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STOCK ASSESSMENT OF SILKY SHARKS IN THE WESTERN AND CENTRAL PACIFIC OCEAN

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Executive summary

This paper presents the first stock assessment of silky shark in the western and central Pacific Ocean. The assessment uses the stock assessment model and computer software known as Stock Synthesis (version 3.21B http://nft.nefsc.noaa.gov/Download.html.). The silky shark model is an age (36 years) structured, spatially aggregated (1 region) and two sex model. The catch, effort, and size composition of catch, are grouped into 4 fisheries, all of which cover the time period from 1995 through 2009.

Silky sharks are most often caught as bycatch in the Pacific tuna fisheries, though some directed mixed species (sharks and tunas/billfish) fisheries do exist. Commercial reporting of landings has been minimal, as has information regarding the targeting, and fate of sharks encountered in the fisheries. Useful data on catch and effort is mostly limited to observer data held by the SPC, but the observer data also suffers from poor coverage. Therefore multiple data gaps had to be overcome through the use of integrated stock assessment techniques and the inclusion of alternate data that reflected different states of nature.

Multiple models with different combinations of the input datasets and structural model hypotheses were run to assess the plausible range of inputs and the resulting estimates of stock status. These models were each given a 'weight' based on the a priori plausibility of the assumptions and data used in each model. The reference case presented here was the highest weighted run. This reference case model is used as an example for presenting model diagnostics, but the most appropriate model run(s) upon which to base management advice will be determined by the Scientific Committee. The sensitivity of the reference model to key assumptions (i.e. regarding the stock recruitment relationship, the catch per unit effort time series, the purse seine catch and size data, the growth model) were explored via sensitivity analyses. The results of these analyses should also be considered when developing management advice.

We have reported stock status in relation to MSY based reference points, but the actual reference points to be used to manage this stock have not yet been determined by the Commission.

This is the first stock assessment for silky sharks in the WCPO. The key conclusions are as follows.

1. Notwithstanding the difficulties inherent in the input data, the size composition data shows consistent declines over the period of the model (1995-2009) which is coupled with increasing fishing mortality, and a recently declining CPUE trend.

2. The results of the model can be split into two categories which are mutually exclusive with respect to the estimates of stock status. These two categories are characterized by the CPUE input. All runs that included the target longline and purse seine CPUE trends estimated a current total biomass in excess of 150,000,000mt. Which is more than 18 times greater than the combined 2010 estimate of bigeye, south Pacific albacore, skipjack and yellowfin tuna total biomass combined. Therefore these runs are not considered plausible. The following results are based on the plausible runs only.

3. This is a low productivity species and this is reflected in the low estimated value for F_{MSY} (0.078) and high estimated value for SB_{MSY} / SB_{zero} (0.38). These directly impact on conclusions about overfishing and the overfished status of the stock.

4. Based on the highest probability model (the reference case), estimated spawning biomass, total biomass and recruitment all decline consistently throughout the period of the model. The biomass declines are driven by the CPUE series, and the recruitment decline is driven through the tight assumed relationship between spawning biomass and recruitment.

5. Estimated fishing mortality has increased to levels far in excess of F_{MSY} ($F_{CURRENT}/F_{MSY}$ = 6.4) and across nearly all plausible model runs undertaken estimated F values were much higher than

F_{MSY} (the 5th and 95th quantiles are 4.12 and 10.799). Based on these results we conclude that overfishing is occurring.

6. Estimated spawning biomass has declined to levels far below SB_{MSY} ($SB_{current}/SB_{msy}$= 0.66) and across all plausible model runs undertaken $SB_{CURRENT}$ is less than SB_{MSY} (the 5th and 95th quantiles are 0.47 and 0.93). Based on these results we conclude that the stock is overfished.
7. Noting that estimates of SB_0 and SB_{MSY} are particularly uncertain as the model domain begins in 1995, it is also useful to compare current stock size to that at the start of the model. Estimated spawning biomass has declined over the model period to 62% of the 1995 value for the reference case, and across the majority of the model runs model runs $SB_{current}/SB_{1995}$ has declined (the 5th and 95th quantiles are 50% decline and a 17% increase).
8. Current catches are higher than the MSY (5,950 mt versus 1,885 mt), further catch at current levels of fishing mortality would continue to deplete the stock below MSY. Current (2005-2008 average) and latest (2009) catches are significantly greater than the forecast catch in 2010 under F_{MSY} conditions (510 mt).
9. The greatest impact on the stock is attributed to bycatch from the longline fishery, but there are also significant impacts from the associated purse seine fishery which catches predominantly juvenile individuals, the fishing mortality from the associated purse seine fishery is above F_{MSY}.
10. Given the bycatch nature of fishery impacts, mitigation measures provides the best opportunity to improve the status of the silky shark population. Existing observer data may provide some information on which measures would be the most effective.
11. Given recent decisions to improve logsheet catch reporting and observer coverage in the longline fishery it is recommended that an updated assessment be undertaken in 2014.

A series of research recommendations are also provided.

1 Background

1.1 Distribution, reproduction and growth

Silky shark (*Carcharhinus falciformis*; FAL) are a circumtropical species found in tropical waters of the Pacific Ocean (Figure 1). Silky sharks inhabit the coastal and oceanic waters of the western and central Pacific ocean (WCPO) are considered a single stock for the purposes of this assessment. Silky sharks are one of the most commonly caught sharks in the tropical tuna fisheries (Clarke et al. 2011), but despite this our understanding of silky sharks biology ecology and movement patterns is limited (Bonfil 2008; Clarke et al. 2005, 2006). Although little directed work in the Pacific Ocean has be completed, information on the movements, migration and distribution of silky sharks in the Pacific can be inferred from previous, globally distributed studies (Strasburg 1958; Springer 1967; Branstetter 1987; Bonfil et al. 1990, 1993, Bonfil 1997, 2008).

Silky sharks show a preference for warmer tropical waters above 23˚C (Last and Stevens 1994). Bonfil (2008) suggests that for the first few years of life silky sharks in the Pacific Ocean lead demersal/semipelagic lifestyles associated with reefs and deeper parts of the continental and insular shelves before moving to more offshore and pelagic environments as sub-adults. At some point, probably when near 130cm in total length (TL), silky sharks switch to a more oceanic habitat where they often join schools of large pelagic fish (such as tuna) and may disperse seasonally from the equator to higher latitudes (Strasburg 1958, Bonfil 2008). Adult silky sharks are known to return seasonally to feed and reproduce in shelf waters, however near term pregnant females and neonates are also found in oceanic waters (Bonfil 2008). This pattern of life stage related movement patterns with adults travelling long distances (maximum recorded is 1,339 km) seems to be valid for silky sharks throughout the world (Kohler et al. 1998, Cadena-Cárdenas 2001, Bonfil 2008).

Multiple reproductive studies have been conducted for these species and reproduction is probably the best know aspect of this species' biology (Gilbert and Schlernitzauer 1965, 1966, Branstetter 1987, Bonfil et al. 1993, Cadena-Cárdenas 2001, Joung et al. 2008). The silky is viviparous with placental embryonic development, recent work by Joung et al. (2008) reports 8-10 pups per litter (based on 4 observations) with a 9-12 month gestation period. Oshitani et al. (2003) collected a larger sample size (153) of pregnant sharks from throughout the pacific and report an average litter size of 6 pups with a sex ration that is not statistically different than 1:1. A one year resting period in the has been suggested for sharks in the Atlantic and Eastern Pacific, though this is unconfirmed in those locals, and no mention of this occurs in the recent literature on silky shark reproduction in WCPO (Branstetter, 1987; Cadena-Cárdenas, 2001). Newborn silky sharks estimated size at birth is 63.5-75.5 cm in the northwest Pacific (Joung et al. 2008). Spawning season in the pacific spans much of the year (February- August) and is less well understood than in the Gulf of Mexico, where it has been estimated to be during the late spring (Branstetter 1987, Bonfil et al. 1993; Bonfil 2008). A positive correlation between maternal size and litter size has been found in both the central and eastern pacific (Cadena-Cárdenas 2001, Oshitani et al. 2003). Estimated sizes at 50% maturity for silky sharks in the western Pacific are 212.5 for males and 210-220 cm TL for females (Figure 2) (Joung et al. 2008).

There are two published studies of age and growth for silky sharks in the Pacific (Oshitani et al. 2003, Joung et al. 2008). Both studies counted growth bands on the vertebral centrum and estimated combined growth curves, however Oshitani et al. (2003) used the convex/concave central surface of longitudinally sectioned vertebrae to estimate the age of silky sharks while Joung et al. (2008) used the more conventional method of examination of translucent and opaque zones. The study by Oshitani et al. yielded estimate of 0.148 for the Von Bertalanffy growth coefficient *k* and an estimate for L_∞ =216.4 cm in pre-caudal length (PCL), while the Joung et al. (2008) study estimated k=0.0838 and L_∞ =332.0 cm TL. Joung et al. (2008) discuss the differences in these studies, the potential reasons for the differences, and contrast the methods used with age and growth studies of silky sharks in the Atlantic. In this study the relationship estimated by Joung et al. was used, with a corresponding longevity of 36 years for females, all reported lengths are in TL.

Estimates of population growth and natural mortality have been obtained using demographic methods for silky sharks in the Gulf of Mexico, with estimates of the intrinsic rate of increase and natural mortality being 0.102 and 0.17-0.21 respectively (Cortés, 2002).

1.2 Fisheries

In the WCPO silky sharks are encountered in small and medium scale multispecies fisheries as well as in the in the tuna longline and purse seine fisheries (Stevens and Wayte 1999, Clarke et al. 2011). For the purposes of this assessment the fisheries affecting silky sharks, can be broadly classified into four fleets, two composed of longline vessels (bycatch and target) and two purse seine (associated and un-associated sets) (Table 1). It should be noted that this study encompasses areas of the Philippines and eastern Indonesia, although it does so without data regarding biomass trends (CPUE) or catch amounts due to lack of information despite the knowledge that silky sharks are caught in small and medium scale fisheries in these areas.

Silky sharks are predominantly encountered as bycatch in the tuna fisheries and the tuna longline fleet has the greatest impact on the stock due to the overall effort. The tuna longline fleet operates throughout the Pacific, and mainly catches juveniles sharks less than 178cm and 191 cm TL for males and females. Observer records do indicate that some targeting has occurred historically in the waters of Papua New Guinea, and given the high value of shark fins and their abundance in the shark fin trade (Clarke et al. 2005, 2006) and low level of observer coverage (annual average coverage has been <1% from 2005-2008), it is likely that targeting does occur in other areas. The fleet from this region was separated from the main longline fleet due to the size of the FAL catch, their reporting of targeting sharks, and the expectation that the factors leading to catching FAL while targeting them would be different than catching FAL as bycatch. Catch and effort data for these fleets were standardized separately (see SC8- SA-IP-11 [Catch per unit effort of silky sharks in the Western Central Pacific Ocean] for more information).

Purse seine fleets usually operate in equatorial waters from 10°N to 10°S; although a Japan offshore purse seine fleet operates in the temperate North Pacific. The vessels mainly target skipjack tuna and FAL are caught in the process. The purse seine fishery is usually classified by set type categories – sets on floating objects such as logs and fish aggregation devices (FADs), which are termed "associated sets" and sets on free-swimming schools, termed "unassociated sets". These different set types have somewhat different spatial distributions, catch per unit effort (CPUE) and catch similar sizes of silky sharks. Although all sizes are present in the catch composition for both types of sets, associated sets in the WCPO catch predominantly small and medium sized sharks (<150cm); which is contrast to the eastern Pacific majority of the bycatch in the associated sets consists of small silky sharks (<90cm TL, Watson et al. 2008)

Information on FAL catches in the WCPO is sparse due to limited observer data collection prior to 1995. Theoretically the bycatch of FAL in the tuna fishery would be affected by the level of effort in the tuna fishery. Estimates of catches have been increasing slowly since 1997 (Figure 2), mainly due to the sustained decline in longline catch rate (Lawson 2011). Historically, most of the purse seine catch has been taken from the western equatorial region, which experienced a sharp increase from about 500,000–800,000 mt in the 1990s to approximately 1,200,000 mt in 2007–2009. This increase along with a large increase in the purse-seine fishery (Williams and Terawasi 2011) in the eastern equatorial region of the WCPO could imply large increases in fishing mortality for FAL over the last two decades.

1.3 Previous assessments

This is the first stock assessment of silky sharks in the WCPO and only the third full integrated stock assessment undertaken for a pelagic shark stock in the Pacific Ocean following the north pacific blue shark assessment of Kleiber et al. (2009) and the oceanic whitetip shark stock assessment by Rice and Harley (2012). Silky sharks, along with oceanic whitetip sharks, were identified in the WCPFC Shark Research Plan (SRP) for assessment during 2011/12. For 2012/13 the focus of the SRP will shift to blue and mako sharks (Clarke and Harley 2010).

2 Data compilation

Data used in the silky assessment consist of catch, effort and length-frequency data for the fisheries defined above. In comparison to most WCPO assessments for tunas, the assessments for silky sharks draw heavily on observer data for estimating CPUE, and catch. Details of the analyses of the observer data for CPUE and catch are provided in separate information papers and only briefly described here. Estimates of the biological parameters were taken from literature (e.g. Cortés 2002, Oshitani et al. 2003, Joung et al. 2008).

2.1 Spatial stratification

The geographical area considered in the assessment corresponds to the western and central Pacific Ocean from 30°N to 30°S and from oceanic waters adjacent to the east Asian coast to 150°W, following the boundaries of the eastern boarder of the WCPO convention area. The assessment model area comprises one region (Figure 1).

2.2 Temporal stratification

The time period covered by the assessment is 1995–2009. Within this period, data were compiled into annual values. The heavy reliance on observer data and the need to conduct two assessments simultaneously (silky sharks and oceanic whitetip sharks) meant that key model inputs were generated in late 2011 and there were still significant data gaps in 2010 observer data.

2.3 Catch Estimates

Estimation of unobserved shark bycatch by pelagic longline and purse seine fisheries is difficult for multiple reasons, including 1) data are generally limited in quantity and quality, 2) sharks are usually taken as bycatch or incidental catch which may be reported as ‘total sharks’ if reported at all (Camhi et al. 2008, Pikitch et al. 2008), 3) when reported, catch data are likely to be biased by underreporting, and nonreporting of discards (Camhi 2008). For example; significant under- and non-reporting of blue shark (*Prionace glauca*) in the Hawaii longline fishery have been documented (Walsh et al. 2002) despite some of the best monitoring circumstances (Walsh et al. 2005, 2007).

Estimates of catches (Lawson 2011) were used (Table 2, Figure 3) as the primary catch series in the silky shark assessment. Because Lawson estimated two time series of catches (for the purse seine and longline), catch data for the four the fisheries defined above had to be estimated by partitioning the total catch according to the annual proportion of effort in each fishery. The annual catch estimates from all fisheries, were expressed in numbers of fish. Based on the methods in Lawson (2011), two alternate catch histories were developed to explore the effect of different estimation techniques and magnitudes in the catch histories (Table 2, Figure 3 & Rice 2012a). The main differences between the methods used to generate previous estimates (Lawson 2011) and this study’s estimates are in the filtering of data to reflect only the core range of the silky shark and that an annual CPUE surface was used as opposed to the temporally-aggregated CPUE surface. A second catch estimate of twice the values estimated in this study was also included grid to explore the effect of much larger catch rates. Annual estimated weight in catch based on catch in numbers (Lawson 2011) is presented in Figure 4.

2.4 CPUE and standardised effort time series

Standardized catch per unit of effort series for all fisheries were used in the current assessment (Figure 5). For technical details and presentation of model fits see Rice (2012b). In brief, standardized CPUE series were estimated for silky sharks in the western central Pacific based on observer data held by SPC and collected over the years 1995- 2009. In late 2011 when the analysis was undertaken, there was insufficient longline observer data for 2010 and these data are critical for both CPUE and catch inputs to the stock assessment. For purposes of analysis the datasets were separated into two longline series (bycatch and target) and two purse seine series (unassociated and associated sets) and a standardized CPUE series was generated for each.

The data underlying the CPUE analysis comes from the same area in the ocean throughout the time series, except for the longline data which is missing the data from the Hawaiian Islands years 2005-2009. The trends in the nominal and standardized CPUE are similar for all defined fisheries except the bycatch longline fishery which differs in the first year and the last 6 years. This difference is based on the effect of including vessel as a covariate (Rice 2012b). Although the longline observer data is useful, inclusion of the observer data from Hawaii would improve the predictive power of these models, recent analysis of Hawaiian observer data (Walsh and Clarke 2011) shows different trends (large fluctuations and no apparent overall change) to the trends estimated by Rice (2012b). In contrast to this, work by Clarke et al. (2011b) on the observer data collected by the Japanese research and training vessels suggests a decline in nominal and standardized CPUE for FAL in the region around Hawaii, despite an overall increase in sets marked as targeting sharks.

2.5 Length-frequency data

Available length-frequency data from SPC holdings for each of the defined fisheries were compiled into 156 2-cm size classes (11-13 cm to 323-325cm). Length-frequency observations consisted of the actual number of FAL measured in each fishery by year. A graphical representation of the availability of length samples is provided in Figure 5. There is evidence of a decrease in the length of FAL caught over the last decade in the longline and purse seine fishery (Clarke 2011) which should inform the assessment model. The weight (effective sample size) of all length frequency data was reduced to 0.01 times the number of individual sets sampled with an alternate run with a scalar of 0.05. The effective sample size is typically lower than the number of fish sampled because the samples are not independent.

The observer data indicates that longline fisheries principally catch immature FAL, within the 70-200cm length range. The purse seine observer data indicates that the equatorial purse-seine fisheries catch larger (and far fewer) silky sharks in the unassociated sets than the associated sets. Although the full range of size class is present in both fisheries, 93% of the silky sharks caught in the associated sets are <150cm TL as opposed to 45% in the unassociated sets. The length frequency information came from roughly the same spatial area throughout the time period for both fleets (Figures 5 and 6) with the exception of the lack of the Hawaiian longline observer data in 2005-2009.

3 Model description – structural assumptions, parameterisation, and priors

As with any model, various structural assumptions have been made in the FAL model. Such assumptions are always a trade-off to some extent between the need, on the one hand, to keep the parameterization as simple as possible, and on the other, to allow sufficient flexibility so that important characteristics of the fisheries and population are captured in the model.

The assessment uses the stock assessment model and computer software known as Stock Synthesis (version 3.21B http://nft.nefsc.noaa.gov/Download.html.). The silky shark model is an age (36 years) structured, spatially aggregated (1 region) and two sex model. The catch, effort, size composition of catch, are grouped into 4 fisheries, all of which cover the time period from 1995 through 2009. The overall stock assessment model can be considered to consist of several individual models, namely (i) the dynamics of the fish population; (ii) the fishery dynamics; (iii) observation models for the data; (iv) parameter estimation procedure; and (v) stock assessment interpretations. Where each sub-model is given a different weight based on the underlying assumptions about the data inputs and fixed parameter values. Detailed technical descriptions of components (i) – (iv) are given in Methot (2011). The main structural assumptions used in the FAL model are discussed below and are summarised for convenience in Tables 3 and 4.

3.1 Population dynamics

The model partitions the population into 36 yearly age-classes in one region, defined as the WCPO between 30˚S and 30˚N and the eastern and western boundaries of the WCPO. The last age-class comprises a "plus group" in which mortality and other characteristics are assumed to be constant. The population is "monitored" in the model at yearly time steps, extending through a time window of 1995-2009. The main population dynamics processes are as follows:

3.1.1 Recruitment

"Recruitment" in terms of the SS3 model is the appearance of age-class 1 fish (i.e. fish averaging 90 cm) in the population. The results presented in this report were derived using one recruitment episode per year, which is assumed to occur at the start of each year. Annual recruitment deviates from a Beverton and Holt stock-recruitment relationship (SRR[2]) were estimates, but tightly constrained reflecting the limited scope for compensation given estimates of fecundity. For the purpose of computing the spawning biomass, we assume a logistic maturity schedule based on length with the age at 50% maturity equal to 215 cm (Joung et al. 2008).

The steepness (h) of the stock-recruitment relationship is defined as the ratio of the equilibrium recruitment produced by 20% of the equilibrium unexploited spawning biomass to that produced by the equilibrium unexploited spawning biomass (Mace and Doonan 1988). It is rare for stock assessment models to reliably estimate steepness, but the key productivity parameters for FAL are extremely low (e.g. very low fecundity). Therefore steepness was fixed and included in the grid at three separate values 0.342, 0.409 and 0.489[3]. Deviations from the SRR were estimated in two parts; the early recruitment deviates for the 5 years prior to the model period; and the main recruitment deviates that covered the model period (1995-2009).

There is no information which indicates that sex ratio differs from parity throughout the lifecycle of FAL. In this assessment the term spawning biomass (SB) is a relative measure of spawning potential and is a unitless term of reference. It is comparable to other iterations of itself (e.g. $SB_{CURRENT}/SB_{MSY}$) but not to total biomass.

3.1.2 Age and growth

The standard assumptions made concerning age and growth in the SS3 model are (i) the lengths-at-age are assumed to be normally distributed for each age-class; (ii) the mean lengths at age are assumed to follow a von Bertalanffy growth curve. For any specific model, it is necessary to assume the number of significant age-classes in the exploited population, with the last age-class being

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[2] An alternative formulation for the relationship between spawning biomass and recruitment was considered based on Taylor et al. (in press). We encountered considerable stability problems in the estimation procedure when using this formulation, e.g. the model 'converged' to a low gradient without actually fitting the CPUE series. For this reason we have not included these model runs in the assessment at this time, but recommend further consideration of this approach in the future.

[3] These values relate to assumed levels of steepness of 0.3, 0.4, 0.5 under the Taylor et al. (in press) parameterization which was not persisted with in the final set of model runs.

defined as a “plus group”, i.e. all fish of the designated age and older. This is a common assumption for any age-structured model. For the results presented here, 36 yearly age-classes have been assumed, as age 36 corresponds to the age at the theoretical maximum length. Growth was not estimated in the model, but rather was fixed according to the relationship in Joung et al. (2008). Growth was assumed to be the same for both sexes (Joung et al. 2008).

3.1.3 Natural mortality

Natural mortality was assumed to be constant throughout age classes and in time, with the natural mortality set according to the values in the grid, the initial reference value of 0.18 assumed based on a range of estimates (0.1-0.21) from demographic methods (Cortés, 2002). For the grid we included alternative values of 0.1 and 0.26.

3.1.4 Initial population size and structure.

It is not assumed that the FAL population is at an unfished state of equilibrium at the start of the model (1995). The population age structure and overall size in the first year is determined as a function of the first years recruitment (R1) offset from virgin recruitment (R0), the initial ‘equilibrium’ fishing mortality, and the recruitment deviations prior to the start of the year. In this model the R1 offset, and the recruitment deviations are estimated. Typically initial fishing mortality is an estimated quantity, but due to the lack of catch at age data (that would be critical to estimate the total mortality experienced by the population at the start of the model) and no information on pre-1995 removals, this was not possible. Instead the initial fishing mortality was fixed at three levels (0.05, 0.1, and 0.2) within the grid. For reference the estimated F_{MSY} was in the range 0.05 to 0.1.

3.2 Fishery dynamics

3.2.1 Selectivity

Selectivity is fishery-specific and was assumed to be time-invariant. Selectivity coefficients have a range of 0-1, and for the longline bycatch fishery selectivity was assumed to be dome shaped with a maximum at 172cm (Figure 9). Selectivity for the target longline fishery was also assumed to be dome shaped but with maximum selectivity value that ranged from 168cm to 204cm. The selectivity for purse seine unassociated sets was assumed to be logistic with size at inflection of 64cm. The selectivity of the purse seine associated sets was estimated using a cubic spline parameterisation[4]. All selectivities were initially estimated with all other parameters fixed at the reference values, to produce the ‘best selectivity estimate’. The resulting estimated selectivity was then fixed at the best estimate for the grid of runs.

3.2.2 Catchability and observation error

Given the lack of information regarding the change in abundance and CPUE, it was assumed that each CPUE trend was directly and independently proportional to abundance. This is calculated by assuming that the expected abundance index is based upon the sum retained catch B_{tf}, summed over the length, age and gender. The expected abundance index *G* is then related to the overall population abundance by

$$G_f = Q_f B_f \varepsilon_f$$

where, Q_f is the catchability coefficient for fishery *f*, ε_f is the observation error that is assumed to be lognormally distributed as: $\ln(\varepsilon_f) \sim N(-0.5\sigma_f^2, \sigma_f^2)$ where σ_f is the standard error of $ln(G_f)$, and *f* index the individual fisheries.

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[4] We used four nodes which allow considerable flexibility in the functional form while minimising the number of parameters required to be estimated.

Uncertainty in the standardized CPUE estimates was included in the model through the use of the nominal annual standard error of the mean ($\sigma/\sqrt{n}$, where σ is the annual standard deviation and n is the number of samples) scaled by the mean annual value to produce the coefficient of variation. This allows the model to reflect the uncertainty in the underlying data rather than standard errors resulting from the standardization process were in some cases unrealistically large or small.

3.3 Observation models for the data

For this model the total objective function is composed of the observation models for three data components– the total catch data, the length-frequency data and the CPUE data, along with the recruitment deviation, and parameter priors.

The objective function L is the weighted sum of the individual components indexed by year *i*, kind *j*, and fishery f for those observations that are fishery specific (the catch, length composition, and CPUE);

$$L = \sum_j \sum_f \omega_{if} L_{if} + \omega_R L_R + \sum_\theta \omega_\theta L_\theta$$

Where ω is a weighting factor for each objective function component, *R* indexes the likelihood for the recruitment deviates and θ indexes the likelihood for the priors. We briefly describe the likelihoods for each component here but omit the details for the sake of brevity, interested readers are referred to the Stock Synthesis Technical documentation (Methot, 2005).

The contribution to the objective function for the recruitment deviations is then defined as

$$L_R = \frac{1}{2\sigma_R^2} \sum_t \hat{R}_t^2 + n_r \ln(\sigma_R)$$

Where $\hat{R}_t$ is the deviation in recruitment which is lognormally distributed with the expected value equal the to the deterministic stock-recruitment curve, σ_R is the standard deviation for recruitment and n_r is the number of years for which recruitment is estimated (Methot, 2005).

The contribution for the parameter priors (L_θ) depends on the distribution for the prior Normal error structures can be used for all priors while symmetric beta distributions were used for the stock recruit parameters. The normal priors distribution for a parameter θ is then

$$L_\theta = 0.5 \left(\frac{\theta - \mu_\theta}{\sigma_\theta} \right)^2$$

where θ is the parameter, which is distributed $N(\mu_\theta, \sigma_\theta)$. The contribution to the objective function for the beta priors is;

$$L_\theta = \left(\ln(1-\theta') - \ln(1-\mu'_\theta) \right) (\theta_A - 1) + \left(\ln(\theta') - \ln(\mu'_\theta) \right) (\theta_B - 1)$$

where θ' is the θ parameter rescaled into [0,1], μ'_θ is the prior mean rescaled into [0,1], , μ_θ is the input prior, σ_θ is the standard deviation after rescaling into [0,1] and θ_A & $\theta_B$are derived quantities relating to the beta function (Methot, 2005).

The contribution of the length composition to the objective function is then defined as

$$L_{LengthComp} = \sum_t \sum_\gamma n_{tfl\gamma} + \sum_l p_{tf\gamma} \ln(p_{tfl\gamma} / \hat{p}_{tfl\gamma})$$

where $n_{tf\gamma}$ is the number of observed lengths in the catch at each time step *t* for fishery f in length bin l, gender γ and $p_{tfl\gamma}$ is the observed proportion of the catch at each time step *t* for fishery f in length bin l, gender γ, and $\hat{p}_{tfl\gamma}$ is the corresponding expected proportion of the catch at each time step *t* for fishery f in length bin l, gender γ (Methot, 2005).

The objective function component for CPUE is defined as

$$L_{CPUE} = 0.5 \sum_t \left(\frac{\ln(G_{tf}) - \ln(\hat{G}_{tf})}{\sigma_{CPUE,t,f}} \right)^2$$

Where for the expected abundance index *G* is then related to the overall population abundance by

$$G_{\ f} = Q_f B_{\ f}\, \varepsilon_{\ f}$$

Where, Q_f is the catchability coefficient for fishery *f*, $\varepsilon_{\ f}$ is the observation error that is assumed to be lognormally distributed as: $\ln(\varepsilon_f) \sim N(-0.5\sigma_f^2\ , \sigma_f^2)$ where $\sigma_{\ f}$ is the standard error of *ln(G$_f$)*, *B$_f$* is the biomass estimate for fishery *f.*

The contribution to the objective function component for catch is defined in terms of biomass, and is defined as

$$L_{CATCH} = 0.5 \sum_v \sum_t \left(\frac{\overline{\mathrm{w}}_{\mathrm{tf}} - \widehat{\mathrm{w}}_{\mathrm{tf}}}{\sigma_{CATCH,t,f}} \right)^2$$

Where $\overline{\mathrm{w}}_{\mathrm{tf}}$, $\widehat{\mathrm{w}}_{\mathrm{tf}}$, and $\sigma_{CATCH,t,f}$ are the observed mean weight, the expected mean weight and the standard deviation (respectively) of the catch by fishery *f* at time *t, v* indexes the observations (Methot, 2005). The observed total catch data were assumed to be unbiased and relatively precise, with the standard error of the log of the catch being 0.05. Because catch was specified in numbers the observed catch was converted to biomass based on the estimated population structure and fishery selectivity.

3.4 Assessment Strategy

Due to the reliance on observer data and the general lack of knowledge of silky shark biology when compared to the tropical tunas, a different approach was taken to this assessment. It was generally difficult to identify with confidence which clearly were the most appropriate data inputs or structural assumptions to make in a model, and/or some of the data inputs are contradictory (e.g. CPUE trends in different fisheries). Therefore the focus was on establishing the key areas of uncertainty and then within each area, identifying a small number of alternative hypotheses that a relative plausibility could be assigned to. In this assessment we identified seven key areas on uncertainty and for each of these we identified 2-3 alternative hypotheses. These are listed below and described in further detail in Table 4, with the reference case parameters listed in bold.

- Catch (3 different time series)
- CPUE (2 alternate scenarios)
- Natural Mortality (3 different values)
- Steepness (3 different values)
- Initial fishing mortality (3 different values)
- Effective Sample Size weighting (2 values)
- Standard Deviation of the Recruitment deviates (2 different values).

We examined all possible combinations to give a 'grid' over 648 models. Each model had its own overall weight calculated as the product of the probability (plausibility) assigned to the hypotheses under each area of uncertainty. The model run which had the most plausible hypothesis under each area of uncertainty was our reference case model, the values associated with each parameter are listed in Table 4.

For simple sensitivity analysis we identified those model runs from the grid which represented just a single change from the reference case model – this gave 11 sensitivity analyses.

3.5 Parameter estimation and uncertainty

The parameters of the model were estimated by maximizing the log-likelihoods of the data plus the log of the probability density functions of the priors, and the normalized sum of the recruitment deviates estimated in the model. The maximization was performed by an efficient optimization using exact numerical derivatives with respect to the model parameters (Fournier et al. 2012). Estimation was conducted in a series of phases, the first of which used arbitrary starting values for most parameters. The control file FAL.ctl documenting the phased procedure, initial starting values and model assumptions is provided in Appendix A.

The Hessian matrix computed at the mode of the posterior distribution was used to obtain estimates of the covariance matrix. This was used in combination with the Delta method to compute approximate confidence intervals for parameters of interest. The four top weighted models were analysed with markov chain Monte Carlo simulation to provide an estimate of the statistical uncertainty with respect to the estimated and derived parameters. 1,000,000 function evaluations thinned every 100 with a 1000 iteration burn in period.

3.6 Stock assessment interpretation methods

Several ancillary analyses were conducted in order to interpret the results of the model for stock assessment purposes. Note that, in each case, these ancillary analyses were completely integrated into the model, and therefore confidence intervals for quantities of interest are available using the Hessian-Delta or MCMC approaches. The standard yield analysis consists of computing equilibrium catch, adult and total biomass, conditional on the current average fishing mortality, and the same reference points at the theoretical MSY. The ratios of the current (or recent average) levels of fishing mortality and biomass to their respective levels at MSY are of interest as reference points.

For the standard yield analysis, the *F* values are determined as the average over some recent period of time. In this assessment, we use the average over the period 2005–2008. The last year in which catch and effort data are available for all fisheries is 2009. We do not include 2009 in the average as fishing mortality tends to have high uncertainty for the terminal data years of the analysis, and the catch and effort data for this terminal year are usually incomplete. Many models had a downward trend in the biomass and an upward trend in the cumulative fishing mortality over the years 2005-2008, so the reference points based on the average current may be biased. Due to uncertainty in the data and the extrapolation necessary to estimate virgin biomass and the corresponding spawning stock size an additional reference point, depletion since 1995 is also used to summarize the impact of fishing.

4 Results

This section provides a detailed summary of the results from the reference-case assessment. Also presented for comparison of important results are the eleven sensitivity analyses. A summary of the overall grid based on the quantiles of the output incorporating the model weights is presented for the runs based on the bycatch CPUE and the overall grid.

4.1 Reference case

Detailed results and diagnostics are presented for the reference case. The reference case model was catch from Lawson (2011), natural mortality = 0.18, initial fishing mortality=0.1, sample size weighting = 0.1, CPUE trend based on the bycatch longline, and SigmaR=0.1 and steepness=0.409. The reference case was one of 4 models with equal weighting, but was selected randomly. Uncertainties in the reference case model are explored via a sensitivity analysis.

4.1.1 Fit of the model to the data, and convergence

A summary of the fit statistics for the reference case and sensitivity analyses is given in Table 5. Due to differences in the catch and effort data sets, the total likelihood values are not comparable between all runs.

The fit of the model to the CPUE data was within expectation for the reference case (bycatch LL CPUE), because the model is constrained by the biology of the species and the catch data do not provide a basis for a large increase and then decrease in biomass the observed trend balances the lack of fit through the observed CPUE with a declining trend (Figure 10). There was a consistent lack of fit for the alternate CPUE data (target LL and both purse seine) (Figure 10). The lack of fit with the alternate CPUE data is driven by the conflict of the CPUE and the biological parameters with respect to the estimated catch.

The size composition of individual length samples is roughly consistent with the predicted size composition of the overall exploitable component of the population (Figure 11). The observed variation in the length composition is likely to reflect variation in the distribution of sampling effort between the individual fisheries and sampling programs given that FAL are predominantly bycatch. The effect of these data has also been down-weighted in the likelihood to reflect this variability.

4.1.2 Recruitment

The time-series of recruitment estimates is shown in Figure 12 with recruitment tightly coupled to the spawning stock biomass size. Overall, recruitment was estimated to decline over the model period (1995-2009) due to a reduction in the spawning stock biomass. A time series of recruitment is presented in Figure 12.

4.1.3 Biomass

The total and spawning biomass trajectories for the reference case are presented in Figure 13. We also present the depletion from 1995 because estimates of overall virgin biomass are uncertain, even in scenarios with excellent data and more so when only recent CPUE data is available and the catch is estimated, such as in the current model. The highest biomass (and lowest depletion) occurs during the initial year of the model and the biomass steadily declines throughout the model period, correspondingly the depletion increases. Time series plots of spawning biomass depletion, relative to 1995 and MSY for all runs and shaded by probability are shown in Figure 14.

4.1.4 Fishing mortality and the impact of fishing

Yearly average fishing mortality rates are shown in Figure 15. The non-target LL is by far the largest component of the overall F, increasingly rapidly from the assumed levels of 0.1 in 1995 to a high of over 0.4 in 2009. The next highest component of F is the associated purse seine fishery which increases to approximately 0.15 by 2009, which on its own is above the estimated F_{MSY} = 0.077. Compared to the longline fleets associated purse seine fishery has a disproportionate effect on the overall fishing relative to the number of fish it catches due to the fact that it catches predominantly juveniles.

4.1.5 Yield and reference point analysis

Biomass estimates, yield estimates, and management quantities for the reference case are presented in Table 7. For the reference-case, MSY is estimated to be 1,885 mt per annum at a level of fishing effort approximately 16% of the current level of fishing mortality. Therefore to reduce fishing mortality to the MSY level would require a reduction of 84%. The level of average current catch (5,950 mt) is higher than the estimated MSY. The estimate of current biomass is 38,200 mt, which is 72.5% of B_{MSY}.

Current estimates of stock depletion are that the total biomass has been reduced to 28% of theoretical equilibrium virgin biomass. Although estimates of virgin biomass are inherently uncertain due to the extrapolation necessary, this level of decline is evident over just the model period, with spawning biomass having been reduced by 38% ($SB_{Current}/SB_{1995}$ = 0.62). This decline is consistent with a $F_{CURRENT}/\tilde{F}_{MSY}$ value of 6.4.

4.1.6 Sensitivity analyses and structural uncertainty grid

Sensitivity to several alternative scenarios was examined in a grid, in which all scenarios were interacted with one another (Table 7). Sensitivity analyses are also presented for the Catch_2, Catch_3, CPUE_2, Nat_M_1, Nat_M_3, Steep_1, Steep_3, Initi_F_1, Initi_F_2, Samp.SZ_2 and SigmaR_2 model runs in Table 7. The biomass and recruitment time series for these runs are shown in Figure 16.

The model was most sensitive to the CPUE input data, which dictated the overall model results with respect to stock status (Table 7). All runs that included the target longline and purse seine CPUE trends estimated a current total biomass in excess of 150,000,000mt. This value is more than 18 times greater than the combined 2010 estimate of bigeye, south Pacific albacore, skipjack and yellowfin tuna total biomass combined. Therefore these runs are not considered plausible; the final results are down weighted to reflect the implausibility regarding the extreme results.

Each scenario was weighted based upon the values included in the model run (Table 4), results are presented here as the uncertainty grid and reflect a re-sampling of the results based on the weights described in Table 4. The reference case and the quantiles structural uncertainty grid are presented in Table 8, for the plausible runs as well as all the runs. The results of the grid are presented as weighted depletion trajectories (of $SB\ /SB_{MSY}$) in Figure 14, and as Kobe plots in Figure 17.

The effects of each of these alternative scenarios on the ratio-based management indicators $SB_{CURRENT}/SB_{MSY}$ (Figure 18), $B_{CURRENT}/B_{MSY}$ (Figure 19), and $F_{CURRENT}/\ \tilde{F}_{MSY}$ (Figure 20) are presented. The choice of CPUE series had the largest effect on the two biomass based management parameters $B_{CURRENT}/B_{MSY}$, and $SB_{CURRENT}/SB_{MSY}$, with initial fishing mortality having the second biggest effect. These two factors along with steepness, natural mortality and sample size weighting were the most influential factors on the management quantity $F_{CURRENT}/\ \tilde{F}_{MSY}$. The full array of management parameters for each alternate variable level (from the reference case) is also presented (Table 7). Both alternate catch time series (Catch_2 and Catch 3) along with the higher natural mortality estimate (Nat_M_3), lower initial fishing mortality (Init_F_1), and the alternate sample size (Samp.Sz_2) and the higher steepness (Steep_3) showed a more pessimistic stock status based on biomass ratios (lower $SB_{CURRENT}/SB_{MSY}$) (Table 7). Based on the management quantity $F_{current}/\ \tilde{F}_{MSY}$ the two the alternate catch time series (Catch_2 and Catch 3) along with the lower natural mortality estimate (Nat_M_1), and the lower steepness (Steep_1) showed a more pessimistic stock status (Table 7). The distributions of management parameters under the different model structure scenarios are also presented (Figure 19 and Figure 20). The 5th and 95th quantiles of structural uncertainty regarding the stock status ranged from 0.47 to 0.93 for $SB_{CURRENT}/SB_{MSY}$, from 0.48 to 0.99 for $B_{CURRENT}/B_{MSY}$ and from 4.1 to 10.8 for $F_{CURRENT}/\tilde{F}_{MSY}$. Note that exactly half of all runs in the grid estimated $F_{CURRENT}$ to be above $\tilde{F}_{MSY}$ (Figure 21), the ones that did not were coincident with unrealistically high estimates of biomass ($\hat{B}_0$>1e+9 mt & $B_{current}$> 150,000,000 mt) and unrealistically low fishing mortality (F=0). As mentioned previously we do not consider these runs to be plausible, results of the entire grid are included in Table 8 for completeness.

4.1.7 Stock status

Fishing mortality rates tended to increase over the modelling period, driven mainly by the increased effort in the longline fleet. The mortality rates remain substantially above the F_{MSY} level, $F_{CURRENT}/F_{MSY}$ =6.4 for the reference case and 6.04 for the median of the plausible runs (Table 8), therefore, we conclude that <u>overfishing of silky sharks is occurring</u>. Total biomass was estimated to be lower than the $\tilde{B}_{MSY}$ level for the reference case and the grid median, the current total biomass is 28% for the reference case and the grid median of the equilibrium unexploited level ($\tilde{B}_0$). The $SB_{CURRENT}/SB_{MSY}$ is 0.66 for the reference case and the grid median. The distribution of $B_{CURRENT}/B_{MSY}$ obtained from the structural uncertainty grid, indicates a high degree of uncertainty associated with the *MSY*-based biomass performance indicators (Table 8). Nonetheless, the only portion of the grid runs which indicated that $SB_{CURRENT}/SB_{MSY}$ or $B_{CURRENT}/B_{MSY}$ is ever above was associated with unrealistic runs. Based on these results the stock is in an overfished state.

5 Discussion

This is the first assessment of FAL sharks done in the Pacific and the second shark assessment conducted for the Western Central Pacific Fisheries Commission. Aside from the unique challanges of assessing a non-target species, silky shark is a very difficult species to assess due to the limitations of the CPUE data, reported landings, total mortality and minimal information on the life history and biology. This creates a situation where it is difficult to observe the effect of fishing on the population's biomass, despite knowing that the species commonly occurs as bycatch in the largest fisheries of the WCPO.

The WCPO assessment is reliant on the CPUE data and the catch estimates to estimate un-fished population sizes. The two different CPUE scenarios used in this analysis had different trends and as expected led to different results. Additional observer data exists and would be useful in constructing CPUE trends and catch estimates. In addition accurate reporting of FAL and other shark catch by commercial vessels would facilitate the estimation of catch. The two alternate catch histories had different magnitudes and but somewhat similar trends, and the resulting estimates of stock status were similar. This indicates that the status results incorporate the alternate assumptions made regarding catch size and trend based on current catch estimates. For example additional information regarding catch, effort and size composition, especially from the Philippines and Indonesia help construct more accurate catch and CPUE trends.

Estimates of biological and life history traits such as growth, natural mortality and the size at maturity are less well understood than for other shark species (e.g. blue and short finned mako sharks) though dependable estimates do exist for the Pacific (growth, and size at maturity) and can be borrowed from other oceans (natural mortality, rate of population increase). These studies are crucial to our understanding not only of the species at an individual level but also at the population level. The stock as a whole is limited by its intrinsic rate of growth and this helps inform and constrain the model. The low productivity of silky sharks helps constrain the model within plausible population dynamics. These factors combined with the reliance on observer data that is characterized by low spatial coverage and spotty temporal continuity necessitates an integrated modelling approach that can incorporate all available data.

Even with integrated models reliance on observer data, estimates rather than reports of landings and broad assumptions regarding a species' ecology and biology can produce different results based upon different sets of assumptions. Because the most appropriate data inputs and structural assumptions were not always clearly identifiable we applied a grid approach to investigating multiple alternate models. The goal of this approach is to produce an assessment that is robust to multiple assumptions regarding the model inputs. To evaluate this modelling framework and summarize the overall results we established a relative probability that could be assigned to each model and was the product of the plausibility of a models assumptions. This is the first time this technique has been applied to a WCPFC assessment but is recommended for assessments where multiple plausible states of nature exist.

The grid and weighting approach is suited for assessments where the data inputs are limited to a recent time period but the species has been historically impacted by fisheries. In this assessment uncertainty regarding the initial depletion was included in the grid because of the lack of historical landings or abundance data. The different levels of the initial depletion had a substantial impact on the terminal depletion levels of the plausible runs with the only runs that indicated the stock not being overfished coming from the first (and lowest) level of initial fishing mortality. This indicates that the historical landings have large impact on the current status and that further studies to quantify historical landings are warranted. This decline in catch rates corresponds with an increase in effort and a generally level estimate of catch (for the reference case) and is consistent with biological information indicating a low productivity stock that is experiencing increasing fishing mortality. The combination of increasing fishing mortality, increasing effort, sustained catch, declining CPUE and constraining biology give some additional certainty that the stock assessment results are in the correct quadrant of the Kobe plot.

Notwithstanding the critical concerns over stock status, in this assessment we have reported stock status in relation to MSY based reference points, but the actual reference points to be used to manage this stock have not yet been considered by the Scientific Committee or Commission. Reference points for bycatch species should be an area of important consideration for the Commission and the oceanic whitetip and silky shark stocks will provide useful candidates for the work.

This assessment addresses regional-scale stock abundance and status. Estimates of management quantities do not reflect upon the status of FAL in the eastern Pacific, or the results of potential localized depletion in either half of the ocean. Further work should include a Pacific wide assessment and inclusion of tagging results. This combined with additional biological work such as determining the pupping frequency, gestation period, and improved estimates of the relationship between length and fecundity could significantly improve any future modelling work. However obtaining adequate sample sizes would come at the cost of sacrificing what may be a significant portion of the fecund population.

Further development of the the methods and inputs for this stock assessment would greatly improve an updated stock assessment, which we recommend for 2014. The advantage of this is that we would have an assessment with 3 more years, potentially 4 more years of data with increased coverage rates for the observer data and better reporting on the levels of bycatch in commercial fisheries. Aside from another stock assessment there is ample opportunity for research regarding FAL, specifically in the areas of growth and reproductive biology, tagging, and MSE.

6 Conclusions

This is the first stock assessment for silky sharks in the WCPO. The key conclusions are as follows.

1. Notwithstanding the difficulties inherent in the input data, the size composition data shows consistent declines over the period of the model (1995-2009) which is coupled with increasing fishing mortality, and a recently declining CPUE trend.

2. The results of the model can be split into two categories which are mutually exclusive with respect to the estimates of stock status. These two categories are characterized by the CPUE input. All runs that included the target longline and purse seine CPUE trends estimated a current total biomass in excess of 150,000,000mt. Which is more than 18 times greater than the combined 2010 estimate of bigeye, south Pacific albacore, skipjack and yellowfin tuna total biomass combined. Therefore these runs are not considered plausible. The following results are based on the plausible runs only.

3. This is a low productivity species and this is reflected in the low estimated value for F_{MSY} (0.077) and high estimated value for SB_{MSY} $/SB_0$ (0.38). These directly impact on conclusions about overfishing and the overfished status of the stock.

4. Based on the highest probability model (the reference case), estimated spawning biomass, total biomass and recruitment all decline consistently throughout the period of the model. The biomass declines are driven by the CPUE series, and the recruitment decline is driven through the tight assumed relationship between spawning biomass and recruitment.

5. Estimated fishing mortality has increased to levels far in excess of F_{MSY} ($F_{CURRENT}/F_{MSY}$ = 6.4) and across nearly all plausible model runs undertaken estimated F values were much higher than F_{MSY} (the 5th and 95th quantiles are 4.12 and 10.84). Based on these results we conclude that overfishing is occurring.

6. Estimated spawning biomass has declined to levels far below SB_{MSY} ($SB_{CURRENT}/SB_{MSY}$= 0.66) and across all plausible model runs undertaken $SB_{CURRENT}$ is less than SB_{MSY} (the 5th and 95th quantiles are 0.47 and 0.93). Based on these results we conclude that the stock is overfished.

7. Noting that estimates of SB_0 and SB_{MSY} are particularly uncertain as the model domain begins in 1995, it is also useful to compare current stock size to that at the start of the model. Estimated spawning biomass has declined over the model period to 62% of the 1995 value for the reference case, and across the majority of the model runs model runs $SB_{CURRENT}/SB_{1995}$ has declined (the 5th and 95th quantiles are 50% decline and a 17% increase).

8. Current catches are higher than the MSY (5,353 mt versus 1,885 mt), further catch at current levels of fishing mortality would continue to deplete the stock below MSY. Current (2005-2008 average) and latest (2009) catches are significantly greater than the forecast catch in 2010 under F_{MSY} conditions (510 mt).

9. The greatest impact on the stock is attributed to bycatch from the longline fishery, but there are also significant impacts from the associated purse seine fishery which catches predominantly juvenile individuals, the fishing mortality from the associated purse seine fishery is above F_{MSY}.

10. Given the bycatch nature of fishery impacts, mitigation measures provides the best opportunity to improve the status of the silky shark population. Existing observer data may provide some information on which measures would be the most effective.

11. Given recent decisions to improve logsheet catch reporting and observer coverage in the longline fishery it is recommended that an updated assessment be undertaken in 2014.

12. As this was the first stock assessment, there are many research activities that could improve future assessments including:

    a. Increased observer coverage in the longline fishery, as this is the major component of fishing mortality. Additional information on the fate and condition at release would allow for a better modelling framework for decision making.

    b. This accuracy of this assessment could be significantly improved with data from Philippines and Indonesia regarding catch, effort and size composition of the corresponding shark catch.

    c. Additional modelling to standardize the CPUE for purse seine fisheries.

    d. Tagging studies which are critical for understanding stock structure and post release survival (e.g. Campana et al. 2009, Moyes et al. 2006).

    e. Further study to develop and implement an MSE approach that would allow for simulation testing of management strategies. This is the preferred framework because it permits direct testing of the benefits of alternative research options for management outcomes. We recommend development of a data simulator that can be used for management strategy evaluation, research prioritization, and simulation testing of stock assessment approaches.

    f. Increased reporting data from commercial fisheries regarding quantity and the fate of silky sharks caught in the longline and purse seine fisheries.

    g. Work to model the change in species composition in the purse seine observer data, from a generic ‘shark’ category to individual species.

h. Biological studies.

i. Studies on growth and reproductive biology – especially female maturity.

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8 References

Beerkircher, L., Shivji, M. and Cortés, E. (2003) A Monte Carlo demographic analysis of the silky shark (*Carcharhinus falciformis*): Implications of gear selectivity. Fishery Bulletin 101, 168–174.

Bonfil, R. (1997) Status of shark resources in the southern Gulf of Mexico and Caribbean: Implications for management. Fisheries Research 29, 101–117.

Bonfil, R. (2008). "The Biology and Ecology of the Silky Shark, Carcharhinus falciformis". In Camhi, M., Pikitch, E.K. and Babcock, E.A.. Sharks of the Open Ocean: Biology, Fisheries and Conservation. Blackwell Science. pp. 114–127.

Bonfil, R., de Anda, D. and Mena, R. (1990) Shark fisheries in México: The case of Yucatán as an example. In: Elasmobranchs As Living Resources: Advances in Biology, Ecology, Systematics, and the Status of the Fisheries (eds. H. L. Pratt Jr., S. H. Gruber and T. Taniuchi). NOAA Technical Report NMFS 90. NOAA/NMFS, Silver Spring, MD, pp. 427–441.

Bonfil, R., Mena, R. and de Anda, D. (1993) Biological parameters of commercially exploited silky sharks, *Carcharhinus falciformis*, from the Campeche Bank, México. In: Conservation Biology of Elasmobranchs (ed. S. Branstetter). NOAA Technical Report NMFS 115. NOAA/NMFS, Silver Spring, MD, pp. 73–86.

Branstetter, S. (1987) Age, growth and reproductive biology of the silky shark, Carcharhinus falciformis, and the scalloped hammerhead, Sphyrna lewini, from the northwestern Gulf of Mexico. Environmental Biology of Fishes 19, 161–173.

Cadena-Cárdenas, L. (2001) Biología reproductiva *Carcharhinus falciformis* (Chondrichthyes Carcharhiniformes: Carcharhinidae), en el Golfo de California. Bachelor's thesis, Departamento de Biología Marina, Universidad Autónoma de Baja California Sur, La Paz, Mexico, 66 pp.

Camhi, M. D. (2008) Conservation status of pelagic elasmobranchs. In: M. D. Camhi, E. K. Pikitch, and E. A. Babcock (eds.), Sharks of the Open Ocean: Biology, Fisheries, and Conservation, pp. 397–417. Blackwell Publishing Ltd. Oxford.

Camhi, M. D., E. Lauck, E. K. Pikitch and E. A. Babcock. (2008) A global overview of commercial fisheries for open ocean sharks. In: M. D. Camhi, E. K. Pikitch, and E. A. Babcock (eds.), Sharks of the Open Ocean: Biology, Fisheries, and Conservation, pp. 166–192. Blackwell Publishing Ltd. Oxford.

Campana, S.E., Joyce, W., Manning, M.J. (2009). Bycatch and discard mortality in commercially caught blue sharks Prionace glauca assessed using archival satellite pop-up tags. Marine Ecology Progress Series 387: 241–253.

Clarke, S. C., McAllister, M. K. and Michielsens, C. G. J. (2005) Estimates of shark species composition and numbers associated with the shark fin trade based on Hong Kong auction data. Journal of Northwest Atlantic Fishery Science 35, 453–465.

Clarke, S., Magnusson, J. E., Abercrombie, D. L., McAllister, M. and Shivji, M. S. (2006) Identification of shark species composition and proportion in the Hong Kong shark fin market based on molecular genetics and trade records. Conservation Biology 20, 201–211.

Clarke, S. (2011) A status snapshot of key shark species in the western and central Pacific and potential mitigation options. WCPFC-SC7-EB-WP-04.

Clarke, S., Harley, S., Hoyle, S., Rice, J. (2011) An Indicator based analysis of key shark species based on data held by SPC-OFP. WCPFC-SC7-EB –WP-04.

Clarke, S., Yokawa, K. Matsunaga, H., Nakano, H. (2011b) Analysis of North Pacific Shark Data from Japanese Commercial Longline and Research/Training Vessel Records. WCPFC-SC7-EB-WP-04. Accessed online at http://www.wcpfc.int/doc/eb-wp-02/analysis-north-pacific-shark-data-japanese-commercial-longline-and-researchtraining-ves

Clarke, S.C. and S.J. Harley. (2010). A Proposal for a Research Plan to Determine the Status of the Key Shark Species. WCPFC-SC6-2010/EB-WP-01. Accessed online at www.wcpfc.int/.../WCPFC-SC6-2010_EB-WP-01_Research_Plan_to_determine_status_of_Key_Shark_Species.pdf

Cortés, E. (2002) Incorporating uncertainty into demographic modelling: Application to shark populations and their conservation. Conservation Biology 16, 1048–1062.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Gilbert, P. W. and Schlernitzauer, D. A. (1965) Placentation in the silky shark, *Carcharhinus falciformi*s and bonnet shark, *Sphyrna tiburo*. The Anatomical Record 151(3), 452.

Joung, S.-J., Chen, C.T., Lee, H.H., Liu, K.-M. (2008) Age, growth, and reproduction of silky sharks, *Carcharhinus falciformis*, in northeastern Taiwan waters. Fisheries Research, 90 (1-3): 78-85.

Kleiber, P., Clarke, S.C., Bigelow, K., Nakano, H., McAllister, M., and Takeuchi, Y. (2009). North Pacific blue shark stock assessment. NOAA Technical Memorandum NMFS-PIFSC-17.

Kohler, N. E., Casey, J. G. and Turner, P. A. (1998) NMFS Cooperative Shark Tagging Program, 1962–93: An atlas of shark tag and recapture data. Marine Fisheries Review 60(2), 1–87.

Last, P. R. and Stevens, J. D. (1994) Sharks and Rays of Australia. CSIRO, Collingwood, Victoria, Australia.

Lawson, T. (2011). Estimation of Catch Rates for Key Shark Species in Tuna Fisheries of the Western and Central Pacific Ocean using Observer Data. WCPFC–SC7–2011 / EB–IP–02

Mace, P.M., and Doonan, I.J. (1988) A generalized bioeconomic simulation model for fish populations. New Zealand Fisheries Research Assessment Document 88/4.

Methot, R. D. (2005). Technical description of the Stock Synthesis II assessment program. NOAA Technical Memorandum SEDAR 16-AW-04.

Methot, R.D. (2011) User Manual for stock synthesis, Model Version 3.23b. http://nft.nefsc.noaa.gov/downloads/SS-323b-documentation.zip

Moyes, C.D., Fragoso, N., Musyl, M.K. and Brill, R.W. (2006) Predicting post-release survival in large pelagic fish. Transactions of the American Fisheries Society 135: 1389–1397.

Oshitani, S., Nakano, H, Tanaka, S. (2003) Age and growth of the silky shark *Carcharhinus falciformis* from the pacific ocean. Fisheries Research 69: 456-464.

Pikitch, E. K., M. D. Camhi and E. A. Babcock. 2008. Introduction to Sharks of the Open Ocean. In: M. D. Camhi, E. K. Pikitch, and E. A. Babcock (eds.), Sharks of the Open Ocean: Biology, Fisheries, and Conservation, pp. 3–13. Blackwell Publishing Ltd. Oxford.

Rice, J. (2012a) Alternative catch estimates Alternative catch estimates for silky and oceanic whitetip sharks in the WCPO. WCPFC-SC8-2012/SA-IP-12

Rice, J. (2012b) Standardization of catch per unit effort for silky sharks in the western central pacific ocean. WCPFC-SC8-2012/ SA-IP-11

Rice J. and Harley, S. (2012), Stock assessment of oceanic whitetip sharks in the western central pacific ocean. WCPFC-SC8-2012/SA WP-06

Springer, S. (1967) Social organization of shark populations. In: Sharks, Skates and Rays (eds. P. W. Gilbert, R. F. Mathews and D. P. Ralls). Johns Hopkins University Press, Baltimore, MD, pp. 141–174.

Stevens, J. D. and Wayte, S. E. (1999) A Review of Australia’s Pelagic Shark Resources. Final Report Project 98/107. Fisheries Research and Development Corporation, Deakin West, Australian Capital Territory, Australia, 64 pp.

Strasburg, D.W. (1958) Distribution, abundance and habits of pelagic sharks in the central Pacific Ocean. Fishery Bulletin 59, 335-361.

Taylor, I. G., V. V. Gertseva, R. D. Methot, M. Maunder. In press. A spawner-recruit relationship based on pre-recruit survival, illustrated with application to spiny dogfish shark. Fisheries Research.

Walsh, W. A., and S. C. Clarke. (2011). Analyses of catch data for silky and silky sharks reported by fishery observers in the Hawaii-based longline fishery in 1995−2010. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396. Pacific Islands Fish. Sci. Cent. Admin. Rep. H-11-10, 43 p. + Appendices.

Walsh, W. A., Bigelow, K. A., and Ito. R. Y. (2007) Corrected catch histories and logbook accuracy for billfishes (Istiophoridae) in the Hawaii-based longline fishery. NOAA Technical Memorandum NMFS-PIFSC-13.

Walsh, W. A., Ito, R. Y., Kawamoto, K. E., and McCracken. M. (2005) Analysis of logbook accuracy for blue marlin (*Makaira nigricans*) in the Hawaii-based longline fishery with a generalized additive model and commercial sales data. Fisheries Research 75:175–192.

Walsh, W. A., Kleiber, P. and McCracken, M. (2002) Comparison of logbook reports of incidental blue shark catch rates by Hawaii-based longline vessels to fishery observer data by application of a generalized additive model. Fisheries Research 58:79–94.

Watson, J.T., Essington, T.E., Lennert-Cody, C.E., Hall, M.A. (2009). Trade-offs in the design of fisheries closure: Management of silky shark bycatch in the eastern Pacific Ocean tuna fishery. Conserv. Biol. 23(3): 626-235.

Williams, P., and Terawasi, P. (2011) Overview of tuna fisheries in the western and central Pacific Ocean, including economic conditions – 2010. WCPFC-SC7-2011/GN WP-1

9 Tables

Table 1: Definition of fisheries for the silky shark analysis in Stock Synthesis 3. Gears: PS_UNA = purse seine unassociated set type; PS_ASSO = purse seine associated set type (log, floating object or FAD set); LL _non-tar= longline non target or bycatch; LL_tar= longline, target fisheries.

Fishery definitions		
Fishery code	Gear	Flag/fleet
1. LL_ non-tar	LL	ALL except PG
2. LL_ tar	LL	ALL
3. PS_ASSO	PS	ALL
4. PS_UNA	PS	ALL

Table 2. Total catch (in thousands of fish) used in the current assessment.

	Estimate Source		
	Lawson (2011)	Present Study	2* Present Study
Year	Catch (1,000s of sharks)		
1995	163.4	306.5	612.9
1996	164.6	411.3	822.6
1997	163.1	191.7	383.3
1998	192.4	159.0	318.0
1999	202.7	296.7	593.4
2000	194.4	259.1	518.3
2001	184.1	292.8	585.6
2002	185.0	263.3	526.7
2003	153.5	279.7	559.3
2004	187.7	317.5	635.1
2005	193.0	218.2	436.4
2006	214.5	299.3	598.6
2007	246.0	427.4	854.8
2008	263.9	423.2	846.3
2009	258.8	488.6	977.2

Table 3. Main structural assumptions used in the reference case model.

Category	Assumption
Observation model for total catch data	Observation errors small, equivalent 0.5 on the log scale.
Observation model for length-frequency data	Normal probability distribution of frequencies with variance determined by sample size and observed frequency. Effective sample size varies among fisheries, assumed at most to be 0.01 times actual sample size.
Recruitment	Occurs as discrete events at the start of each year. Spatially-aggregated recruitment is related to spawning biomass in the prior year via a Beverton-Holt SRR (steepness fixed at the 0.409). Deviates from annual recruitment are estimated with the maximum fixed standard deviation set to 0.1.
Initial population	The population age structure and overall size in the first year is determined as a function of the first years' recruitment (R1) offset from virgin recruitment (R0), the initial 'equilibrium' fishing mortality, and the recruitment deviations prior to the start of the year. The R1 offset, and the recruitment deviations are estimated. The initial fishing mortality was fixed at 0.1 for the reference case.
Age and growth	36 yearly age-classes, with the last representing a plus group. Individual age-classes have independent mean lengths constrained by von Bertalanffy growth curve. Mean weights were computed internally by estimating the distribution of weight-at-age from the distribution of length-at-age and applying the weight-length relationship $W = aL^b$(a=2.92e-06, b=3.15, based on a study from FAL in the western central pacific (Joung et al. 2008)).
Selectivity	The longline bycatch fishery selectivity was assumed to be dome shaped with the maximum selectivity occurring at 172cm. Selectivity for the target longline fishery was assumed to be dome shaped with a maximum selectivity value at 170cm. The selectivity of the purse seine associated sets was estimated using a cubic spline parameterisation. Selectivity's for purse seine unassociated sets were assumed to be logistic with size at inflection of 63.
Catchability	Catchability is calculated independently for all fisheries and each CPUE trend was directly and independently proportional to abundance via the catchability term.
Natural mortality	Natural mortality was assumed to be constant throughout age classes and in time, with the natural mortality for the reference case set according to 0.18, calculated according to the relationship of Pauly (1980).

Table 4. Key areas of uncertainty included in the grid. The values from the reference case model are highlighted in bold.

Variable	Number of levels	values	Weights
Catch	3	**Lawson**, present study , 2* present study	0.6, 0.2, 0.2
CPUE Time series	2	**LL_ non-tar**; LL_Tar&PS_ASSO&PS_UNA	0.75, 0.25
Natural Mortality	3	0.1, **0.18**, 0.26	0.25, 0.5, 0.25
Steepness	3	0.34, **0.41**, 0.49	0.25, 0.5, 0.25
Initial Fishing mortality	3	0.05, **0.1**, 0.2	0.2, 0.4, 0.4
Sample size weighting	2	**0.01**, 0.05	0.5, 0.5
Sigma R	2	**0.1**, 0.25	0.67, 0.33

Table 5. Comparison of the objective function and likelihood components. Those with grey shading are directly comparable and lower is better.

	Objective function component					
Model Run	Catch	Survey	Length_comp	Recruitment	Priors	TOTAL
Reference	**4.10E-04**	**61.93**	**35.11**	**-21.90**	**0.16**	**75.31**
Catch 2	5.77E-03	58.20	35.26	-22.05	0.14	71.55
Catch 3	5.77E-03	58.20	35.26	-22.05	0.11	71.52
CPUE 2	7.80E-08	235.97	35.35	-5.15	0.03	266.19
Nat_M_1	**2.46E-04**	**61.62**	**37.58**	**-22.45**	**0.19**	**76.94**
Nat_M_3	**3.27E-04**	**61.82**	**37.10**	**-21.41**	**0.14**	**77.65**
Steep_1	**1.67E-04**	**63.51**	**35.04**	**-22.05**	**0.16**	**76.66**
Steep_3	**9.15E-04**	**60.52**	**35.33**	**-21.69**	**0.17**	**74.33**
Init_F_1	**4.47E-04**	**60.10**	**35.16**	**-21.86**	**0.17**	**73.58**
Init_F_3_	**3.20E-04**	**68.02**	**35.34**	**-21.90**	**0.15**	**81.61**
Samp.Sz_2	3.93E-04	62.51	88.83	-22.35	0.16	129.16
SigmaR_2	1.62E-04	49.30	36.23	-7.38	0.17	78.32

Table 6: Description of symbols used in the management quantity analysis

Management Quantity	Units	Description
C_{Latest}	t	Estimated catch in 2009
$C_{Current}$	t per annum	Average Current (2005- 2008) Catch
$\tilde{Y}_{F_{MSY}}$	t per annum	Theoretical equilibrium yield at F_{MSY}, or maximum sustainable yield (MSY).
$\tilde{B}_0$	t	Equilibrium total unexploited biomass
$\tilde{B}_{MSY}$	t	Equilibrium total biomass at MSY
$B_{current}$	t	Average Current (2005-2008) total biomass
$\tilde{SB}_0$	t	Equilibrium unexploited adult biomass
$\tilde{SB}_{MSY}$	t	Equilibrium adult biomass at MSY
$SB_{current}$	t	Average Current (2005-2008) adult biomass
SB_{1995}		Estimated adult biomass in 1995
F_{msy}		Average Current (2005-2008) fishing mortality.
$F_{current}$		Fishing mortality producing the maximum sustainable yield (MSY)

Table 7: Estimates of management quantities for the reference case and sensitivity runs. For a details on the management quantities, see Table 6.

Management Quantity	Units	Reference	Catch_2	Catch_3	CPUE_2	Nat_M_1	Nat_M_3	Steep_1	Steep_3	Init_F_1	Init_F_3_	Samp.Sz_2	SigmaR_2
C_{Latest}	t	5,950	11,761	23,522	7,222	7,655	5,008	6,222	5,661	5,989	5,890	5,975	6,155
$C_{Current}$	t per annum	5,353	8,284	16,568	5,928	6,704	4,573	5,514	5,180	5,405	5,237	5,348	5,659
$\tilde{Y}_{F_{MSY}}$	t per annum	1,885	2,926	5,851	7,326,420	2,244	1,641	1,571	2,139	1,656	2,433	1,889	1,822
$\tilde{B}_0$	t	136,918	206,795	413,594	548,594,000	308,527	85,633	156,072	120,653	120,265	176,904	137,305	132,627
$\tilde{B}_{MSY}$	t	52,669	79,144	158,291	211,652,313	121,104	32,333	64,974	42,251	46,262	68,057	52,821	51,027
$B_{current}$	t	38,200	57,037	114,074	434,338,000	88,684	24,742	44,758	32,700	39,921	36,064	38,355	43,104
$S\tilde{B}_0$	t	2,069	3,124	6,249	8,288,150	5,333	984	2,358	1,823	1,817	2,673	2,074	2,004
$S\tilde{B}_{MSY}$	t	796	1,196	2,391	3,197,640	2,093	372	982	638	699	1,028	798	771
$SB_{current}$	t	525	786	1,572	6,134,868	1,488	234	642	428	550	494	525	627
$B_{current} / \tilde{B}_0$		0.279	0.276	0.276	0.792	0.287	0.289	0.287	0.271	0.332	0.204	0.279	0.325
$B_{current} / \tilde{B}_{MSY}$		0.725	0.721	0.721	2.052	0.732	0.765	0.689	0.774	0.863	0.530	0.726	0.845
$SB_{current} / S\tilde{B}_0$		0.254	0.251	0.251	0.740	0.279	0.238	0.272	0.235	0.303	0.185	0.253	0.313
$SB_{current} / S\tilde{B}_{MSY}$		0.660	0.657	0.657	1.919	0.711	0.631	0.654	0.670	0.787	0.481	0.658	0.813
$SB_{Current} / SB_{1995}$		0.623	0.617	0.617	1.816	0.736	0.554	0.668	0.576	0.508	0.954	0.621	0.767
$\tilde{B}_{MSY} / \tilde{B}_0$		0.385	0.383	0.383	0.386	0.393	0.378	0.416	0.350	0.385	0.385	0.385	0.385
$S\tilde{B}_{MSY} / S\tilde{B}_0$		0.385	0.383	0.383	0.386	0.393	0.378	0.416	0.350	0.385	0.385	0.385	0.385
$F_{current}$		0.495	0.501	0.517	0.000	0.531	0.433	0.569	0.481	0.473	0.432	0.442	0.467
F_{msy}		0.077	0.074	0.074	0.084	0.072	0.081	0.056	0.100	0.077	0.077	0.077	0.077
$F_{current} / \tilde{F}_{MSY}$		6.443	6.739	6.951	5E-04	7.345	5.319	10.154	4.816	6.158	5.605	5.740	6.045

Table 8: Estimates of management quantities for the Reference, median, 5th and 95th quantiles of the of the uncertainty grid. For a details on the management quantities, see Table 6. Plausible results are based on the bycatch CPUE, results based on the entire grid are included for completeness.

			Bycatch CPUE runs			All Runs		
Management Quantity	Units	Reference	Median	5th Quantile	95th Quantile	Median	5th Quantile	95th Quantile
C_{Latest}	t	5,950	7,550	5,029	25,492	7,655	5,087	29,482
$C_{Current}$	t per annum	5,353	6,628	4,573	18,021	6,663	4,619	19,682
$\tilde{Y}_{F_{MSY}}$	t per annum	1,885	2,433	1,504	7,375	3,119	1,536	9,812,040
$\tilde{B}_0$	t	136,918	198,915	85,633	745,643	285,765	88,679	1,060,990,000
$\tilde{B}_{MSY}$	t	52,669	76,755	31,245	281,989	115,963	33,487	422,913,020
$B_{current}$	t	38,200	49,870	25,498	163,991	78,105	26,862	768,003,087
$S\tilde{B}_0$		2,069	2,768	984	12,889	4,554	1,019	18,340,100
$S\tilde{B}_{MSY}$		796	1,031	359	4,874	1,700	385	7,310,420
$SB_{current}$		525	667	234	2,880	1,158	256	12,567,275
$B_{current} / \tilde{B}_0$		0.279	0.279	0.186	0.371	0.302	0.191	1.011
$B_{current} / \tilde{B}_{MSY}$		0.725	0.725	0.475	0.992	0.793	0.483	2.770
$SB_{current} / S\tilde{B}_0$		0.254	0.253	0.172	0.355	0.277	0.176	0.911
$SB_{current} / S\tilde{B}_{MSY}$		0.660	0.660	0.473	0.930	0.711	0.476	2.463
$SB_{Current} / SB_{1995}$		0.623	0.736	0.504	1.174	0.871	0.506	3.012
$\tilde{B}_{MSY} / \tilde{B}_0$		0.385	0.385	0.341	0.420	0.385	0.341	0.420
$S\tilde{B}_{MSY} / S\tilde{B}_0$		0.385	0.385	0.341	0.420	0.385	0.341	0.420
$F_{current}$		0.495	0.470	0.400	0.593	0.447	0.000	0.579
F_{msy}		0.077	0.077	0.054	0.105	0.077	0.054	0.107
$F_{current} / \tilde{F}_{MSY}$		6.443	6.045	4.129	10.842	5.531	0.000	10.154

10 Figures

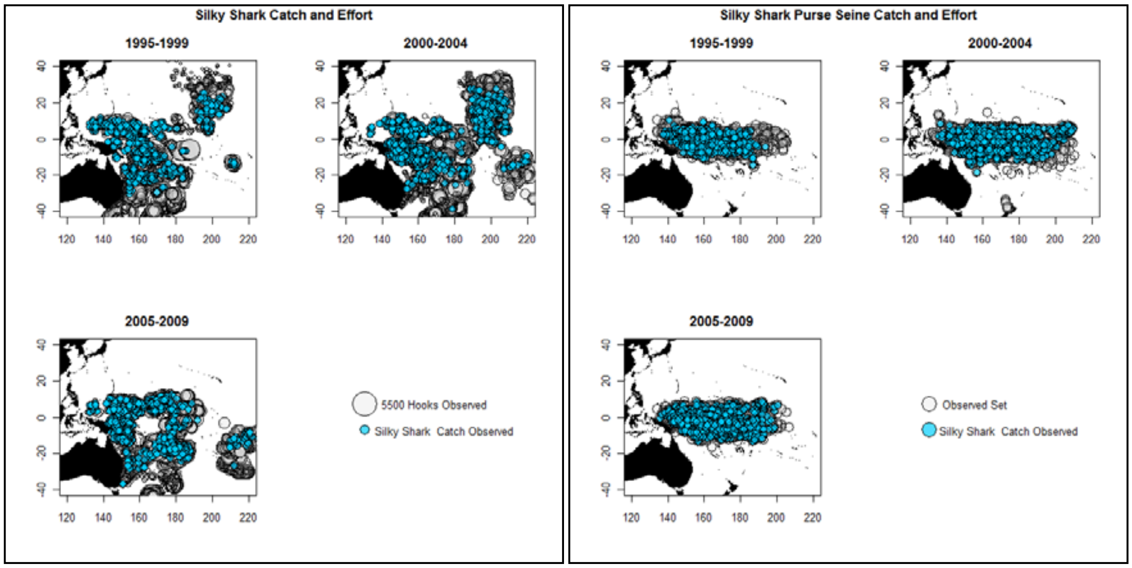

Figure 1. Distribution of the observed silky shark catches by fishing method (longline – left; purse seine – right) during 1995-2009.

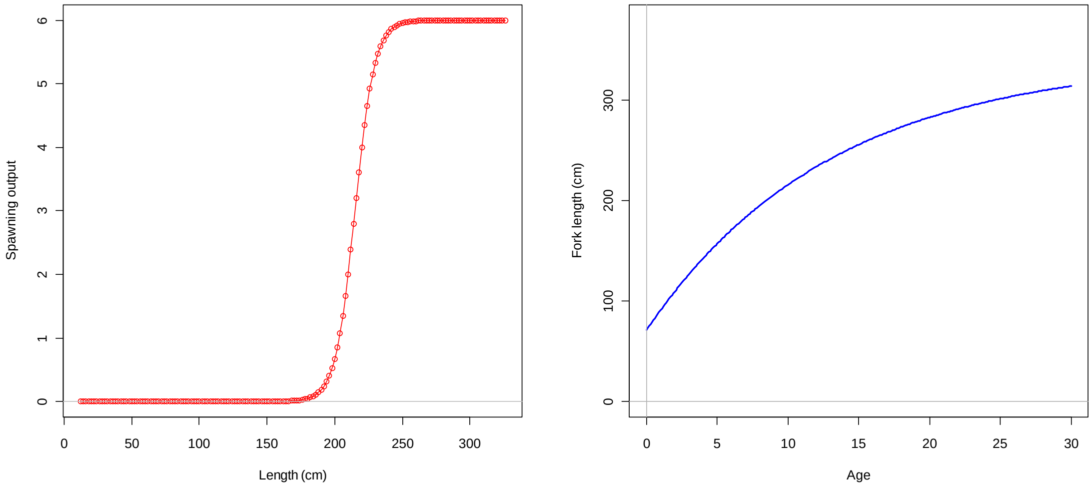

Figure 2. Important biological parameters assumed in the assessment; length at maturity (left panel) and the growth curve (right panel) both taken from Joung et al. 1998.

Figure 3. Estimated oceanic white tip catches in all fisheries by estimation study. The black line is from Lawson (2011), the green and red lines follow a similar methodology and are based on analysis unique for this study.

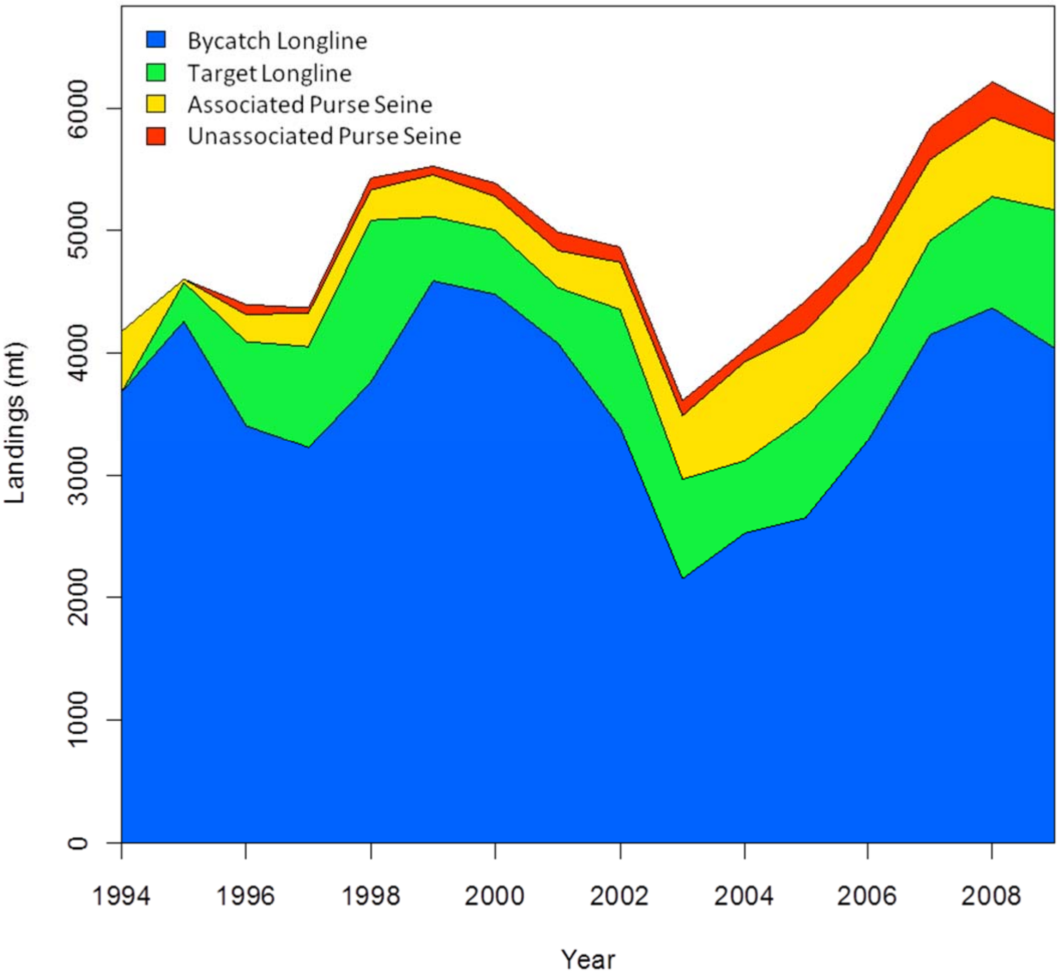

Figure 4. Annual estimated silky shark catch (in weight) in the WCPO by fleet (fishing method), 1995-2009(Based on Lawson 2011, black line Figure 3) .

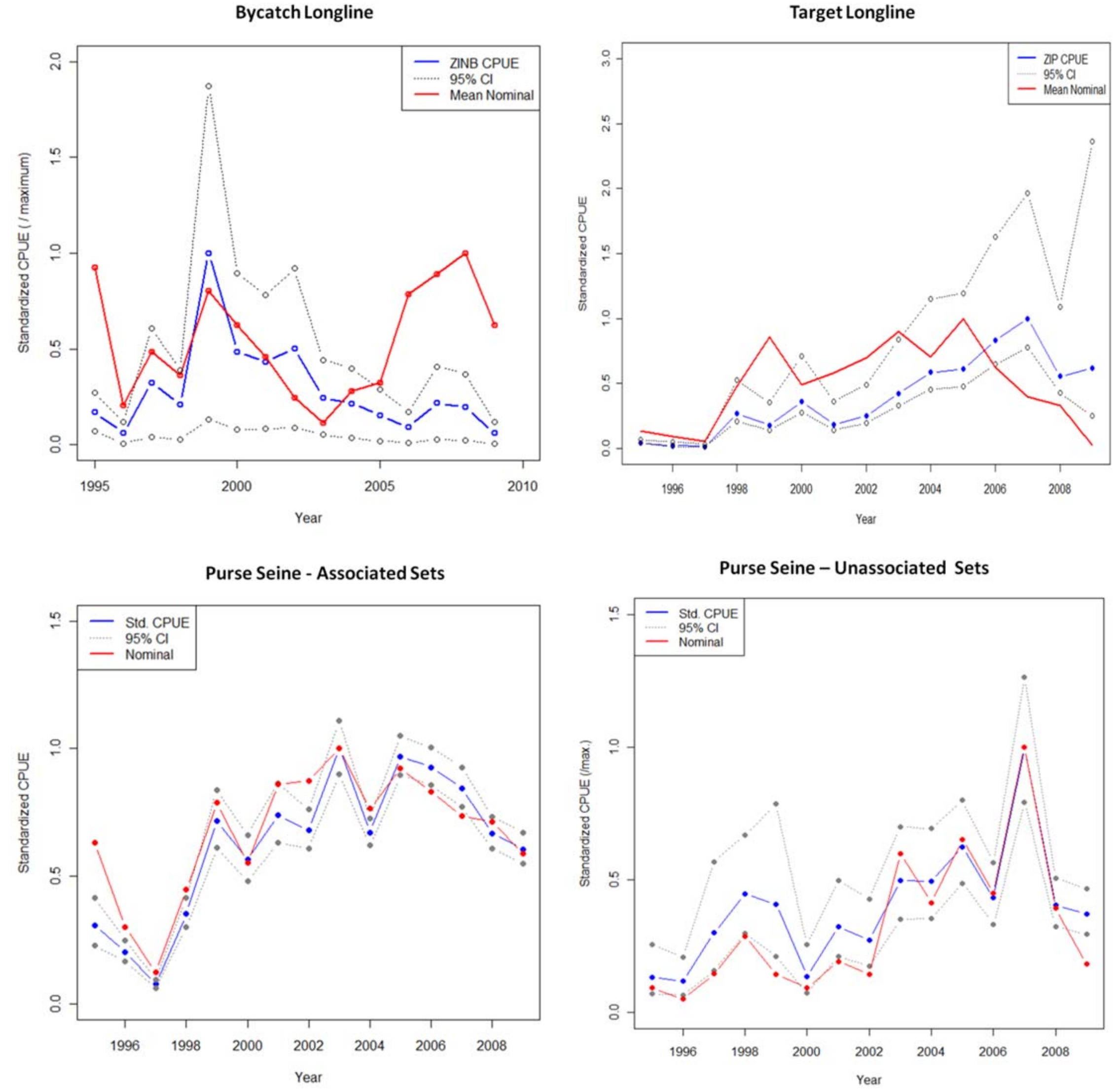

Figure 5. Standardized and nominal silky shark CPUE time series for each of the four fisheries.

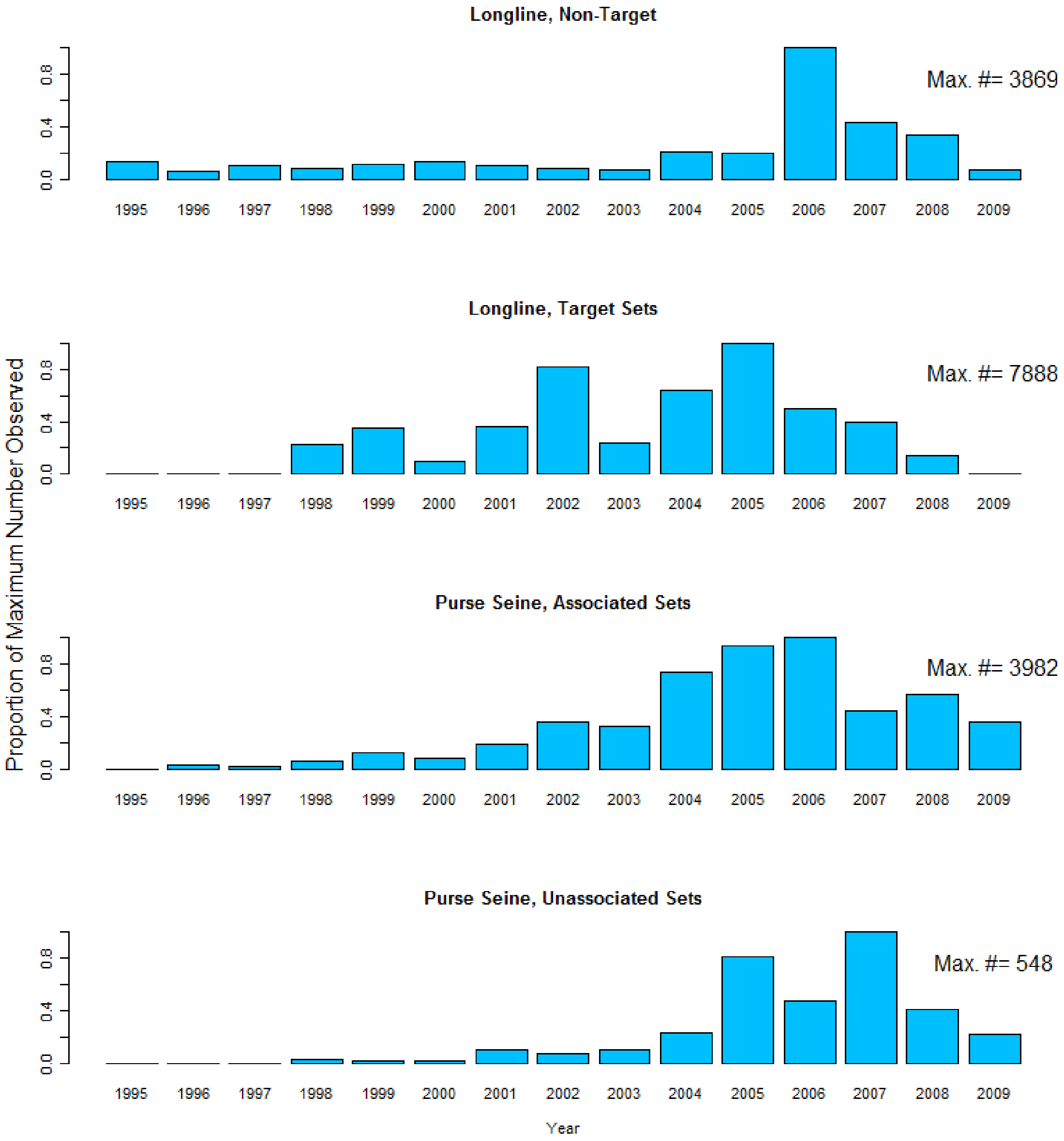

Figure 6. Number of length measurements by fishery and year. The histogram bars are proportional to the maximum number of fish measured in a fishery/year (the value presented in the upper right hand corner).

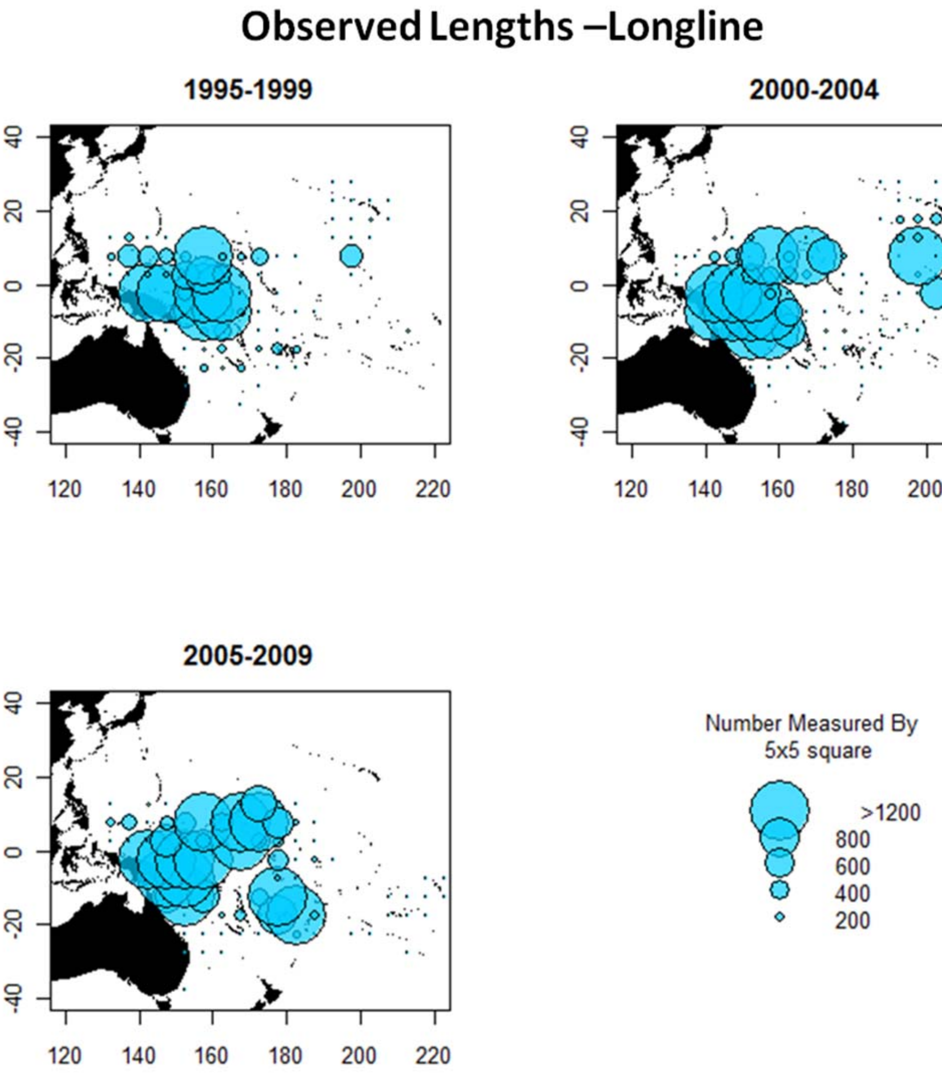

Figure 7. Number and location of silky sharks measured in the longline fishery (both target and bycatch) by 5-year block in 5x5 degree squares.

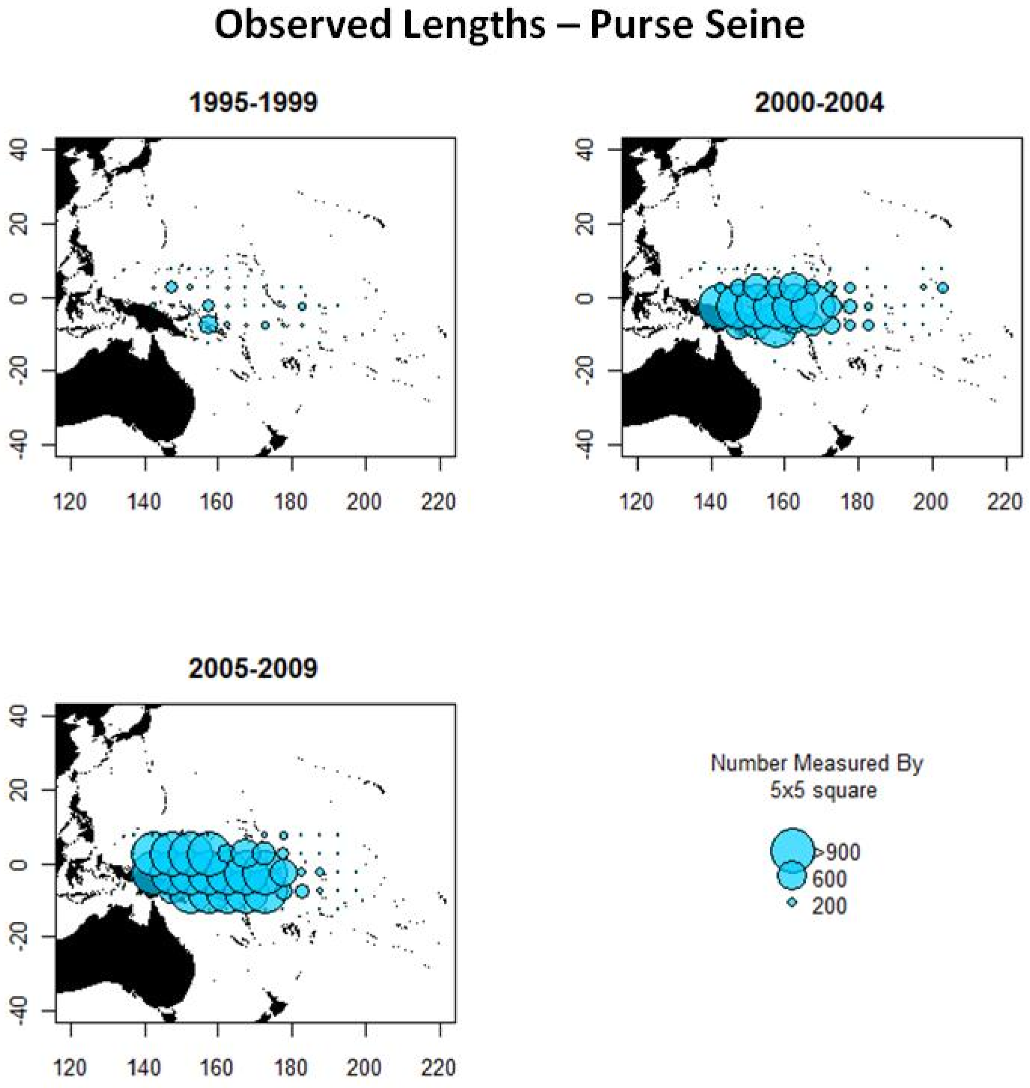

Figure 8. Number and location of silky sharks measured in the purse seine fishery by 5year block in 5x5 degree squares.

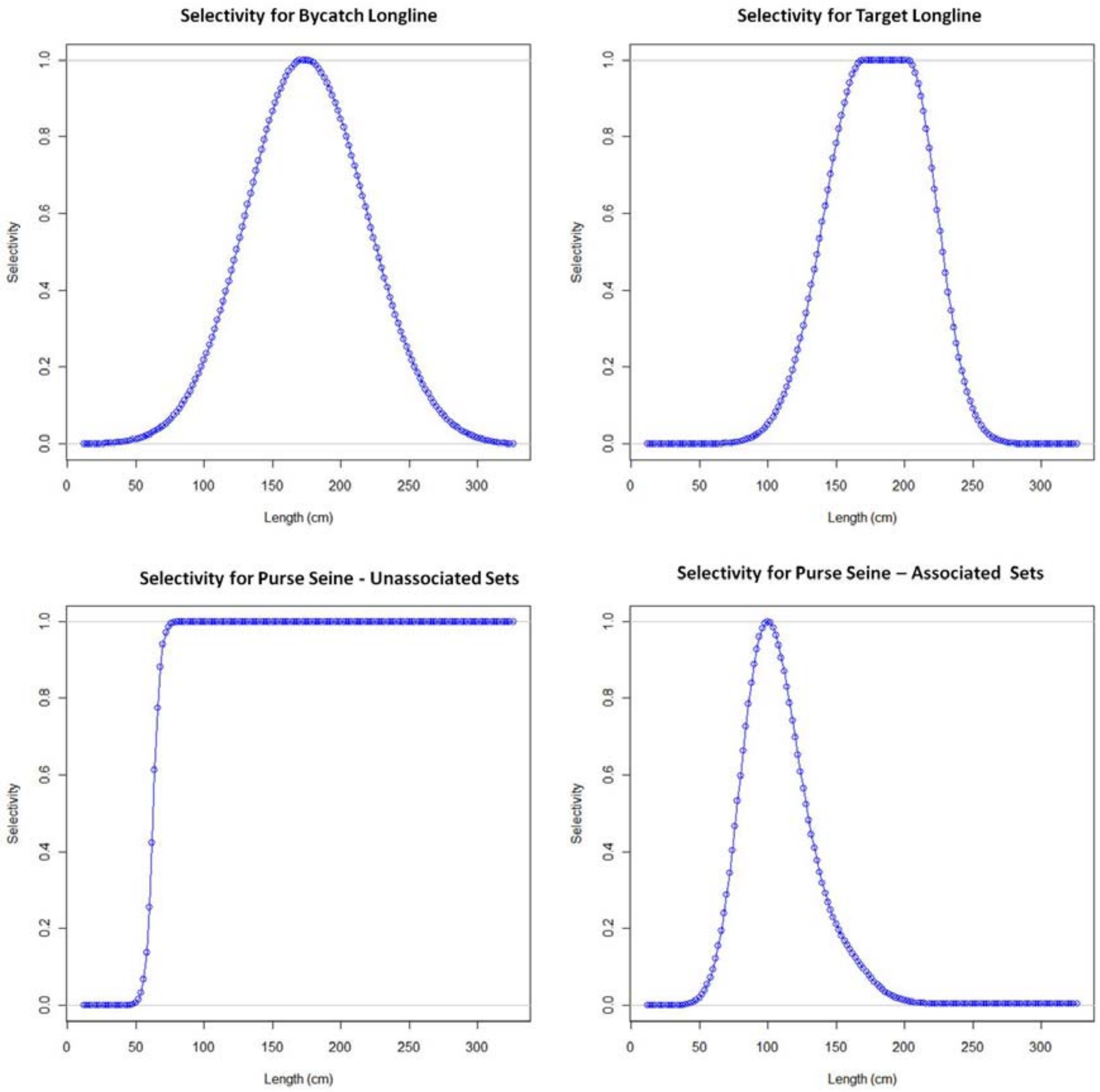

Figure 9. Selectivity by fleet. The top left is longline bycatch, top right is longline target, lower left is unassociated purse seine lower right is associated purse seine. Selectivity for males and females is the same.

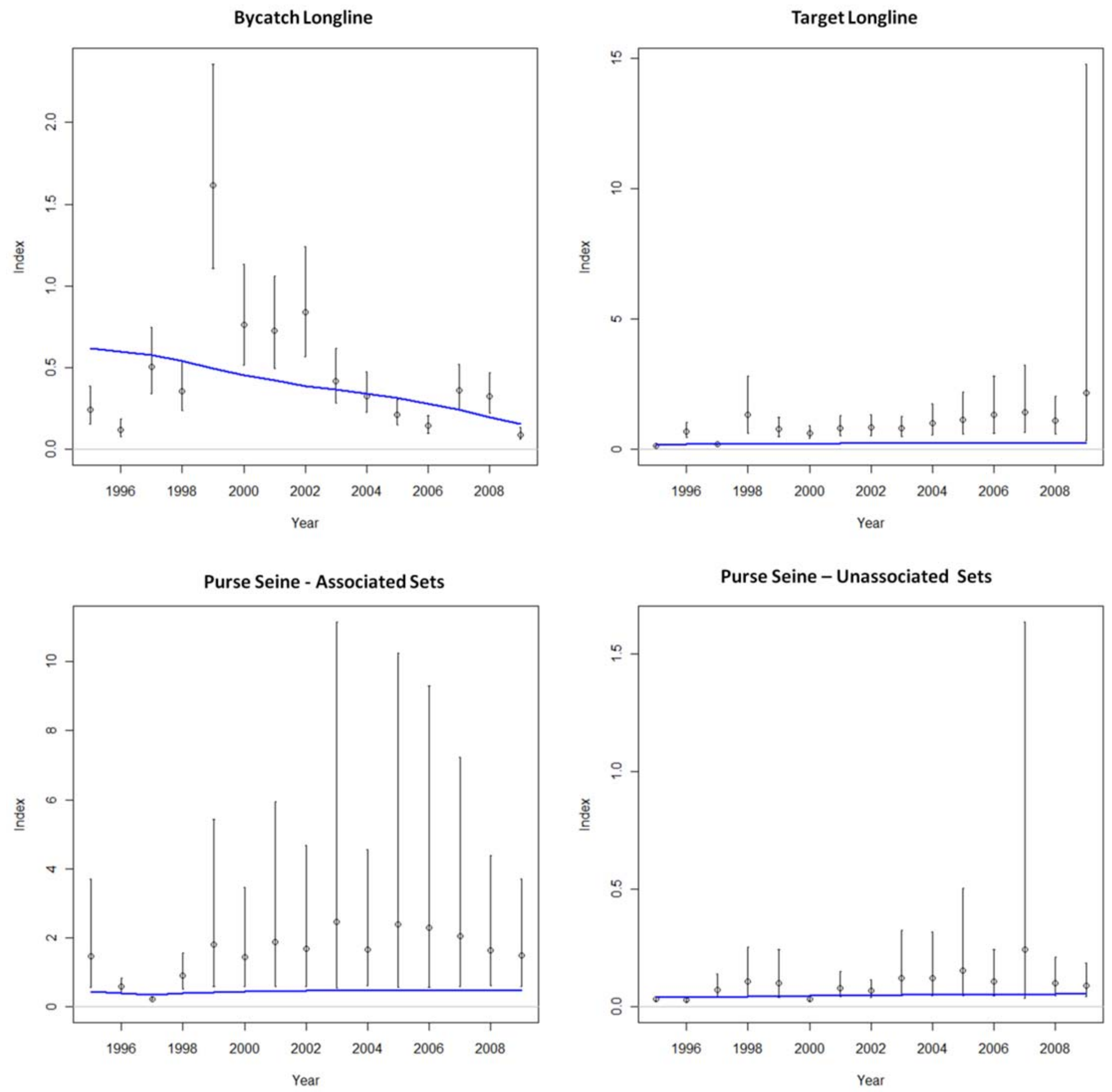

Figure 10. A comparison of the observed LL bycatch (top left panel) CPUE (empty circles with 95% confidence intervals) and model fit (blue solid line) for the reference case. The observed CPUE and model fit for the CPUE 2 sensitivity run is shown with the target longline (top right panel), purse seine (bottom row, associated sets on the left).

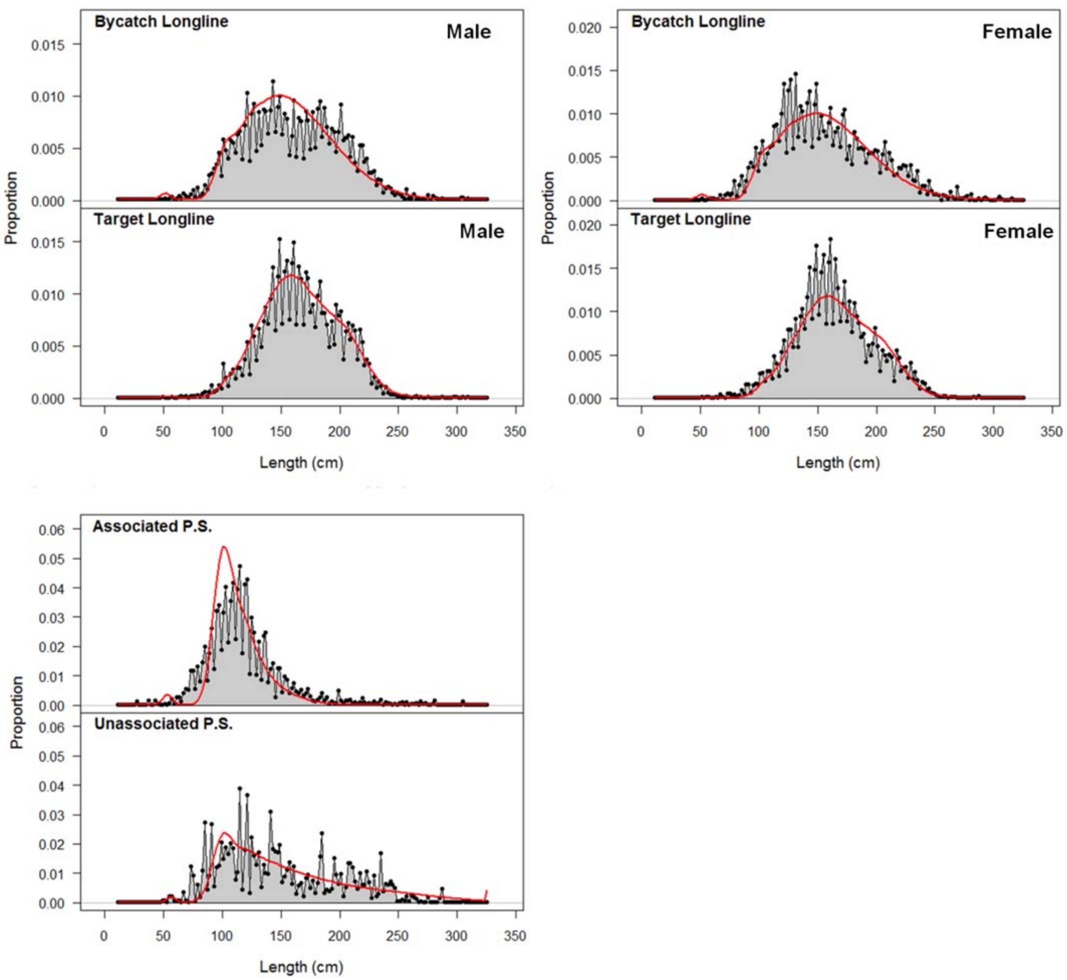

Figure 11. Predicted catch at length (red line) and observed lengths (black line and grey shaded area) in the longline fishery by fleet for the reference case model. Samples and predictions are pooled across all years. The top four panels are for the longline fisheries (males on the left and females on the right), the bottom two panels are for the purse seine fisheries in which the length composition was unsexed.

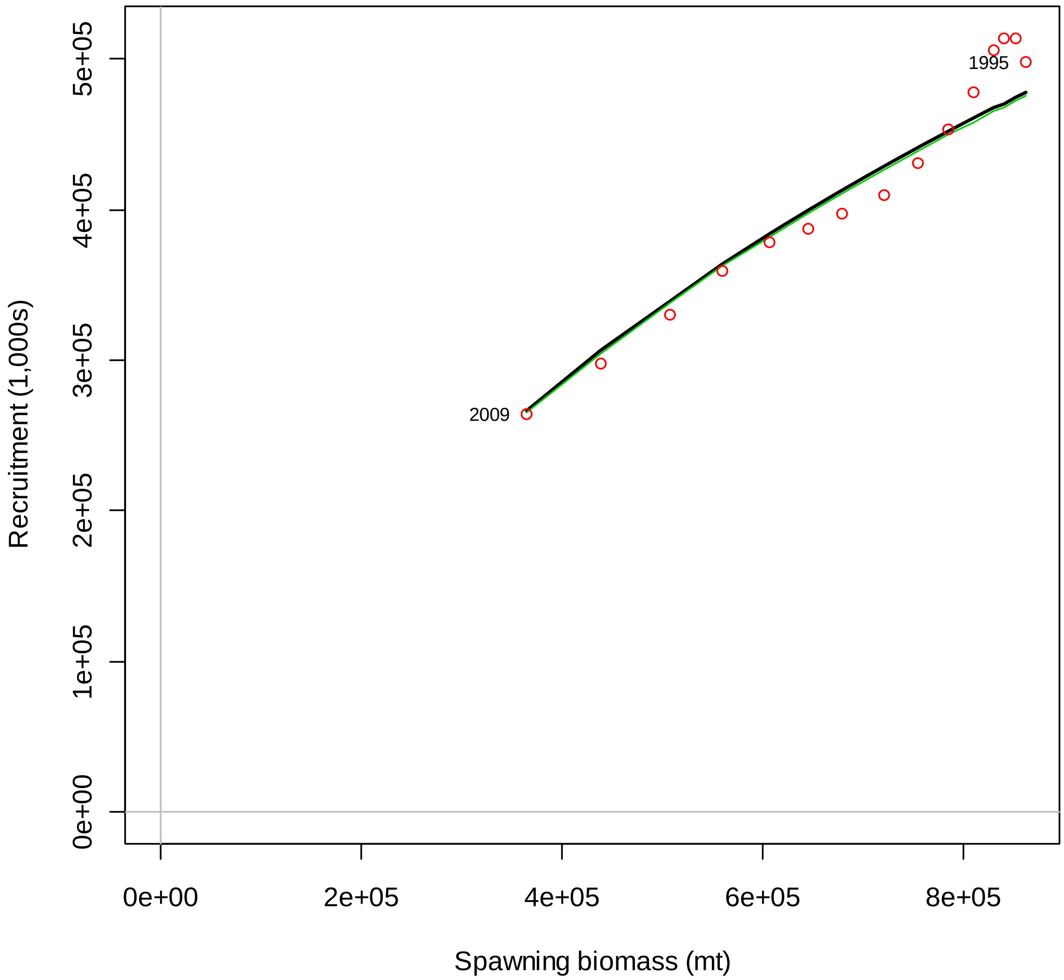

Figure 12. Spawning biomass per recruitment estimates and the assumed Beverton and Holt stock-recruitment relationship (SRR) based on assuming steepness of 0.409.

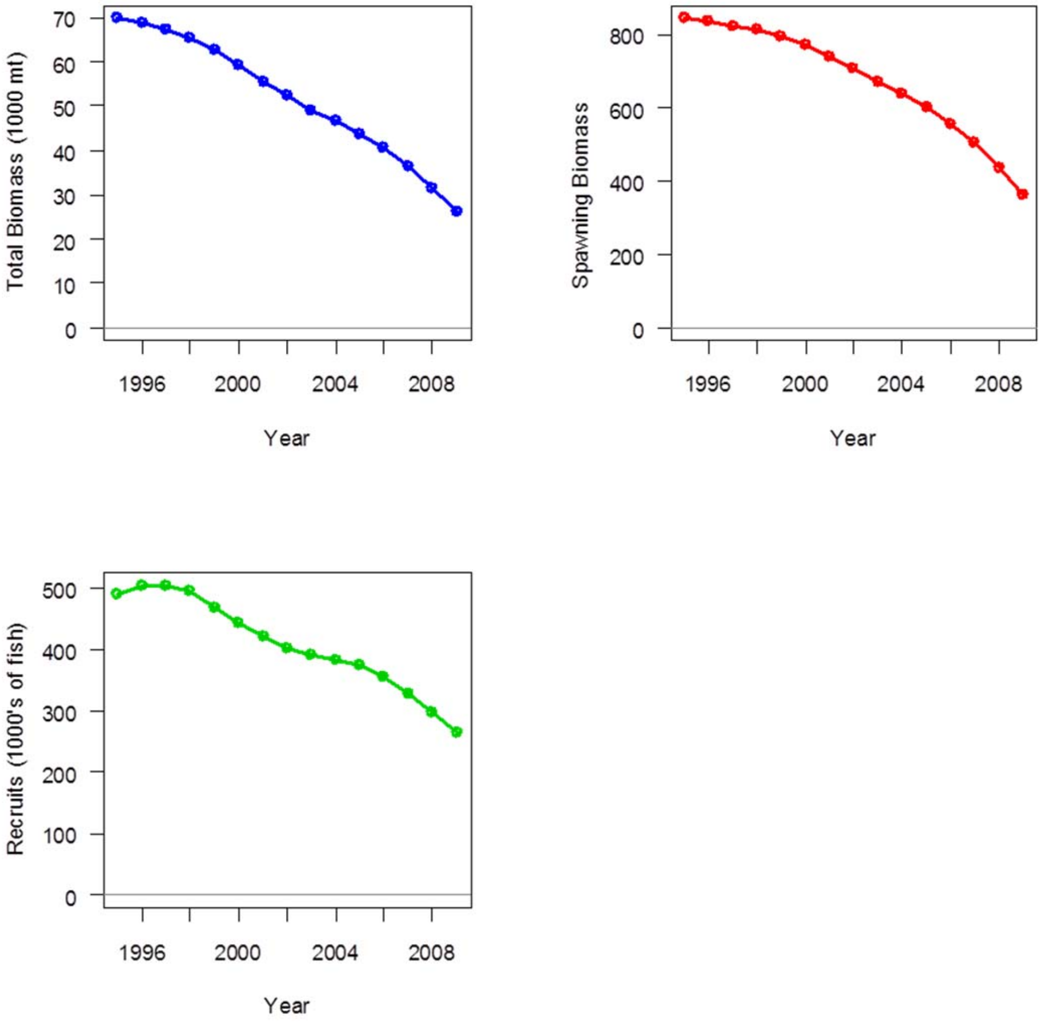

Figure 13. Estimated total biomass (top left, 1000 metric tons), estimated spawning biomass (top right) and estimated annual recruitment (1000's of fish) in the WCPO for the reference case.

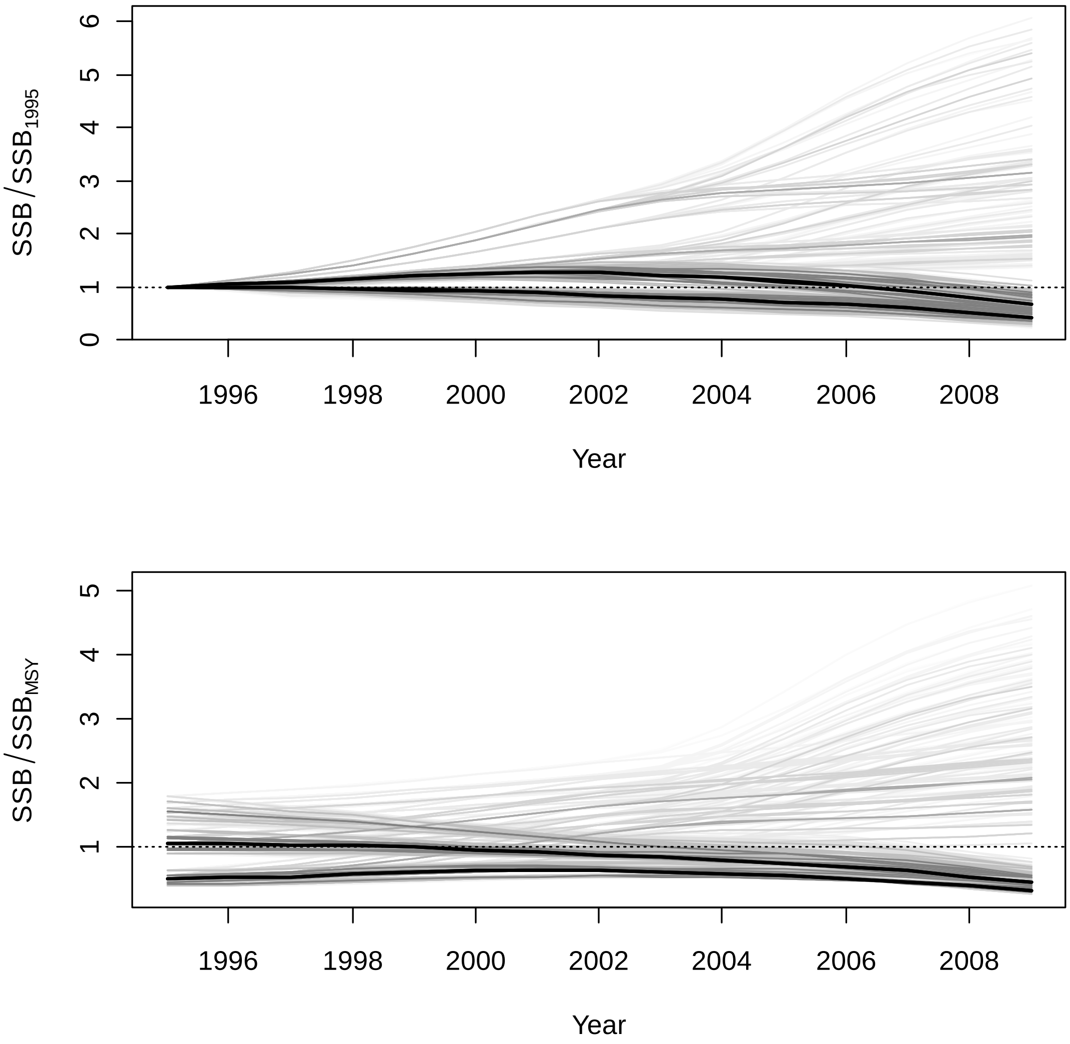

Figure 14. Changes in the spawning biomass relative to the first year of the model (1995 – top panel) and SBmsy (bottom panel). Each line represents one of 648 runs from the grid and the darker the line, the higher the assigned weight (plausibility) for that model run.

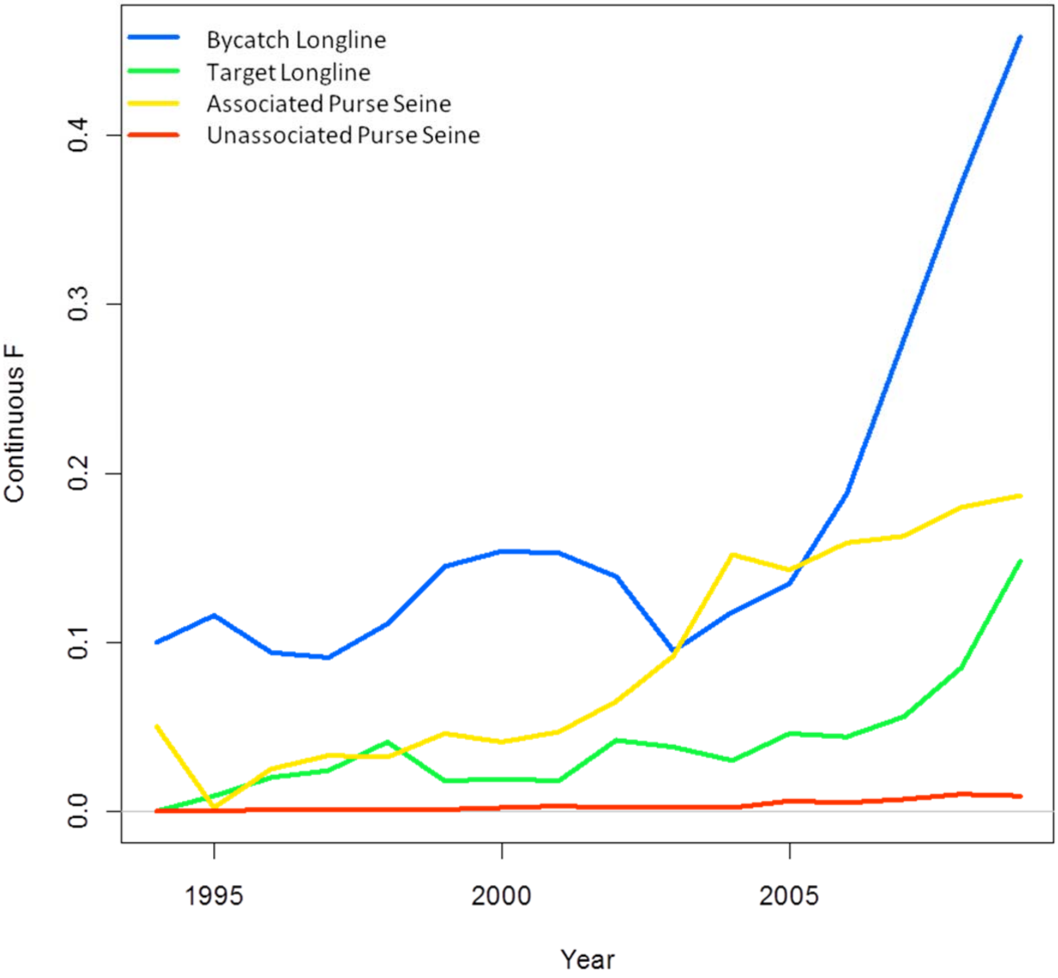

Figure 15. Estimated fishing mortality by fleet for the reference case over the model period.

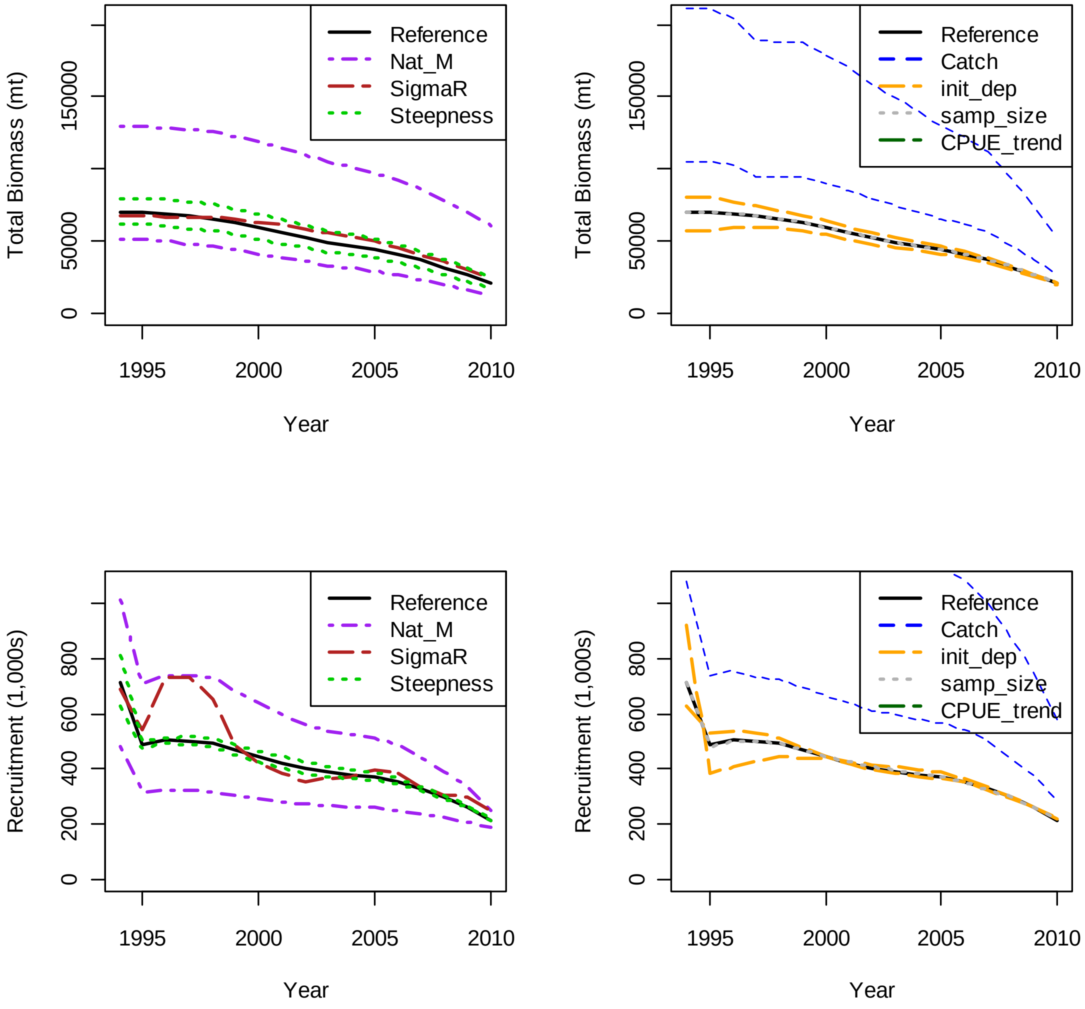

Figure 16. Sensitivity analysis effects on total biomass (top) and recruitment (bottom) of alternate variable levels on the reference case. The figures on the left show the effects of the natural mortality, SigmaR (the s.d. on the recruitment devs.), and the steepness. The figures on the right show the effects of changing the catch inputs, initial depletion, sample size down weighting, and the CPUE inputs. Note that in the right hand side panels the sensitivity CPUE_trend is not visible because it exceeds the limits of the y axis.

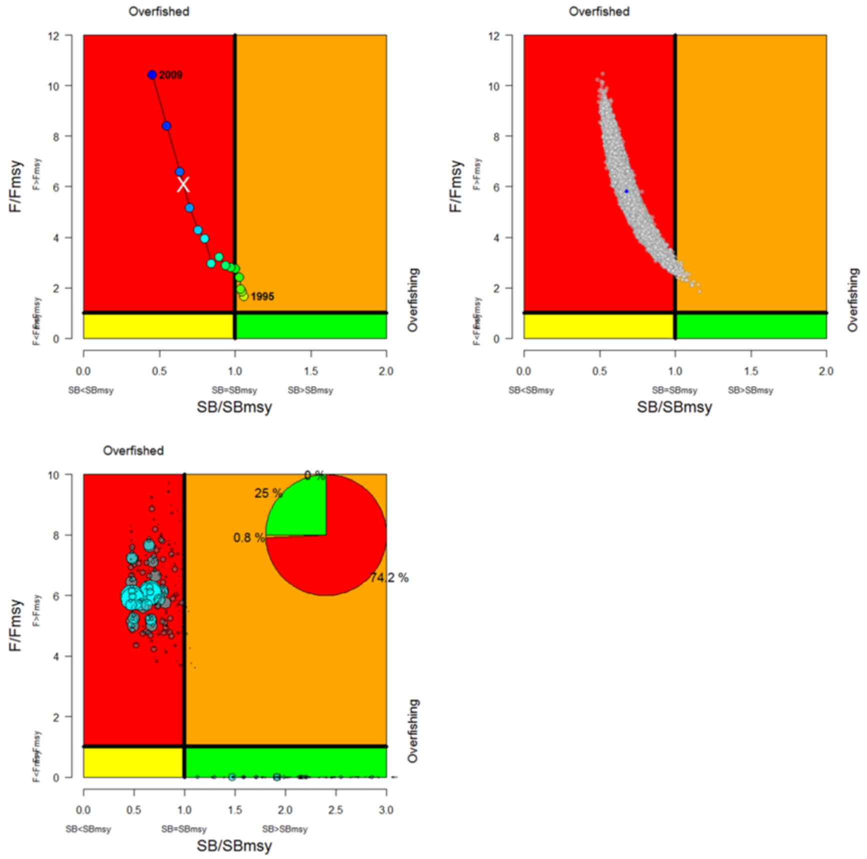

Figure 17. Kobe plots indicating annual stock status, relative to SB_{MSY} (x-axis) and F_{MSY} (y-axis). These present the reference points for the reference model for the period 1995–2009 (top left panel), and for the statistical uncertainty for the current (average 2005-2008) conditions based on MCMC analysis (top right panel, blue dot indicates the current estimate) and based on the current (average of 2005-2008) estimates for all 648 models in the grid (bottom panel). In the bottom plot the size of the circle is proportional to the weight (plausibility) of the model run. Note that the axes range differ in each graph.

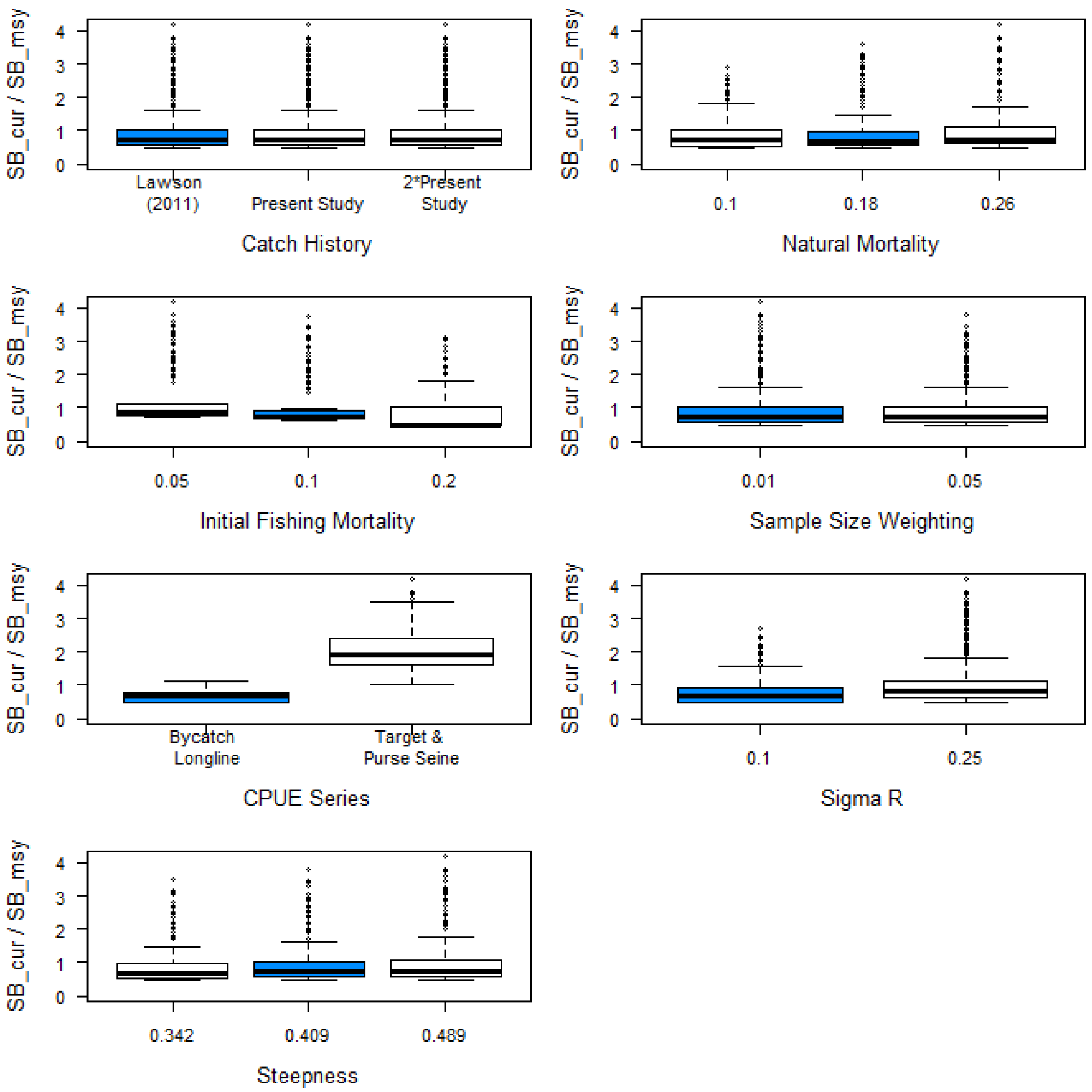

Figure 18. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter Spawning $SB_{CURRENT}/SB_{MSY}$.

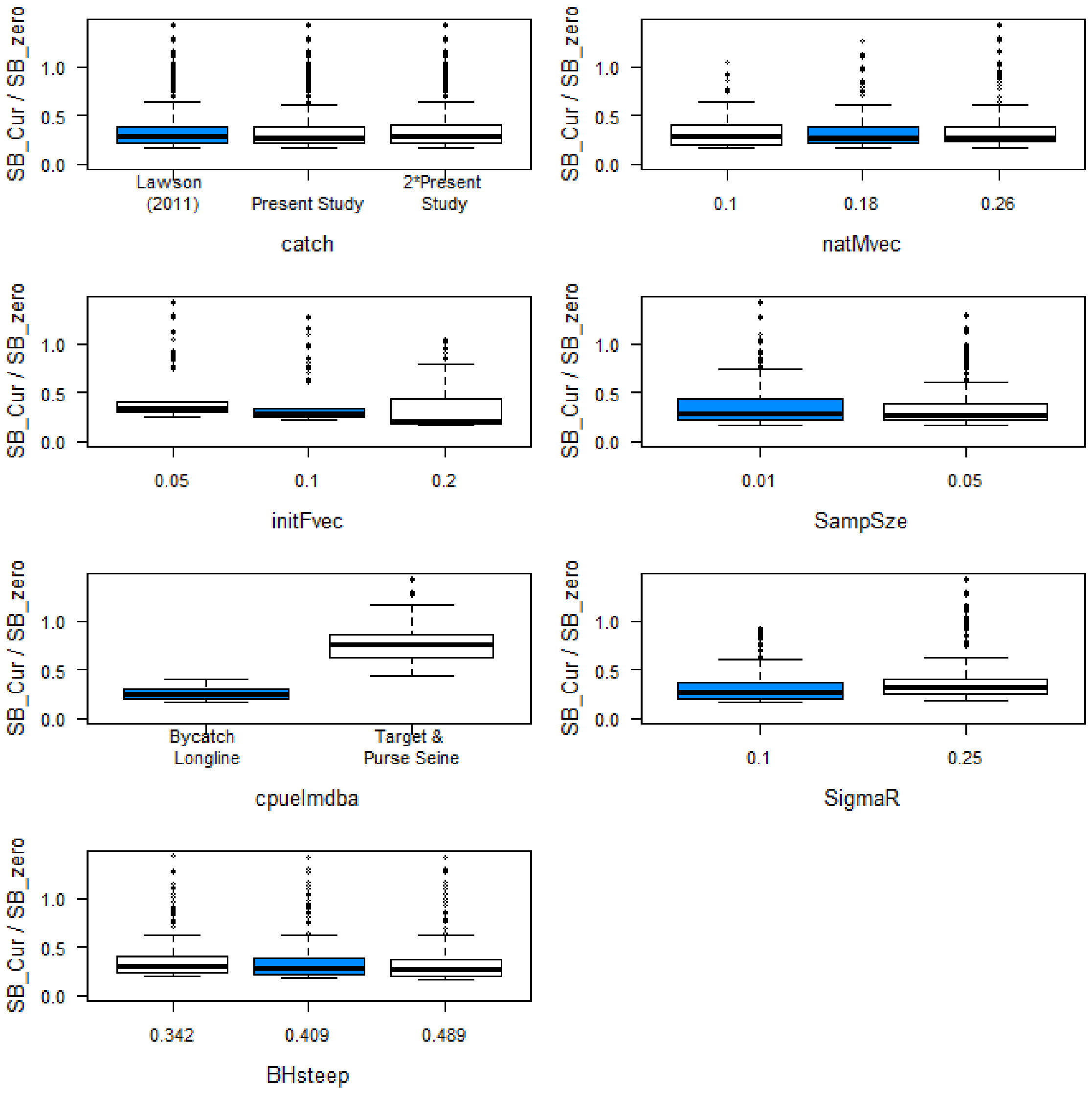

Figure 19. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter $SB_{CURRENT}$ / SB_0.

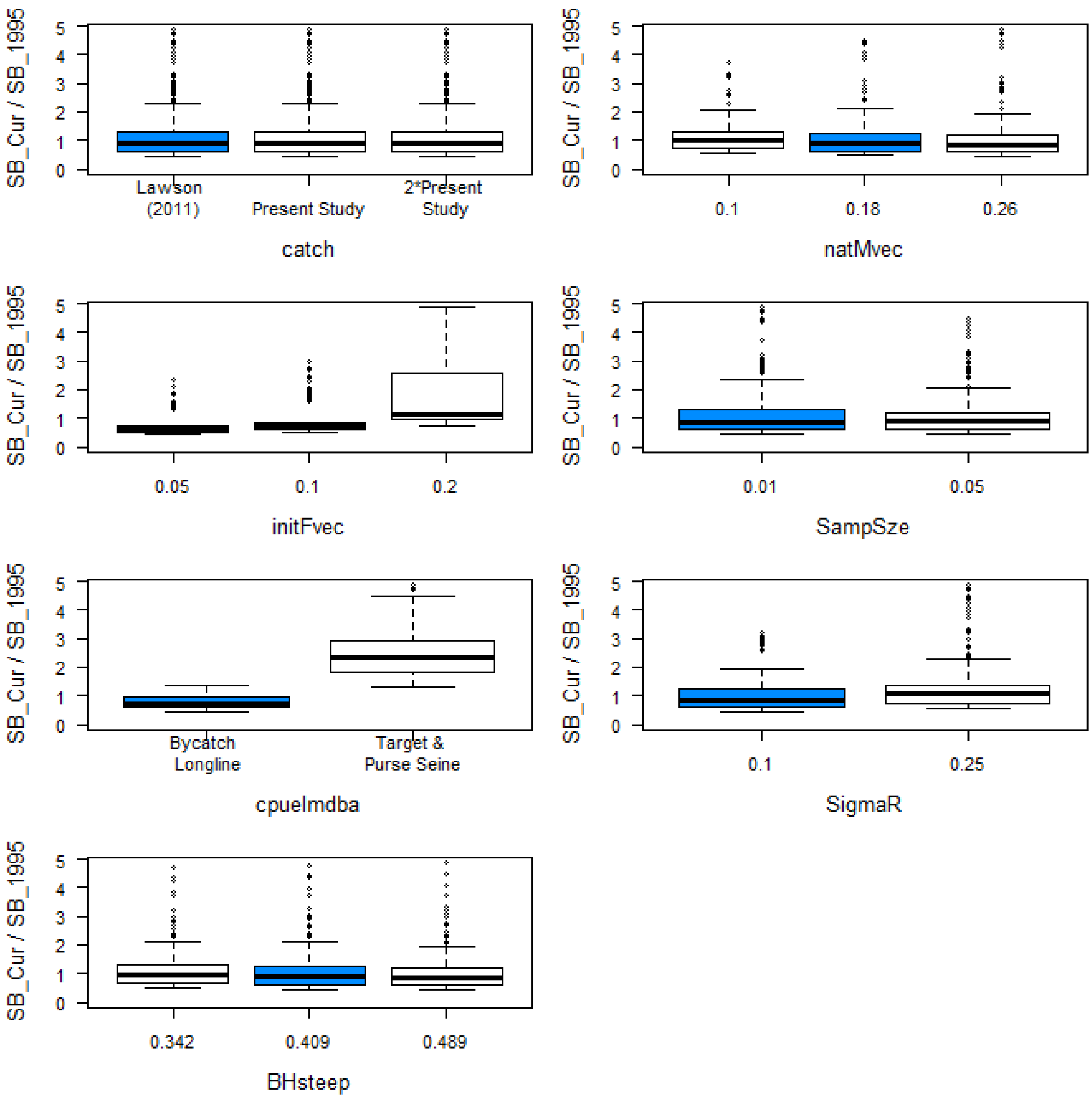

Figure 20. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter $SB_{CURRENT}$ / SB_{1995}.

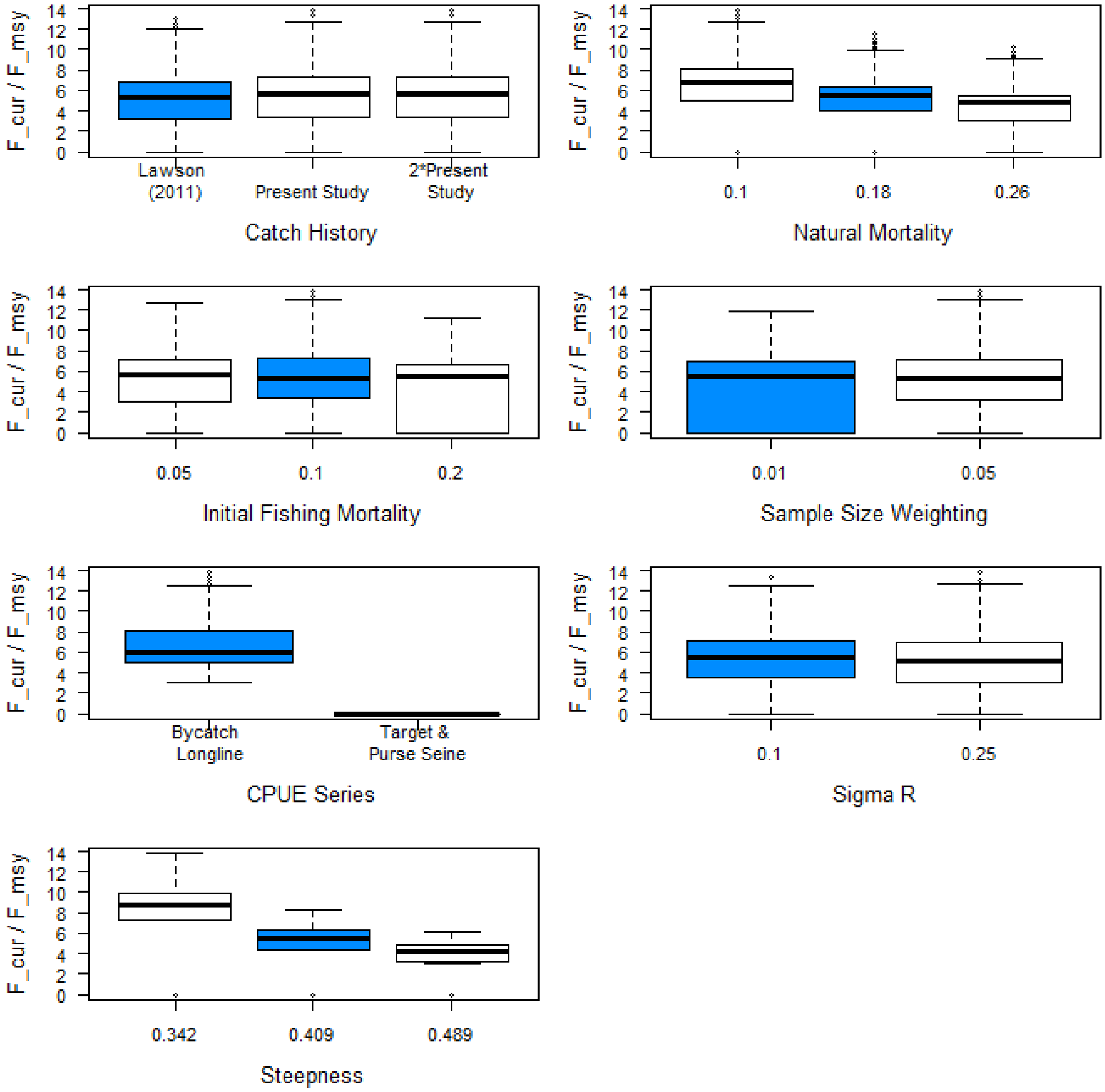

Figure 21. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter $F_{CURRENT}/F_{MSY}$.

11 Appendix 1: Control File for SS3 model

```
# FAL-WCPO model. Developed by Joel Rice (joelr@spc.int)on 21/11/2011
#_data_and_control_files: FAL.dat // FAL.ctl
#_SS-V3.21d-win64-safe;_05/22/2011;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB
# FISHERY DEFINITIONS
1  #_N_Growth_Patterns
1 #_N_Morphs_Within_GrowthPattern
#_Cond 1 #_Morph_between/within_stdev_ratio (no read if N_morphs=1)
#_Cond  1 #vector_Morphdist_(-1_in_first_val_gives_normal_approx)
#
#_Cond 0  #  N recruitment designs goes here if N_GP*nseas*area>1
#_Cond 0  #  placeholder for recruitment interaction request
#_Cond 1 1 1  # example recruitment design element for GP=1, seas=1, area=1
#
#_Cond 0 # N_movement_definitions goes here if N_areas > 1
#_Cond 1.0 # first age that moves (real age at begin of season, not integer) also cond on do_migration>0
#_Cond 1 1 1 2 4 10 # example move definition for seas=1, morph=1, source=1 dest=2, age1=4, age2=10
#
0 #_Nblock_Patterns
#_Cond 0 #_blocks_per_pattern
# begin and end years of blocks
#
0.5 #_fracfemale
0 #_natM_type:_0=1Parm; 1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withseasinterpolate
  #_no additional input for selected M option; read 1P per morph
2 # GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2; 3=not implemented; 4=not implemented
1 #_Growth_Age_for_L1
12 #_Growth_Age_for_L2 (999 to use as Linf)
0 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
1 #_CV_Growth_Pattern:  0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A); 4 logSD=F(A)
1 #_maturity_option:  1=length logistic; 2=age logistic; 3=read age-maturity matrix by growth_pattern; 4=read
age-fecundity; 5=read fec and wt from wtatage.ss
#_placeholder for empirical age-maturity by growth pattern
8 #_First_Mature_Age
2 #_fecundity option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b; (4)eggs=a+b*L; (5)eggs=a+b*W
0 #_hermaphroditism option:  0=none; 1=age-specific fxn
3 #_parameter_offset_approach (1=none, 2= M, G, CV_G as offset from female-GP1, 3=like SS2 V1.x)
1 #_env/block/dev_adjust_method (1=standard; 2=logistic transform keeps in base parm bounds; 3=standard
w/ no bound check)
#
#_growth_parms
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
 -3 3 0.18 0.2 0 0.8 -3 0 0 0 0 0 0 0 # NatM_p_1_Fem_GP_1
 70 100 90.9988 90.9988 0 10 -4 0 0 0 0 0.5 0 0 # L_at_Amin_Fem_GP_1
 40 350 233.882 233.882 0 10 -2 0 0 0 0 0.5 0 0 # L_at_Amax_Fem_GP_1
 0.05 0.15 0.0838 0.0838 0 0.8 -4 0 0 0 0 0.5 0 0 # VonBert_K_Fem_GP_1
 -10 10 1 1 0 0.8 -4 0 0 0 0 0.5 0 0 # Richards_Fem_GP_1
 0.01 1 0.085 0.0834877 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_young_Fem_GP_1
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_old_Fem_GP_1
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # NatM_p_1_Mal_GP_1
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # L_at_Amin_Mal_GP_1
 -3 3 0 0 0 0.8 -2 0 0 0 0 0.5 0 0 # L_at_Amax_Mal_GP_1
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # VonBert_K_Mal_GP_1
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # Richards_Mal_GP_1
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_young_Mal_GP_1
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 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_old_Mal_GP_1
 -3 3 2.92e-006 2.92e-006 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_1_Fem
 -3 3.5 3.15 3.15 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_2_Fem
 -3 300 215 55 0 0.8 -3 0 0 0 0 0.5 0 0 # Mat50%_Fem
 -3 3 -0.138 -0.138 0 0.8 -3 0 0 0 0 0.5 0 0 # Mat_slope_Fem
 -3 9 6 1 0 0.8 -3 0 0 0 0 0.5 0 0 # Eggs_scalar_Fem
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # Eggs_exp_len_Fem
 -3 3 2.92e-006 2.92e-006 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_1_Mal
 -3 4 3.15 3.15 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_2_Mal
 -4 4 0 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_GP_1
 -4 4 0 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_Area_1
 -4 4 4 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_Seas_1
 1 1 1 1 -1 99 -3 0 0 0 0 0.5 0 0 # CohortGrowDev
#
#_Cond 0  #custom_MG-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no MG-environ parameters
#
#_Cond 0  #custom_MG-block_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no MG-block parameters
#_Cond No MG parm trends
#
#_seasonal_effects_on_biology_parms
 0 0 0 0 0 0 0 0 0 0 #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no seasonal MG parameters
#
#_Cond -4 #_MGparm_Dev_Phase
#
#_Spawner-Recruitment
3 #_SR_function: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop; 7=survival_3Parm
#_LO HI INIT PRIOR PR_type SD PHASE
 3 15 6.56893 12.3 0 10 1 # SR_LN(R0)
 0.2 0.7 0.409 0.5 2 0.05 -3 # SR_BH_steep
 0 2 0.1 0.6 0 0.8 -3 # SR_sigmaR
 -5 5 0 0 0 1 -3 # SR_envlink
 -5 5 0 0 0 1 -1 # SR_R1_offset
 0 0 0 0 -1 99 -99 # SR_autocorr
0 #_SR_env_link
1 #_SR_env_target_0=none;1=devs;_2=R0;_3=steepness
2 #do_recdev:  0=none; 1=devvector; 2=simple deviations
1995 # first year of main recr_devs; early devs can preceed this era
2009 # last year of main recr_devs; forecast devs start in following year
2 #_recdev phase
1 # (0/1) to read 13 advanced options
 -5 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
 -2 #_recdev_early_phase
 0 #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
 1 #_lambda for Fcast_recr_like occurring before endyr+1
 -2 #_last_early_yr_nobias_adj_in_MPD
 -1 #_first_yr_fullbias_adj_in_MPD
 2006 #_last_yr_fullbias_adj_in_MPD
 2007 #_first_recent_yr_nobias_adj_in_MPD
 0.85 #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for all estimated recdevs)
 0 #_period of cycles in recruitment (N parms read below)
 -15 #min rec_dev
 15 #max rec_dev
 0 #_read_recdevs
#_end of advanced SR options
```

```
#
#_placeholder for full parameter lines for recruitment cycles
# read specified recr devs
#_Yr Input_value
#
#Fishing Mortality info
0.2 # F ballpark for tuning early phases
1996 # F ballpark year (neg value to disable)
3 # F_Method:  1=Pope; 2=instan. F; 3=hybrid (hybrid is recommended)
3 # max F or harvest rate, depends on F_Method
# no additional F input needed for Fmethod 1
# if Fmethod=2; read overall start F value; overall phase; N detailed inputs to read
# if Fmethod=3; read N iterations for tuning for Fmethod 3
3  # N iterations for tuning F in hybrid method (recommend 3 to 7)
#
#_initial_F_parms
#_LO HI INIT PRIOR PR_type SD PHASE
 0 1 0.1 0.1 0 99 -1 # InitF_1F_NonTarLL
 0 1 0 0.01 0 99 -1 # InitF_2F_YesTarLL
 0.05 1 0.05 0.1 0 99 -1 # InitF_3F_AssoPS
 0 1 0 0.01 0 99 -1 # InitF_4F_UnAssoPS
#
#_Q_setup
 # Q_type options:  <0=mirror, 0=median_float, 1=mean_float, 2=parameter, 3=parm_w_random_dev,
4=parm_w_randwalk, 5=mean_unbiased_float_assign_to_parm
 #_Den-dep  env-var  extra_se  Q_type
 0 0 0 0 # 1 F_NonTarLL
 0 0 0 0 # 2 F_YesTarLL
 0 0 0 0 # 3 F_AssoPS
 0 0 0 0 # 4 F_UnAssoPS
 0 0 0 0 # 5 S_NonTarLL
 0 0 0 0 # 6 S_YesTarLL
 0 0 0 0 # 7 S_AssoPS
 0 0 0 0 # 8 S_UnAssoPS
#
#_Cond 0 #_If q has random component, then 0=read one parm for each fleet with random q; 1=read a parm
for each year of index
#_Q_parms(if_any)
#
#_size_selex_types
#_Pattern Discard Male Special
 24 0 0 0 # 1 F_NonTarLL
 24 0 0 0 # 2 F_YesTarLL
 27 0 0 4 # 3 F_AssoPS
 1 0 0 0 # 4 F_UnAssoPS
 5 0 0 1 # 5 S_NonTarLL
 5 0 0 2 # 6 S_YesTarLL
 5 0 0 3 # 7 S_AssoPS
 5 0 0 4 # 8 S_UnAssoPS
#
#_age_selex_types
#_Pattern ___ Male Special
 11 0 0 0 # 1 F_NonTarLL
 11 0 0 0 # 2 F_YesTarLL
 11 0 0 0 # 3 F_AssoPS
 11 0 0 0 # 4 F_UnAssoPS
 11 0 0 0 # 5 S_NonTarLL
```

```
 11 0 0 0 # 6 S_YesTarLL
 11 0 0 0 # 7 S_AssoPS
 11 0 0 0 # 8 S_UnAssoPS
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
 14 300 172.246 50 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_1P_1_F_NonTarLL
 -15 15 -9.18625 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_1P_2_F_NonTarLL
 -15 15 8.14063 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_1P_3_F_NonTarLL
 -15 15 8.29226 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_1P_4_F_NonTarLL
 -15 15 -15 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_1P_5_F_NonTarLL
 -15 15 -15 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_1P_6_F_NonTarLL
 14 300 170.027 50 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_2P_1_F_YesTarLL
 -15 15 -1.38388 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_2P_2_F_YesTarLL
 -15 15 7.40335 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_2P_3_F_YesTarLL
 -15 15 6.86228 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_2P_4_F_YesTarLL
 -15 15 -15 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_2P_5_F_YesTarLL
 -15 15 -15 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_2P_6_F_YesTarLL
 -15 15 0 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSpline_Code_F_AssoPS_3
 -15 15 0.0001 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSpline_GradLo_F_AssoPS_3
 -15 15 -0.0001 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSpline_GradHi_F_AssoPS_3
 40 240 100 200 1 0 -4 0 0 0 0 0.5 0 0 # SizeSpline_Knot_1_F_AssoPS_3
 40 240 150 200 1 0 -4 0 0 0 0 0.5 0 0 # SizeSpline_Knot_2_F_AssoPS_3
 40 240 175 200 1 0 -4 0 0 0 0 0.5 0 0 # SizeSpline_Knot_3_F_AssoPS_3
 40 240 225 200 1 0 -4 0 0 0 0 0.5 0 0 # SizeSpline_Knot_4_F_AssoPS_3
 -15 15 8.37772 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSpline_Val_1_F_AssoPS_3
 -15 15 6.82497 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSpline_Val_2_F_AssoPS_3
 -15 15 5.77554 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSpline_Val_3_F_AssoPS_3
 0 15 3.04248 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSpline_Val_4_F_AssoPS_3
 1 200 62.7967 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_4P_1_F_UnAssoPS
 -200 200 7.67376 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_4P_2_F_UnAssoPS
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_5P_1_S_NonTarLL
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_5P_2_S_NonTarLL
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_6P_1_S_YesTarLL
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_6P_2_S_YesTarLL
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_7P_1_S_AssoPS
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_7P_2_S_AssoPS
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_8P_1_S_UnAssoPS
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_8P_2_S_UnAssoPS
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_1P_1_F_NonTarLL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_1P_2_F_NonTarLL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_2P_1_F_YesTarLL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_2P_2_F_YesTarLL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_3P_1_F_AssoPS
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_3P_2_F_AssoPS
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_4P_1_F_UnAssoPS
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_4P_2_F_UnAssoPS
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_5P_1_S_NonTarLL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_5P_2_S_NonTarLL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_6P_1_S_YesTarLL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_6P_2_S_YesTarLL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_7P_1_S_AssoPS
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_7P_2_S_AssoPS
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_8P_1_S_UnAssoPS
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_8P_2_S_UnAssoPS
#_Cond 0 #_custom_sel-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no enviro fxns
#_Cond 0 #_custom_sel-blk_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no block usage
```

```
#_Cond No selex parm trends
#_Cond -4 # placeholder for selparm_Dev_Phase
#_Cond 0 #_env/block/dev_adjust_method (1=standard; 2=logistic trans to keep in base parm bounds;
3=standard w/ no bound check)
#
# Tag loss and Tag reporting parameters go next
0  # TG_custom:  0=no read; 1=read if tags exist
#_Cond -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0  #_placeholder if no parameters
#
1 #_Variance_adjustments_to_input_values
#_fleet: 1 2 3 4 5 6 7 8
  0 0 0 0 0 0 0 0 #_add_to_survey_CV
  0 0 0 0 0 0 0 0 #_add_to_discard_stddev
  0 0 0 0 0 0 0 0 #_add_to_bodywt_CV
  0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 #_mult_by_lencomp_N
  1 1 1 1 1 1 1 1 #_mult_by_agecomp_N
  1 1 1 1 1 1 1 1 #_mult_by_size-at-age_N
#
1 #_maxlambdaphase
1 #_sd_offset
#
24 # number of changes to make to default Lambdas (default value is 1.0)
# Like_comp codes:  1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq; 7=sizeage; 8=catch;
# 9=init_equ_catch; 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp; 15=Tag-comp;
16=Tag-negbin
#like_comp fleet/survey  phase  value  sizefreq_method
 1 1 1 0 1
 1 2 1 0 1
 1 3 1 0 1
 1 4 1 0 1
 1 5 1 1 1
 1 6 1 0 1
 1 7 1 0 1
 1 8 1 0 1
 4 1 1 1 1
 4 2 1 1 1
 4 3 1 1 1
 4 4 1 1 1
 4 5 1 0 1
 4 6 1 0 1
 4 7 1 0 1
 4 8 1 0 1
 9 1 1 0 1
 9 2 1 0 1
 9 3 1 0 1
 9 4 1 0 1
 9 5 1 0 1
 9 6 1 0 1
 9 7 1 0 1
 9 8 1 0 1
#
# lambdas (for info only; columns are phases)
#  0 #_CPUE/survey:_1
#  0 #_CPUE/survey:_2
#  0 #_CPUE/survey:_3
#  0 #_CPUE/survey:_4
#  1 #_CPUE/survey:_5
```

```
#  0 #_CPUE/survey:_6
#  0 #_CPUE/survey:_7
#  0 #_CPUE/survey:_8
#  1 #_lencomp:_1
#  1 #_lencomp:_2
#  1 #_lencomp:_3
#  1 #_lencomp:_4
#  0 #_lencomp:_5
#  0 #_lencomp:_6
#  0 #_lencomp:_7
#  0 #_lencomp:_8
#  0 #_init_equ_catch
#  1 #_recruitments
#  1 #_parameter-priors
#  1 #_parameter-dev-vectors
#  1 #_crashPenLambda
0 # (0/1) read specs for more stddev reporting
 # 0 1 -1 5 1 5 1 -1 5 # placeholder for selex type, len/age, year, N selex bins, Growth pattern, N growth ages, NatAge_area(-1 for all), NatAge_yr, N Natages
 # placeholder for vector of selex bins to be reported
 # placeholder for vector of growth ages to be reported
 # placeholder for vector of NatAges ages to be reported
999
```