

## INFORMATION ON THE EXISTING KNOWLEDGE ON THE LIFE HISTORY TRAITS OF SHORTFIN MAKO, *ISURUS OXYRINCHUS*

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### SUMMARY

*For the improvement of future stock assessment of shortfin mako (*Isurus oxyrinchus*) in the Atlantic Ocean, the importance of review for biological parameter was addressed. In the last stock assessment meeting, the uncertainty about catch statistics, catchability and biological parameter was discussed regarding the poor fitting of estimated biomass trend to the observed trend on CPUE. Even granting that there may be unignorable amount of unreported catch, it cannot explain the increase of CPUE consistently observed in many fleets by itself. It is valuable to reassess the existing assumption that intrinsic rate of natural increase ( $r$ ) of this species is quite low, rounding up existing knowledge on the biological parameter. In this document, we provide the information on the current status of biological studies for the populations in the North Pacific, focusing on the growth analysis, because we have latest study in this area and, needless to say, growth parameter plays an integral role in the population dynamics among various biological parameters. We also discuss the important points to be taken into account in the preparation of future research plan.*

### RÉSUMÉ

*L'importance de l'examen des paramètres biologiques a été soulignée pour améliorer les futures évaluations du stock de requin-taube bleu (*Isurus oxyrinchus*) dans l'Atlantique. Au cours de la dernière réunion d'évaluation du stock, les incertitudes liées aux statistiques de capture, à la capturabilité et aux paramètres biologiques ont été discutées en ce qui concerne l'ajustement médiocre de la tendance de la biomasse estimée à la tendance observée de la CPUE. Même en concevant qu'il pourrait y avoir un volume patent de prises non déclarées, ceci n'explique pas l'augmentation de la CPUE constamment observée dans de nombreuses flottilles. Il est nécessaire de réévaluer le postulat existant, selon lequel le taux intrinsèque d'augmentation naturelle ( $r$ ) de cette espèce est assez faible, en regroupant les connaissances existantes sur les paramètres biologiques. Dans le présent document, nous fournissons des informations sur l'état actuel des études biologiques pour les populations du Pacifique nord, en nous concentrant sur l'analyse de la croissance, étant donné que des études ont dernièrement été menées dans cette zone et qu'il est flagrant que le paramètre de croissance joue un rôle-clé dans la dynamique de la population parmi les divers paramètres biologiques. Nous discutons également des points importants à prendre en considération dans l'élaboration du futur programme de recherche.*

### RESUMEN

*Con el fin de mejorar las futuras evaluaciones de stock de marrajo dientuso (*Isurus oxyrinchus*) en el océano Atlántico, se trata la importancia de revisar los parámetros biológicos. En la última reunión de evaluación de stock, se debatieron las incertidumbres sobre las estadísticas de captura, la capturabilidad y los parámetros biológicos, en lo que concierne al mediocre ajuste de la tendencia de biomasa estimada a la tendencia observada para la CPUE. Incluso dando por sentado que podría haber una cantidad insoslayable de capturas no comunicadas, esto no podría explicar por sí mismo el incremento de la CPUE observado de forma constante en varias flotas. Sería adecuado volver a evaluar el supuesto existente de que la tasa intrínseca de incremento natural ( $r$ ) de esta especie es bastante lenta, completando los conocimientos existentes sobre parámetros biológicos. En este documento se proporciona información sobre el estado actual de los estudios biológicos para las poblaciones del Pacífico norte, y se centra en análisis de crecimiento, porque hay estudios muy recientes en este campo y huelga decir que los parámetros de crecimiento desempeñan un papel integral en la dinámica de población entre*

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*los diferentes parámetros biológicos. También discutimos puntos importantes que se tienen que tener en cuenta en la preparación de los planes futuros de investigación.*

#### KEYWORDS

*Shortfin mako, Life history, Growth curves, Sexual maturity, Fecundity, Population dynamics, Vulnerability*

## 1. Introduction

In the last stock assessment meeting of Atlantic shortfin mako (*Isurus oxyrinchus*) in 2012, it was indicated that the stock status of the Atlantic population is healthy and that the probability of overfishing is low (ICCAT 2012). However, the results of assessment showed inconsistencies between estimated biomass trajectories and input CPUE trends, which were gradually increasing or flat. It was indicated that this inconsistency caused wide confidence intervals in the estimated trend of biomass and parameters. In order to resolve this problem for better assessment, the possibility of following uncertainty was discussed; large amount of unreported catch in the past, temporal change of catchability and the assumption of the relatively low productivity for this species.

Regarding the uncertainty in the historical catch, the working group found various problems such as absence of species-specific catch prior to 1997 and lack of information from artisanal fisheries, and discrepancy of record among databases. In this context, the revision of catch and development of alternative model for providing management advice that are less dependent on absolute catch data were included in the special research program on sharks.

Especially, the existence and significance of unreported catch was highlighted and it was suggested that there should be quite large contrast in the catch between the past (1980s) and recent years for the recent increasing trend of standardized CPUEs from three major fleets (US, Spain and Japan) to be explained by the Bayesian surplus production model. However, shortfin mako has been caught as the bycatch in the longline fishery targeting tuna and swordfish and thus the amount of catches by these operations is assumed to be rather minor. Under this situation, the existence of large amount of cryptic is supposed not to be principal especially in the period before 1990s and it is difficult to attribute the uncertainty mainly to the unreported catch.

Aside from this, there is a viewpoint that the level of the stock has been increasing due to higher productivity than previously thought, regarding the increasing trend of abundance indices from major fleets. The productivity of this species has not been discussed in depth and we propose to review the existing knowledge on the biological parameters relating to the productivity of this species. The arrangement of what is known and not will help to design the research plan to reduce uncertainty associated with its productivity. As a first step, we introduce the existing knowledge and ongoing research on the growth and reproduction of this species with information on the new finding.

## 2. Information on the studies of growth and reproduction of shortfin mako

One of unique characteristics about the life history traits of this species is sexual dimorphism both in size and life history parameters (**Table 1-3**). Recent study suggests the existence of sexual segregation (Mucientes *et al.* 2006) and ontogenetic difference in distribution (Semba and Yokawa 2011), but we focus on the information on growth and reproduction in this document.

### 2.1 Growth studies

There have been many studies on the age and growth of the shortfin mako both in the Pacific and the Atlantic (**Table 2**). The intersexual differences in growth rate have been indicated in many studies and females grow larger than males (Pratt and Casey 1983, Bishop *et al.* 2006, Natanson *et al.* 2006, Semba *et al.* 2009). In addition to this intraspecific difference, geographic differences in growth rate have been suggested among studies in both sexes (**Figure 1**). It is important to consider if such difference comes from geographical difference or other technical differences such as size and range of sample, enhancement methods (e.g. section vs whole centrum), fitting model or criteria of growth ring (Cailliet *et al.* 1990, Semba *et al.* 2009). Aside from this, the periodicity of growth band pair formation is a prominent factor causing the differences in the growth rate among studies.

Previously, conflicting results were suggested with regards to the periodicity of growth band pair deposition between the North Pacific (annual deposition; Cailliet *et al.* 1983) and the North Atlantic (biannual; Pratt and Casey 1983). This conflict has been settled by studies using bomb radiocarbon and oxytetracycline (OTC) injection in individuals from the Atlantic Ocean (Campana *et al.* 2002; Natanson *et al.* 2006; Ardizzone *et al.* 2006). These results confirmed that one growth band pair is formed annually in individuals from both the Pacific and the Atlantic oceans. However, Wells *et al.* (2013) indicated biannual deposition of growth bands in vertebrae for the first 5 years of individuals collected off southern California on the basis of OTC injection tagging, length-frequency modal analysis and tag-recapture growth model. In the North Pacific, Ribot-Carballal *et al.* (2005) and Semba *et al.* (2009) indicated the annual growth band pair deposition for individuals collected off the coast of Baja California and from the central and western North Pacific, respectively. Wells *et al.* (2013) raised an issue that the periodicity of growth band pair deposition may change ontogenetically from biannual (juvenile) to annual (adult), considering the two Atlantic studies suggested annual periodicity for older individuals. Aside from this, we have developed a hypothesis that this conflict may come from the difference in the enhancing methods (i.e., their two bands correspond to our one band) and prepared for the cross-reading between Japan and USA using same specimen as the first step.

## 2.2 Reproduction

In terms of the reproductive biology of *Isurus oxyrinchus*, its mature size, birth size, and litter size have been reported in various areas (**Table 1 and 3**). Results suggest that female-biased sexual size dimorphism is common and that females give birth from winter to spring to litters of 4–26 embryos with total lengths of 70–80 cm (Stevens 1983; Mollet *et al.* 2000; Francis and Duffy 2005; Joung and Hsu 2005; Semba *et al.* 2011), although summer parturition has been reported by Duffy and Francis (2001). In contrast, there are relatively few inferences about the mating period (Joung and Hsu 2005; Semba *et al.* 2011) and the variance in the reported gestation periods is large, ranging from 9 months (Semba *et al.* 2011) to 25 months (Joung and Hsu 2005). As the details of resting period has not been clarified, the reproductive cycle remains lack of consensus whether to take two (Semba *et al.* 2011) or three years (Mollet *et al.* 2000; Joung and Hsu 2005). The difficulty in the study on the reproductive traits, especially for the period of gestation, resting and mating, derives from the lack of record of adult females worldwide.

Geographical differences in the maturity size have been suggested for both sexes (**Table 1**). As most of this study used logistic model to estimate the 50% size at maturity, the observed difference may be due to the criteria of maturity and size composition of samples. For further improvement of estimate accuracy for size maturity and reproductive cycle, we have resumed collection of biological sampling from adult females in the North Pacific. As another important aspect, the relationship between litter size and maternal size has been controversial whether there is positive relationship (Mollet *et al.* 2000; Semba *et al.* 2011) or not (Joung and Hsu 2005). This discrepancy may be resolved by collection of wide size range of pregnant females.

## 3. Conclusion and future research

In the north Atlantic, Natanson *et al.* (2006) and Ardizzone *et al.* (2006) provided relatively sound estimate of growth parameters considering the size and range of specimen, validation of growth band pair deposition at present. Meanwhile, the new finding indicated by Wells *et al.* (2013) will be future agenda for growth study. On the other hand, there is a room for improvement of reproductive parameters for the Atlantic population. As indicated before, the main obstacle in this area lies in difficulty to obtain adult individuals. From the existing knowledge in the North Pacific, large females tend to occur in the southern and warmer area and may exhibit particular behaviour different from other component of population (Semba and Yokawa 2011). For future research plan, it may be necessary to take into account such sex and ontogenetically specific distribution pattern.

For revision of productivity of this species, other parameters such as longevity, survival rate are necessary to be estimated.

That being said, under existing conditions with little prospect for rapid progress of the study in this area, the review of existing knowledge is equally important. As indicated in **Table 1-3**, there is great variability in many life history parameters and its degree is different depending on the parameter. Furthermore, some parameter, for example, the longevity, varies also depending on criteria as indicated in Natanson *et al.* (2006).

With the accumulation of new information year by year, it is essential to closely examine each component associated with intrinsic rate of natural increase (e.g. check and comparison of sample size, range and applied model, definition and so on), in order to obtain the most appropriate estimate inputted in stock assessment models.

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**Table 1.** Summary table on general life history trait for shortfin mako.

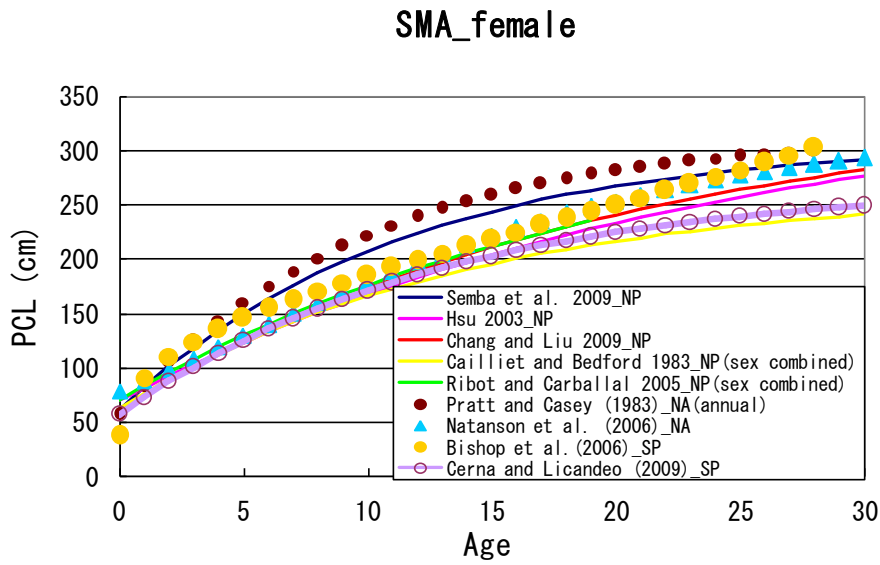
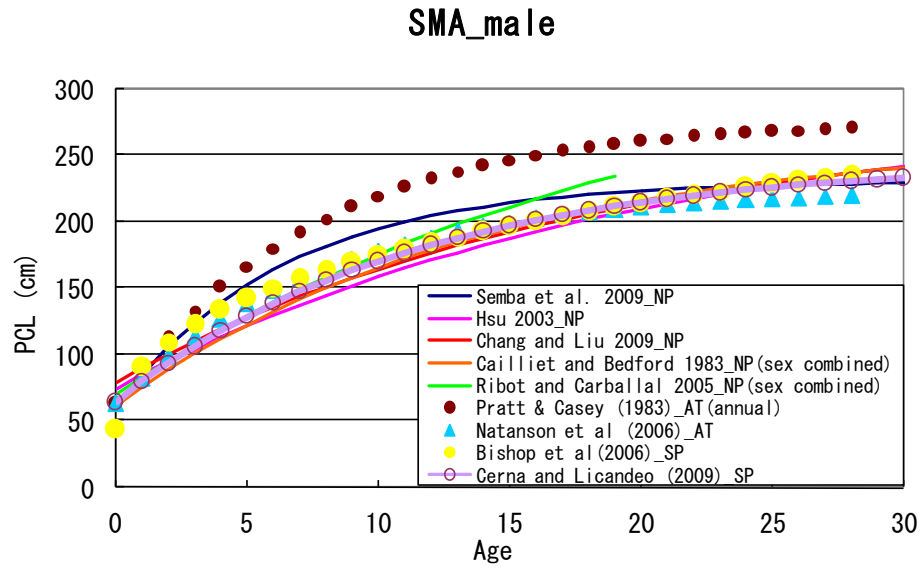
| Parameter                                                    | Value                                                    | Citation                                                     | Covered Area                                          | Notes                                                  |
|--------------------------------------------------------------|----------------------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------|--------------------------------------------------------|
| Length at birth (cm)                                         | 70 (TL)                                                  | Mollet et al. (2000)                                         | global                                                |                                                        |
|                                                              | 74 (TL)                                                  | Joung & Hsu (2005)                                           | NW Pacific                                            |                                                        |
|                                                              | 70 (TL)                                                  | Cliff et al. (1990)                                          | South Africa                                          |                                                        |
|                                                              | 70 (TL)                                                  | Stevens (1983)                                               | South Pacific                                         |                                                        |
|                                                              | 70-80 (TL)                                               | Duffy and Francis (2001)                                     | South Pacific                                         |                                                        |
|                                                              | 65-75 (TL)                                               | Pratt and Casey 1983                                         | Atlantic                                              |                                                        |
|                                                              | 59-60 cm (PCL) ...72 to 74 (TL)                          | Semba et al. 2011                                            | NWC Pacific                                           |                                                        |
| Length at 1st maturity (cm)                                  | 180-183                                                  | Bigelow and Schroeder 1948,                                  |                                                       |                                                        |
|                                                              | M: 180<br>F: 210-290 (est)                               | Cailliet et al. 1983<br>Maia et al. 2007<br>Maia et al. 2007 | Atlantic<br>Atlantic                                  |                                                        |
| Length at 50% maturity (cm)                                  | M: 180 cm (TL)                                           | Conde-Moreno and Galvan-Magana                               | NE Pacific                                            |                                                        |
|                                                              | M: 210 (TL)                                              | Joung and Hsu 2005                                           | NW Pacific                                            |                                                        |
|                                                              | F:278 (TL)                                               | Joung and Hsu 2005                                           | NW Pacific                                            |                                                        |
|                                                              | M: 156 (PCL)                                             | Semba et al. 2011                                            | NWC Pacific                                           |                                                        |
|                                                              | F: 256 (PCL)                                             | Semba et al. 2011                                            | NWC Pacific                                           |                                                        |
|                                                              | M: 200-220                                               | Pratt and Casey 1983                                         | Atlantic                                              |                                                        |
|                                                              | F: 298 (TL)                                              | Mollet et al. 2000                                           | western NA                                            |                                                        |
|                                                              | F: 273 (TL)                                              | Mollet et al. 2000                                           | southern hemisphere                                   |                                                        |
|                                                              | M: 180-185 (FL)                                          | Francis and Duffy 2005                                       | South Pacific                                         |                                                        |
|                                                              | F: 275-285 (FL)                                          | Francis and Duffy 2005                                       | South Pacific                                         |                                                        |
|                                                              | M: 195 (TL)                                              | Stevens 2005                                                 | South Pacific                                         |                                                        |
|                                                              | F: 280 (TL)                                              | Stevens 2005                                                 | South Pacific                                         |                                                        |
| M: 180 (FL)                                                  | Maia et al. 2007                                         | NE Atlantic                                                  |                                                       |                                                        |
| F: 210-290 (FL)                                              | Maia et al. 2007                                         | NE Atlantic                                                  |                                                       |                                                        |
| M: 185 (FL)                                                  | Natanson et al. 2006                                     | North Atlantic                                               |                                                       |                                                        |
| F: 275 (FL)                                                  | Natanson et al. 2006                                     | North Atlantic                                               |                                                       |                                                        |
| Maximum length (cm)                                          | 396                                                      | Bigelow and Schroeder 1948                                   |                                                       |                                                        |
|                                                              | 351                                                      | Applegate 1977                                               |                                                       |                                                        |
|                                                              | 337                                                      | Uchida et al. 1987                                           | around Okinawa                                        |                                                        |
|                                                              | F: 347                                                   | Bishop et al. 2006                                           | South Pacific                                         |                                                        |
|                                                              | F: 330                                                   | Cerna and Licandeo 2009                                      | South Pacific                                         |                                                        |
|                                                              | M: 270 (FL)<br>F: 361 (FL)                               | Compagno 2001                                                | global                                                |                                                        |
| Age at 1st maturity                                          | 7-8                                                      | Cailliet et al. 1983                                         | NE Pacific                                            |                                                        |
|                                                              | M: 7                                                     | Ribot-Carballal et al. 2005                                  | NE Pacific                                            |                                                        |
|                                                              | F: 15                                                    | Ribot-Carballal et al. 2005                                  | NE Pacific                                            |                                                        |
| Age at 50% maturity ※<br>Depending upon band pair deposition | M: 5 years                                               | Semba et al. 2011                                            | NWC Pacific                                           |                                                        |
|                                                              | F: 17 years                                              | Semba et al. 2011                                            | NWC Pacific                                           |                                                        |
|                                                              | M: 8                                                     | Natanson et al. 2006                                         | North Atlantic                                        |                                                        |
|                                                              | F: 18                                                    | Natanson et al. 2006                                         | North Atlantic                                        |                                                        |
|                                                              | M: 7-9 (6.9 probit), 8-9 (indirect)                      | Bishop et al. 2006                                           | South Pacific                                         |                                                        |
|                                                              | F: 19-21 (19.1 probit), 20-21 (indirect)                 | Bishop et al. 2006                                           | South Pacific                                         |                                                        |
| Longevity ※<br>Depending upon band pair deposition           | 45 (theoretical:VBGF)                                    | Cailliet et al. 1983                                         | NE Pacific                                            |                                                        |
|                                                              | 28 (theoretical:VBGF)                                    | Smith et al. 1998                                            |                                                       |                                                        |
|                                                              | 21-22(inference:bomb radiocarbon)                        | Campana et al. 2002                                          | Atlantic                                              |                                                        |
|                                                              | 24(vertebral cross-sections)                             | Campana et al. 2004a                                         | Atlantic                                              |                                                        |
|                                                              | M: 9(vertebral band counts)                              | Ribot-Carballal et al. 2005                                  | NE Pacific                                            |                                                        |
|                                                              | F: 18(vertebral band counts)                             | Ribot-Carballal et al. 2005                                  | NE Pacific                                            |                                                        |
|                                                              | M:29 years (obs), 21 (95%Lmax, taol)                     | Natanson et al. 2006                                         | North Atlantic                                        |                                                        |
|                                                              | F: 32 years (obs, tag), 38 (95%Lmax)                     | Natanson et al. 2006                                         | North Atlantic                                        |                                                        |
|                                                              | F: 31(bomb radiocarbon)                                  | Ardizzone et al. 2006                                        | NW Atlantic                                           |                                                        |
|                                                              | M: 29(vertebral band counts)                             | Bishop et al. 2006                                           | South Pacific                                         |                                                        |
|                                                              | F: 28(vertebral band counts)                             | Bishop et al. 2006                                           | South Pacific                                         |                                                        |
|                                                              | M: 14(vertebral band counts)                             | Semba et al. 2009                                            | NWC Pacific                                           |                                                        |
| F: 20(vertebral band counts)                                 | Semba et al. 2009                                        | NWC Pacific                                                  |                                                       |                                                        |
| 25+(vertebral band counts)                                   | Cerna and Licandeo 2009                                  | South Pacific                                                |                                                       |                                                        |
| M:31 years                                                   | Chang and Liu 2009                                       | South Pacific?                                               |                                                       |                                                        |
| F: 41 years                                                  | Chang and Liu 2009                                       | NW Pacific?                                                  |                                                       |                                                        |
| Length conversions                                           | FL=0.9286*TL-1.7101                                      | Kohler et al. 1995                                           | western NA                                            | n = 199, r2 =0.9972, range 70-368 cm TL, 65-338 cm PCL |
|                                                              | FL=0.913*TL-0.397                                        | NOAA SWFSC                                                   | North Pacific                                         |                                                        |
|                                                              | FL=2.402*AL+9.996                                        | NOAA SWFSC                                                   | North Pacific                                         |                                                        |
|                                                              | PCL=0.816*TL+0.784                                       | Joung & Hsu 2005                                             | NW Pacific                                            | n = 1240, r2 =0.986, range 80-375 cm TL, 65-301 cm PCL |
|                                                              | FL=0.89*TL+0.952                                         | Joung & Hsu 2005                                             | NW Pacific                                            | n = 1236, r2 = 0.986,range 80-375 cm TL, 72-332 cm FL  |
|                                                              | M: PCL=2.04*DL+12.1                                      | Semba et al. 2009                                            | NW Pacific                                            | n=55, r2=0.97                                          |
|                                                              | F: PCL=2.18*DL+7.79                                      | Semba et al. 2009                                            | NW Pacific                                            | n=76, r2=0.99                                          |
| PCL=0.84*TL-2.13                                             | Semba et al. 2009                                        | NW Pacific                                                   | n=131, r2=0.99                                        |                                                        |
| PCL=0.91*FL-0.95                                             | Semba et al. 2009                                        | NW Pacific                                                   | n = 1236, r2 = 0.986,range 80-375 cm TL, 72-332 cm FL |                                                        |
| Length weight                                                | All: Wt(kg)=5.243 x 10 <sup>-6</sup> FL <sup>3.141</sup> | Kohler et al. 1995                                           | North Atlantic                                        |                                                        |
|                                                              | All: Wt(kg)=1.103 x 10 <sup>-5</sup> FL <sup>3.009</sup> | NOAA SWFSC Juvy Survey                                       | North Pacific                                         |                                                        |
|                                                              | All: Wt(kg)=1.1 x 10 <sup>-5</sup> TL <sup>2.95</sup>    | Joung & Hsu 2005                                             | North Pacific                                         |                                                        |
|                                                              | M: Wt(kg)=2.8 x 10 <sup>-5</sup> TL <sup>2.771</sup>     | Chang and Liu 2009                                           | North Pacific                                         |                                                        |
|                                                              | F: Wt(kg)=1.9 x 10 <sup>-5</sup> TL <sup>2.847</sup>     | Chang and Liu 2009                                           | North Pacific                                         |                                                        |

**Table 2.** Summary table on growth parameter for shortfin mako.

| Age and Growth Study            | VB model: $L_t = L_{\infty}[1 - e^{-K(t-t_0)}]$       |                             |                      | Notes1 (Aging method)                                                                                                                                                                                                                                                                                                                                                                                                         | Notes2                                                                  | Notes3                                                                                                                                                                                                                                                   |
|---------------------------------|-------------------------------------------------------|-----------------------------|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth models                   | All: $FL_t = 292.8[1 - e^{-0.072(t+3.75)}]$           | Cailliet & Bedford 1983     | North Pacific        | makovertebral centra: x-radiography whole vertebrae stained w/ silver nitrate sagittal sections of vertebra centra sagittal sections of vertebra centra<br><br>sagittal sections of vertebra centra sagittal sections of vertebra centra<br><br>half-cut vertebral centra w/ shadowing method half-cut vertebral centra w/ shadowing method vertebral band counts (sectioned centra) vertebral band counts (sectioned centra) | centrum edge analysis<br>centrum edge analysis<br>centrum edge analysis | VBGF and Gompertz, tag-recapture methods** (Natanson et al. 2006)VBGF and Gompertz, Schnute generalized growth model*** (Bishop et al. 2006)modified VBGF with birth length fixed (Semba et al. 2009)VBGF (Campana et al. 2004, Cerna and Licandeo 2009) |
|                                 | All: $FL_t = 375.4[1 - e^{-0.05(t+4.7)}]$             | Ribot-Carballal et al. 2005 | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: $FL_t = 302.2[1 - e^{-0.052(t+9.04)}]$             | Bishop et al. 2006          | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F: $FL_t = 820.1[1 - e^{-0.013(t+11.3)}]$             | Bishop et al. 2006          | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: $FL_t = 321.8[1 - e^{-0.049(t+6.07)}]$             | Hsu 2003                    | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F: $FL_t = 403.62[1 - e^{-0.040(t+5.27)}]$            | Hsu 2003                    | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: $FL_t = 253.3[1 - e^{-0.125(L+71.6)}]$             | Natanson et al. 2006        | North Atlantic       |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F: $FL_t = 365.6[1 - e^{-0.087(L+88.4)}]$             | Natanson et al. 2006        | North Atlantic       |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: $TL_t = 332.1[1 - e^{-0.056(t+6.08)}]$             | Chang and Liu 2009          | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F: $TL_t = 413.8 - [(413.8 - 74) * e^{-0.05t}]$       | Chang and Liu 2009          | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: $PCL_t = 60 + 171.3(1 - \exp(-\frac{0.156t}{11}))$ | Semba et al. 2009           | NWC Pacific          |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F: $PCL_t = 60 + 248.6(1 - \exp(-\frac{0.156t}{11}))$ | Semba et al. 2009           | NWC Pacific          |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: $TL_t = 296.60 [1 - e^{-0.087(t+3.58)}]$           | Cerna and Licandeo 2009     | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F: $TL_t = 325.29 [1 - e^{-0.076(t+3.18)}]$           | Cerna and Licandeo 2009     | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | K                                                     | 0.072                       | Cailliet et al. 1983 |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| 0.05                            |                                                       | Ribot-Carballal et al. 2005 | NE Pacific           |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: 0.125 (CI 0.016) (3para)     |                                                       | Natanson et al. 2006        | North Atlantic       |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: 0.087 (CI 0.013) (3paraGomp) |                                                       | Natanson et al. 2006        | North Atlantic       |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: 0.052 (SE 0.011)             |                                                       | Bishop et al. 2006          | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: 0.013 (SE 0.009)             |                                                       | Bishop et al. 2006          | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: 0.049                        |                                                       | Hsu 2003                    | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: 0.040                        |                                                       | Hsu 2003                    | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: 0.056                        |                                                       | Chang and Liu 2009          | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: 0.05                         |                                                       | Chang and Liu 2009          | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: 0.16 (S.E. 0.0175)           |                                                       | Semba et al. 2009           | NWC Pacific          |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: 0.090 (S.E. 0.0091)          |                                                       | Semba et al. 2009           | NWC Pacific          |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: 0.087                        |                                                       | Cerna and Licandeo 2009     | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: 0.076                        |                                                       | Cerna and Licandeo 2009     | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| L <sub>∞</sub>                  |                                                       | 321 (TL)                    | Cailliet et al. 1983 | NE Pacific                                                                                                                                                                                                                                                                                                                                                                                                                    | sex combined<br>sex combined                                            |                                                                                                                                                                                                                                                          |
|                                 | 411 (TL)                                              | Ribot-Carballal et al. 2005 | NE Pacific           |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: 253.3 (CI 8.3):FL                                  | Natanson et al. 2006        | North Atlantic       |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F: 365.6 (Gompertz):FL                                | Natanson et al. 2006        | North Atlantic       |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: 302.3 (SE 22.2) (FL)                               | Bishop et al. 2006          | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F: 820.1 (SE 391.0) (FL)                              | Bishop et al. 2006          | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: 321.8 (FL)                                         | Hsu 2003                    | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F: 403.62 (FL)                                        | Hsu 2003                    | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: 332.1 (TL)                                         | Chang and Liu 2009          | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F:                                                    | Chang and Liu 2009          | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: 231.0 (S.E. 15.5) (PCL)                            | Semba et al. 2009           | NWC Pacific          |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F: 308.3 (S.E. 21.7) (PCL)                            | Semba et al. 2009           | NWC Pacific          |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | M: 296.6 (TL)                                         | Cerna and Licandeo 2009     | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | F: 325.29 (TL)                                        | Cerna and Licandeo 2009     | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
|                                 | t <sub>0</sub>                                        | -3.75                       | Cailliet et al. 1983 | NE Pacific                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                         |                                                                                                                                                                                                                                                          |
| -4.7                            |                                                       | Ribot-Carballal et al. 2005 | NE Pacific           |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: L0 71.6 (CI 5.9)             |                                                       | Natanson et al. 2006        | North Atlantic       |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: L0 61.2 (CI 7.4)             |                                                       | Natanson et al. 2006        | North Atlantic       |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: 88.4 (CI 6.6) (Gomp)         |                                                       | Natanson et al. 2006        | North Atlantic       |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: -9.0 (SE 1.5)                |                                                       | Bishop et al. 2006          | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: -11.3 (SE 2.1)               |                                                       | Bishop et al. 2006          | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: -6.07                        |                                                       | Hsu 2003                    | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: -5.27                        |                                                       | Hsu 2003                    | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: -6.08                        |                                                       | Chang and Liu 2009          | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F:                              |                                                       | Chang and Liu 2009          | North Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: L0 59.7 (fixed:PCL)          |                                                       | Semba et al. 2009           | NWC Pacific          |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: L0 59.7 (fixed:PCL)          |                                                       | Semba et al. 2009           | NWC Pacific          |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| M: -3.58                        |                                                       | Cerna and Licandeo 2009     | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |
| F: -3.18                        |                                                       | Cerna and Licandeo 2009     | South Pacific        |                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                         |                                                                                                                                                                                                                                                          |

**Table 3.** Summary table on reproductive traits for shortfin mako.

| Reproduction                               | Aplacental viviparity with                                                                                                                         | Wourms 1977, Mollet et al. 2000                                                                                                                                  | Notes                                                                                                |
|--------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Litter size (average:12)                   | 4-15(mean=11.1)<br>16 (N=1)<br>8-17(mean=11.8)<br>4-16, avg. 12<br>9-14<br>4-8<br>4-25, increasing w/ maternal size                                | Joung & Hsu 2005<br>Uchida et al. 1987<br>Semba et al. 2011<br>Stevens 1983<br>Cliff et al. 1990<br>Duffy and Francis (2001)<br>Mollet et al. 2000, Compagno     | NW Pacific around Okinawa<br>NWC Pacific<br>South Pacific<br>South Africa<br>South Pacific<br>global |
| Relationship (maternal size - litter size) | not detected<br>detected<br>LS=0.810*TL <sup>2.346</sup><br>LS=0.12*PCL-21.4                                                                       | Joung & Hsu 2005<br>Duffy and Francis (2001)<br>Mollet et al. (2000)<br>Semba et al. (2011)                                                                      | NW Pacific<br>South Pacific<br>global<br>NWC Pacific                                                 |
| Gestation (month)                          | 9-13<br>23-25<br>18<br>18<br>> 21<br>15-18                                                                                                         | Semba et al. 2011<br>Joung & Hsu 2005<br>Stevens 1983<br>Cliff et al. 1990<br>Duffy and Francis (2001)<br>Mollet et al. 2000, Compagno                           | NWC Pacific<br>NW Pacific<br>South Pacific<br>South Africa<br>South Pacific<br>global                |
| Breeding frequency                         | 3 years<br>3 years<br>2 years                                                                                                                      | Mollet et al. 2000<br>Joung & Hsu 2005<br>Semba et al. 2011                                                                                                      | global<br>NW Pacific<br>NWC Pacific                                                                  |
| Parturition season (Mostly winter-spring)  | late winter-midspring<br>Nov. (May in N Hemis.)<br>Nov. (May in N Hemis.)<br>Sep. - Feb. (Mar.-Aug. in N Hemis.)<br>Dec.-Jul.<br>Apr.<br>Jan.-Jun. | Mollet et al. (2000)<br>Stevens (1983)<br>Cliff et al. (1990)<br>Duffy and Francis (2001)<br>Joung & Hsu (2005)<br>Pratt and Casey (1983)<br>Semba et al. (2011) | global<br>South Pacific<br>South Africa<br>South Pacific<br>NW Pacific<br>N Atlantic<br>NWC Pacific  |
| Mating season                              | Jan-Jun<br>Apr-Sep                                                                                                                                 | Joung & Hsu 2005<br>Semba et al. 2011                                                                                                                            | NW Pacific<br>NWC Pacific                                                                            |



**Figure 1.** Growth curve for male (upper) and female (lower) shortfin mako previously estimated.