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

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Executive summary

This paper presents an update from the first stock assessment of silky shark in the western and central Pacific Ocean that was submitted to SC8 in August 2012. The main changes are the inclusion of a greater number of CPUE and catch time series in the analysis. 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.

As requested by the 2013 Pre-Assessment Workshop we have presented key model results for each set of catch and CPUE series separately, the SPC bycatch longline (no HW) and Japanese RTV series combined, and for all model runs combined. The main results presented in the executive summary refer to the model runs with SPC bycatch longline (no HW) and Japanese RTV series combined, but all model results are available for the consideration of SC9.

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

1. 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 CPUE trend estimated a current total biomass in excess of 150,000,000mt. This 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.
2. 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.

3. This is a low productivity species and this is reflected in the low estimated value for F_{MSY} (0.08) and high estimated value for SB_{MSY} / SB_0 (0.39). These directly impact on conclusions about overfishing and the overfished status of the stock.
4. Based on the reference case the 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} ($F_{CURRENT}/F_{MSY}$ = 4.48) and across nearly all plausible model runs undertaken estimated F values were much higher than F_{MSY} (the 5th and 95th quantiles are 1.41 and 7.96). <u>Based on these results we conclude that overfishing is occurring</u>.
6. Estimated spawning biomass has declined to levels below SB_{MSY} ($SB_{CURRENT}/SB_{MSY}$= 0.70) and for the majority of the model runs undertaken, $SB_{CURRENT}$ is less than SB_{MSY} (the 5th and 95th quantiles are 0.51 and 1.23). <u>Based on the distribution of these results we conclude that it is highly likely that the stock is in an overfished state</u>.
7. Notwithstanding the bullet point above, that estimates of SB_0 and SB_{MSY} are uncertain as the model domain begins in 1995, so 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 67% of the 1995 value for the reference case, and across the majority of the model runs $SB_{CURRENT}/SB1995$ has declined (the 5th and 95th quantiles are 39% decline and a 67% increase).
8. Current catches are higher than the MSY (5,331 mt versus 1,994 mt), further catch at current levels of fishing mortality would continue to deplete the stock below SB_{MSY}. Current (2005-2008 average) and latest (2009) catches are significantly greater than the forecast catch in 2010 under F_{MSY} conditions (approximately 600 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.
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, and noting the concerns regarding stock status outlined in this assessment, it is recommended that an updated assessment be undertaken in 2014 if the key data sets (JPN RTV and Hawaiian longline observer) are available for analysis.

A series of research recommendations are also provided.

1 Background

This paper represents a follow-up to first silky shark assessment presented in Rice and Harley (2012a). This assessment was not accepted by the Scientific Committee who recommended further modelling work be undertaken (see Appendix 4 for details of their request). This additional work was first presented to WCPFC9 in December 2012 (OFP, 2012) and was subsequently reviewed by the Pre-Assessment Workshop held in April 2013 (OFP, 2013) before being finalized.

A comparison of the results of this assessment compared to that in Rice and Harley (2012a) was provided in OFP (2012) and is also provided in Appendix 3 of the current paper.

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 that 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. 2011a), 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 known 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 ratio that is not statistically different than 1:1. A one year resting period 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 over 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 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 respectively. 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 Rice 2012a, b and Rice 2013 for more information).

Purse seine fleets usually operate in equatorial waters from 10°N to 10°S; although a Japanese 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 and catch per unit effort (CPUE), and also catch different 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 where the majority of the bycatch in the associated sets consists of small silky sharks (<90cm TL, Watson et al. 2009).

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 3), 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 paper presents an update from the first stock assessment of silky shark in the western and central Pacific Ocean that was submitted to SC8 in August 2012 (Rice and Harley 2012a). Appendix 4 contains the SC8 recommendations on the assessment – in particular the requests for additional work that are covered in this updated assessment.

The main changes are the inclusion of a greater number of CPUE and catch time series in the analysis. This is only the forth full integrated stock assessment undertaken for a pelagic shark stock in the Pacific Ocean following the north Pacific blue shark assessments of Kleiber et al. (2009) and Rice and Harley (2013), and the oceanic whitetip shark stock assessment by Rice and Harley (2012b).

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 Rice (2012; 2013) 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 of 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

These are described in Rice (2012a; 2013) and the key aspects are repeated below.

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 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. An alternative catch history was developed based on the SPC held observer data to explore the effect of different trends and magnitudes in the catch histories (Rice 2012a). Because these two catch trends used similar methods and different subsets of the same dataset, two estimates from Clarke (2009) were used, with values updated to 2009. These catch estimates were based on trade data extrapolated using various fishery indices such as tuna catch and area (Clarke 2005).

2.4 CPUE and standardised effort time series

Standardized catch per unit of effort series were used as indices of abundance (Figure 5). For technical details and presentation of standardization model fits see Rice (2013). In brief, standardized CPUE series were estimated for silky sharks in the western central Pacific based on observer data held by SPC (SPC LL No Hawaii, the Target LL, purse seine catch/set and purse seine catch /mt), observer data from Hawaii (HI LL, Walsh and Clarke 2011) and observer data collected by the Japanese research and training vessels (JPN_RTV Clarke et al. 2011b).

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 6. 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 7 and 8) 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 estimated, 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 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.

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[2] An alternative formulation for the relationship between spawning biomass and recruitment was considered based on Taylor et al. (2003). 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 we have more recently successfully used this for the assessment of blue shark in the North Pacific and 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. (2013) parameterization which was not included in the final set of model runs.

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 of 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.

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 which 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.

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

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;

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

where θ' is the θ parameter rescaled into [0,1], ${\mu'}_\theta$ 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

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

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*, ε_f is the observation error that is assumed to be lognormally distributed as: $\ln\left(\varepsilon_f\right) \sim N(-0.5\sigma_f^2 \, , \sigma_f^2)$ where σ_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, and because it was generally difficult to identify with confidence which clearly were the most appropriate data inputs or structural assumptions to make in a model, 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 (4 time series)
- CPUE (6 scenarios)
- Natural Mortality (3 values)
- Steepness (3 values)
- Initial fishing mortality (3 values)
- Effective Sample Size weighting (2 values)
- Standard Deviation of the Recruitment deviates (2 values).

We examined all possible combinations to give a 'grid' over 2592 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 option are listed in Table 4. Because the CPUE series are all equally weighted, the reference case was chosen randomly from the multiple highest weighted models.

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 16 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 1.

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 reference case model was analysed with Markov Chain Monte Carlo simulations 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 biomass 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 and is based on advice from the Pre-Assessment Workshop (OFP, 2013). Also presented for comparison of important results are the 16 sensitivity analyses.

As requested by the 2013 Pre-Assessment Workshop we have presented key model results for each set of catch and CPUE series separately, the SPC bycatch longline (no HW) and Japanese RTV series combined, and for all model runs combined. The main results presented here refer to the model runs with SPC bycatch longline (no HW) and Japanese RTV series combined, but all model results are available for the consideration of SC9 and summaries for each CPUE and catch series and the overall grid are provided in Appendix2.

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 24 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) (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 13.

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 0.3 in 2009. The next highest component of F is the associated purse seine fishery which increases to approximately 0.125 by 2009, which on its own is above the estimated F_{MSY} = 0.084. Compared to the longline fleets, the 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 defined in Table 6 and presented in Table 7. For the reference-case, MSY is estimated to be 1,994 mt per annum at a level of fishing effort approximately 22% of the current level of fishing mortality. Therefore to reduce fishing mortality to the MSY level would require a reduction in fishing mortality of 78%. The level of average current catch (5,331 mt) is higher than the estimated MSY. The estimate of current biomass is 44,988 mt, which is 78% of B_{MSY}.

Current estimates of stock depletion are that the total biomass has been reduced to 30% of theoretical equilibrium virgin biomass. Although estimates of virgin biomass are inherently uncertain due to the extrapolation necessary, declines are evident over just the model period, with spawning biomass having been reduced by 33% ($SB_{Current}/SB_{1995}$ = 0.66). This decline is consistent with a $F_{CURRENT}/\tilde{F}_{MSY}$ value of 4.4.

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_4, Catch_5, CPUE_3, CPUE_4, CPUE_5, CPUE_6, CPUE_7, Nat_M_1 , Nat_M_3, Steep_1, Steep_3 Init_F_1, Init_F_3, SampSz_2, 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 and Table 9). 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.

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 from the structural uncertainty grid runs that included the SPC no-Hawaii longline series and the JPN RTV CPUE series are presented in Table 8. Grid results for the entire grid and each CPUE and catch series are provided in Appendix 2. 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), $SB_{CURRENT}/SB_0$ (Figure 19), $SB_{CURRENT}/SB_{1995}$ (Figure 20), and $F_{CURRENT}/\ \tilde{F}_{MSY}$ (Figure 21) 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). The alternate catch time series (Catch_2, Catch_4 and Catch 5) had little effect on the stock status. 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). The 5th and 95th quantiles of structural uncertainty based on runs using the SPC no-Hawaii longline series and the JPN RTV CPUE series regarding the stock status ranged from 0.51 to 1.23 for $SB_{CURRENT}/SB_{MSY}$, from 0.55 to 1.39 for $B_{CURRENT}/B_{MSY}$ and from 1.41 to 7.96 for $F_{CURRENT}/\tilde{F}_{MSY}$. Results of the entire grid are included in Appendix 2 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, $F_{CURRENT}/F_{MSY}$ =4.48 for the reference case and 3.39 for the median of the runs that included the SPC no-Hawaii longline series and the JPN RTV CPUE series (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 30% for the reference case and 34% for the grid median of the equilibrium unexploited level ($\tilde{B}_0$ Table 8). The $SB_{CURRENT}/SB_{MSY}$ is 0.70 for the reference case and 0.82 for the grid median based on the SPC Non target LL and the JPNRTV. For the majority of the SPC Non target LL and the JPNRTV runs undertaken, $SB_{CURRENT}$ is less than SB_{MSY} (the 5th and 95th quantiles are 0.51 and 1.23). <u>Based on the distribution of these results we conclude that it is highly likely that the stock is in an overfished state</u>.

The distribution of stock status as a function of the CPUE and catch inputs with respect to the Kobe plot is described in Table 9. This table highlights the Effect that the CPUE inputs, in particular the target longline have on the overall results.

5 Discussion

Aside from the unique challenges 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 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 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. 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 model's 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 a 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 general 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 methods and inputs for this stock assessment would greatly improve an updated stock assessment, which we recommend for 2014 if the key data sets (JPN RTV and Hawaiian longline observer) are available for analysis. 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. The next assessment should consider the Low Fecundity Spawner Recruitment relationship of Taylor et al. (2013) which wasn't used here, but has been successfully applied to blue shark in the North Pacific Ocean.

6 Conclusions

This is an update to the first stock assessment for silky sharks in the WCPO considered by SC8 in August 2012. The key conclusions are as follows.

1. 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 CPUE trend estimated a current total biomass in excess of 150,000,000mt. This 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.
2. 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.
3. This is a low productivity species and this is reflected in the low estimated value for F_{MSY} (0.08) and high estimated value for SB_{MSY}/SB_0 (0.39). These directly impact on conclusions about overfishing and the overfished status of the stock.
4. Based on the reference case the 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} ($F_{CURRENT}/F_{MSY}$ = 4.48) and across nearly all plausible model runs undertaken estimated F values were much higher than F_{MSY} (the 5th and 95th quantiles are 1.41 and 7.96). <u>Based on these results we conclude that overfishing is occurring</u>.
6. Estimated spawning biomass has declined to levels below SB_{MSY} ($SB_{CURRENT}/SB_{MSY}$= 0.70) and for the majority of the model runs undertaken, $SB_{CURRENT}$ is less than SB_{MSY} (the 5th and 95th

quantiles are 0.51 and 1.23). Based on the distribution of these results we conclude that it is highly likely that the stock is in an overfished state.

7. Notwithstanding the bullet point above, estimates of SB_0 and SB_{MSY} are uncertain as the model domain begins in 1995, so 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 67% of the 1995 value for the reference case, and across the majority of the model runs model runs $SB_{CURRENT}/SB1995$ has declined (the 5th and 95th quantiles are 39% decline and a 67% increase).
8. Current catches are higher than the MSY (5,331 mt versus 1,994 mt), further catch at current levels of fishing mortality would continue to deplete the stock below SB_{MSY}. Current (2005-2008 average) and latest (2009) catches are significantly greater than the forecast catch in 2010 under F_{MSY} conditions (approximately 600 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.
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, and noting the concerns regarding stock status outlined in this assessment, it is recommended that an updated assessment be undertaken in 2014 if the key data sets (JPN RTV and Hawaiian longline observer) are available for analysis.
12. As this was an update to 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. Data from Philippines and Indonesia regarding catch, effort and size composition of shark catches.
    c. Tagging studies which are critical for understanding stock structure and post release survival (e.g. Campana et al. 2009, Moyes et al. 2006).
    d. Studies on growth and reproductive biology – especially female maturity to inform the use of the Low Fecundity Spawner Recruitment relationship of Taylor et al. (2013).

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9 Tables

Table 1: Definition of fisheries for the silky shark assessment. 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 numbers) used in the current assessment

	Estimate Source			
year	Lawson	Rice	FAL-area	FAL-tuna
1995	184800	306450	140100	296700
1996	164561	411300	149400	302900
1997	163102	191670	161200	334000
1998	192422	158990	172100	403000
1999	202172	296680	192900	399600
2000	194358	259140	224800	486000
2001	184069	292790	276100	559600
2002	185042	263330	279400	604100
2003	153544	279670	298600	605200
2004	187679	317550	263500	569700
2005	192976	218220	252500	557400
2006	214454	299320	229000	515700
2007	245999	427390	248700	627400
2008	263904	423160	237500	599100
2009	258790	488610	238500	633800

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 the 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 (CATCH 1)**, Rice (CATCH 2), Clarke Area (CATCH 3), Clarke Tuna (CATCH 4)	0.3, 0.2, 0, 0.25 , 0.25
CPUE Time series	2	**LL_obs_no_HI (CPUE 2);** JPN_RTV (CPUE 3), LL_Tar (CPUE 4), PS_Catch/Set (CPUE 5), PS_Catch/MT (CPUE 6), HI_LL OBS (CPUE 7)	0.1667, 0.1667, 0.1667, 0.1667, 0.1667, 0.1667
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. The runs that are directly comparable are the Reference are Nat_M_1, Nat_M_3, Steep_1, Steep_3, Init_F_1, Init F_3. Lower is better.

	Catch	Survey	Length_comp	Recruitment	Parm_priors	TOTAL
Reference	0.00	19.33	34.96	-23.39	0.16	31.05
Catch_2	0.00	19.46	35.08	-23.40	0.14	31.27
Catch_4	0.00	18.94	35.08	-23.42	0.15	30.76
Catch_5	0.00	19.50	35.06	-23.41	0.11	31.25
CPUE_3	0.00	-11.01	34.96	-23.43	0.14	0.66
CPUE_4	0.00	182.62	35.59	-12.35	0.03	205.90
CPUE_5	0.00	-12.01	34.95	-23.34	0.14	-0.25
CPUE_6	0.00	-2.32	34.90	-23.09	0.16	9.65
CPUE_7	0.00	5.20	35.01	-23.48	0.13	16.86
Nat_M_1	0.00	19.15	37.45	-23.40	0.18	33.38
Nat_M_3	0.00	19.61	36.70	-23.35	0.14	33.10
Steep_1	0.00	19.00	34.95	-23.41	0.15	30.70
Steep_3	0.00	19.65	35.08	-23.37	0.17	31.53
Init_F_1	0.00	19.77	34.95	-23.37	0.17	31.51
Init_F_3	0.00	18.36	35.34	-23.42	0.15	30.43
SampSz_2	0.00	19.38	88.12	-23.37	0.16	84.29
SigmaR_2	0.00	18.39	35.09	-13.75	0.16	39.89

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

Management Quantity	Units	Description
C_latest	t	Estimated catch in 2009
C_cur	t per annum	Average Current (2005- 2008) Catch
Y_MSY	t per annum	Theoretical equilibrium yield at FMSY, or maximum sustainable yield (MSY).
B_zero	t	Equilibrium total unexploited biomass
B_msy	t	Equilibrium total biomass at MSY
B_cur	t	Average Current (2005-2008) total biomass
SB_zero	t	Equilibrium unexploited adult biomass
SB_msy		Equilibrium adult biomass at MSY
SB_cur		Average Current (2005-2008) adult biomass
SB_1995		Estimated adult biomass in 1995
F_msy		Average Current (2005-2008) fishing mortality.
F_cur		Fishing mortality producing the maximum sustainable yield (MSY)

Table 7. Estimates of Managment quantities for th reference case and sensitivity runs. For details onf the managment quantities see Table 6.

	Units	Reference	Catch_2	Catch_4	Catch_5	CPUE_3	CPUE_4	CPUE_5	CPUE_6	CPUE_7
C_latest	t	6,090	12,264	9,567	25,513	6,523	7,227	6,556	6,264	6,669
C_cur	t per annum	5,331	8,328	6,562	16,020	5,564	5,981	5,539	5,376	5,629
Y_MSY	t per annum	1,994	3,134	2,389	5,401	2,665	6,092,720	2,751	2,096	3,328
B_zero	t	149,368	229,893	175,221	395,969	201,352	467,638,000	207,899	157,469	252,219
B_msy	t	57,660	88,556	67,494	152,523	77,785	180,878,468	80,314	60,804	97,459
B_cur	t	44,988	70,520	58,407	140,462	82,887	364,973,250	87,142	51,144	118,832
SB_zero		2,257	3,473	2,647	5,982	3,042	7,065,070	3,141	2,379	3,811
SB_msy		871	1,338	1,020	2,304	1,175	2,732,710	1,213	919	1,472
SB_cur		613	966	817	1,978	1,154	5,318,520	1,207	692	1,671
B_cur/B_zero		0.301	0.307	0.333	0.355	0.412	0.78	0.419	0.325	0.471
B_cur/B_msy		0.78	0.796	0.865	0.921	1.066	2.018	1.085	0.841	1.219
SB_cur/SB_zero		0.272	0.278	0.309	0.331	0.379	0.753	0.384	0.291	0.438
SB_cur/SB_msy		0.704	0.722	0.801	0.858	0.982	1.946	0.995	0.753	1.135
SB_cur/SB_1995		0.667	0.682	0.757	0.811	0.931	1.847	0.943	0.713	1.076
B_msy/ B_zero		0.386	0.385	0.385	0.385	0.386	0.387	0.386	0.386	0.386
SB_msy/SB_zero		0.386	0.385	0.385	0.385	0.386	0.387	0.386	0.386	0.386
F_cur		0.374	0.369	0.353	0.359	0.198	0	0.183	0.323	0.139
F_msy		0.084	0.078	0.078	0.078	0.086	0.089	0.086	0.084	0.086
F_cur/F_msy		4.476	4.726	4.522	4.599	2.316	0.001	2.141	3.828	1.613

	Units	Nat_M_1	Nat_M_3	Steep_1	Steep_3	Init_F_1	Init_F_3	SampSz_2	SigmaR_2
C_latest	t	7,619	5,261	6,315	5,859	6,140	5,999	6,100	5,983
C_cur	t per annum	6,620	4,603	5,477	5,179	5,387	5,205	5,324	5,248
Y_MSY	t per annum	2,276	1,826	1,662	2,265	1,762	2,537	1,989	2,060
B_zero	t	325,676	97,063	169,891	132,028	132,110	189,649	149,021	153,894
B_msy	t	128,486	36,742	70,886	46,477	51,002	73,197	57,527	59,392
B_cur	t	96,458	32,041	52,086	39,068	47,281	41,523	44,713	44,999
SB_zero		5,630	1,116	2,567	1,995	1,996	2,865	2,251	2,325
SB_msy		2,221	422	1,071	702	771	1,106	869	897
SB_cur		1,614	302	741	507	647	564	607	623
B_cur/B_zero		0.296	0.33	0.307	0.296	0.358	0.219	0.3	0.292
B_cur/B_msy		0.751	0.872	0.735	0.841	0.927	0.567	0.777	0.758
SB_cur/SB_zero		0.287	0.27	0.289	0.254	0.324	0.197	0.27	0.268
SB_cur/SB_msy		0.727	0.714	0.692	0.722	0.839	0.51	0.698	0.694
SB_cur/SB_1995		0.756	0.629	0.708	0.624	0.543	1.015	0.662	0.657
B_msy/ B_zero		0.395	0.379	0.417	0.352	0.386	0.386	0.386	0.386
SB_msy/SB_zero		0.395	0.379	0.417	0.352	0.386	0.386	0.386	0.386
F_cur		0.44	0.287	0.446	0.347	0.354	0.337	0.336	0.386
F_msy		0.08	0.087	0.061	0.109	0.084	0.083	0.084	0.083
F_cur/F_msy		5.508	3.28	7.33	3.19	4.219	4.058	4.015	4.653

Table 8 Estimates of management quantities for the reference case and based on runs using the SPC no-Hawaii longline series and the JPN RTV CPUE series.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	10966	5696	30492
C_cur	5331	7182	4834	19498
Y_MSY	1994	3426	1921	8023
B_zero	149368	280848	127704	862123
B_msy	57660	107980	46477	345412
B_cur	44988	98690	41053	272450
SB_zero	2257	3927	1485	14902
SB_msy	871	1567	556	5971
SB_cur	613	1297	447	4634
B_cur/B_zero	0.30	0.34	0.22	0.51
B_cur/B_msy	0.78	0.90	0.55	1.39
SB_cur/SB_zero	0.27	0.32	0.20	0.47
SB_cur/SB_msy	0.70	0.82	0.51	1.23
SB_cur/SB_1995	0.67	0.93	0.61	1.67
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.29	0.13	0.48
F_msy	0.08	0.08	0.06	0.11
F_cur/F_msy	4.48	3.39	1.41	7.96

Table 9 Distribution of stock status outcomes (percentage of model runs in each quadrant of the Kobe plot) for models that included different CPUE and catch time series.

	Kobe plot quadrant			
CPUE	**RED**	**ORANGE**	**GREEN**	**YELLOW**
Non-target LL (no Hawaii)	87	13	0	0
Japanese research and training vessels	52	45	3	0
Target LL	0	0	100	0
Purse seine (catch per set)	58	35	7	0
Purse seine (catch per mt of tuna)	83	17	0	0
Hawaiian LL	36	36	28	0

Catches	**RED**	**ORANGE**	**GREEN**	**YELLOW**
Lawson	57	19	24	0
Rice	58	18	24	0
Clarke (area based)	50	28	22	0
Clarke (tuna catch based)	46	33	22	0

10 Figures

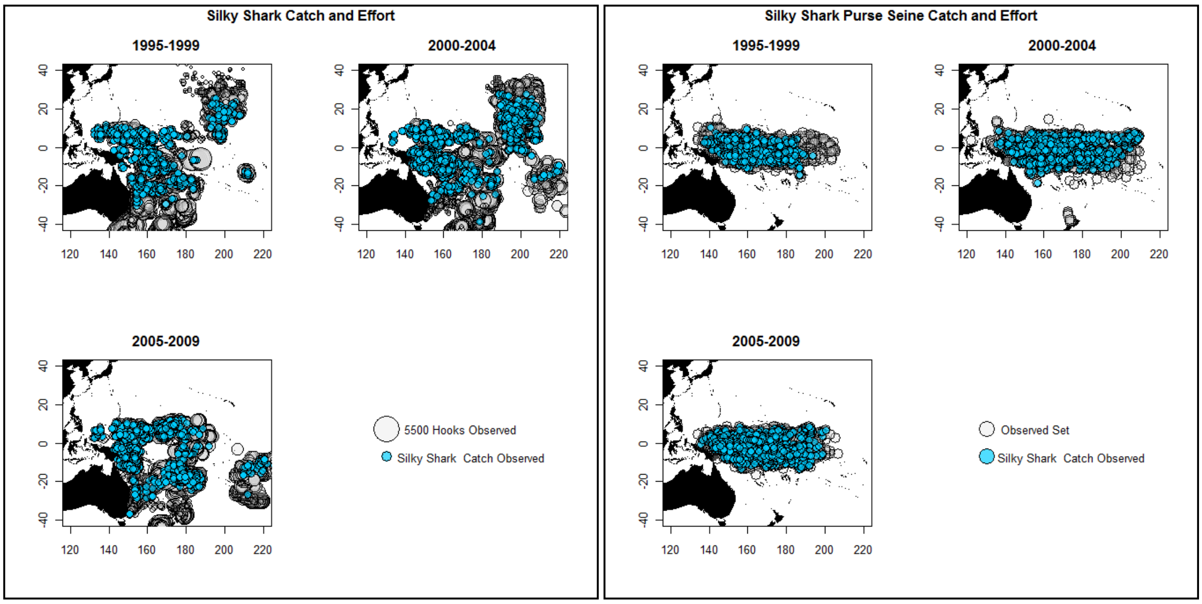

Figure 1. Distribution of the observed silky shark catches by fishing method (longline – left; purse seine – right) during 1995-2009.

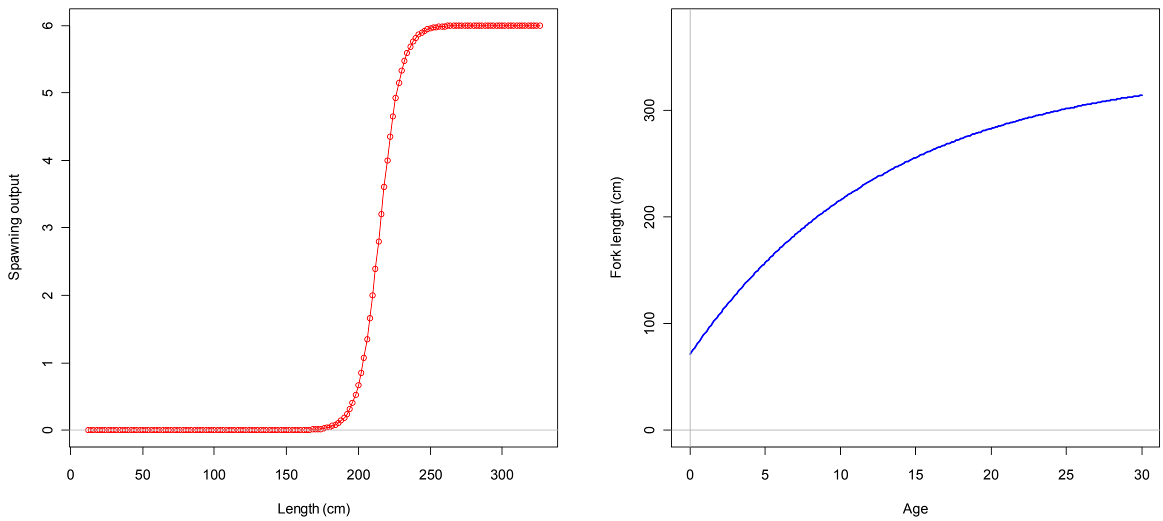

Figure 2. Important biological parameters assumed in the assessment; length at maturity (left panel) and the growth curve (right panel) both taken from Joung et al. 1998.

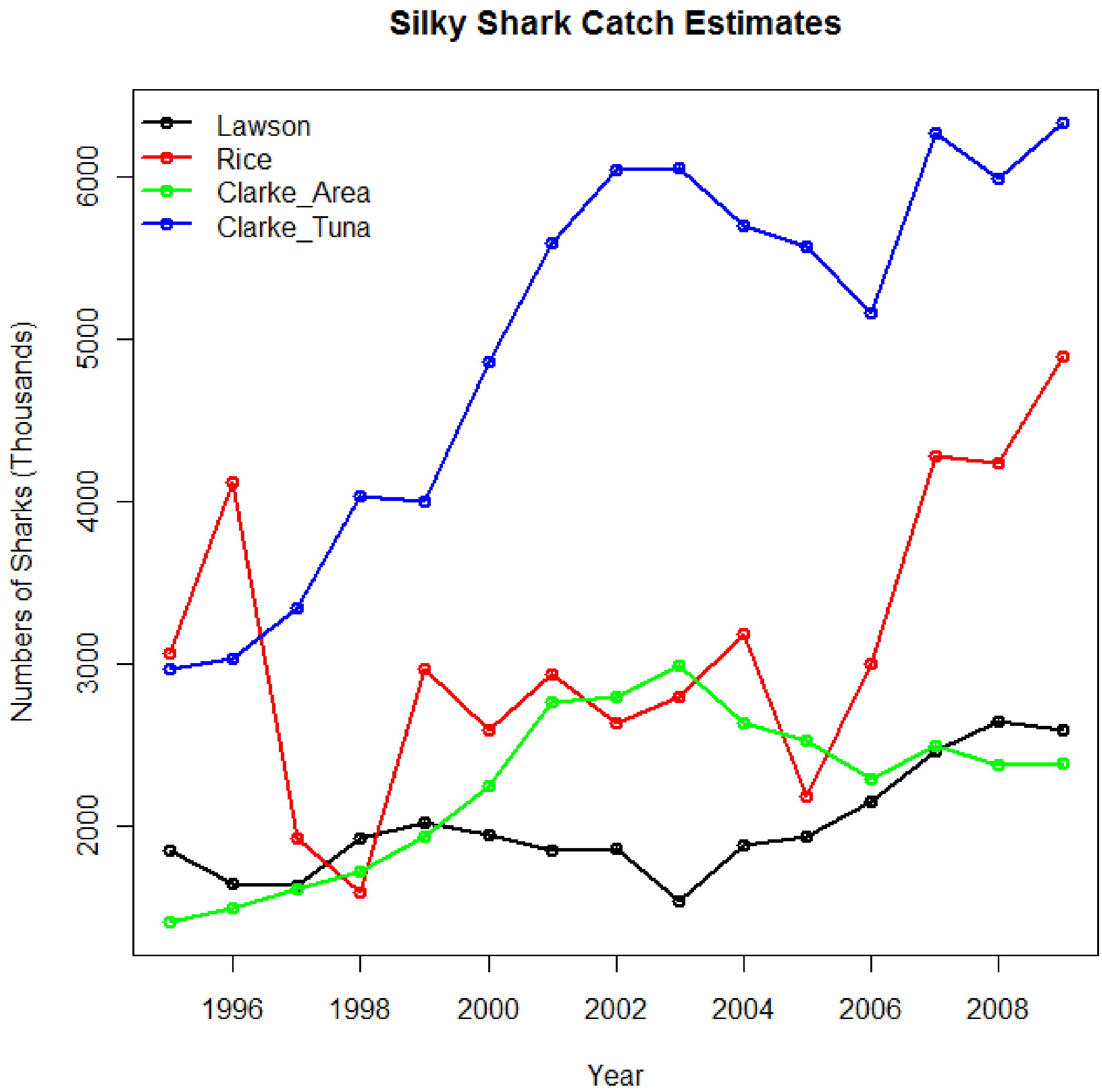

Figure 3. Estimated oceanic white tip catches in all fisheries by estimation study (see Rice 2013 for details).

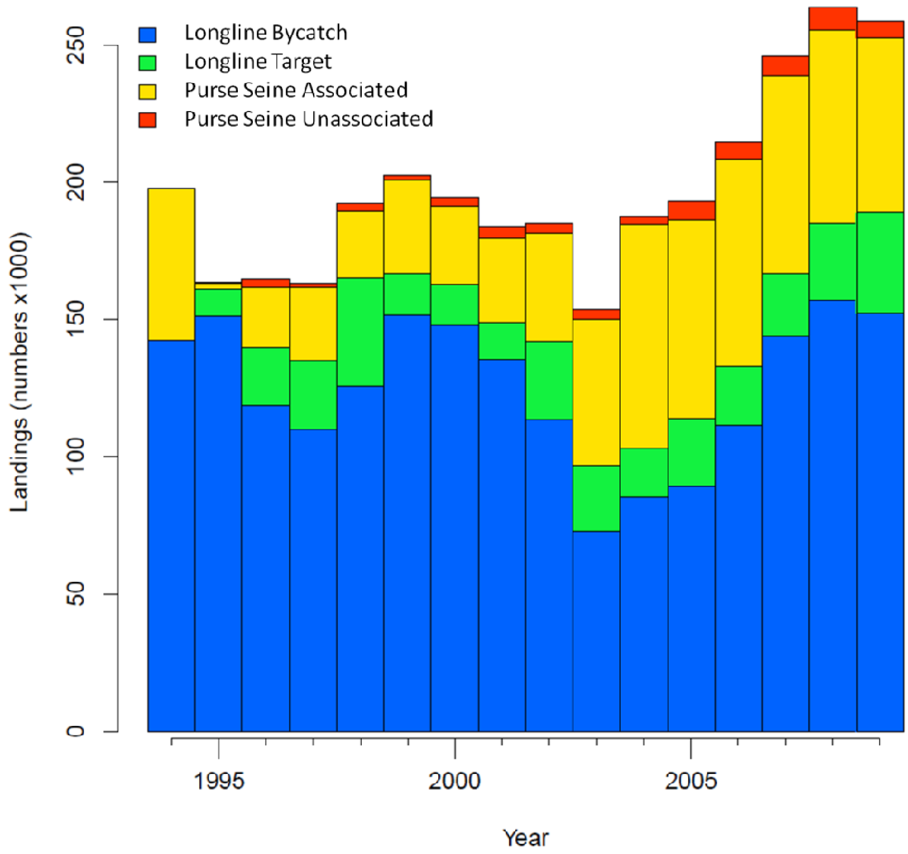

Figure 4. Annual estimated silky shark catch (in weight) in the WCPO by fleet (fishing method), 1995-2009 (Based on Lawson 2011, black line Figure 3) .

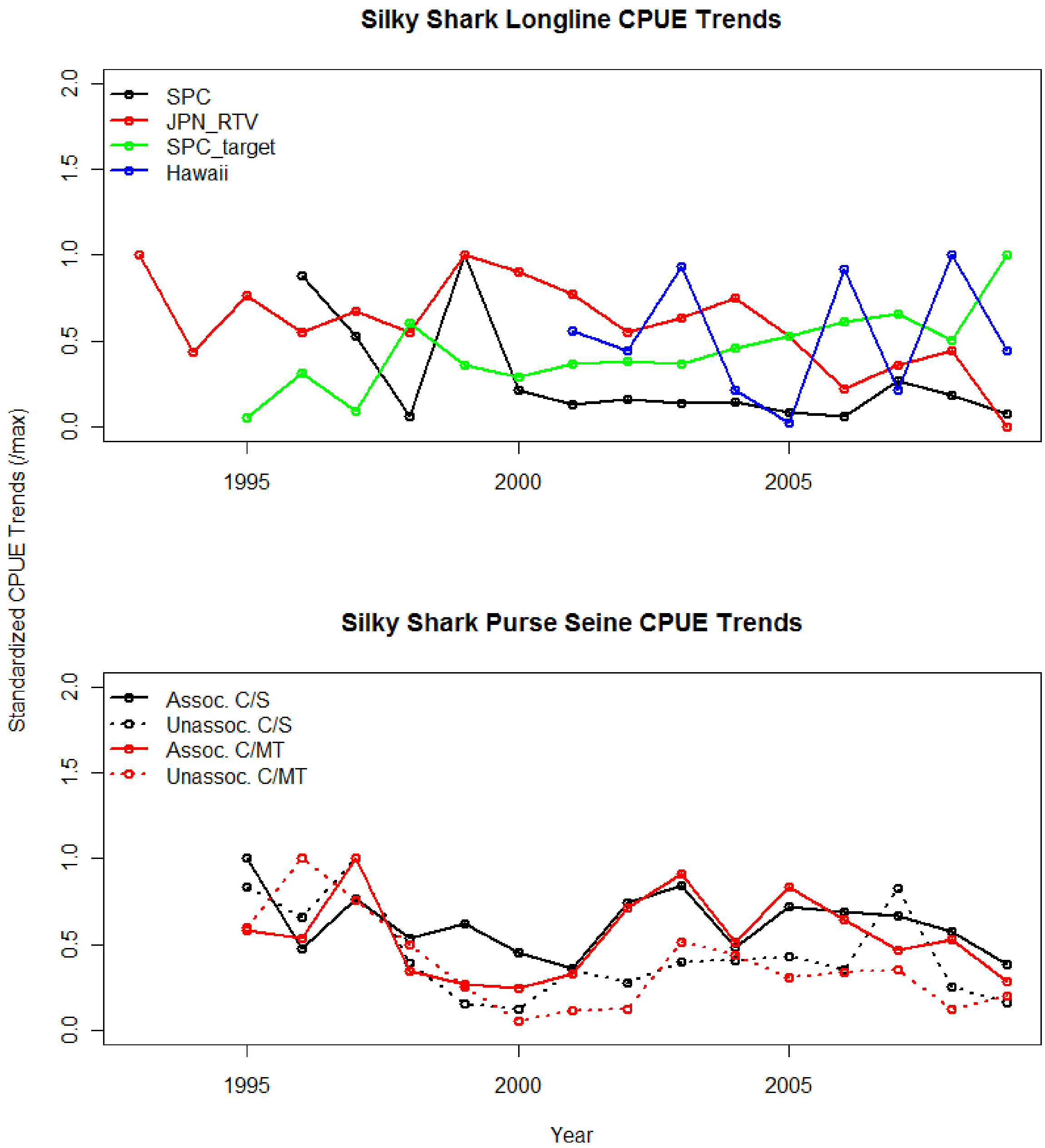

Figure 5. Standardized silky shark CPUE time series included in the assessment (see Rice 2013 for further details).

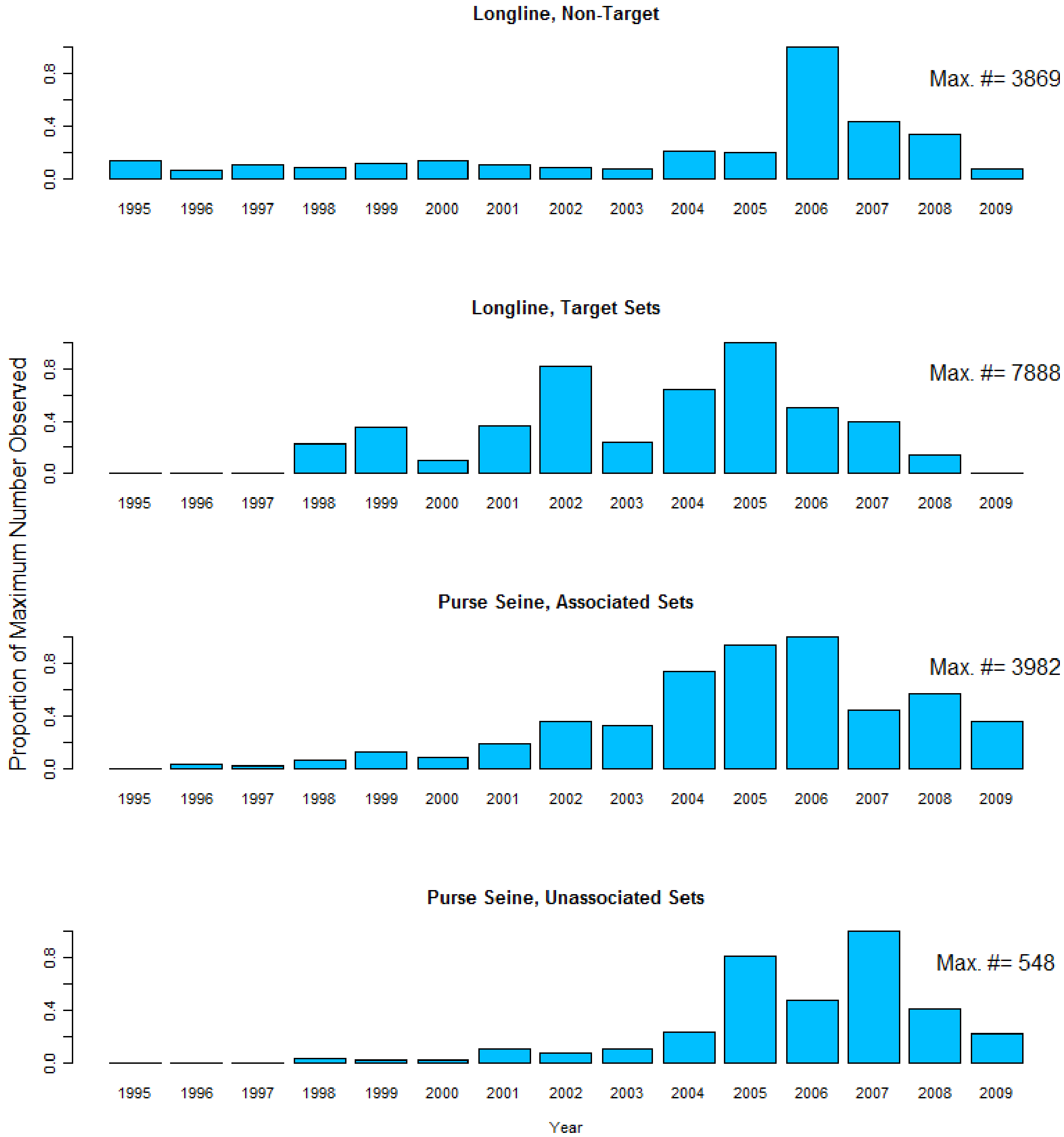

Figure 6. Number of length measurements by fishery and year. The histogram bars are proportional to the maximum number of fish measured in a fishery/year (the value presented in the upper right hand corner).

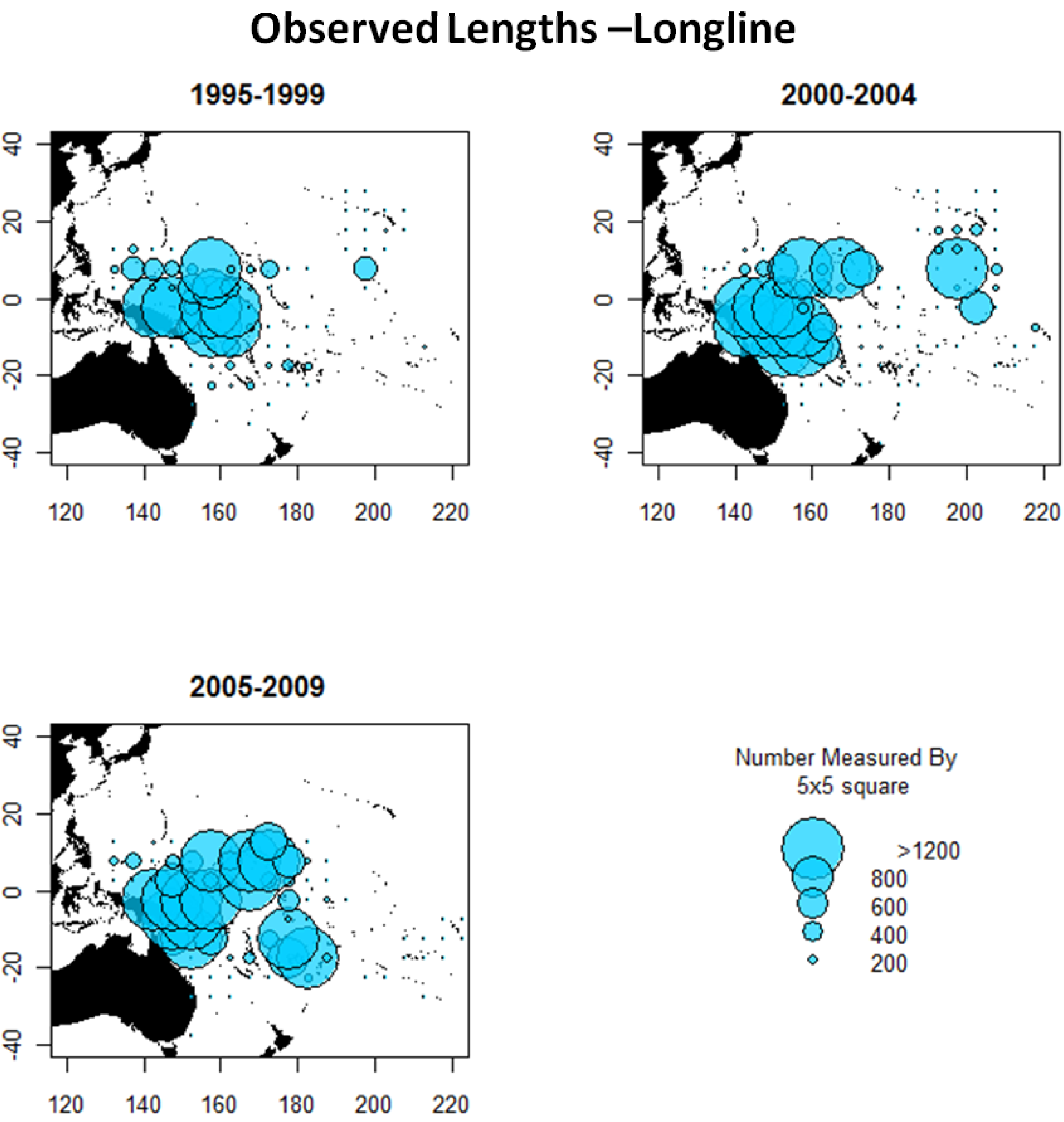

Figure 7. Number and location of silky sharks measured in the longline fishery (both target and bycatch) by 5-year block in 5x5 degree squares.

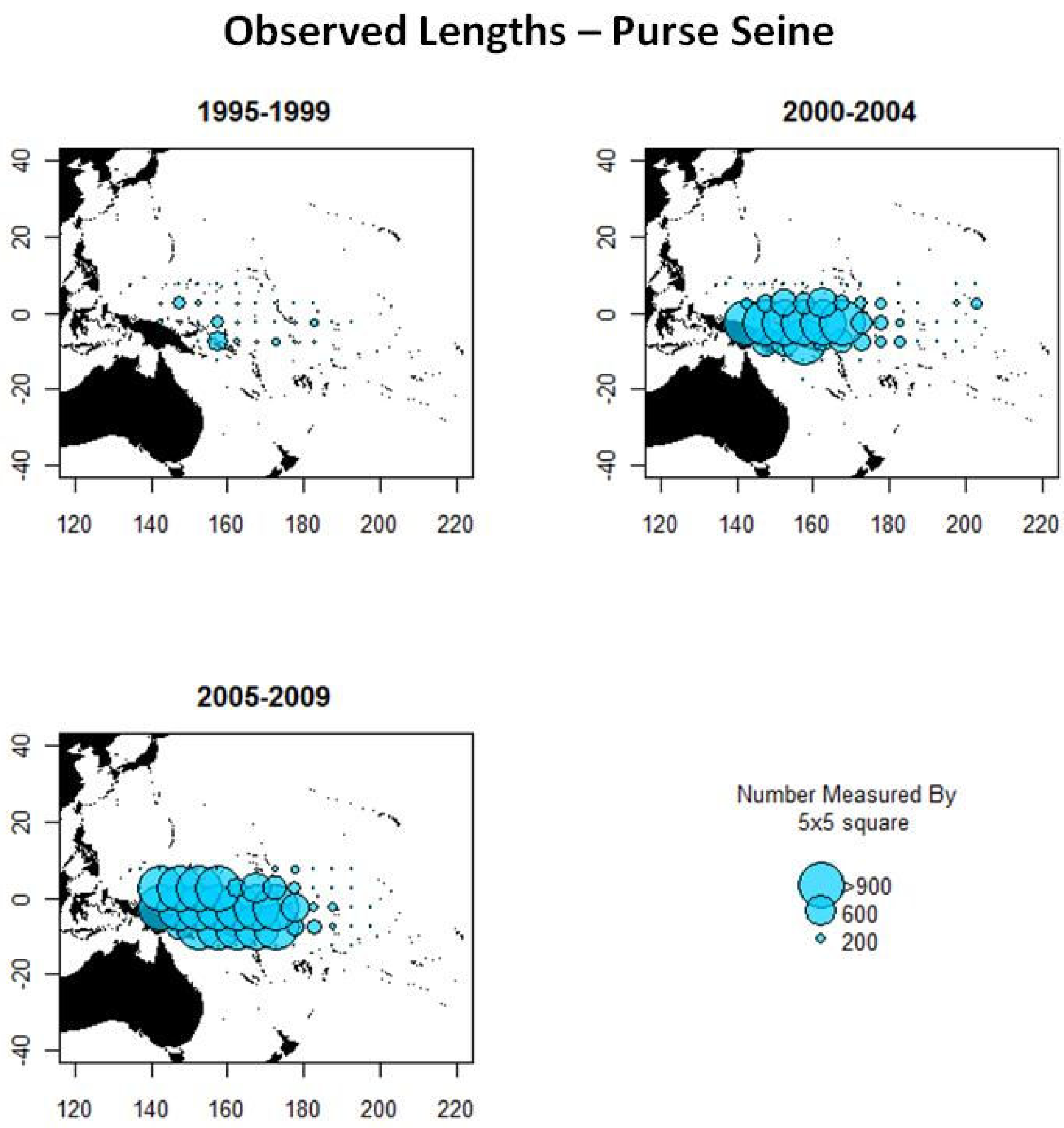

Figure 8. Number and location of silky sharks measured in the purse seine fishery by 5year block in 5x5 degree squares.

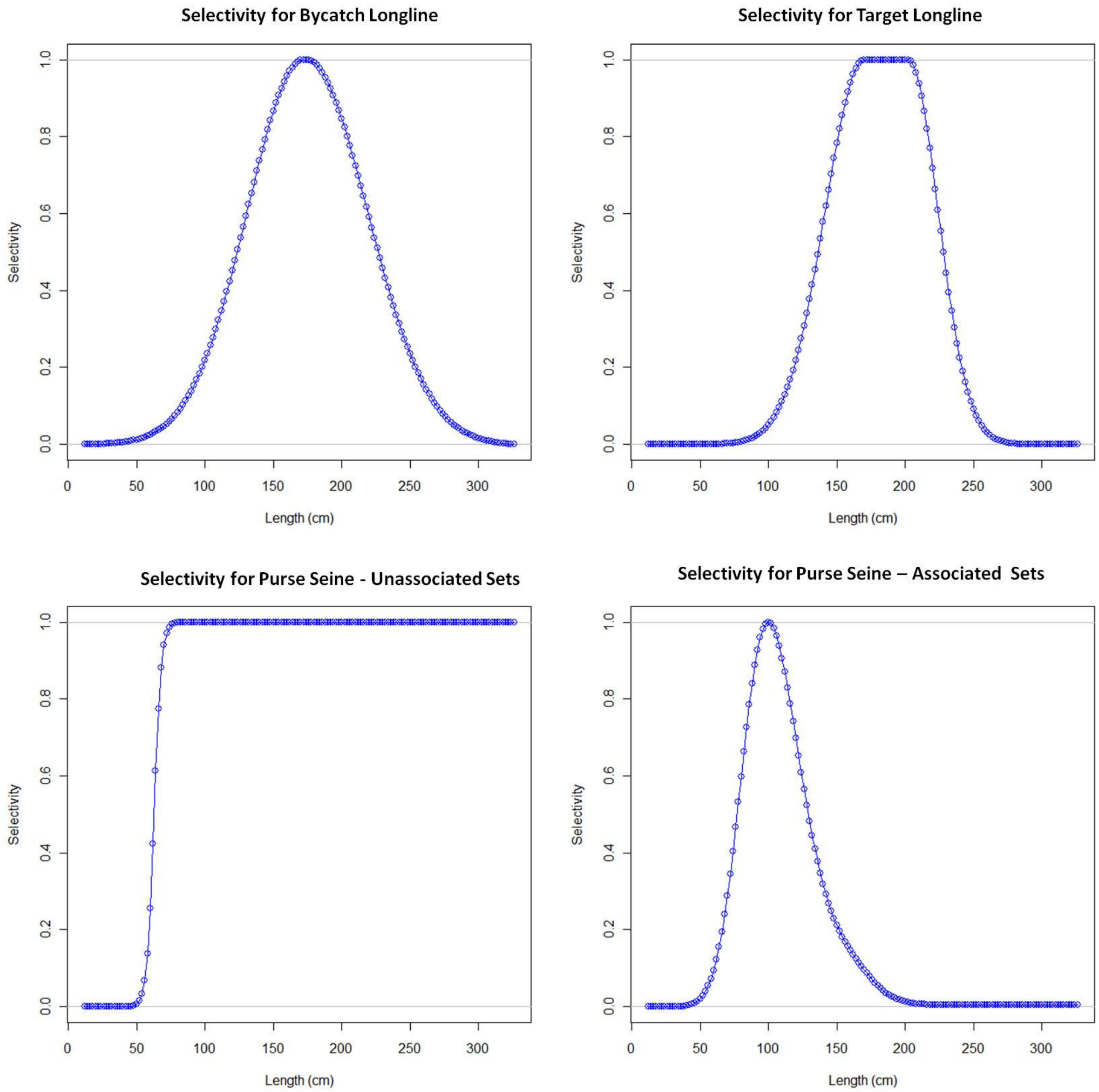

Figure 9. Selectivity by fleet. The top left is longline bycatch, top right is longline target, lower left is unassociated purse seine lower right is associated purse seine. Selectivity for males and females is the same.

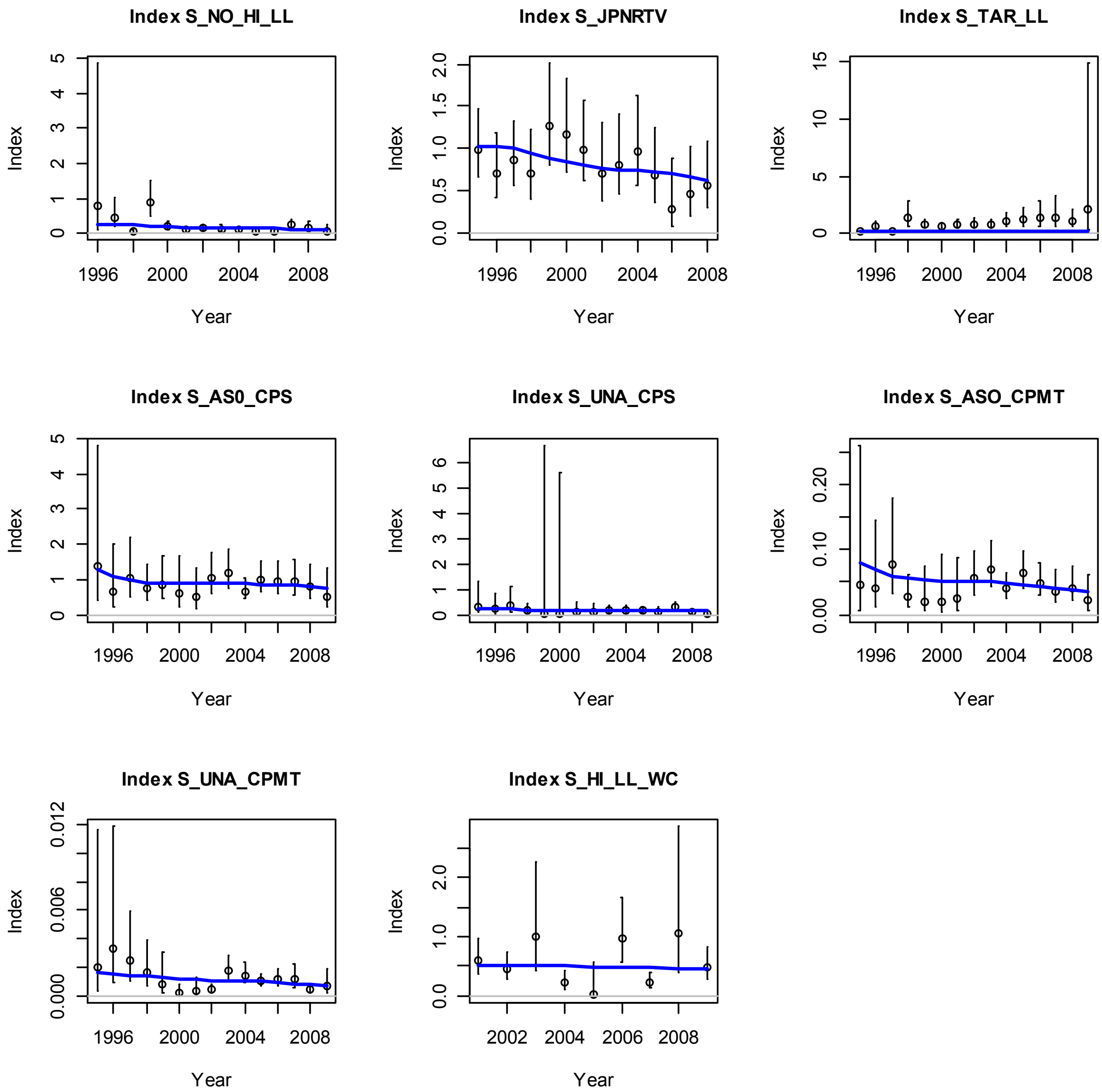

Figure 10. Fits to the observed CPUE series used in the assessment with blue lines giving the model predictions and observations given by the empty circles with 95% confidence intervals. Each fit relates to the model in which it was used: Index S_NO_HI_LL is the SPC bycatch CPUE series that excludes Hawaiian data that was the reference case and CPUE2; S_JPNRTV (CPUE 3); S_TAR_LL (CPUE 4); S_AS0_CPS and S_UNA_CPS (CPUE 5); S_ASO_CPMT and S_UNA_CPMT (CPUE 6); and S_HI_LL_WC (CPUE 7).

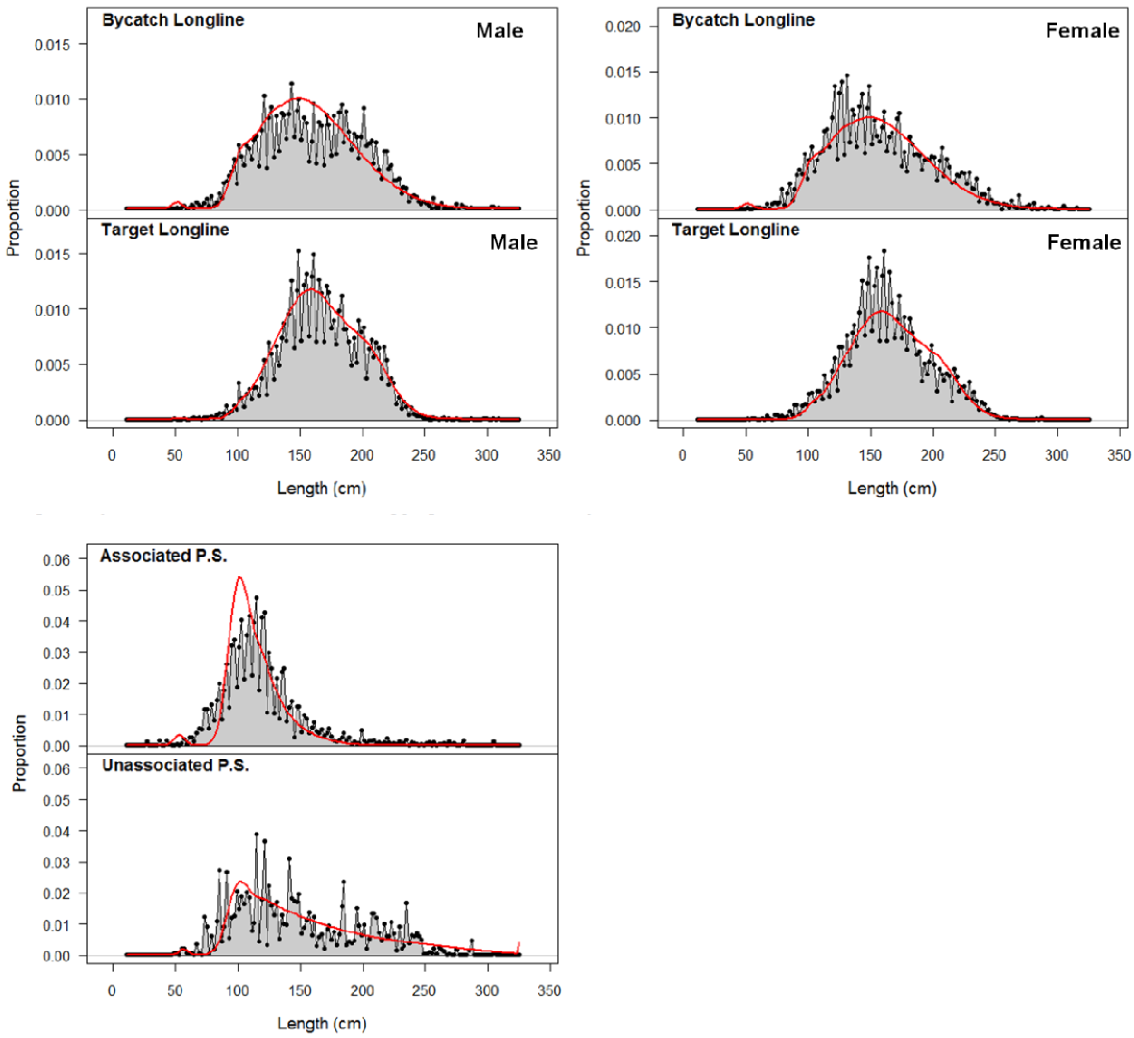

Figure 11. Predicted catch at length (red line) and observed lengths (black line and grey shaded area) in the longline fishery by fleet for the reference case model. Samples and predictions are pooled across all years. The top four panels are for the longline fisheries (males on the left and females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

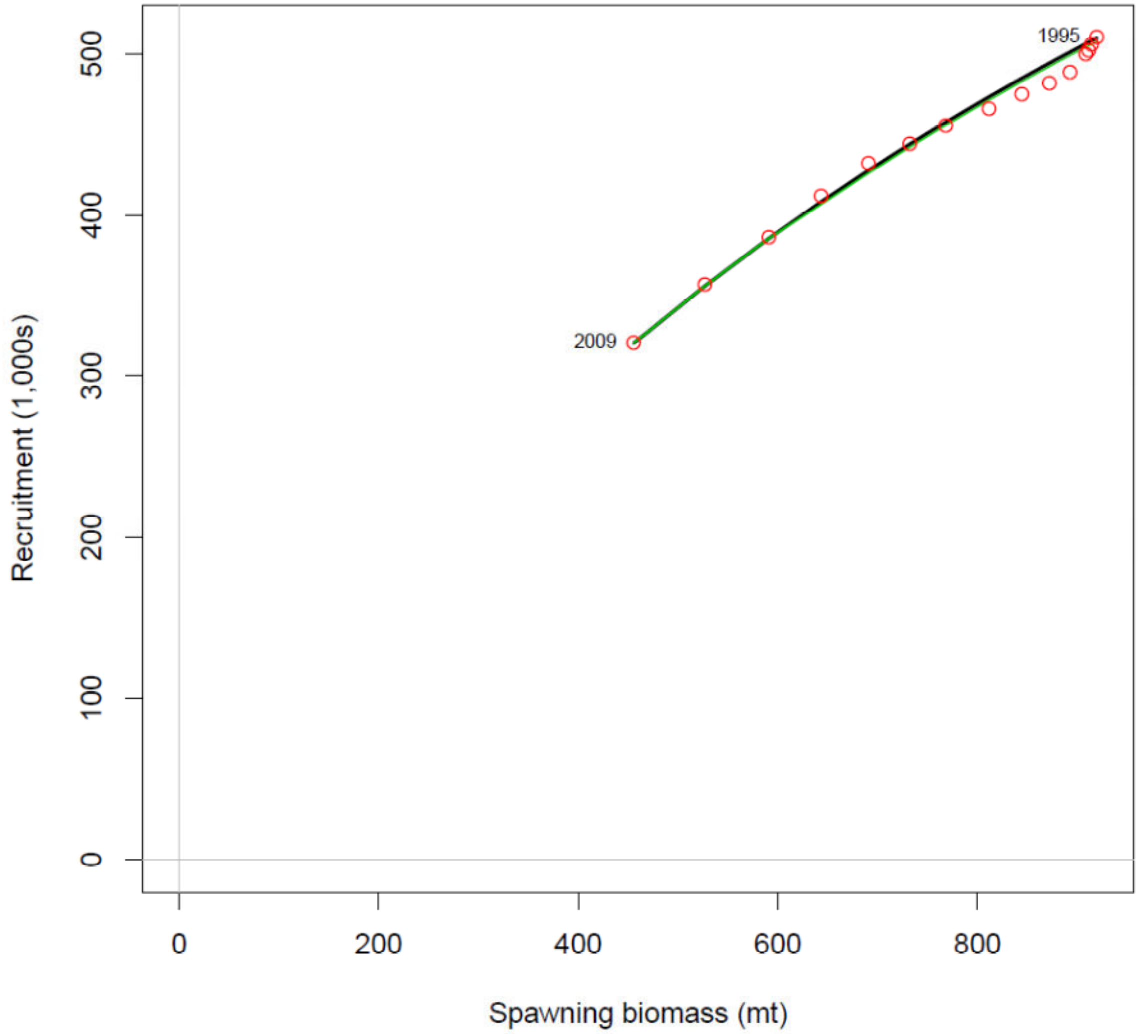

Figure 12. Spawning biomass per recruitment estimates and the assumed Beverton and Holt stock-recruitment relationship (SRR) based on assuming steepness of 0.409.

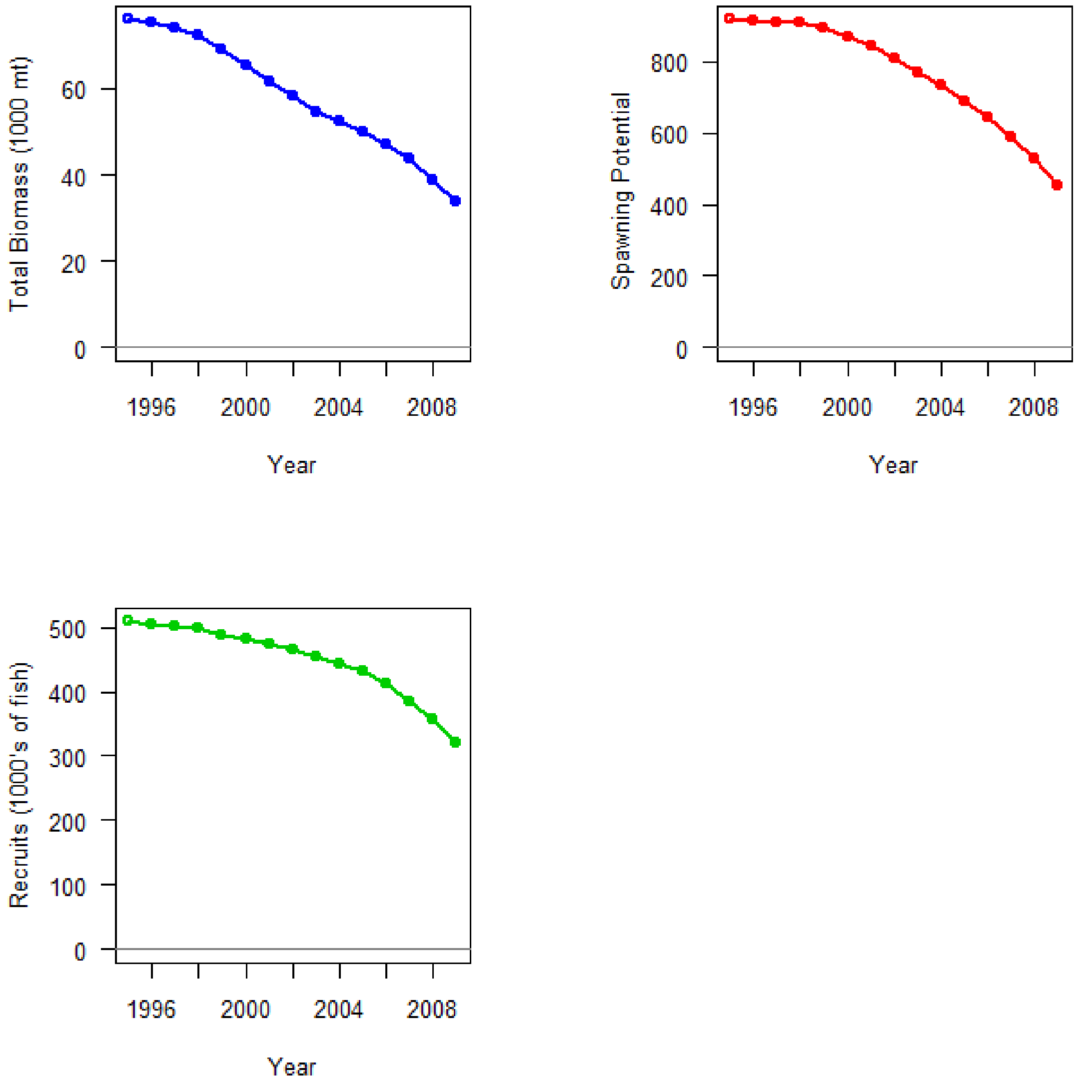

Figure 13. Estimated total biomass (top left, 1000 metric tons), estimated spawning biomass (top right) and estimated annual recruitment (1000's of fish) in the WCPO for the reference case.

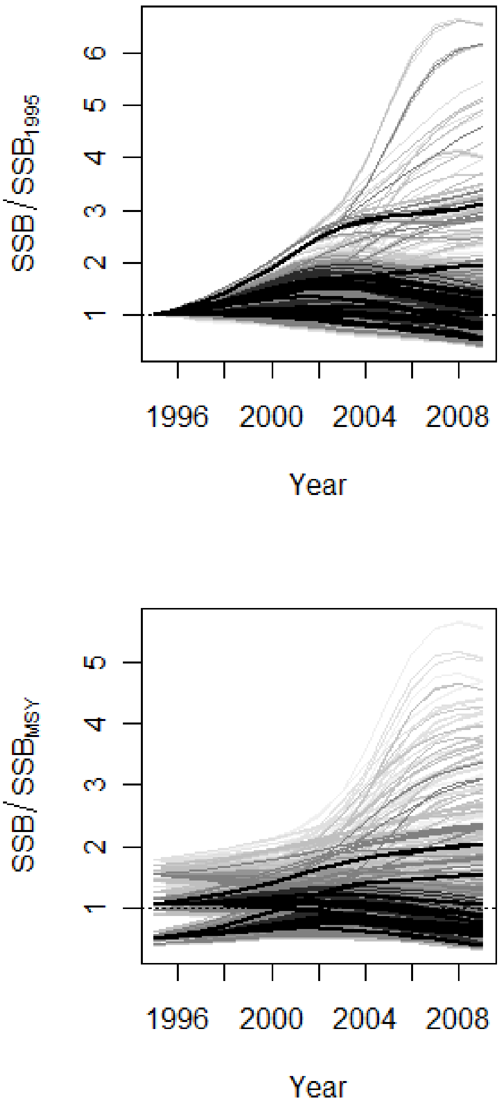

Figure 14. Changes in the spawning biomass relative to the first year of the model (1995 – top panel) and SBmsy (bottom panel). Each line represents one of 2592 runs from the grid and the darker the line, the higher the assigned weight (plausibility) for that model run.

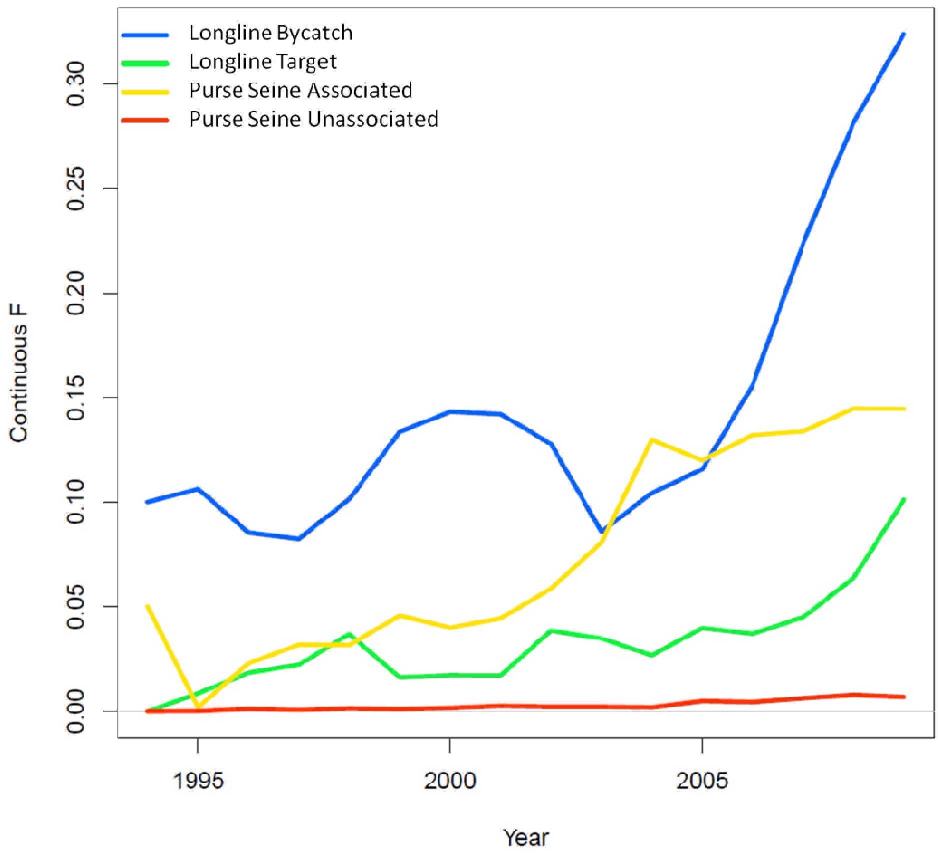

Figure 15. Estimated fishing mortality by fleet for the reference case over the model period.

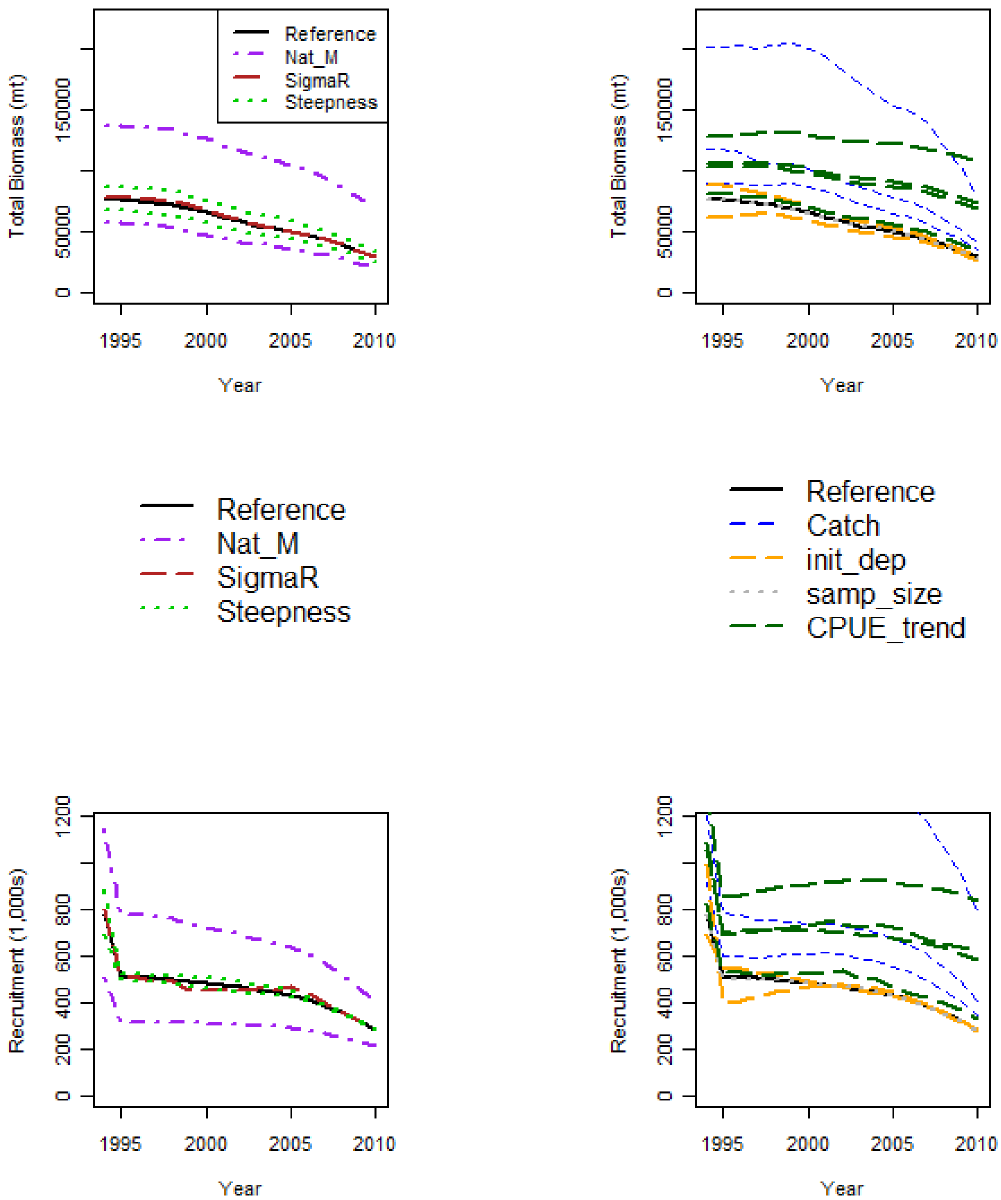

Figure 16. Sensitivity analysis effects on total biomass (top) and recruitment (bottom) of alternate variable levels on the reference case. The figures on the left show the effects of the natural mortality, SigmaR (the s.d. on the recruitment devs.), and the steepness. The figures on the right show the 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.

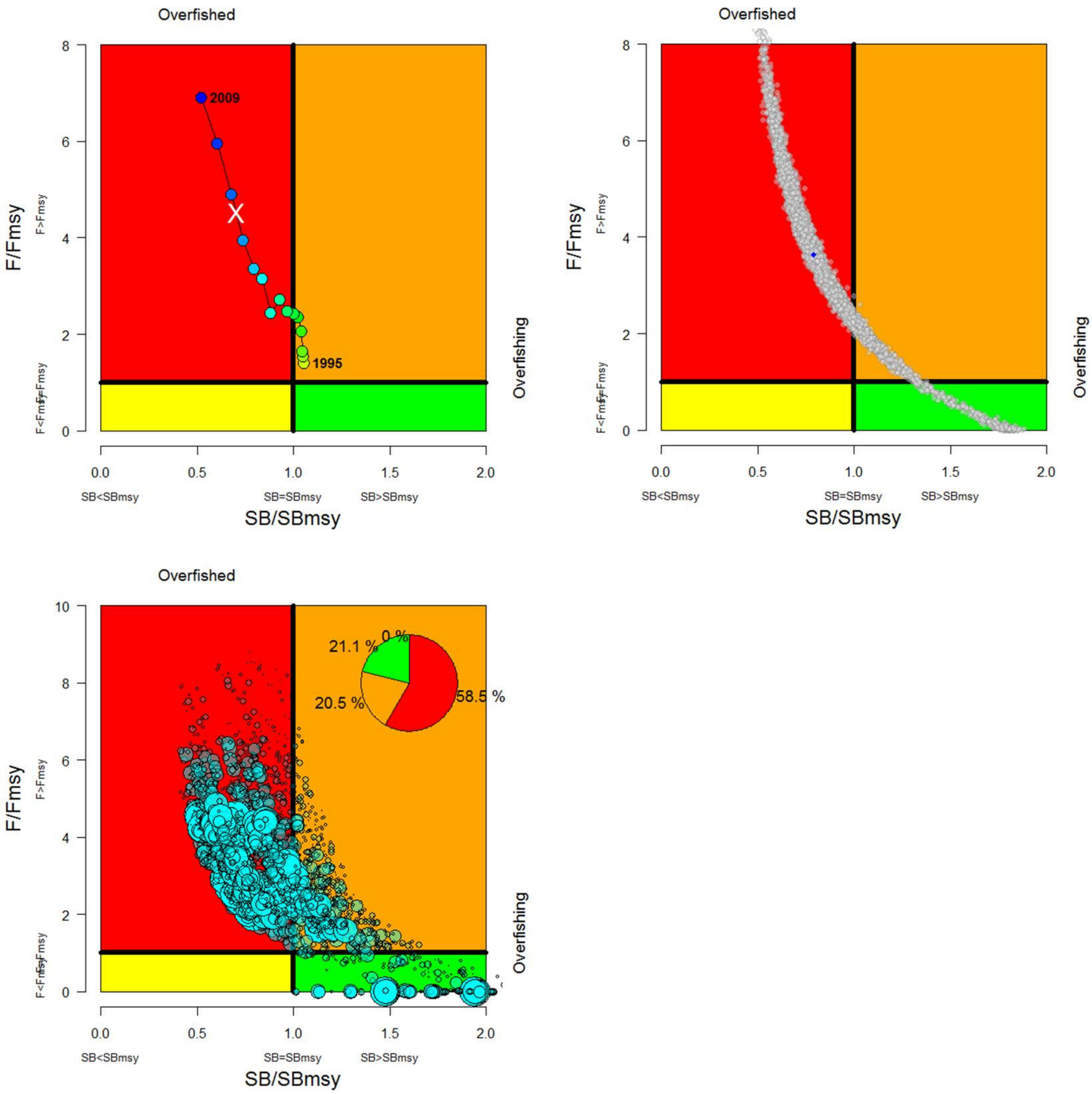

Figure 17. Kobe plots indicating annual stock status, relative to SB_{MSY} (x-axis) and F_{MSY} (y-axis). These present the reference points for the reference model for the period 1995–2009 (top left panel) with the white X for the current (avg. of 2005 – 2008), and for the statistical uncertainty for the current (average 2005-2008) conditions based on the MCMC analysis (top right panel) and based on the current (average of 2005-2008) estimates for all 2592 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.

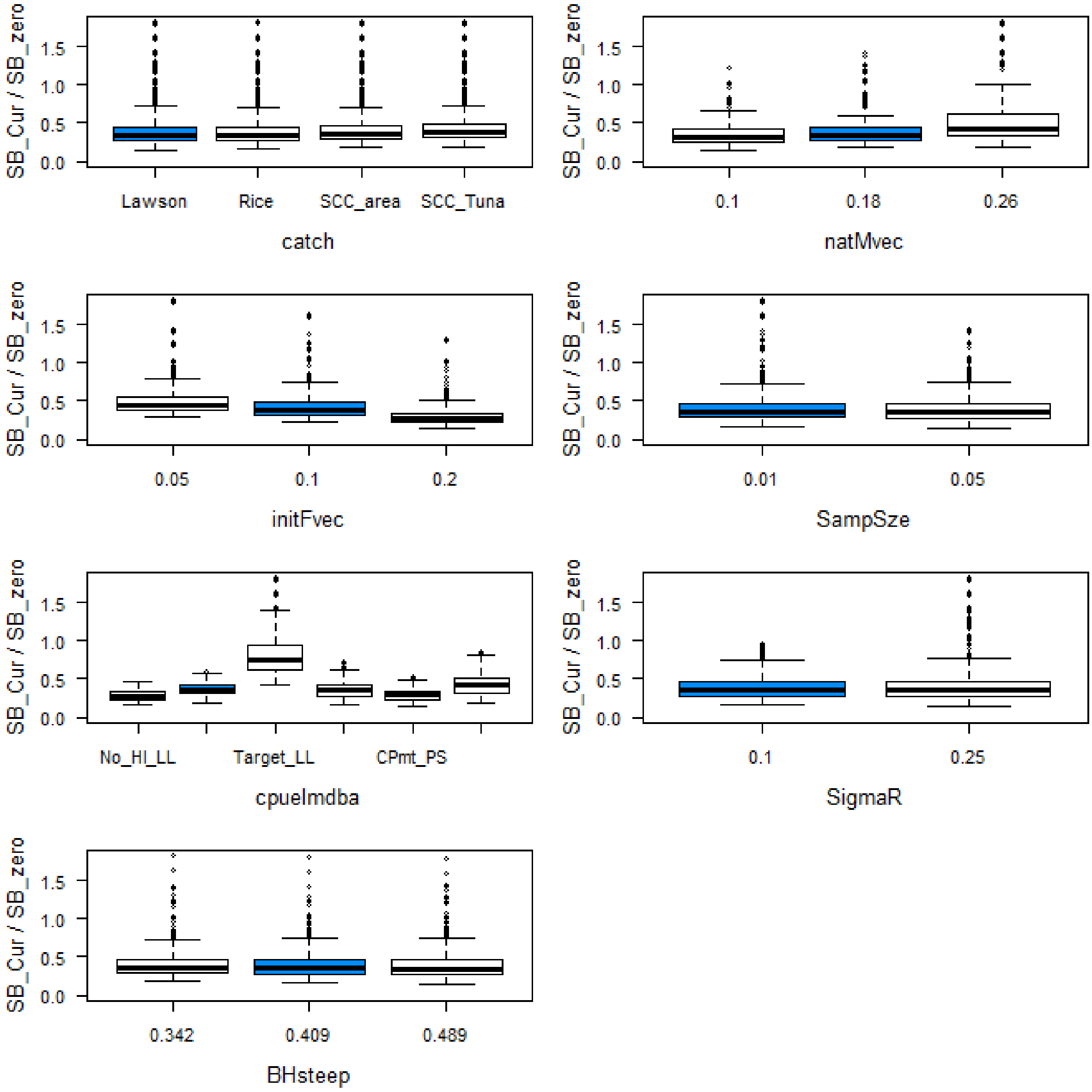

Figure 18. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter Spawning $SB_{CURRENT}/SB_{MSY}$.

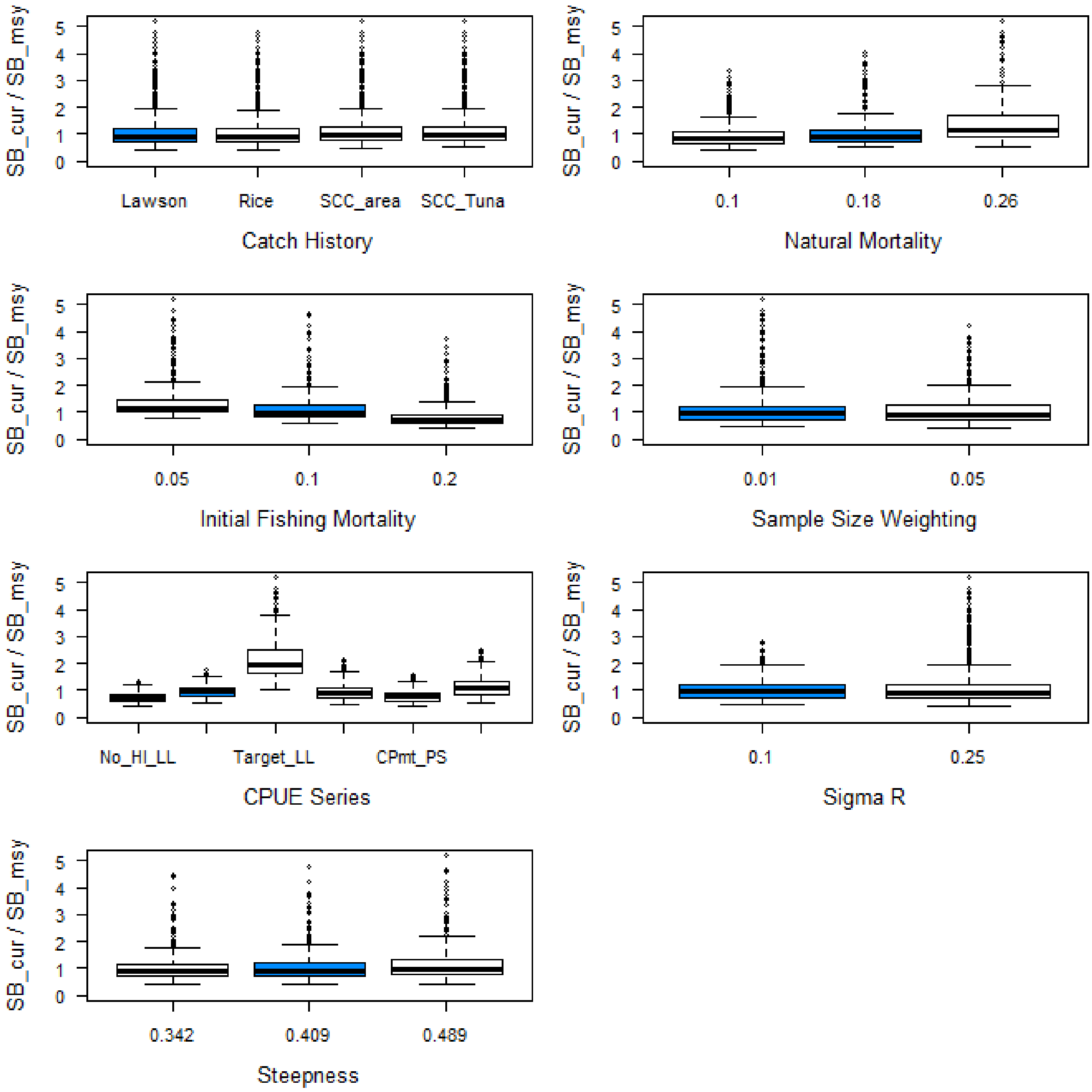

Figure 19. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter $SB_{CURRENT}$ / SB_0.

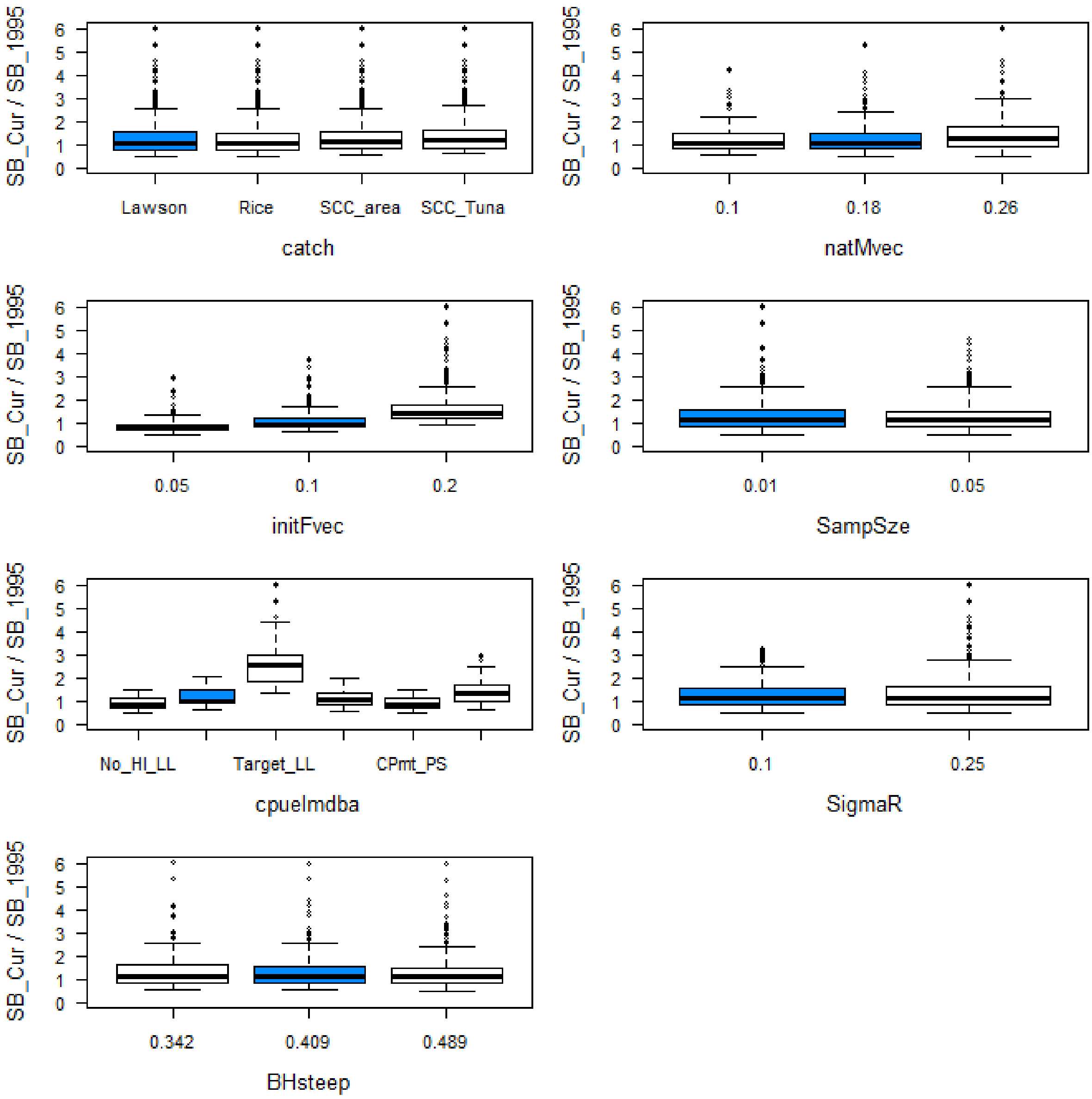

Figure 20. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter $SB_{CURRENT}$ / SB_{1995}.

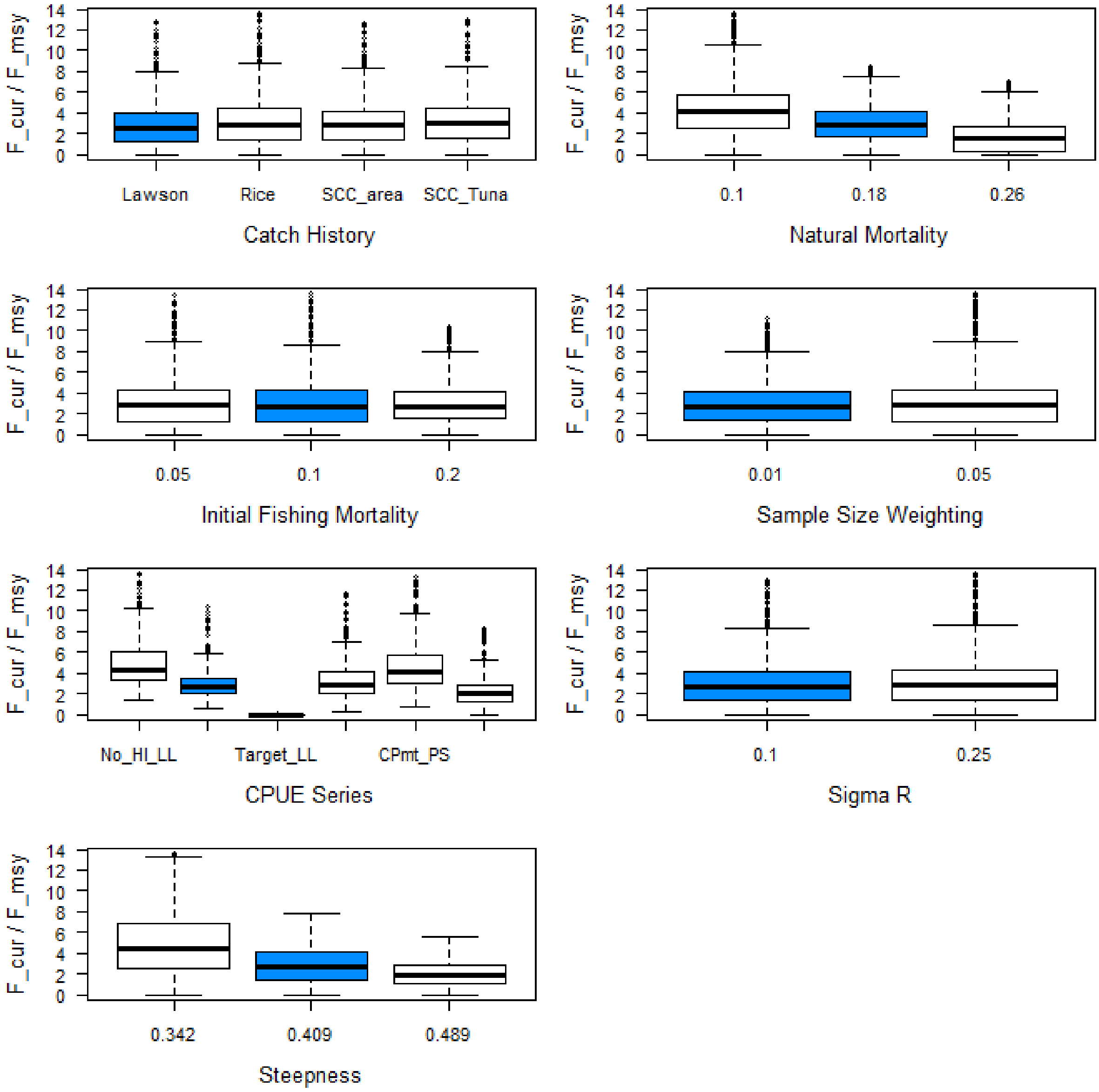

Figure 21. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter $F_{CURRENT}/F_{MSY}$.

11 Appendix 1: Control File for SS3 model

```
_SS-V3.21d-win64-safe;_05/22/2011;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB
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
0 #_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
 -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 6.65596 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
#
all recruitment deviations
#DisplayOnly 0 # Early_InitAge_5
#DisplayOnly 0 # Early_InitAge_4
#DisplayOnly 0 # Early_InitAge_3
#DisplayOnly 0 # Early_InitAge_2
#DisplayOnly 0 # Early_InitAge_1
#DisplayOnly 0.00422917 # Main_RecrDev_1995
#DisplayOnly -0.000264621 # Main_RecrDev_1996
#DisplayOnly -0.00637532 # Main_RecrDev_1997
#DisplayOnly -0.00903816 # Main_RecrDev_1998

```
#DisplayOnly -0.0221679 # Main_RecrDev_1999
#DisplayOnly -0.0221076 # Main_RecrDev_2000
#DisplayOnly -0.0160356 # Main_RecrDev_2001
#DisplayOnly -0.0109021 # Main_RecrDev_2002
#DisplayOnly -0.000156095 # Main_RecrDev_2003
#DisplayOnly 0.00494055 # Main_RecrDev_2004
#DisplayOnly 0.0146801 # Main_RecrDev_2005
#DisplayOnly 0.01276 # Main_RecrDev_2006
#DisplayOnly 0.00185953 # Main_RecrDev_2007
#DisplayOnly 0.00124062 # Main_RecrDev_2008
#DisplayOnly 0.00044676 # Main_RecrDev_2009
#DisplayOnly 0 # ForeRecr_2010
#DisplayOnly 0 # Impl_err_2010
#
#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_HI_LL
 0 0 0 0 # 6 S_NO_HI_LL
 0 0 0 0 # 7 S_JPNRTV
 0 0 0 0 # 8 S_TAR_LL
 0 0 0 0 # 9 S_AS0_CPS
 0 0 0 0 # 10 S_UNA_CPS
 0 0 0 0 # 11 S_ASO_CPMT
 0 0 0 0 # 12 S_UNA_CPMT
 0 0 0 0 # 13 S_HI_LL_WC
#
#_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_HI_LL
 5 0 0 1 # 6 S_NO_HI_LL
 5 0 0 1 # 7 S_JPNRTV
 5 0 0 2 # 8 S_TAR_LL
```

```
 5 0 0 3 # 9 S_AS0_CPS
 5 0 0 4 # 10 S_UNA_CPS
 5 0 0 3 # 11 S_ASO_CPMT
 5 0 0 4 # 12 S_UNA_CPMT
 5 0 0 1 # 13 S_HI_LL_WC
#
#_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_HI_LL
 11 0 0 0 # 6 S_NO_HI_LL
 11 0 0 0 # 7 S_JPNRTV
 11 0 0 0 # 8 S_TAR_LL
 11 0 0 0 # 9 S_AS0_CPS
 11 0 0 0 # 10 S_UNA_CPS
 11 0 0 0 # 11 S_ASO_CPMT
 11 0 0 0 # 12 S_UNA_CPMT
 11 0 0 0 # 13 S_HI_LL_WC
#_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_HI_LL
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_5P_2_S_HI_LL
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_6P_1_S_NO_HI_LL
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_6P_2_S_NO_HI_LL
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_7P_1_S_JPNRTV
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_7P_2_S_JPNRTV
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_8P_1_S_TAR_LL
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_8P_2_S_TAR_LL
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_9P_1_S_AS0_CPS
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_9P_2_S_AS0_CPS
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_10P_1_S_UNA_CPS
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_10P_2_S_UNA_CPS
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_11P_1_S_ASO_CPMT
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_11P_2_S_ASO_CPMT
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_12P_1_S_UNA_CPMT
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_12P_2_S_UNA_CPMT
```

1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_13P_1_S_HI_LL_WC
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_13P_2_S_HI_LL_WC
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_HI_LL
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_5P_2_S_HI_LL
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_6P_1_S_NO_HI_LL
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_6P_2_S_NO_HI_LL
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_7P_1_S_JPNRTV
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_7P_2_S_JPNRTV
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_8P_1_S_TAR_LL
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_8P_2_S_TAR_LL
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_9P_1_S_AS0_CPS
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_9P_2_S_AS0_CPS
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_10P_1_S_UNA_CPS
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_10P_2_S_UNA_CPS
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_11P_1_S_ASO_CPMT
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_11P_2_S_ASO_CPMT
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_12P_1_S_UNA_CPMT
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_12P_2_S_UNA_CPMT
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_13P_1_S_HI_LL_WC
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_13P_2_S_HI_LL_WC
#_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 9 10 11 12 13
0 0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_survey_CV
0 0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_discard_stddev
0 0 0 0 0 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 0.01 0.01 0.01 0.01 0.01 #_mult_by_lencomp_N
1 1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_agecomp_N
1 1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_size-at-age_N
#
1 #_maxlambdaphase
1 #_sd_offset
#
39 # 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 0 1

```
 1 6 1 1 1
 1 7 1 0 1
 1 8 1 0 1
 1 9 1 0 1
 1 10 1 0 1
 1 11 1 0 1
 1 12 1 0 1
 1 13 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
 4 9 1 0 1
 4 10 1 0 1
 4 11 1 0 1
 4 12 1 0 1
 4 13 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
 9 9 1 0 1
 9 10 1 0 1
 9 11 1 0 1
 9 12 1 0 1
 9 13 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
#  0 #_CPUE/survey:_5
#  1 #_CPUE/survey:_6
#  0 #_CPUE/survey:_7
#  0 #_CPUE/survey:_8
#  0 #_CPUE/survey:_9
#  0 #_CPUE/survey:_10
#  0 #_CPUE/survey:_11
#  0 #_CPUE/survey:_12
#  0 #_CPUE/survey:_13
#  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 #_lencomp:_9
#  0 #_lencomp:_10
#  0 #_lencomp:_11
#  0 #_lencomp:_12
#  0 #_lencomp:_13
#  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

12 APPENDIX 2: Break downs of Key Results by CPUE and Catch Series

Figure A2.0: Management quantities for the reference and the entire grid.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	10421	5843	31447
C_cur	5331	6991	4929	19670
Y_MSY	1994	4111	2003	7678220
B_zero	149368	365152	138545	628092000
B_msy	57660	141212	51366	242375913
B_cur	44988	128754	44713	519849575
SB_zero	2257	5636	1702	9489210
SB_msy	871	2158	641	3835460
SB_cur	613	1841	528	7569170
B_cur/B_zero	0.30	0.39	0.22	0.91
B_cur/B_msy	0.78	1.01	0.56	2.43
SB_cur/SB_zero	0.27	0.36	0.21	0.87
SB_cur/SB_msy	0.70	0.92	0.53	2.40
SB_cur/SB_1995	0.67	1.11	0.64	2.94
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.22	0.00	0.46
F_msy	0.08	0.08	0.06	0.11
F_cur/F_msy	4.48	2.71	0.00	7.33

Key Results by the SPC _LL and JP_RTV series.

Table A2.1 Management quantities for the reference and grid based only on the SPC LL and JP_RTV CPUEs.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	10966	5696	30492
C_cur	5331	7182	4834	19498
Y_MSY	1994	3426	1921	8023
B_zero	149368	280848	127704	862123
B_msy	57660	107980	46477	345412
B_cur	44988	98690	41053	272450
SB_zero	2257	3927	1485	14902
SB_msy	871	1567	556	5971
SB_cur	613	1297	447	4634
B_cur/B_zero	0.30	0.34	0.22	0.51
B_cur/B_msy	0.78	0.90	0.55	1.39
SB_cur/SB_zero	0.27	0.32	0.20	0.47
SB_cur/SB_msy	0.70	0.82	0.51	1.23
SB_cur/SB_1995	0.67	0.93	0.61	1.67
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.29	0.13	0.48
F_msy	0.08	0.08	0.06	0.11
F_cur/F_msy	4.48	3.39	1.41	7.96

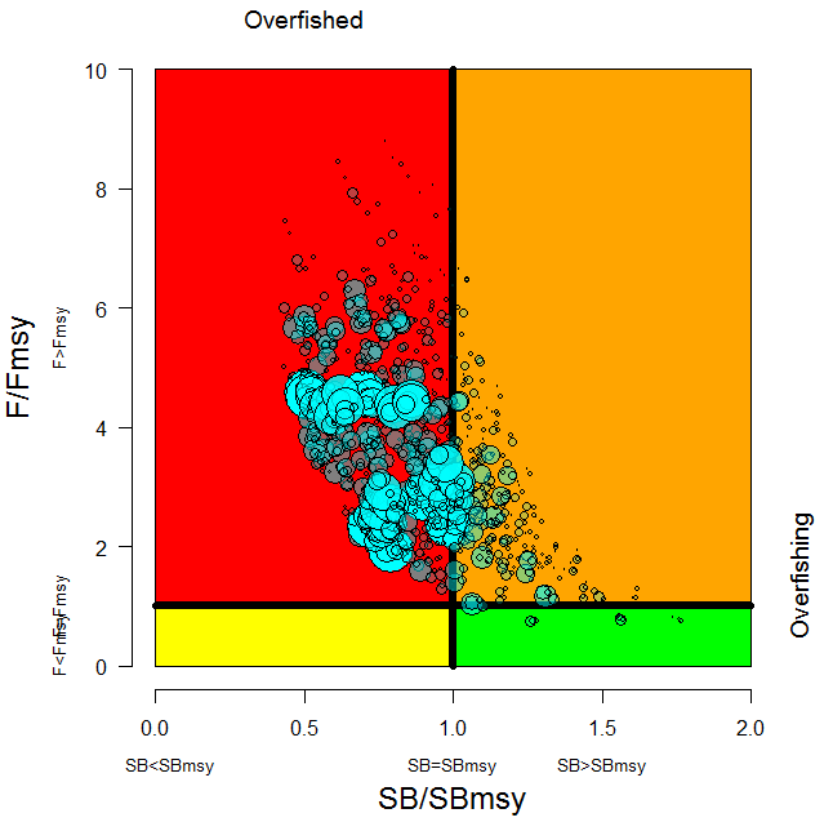

Figure A2.1: Kobe plot from the grid based only on the SPC LL and JP_RTV CPUEs.

Key Results by the SPC _LL CPUE series.

Table A2.2 Management quantities for the reference and grid based only on the SPC LL CPUE.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	10759	5434	30042
C_cur	5331	7123	4690	19062
Y_MSY	1994	2937	1754	6970
B_zero	149368	237839	113353	781495
B_msy	57660	91580	42131	302873
B_cur	44988	70416	36633	239129
SB_zero	2257	3433	1303	13509
SB_msy	871	1338	491	5235
SB_cur	613	937	349	4006
B_cur/B_zero	0.30	0.31	0.21	0.43
B_cur/B_msy	0.78	0.79	0.51	1.15
SB_cur/SB_zero	0.27	0.28	0.19	0.39
SB_cur/SB_msy	0.70	0.72	0.51	1.02
SB_cur/SB_1995	0.67	0.81	0.56	1.30
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.35	0.22	0.52
F_msy	0.08	0.08	0.06	0.11
F_cur/F_msy	4.48	4.32	2.49	8.45

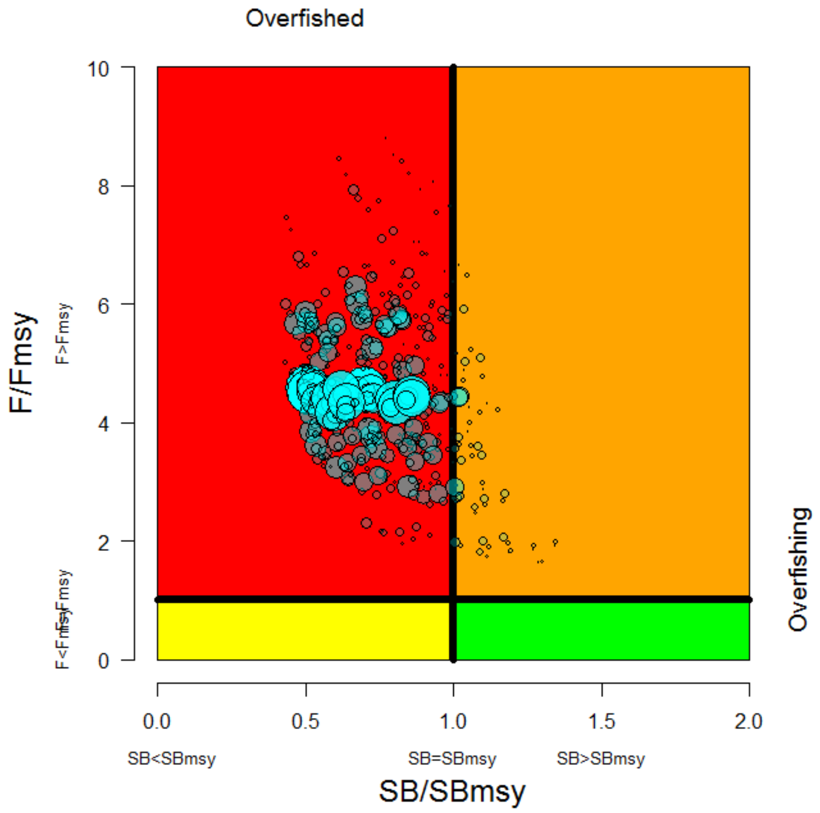

Figure A2.2: Kobe plot from the grid based only on the SPC LL CPUE.

Key Results by the JP_RTV CPUE series.

Table A2.3 Management quantities for the reference and grid based only on the JP_RTV CPUE.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	11419	5853	31413
C_cur	5331	7540	4943	19578
Y_MSY	1994	3794	2194	8586
B_zero	149368	311072	158309	954889
B_msy	57660	120277	56961	381166
B_cur	44988	115892	68410	305797
SB_zero	2257	4425	1998	16506
SB_msy	871	1687	735	6589
SB_cur	613	1593	772	5300
B_cur/B_zero	0.30	0.39	0.24	0.54
B_cur/B_msy	0.78	1.02	0.64	1.46
SB_cur/SB_zero	0.27	0.36	0.25	0.49
SB_cur/SB_msy	0.70	0.94	0.64	1.30
SB_cur/SB_1995	0.67	1.00	0.70	1.80
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.21	0.10	0.41
F_msy	0.08	0.08	0.06	0.11
F_cur/F_msy	4.48	2.71	1.06	5.51

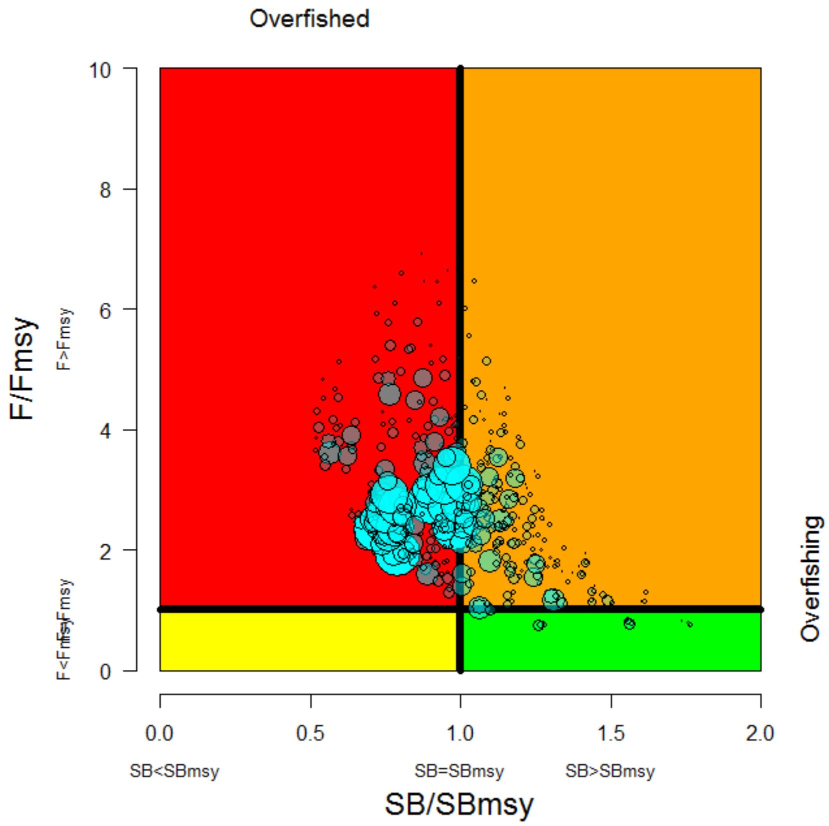

Figure A2.3: Kobe plot from the grid based only on the JPRTV.

Key Results by the Target LL CPUE series.

Table A2.4 Management quantities for the reference and grid based only on the Target LL CPUE.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	12845	6365	34387
C_cur	5331	8179	5276	21006
Y_MSY	1994	6192850	3048260	11812700
B_zero	149368	506528000	199914000	1789370000
B_msy	57660	191323807	75189032	726098099
B_cur	44988	377340000	202406750	983112500
SB_zero	2257	7652620	2297660	30930800
SB_msy	871	2890520	867474	12551200
SB_cur	613	5423598	2071523	17095725
B_cur/B_zero	0.30	0.79	0.46	1.37
B_cur/B_msy	0.78	2.04	1.22	3.64
SB_cur/SB_zero	0.27	0.76	0.47	1.38
SB_cur/SB_msy	0.70	1.96	1.20	3.66
SB_cur/SB_1995	0.67	2.56	1.43	4.65
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.00	0.00	0.00
F_msy	0.08	0.08	0.06	0.12
F_cur/F_msy	4.48	0.00	0.00	0.00

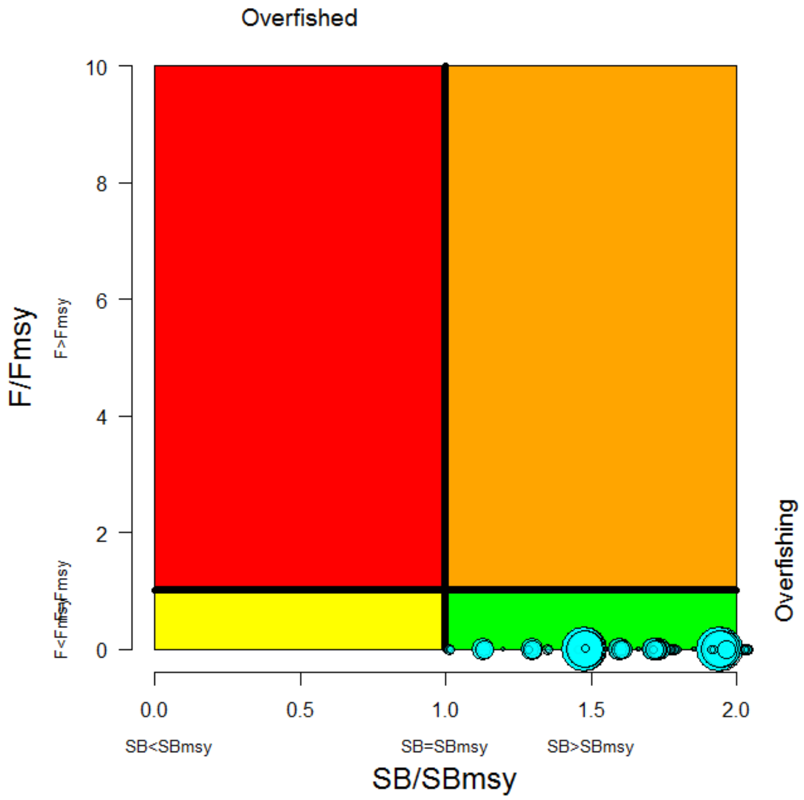

Figure A2.4: Kobe plot from the grid based only on the model runs using the target LL cpue series.

Key Results by the Purse Seine Catch per set series.

Table A2.5 Management quantities for the reference and grid based only on the purse seine catch per set CPUE.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	11310	5902	30586
C_cur	5331	7455	4919	19094
Y_MSY	1994	3650	2302	8321
B_zero	149368	293995	165638	820158
B_msy	57660	113308	59652	333314
B_cur	44988	110966	62576	280945
SB_zero	2257	4188	2006	14177
SB_msy	871	1611	747	5762
SB_cur	613	1520	729	4319
B_cur/B_zero	0.30	0.39	0.22	0.59
B_cur/B_msy	0.78	0.98	0.55	1.56
SB_cur/SB_zero	0.27	0.35	0.22	0.53
SB_cur/SB_msy	0.70	0.91	0.56	1.39
SB_cur/SB_1995	0.67	0.99	0.70	1.54
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.23	0.08	0.43
F_msy	0.08	0.08	0.06	0.11
F_cur/F_msy	4.48	2.89	0.89	6.20

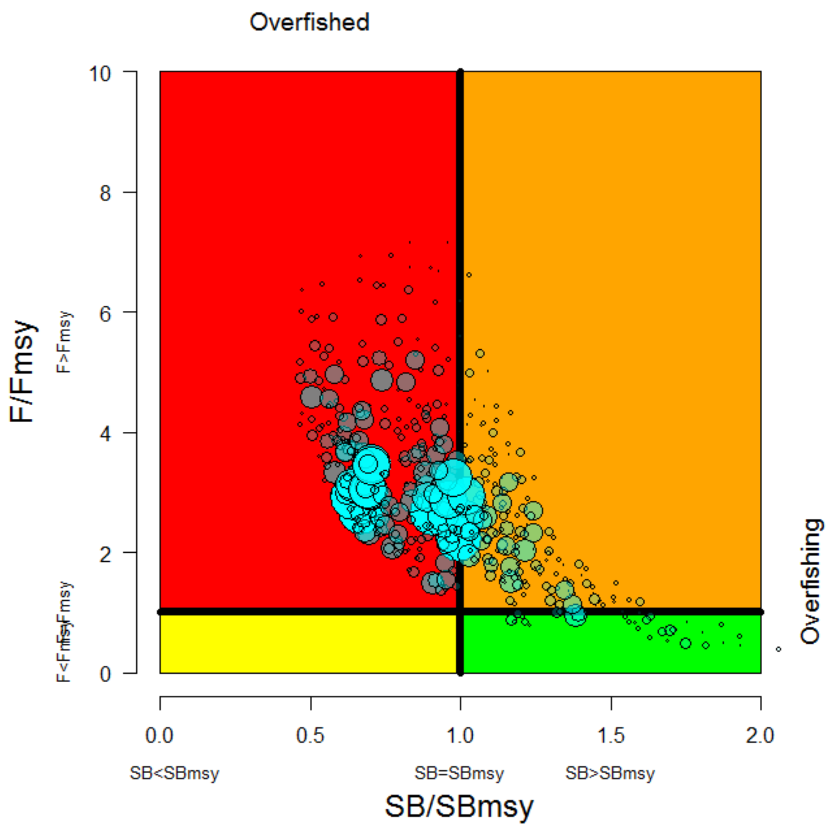

Figure A2.5: Kobe plot from the grid based only on the model runs using the purse seine catch per set cpue series.

Key Results by the Purse Seine Catch per metric ton series.

Table A2.6 Management quantities for the reference and grid based only on the purse seine catch per metric ton CPUE.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	11094	5694	30264
C_cur	5331	7269	4780	18919
Y_MSY	1994	2994	1838	6662
B_zero	149368	240350	125957	740588
B_msy	57660	92398	46603	292259
B_cur	44988	74797	41901	223760
SB_zero	2257	3526	1466	12802
SB_msy	871	1368	539	5052
SB_cur	613	973	412	3764
B_cur/B_zero	0.30	0.32	0.19	0.47
B_cur/B_msy	0.78	0.83	0.49	1.24
SB_cur/SB_zero	0.27	0.29	0.19	0.41
SB_cur/SB_msy	0.70	0.75	0.49	1.06
SB_cur/SB_1995	0.67	0.81	0.58	1.27
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.33	0.17	0.54
F_msy	0.08	0.08	0.06	0.11
F_cur/F_msy	4.48	4.10	1.85	8.68

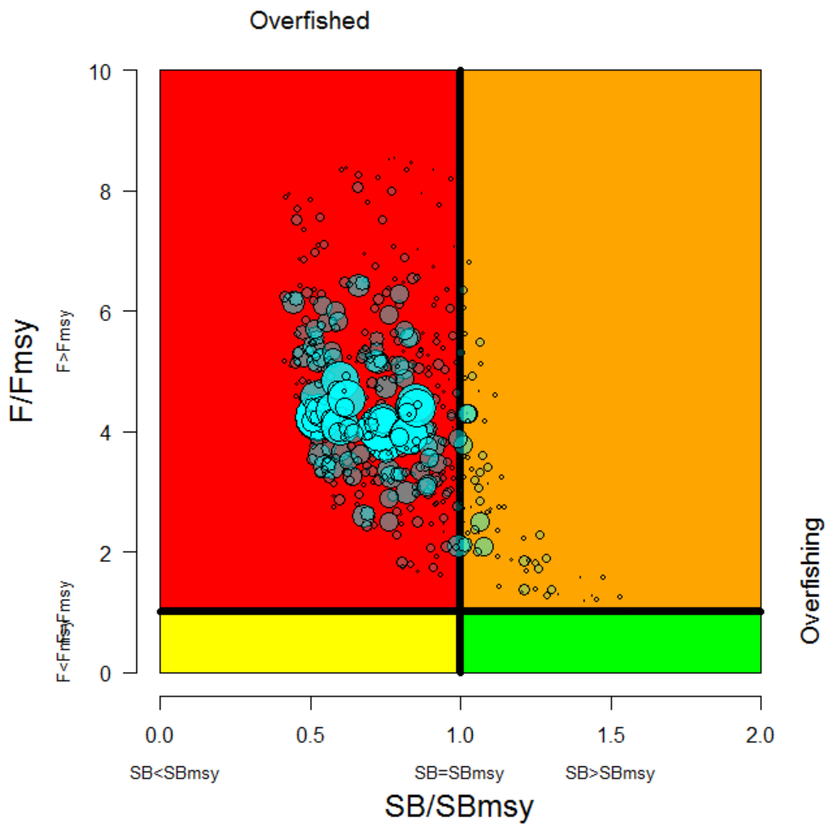

Figure A2.6: Kobe plot from the grid based only on the model runs using the purse seine catch per metric ton cpue series.

Key Results by the Catch Series from Lawson 2011.

Table A2.7 Management quantities for the reference and grid based only on runs using catch from Lawson 2011.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	6451	5521	8124
C_cur	5331	5458	4672	6905
Y_MSY	1994	2845	1762	6600860
B_zero	149368	242121	122395	577611000
B_msy	57660	93744	44645	223340387
B_cur	44988	84792	38927	377340000
SB_zero	2257	3529	1448	8726530
SB_msy	871	1413	527	3374220
SB_cur	613	1204	412	5521255
B_cur/B_zero	0.30	0.38	0.21	0.91
B_cur/B_msy	0.78	0.96	0.53	2.51
SB_cur/SB_zero	0.27	0.34	0.20	0.88
SB_cur/SB_msy	0.70	0.88	0.51	2.45
SB_cur/SB_1995	0.67	1.03	0.60	2.95
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.21	0.00	0.46
F_msy	0.08	0.09	0.06	0.12
F_cur/F_msy	4.48	2.46	0.00	7.10

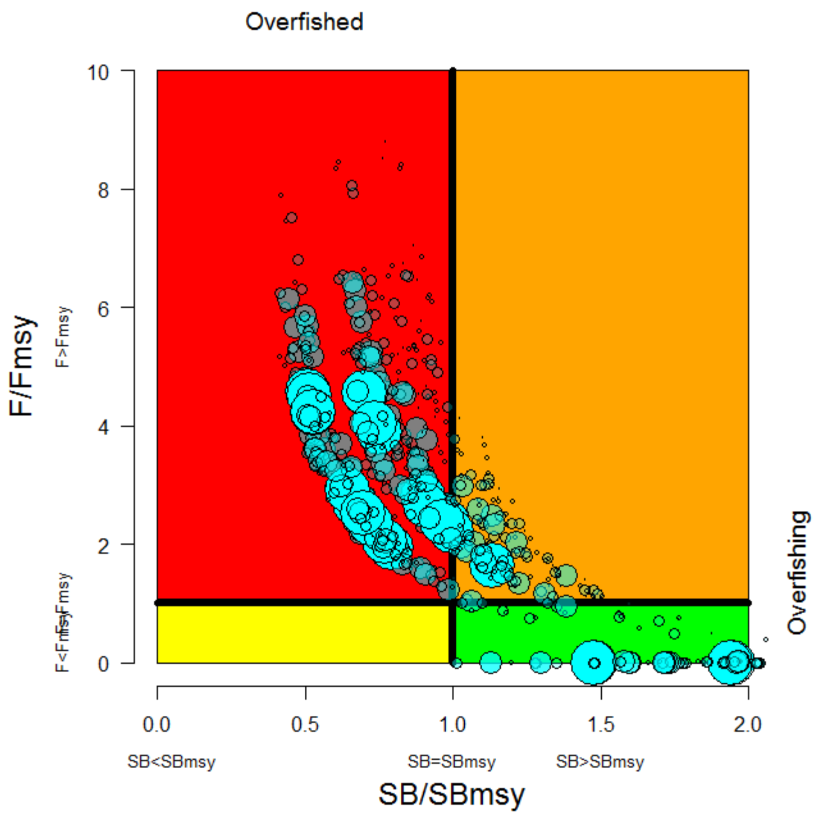

Figure A2.7: Kobe plot from the grid based only on the model runs catch from Lawson 2011.

Key Results by the Catch Series from Rice 2012.

Table A2.8 Management quantities for the reference and grid based only on runs using catch from Rice 2012.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	13059	11327	15956
C_cur	5331	8558	7293	10859
Y_MSY	1994	4372	2777	8427770
B_zero	149368	361824	187887	628091000
B_msy	57660	143852	68402	261899244
B_cur	44988	128946	60996	486343000
SB_zero	2257	5324	2182	9489190
SB_msy	871	2144	807	3956770
SB_cur	613	1815	670	7087153
B_cur/B_zero	0.30	0.38	0.21	0.91
B_cur/B_msy	0.78	0.97	0.54	2.52
SB_cur/SB_zero	0.27	0.34	0.20	0.88
SB_cur/SB_msy	0.70	0.88	0.52	2.45
SB_cur/SB_1995	0.67	1.06	0.60	2.94
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.22	0.00	0.47
F_msy	0.08	0.08	0.06	0.11
F_cur/F_msy	4.48	2.79	0.00	7.51

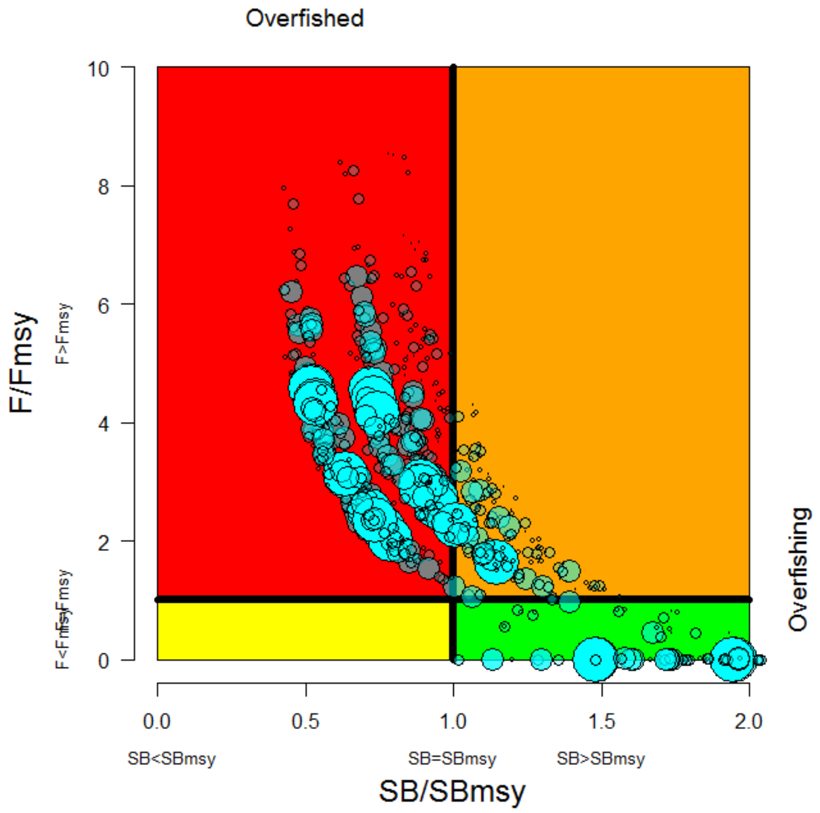

Figure A2.8: Kobe plot from the grid based only on the model runs catch from Rice 2012.

Key Results by the Catch Series from Clarke's Area method .

Table A2.9 Management quantities for the reference and grid based only on runs using catch based on Clarke's area method.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	10150	8783	12484
C_cur	5331	6738	5749	8604
Y_MSY	1994	3312	2128	6938780
B_zero	149368	268712	142044	585292000
B_msy	57660	107978	51400	225785309
B_cur	44988	103411	50416	382906500
SB_zero	2257	3971	1636	8842580
SB_msy	871	1617	606	3411160
SB_cur	613	1412	539	5602703
B_cur/B_zero	0.30	0.40	0.23	0.91
B_cur/B_msy	0.78	1.03	0.58	2.43
SB_cur/SB_zero	0.27	0.37	0.22	0.87
SB_cur/SB_msy	0.70	0.95	0.57	2.40
SB_cur/SB_1995	0.67	1.15	0.67	2.94
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.22	0.00	0.44
F_msy	0.08	0.08	0.06	0.11
F_cur/F_msy	4.48	2.79	0.00	7.13

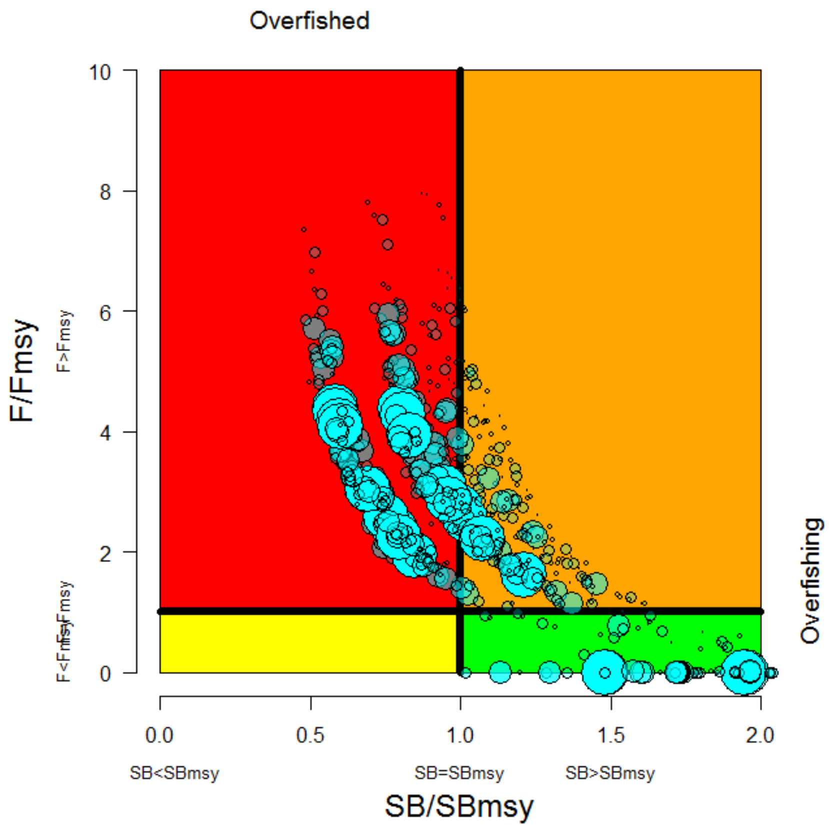

Figure A2.9: Kobe plot from the grid based only on the model runs using catch based on Clarke's area method.

Key Results by the Catch Series from Clarke's Tuna method.

Table A2.10 Management quantities for the reference and grid based only on runs using catch based on Clarke's area method.

	Reference	Grid_Median	Grid_5%	Grid_95%
C_latest	6090	26855	23180	33331
C_cur	5331	16379	13903	20833
Y_MSY	1994	7382	4698	9224210
B_zero	149368	602757	309505	628095000
B_msy	57660	235876	112564	261931818
B_cur	44988	235158	116478	559387500
SB_zero	2257	8802	3557	9489240
SB_msy	871	3495	1298	3957260
SB_cur	613	3353	1192	8279038
B_cur/B_zero	0.30	0.41	0.24	0.91
B_cur/B_msy	0.78	1.05	0.61	2.52
SB_cur/SB_zero	0.27	0.38	0.23	0.88
SB_cur/SB_msy	0.70	0.98	0.60	2.45
SB_cur/SB_1995	0.67	1.19	0.69	2.94
B_msy/ B_zero	0.39	0.39	0.34	0.42
SB_msy/SB_zero	0.39	0.39	0.34	0.42
F_cur	0.37	0.24	0.00	0.46
F_msy	0.08	0.08	0.06	0.11
F_cur/F_msy	4.48	3.00	0.00	7.74

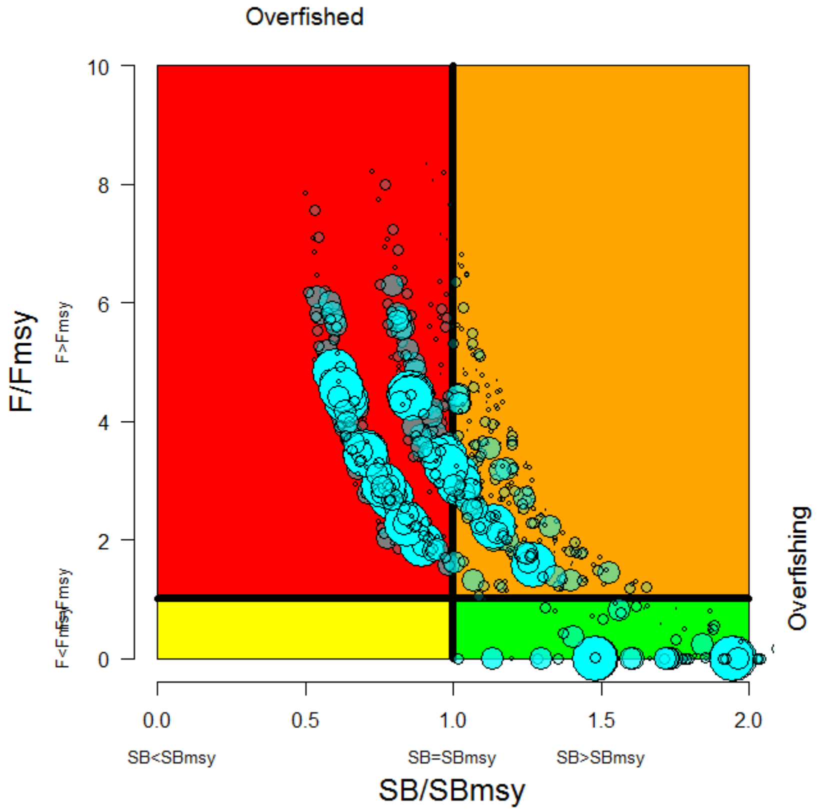

Figure A2.10: Kobe plot from the grid based only on the model runs using catch based on Clarke's Tuna method.

13 APPENDIX 3. Key Results from WCPFC9-2012-IP1:3Progress on the updated silky shark stock assessment in the WCPO

At SC8 the first stock assessment for silky shark in the Western Central Pacific Ocean was presented. The conclusions made by SC8 regarding this assessment are provided in Attachment 1 of this paper and are briefly summarized below:

- The conclusions on stock status from the stock assessment depended heavily on the catch per unit effort series used. Some indices suggested major sustainability concerns and other suggested no concerns;
- A level of discomfort that the non-target longline catch per unit effort series showed patterns that could be an artifact due to gaps in data for one fleet;
- A conclusion that it was not possible to provide management advice based on the assessment at this time; and
- A recommendation to update the assessment and in doing so address concerns over some data conflicts (including the purse seine CPUE) and include other data series that were available, but not included in the assessment.

The purpose of this paper is to provide an update on progress since SC8 towards an updated assessment for silky shark in the WCPO. This paper does not include detailed data or analysis descriptions – these will be provided in the working paper(s) for the full assessment provided to SC9. In this paper were compare the original and updated Kobe plot describing the stock status (Figure 1). Note that for the shark assessments for WCPFC, we have preferred to describe stock status with a large number of model runs (that include different assumptions and data sets) to capture uncertainty.

In response to requests from SC8, we have:

- addressed concerns over the partial inclusion of the Hawaiian longline data;
- addressed the conflict between the purse seine CPUE and other CPUE series that seems to have been driven by our exclusion of unidentified sharks from the data set. These were most likely silky sharks, and their inclusion has reduced the conflict; and
- included two alternative longline series, one derived solely from Hawaiian longline data, and a second derived from Japanese research and training vessels.

A detailed breakdown of the stock status outcomes against particular data inputs is provided in Table 1. A summary of the changes from the SC8 assessment and the impacts that they had are provided in Table 2.

The conclusions regarding this updated assessment are:

- Any conclusions regarding stock status are strongly dependent on which CPUE series is believed to be a true reflection of trends in abundance.

- The revised stock assessment is slightly more optimistic that the one presented to SC8, though most CPUE series lead to conclusions that the stock is subject to overfishing and more than half also suggest that it is overfished.
- Across all combinations of CPUE series, catch series, and alternative biological assumptions, 58.5% of the runs are in the red quadrant, 20.5% are in the orange quadrant and only 21% are in the green. Almost all the 'green runs' are for the target longline series, and these runs do not provide plausible estimates of population biomass.

Table A3.1. Distribution of stock status outcomes (percentage of model runs in each quadrant of the Kobe plot) for models that included different CPUE and catch time series (see Table 2 for further details of the data sets).

	Kobe plot quadrant			
CPUE	**RED**	**ORANGE**	**GREEN**	**YELLOW**
Non-target LL (no Hawaii)	87	13	0	0
Japanese research and training vessels	52	45	3	0
Target LL	0	0	100	0
Purse seine (catch per set)	58	35	7	0
Purse seine (catch per mt of tuna)	83	17	0	0
Hawaiian LL	36	36	28	0

Catches	**RED**	**ORANGE**	**GREEN**	**YELLOW**
Lawson	57	19	24	0
Rice	58	18	24	0
Clarke (area based)	50	28	22	0
Clarke (tuna catch based)	46	33	22	0

Table A3.2. Summary of the key changes to the stock assessment presented to SC8 and the impacts of these on predicted stock status.

Change to the assessment	Impact on stock status
The partial data for the Hawaiian longline fleet was removed from the non-target longline index.	The **revised** non-target index led to small improvements in stock status, but model runs that included this CPUE series resulted predominantly in an overfished state with overfishing occurring (red quadrant of the Kobe plot)
Inclusion of the "Hawaii-only" longline series from Walsh and Clarke (2011[5])	This **new** series was the most optimistic of the non-target series, but was quite variable. Model runs were split almost equally between red, orange, and green quadrants of the Kobe plot.
Inclusion of the Japanese longline research and training vessel series from Clark et al. (2011[6])	This **new** series results in estimates of stock status in the red / orange quadrant, i.e., with overfishing occurring and some model runs also predicting that the stock is overfished.
Replacing the purse seine CPUE series with two alternative series that both include the large numbers of 'unidentified shark' that were excluded from the previous series – detailed observer reports of the species composition of sharks in purse seine catches indicates that a very high proportion would likely have been silky sharks.	These **new** series result in estimates of stock status predominantly in the red quadrant, but with a significant amount of orange (and a little green).
Inclusion of two alternative catch series based on the analyses of market / trade based data of Clarke (2005[7]). The advantage of these estimates is that they are independent of the catch and effort data used to generate the other catch series considered.	The **new** catch series had minimal impact compared to the impact of the different catch per unit effort series used. These new catch series gave slightly more optimistic estimates of stock status (less red and more orange) compared to the model runs undertaken using the alternative catch series.

[5] Walsh, W.A. and Clarke, S. 2011. Catch Data for Oceanic Whitetip and Silky Sharks from Fishery Observers Document Changes in Relative Abundance in the Hawaii-based Longline Fishery in 1995–2010. WCPFC-SC7-2011/EB-WP-03.

[6] Clarke, S., Yokawa, K., Matsunaga, H. and Nakano, H. 2011. Analysis of North Pacific Shark Data from Japanese Commercial Longline and Research/Training Vessel Records. WCPFC-SC7-2011/EB-WP-02.

[7] Clarke, S.C. 2005. An alternative estimate of catches of five species of sharks in the Western and Central Pacific Ocean based on shark fin trade data. WCPFC – SC5- 2005/EB-WP-02.

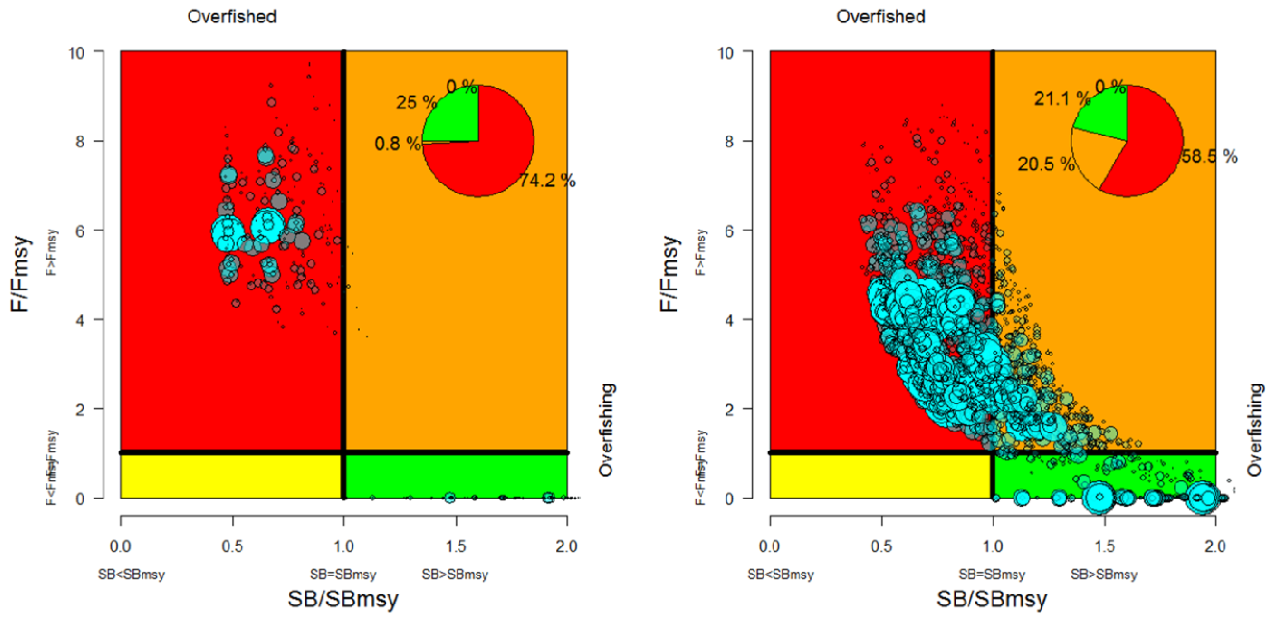

Figure A3 1. Kobe plots indicating annual stock status, relative to SB_{MSY} (x-axis) and F_{MSY} (y-axis). These present the reference points and based on the current (average of 2005-2008) estimates for all 648 models form the analysis delivered to SC8 (left panel), and the current (average of 2005-2008) estimates for all 2592 models in the updated analysis (right panel). In each plot the size of the circle is proportional to the weight (plausibility) of the model run, respectively.

Appendix 4: Extract from the Executive Summary of the SC8 report

Silky Shark

Status and trends

53. The 2012 silky shark assessment was the first assessment completed for this species. There is conflict among the different CPUE series and this conflict carries through the assessment to indicate very different management implications. The longline bycatch series suggests significant declines in abundance (and overfishing), while the models incorporating the purse seine CPUE series resulted in unrealistically high biomass estimates, with no sustainability concerns.

54. It might be expected that the CPUE series developed on longline bycatch would be more reflective of changes in abundance than the target longline CPUE series, which is extremely spatially limited, or the purse seine CPUE series which has no clear measure of fishing effort. The SC considered that the incorporation of additional existing observer data could lead to significantly different conclusions from the assessment, and therefore additional work is required. Therefore, the SC concluded that it was not possible to determine estimates of stock status and yields.

55. SC8 noted the findings of WCPFC-SC7-2011/EB-WP-03 which state:
"Although silky sharks have been shown to have declining catch rate trends in past studies in the Pacific, no strong trends were found in recent (2011) WCPO analyses. Nevertheless, declining size trends in two datasets, declining catch rates in these two datasets for the most recent years of the time series, and increasing removals all indicate a need for close, ongoing monitoring of indicators. Further research may allow better definition of trends and a clearer depiction of stock status."

Refining standardized CPUE and the assessment

56. There is large structural uncertainty in the silky shark assessment which needs to be addressed in future assessments, however the 2012 silky shark assessment represents the best available information. The conflicting trends in the standardized longline (declines after 2004) and purse seine (increases in most of the time series) fisheries require further investigation. The model fit to the highly influential bycatch longline series is poor. Particular investigation should be made on the divergence between standardized and nominal CPUE after 2004 which occurs when vessel effects are incorporated into the standardization process.

Management Advice and Implications

57. Noting SC8s concerns over the data conflict and potential biases in the silky shark assessment, it is not possible to provide management advice based on the assessment at this time. However, noting that some basic fishery indicators (e.g. mean lengths and some CPUE series) are showing declines in recent years, the SC recommends no increase in fishing mortality on silky sharks.

58. Further, recognizing that the major fishery impacts relate to non-target fisheries, the SC recommends that the Commission consider mitigation measures to reduce the impact of these non-target fisheries as a precautionary measure. SC8 recommends that the silky shark assessment be updated to incorporate all potentially important data series.