of conversion factors. The tables attached to this report cover most of the key sources of information and often these important considerations have been summarized, but in some cases it may be necessary to refer to the original studies or datasets. In cases where there is no information available, proxy parameters can be selected with the help of the alternative parameters and caveats shown in the attached tables.

It was noted that in some of the more basic stock assessment models (e.g. a Bayesian Surplus Production model) life history parameters would only be used for calculating a prior for the intrinsic rate of increase, '*r*'. In such case, it is recommended to use the female parameters, if available. In an integrated model (e.g. SS3, CASAL or Multifan-CL) sex-specific parameters should be used if important differences in life history and spatial ecology between sexes are known or expected.

Finally, it was recommended that sensitivity analyses should be undertaken for all parameters identified in the attached species tables as having important uncertainties (e.g. age and growth, reproductive periodicity, age at maturity and conversion factors). The tables can assist in specifying the appropriate range of values to test in sensitivity model runs.

5 Recommendations for Further Work to Better Understand Shark Life History Parameters

The panel discussed a number of recommendations for further studies in the field of shark life history. These recommendations cover both species-specific needs as well as methodological issues that would benefit a variety of species.

In terms of multi-species methodological studies, the panel considered that a very useful and practical study could be conducted to review all available length-length and length-weight conversion factors in detail, comparing coefficients and excluding any dubious values. The goal of this study would be to identify which conversion factors are most appropriate for each species and region. At present, uncertainty in conversion factors adds unnecessary "noise" to inter-regional comparisons across a wide range of fishery analyses. It was noted that ICCAT is undertaking a length-weight conversion factor review for a combined dataset from several countries to develop more consistent conversion factors. Their methodology may help elucidate appropriate methods to be applied in a Pacific-wide review.

The panel also recommended studies to improve the ability to accurately age sharks. This work is critical because it could lead to important revisions to growth curves which may significantly affect input parameters for assessment models. There are two important aspects to this work. First, ageing by different readers and laboratories should be standardized through calibration studies. It was noted that ISC is already progressing this work for BSH and SMA in the North Pacific using reference vertebral sets for each species and multiple methods of enhancement. It may be possible for ISC to share those results with any laboratories doing similar work in the South Pacific in order to expand the regional scope of work to the entire Pacific. Second, given the current uncertainty about whether vertebral band pair deposition changes over the course of an individual shark's life span it is necessary to conduct validation/verification of growth band pair periodicity through studies such as oxytetracycline (OTC) injection, marginal increment analysis, centrum edge analysis or bomb radiocarbon (for older samples) methods. These studies would considerably reduce the uncertainty associated with understanding the population age structure. As it would be a large undertaking to do this work for all key shark species, it was recommended that a detailed review be conducted, using the findings and references from this workshop as a starting point, to identify for which species, for which ages within those species, and for which regions the uncertainties are highest. The feasibility of conducting validation/verification, for example with regard to the ease of sampling and the availability of appropriate expertise, should also be assessed.

A third theme for which multi-species work was considered essential is reproductive studies. A lack of data, or wide variation in the data available, on the periodicity and seasonality of reproduction was noted in each of the species summaries prepared by the panel, but was highlighted as particularly critical for blue and shortfin mako sharks. The blue shark is abundant and relatively well-studied but at least two patterns of reproductive periodicity and seasonality have been identified in the North Pacific, and potentially a third in the South Pacific (Section 3.1.2). There is surprisingly more data on the reproductive periodicity of the less common shortfin mako shark, but there is still considerable uncertainty over whether it reproduces every two or three years (Section 3.2.2). For some of the other species such as the longfin mako, the three threshers and the smooth hammerhead those parameters are still unknown. As these issues are major contributors to uncertainty in population assessments, further studies of reproductive periodicity are urgently required.

In terms of species-specific studies, three in particular were identified as high priorities:

- The relationship between maternal length and litter size in shortfin mako sharks should be further explored. The first step would be to conduct a meta-analysis of existing studies and if necessary then collect more adult female samples. This work is important to explore the effect of the removal of large females, and the resulting reduction in average size, on the change in fecundity of the population. ISC has begun a meta-analysis of shortfin mako reproductive biology for the North Pacific.

- An interesting study was also raised for hammerhead sharks for which uncertainty over the periodicity of vertebral band pair deposition has a substantial influence on demographic models. These species are becoming increasingly hard to study given CITES restrictions on sample collection and transport. However, there may be historical samples of smooth hammerhead shark in Western Australia that have not yet been aged, and there are samples of scalloped hammerhead sharks in eastern Australia that have already been aged. The smooth hammerhead samples could be aged and then both smooth and scalloped hammerheads could be assessed in Australia using near-infrared spectroscopy analysis to determine the most probable vertebral band pair deposition rate. Samples from the Atlantic could probably also be included because they are held in Florida at a CITES-certified lab and could probably be received by CITES-certified organizations in Australia. Analysis of these existing samples could be a major advance in understanding Pacific hammerhead populations as well as have global impact and benefit.

- A third study was suggested that would focus on comparing life history parameters for the silky shark between the western and eastern Pacific. The ACIAR PNG Shark Project has a number of samples from the western region; samples may also be available from Ecuador in the east (possibly in the Cervantes-Gutierrez laboratory). This type of analysis could be a major contribution to a pan-Pacific stock status assessment of silky shark in the next assessment cycle.

Beyond these methodological and species-specific recommendations, the panel also considered how these life history issues should be integrated into a broader Pacific shark work plan. It was acknowledged that such a plan would inevitably be led by the stock status assessment priorities and schedules set by the relevant international organizations and projects, and that life history information would be necessary to support, rather than lead, that process. Nevertheless, tuna RFMOs were urged to be more proactive in setting a research agenda for life history and stock structure research so that the critical issues for management can be addressed. Once this agenda is set, this then provides a framework for national collaboration projects. Without such a framework, major uncertainties in life history parameters will persist and may undermine robust assessments.

The influence of recent shark management measures on sample collection programmes was raised several times during the meeting. It was considered that the listing of several of the key pelagic shark species by the Convention on International Trade in Endangered Species (CITES) is impeding scientific research due to constraints this places on obtaining and sharing samples. As this is counterproductive to species conservation, efforts should be made to overcome current obstacles. One first step would be to communicate the panel's concerns to the CITES Secretariat and Animals Committee. Another step could be for projects providing ongoing support for national implementation (e.g. Non-Detriment Findings (NDFs)) to try to address these issues at the national level as much as possible. It was suggested that it might be useful for a small study to look into how sample collection and sharing has been achieved for other highly migratory, CITES-listed species. It was recognized that CITES listing can also be an impetus for the funding of further biological studies, and therefore it is important to describe how proposals for improving shark life history information would assist with CITES processes such as NDFs.

The panel discussed the idea of including sharks within the WCPFC tissue bank system (SPC 2014). The panel considered that rather than working through such tissue banks it might be easier for the handful of countries that have samples, expertise and interest to collaborate on specific research projects. For example, it may not be necessary to transport vertebral samples (which is perhaps the most urgent sample need), rather these could be scanned and shared as images. This could avoid some of the complications currently posed by CITES permitting processes.

Lastly, the panel remarked that although life history work tends to focus on the more common species, it is critical not to neglect rare, vulnerable and/or poorly known species that may be experiencing adverse population-level impacts from fisheries. Species such as the crocodile shark (*Pseudocarcharias kamoharai*), longfin mako, the Mobulidae (mantas and devil rays) and the whale shark may be more difficult to sample, but are also worthy of further biological study.

6 Documentation and Archiving

The database of references and bibliographic materials compiled for this meeting will be preserved as a group library in a cloud-based Zotero work space. The library currently contains over 270 documents classified by species and life history parameter. As there are no resources available to update this library, it will represent a static picture of the information available as of the end of April 2015. Access can be provided to the Zotero online repository on a read-only basis through application to Dr Shelley Clarke, ABNJ Technical Coordinator-Sharks and Bycatch at shelley.clarke@wcpfc.int.

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Annex A. Parameters for the blue shark, *Prionace glauca* (North Pacific)

BSH-North	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	t_0=-1.113 yr (M, n=38), -0.795 yr (F, n=88) t_0=-1.38 yr (M, n=43), -1.01 yr (F, n=152) L_0=36 cm PCL t_0=-0.759 yr (M, n=148), -0.849 (F, n=123) L_0=35-60 cm TL t_0=-2.15 yr (M, n=122), -2.44 (F, n=62) L_0=40.1 cm TL t_0=-1.554 yr (M, n=181), -1.123 (F, n=250)	Cailliet & Bedford 1983 Tanaka 1984 Nakano 1994 Nakano & Seki 2002 Blanco-Parra et al. 2008 Joung et al. 2011 Hsu et al. 2011, 2012	t_0=-1.35 yr (M,n=287), -1.77 (F, n= 119) t_0=-1.075 yr (combined, n=308) L_0= 45 cm t_0=-1.330 yr (combined, n=30)	Skomal & Natanson 2003 Aires-da-Silva 1996 Pratt 1979 Henderson et al 2001	
Age at maturity (T_{50}) (by sex)	4-6 (M, n=148), 5-7 (F, n=123) 4.0 (M, n=181), 4.3 (F, n=250)	Nakano 1994 Hsu et al. 2011, 2012	M: 4-5 F: 5 years	Skomal & Natanson 2003	
Growth coefficient (K) (by sex)	0.175 (M, n=38), 0.251 (F, n=88) 0.094 (M, n=43), 0.116 (F, n=152) (110-280 cm TL) 0.129 (M, n=148), 0.144 (F ,n=123) 0.1 (M , n=122, 81-270 cm TL), 0.15 (F, n=62, 90-252 cm TL) 0.121 (M, n=181), 0.172 (F, n=250)	Cailliet & Bedford 1983 Tanaka 1984 Nakano 1994 Blanco-Parra et al. 2008 Hsu et al. 2011, 2012	0.18 (M, n= 287) 0.13 (F, n= 119) 0.138 (combined, n=308) 0.120 (combined, n=30)	Skomal & Natanson 2003 Aires-da-Silva 1996 Henderson et al 2001	

BSH-North	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Age at recruitment	0-1				
Maximum length (observed, L_{inf}) (by sex)	295.3 cm TL(M, n=38), 241.9 cm TL(F, n=88)	Cailliet & Bedford 1983	282.3 cm FL (M, n=287) 310.8 cm FL (F, n=119) (n=49-312 cm FL)	Skomal & Natanson 2003	
	380 cm TL (observed)	Hart 1973			
	369 cm TL (M, n=43), 304 cm TL (F, n=152) (110-280cm TL)	Tanaka 1984			
	289.7 cm PCL (M, n=148), 243.3 cm FL (F, n=123)	Nakano 1994	340.0 cm TL (combined, n=308)	Aires-da-Silva 1996	
	375.8 cm TL (M, n=181), 317.4 cm TL(F, n=250)	Hsu et al. 2011	376.5 cm TL (combined, n=30)	Henderson et al 2001	
	237.5 cm TL (F, n=62, 90-252 cm TL), 299.9 cm TL (M, n=122, 81-270 cm TL)	Blanco-Parra et al. 2008			
Longevity (T_{max}) (by sex)	16 (M, n=122), 12 (F, n=62)	Blanco-Parra et al. 2008	16 (M, n=287), 15 (F, n=119)	Skomal & Natanson 2003	
	26-28 (M), 20-24 (F)	Rice & Semba 2014			
	20.2 (M, n=181), 28.6 (F, n=250)	Hsu et al. 2011, 2012			
REPRODUCTION					
Length at maturity (by sex) (L_{50})	150-155 cm PCL (M), 159 cm PCL (F)	Nakano et al. 1985	220 cm TL (ATL)	Pratt 1979	Still not certain since values vary a bit across studies
	140-160 cm PCL (186-212 cm TL) (both sexes	Nakano 1994			
	184.6 cm TL (M, n=576), 193.4 cm TL (F, n=503)	Joung et al. 2011			

BSH-North	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	184 cm TL (183-186, 95% CI) for male (n=631), 196 cm TL (191-200, 95% CI) for female (n=402)	Carrera- Fernández 2010			
Gestation period	9-12 months 9-11 months	Pratt 1979, Cailliet & Bedford 1983 Carrera- Fernández 2010			
Reproductive Cycle	24 months 12 months	Joung et al. 2011 Suda 1953			Still uncertain as studies vary
Spawning Period/Mating Period	Spring and summer in central Pacific (spawning season) Feb-March off Taiwan (pupping season)	Nakano 1994 Joung et al. 2011			Variable among studi,es
Litter size (mean & range)	25-30 in average (1-54) 25.2 (2-52) 34 in average (PACIN and PACIS)	Suda 1953, Nakano et al. 1985 Joung et al. 2011 Mejuto & Garcia-Cortés 2005	37 in average (ATLC) 39 in average (ATLN) 38 in average (INDI) 30 in average (8-62) 37 in average (ATL)	Mejuto & Garcia-Cortés 2005 Mejuto & Garcia-Cortés 2005 Mejuto & Garcia-Cortés 2005 Hazin et al. 1994 Castro & Mejuto 1995	
Maturity ogive (logistic curve parameters)	P=1/(1+exp(31.571-0.171TL) (M, n=576)				Maturity ogive (logistic curve parameters)
OTHER					
Conversion factors (length:length, length:weight) (by sex)	PCL=-2.505+0.762 TL (n=267, r=0.999) PCL=0.762*TL-2.505 (n=267, r=0.999) FL=0.829*TL-1.122 FL=2.746*AL+11.803	Nakano & Seki 2003 Nakano et al. 1985 NOAA SWFSC (unpub. data) NOAA SWFSC (unpub. data)	All: $FL_t = 285.4[1-e^{-0.17(t+1.41)}]$ (ATL)	Skomal & Natanson 2003	

BSH-North	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	TL=0.286*AL-2.474	NOAA SWFSC(unpub. data)	M: FL_t= 282.3[1-$e^{-0.18(t+1.35)}$] (ATL)	Skomal & Natanson 2003	
	All: Wt(kg)=2.57 x 10^{-5} $TL^{3.05}$ (n=150, r=0.849)	Harvey 1989			
	M: Wt(kg)=3.838 x 10^{-6} $TL^{3.174}$(n=285,r=0.997)	Nakano et al. 1985			
	F: Wt(kg)=2.328 x 10^{-6} $PL^{3.294}$(n=148,r=0.994)	Nakano et al. 1985			
	M: Wt(kg)=3.293 x 10^{-6} $PL^{3.225}$ (n=2910, r=0.993)	Nakano 1994	F: FL_t= 286.8[1-$e^{-0.16(t+1.56)}$] (ATL)	Skomal & Natanson 2003	
	F: Wt(kg)=5.388 x 10^{-6} $PL^{3.102}$ (n=2890, r=0.992)	Nakano 1994	FL=0.8313*TL+1.39	Kohler et al. 1995	
	All: Wt(kg)=5.009 x 10^{-6} $FL^{3.054}$	NOAA SWFSC (unpub. data)	PCL=0.9075*FL-0.3956	Kohler et al. 1995	
	All: Wt(kg)=1 x 10^{-6} $FL^{3.23}$ (n=44, 0.91)	Joung et al. 2011			
Stock Delineation/Range	Equator	Sippel et al. 2011			
-Genetics	Weak or no differentiation in Pacific but can be separated into North and South stocks for management purpose	Taguchi et al. 2015			Blue sharks are caught at/near equator but at lower C/E
-Tagging	NP distinct from SP, no observed crossing of equator yet	Sippel et al. 2011, Block et al 2011, Musyl et al 2011, Urbisci et al. 2013	11 samples were tagged with PSAT tags to record the horizontal and vertical movements in Atlantic ocean	Queiroz et al. 2010	
Habitat Use /Env'l Preferences (temp, depth)	Spatial segregation by size and sex apparent; more abundant in temperate regions, water temps >25-6, depth surface to 300+ m	Nakano 1994, Nakano & Seki 2003, Urbisci et al. 2013, Weng et al. 2005, Musyl 2011			
Mixing Areas	Mating ground:20-30N, Parturition ground: 35-45N, nursery ground: 30-35N (male), north of 45 (female)	Nakano 1994, Nakano & Seki 2003			
Migration	Wide-ranging, seasonal	Nakano 1994, Nakano &			

BSH-North	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	migration patterns apparent but not well defined	Seki 2003			
Natural mortality	0.187-0.413	Tsai et al. 2013			
	0.551-0.089 (M), 0.535-0.101 (F) based on Wroblewski method using Nakano (1994) growth equation 0.359-0.085 (M), 0.366-0.099 (F) based on Wroblewski method using Hsu et al. (2001) growth equation	Rice & Semba 2014			
-life history-based					
-catch curves					
Steepness					
Intrinsic rate of increase (r or λ)	λ =1.131-1.82 (1-yr reproductive cycle)	Tsai et al. 2013	r=0.34	Cortés 2002 and Kleiber et al. 2009	
	λ =1.041-1.580 (2-yr reproductive cycle) r=0.34	Chin & Liu 2012			
Intrinsic rebound potential ($r_{Z(MSY)}$)	$r_{1.5M}$ = 0.035	Smith et al. 2008			

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Annex B. Parameters for the blue shark, *Prionace glauca* (South Pacific)

BSH-South	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	t_0 =-1.482 yr (M, n=173) and -1.294 yr (F, n=86) t_0 =-1.257 (M, n=140) and -1.047yr (F, n=288).	Hsu et al. 2012 Manning & Francis, 2005	t0 = −1.66 yr (combined) (S. African) t_0=-1.01 yr (combined, n=236) (ATLS)	Jolly et al. 2013 Hazin & Lessa, 2005	
Age at maturity (T_{50}) (by sex)	**8** yr (M, n=286) and **7**-9 yr (F, n=650) (age-at-maturity)	Francis & Duffy,2005	7 yr for male and 6 yr for female**.** (S. African) 5 yr for male and female (first maturity) (ATLS)	Jolly et al. 2013 Hazin & Lessa, 2005	
Growth coefficient (K) (by sex)	0.128 yr^{-1} (M, n=173, 117-315 cm TL) and 0.164 yr^{-1} (F, n=86, 110-297 cm TL). 0.088 yr^{-1} (M, n=140) and 0.126 yr^{-1} (F, n=288).	Hsu et al. 2012 Manning & Francis, 2005	0.12 y^{-1} (combined) (S. African) 0.1571 yr^{-1} (combined, n=236) (ATLS)	Jolly et al. 2013 Hazin & Lessa, 2005	
Age at recruitment					
Maximum length (observed, L_{inf}) (by sex)	L_∞ = 376.6 cm TL (M, n=173, 117-315 cm TL) and 330.4 cm TL (F, n=86,110-297 cm TL). L_∞ =342.9 cm FL (M, n=140) and 267.49 cm FL (F, n=288).	Hsu et al. 2012 Manning & Francis 2005	L_∞ = 311.6 cm TL (combined) L_∞ = 352.1 cm TL (conbumed ,n=236) L_{obs}=310cm TL	Jolly et al. 2013 Hazin & Lessa, 2005	
Longevity (T_{max}) (by sex)	27.0 yr (M, n=173) and 21.1 yr (F, n=86). 22.76 yr (M, n=140) and 19.73 (F, n=288).	Hsu et al. 2012 Manning & Francis 2005			

BSH-South	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
REPRODUCTION					
Length at maturity (by sex) (L_{50})	190-195 cm FL (M, n=286) and 170- 190 cm FL (F, n=650) (age-at-maturity) 190.3 cm TL (M, n=577, 52-310 cm TL) and 199.2 cm TL(F, n=576, 56-249 cm TL).	Francis & Duffy,2005 Bustamante & Bennett 2013	201.4 cm TL for males and 194.4 cm TL for females. 225 cm TL for male and 228 cm TL for female (first maturity)	Jolly et al. 2013 Hazin & Lessa 2005	
Gestation period					
Reproductive Cycle			Gestation takes about 9 to 10 months.	Hazin & Lessa, 2005	
Spawning Period/Mating Period			April to June.	Amorim 1992	
Litter size (mean & range)	35(13-68)	Zhu et al. 2011	43 34 in average (South Atlantic)	Jolly et al. 2013 Mejuto & Garcia-Cortés 2005	
Embryonic sex ratio	1:1	Zhu et al. 2011			
Maturity ogive (logistic curve parameters)					
OTHER					
Conversion factors (length:length, length:weight) (by sex)	FL = -1.615 +0.838 TL_{nat} (n=273) FL = 0.745 +1.092 PCL (n=12657) M: Log10(Weight, kg) = -5.802 + 3.282Log10(FL) (n=1666, R^2=0.942) F: Log10(Weight, kg) = -6.196 + 3.485Log10(FL) (n=3053, R^2=0.948)	Francis & Duffy2005 Ayers et al. 2004			
Stock Delineation/Range	Equator	Sippel et al. 2011			
-Genetics	Weak or no differentiation in Pacific but can be separated into North and South stocks for management purpose	Taguchi et al. 2015			Blue sharks are caught at/near equator but at lower rates

BSH-South	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
-Tagging	NP distinct from SP, no observed crossing of equator yet	Sippel et al. 2011, Block et al. 2011, Musyl et al.2011	South stocks (Atlantic)	Carvalho et al. 2015	
Habitat Use /Env'l Preferences (temp, depth)					
Mixing Areas					
Migration					
Natural mortality					
-life history-based	0.19 yr^{-1} (M) and 0.21 yr^{-1} (F) (Hoenig's).	Manning & Francis 2005	0.26 yr^{-1} (combined)	Hazin & Lessa, 2005	
-catch curves					
Steepness					
Intrinsic rate of increase (r or λ)			r=0.34	Cortés 2002	
Intrinsic rebound potential ($r_{Z(MSY)}$)					

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Annex C. Parameters for the shortfin mako shark, *Isurus oxyrinchus* (North Pacific)

SMA-North	North Pacific Parameters (if any)		Other Regions Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0)	74 TL 74 TL M: 53 PCL; F: 57 PCL (smallest observed age-0 sharks) 59-60 cm PCL (range= 57.2-61.6) 60 cm PCL (range= 59.4 - 66.8 cm (taken from Semba et al. 2011)) ≥60.5 cm TL	Joung & Hsu 2005 Chang & Liu 2009 (cites Joung & Hsu 2005) Semba et al. 2009 Semba et al. 2011 Kai et al. 2015 Cailliet & Bedford 1983 (cites Garrick 1967)	70 TL 70 TL 60-70 TL 70-80 TL 65-75 TL 65-70 TL 90 FL M: 81 FL; F: 88 FL M: L_0 71.6 ; F: L_0 81.2; F: 88.4 (Gomp) 61 cm	Mollet et al. 2000 Cliff et al. 1990; Gilmore 1993 Duffy & Francis 2001 Pratt & Casey 1983 Bustamante et al. 2013 Groeneveld et al. 2015 Doño et al. 2015 Natanson et al. 2006 Bishop et al. 2006	
Age at zero length: t_0	-3.75 (sex combined; n=44) -4.7 (sex combined; n= 109) M: -3.77 (n= 133) F: -3.65 (n=215) M: -6.08 (n=130) -8.50	Cailliet & Bedford 1983 Ribot-Carballal et al. 2005 Hsu 2003 Chang & Liu 2009 (cites Chang (unpub. data) Semba et al. 2011	M: -9.0 ; F: -11.3 M: -3.58; F: -3.18 M: -7.52; F: -6.18	Bishop et al. 2006 Cerna & Licandeo 2009 Doño et al. 2015	Uncertain because growth parameters depend on ages assigned and band pair deposition assumption.
Age at maturity (T_{50}) (by sex)	M: 7 y; F:15 y (first maturity) M: 5.2 y; F:17.2 y	Ribot-Carballal et al. 2005 Semba et al. 2011	M: 7 years; F: 15 years (first parameter) M: 8 years; F: 18 years	Groeneveld et al. 2014 Natanson et al. 2006	Uncertain because of band pair deposition hypotheses and differences between studies

SMA-North	North Pacific Parameters (if any)		Other Regions Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	M: 6 y; F: 16 y M: 13 y; F: 19 y 7-8 years (sex combined, first maturity; n= 44) M: 13-14 (n=133); F: 17-18 (n=215)	Semba et al. 2009 Chang & Liu 2009 (cites Joung & Hsu 2005 and Chang unpublished 2006 M.S. thesis) Cailliet et al. 1983 Hsu 2003	M: 7-9 (6.9 probit), 8-9 (indirect); F: 19-21 (19.1 probit), 20-21 (indirect)	Bishop et al. 2006	
Growth coefficient (*K*) (by sex)	M: 0.056; F:0.05 (size at birth fixed for female curve) M: 0.19 ; F: 0.25 (for juveniles 0-2 ages) (n=124,575) 0.072 (sex combined; n=44) 0.05 (sex combined; n=109) M: 0.07 (n=133); F: 0.05 (n=215) M: 0.156 (n= 128); F: 0.090 (n=147)	Chang & Liu 2009 (cites Chang unpublished – Chang 2006 M.S. thesis) Kai et al. 2015 Cailliet et al. 1983 Ribot-Carballal et al. 2005 Hsu 2003 Semba et al. 2009	M: 0.087; F: 0.076 M: 0.125, F: 0.087 (3paraVBFG) M: 0.052; F: 0.013 0.113 (sex combined) M: 0.021; F: 0.035	Cerna & Licandeo 2009 Natanson et al. 2006 Bishop et al. 2006 Groeneveld et al. 2014 Doño et al. 2015	Uncertain because of band pair deposition hypotheses and differences between studies
Age at recruitment	0-1 years	Kai et al. 2015	0-1 years	Bishop et al. 2006; Francis 2013	
Maximum length ($L\infty$) (by sex) from curve	M: 274.4 cm PCL; F: 239.4cm PCL (for juvenile 0-2 ages) (n= 124,575) M: 231.3 PCL (n=128); F: 308.6 PCL (n=147) 321 TL (sex combined; n=44) 411 TL (sex combined; n=109)	Kai et al. 2015 Semba et al. 2009 Cailliet & Bedford 1983 Ribot-Carballal et al. 2005	M: 296.6 cm PCL; F: 325.29 cm PCL M: 253.3 FL; F: 365.6 FL (Gompertz) M: 302.3 FL ; F: 820.1 FL 285 FL (sex combined)	Cerna & Licandeo 2009 Natanson et al. 2006 Bishop et al. 2006 Groeneveld et al. 2014	

SMA-North	North Pacific Parameters (if any)		Other Regions Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	M: 301 cm TL (n=133); F: 403 cm TL (n=215) range= 80-375 cm TL M: 332.1 cm TL; F: 413.8 cm TL	Hsu 2003 Chang & Lui 2009 (cites Chang unpublished – Chang 2006 M.S. thesis)	M: 580 FL; F: 416 FL	Doño et al. 2015	For Doño et al. 2015: Bayesian model estimate; paper admits likely overestimate
Maximum Length (observed)	351 TL 337 TL 321 cm TL M: 296 cm TL, F: 395 cm TL 375 cm TL (sex combined; n=348, range= 80-375) F: 373 cm TL	Applegate 1977 Uchida et al. 1987(obtained via Gilmore et al. 1993) Cailliet & Bedford 1983 Compagno 2001 Hsu 2003 Lyons et al. 2015	396.2 cm TL (referenced as "they reach at least 13 ft") F: 347 cm FL; M: 270 FL F: 585 cm TL (577-619 cm)	Bigelow & Schroeder 1948; Roedel & Ripley 1950 Bishop et al. 2006 Kabaskal & De Maddalena 2011	
Longevity (observed oldest) (by sex)	M: 13+; F: 19+ (n= 275) M: 9; F: 18 (age range= 0-18, n= 109) F: 30.8; M: 23.6	Semba et al. 2009 Ribot-Carballal et al. 2005 Chang & Liu 2009 (cites Chang unpublished - Chang 2006 M.S. thesis)	21-24 years M: >29; F: >28 F: 31 M: 21; F: 38 25+	Campana et al. 2002; Campana et al. 2005 Bishop et al. 2006 Ardizzone et al. 2006 Natanson et al. 2006 Cerna & Licandeo 2009	Depends on band pair deposition Longevity may be considerably greater because of (a) failure to sample oldest sharks, and (b) potentially non-resolvable bands near centrum margin as per porbeagle
Longevity (theoretical) *Tmax*	45 years 28 years M: 31 years; F: 41 years	Cailliet et al. 1983 Smith et al. 1998 (referencing Stevens 1983; Pratt & Casey 1983; Cailliet & Bedford 1983) Chang & Liu 2009 (cites Chang unpublished – Chang	M: 29; F: 32	Natanson et al. 2006	Depends on band pair deposition

SMA-North	North Pacific Parameters (if any)		Other Regions Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
		2006 M.S. thesis multiplied by 1.3 as in Cortés 2002)			
REPRODUCTION					
Length at maturity (by sex) (L_{50})	M: 180 TL (range= 168- 209.9 cm TL, n= 148) M: 210 cm TL (range=184-213); n=498 F: 278 cm TL (range= 260-296; n= N/A M:156 cm PCL (range= 62-205 cm; n= 123); F: 256 cm PCL (range= 66-310; n= 353) M: 210 TL; F: 277 TL 182.8 TL (sex combined) M: 180 cm TL (n= 219) M: 210.1 cm TL (n= 481, range = 80-289); F: 260-283 cm TL (n=186, range= 80-375) (total n= 667)	Conde-Moreno & Galvan-Magaña 2006 Joung & Hsu 2005 Semba et al. 2011 Chang & Liu 2009 (cites Joung & Hsu 2005 and Chang unpublished – Chang 2006 M.S. thesis) Cailliet et al. 1983 Ribot-Carballal et al. 2005 Hsu 2003	M: 180 FL; 210-290 FL (est) M: 200-220 FL F: 273-298 TL M: 180-185 FL; F: 275-285 FL M: 182.9 cm TL (range= 180-185); F: 280.1 TL (range= 275-285 cm) M: 185 FL; F: 275 FL M: 180.2 TL M: 190 cm FL (n= 601); F: 250 cm FL	Maia et al. 2007 Pratt & Casey 1983 Mollet et al. 2000 Francis & Duffy 2005 Natanson et al. 2006 Bustamante & Bennett 2013 Groeneveld et al. 2014	
Gestation period (months)	9-13 23-25 23-25	Semba et al. 2011 Joung & Hsu 2005 Hsu 2003	8-10 months 15-18 18 >21 12	Mollet et al. 2000; Compagno 2001; Snelson et al. 2008 Stevens 1983; Cliff et al. 1990 Duffy & Francis 2001 Pratt & Casey 1983	

SMA-North	North Pacific Parameters (if any)		Other Regions Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Reproductive Cycle	3 years (n =11) 3 years No estimate given but authors indicate perhaps shorter than previously published 3 year estimates	Joung & Hsu 2005 Hsu 2003 Semba et al. 2011	3 years	Mollet et al. 2000	Joung & Hsu 2005 indicate that the breeding periodicity needs to be confirmed.
Spawning Period/Mating Period	Apr-Sep Jan- Jun	Semba et al. 2011 Joung & Hsu 2005	Pupping late winter to mid summer (possibly year-round), peaking in spring	Duffy & Francis 2001; Bishop et al. 2006	
Pupping Period	Jan. - Jun. Year-round Dec-July Spring	Semba et al. 2011 Kai et al. 2015 (as inferred from Stevens 1983; Cliff et al. 1990; Mollet et al. 2000; Duffy & Francis 2001; Joung & Hsu 2005; Semba et al. 2011) Joung & Hsu 2005, Uchida et al. 1987 (obtained via Gilmore et al. 1993)	late winter-midspring Nov. (May in N. Hemis.) Sep. –Feb. (Mar. –Aug. in N. Hemis) April Winter to early spring June-Nov. Spring/summer	Mollet et al. 2000 Stevens 1983; Cliff et al. 1990 Duffy & Francis 2001 Pratt & Casey 1983 Bustamante et al. 2013 Groeneveld et al. 2014 Gilmore 1993	
Litter size (mean & range)	11.1 (range 4-15; n= 22) 11.8 (range= 8-17; n= 10) 4-15 16 11.15 (range= 4-15; n= 19)	Joung & Hsu 2005 Semba et al. 2011 Chang & Liu 2009 (referencing Joung & Hsu 2005 and Hsu 2003) Uchida et al. 1987 Hsu 2003	12.5 4-25, increasing with maternal size	Mollet et al. 2000; Compagno 2001 Stevens 1983; Duffy & Francis 2001; Cliff et al. 1990; Groeneveld et al. 2014; Branstetter 1981; Gilmore 1993	Some evidence of increasing pup number with increasing female size
Embryonic sex ratio	103: 111 (n=20 litters) 1:1 (birth) (n=6 litters)	Joung & Hsu 2005, Semba et al. 2011			

SMA-North	North Pacific Parameters (if any)		Other Regions Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	1:1 (<130 kg) (n=1668)	Chang & Liu 2009 (cites Chang unpublished – Chang 2006 M.S. thesis)			
Maturity ogive (logistic curve parameters)	M: a=-26.01; b=0.17 F: a= -40.19; b= 0.16 M: a= -20.036; b= 0.095 F: a= -92.837; b= 0.335	Semba et al. 2011 Joung & Hsu 2005			
OTHER					
Conversion factors (length:length, length:weight) (by sex)	*Length: Length* All: PCL=0.816*TL+0.784 (range=80-375 cm TL; n= 1240) All: FL=0.890*TL+0.952 (range= 80-375 cm TL; n= 1236) M: PCL=2.04*DL+12.1 (n= 55) F: PCL=2.18*DL+7.79 (n= 76) All: PCL=0.84*TL-2.13 (n= 131) All: PCL=0.91*FL-0.95 (n=130) (ranges 57-187 both sexes) All: FL = 0.913*(TL)-0.397 (n= 2177) All: FL = 2.402*(AL)+9.996 (n= 3250) Unsexed: PCL = 2.13*DL + 9.38 *Length: Weight* All: Wt(kg)=1.103 x 10^{-5} $FL^{3.009}$ All: Wt(kg)=1.1 x 10^{-5} $TL^{2.95}$ (range= 80-345 cm TL; n= 612) M: Wt(kg)=2.8 x 10^{-5} $TL^{2.771}$ (n=807)	Joung & Hsu 2005 Semba et al. 2009 Wells et al. 2013 Kai et al. 2015 (using data from Semba et al. 2009) NOAA SWFSC (unpub. data) Joung & Hsu 2005 Chang & Liu 2009 (cites Chang unpublished - Chang	*Length: Length* All: FL=0.9286*TL-1.7101 All:FL= 0.973 + 0.968 CFL (n= 30; range= 113-287cm FL) All: FL= 0.766 + 1.100 PCL (n=999; range= 61-346 cm FL) All: FL= 0.821 + 0.911TL_{nat} (n= 399; range= 70-346 cm FL) CFL= -1.7101 + 0.9286 CTL (n= 199; range= 65-338 CFL) F: FL= 0.905TL + 1.345 (n=5542; range= 75-330 cm TL) M: FL=0.894TL + 2.912 (n= 5149; range= 76-285 cm TL) *Length: Weight* All: Wt(kg)=5.243 x 10^{-6} $FL^{3.141}$	Kohler et al. 1995 Cerna & Licandeo 2009 Kohler et al. 1995	ISC SHARKWG is comparing relationships to determine most plausible equations Note: DL=AL

SMA-North	North Pacific Parameters (if any)		Other Regions Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	F: Wt(kg)=1.9 x 10^{-5} $TL^{2.847}$ (n= 1137) All: FL= 0.90*TL – 0.06 (n= 1245) All: PCL= 0.82*TL + 0.01 (n= 1245) All: W= 9.1x$10^{-6}$$TL^{2.98}$ (n=612)	2006 M.S. thesis Hsu 2003			
Stock Delineation/Range					
-Genetics	Data suggest single stock of shortfin mako in the North Pacific Ocean (n=840 (Michaud et al. 2011); n= 501 mtDNA, 637 msats (Taguchi et al. 2015))	Michaud et al. 2011 Taguchi et al. 2015			Microsatellite data show no differentiation, mtDNA show N-S difference and SE-SW difference
-Tagging	NP distinct from SP, one observed crossing of equator	Sippel et al. 2011 Urbisci et al. 2013 Block et al. 2011 Bolton (2011) cited in Bruce (2014)	Regular movements among NZ, eastern Australia and islands of SW Pacific. Some longer distance recaptures from French Polynesia and Philippines	Holdsworth & Saul 2013; M. Francis (unpubl. data); P. Rogers (unpubl. data)	
Habitat Use /Env'l Preferences (temp, depth)	Mostly epipelagic >95% of time in water temps 9-25˚C, and surface to 400+ m depths	Musyl et al. 2011 NOAA SWFSC (unpub. data) Sepulveda et al. 2004	Continental shelf (especially juveniles) and open ocean	Last & Stevens 2009; Abascal et al. 2011; Loefer et al. 2005; P. Rogers (unpubl. data); Stevens et al. 2010	
Mixing Areas	Evidence of spatial segregation but not fully understood, nursery areas and mating grounds hypothesized	Sippel et al. 2015 Semba & Yokawa 2011			
Migration	Wide-ranging, seasonal migration patterns apparent but not well defined	Sippel et al. 2011 Urbisci et al. 2013 Sippel et al. 2015			
Steepness	N/A				
Intrinsic rate of increase (r or λ)	M: 1.088 (2-yr cycle)- 1.056 (3-yr) F: 1.069 (20yr)- 1.047 (3-yr) Unsexed: 1.078 (2-yr cycle); 1.053 (3-yr)	Tsai et al. 2014	0.058	ICCAT 2012 shortfin mako stock assessment and ecological risk assessment meeting	Large uncertainty because depends on band pair deposition and breeding periodicity

SMA-North	North Pacific Parameters (if any)		Other Regions Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
			0.014 and 0.074 (old animals) 1.401 0.073 0.071 0.014	ICCAT 2008, Cortés 2008 Cortés 2002 Cortés 2010 Smith et al. 1998 Takeuchi et al. 2005	
Intrinsic rebound potential ($r_{Z(MSY)}$)	N/A		$r_{1.5M}$ = 0.036	Smith et al. 2008	Uncertain because it depends on breeding periodicity and band pair deposition rate to determine age at maturity and maximum reproductive age
Natural mortality	M: 0.119-0.141 F: 0.091-0.124 M: 0.199 (range=0.093-0.200); F: 0.107 (range= 0.077-0.242) M: 0.089-0.203; F: 0.077-0.244	Tsai et al. 2014 Tsai et al. 2011 Chang & Liu 2009 (using parameter estimates from Joung & Hsu 2005, Chang unpublished and methods of Hoenig, Jensen and Peterson & Wroblewski)	0.16 0.10-0.15 0.1266 (avg)	Smith et al. 1998 Bishop et al. 2006 Takeuchi et al. 2005	Large uncertainty because it depends on band pair deposition assumption for age at maturity, longevity, growth coefficient and size at age
-life history-based	M: 0.089-0.20 /year F: 0.078-0.242 /year	Tsai et al. 2014			
-catch curves					

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Annex D. Parameters for the shortfin mako shark, *Isurus oxyrinchus* (South Pacific)

SMA-S	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
Lengths are fork length and sexes combined unless otherwise stated	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	L_0 = 61 cm N/A	Bishop et al. 2006			
Age at maturity (T_{50}) (by sex)	M: 7-9 years F: 19-21 years	Bishop et al. 2006			
Growth coefficient (K) (by sex)	N/A. Best fit model is Schnute model	See Bishop et al. 2006 for male and female Schnute parameters			
Age at recruitment	0-1 years	Bishop et al. 2006, Francis 2013			Based on length range of bycatch in New Zealand
Maximum length (observed, L_{inf}) (by sex)	F: 347 cm FL; M: 270 FL L_{inf} N/A	Bishop et al. 2006 See Bishop et al. 2006 for male and female Schnute model parameters			For further information from outside the South Pacific see Annex C above
Longevity (T_{max}) (by sex)	M: > 29 years F: > 28 years	Bishop et al. 2006			Longevity may be considerably greater because of (a) failure to sample oldest sharks, and (b) potentially non-resolvable bands near centrum margin as per porbeagle
REPRODUCTION					
Length at maturity (by sex) (L_{50})	M: 180-185 cm F: 275-285 cm	Francis & Duffy 2005			
Gestation period	N/A				For further information from outside the South Pacific see Annex C above
Reproductive Cycle	N/A				For further information from outside the South Pacific see Annex C above
Spawning Period/Mating Period	Pupping late winter to mid summer (possibly year-round), peaking in spring	Duffy & Francis 2001, Bishop et al. 2006			For further information from outside the South Pacific see Annex C above
Litter size (mean & range)	N/A				For further information from outside the South Pacific see Annex C above

SMA-S	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
Lengths are fork length and sexes combined unless otherwise stated	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Embryonic sex ratio	N/A				For further information from outside the South Pacific see Annex C above
Maturity ogive (logistic curve parameters)	N/A				
OTHER					
Conversion factors (length:length, length:weight) (by sex)	Length:length Numerous regressions available Length:weight Log_{10}Weight= -4.622 +2.847 log_{10}FL (N = 1016)	Francis 2006, Ayers et al. 2004		Cerna & Licandeo 2009	SE Pacific FL vs TL regressions (by separate sex) have very large sample sizes. Although they have not been listed here they may be applicable to the SW Pacific stock.
Stock Delineation/Range	Worldwide in tropical and warm temperate waters (but avoids equatorial regions?)	Last & Stevens 2009			
-Genetics	Separate stocks in Atlantic, North Pacific, SW Pacific and SE Pacific	Michaud et al. 2011			
-Tagging	Regular movements among NZ, eastern Australia and islands of SW Pacific. Some longer distance recaptures of NZ sharks from French Polynesia and Philippines	Sippel et al. 2011, Holdsworth & Saul 2013, M. Francis (unpubl. data), P. Rogers (unpubl. data)			
Habitat Use /Env'l Preferences (temp, depth)	Continental shelf (especially juveniles) and open ocean	Last & Stevens 2009, M. Francis (unpubl. data), P. Rogers (unpubl. data)			
Mixing Areas	N/A				
Migration	N/A				
Natural mortality					
-life history-based	0.10-0.15	Bishop et al. 2006			
-catch curves					
Steepness	N/A				
Intrinsic rate of increase (r or λ)	N/A				
Intrinsic rebound potential ($r_{Z(MSY)}$)	N/A				

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Annex E. Parameters for the longfin mako shark, *Isurus paucus*

LMA	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
Lengths are total length. Sexes combined unless otherwise stated	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	L_0 = 97-120 cm N/A	Compagno 2001, Snelson et al. 2008			
Age at maturity (T_{50}) (by sex)	N/A				
Growth coefficient (K) (by sex)	N/A				Branstetter 1990 suggested similar-sized *I. oxyrinchus* and *I. paucus* have similar numbers of vertebral band pairs
Age at recruitment	0-1 years	Coelho et al. 2012			Based on length range of bycatch in Atlantic
Maximum length (observed, L_{inf}) (by sex)	L_{max} = 417 cm L_{inf} N/A	Compagno 2001			
Longevity (T_{max}) (by sex)	N/A				
REPRODUCTION					
Length at maturity (by sex) (L_{50})	M: Between 205 cm and 215 cm F: about 245 cm	Compagno 2001, Queiroz et al. 2006, White 2007, Snelson et al. 2008, Last & Stevens 2009			
Gestation period	N/A				
Reproductive Cycle	N/A				
Spawning Period/Mating Period	Pupping possibly in winter	Gilmore 1993			Very small sample size and poorly determined
Litter size (mean & range)	2-4 (usually 2)	Snelson et al. 2008			
Embryonic sex ratio	N/A				
Maturity ogive (logistic curve parameters)	N/A				
OTHER					
Conversion factors (length:length, length:weight) (by sex)	N/A				
Stock Delineation/Range	Worldwide in tropical and warm temperate waters	Last & Stevens 2009			
-Genetics					

LMA	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
Lengths are total length. Sexes combined unless otherwise stated	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
-Tagging	Maximum distance travelled by 5 tagged and recaptured sharks in the NW Atlantic was 3420 km; another travelled 1590 km	Kohler et al. 1998, Kohler & Turner 2001			Very small sample size[2]
Habitat Use /Env'l Preferences (temp, depth)	Epipelagic, possibly mesopelagic in deep water. Observed from a submersible at 760 m	Clark & Kristoff 1990, Compagno 2001			
Mixing Areas	N/A				
Migration	N/A				
Natural mortality	N/A				
-life history-based					
-catch curves					
Steepness	N/A				
Intrinsic rate of increase (r or λ)	N/A				
Intrinsic rebound potential ($r_{Z(MSY)}$)	N/A				

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[2] This applies to all fields in the table.

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Annex F. Parameters for the silky shark, *Carcharhinus falciformis*

FAL	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	Length at birth 65-81 cm TL Embryos recorded up to 80 cm TL (n= 20 litters) Embryos recorded up to 53 cm FL (66.5 cm TL*) (n= 28 litters). Length at birth 63.5–75.5 cm TL (n= 4 litters). t0= −2.761 (combined sex) (n= 250, size range used to estimate BVGF not provided but at least up to 256 cm TL) Length at birth 48-60 cm PL(65-81 cm TL**) (n=153 litters) t0= -1.76 yrs (combined sex) (n=298, size range not provided for BVGF estimation, probably from 48-216 cm PCL, 65-288 cm TL**) t0 = -2.98 (combined sex) (n=145, size range 88-260 cm TL for VBGF estimation)	Bonfil 2008 Hoyos-Padilla et al. 2012 García-Cortés et al. 2011 Joung et al. 2008 Oshitani et al. 2003 Sánchez de Ita et al. 2011.			In general low number of pregnant females is reported in reproductive studies. Variability in reproductive parameters probably related to biological variation rather than uncertainty.
Age at maturity (T_{50}) (by sex)	5-6 years males 6-7 years females 9.3 years males 9.2–10.2 years females	Oshitani et al. 2003 Joung et al. 2008	15 years for females and 13 years for males.	Hall et al. 2012	Age not validated directly to date. Hall et al. (2012) is for the Indian Ocean

FAL	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Growth coefficient (K) (by sex)	0.148 (combined sex) (n=298, size range used to estimate VBGF not provided, probably from 48-216 cm PCL, 65-288 cm TL**)	Oshitani et al. 2003			Vertebrae of individuals from different regions in Oshitani et al. 2003, therefore it is possible that samples represent a mix of two stocks.
	0.14 (combined sex) (n=145, size range used to estimate VBGF 88-260 cm TL)	Sánchez de Ita et al. 2011			
	0.08 (combined sex) (n= 250, size range used to estimate BVGF not provided but at least to 256 cm TL)	Joung et al. 2008			
			0.09 (combined sex)	Soriano-Velásquez et al. 2006	Sample size and size range used unknown
			0.099 (combined sex) (n= 21, size range 50-157 cm TL)	Cruz-Jiménez et al. 2014	Low sample size, growth parameter based in backcalculated lengths-at-age.
			0.066 (combined sex) (n= 200).	Hall et al. 2012	Indian Ocean
Age at recruitment					Unknown, but in several fisheries caught shortly after they are born.
Maximum length (observed, L_{inf}) (by sex)	Observed= 330 cm TL	Compagno 1984	320 cm TL	Soriano-Velásquez et al. 2006	Sample size and size range used unknown (Soriano-Velásquez et al. 2006).
	L_{inf} 216.4 cm PL (288 cm TL**) (combined sex) (n=298, size range range used to estimate VBGF not provided, probably from 48-216 cm PCL, 65-288 cm TL**)	Oshitani et al. 2003	L_{inf} 240 cm TL (combined sex) (n=145, size range 88-260 cm TL)	Sánchez de Ita et al. 2011	Linf low related to the low maximum size sampled in Sánchez de Ita et al. 2011
	332.0 cm TL (combined sex) (n= 250, size range used to estimate BVGF not provided but	Joung et al. 2008	Linf 258 cm TL (combined sexe) (n= 21, size range 50-157 cm TL)	Cruz-Jiménez et al. 2014.	Low sample size, growth parameter based in backcalculated lengths-at-age in Cruz-Jiménez et al. 2014

FAL	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	at least to 256 cm TL)		Linf 2994 mm TL (combined sexes) (n=200)	Hall et al. 2012	Indian Ocean
Longevity (T_{max}) (by sex)	Maximum number of growth bands observed: 8 years males 13 years females 14 years males 16 years females 11 years females 14 years males	Oshitani et al. 2003 Sánchez de Ita et al. 2011 Joung et al. 2008	30 years 32 years 19 growth band pairs females 20 growth band pairs males	Soriano-Velásquez et al. 2006 Cruz-Jiménez et al. 2014 Hall et al. 2012	The maximum length of sampled individuals is relatively low in most studies. Age has not been validated directly. Oshitani et al.2003 may have mixed data from both Pacific stocks. Not clear how maximum age was estimated. (Soriano-Velásquez et al. 2006) Estimated maximum age from maximum reported length in Cruz-Jiménez et al. 2014. Indian Ocean
REPRODUCTION					
Length at maturity (by sex) (L_{50})	Males L50= 182 (180-182 95%CI) cm of TL (n= 116). Mature females with oviducal glands width of 20-40 mm at 180 cm TL, L50=180 (179-180 95% CI) cm of TL (n=179). WC Pacific females 202-218 cm TL, males 210-214 cm TL. E Pacific both sexes 180 cm TL. Females mature at 145-150 cm PCL (193-200 cm TL**), males at 135-140 (180-187 cm TL**) Males L50= 212.5 cm TL and females L50= 210–220 cm TL	Hoyos-Padilla et al. 2012 Bonfil 2008 Oshitani et al. 2003 Joung et al. 2008			In Hoyos-Padilla 2012 the upper confidence intervals are similar to the L50s; this should be reviewed.

FAL	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
			2156 mm for females and 2076 for males	Hall et al. 2012.	Indian Ocean
Gestation period	12 months 11-12 months	Bonfil 2008 Hoyos-Padilla et al 2012			Not clear how the period was estimated if the reproductive cycle is asynchronic.
Reproductive Cycle	Probably two years (one year of pregnancy and a resting year).	Bonfil 2008. Hoyos-Padilla et al. 2012.			Low sampling number of pregnant females in several studies and large variability prevent a good estimation of the reproductive periodicity. Unpublished studies showed that the ovocites size in females with full term embryos support the hypothesis that the cycle is not annual, However, vitellogenic ovocites growth rates also indicate it might take less than one complete year to reach their ovulation size after parturition. Thus the cycle might be between 1-2 years (Cadena-Cárdenas 2001 Ortíz-Pérez 2011 Galván-Tirado 2007).
Spawning Period/Mating Period	No season defined, but the ripe season of parturition might occur from May to July No seasonal cycle.	Oshitani et al. 2003 Bonfil 2008.	In the central Pacific parturition from February to August.	Bonfil 2008	
Litter size (mean & range)	2-9(average 5) (n=20 pregnant females). Up to 16 (commonly 6-12). Maternal size positively correlated with litter size). 2-18 (Average 5.5). Litter	Hoyos-Padilla et al. 2012. Bonfil 2008 Bonfil 2008. García-Cortés et al. 2011	2-14 (average= 7.2)	Hall et al. 2012	Indian Ocean (Hall et al. 2012)

FAL	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	size=b-18.5709+0.143531*FL (P<0.01) (n= 28 pregnant females) 1-16 (Average= 6.2), Litter size=0.098*PCL-8.600 (r2=0.256, n=153) 8–10 (n=36 embryos in 4 litters)	 Oshitani et al. 2003 Joung et al. 2008			
Embryonic sex ratio	1:1 (P > 0.05) (n=36 embryos in 4 litters) 1:1.06 (n=153 embryos)	Joung et al. 2008 Oshitani et al. 2003			
Maturity ogive (logistic curve parameters)	P=1/(1+e29.264−0.138TL) (n = 256, p < 0.01) (Males)	Joung et al. 2008			
OTHER					
Conversion factors (length:length, length:weight) (by sex)	TL=2.08+1.32PCL (r2=0.99, n=84, range size 48-148 cm PCL, 65-197 cm TL **) FL=1.09+1.03PCL (r2=0.98, n=362, range size 48-184 cm PCL, 65-245 cm TL**) FL = 1.09PCL + 1.10 (r2 = 0.99, n = 469), TL = 1.21FL + 2.36 (r2 = 0.98, n = 469) TL = 1.31PCL + 3.64 (r2 = 0.98, n = 469), W= 2.92×10−6 TL3.15 (n = 469, p < 0.01).	Oshitani et al. 2003 Joung et al .2008			
Stock Delineation/Range					
-Genetics	Low but significant evidence of two stocks in the Pacific Ocean: eastern (EPO) and western	Galván-Tirado et al. 2013	Both stocks probably divided by the Pacific Islands	Bonfil 2008	
-Tagging					Most of the tagging studies have been undertaken in the Atlantic (Bonfil 2008); tagging studies are needed for the Pacific

FAL	Pacific Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Habitat Use /Env'l Preferences (temp, depth)	Tropical, up to 23 C Up to 500 m, occasionally recorded at 18 m, mosty between 23-24 C	Last & Stevens 2009 Compagno 1984			
Mixing Areas	Sexual segregation in the Pacific	Strasburg 1958			No recent studies.
Migration	Migrations recorded from equator to high latitudes during summer in the Pacific	Strasburg 1958			No recent studies.
Natural mortality					
-life history-based	M= 0.179 M= 0.26	Smith et al. 1998 Furlong-Estrada et al. 2014			
-catch curves					
Steepness					
Intrinsic rate of increase (*r* or λ)	r= 0.163 14% annual growth during 2006-2010 and 33% during 2009-2010	Soriano-Velásquez et al. 2006 Aires-da-Silva et al. 2014	0.048 0.063	Beerkircher et al. 2003 Cortés et al. 2010	Aires-da-Silva et al. 2014 suggest the rate of increase 2009-2010 is too big and might be related to other factors Atlantic Atlantic
Intrinsic rebound potential ($r_{Z(MSY)}$)	0.043	Smith et al. 1998			

*TL converted with Joung et al 2008 equation.
**TL converted with Oshitani et al. 2003 equation.

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Annex G. Parameters for the oceanic whitetip shark, *Carcharhinus longimanus*

OCS	Pacific Parameters		Parameters from Other Oceans		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth, observed	45-55 PCL (63-77 TL)[3] 64 TL 54-64 (mean 59) TL	Seki et al. 2008 Chen 2006 in Liu & Tsai 2011 Stevens 1984	70 TL 65 TL 50-66 TL	Cortés 2008 Branstetter 1990 White 2007	
Length at birth, estimated (L_0, or Age at zero length: t_0)	-2.698 (t_0)	Seki et al. 1998 (n=111 (M), PCL 54-172 cm; n=114 (F), PCL 50-195 cm)	-3.342 (t_0 backcalculated) -3.391 (observed)	Lessa et al 1999 (n=110)	
Age at maturity (T_{50}) (by sex)	4-5 yrs (estimated from VBGF) 8.23 (estimated from VBGF)	Seki et al. 1998 (n=111 (M), PCL 54-172 cm; n=114 (F), PCL 50-195 cm) Chen 2006 in Liu & Tsai 2011 (n=112)	7-8 yrs (estimated from backcalculated VBGF) 6-7 yrs (estimated from the VBGF) 6.5(5-8) (estimated from the VBGF) 4.5 (3-6) (method unknown)	Lessa et al. 1999 (n=110) Cortés 2008 Cortés 2002	
Growth coefficient (K) (by sex)	0.103 (M&F, VBGF) 0.04-0.09	Seki et al. 1998 (111 M, PCL 54-172 cm; 114 F, PCL 50-195 cm) Saika & Yoshimura 1985 in Branstetter 1990	0.075 (backcalculated) 0.099 (observed)	Lessa et al. 1999 (n=110)	
Age at recruitment					
Maximum length (observed, L_{inf}) (by sex)	245 PCL (342 TL)[4]	Seki et al. 2008 (n=225)	272 TL	Cortés 2002, 2008	

[3] TL=1.397PCL
[4] Ibid.

OCS	Pacific Parameters		Parameters from Other Oceans		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	251 TL (M) 266 TL (F) 268 TL (M)	Stevens 1984 (n=3 (M), n=17(F)) Chen 2006 in Liu & Tsai 2011 (n=112)	261 TL (F) 245 TL (M) 275+ TL 285 TL (observed) 325 TL (backcalc)	White 2007 (n=16 (F), n=15 (M)) Branstetter 1990 Lessa et al 1999 (n=110)	
Longevity (T_{max}) (by sex)	11 yrs 36 yrs (estimated from a growth model of Seki et al. 1999)	Seki et al. 2008 (n=225) Rice 2012	17 yrs	Lessa et al 1999 (n=110)	17 yrs appears to be the most reasonable value
REPRODUCTION					
Length at maturity (by sex) (L_{50})	M: 120-140 PCL (168-196 TL)[5] F: 125-135 PCL (175-189 TL 195 TL F: 200 TL	Seki et al. 1998 (n=136 (M); n=85 (F)) Chen 2006 in Liu & Tsai 2011 (n=112) Stevens 1984 (n=17)	M: 160-196TL F: 181-203 TL 180-190 TL (both sexes) F: 170 TL M: 170-190 TL	Coelho et al. 2009 (n=57 (M), n=47 (F)) Lessa et al. 1999 (n=110) Tambourgi et al. (2013) (n=118 (F), n=116 (M))	
Gestation period	9 mo. (Pacific) 12 mo.	Bonfil et al. 2008 Chen 2006 in Liu & Tsai 2011	10-12 mo	Coelho et al. 2009 (n=47)	
Reproductive Cycle	Every year	Chen 2006 in Liu & Tsai 2011	Every other year Resting period of 12 mo.	Tambourgi et al 2013 (n=6) Backus (1956) and Seki et al. (1998) in Snelson 2008	most data suggest a resting period of one year
Spawning Period/Mating Period	North Pacific: ovulation June-July Parturition Feb-July;	Seki et al. 1998 (n=85 (F))			need better data for the South Pacific; inconsistencies in timing may be due to regional variation or to a

[5] TL=1.397PCL

OCS	Pacific Parameters		Parameters from Other Oceans		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	South Pacific: ovulation in November North Pacific: parturition in summer Mating Mar-May; Part. Jan-Mar	 Saika & Yoshimura 1985 Stevens 1984			naturally plastic reproductive seasonality
Litter size (mean & range)	6.2 (1-14); mode=5 (Litter size=0.0502PCL-1.52)(North Pacific) 5.5 (1-12) (South Pacific) 10 3-14 (mean 8) 4-8 (6.8)	Seki et al. 1998 (n=97) Seki et al. 1998 (n="small") Chen 2006 in Liu & Tsai 2011 (n=2) Saika & Yoshimura 1985 (n=8) Stevens 1984 (n=5)	12-16 1-14 (9.6) 1-10 (6)	Branstetter 1990 Coelho et al 2009 (n=3) Tambourgi et al. 2013 (n=6)	
Embryonic sex ratio	1:1 1M:1.04F	Seki et al 1998 (n=97, North Pacific only) Saika & Yoshimura 1985	1M:1.8F	Tambourgi et al. 2013 (n=28 from 6 females)	
Maturity ogive (logistic curve parameters)					
MORTALITY					
OTHER					
Conversion factors (length:length, length:weight) (by sex)	TL=1.397PCL $W=3.0778x10^{-5}xPCL^{2.86}$ (M)	Seki et al 1998 (estimated from Bass et al. 1973) Seki et al 1998 (n=133)	TL:1.13477FL+12.53738	ICCAT 2014	

OCS	Pacific Parameters		Parameters from Other Oceans		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	$W=5.076x10^{-5}xPCL^{2.761}$ (F) $W=1.66*10^{-5}xTL^{2.819}$ $W=1.405*10^{-7}L^{3.72}$	Seki et al 1998 (n=128) Chen 2006 in Liu & Tsai 2011 (n=188) Stevens 1984 (n=17)			
Stock Delineation/Range					
-Genetics					
-Tagging					
Habitat Use /Env'l Preferences (temp, depth)	0-152m; Usually >20^{o}C; Tropical, common from 20N-20S; prefers open water Found 30N-35S Found <50m and >25^{o}C day and night	Bonfil et al. 2008 Francis 2014 Musyl et al. 2011	Rarely deeper than 150m; 24-26C	Carlson & Gulak 2012	
Mixing Areas	Pupping in FSM-RMI-Kiribati (140W-150E, 10N)	Bonfil et al. 2008			
Migration	2314 nmi (4286 km)	Musyl et al. 2011			
Natural mortality	0.10-0.26 (0.18)	Rice 2012 (based on Cortés 2002)			
-life history-based					
-catch curves					
Steepness	0.342-0.489 (0.409)	Rice 2012			
Intrinsic rate of increase (*r* or λ)			r=0.067 (0.028-0.112)[6] r=0.094 (0.06-0.137) r=0.111 (0.038-0.197) r=0.15 (0.12-0.18)	Cortés 2008 Cortés et al. 2010 Cortés et al. 2002 Murua et al. 2012	Cortés (2010) appears to be the most reasonable value ; Murua et al. (2012) may not be as reliable because it used a mix of Atlantic and Indian Ocean values as inputs
Intrinsic rebound potential ($r_{Z(MSY)}$)	0.081	Smith et al 1998			

[6] Estimates represent the approximate maximum biologically possible limit at low population densities.

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Annex H. Parameters for the bigeye thresher shark, *Alopias superciliosus*

BTH	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	From VB (t_0): F: -4.21; M: -4.24; Obs (Chen et al 1997): 135-140 cm TL Obs (Gilmore): 100-105 cm TL;	Liu et al 1998 Chen et al 1997 Gilmore 1993	from VB (L_0): F= 111 cm FL M=93 cm FL	Fernandez-Carvalho et al 2011	
Age at maturity (T_{50}) (by sex)	F:12.3-13.4 yrs M: 9-10 yrs	Liu et al 1998			
Growth coefficient (K) (by sex)	F: 0.092; M: 0.088	Liu et al 1998	F: 0.06 M: 0.18	Fernandez-Carvalho et al 2011	Liu (1998): Ages estimated from vertebrae and verified with LFA; N=321 (N_F=214; N_M=107) Fernandez-Carvalho et al (2011) from tropical NE Atlantic (N=117)
Age at recruitment					
Maximum asymptotic length (observed, L_{inf}) (by sex)	L_{inf} F: 224.6 cm PCL; M: 218.8 cm PCL	Liu et al 1998	Linf: F = 293 cm FL (265.2cm PCL)[7] M = 206 cm FL (182.4cm PCL)[8]	Fernandez-Carvalho et al 2011	Liu et al (1998) Ages estimated from vertebrae and verified with LFA; N=321 (N_F=214; N_M=107) Fernandez-Carvalho et al (2011) (N=117)
Maximum observed age Longevity (T_{max}) (by sex)	Estimated for the largest observed size: F: 21; M: 20	Liu et al 1998	Maximum observed age F: 22; M: 17	Fernandez-Carvalho et al 2011	
REPRODUCTION					
Length at maturity (by sex) (L_{50})	F: 332-341.1 cm TL; M: 270.1-287.6 cm TL	Chen et al 1997	M: between 279.0-283.0 TL F: < 350.1 TL	White 2007 (Indian Ocean)	Chen et al. (1997) from ogives; White (2007) from observations

[7] TL=15.3+1.81*PCL; TL=13.3+1.69*FL (Liu et al. 1998)
[8] Ibid.

BTH	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Gestation period	Could not be determined as most adult females are pregnant throughout the year	Chen et al 1997			
Reproductive Cycle					
Spawning Period/Mating Period	No fixed mating or birthing season	Chen et al 1997			
Litter size (mean & range)	2	Chen et al 1997	2	White 2007 (Indian Ocean)	
Embryonic sex ratio	1:1	Chen et al 1997			
Maturity ogive (logistic curve parameters)					
OTHER					
Conversion factors (length:length, length:weight) (by sex)	Females: TL=15.3+1.81PCL TL=13.3+1.69FL $W=6.87x10^{-5}PCL^{2.769}$ $W=1.02x10^{-5}TL^{2.78}$ Males: TL=15.1+1.76PCL TL=26.3+1.56FL $W=9.93x10^{-5}PCL^{2.685}$ $W=3.73x10^{-5}TL^{2.57}$	Liu et al. 1998	Females: TL=1.75xFL-3.20 TL=1.75xPCL-4.96 Males: TL=1.62xFL+164.74 TL=1.70xPCL+192.31 FL=0.5598TL+17.666 $W=9.1069*10^{-6}FL^{3.0802}$	White 2007 (Indian Ocean) Kohler et al. 1995 (NW Atl)	White 2007 had a low sample size (N<=16)
Stock Delineation/Range					
-Genetics	Non-significant differentiation between Indo-Pacific and Atlantic	Trejo 2005			Trejo 2005: Small sample size (N=64); used mitochondrial DNA control region
-Tagging					
Habitat Use /Env'l Preferences (temp, depth)	Strong diel movement: Day: 200-500m deep; Night: 80-130m deep Strong diel movement: Day: 400-500m deep; Night: 10-50m deep	Nakano et al. 2003 Weng & Block 2004; Musyl et al. 2011	Day time: 240-360m deep; 10-16.8C temp	Cao et al 2011	Nakano (acoustics): Low sample size (N=2), short-term study (72h), only tagged juveniles Weng & Block (PSATs): Low sample size (N=2) Cao et al (Fishery): Data from fishery and dependent on hooks setting depth

BTH	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Mixing Areas					
Migration	Parturition and nursery grounds in the North Pacific proposed at 10N-15N / 150–180 W	Matsunaga & Yokawa 2013			
Natural mortality					
-life history-based	M=0.223	Smith et al 2008		Hoenig equation	
-catch curves					
Steepness					
Intrinsic rate of increase (*r* or λ)	Lambda 0.996 (0.978–1.014)	Cortés 2002 (NW Pacific)	*r* 0.009 (-0.001, 0.018)	Cortés et al. 2012 (Atlantic)	
Intrinsic rebound potential ($r_{Z(MSY)}$)	$r_{z(MSY)}$=0.016	Smith 2008		NW Pacific and NW Atl; considering $z_{(MSY)}$=1.5M	

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Annex I. Parameters for the pelagic thresher shark, *Alopias pelagicus*

PTH	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	Observed: 158-190 TL; From VB: F: -7.67; M: -5.48	Liu et al 1999	Obs: 130-144 TL	White 2007	Liu et al 1999 estimated from VB and observed White 2007 observed
Age at maturity (T_{50}) (by sex)	F: 8.0-9.2 yrs; M: 7.0-8.0 yrs	Liu et al 1999			Estimated from observations
Growth coefficient (K) (by sex)	F: 0.085; M: 0.118	Liu et al 1999	Sex.comb k = 0.12	Drew et al 2015 (Indonesia)	Liu et al 1999 Sample size N=269 (N_F=155; N_M=114) Drew et al 2015 N=158 Range = 140.0–325.2cm TL
Age at recruitment					
Maximum asymptotic length (observed, L_{inf}) (by sex)	F: 197.2 cm PCL; M: 182.2 cm PCL	Liu et al 1999	Sex.comb 328.1cm TL (167.1cm PCL)[9]	Drew et al 2015 (Indonesia)	Liu et al 1999 Sample size N=269 (N_F=155; N_M=114) Drew et al 2015 N=158 Range = 140.0–325.2cm TL
Longevity (T_{max}) (by sex)	F: 16 yrs; M: 14 yrs F: 28.5 yrs; M: 17.5 yrs	Liu et al 1999 Liu et al 1999			Max obs ages Extrapolated from growth rates to the largest sizes

[9] M:TL=2.33+1.89*PCL; F: TL=2.34+1.93*PCL (Liu et al. 1999)

PTH	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
REPRODUCTION					
Length at maturity (by sex) (L_{50})	Taiwan: F: 282-292 cm TL M: 267-276 cm TL (Ecuador): F: 151.4 cm PCL M: 144.3 cm PCL	Liu et al 1999 Romero-Caicedo 2014	Indonesia F: 285.3 (276.4-290.0) TL; M: 264.8 (260.1-268.5) TL;	White 2007	Liu et al 1999: Estimated from observations N_M=323 N_F= 508 White 2007 N_F=287; F_{range}=152.1-326.0 TL; N_M=217; M_{range}=130.9-324.0 Romero-Caicedo 2014 N_F=140; F_{range}=70-180 cm PCL; N_M=101; M_{range}=68-183 cm PCL
Gestation period	Pregnancy period is close to 9 months	Romero-Caicedo 2014			
Reproductive Cycle			Cycle without seasonality	White 2007	
Spawning Period/Mating Period					
Litter size (mean & range)	2	Liu et al 1999; Romero-Caicedo 2014	2	White 2007	
Embryonic sex ratio	1:1	Liu et al 1999; Romero-Caicedo 2014	1:1	White 2007	
Maturity ogive (logistic curve parameters)					
OTHER					
Conversion factors (length:length, length:weight) (by sex)	Liu et al 2006: $W=2.25*10^{-4}*PCL^{2.533}$ Females: TL=2.34+1.93PCL $W=1.59x10^{-4}PCL^{2.613}$ $W=4.61x10^{-5}TL^{2.494}$ Males: TL=2.33+1.89PCL $W=1.96x10^{-4}PCL^{2.562}$ $W=3.98x10^{-5}TL^{2.52}$ Males: TL=18.044+1.7362PCL	Liu et al 2006 Liu et al. 1999 Romero-Caicedo 2014	Sex comb: TW = $4.0x10^{-7}$TL3.217 Females: TL=1.72xFL+333.36 TL=1.98xPCL+195.58 Males: TL=1.85xFL+123.12 TL=2.05xPCL+101.71	White 2007	

PTH	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	Females: TL=23.009+1.7146PCL				
Stock Delineation/Range					
-Genetics	Genetic separation between East and West Pacific	Trejo 2005; Cardeñosa et al. 2014			Trejo 2005: Small sample size (N=91); used mitochondrial DNA control region
-Tagging					
Habitat Use /Env'l Preferences (temp, depth)					
Mixing Areas					
Migration					
Natural mortality					
-life history-based	M_0.132 M=0.155	Liu et al 2006 Smith et al 2008		Hoenig equation	
-catch curves	Z from length-converted catch curves: 0.208-0.277 $year^{-1}$.	Liu et al 2006			
Steepness					
Intrinsic rate of increase (*r* or λ)	Lambda (CI): Without F: 1.058 (1.014–1.102); Current F: 0.979 (0.921–1.030). Lambda (CI) 1.020 (1.001–1.041)	Tsai et al 2010 Cortés 2002			
Intrinsic rebound potential ($r_{Z(MSY)}$)	$r_{z(MSY)}$=0.024	Smith 2008		NW Pacif; considering $z_{(MSY)}$=1.5M	

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Annex J. Parameters for the common thresher shark, *Alopias vulpinus*

ALV	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	Smith (est VB) t_0=-2.88 Gilmore (obs. size at birth): 111-149 cm TL Cailliet & Bedford (est, from VBGF): 158 cm TL	Smith et al 2008a Gilmore 1993 Cailliet & Bedford 1983	t0= −4.82	Gervelis & Natanson 2013 (NW Atl)	Cailliet & Bedford mention their L_0 from VB is probably overestimated Gervelis & Natanson 2013 Only have t0 for females
Age at maturity (T_{50}) (by sex)	Smith Sex combined: ~5 yrs Cailliet & Bedford: Sex-combined: 3-7 years	Smith et al 2008a Cailliet & Bedford 1983			
Growth coefficient (*K*) (by sex)	Sex combined: 0.129 Sex combinded: 0.108	Smith et al 2008a Cailliet & Bedford 1983	M: 0.215 F: 0.158 M=0.17 F=0.09	Cailliet & Bedford 1983 Gervelis & Natanson 2013 (NW Atl)	<u>Smith et al 2008a</u> Also present sex-specific parameters but have many undetermined sexes so preferable to use combined sexes <u>Cailliet & Bedford 1983</u> Sample size per sex very small (N_M=16; N_F=23) (unk sexes), so preferable to used combined sexes (N=143) Gervelis & Natanson 2013 NF=173 NM=135 Range= 56-264 cm FL. Vertebral band pairs assumed to be deposited annually.
Age at recruitment					

ALV	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Maximum asymptotic length (observed, L_{inf}) (by sex)	Sex combined: 465cm TL Sex combined: 650.9 cm TL	Smith et al 2008a Cailliet & Bedford 1983	M: 492.7 cm TL F:636.0 cm TL M=225.4 cm FL (404.7cm TL)[10] F=274.5 cm FL (494.4cm TL)[7]	Cailliet & Bedford 1983 Gervelis & Natanson 2013 (NW Atl)	Smith et al 2008a Also present sex-specific parameters but have many undetermined sexes so preferable to use combined sexes Cailliet & Bedford 1983 Sex-specific sample small (N_M=16; N_F=23), so preferable to used combined sexes (N=143) Gervelis & Natanson 2013 NF=173 NM=135 Range= 56-264 cm FL. Vertebral band pairs assumed to be deposited annually.
Longevity (T_{max}) (by sex)	Max F ages = 25 yrs Max est ages = 15 yrs	Smith et al 2008a Cailliet & Bedford 1983	Max est ages: M=22 F=24	Gervelis & Natanson 2013 (NW Atl)	
REPRODUCTION					
Length at maturity (by sex) (L_{50})	Combined sex: ~303cm TL M: 330 cm TL F: 260-315 cm TL	Smith et al 2008a Cailliet & Bedford 1983	M=188 cm FL (181-198 cm FL) F=216 cm FL (208-224 cm FL)	Natanson & Gervelis 2013 (NW Atl)	Natanson & Gervelis 2013 N_M=130 N_F=256
Gestation period					
Reproductive Cycle	Annual	Cailliet & Bedford 1983			
Spawning Period/Mating Period			Parturition from late spring to late summer	Natanson & Gervelis 2013 (NW Atl)	
Litter size (mean & range)	4 pups	Cailliet & Bedford 1983	Mean=3.7 SE=0.26 N=12	Natanson & Gervelis 2013 (NW Atl)	
Embryonic sex ratio			1:1	Natanson & Gervelis 2013 (NW Atl)	

[10] Combined sexes: FL=0.5474TL+7.0262 (S. Kohin, pers. comm.)

ALV	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Maturity ogive (logistic curve parameters)					
OTHER					
Conversion factors (length:length, length:weight) (by sex)	FL=0.533TL-1.2007 FL=2.3627AL + 16.82	S. Kohin (pers. comm.)	FL=0.5474TL+7.0262 $W=1.8821*10^{-4}FL^{2.5188}$	Kohler et al. 1995 (NW Atl)	
Stock Delineation/Range					
-Genetics	Genetic heterogeneity between Indo-Pacific and Atlantic	Trejo 2005			<u>Trejo 2005:</u> Small sample size (N=108); used mitochondrial DNA control region
-Tagging					
Habitat Use /Env'l Preferences (temp, depth)	<u>Cartamil (2011) (archival)</u> Mostly in shallow waters (15-20m deep), with occasional deep dives to >200m during the day <u>Cartamil (2010a,b) (acoustics)</u> Day: vertical movements with vertical excursions below the thermocline; Night: sharks remain within the mixed layer.	Cartamil et al. 2011 Cartamil et al. 2010a,b	<u>Cao et al 2011 (fishery catches):</u> Day time: 120-240m deep; 18-20C temp	Cao et al 2011	Cartamil 2011: Low sample size (Nrecovered=5); Cao et al 2011: Data from fishery that is dependent on the hooks setting depth
Mixing Areas					
Migration					
Natural mortality					
-life history-based	M=0.176	Smith et al 2008b (NE Pacific)		Hoenig equation	
-catch curves					
Steepness					
Intrinsic rate of increase (*r* or λ)	Lambda: 1.125 (1.078–1.178)	Cortés 2002 (NE Pacific)			
Intrinsic rebound potential ($r_{Z(MSY)}$)	$r_{z(MSY)}$=0.037	Smith et al 2008b (NE Pacific)		NE Pacif; considering $z_{(MSY)}$=1.5M	

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Annex K. Parameters for the porbeagle, *Lamna nasus*

POR (southern population only)	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
Fork length used throughout. Sexes combined unless otherwise stated	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	L_0: 58-67 cm t_0: M: -4.22 F: -6.10	Francis & Stevens 2000, Francis (unpubl. data) Francis 2015	t_0: M: -4.75 F: -6.86	Francis et al. 2007	Few embryos and juveniles in overlap range Vertebral band pairs difficult to count and they disappear at margin in older sharks. Ages > 20 under-estimated. Francis (2015) used a different interpretation of band pairs (grouping those regarded as separate by Francis et al. 2007) resulting in growth curves shifted left by 1-2 years. Both interpretations are consistent with bomb radiocarbon dating as the latter is not precise enough to distinguish the two.
Age at maturity (T_{50}) (by sex)	M: 6.3–8.2 years F: 13.0–16.3 years	Francis 2015	M: 8-11 years F: 15-18 years	Francis et al. 2007	See above
Growth coefficient (K) (by sex)	M: 0.133 F: 0.086	Francis 2015	M: 0.112 F: 0.060	Francis et al. 2007	See above
Age at recruitment	0-1 years	Francis & Stevens 2000, Francis 2013			
Maximum length (observed, L_{inf}) (by sex)	L_{max}: M: 204 cm F: 208 cm L_{inf}: M: 185.77 cm F: 210.86 cm	Francis et al. 2008, Francis 2013 Francis 2015	L_{inf}: M: 182.2 cm F: 233.0 cm	Francis et al. 2007	Large females rarely caught so L_{max} may be an under-estimate. Larger sharks reported but may be unreliable.
Longevity (T_{max}) (by sex)	~ 65 years	Francis et al. 2007			

POR (southern population only)	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
Fork length used throughout. Sexes combined unless otherwise stated	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
REPRODUCTION					
Length at maturity (by sex) (L_{50})	M: 140-150 cm F: 170-180 cm	Francis & Duffy 2005			Few females in transition range
Gestation period	8-9 months	Francis & Stevens 2000, Francis (unpubl. data)			No early stage embryos, and high variation in length of embryos at any one time, make estimation difficult. Assumes embryonic growth rate constant at 7.5 cm/month
Reproductive Cycle	1 year?	Francis & Stevens 2000, Francis (unpubl. data)			Cannot currently be determined. Probably annual, but possibly biennial (Francis & Stevens 2000)
Spawning Period/Mating Period	Pupping April-September, peaking June-July. Mating unknown but probably spring (Oct-Dec)	Francis & Stevens 2000. Mating period estimated by backwards extrapolation of plot of embryonic length versus time			Poorly estimated
Litter size (mean & range)	Range 1-4, usually 4. Average 3.74	Francis & Stevens 2000, Francis (unpubl. data)			
Embryonic sex ratio	92 males: 72 females (not sig. diff. from 1:1)	Francis & Stevens 2000, Francis (unpubl. data)			
Maturity ogive (logistic curve parameters)	N/A				
OTHER					
Conversion factors (length:length, length:weight) (by sex)	$FL=0.3369+0.8896\ TL_{nat}$ (N=6038) $Log_{10}Weight= -4.669 +2.924\ log_{10}FL$ (N = 2457)	Francis 2013 Ayers et al. 2004			Most data from juveniles < 150 cm FL
Stock Delineation/Range	Southern Hemi-sphere and North Atlantic	Last & Stevens 2009			
-Genetics	Southern Hemi-sphere population distinct from North Atlantic	Testerman (unpubl. data), Kitamura & Matsunaga 2009			Only mtDNA control region used. Few collection sites in SH and some samples small

POR (southern population only)	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
Fork length used throughout. Sexes combined unless otherwise stated	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	population				
-Tagging	Longitudinal movements of 2000-4000 km	Matsunaga (unpubl. data), Francis & Holdsworth (unpubl. data)			Number of tag recaptures very small (2 and 10 respectively)
Habitat Use /Env'l Preferences (temp, depth)	Open ocean and occasionally coastal waters. Diel vertical migration	Bagley et al. 2000, Francis & Stevens 2000, Francis & Holdsworth (unpubl. data)			Number of tag recaptures very small
Mixing Areas	N/A				
Migration	North-South seasonal migration. Longitudinal migration probably occurs also	Matsunaga (unpubl. data), Francis & Holdsworth (unpubl. data)			Number of tag recaptures very small (2 and 10 respectively)
Natural mortality					
-life history-based	Probably < 0.1	Clarke et al. 2013	0.06	Hoenig's 1983 teleost regression $\ln Z = 1.46 - 1.01 \ln t_{max}$	Poorly estimated. Based on longevity of 65 years and Hoenig's method
-catch curves					
Steepness	N/A				
Intrinsic rate of increase (r or λ)	N/A				
Intrinsic rebound potential ($r_{Z(MSY)}$)	N/A				

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Annex L. Parameters for the smooth hammerhead, *Sphyrna zygaena*

SPZ- Smooth hammerhead *Sphyrna zygaena*	Preferred Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	M:-0.72 yr F: -1.31 yr (t_o fr VB) 540-640 mm TL ~650 mm FL (observed)	Chow 2004 in Liu & Tsai 2011 (M: n=96; F: n=70) Francis 2010 Stevens 1984	M:390mm FL F:390mm FL (Assigned L_o)	Rosa et al 2015	
Age at maturity (T_{50}) (by sex)			M: 15 yr F: 22 yr (from length at maturity data into VB curve)	Rosa et al 2015	SAM from L&S into Rosa growth curve
Growth coefficient (K) (by sex)	M: 0.128 yr^{-1} F: 0.111 yr^{-1}	Chow 2004 in Liu & Tsai 2011	M: 0.15yr^{-1} F: 0. 139yr^{-1}a (where L_0 fixed at 39 cm)	Rosa et al 2015	
Age at recruitment	Unknown				
Maximum length (observed, L_{inf}) (by sex)	M: 3588 mm TL F: 3752 mm TL (L_∞ fr VB)	Chow 2004 in Liu & Tsai 2011	M: 2365 mm FL F: 2503mm FL (L_∞ fr VB)	Rosa et al 2015	L_0 is fixed parameter which may lead to under-estimation of this parameter
Longevity (T_{max}) (by sex)			M: 24 yr F: 25yr	Rosa et al 2015	Data may be in Chow 2004 but needs translation
REPRODUCTION					
Length at maturity (by sex) (L_{50})	M: 222 cm FL F: 240 cm FL	Stevens 1984			
Gestation period	10-11 months	Stevens 1984			
Reproductive Cycle	Seasonal; unknown periodicity	Stevens 1984			
Spawning Period/Mating Period	Mating: summer Ovulation: Autumn Birth: Summer	Stevens 1984			
Litter size (mean & range)	20-49 mean 32	Stevens 1984			

SPZ- Smooth hammerhead *Sphyrna zygaena*	Preferred Parameters (if any)		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Embryonic sex ratio	1:1	Stevens 1984			
Maturity ogive (logistic curve parameters)	Unknown				
OTHER					
Conversion factors (length:length, length:weight) (by sex)	FL = 12.72 + 0.84 TL W=5.27e10-7TL^3.42	Coelho et al. 2011 Stevens 1984			
Stock Delineation/Range					
-Genetics	Separation of east and west South Pacific	Hernandez Munoz 2013; Testerman 2014			
-Tagging			Some tag movement > 1000 km	Kohler al. 1998	
Habitat Use /Env'l Preferences (temp, depth)	Juveniles in coastal and adults more often in the open ocean				
Mixing Areas	Unknown				
Migration	Unknown				
Natural mortality					
-life history-based	Unknown				
-catch curves	Unknown				
Steepness	Unknown				
Intrinsic rate of increase (*r* or λ)	Unknown				
Intrinsic rebound potential ($r_{Z(MSY)}$)	Unknown				

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Annex M. Parameters for the scalloped hammerhead, *Sphyrna lewini*

SPL	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	M: 519 mm TL F: 439 mm TL (L_o fr VB) 450-500 mm TL (observed) 465-563 mm STL	Drew et al. 2015 Stevens & Lyle 1989 Harry et al 2011	M:-0.746 yr F:-0.413 yr (t_o fr VB) 430-560 mm TL	Chen et al 1990 White et al. 2008	Also data from Harry et al 2011 which is very similar to Drew et al. 2015
Age at maturity (T_{50}) (by sex)	M: 8.9 yr F: 13.2 yr (from aged individuals)	Drew et al. 2015	M: 3.8 yr F: 4.1 yr (from size at maturity into growth curve)	Chen et al 1990	Differences between Drew et al (2015)and Chen et al (1990) reflect the differences between one and two band pairs per year in vertebrae.
Growth coefficient (K) (by sex)	M: 0.075 yr^{-1} F: 0.095 yr^{-1}	Drew et al. 2015	M:0.222 yr^{-1} F:0.249 yr^{-1}	Chen et al 1990	
Age at recruitment	Unknown, but juveniles are known to occur in shelf waters				
Maximum length (observed, L_{inf}) (by sex)	M: 3034 mm TL F: 3075 mm TL (L_∞ fr VB) M: 3460 mm TL F: 3010 mm TL (observed)	Drew et al. 2015 Stevens & Lyle 1989	M:3210 mm TL F:3200 mm TL (L_∞ fr VB)	Chen et al 1990	
Longevity (T_{max}) (by sex)	M:21yr F:35yr	M: Harry et al. 2011 F: Drew et al. 2015	M:10.6 yr F:14 yr 18.6 yr F: 12.5yr M: 11yr	Chen et al 1990 Anislado-Tolentino & Robinson-Mendoza 2001 Anislado-Tolentino et al 2008	Differences reflect the uncertainty in the periodicity of band formation for this species

SPL	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
REPRODUCTION					
Length at maturity (by sex) (L_{50})	M: 1980 mm TL F: 2100 mm TL	Chen et al 1990	M: 1471 mm STL (tropical) M: 2043 mm STL F: 2000 mm TL	M: Harry et al 2011 F: Stevens &Lyle 1989	
Gestation period	10 months	Chen et al 1988			Difficult to determine in some locations because pregnant females are rarely caught
Reproductive Cycle	Seasonal; biennial cycle	Liu & Chen 1999; White et al. 2008			
Spawning Period/Mating Period	Mating: summer Ovulation: summer-autumn Birth: summer	Stevens & Lyle 1989	Mating: uncertain Ovulation: autumn Birth: summer	Chen et al 1988	Timing of reproductive cycle varies between regions, and also spread over a large part of the year. However, there is a peak of pupping depending on region
Litter size (mean & range)	12-38 mean 25.8 Fec = 0.179TL - 26.105	Chen et al. 1988	14-41 mean 25.3 Fec = 0.035TL - 71.1	White et al. 2008	
Embryonic sex ratio	1:1	Chen et al. 1988	1:1	Stevens & Lyle 1989	
Maturity ogive (logistic curve parameters)	a: -25.29 b: 0.017 L_{50}: 1471 mm STL (trop.) a: -35.12 b: 0.017 L_{50}: 2043 mm STL (temp.)	Harry et al 2011			
OTHER					
Conversion factors (length:length, length:weight) (by sex)	M&F STL = 15.38 + 1.30FL TL=1.296 FL +0.516 F: w=2.82e10-6 TL^3.129 M: w=1.35e10-6TL^3.252	Harry et al 2011 Piercy et al 2007 Chen et al 1990	W=3.99e10-3 TL^3.03 F: w=2e10-5 TL ^2.8 M: w=1.05e10-5TL^2.87	Stevens & Lyle 1989 Anislado-Tolentino & Robinson-Mendoza 2001	There are a range of other conversion factors available
Stock Delineation/Range					

SPL	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
-Genetics	Some within basin structure. Female philopatry to specific coastal areas	Daly-Engel et al. 2012			Sample numbers could be improved to make the results more robust
-Tagging	Demonstrated movement up to 3000 km	Kohler et al 1998; Kohler & Turner2001; Diemer et al. 2014			
Habitat Use /Env'l Preferences (temp, depth)	Coastal and open ocean				
Mixing Areas	Unknown				
Migration	Unknown				
Natural mortality					
-life history-based	0.107yr^{-1}	Chen & Yuan 2006			
-catch curves	unavailable				
Steepness	Unknown				
Intrinsic rate of increase (r or λ)	0.086	Chen & Yuan 2006	0.205	Liu & Chen 1999	Differences in results because of the variation in life history parameters
Intrinsic rebound potential ($r_{Z(MSY)}$)	0.015-0.03	Smith et al 2008			

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Annex N. Parameters for the great hammerhead, *Sphyrna mokarran*

SPK	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	M (n=43) &F (n=51):700 mm STL (Assigned Lo) M&F: ~650 mm TL (observed)	Harry et al. 2011 Stevens & Lyle 1989	M:-1.99 yr F:-2.86 yr (to from VB) Converted: to Lo – M: 912 mm STL F: 1051mm STL)	Piercy et al 2010 (Atlantic)	Harry et al. 2011 few pregnant females – largest near term embryos were 705 and 710 mm STL
Age at maturity (T_{50}) (by sex)	M(n=42) &F (n=24):8.3yr (7.4-9.5 yr)(Pooled M+F)	Harry et al. 2011	M&F: 5-6 yrs	Piercy et al 2010	Harry et al. 2011- small M and F samples size and minimal difference between M&F so sexes combined.
Growth coefficient (K) (by sex)	M(n=43) &F (n=51): 0.079 yr^{-1}	Harry et al. 2011	M: 0.16yr^{-1}(n=111) F: 0.11yr^{-1}(n=105)	Piercy et al 2010	
Age at recruitment	Unknown				
Maximum length (observed, L_{inf}) (by sex)	M (n=43) &F (n=51): 4027 mm STL (Linf from VB)	Harry et al. 2011	M: 2642 mm FL (3346 mm STL)(n=111) F: 3078 mm FL (3893 mm STL)(n=105)	Piercy et al 2010.	
Longevity (T_{max}) (by sex)	M: 42yr (n=2) F: 45yr (obs n=1)	M: Passeroti et al. 2010 F: Tovar-Ávila & Gallegos-Camacho 2014			Passerotti-bomb radiocarbon validated. Tovar-Avila -vertebral counts
REPRODUCTION					
Length at maturity (by sex) (L_{50})	M(n=59)&F(n=26): 2279 mm (2149-2429) STL (Pooled M+F)	Harry et al. 2011	M: 225cm TL F: 210cm TL	Stevens & Lyle 1989 (Pacific values)	Harry et al. 2011- small M and F samples size and minimal difference between M&F so sexes combined.
Gestation period	11 months	Stevens & Lyle 1989			
Reproductive Cycle	Seasonal; biennial (likely)	Stevens & Lyle 1989			Only about half mature females were pregnant, and those with near term embryos did not contain a yolked follicles so likely breed every other year.
Spawning Period/Mating Period	Mating: spring Ovulation: Summer (peak but extended	Stevens & Lyle 1989			

SPK	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
	period) Birth: Summer				
Litter size (mean & range)	6-33(n=30) mean 15.4	Stevens & Lyle 1989	15-23 (15 and 23 are means)	Piercy et al 2010.	Stevens & Lyle 1989 stated "There is a significant relationship between increasing maternal length and litter size" but r/ship not provided.
Embryonic sex ratio	1:1 (n=385)	Stevens & Lyle 1989			
Maturity ogive (logistic curve parameters)	Unknown				
OTHER					
Conversion factors (length:length, length:weight) (by sex)	STL= 3.58+1.29FL (sexes combined)(n=261) W=1 .23x10^{-3}xSTL$^{3.24}$(sexes combined)(n=117)	Stevens & Lyle 1989	STL = 49·01+1·29FL (sexes combined)(n=46) STL = 74·19 + 1·39PCL (sexes combined) (n=46) STL = 3.472+1.2533FL(sexes combined)(n=216)	Harry et al. 2011 Piercy et al. 2010	
Stock Delineation/Range					
-Genetics	Unknown				
-Tagging	Unknown				
Habitat Use /Env'l Preferences (temp, depth)	Coastal and open ocean				
Mixing Areas	Unknown				
Migration	Unknown				
Natural mortality					
-life history-based	Unknown				
-catch curves	Unknown				
Steepness	Unknown				
Intrinsic rate of increase (r or λ)	Unknown				
Intrinsic rebound potential ($r_{Z(MSY)}$)	Unknown				

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Annex O. Parameters for the winghead, *Eusphyra blochii*

EUB	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Estimated length at birth (L_0) Empirical length at birth	496 mm TL(L_0 from VB) 475 mm TL (both are sexes combined)	Smart et al. 2013 Smart et al. 2013			Empirical length at birth measurement attained from a free swimming individual with an open umbilical scar.
Age at maturity (T_{50}) (by sex)	6.9 years (male) 7.2 years (female)	Smart et al. 2013			Calculated by inserting L_{50} values from Stevens & Lyle 1989 into VB equation from Smart et al. 2013
Growth coefficient (K) (by sex)	0.12yr^{-1} (sexes combined)	Smart et al. 2013			Small Sample Size (n=14) – The growth estimates are appropriate and considered accurate as the entire size range was included. The only uncertainty is whether or not this curve is representative of the whole population due to small sample size
Age at recruitment	Unknown				
Estimated Maximum length (, L_{inf}) (sexes combined) Empirical Maximum length	1710 mm TL(Linf from VB) 1720 mm TL	Smart et al. 2013 Smart et al. 2013			
Longevity (T_{max}) (by sex)	21 yr estimated from vertebral growth band pairs	Smart et al. 2013			
REPRODUCTION					
Length at maturity (by sex) (L_{50})	M: 108 cm TL F: 120 cm TL	Stevens & Lyle 1989			
Gestation period	10-11 months	Stevens & Lyle 1989			
Reproductive Cycle	Seasonal	Stevens & Lyle 1989			
Spawning Period/Mating Period	Mating: summer Ovulation: autumn Birth: summer	Stevens & Lyle 1989			
Litter size (mean & range)	6-25 (mean 11.8)	Stevens & Lyle 1989			
Embryonic sex ratio	1:1	Stevens & Lyle 1989			
Steepness	Unknown				

EUB	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Intrinsic rate of increase (*r* or λ)	Unknown				
Intrinsic rebound potential ($r_{Z(MSY)}$)	Unknown				
Maturity ogive (logistic curve parameters)	Unknown				
OTHER					
Conversion factors (length:length, length:weight) (by sex)	TL= 1.31FL+3.10 W=2.71 x10-4 TL^3.56	Stevens & Lyle 1989			
Stock Delineation/Range					
-Genetics	Unknown				
-Tagging	Unknown				
Habitat Use /Env'l Preferences (temp, depth)	Tropical Coastal areas	Stevens & Lyle 1989			
Mixing Areas	Unknown				
Migration	Unknown				
Natural mortality					
-life history-based	Unknown				
-catch curves	Unknown				
Steepness	Unknown				
Intrinsic rate of increase (*r* or λ)	Unknown				
Intrinsic rebound potential ($r_{Z(MSY)}$)	Unknown				

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Annex P. Parameters for the whale shark, *Rhincodon typus*

RHN	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
AGE & GROWTH (by sex where possible)					
Length at birth (L_0, or Age at zero length: t_0)	L0= 0.64 m TL L0= 0.78 m TL L0= 46-64 cm TL from two neonates reported in Philippines	Joung et al. 1996, used by Hsu et al. 2014b Hsu et al. 2014a Aca & Schmidt 2011 in Hsu et al. 2014b.			Based in the largest size of embryo observed.
Age at maturity (T_{50}) (by sex)	Males with 20 or more growth band pairs were mature, One female with 22 growth band pairs was maturing Age at maturity for males 17 years, for females 19–22 years (n= 73).	Wintner 2000 Hsu et al. 2014b	30 yrs (males) if L50 provided by Norman & Stevens 2007 and Wintner 2000 age information are combined	Norman & Stevens 2007	Linear relationship between length and growth band pairs prevented growth parameters estimation. Annual growth band pair periodicity determined based in one individual in captivity (Cailliet et al. 1986 as cited in Wintner 2000). Validated by marginal increment ratio and centrum edge analysis, band pairs were postulated to be formed twice a year.
Growth coefficient (K) (by sex)	0.037 yr-1 But assuming annual band pair formation= 0.021 yr-1 (combined sexes) (n=92, size range 1.6-9.88 m TL).	Hsu et al. 2014b			

RHN	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
			0.031-0.051 yr-1	Pauly 2002	Theoretical approximation assuming *C. maximus* growth is similar (based in length-weight relationship and gills length).
			Growth rates during 347-1068 days using laser photogrammetry was undetectable, suggesting very slow growth.	Rohner et al. 2015	
			Mean growth per year in captivity 29.5 cm TL (during 2056 days) for a 4.5 m male shark. 21.6 cm (1040 days) and 4.85 m male 25.5 cm (458 days) respectively.	Uchida et al. 2000	
Age at recruitment					
Maximum length (observed, L_{inf}) (by sex)	Observed: at least 12 m TL, probably 20 m TL.	Stevens 2007			Stevens (2007) suggests that reports over 12 m TL are probably an overestimation.
	Up to 990 cm TL observed in Western Indian Ocean	Rohner et al. 2015			
	Linf= 16.8 m TL (Combined sexes) (n=92, size range 1.6-9.88 m TL). But assuming annual band pair formation= 15.34 m TL	Hsu et al. 2014b			Only one individual observed by Hsu et al. 2014b was mature (male)
			12.7 m TL reported in the Caribbean	Graham & Roberts 2007	

RHN	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
			Linf= 14 m TL	Pauly 2002	Theoretical
Longevity (T_{max}) (by sex)	Maximum observed number of growth band pairs: 27 for females and 31 for males. Maximum number of observed growth band pairs= 25 for a 6.38 m TL female and 42 for a 9.88-m TL male. Estimated= 80.4 years. 26 growth bandpairs for a male 738 cm TL and 22 growth band pairs for a 630 cm TL female in the Western Indian Ocean	Wintner 2000 Hsu et al. 2014b Rohner et al. 2015	60-100 yrs	Pauly 2002	Theoretical
REPRODUCTION					
Length at maturity (by sex) (L_{50})	L50~8 m and L95~9 m TL (males) Observation of mature males over 9 m TL Three males between 905-920 cm TL and one female of 859 cm TL observed were immature. Mature males of 670-755 cm PCL (846-950 cm TL*), and one female of 445 cm PCL (572 cm TL*) were maturing. Only one female mature has been reported (~10.6 m TL). L50= 916 cm TL (n=79).	Norman & Stevens 1997 Colman 1997 Beckley et al. 1997 in Stevens 2007 Wintner 2000 Joung et al. 1996 Rohner et al. 2015			

RHN	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
Gestation period					
Reproductive Cycle					
Spawning Period/Mating Period					
Litter size (mean & range)	300	Joung et al. 1996			Only one litter
Embryonic sex ratio					
Maturity ogive (logistic curve parameters)					
OTHER					
Conversion factors (length:length, length:weight) (by sex)	TL=1.2182PCL+33.036 (n=41, range cm Adults: TL=1.252PCL+20.308 (n=21, range= 254-780 cm PCL, 95%CI= 1.18-1.325 for the slope, r2=0.986) FL=1.106PCL+7.919 (n=7, range= 422-770 cm PCL, 95%CI= 1.028-1.184 for the slope, r2=0.996) TL=1.063FL+26.491 (n=8, range= 473-850 cm FL, 95%CI= 0.893-1.234 for the slope, r2=0.975) Embryos: TL=1.306PCL+1.226 (n=9, range= 26-48 cm PCL, 95%CI= 1.182-1.43 for the slope, r2=0.989).	Wintner 2000 and Rohner et al 2011 in Rohner et al. 2015 Wintner 2000 (combining data with Beckley et al. 1997 for adults relationships and data from Bass et al 1975, Wolfson 1983 and Chang et al. 1997 for the embryos relationship)			Estimations based in low sample numbers, particularly for FL-PCL and TL-FL.
Stock Delineation/Range					

RHN	Pacific Parameters		Alternative Parameters		Identified Uncertainties/Data Quality Issues
	Parameter & Value	Data Source(s)	Parameter & Value	Data Source(s)	
-Genetics	Evidence of at least two populations (one in the Gulf of México and another in the Indo-Pacific) based in mitochondrial and microsatellite DNA analysis. Genetic structure suggests all whale sharks are not part of a single world metapopulation.	Vignaud et al. 2014	No genetic population structure found across Pacific and Indian Ocean indicating dispersion between both oceans. Low genetic differentiation was found between Caribbean, Pacific and Indian Ocean, genetic studies show high connectivity among oceans.	Castro et al. 2007, Schmidt et al. 2009, Sequeira et al. 2013.	The study of Vignaud et al. 2014 has a better sample number and larger collecting sites.
-Tagging	High connectivity between Oceans	Graham & Roberts 2007, Sequeira et al. 2013			
Habitat Use /Env'l Preferences (temp, depth)	Narrow temperature range (not specified)	Sequeira et al. 2012			
Mixing Areas					
Migration					
Steepness					
Intrinsic rate of increase (r or λ)					
Intrinsic rebound potential ($r_{Z(MSY)}$)					
Natural mortality					
-life history-based			0.088 yr-1	Pauly 2002	Based in the theoretical longevity
-catch curves					

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Annex Q. Abstract for "In Review" Study on Oceanic Whitetip Shark in the Western North Pacific

Estimates of life history parameters of the oceanic whitetip shark,* Carcharhinus longimanus*, in the Western North Pacific Ocean

Shoou-Jeng Joung, Nien-Fu Chen, Hua-Hsun Hsu and Kwang-Ming Liu

The oceanic whitetip shark, *Carcharhinus longimanus*, has been listed on the CITES Appendix II and prohibited from retention on board by several Regional Fisheries Management Organizations. In this study, age, growth, and reproduction of the oceanic whitetip shark in the western North Pacific Ocean was estimated based on 188 specimens (99 females and 89 males), from samples collected before the prohibition of retention (from November 2002 to January 2006) at the Nan Fan Ao fish market, in northeastern Taiwan. The sexes-combined relationship between body weight (W) and total length (TL) was estimated as follows: $W=1.66\times10^{-5}TL^{2.891}$ (n=188, P<0.01). The relationship between TL and the pre-caudal vertebral centrum radius (R) for sexes-combined data was described using the following equation: $TL=29.983+20.991R$ (n=112, P<0.05). Growth band pairs (including translucent and opaque bands) in pre-caudal vertebrae were determined to form once annually, based on marginal increment ratio analysis. The maximum number of growth band pairs was 12 for both sexes. The two-parameter von Bertalanffy growth function best fit the observed length-at-age data, and sex-specific growth equations were not significantly different; thus, the sexes-combined growth parameters were estimated as: asymptotic length (L_∞) = 309.4 cm TL, growth coefficient = 0.0852 yr^{-1} with size at birth setting 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 50% maturity were estimated to be 194.7 cm and 200.1 cm TL corresponding to 8.2 years and 8.7 years for females and males, respectively.

Annex R. Abstract for Unpublished Study on Smooth Hammerhed Shark in the Western North Pacific

Studies on age and growth of smooth hammerhead,* Sphyrna zygaena*, in northeastern Taiwan waters

Yu-Ching Chow

Age and growth of the smooth hammerhead shark, *Sphyrna zygaena*, in the northeastern waters of Taiwan was examined from growth bands of the vertebral centra. A total of 304 individuals (including 147 females and 157 males) were collected from August 2002 to October 2003 at Nan Fan Ao fish market. The individuals were mainly captured by harpoon and longline from surface to 200 m depth. The maximum number of opaque bands was counted to be 16 and 14 for female and male, respectively. The monthly changes of the marginal increment indicated that opaque zones on vertebral centra were formed once per year between April and June. The parameters of the von Bertalanffy growth equations for this species obtained from nonlinear regressions were as follows: L_∞=357.5cm TL, K= 0.1108 yr^{-1}, t_0 = -1.306 yr for females; and L_∞ = 358.8 cm TL, K = 0.128 yr^{-1}, t0 = -0.721 yr for males. The growth rates for both females and males were estimated to be 32.2 cm yr^{-1} and 36.8 cm yr^{-1} for the first year; 20.7-28.8cm yr^{-1} and 22.1-32.4 cm yr^{-1} for years 2-5; 11.9-18.5 cm yr^{-1} and 11.6-19.4 cm yr^{-1} for years 6-10; and 6.1-10.6 cm yr^{-1}, and 7-10.2 cm yr^{-1} for years 11-16 and 11-20. The ages at maturity were 11.0 yr and 7.5 yr for females and males, respectively.