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Stock assessment of oceanic whitetip sharks in the western and central Pacific Ocean

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Executive summary

This paper presents the first stock assessment of oceanic whitetip shark in the western and central Pacific Ocean (WCPO). 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 oceanic whitetip 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 covering the time period from 1995 through 2009.

Oceanic whitetip 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, especially in the longline fishery. 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 stock status for oceanic whitetips. Each model was 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.

The key conclusions of the first stock assessment for oceanic whitetip sharks in the WCPO are as follows:

1. Notwithstanding the uncertainties inherent in the input data, the catch, CPUE, and size composition data all show consistent declines over the period of the model (1995-2009).
2. This is a low fecundity species and this is reflected in the low estimated value for F_{MSY} (0.07) and high estimated value for SB_{MSY}/SB_0 (0.424). These directly impact the conclusions about overfishing and the overfished status of the stock.
3. 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.
4. Estimated fishing mortality has increased to levels far in excess of F_{MSY} ($F_{CURRENT} / F_{MSY}$ = 6.5) and across all model runs undertaken estimated F values were much higher than F_{MSY} (the 5th and 95th quantiles are 3 and 20). Based on these results we conclude that overfishing is occurring.
5. Estimated spawning biomass has declined to levels far below SB_{MSY} ($SB_{CURRENT}/SB_{MSY}$ = 0.153) and across all model runs undertaken $SB_{current}$ is much lower than SB_{MSY} (the 5th and 95th quantiles are 0.082 and 0.409). Based on these results we conclude that the stock is overfished.
6. Noting that estimates of SB_0 and SB_{MSY} are particularly uncertain as the model domain begins in 1995, it is also useful to compare current stock size to that at the start of the model. Estimated

spawning biomass has declined over the model period by 86% and across all model runs undertaken $SB_{CURRENT}$ is much lower than SB_{1995} (the 5th and 95th quantiles indicate a decline to 8.7% and 45.8% of SB_{1995}).

7. Current catches are lower than the MSY (2,001 versus 2,700), but this is not surprising given the estimated stock status and fishing mortality. Current (2005-2008 average) and latest (2009) catches are significantly greater than the forecast catch in 2010 under F_{MSY} conditions (230 mt).
8. The greatest impact on the stock is attributed to bycatch from the longline fishery, with lesser impacts from target longline activities and purse seining.
9. Given the bycatch nature of fishery impacts, mitigation measures provide the best opportunity to improve the status of the oceanic whitetip population. Existing observer data may provide some information on which measures would be the most effective.
10. Given recent decisions to improve logsheet catch reporting and observer coverage in the longline fishery it is recommended that an updated assessment be undertaken in 2014.

A series of research recommendations is also provided.

1 Background

1.1 Biology

Oceanic whitetip shark (*Carcharhinus longimanus*; OCS) are a circumtropical species found in tropical waters of the Pacific Ocean (Figure 1). Oceanic whitetip sharks in the western and central Pacific Ocean (WCPO) are considered a single stock for assessment purposes. The oceanic whitetip shark was once considered one of the most common sharks in all tropical oceans of the world (Bonfil et al. 2008). Although OCS are frequently caught in commercial fisheries and their fins command high commercial value, few papers have been published on this species (Bonfil et al. 2008; Clarke et al. 2005, 2006).

Oceanic whitetip sharks are truly oceanic and show a clear preference for the open ocean water between 10˚S and 10˚N, but can be found in decreasing numbers out to latitudes of 30˚N and 30˚S with decreasing abundance with greater proximity to continental shelves (Backus et al. 1956**,** Strasburg, 1958; Compango, 1984, Bonfil et al. 2008). Commonly found in waters warmer than 20˚C, catches of OCS have been reported in water temperatures down to 15˚C (Bonfil et al. 2008). Data from Japanese research and training tuna longliners show that oceanic whitetip sharks are found throughout the North Pacific but there are a large number of contiguous zero catch records in the north central Pacific (the region north of Hawaii) (Clarke et al. 2011). Previous analysis on the distribution of OCS has shown that in the Pacific, newborn and pregnant sharks occur between the equator and 20˚N, (Bonfil et al. 2008), but recent analysis found that no particular subset of life stage or sex dominated the oceanic whitetip's distribution (Clarke et al. 2011).

Little is known about the movement or possible migration paths for oceanic whitetips in the Pacific, though tagging studies in the Atlantic ocean indicate movement along the equator and from southern latitudes (off Brazil) to the equator (Kohler et al. 1998, Bonfil et al. 2008).

The oceanic whitetip is viviparous with placental embryonic development, though few reproductive studies have been conducted for these species. Seki et al. (1998) suggest an average fecundity of 6 pups per female and a 9-12 month gestation period for OCS in the Pacific. Estimated sizes at maturity are 168-196cm for males and 175-189cm TL for females, Figure 2 shows the combined maturity curve. Seki et al. (1998) also found a weak positive correlation between maternal size and litter size.

The first studies of growth were conducted by Saika and Yoshimura (1985) which yielded estimates of 0.04-0.09 for the Von Bertalanffy growth coefficient *k.* Seki et al. (1998) estimated a growth coefficient of 0.103 and a t_0 =2.698 based on counting annual bands on 225 vertebral centra, with the assumption that one band is laid down each year. This parameterization would correspond to a theoretical L_∞ of approximately 340cm (TL) which corresponds to an age of approximately 36 based on Seki et al. 1998 (Figure 2). Oceanic whitetip growth is considered slow compared to other pelagic sharks, namely blue, mako, and silky (Branstetter, 1990). In the Pacific, approximate age estimates from counting annuli on vertebral bands suggest oceanic white tips reach sexual maturity after about between 4-7 years (170-200 cm) and with the maximum observed age in the WCPO of 11 years, (Seki et al. 1998).

Estimates of population growth have been obtained using demographic methods; with independent estimates of the intrinsic rate of increase being equal to 0.081 (Smith et al. 1998) and 0.11 (Cortés, 2002).

Overall the biology of OCS, in particularly its fecundity, indicates that it is likely to be a species with low resilience to fishing – even among shark species - and minimal capacity for compensation. This is reflected in the current stock assessment.

1.2 Fisheries

In the WCPO oceanic whitetip sharks are encountered in longline and purse seine fisheries (Bonfil and Abdallah, 2004). For the purposes of this assessment the fisheries affecting OCS, 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).

Although OCS are predominantly encountered as bycatch, the tuna longline fleet has the greatest impact (based on fishing mortality) on the stock due to the overall effort. The tuna longline fleet operates throughout the western central Pacific, and mainly catches juveniles (sharks <170 cm). Observer records do indicate that some targeting has occurred historically in the waters near Papua New Guinea, and given the high value of shark fins (especially those of OCS – Clarke et al. 2005) 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. Fleets from this region were separated from the main longline fleet due to the size of the OCS catch, their reporting of targeting sharks, and the expectation that the factors leading to catching OCS while targeting them would be different than those when catching OCS as bycatch. Details of the catch and effort standardization are provided in Rice (2012b).

Purse seine fleets usually operate in equatorial waters from 10°N to 10°S; although a Japan offshore purse seine fleet operates in the temperate North Pacific. The vessels mainly target skipjack tuna and OCS 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), but catch similar sizes of oceanic whitetip sharks.

Information on OCS catches in the WCPO is sparse due to limited observer data collection prior to 1995. Theoretically the bycatch of OCS in the tuna fishery would be affected by the level of effort in the tuna fishery. Estimates of OCS catches have been decreasing steadily since 1997 (Figure 3), mainly due to the sustained decline in longline catch rate (Lawson 2011). Recent increases in overall longline effort along with the large increase in the purse-seine fishery (Williams and Terawasi 2011) in the equatorial region of the WCPO could imply large increases in fishing mortality for OCS over the last two decades.

1.3 Previous assessments

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

2 Data compilation

Data used in the oceanic whitetip 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 OCS and silky shark draw heavily on observer data for estimating CPUE, and catch. Details of the analyses of the observer data for CPUE and catch are provided in separate information papers and only briefly described here. Estimates of the biological parameters were taken from literature (Bonfil and Abdallah, 2004; Bonfil et al. 2008; Seki et al., 1998).

2.1 Spatial stratification

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

2.2 Temporal stratification

The time period covered by the assessment is 1995–2009. Within this period, data were compiled into annual values. The heavy reliance on observer data and the need to conduct two assessments simultaneously (OCS and silky sharks) meant that key model inputs were generated in 2011 and there were still significant data gaps in 2010 observer data, therefore it was not possible to extend the model to 2010.

2.3 Catch Estimates

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

Estimates of catches from Lawson (2011) were used (Table 2, Figure3) as the primary catch series in the OCS assessment. Because Lawson estimated two time series of catches (for the purse seine and longline), catch data for the fisheries defined above had to be estimated by partitioning the total catch according to the annual proportion of effort in each fishery. The annual catch estimates from all fisheries, were expressed in numbers of fish. Based on the methods in Lawson (2011), two alternate catch histories were developed to explore the effect of different trends and magnitudes in the catch histories (Table 2, Figure 3 & Rice 2012a). The main differences between the methods used to generate previous estimates (Lawson 2011) and this study's estimates of catch are that the data were filtered to represent only the core habitat of the OCS and that an annual CPUE surface was used as opposed to the temporally-aggregated CPUE surface (Rice 2012a). A second catch estimate of twice the values estimated in this study was also included in the grid to explore the effect of much larger catch rates. Annual estimated weight in catch based on estimated numbers (Lawson 2011) is presented in Figure 4.

2.4 CPUE and standardised effort time series

Standardized catch per unit of effort series for all fisheries were used in the current assessment (Figure 5), for technical details and presentation of model fits see Rice (2012b). In brief, standardized CPUE series were estimated for oceanic whitetip sharks in the western central Pacific based on observer data held by SPC and collected over the years 1995-2009. In 2011 when the analysis was undertaken, there was insufficient longline observer data for 2010 and these data are critical for both CPUE and catch inputs to the stock assessment.

All series share the same general trend with the highest values prior to 2000 and a subsequent decline thereafter. Each standardized CPUE trend is also similar to the nominal data. The data underlying the analysis comes from the same area in the ocean throughout the time series, except for the longline data which is missing the data from the Hawaiian Islands for the period since 2005. This suggests that the decline in standardized (and nominal) CPUE is not a factor of the lack of observations in the Hawaiian Islands but rather a result of an overall decline in oceanic whitetip CPUE. A separate analysis of the Hawaiian data reveals similar trends (Walsh and Clarke 2011).

2.5 Length-frequency data

Available length-frequency data 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 OCS 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 OCS 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 sets from which the sharks were 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 the all longline fisheries principally catch immature OCS, within the 70-200cm length range. The purse seine observer data indicates that the equatorial purse-seine fisheries catch OCS of roughly the same size, regardless of whether they are from associated or unassociated sets, though the latter are poorly sampled with only 255 OCS measured in unassociated sets in the last 15 years. 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 OCS assessment. 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 oceanic whitetip 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 OCS 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 110 cm given the current growth curve) 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 175cm (Seki et al. 1998). There is no information which indicates that sex ratio differs from parity throughout the lifecycle of OCS.

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 OCS 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]. In contrast to tuna, stronger inference about the value of steepness for this shark species is made possible by the sharks' reproductive method and life history strategy. Deviations from the SRR were estimated in two parts, one 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 OCS. 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 Seki et al. (1998). Growth was assumed to be the same for both sexes (Seki et al. 1998, Lessa et al. 1999)

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 (0.12-0.32) from demographic methods (Cortés, 2002). For the grid we included alternative values of 0.1 and 0.26.

3.1.4 Initial population size and structure.

It is not assumed that the OCS 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

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

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

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 0.09.

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 increase with age and to remain at the maximum once attained (Figure 9). Selectivity for the target longline fishery was assumed to be dome shaped with a maximum selectivity value at 180 cm. Selectivity's for purse seine associated sets were assumed to be logistic with size at inflection of 110. The selectivity of the purse seine associated sets was estimated using a cubic spline parameterisation[4]. Though not ideal, 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 this best estimate for the grid of runs.

3.2.2 Catchability and observation error

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

$$G_f = Q_f B_f \varepsilon_f$$

Where, Q_f is the catchability coefficient for fishery f, and 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.

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

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

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

where ω is an additional 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 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.

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], μ'_θ is the prior mean rescaled into [0,1], , μ_θ is the input prior, σ_θ is the standard deviation after rescaling into [0,1] and θ_A & θ_B are derived quantities relating to the beta function.

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

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

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

The objective function component for CPUE is defined as

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

where for the expected abundance index *G* is then related to the overall population abundance by
$G_f = Q_f B_f \varepsilon_f$
where, Q_f is the catchability coefficient for fishery *f*, 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 B_f is the biomass for fishery *f*.

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

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

where $\bar{w}_{tf}$, $\hat{w}_{tf}$, and $\sigma_{CATCH,t,f}$ are the observed mean weight, the expected mean weight and the standard deviation (respectively) of the 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 initially 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 generally poorer input data for oceanic whitetip shark when compared to the tropical tunas, a different approach was taken to this assessment. It was generally difficult to identify with confidence which clearly were the most appropriate data inputs or structural assumptions to make in a model, and/or some of the data inputs are contradictory (e.g. CPUE trends in different fisheries). Therefore the focus was on establishing the key areas of uncertainty and then within each area, identifying a small number of alternative hypotheses that a relative plausibility could be assigned to. In this assessment we identified seven key areas on uncertainty and for each of these we identified 2-3 alternative hypotheses. These are listed below and described in further detail in Table 4.

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

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

For simple sensitivity analysis we identified those model runs from the grid which represented just a single change from the reference case model (components listed in bold in Table 4) – this gave 11 sensitivity analyses.

3.5 Parameter estimation and uncertainty

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

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

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. Many models had a downward trend in the biomass and an upward trend in the cumulative fishing mortality over the years 2005-2008, so the reference points based on the average current may be biased. Due to uncertainty in the data and the extrapolation necessary to estimate virgin biomass and the corresponding spawning stock size an additional reference point, depletion since 1995 is also used to summarize the impact of fishing.

4 Results

This section provides a detailed summary of the results from the reference-case assessment. Also presented for comparison of important results are the eleven sensitivity analyses. Finally we also summarise the overall grid based on quantiles that incorporate the model weights.

4.1 Reference case

The reference case model was catch from Lawson (2011), natural mortality = 0.18, initial fishing mortality=0.1, sample size weighting = 0.1, CPUE trend based on the bycatch longline, and SigmaR=0.1 and steepness=0.409. The reference case was one of 4 models with equal weighting, but was selected randomly.

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 runs.

The fit of the model to the CPUE data was acceptable for both the reference case (bycatch LL CPUE) and the alternate CPUE data (target LL and both purse seine) (Figure 10), but there was a consistent pattern with the observed CPUE (bycatch longline) displaying a slight upturn over the past four years which the model did not predict. This might reflect some recent improvement in stock status, but given the greater uncertainty of the most recent data points this cannot be confirmed.

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 OCS 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 estimated spawning biomass and recruitment relationship 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 in scenarios with excellent data and even more so when only recent CPUE data is available and the catch is estimated, as with 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 longline has by far the largest component of the overall F, increasingly rapidly from the assumed levels of 0.1 in 1995 to a high of over 0.4 in the final year of the model. The next highest component of fishing mortality is the target longline fishery, with an approximate F of 0.05 in the final year of the model.

4.1.5 Yield and reference point analysis

Biomass estimates, yield estimates, and management quantities for the reference case are presented (Table 7). For the reference-case, MSY is estimated to be 2,700 mt per annum at a level of fishing effort approximately 14% of the current level of fishing mortality. Therefore to reduce fishing mortality to the MSY level would require a reduction of 86%. Though the level of average current catch (2,001 mt) is lower than the estimated MSY, the average masks the declining trend of the catch time series and should be compared to C_{LATEST} which is 1,802 mt. The estimate of current biomass is approximately 7,300 mt.

Current estimates of the stock depletion are that the total biomass has been reduced to 6.6% of theoretical equilibrium virgin biomass. Although estimates of virgin biomass are inherently uncertain due to the extrapolation necessary, a large of decline is evident over the model period alone, with spawning biomass having been reduced by 86% (SB_{LATEST}/SB_{1995} = 0.14). This decline is consistent with a $F_{CURRENT}/\tilde{F}_{MSY}$ value of 6.694.

4.1.6 Sensitivity analyses and structural uncertainty grid

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

Each scenario was weighted based upon the values included in the model run (Table 3), results are presented here as the uncertainty grid and reflect a re-sampling of the grid results based on the weights listed in Table 3. The reference case and the structural uncertainty grid are presented in Table 8. The results of the grid are presented as weighted depletion trajectories (of SB/SB_{msy}) in Figure 14, and as Kobe plots in Figures 17.

The effects of each of these parameter levels on the ratio-based management indicators $SB_{CURRENT}/SB_{MSY}$, $B_{CURRENT}/B_{MSY}$, $SB_{CURRENT}/SB_{1995}$ and $F_{CURRENT}/F_{MSY}$ are presented in Figures 18-21. Catch, natural mortality and the initial depletion had the largest effect on the two biomass based management parameters $B_{CURRENT}/B_{MSY}$, and $SB_{CURRENT}/SB_{MSY}$. These factors along with steepness were the most influential factors on the management quantity $F_{CURRENT}/F_{MSY}$. The full array of management parameters for each alternate variable level (from the reference case) is also presented (Table 7). Both alternate catch time series (Catch_2 and Catch 3), along with the alternate CPUE series based on the target longline and purse seine fisheries (CPUE_2), the lower natural mortality estimate (Nat_M_1), and the lower steepness (Steep_1) showed a more pessimistic stock status (higher $F_{CURRENT}/F_{MSY}$ and lower biomass ratios) than the bycatch longline indices of abundance (Table 7). The 5th and 95th quantiles of structural uncertainty regarding the stock status ranged from 0.082 to 0.409 for $SB_{current}/SB_{msy}$, from 0.079 to 0.454 for $B_{CURRENT}/B_{MSY}$ and from 3 to 20 for $F_{CURRENT}/F_{MSY}$ (Table 8).

4.1.7 Stock status

Fishing mortality rates tended to increased over the modelling period, driven mainly by the increased effort in the longline fleet. They remain substantially above the F_{MSY} level, $F_{CURRENT}/F_{MSY}$=6.69 for the reference case and 6.9 for the grid median (Table 8). All runs in the grid estimated $F_{current}$ to be above $\tilde{F}_{MSY}$ (Figures 17 & 21). Therefore, we conclude that overfishing of oceanic whitetip sharks is occurring.

Total spawning biomass was estimated to be lower than the $\widetilde{SB}_{MSY}$ level throughout the grid, the current total spawning biomass is approximately 6.5% (and 7 % for the grid median) of the equilibrium unexploited level ($\widetilde{SB}_0$). The distribution of $SB_{current}/SB_{msy}$, obtained from the structural uncertainty grid, indicates a high degree of uncertainty associated with the MSY-based biomass performance indicators (Table 8). Nonetheless, none of the grid runs indicated that $SB_{CURRENT}/SB_{MSY}$ is ever above 0.409 and that $B_{CURRENT}/B_{MSY}$ is never above 0.45. Based on these results the stock is in an overfished state.

5 Discussion

This is the first assessment of OCS sharks done in the Pacific and the first shark assessment conducted for the Western Central Pacific Fisheries Commission. Aside from the unique challanges of assessing a non-target species, oceanic whitetip shark is a very difficult species to assess due to the limited 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.

This assessment is reliant on the CPUE data and catch estimates to estimate un-fished population sizes in the WCPO and the impact of fishing on stock. The two different CPUE scenarios used in this analysis had similar trends and as expected led to similar results. The alternate catch histories had different trends, and magnitudes, but the resulting estimates of stock status were similar. This indicates that the status results incorporate the alternate assumptions made regarding catch size and trend. Additional accurate reporting of OCS and other shark catch by commercial vessels would facilitate the estimation of catch and could improve the stock assessment. For example additional information regarding catch, effort and size composition from regions that are currently data deficient such as the Philippines and Indonesia would 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. 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 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 each models assumptions. This is the first time this technique has been applied to a WCPFC assessment and 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. Across different levels of the initial depletion the terminal depletion levels were similar because all of the standardized CPUE time series showed a significant decrease in CPUE since the late 1990s. This decline in CPUE corresponds with a decline in catch (for the reference case) and is consistent with biological information indicating a low productivity stock. These factors (declining catch, declining CPUE and constraining biology) give some additional certainty that the stock assessment results are in the correct quadrant of the Kobe plot.

These results suggest considerable concern over the future of this stock and this has already been recognised by the WCPFC through the adoption of a Conservation and Management (CMM2011-04) which bans the retaining on board, transshipping, storing and landing of oceanic whitetip sharks and requires all oceanic whitetip sharks to be released in a manner that results in as little harm to the shark as possible. It is not clear if this will be sufficient and we recommend an examination of existing observer data to see if further direct mitigation measures can be identified.

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 OCS 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 over the next two years would greatly improve the assessment and we recommend that this assessment be updated in 2014. The advantage of this is that we would then have an assessment with three to four more years of data with increased observer coverage rates and better reporting on the levels of bycatch in commercial fisheries.

6 Conclusions

The key conclusions of the first stock assessment for oceanic whitetip sharks in the WCPO are as follows:

1. Notwithstanding the difficulties inherent in the input data, the catch, CPUE, and size composition data all show consistent declines over the period of the model (1995-2009).
2. This is a low fecundity species and this is reflected in the low estimated value for F_{MSY} (0.07) and high estimated value for SB_{MSY} $/SB_{ZERO}$ (0.424). These directly impact the conclusions about overfishing and the overfished status of the stock.

3. 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.
4. Estimated fishing mortality has increased to levels far in excess of F_{MSY} ($F_{CURRENT}$/ F_{MSY} = 6.5) and across all model runs undertaken estimated F values were much higher than F_{MSY} (the 5th and 95th quantiles are 3 and 20). <u>Based on these results we conclude that overfishing is occurring</u>.
5. Estimated spawning biomass has declined to levels far below SB_{MSY} ($SB_{CURRENT}/SB_{MSY}$ = 0.153) and across all model runs undertaken $SB_{CURRENT}$ is much lower than SB_{MSY} (the 5th and 95th quantiles are 0.082 and 0.409). <u>Based on these results we conclude that the stock is overfished</u>.
6. Noting that estimates of SB_0 and SB_{MSY} are particularly uncertain as the model domain begins in 1995, it is also useful to compare current stock size to that at the start of the model. Estimated spawning biomass has declined over the model period by 86% and across all model runs undertaken$SB_{CURRENT}$ is much lower thanSB_{1995} (the 5th and 95th quantiles indicate a decline to 8.7% and 45.8% of SB_{1995}).
7. Current catches are lower than the MSY (2,001 versus 2,700), but this is not surprising given the estimated stock status and fishing mortality. Current (2005-2008 average) and latest (2009) catches are significantly greater than the forecast catch in 2010 under F_{MSY} conditions (230 mt).
8. The greatest impact on the stock is attributed to bycatch from the longline fishery, with lesser impacts from target longline activities and purse seining.
9. Given the bycatch nature of fishery impacts, mitigation measures provides the best opportunity to improve the status of the oceanic whitetip population. Existing observer data may provide some information on which measures would be the most effective.
10. Given recent decisions to improve logsheet catch reporting and observer coverage in the longline fishery it is recommended that an updated assessment be undertaken in 2014.
11. As this was the first stock assessment, there are many research activities that could improve future assessments including:
    a. Increased observer coverage, as planned by the WCPFC, (including biological data collection) 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. Biological studies of the growth and reproductive biology – especially female maturity (balancing the need to preserve the stock).
    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. Increased reporting data from commercial fisheries regarding quantity and the fate of oceanic whitetip sharks caught in the longline and purse seine fisheries.
    e. Implementation of management strategy evaluation (MSE) to develop strategies that are robust to the level of uncertainty that exists in the current assessment (e.g., the considerable uncertainty inherent in even the basic catch statistics). The costs and benefits of research and monitoring options (e.g. higher levels of longline observer coverage) can be integrated.
    f. Work to estimate the model the change in species composition in the purse seine observer data (from a generic 'shark' category to individual species) and back extrapolate to more clearly trend.

g. Increased modelling to standardize the CPUE for purse seine fisheries.

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9 Tables

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

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

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

	Estimate Source		
	Lawson (2011)	Present Study	2* Present Study
Year	Catch (1,000s of sharks)		
1995	237.0	79.0	158.1
1996	198.5	65.1	130.2
1997	189.7	60.2	120.4
1998	253.1	67.0	134.0
1999	227.3	85.8	171.6
2000	189.6	83.4	166.9
2001	125.0	93.6	187.3
2002	112.7	105.5	211.1
2003	90.1	97.4	194.9
2004	101.9	92.0	184.0
2005	75.7	85.3	170.6
2006	47.6	85.8	171.7
2007	52.4	114.4	228.7
2008	56.1	113.7	227.4
2009	53.7	102.9	205.8

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 the with maximum fixed standard deviation set to 0.1.
Initial population	The population age structure and overall size in the first year is determined as a function of the first years' recruitment (R1) offset from virgin recruitment (R0), the initial 'equilibrium' fishing mortality, and the recruitment deviations prior to the start of the year. The R1 offset, and the recruitment deviations are estimated. The initial fishing mortality was fixed at 0.1 for the reference case.
Age and growth	36 yearly age-classes, with the last representing a plus group. Individual age-classes have independent mean lengths constrained by von Bertalanffy growth curve. Mean weights were computed internally by estimating the distribution of weight-at-age from the distribution of length-at-age and applying the weight-length relationship $W = aL^b$(a=2.016667e-05, b=2.761, based on a study from OCS in the western central pacific (Seki et al. 1998)).
Selectivity	The longline bycatch fishery selectivity was assumed to increase with age and to remain at the maximum once attained. Selectivity for the target longline fishery was assumed to be dome shaped with a maximum selectivity value at 180 cm. Selectivity's for purse seine unassociated sets were assumed to be logistic with size at inflection of 110cm. The selectivity of the purse seine associated sets was estimated using a cubic spline parameterisation.
Catchability	Catchability is calculated independently for all fisheries and each CPUE trend was directly and independently proportional to abundance via the catchability term.
Natural mortality	Natural mortality was assumed to be constant throughout age classes and in time, with the natural mortality for the reference case set according to 0.18, calculated according to the relationship of Pauly (1980).

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

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

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

	Objective function component					
Model Run	Catch	CPUE	Length_comp	Recruitment	Priors	TOTAL
Reference	**1.73E-08**	**-9.89**	**63.04**	**-32.99**	**0.02**	**20.18**
Catch 2	7.31E-06	7.31	63.69	-31.90	0.01	39.12
Catch 3	7.23E-06	7.32	63.69	-31.90	0.03	39.13
CPUE 2	9.99E-03	94.54	62.91	-30.09	0.02	127.39
Nat_M_1	**1.79E-08**	**-9.90**	**66.90**	**-33.11**	**0.02**	**23.90**
Nat_M_3	**1.75E-08**	**-10.10**	**62.34**	**-32.87**	**0.03**	**19.40**
Steep_1	**1.76E-08**	**-9.83**	**63.54**	**-33.04**	**0.02**	**20.69**
Steep_3	**1.74E-08**	**-9.88**	**62.78**	**-32.93**	**0.02**	**20.00**
Init_F_1	**1.74E-08**	**-9.92**	**63.45**	**-33.00**	**0.02**	**20.56**
Init_F_3_	**1.73E-08**	**-9.67**	**62.59**	**-32.99**	**0.03**	**19.96**
Samp.Sz_2	1.73E-08	-9.86	88.18	-32.96	0.02	45.38
SigmaR_2	1.74E-08	-11.87	62.86	-18.80	0.02	32.21

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

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

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

Management Quantity	Units	Reference	Catch_2	Catch_3	CPUE_2	Nat_M_1	Nat_M_3	Steep_1	Steep_3	Init_F_1	Init_F_3_	Samp.Sz_2	SigmaR_2
C_{Latest}	t	1,802	3,160	6,321	1,451	2,534	1,468	1,984	1,630	1,820	1,779	1,803	1,785
$C_{Current}$	t per annum	2,001	3,707	7,414	1,891	2,822	1,625	2,195	1,811	2,028	1,967	2,004	2,010
$\tilde{Y}_{F_{MSY}}$	t per annum	2,700	1,645	3,290	2,606	3,596	2,244	2,279	3,000	2,380	3,318	2,697	2,734
$\tilde{B}_0$	t	110,447	67,513	135,032	106,461	230,313	70,350	122,226	99,683	97,390	135,715	110,327	111,860
$\tilde{B}_{MSY}$	t	46,780	28,593	57,188	45,102	99,195	29,001	54,400	39,828	41,249	57,483	46,729	47,377
$B_{current}$	t	7,295	11,212	22,426	4,493	11,436	5,647	8,896	5,917	7,543	7,006	7,327	7,405
$S\tilde{B}_0$		3,537	2,162	4,324	3,409	6,380	2,330	3,914	3,192	3,119	4,346	3,533	3,582
$S\tilde{B}_{MSY}$		1,498	916	1,831	1,444	2,748	960	1,742	1,275	1,321	1,841	1,496	1,517
$SB_{current}$		229	347	694	137	366	156	288	177	237	220	231	230
$B_{current} / \tilde{B}_0$		0.066	0.166	0.166	0.042	0.050	0.080	0.073	0.059	0.077	0.052	0.066	0.066
$B_{current} / \tilde{B}_{MSY}$		0.156	0.392	0.392	0.100	0.115	0.195	0.164	0.149	0.183	0.122	0.157	0.156
$SB_{current} / S\tilde{B}_0$		0.065	0.161	0.161	0.040	0.057	0.067	0.074	0.055	0.076	0.051	0.065	0.064
$SB_{current} / S\tilde{B}_{MSY}$		0.153	0.379	0.379	0.095	0.133	0.163	0.165	0.139	0.179	0.120	0.154	0.152
$SB_{Current} / SB_{1995}$		0.139	0.342	0.342	0.086	0.161	0.127	0.158	0.119	0.121	0.181	0.141	0.140
$\tilde{B}_{MSY} / \tilde{B}_0$		0.424	0.424	0.424	0.424	0.431	0.412	0.445	0.400	0.424	0.424	0.424	0.424
$S\tilde{B}_{MSY} / S\tilde{B}_0$		0.424	0.424	0.424	0.424	0.431	0.412	0.445	0.400	0.424	0.424	0.424	0.424
$F_{current}$		0.469	0.662	0.655	0.861	0.479	0.202	0.535	0.459	0.356	0.249	0.243	0.464
F_{msy}		0.070	0.071	0.071	0.070	0.047	0.091	0.051	0.092	0.070	0.070	0.070	0.070
$F_{current} / \tilde{F}_{MSY}$		6.694	9.298	9.197	12.324	10.287	2.229	10.560	4.992	5.080	3.556	3.469	6.616

Table 8: Estimates of management quantities for the Reference, median, 5th and 95th quantiles of the of the uncertainty grid. For a details on the management quantities, see Table 6.

Management Quantity	Units	Reference	Grid Median	Grid 5%	Grid 95%
C_{Latest}	t	1,802	2,218	1,295	6,962
$C_{Current}$	t per annum	2,001	2,703	1,593	8,131
$\tilde{Y}_{F_{MSY}}$	t per annum	2,700	2,713	1,484	4,831
$\tilde{B}_0$	t	110,447	111,973	56,366	309,263
$\tilde{B}_{MSY}$	t	46,780	47,300	22,321	133,204
$B_{current}$	t	7,295	8,672	3,864	26,001
$\tilde{SB}_0$		3,537	3,554	1,848	8,566
$\tilde{SB}_{MSY}$		1,498	1,505	739	3,690
$SB_{current}$		229	280	112	820
$B_{current} / \tilde{B}_0$		0.066	0.073	0.034	0.192
$B_{current} / \tilde{B}_{MSY}$		0.156	0.175	0.079	0.454
$SB_{current} / \tilde{SB}_0$		0.065	0.069	0.034	0.173
$SB_{current} / \tilde{SB}_{MSY}$		0.153	0.166	0.082	0.409
$SB_{Current} / SB_{1995}$		0.139	0.181	0.087	0.458
$\tilde{B}_{MSY} / \tilde{B}_0$		0.424	0.424	0.399	0.449
$\tilde{SB}_{MSY} / \tilde{SB}_0$		0.424	0.424	0.399	0.449
$F_{current}$		0.469	0.461	0.243	0.909
F_{msy}		0.070	0.070	0.035	0.093
$F_{current} / \tilde{F}_{MSY}$		6.694	6.940	3.001	20.026

10 Figures

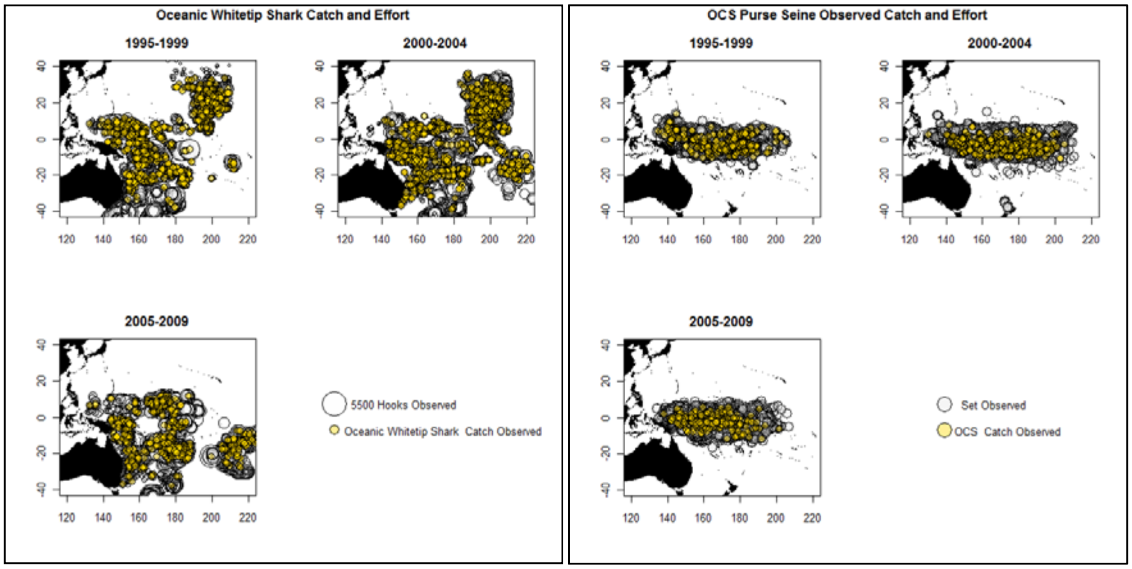


Figure 1. Distribution of the observed oceanic whitetip shark catches by fishing method (longline – left; purse seine – right) during 1995-2009.

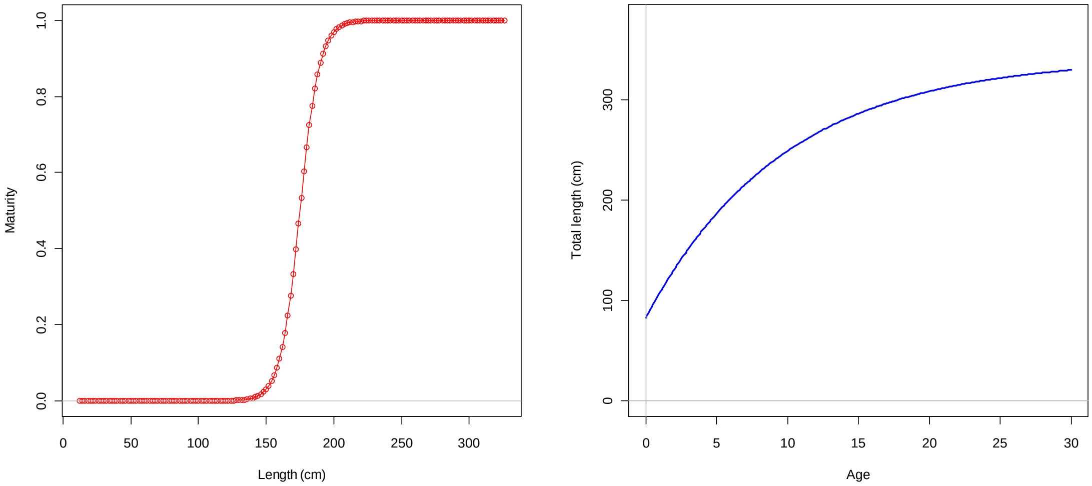


Figure 2. Important biological parameters assumed in the assessment; length at maturity (left panel) and the growth curve (right panel) both taken from Seki et al. 1998.

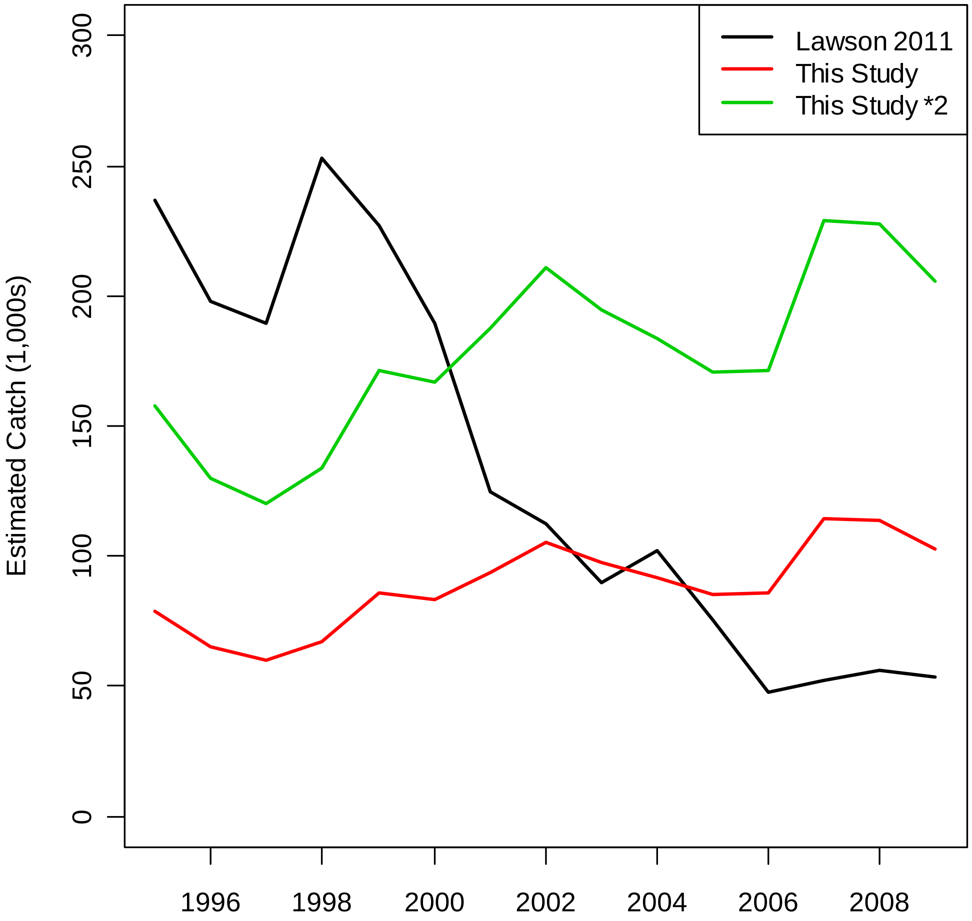


Figure 3. Estimated oceanic white tip catches in all fisheries by estimation study. The black line is from Lawson (2011), the green and red lines follow a similar methodology and are based on analysis unique for this study.

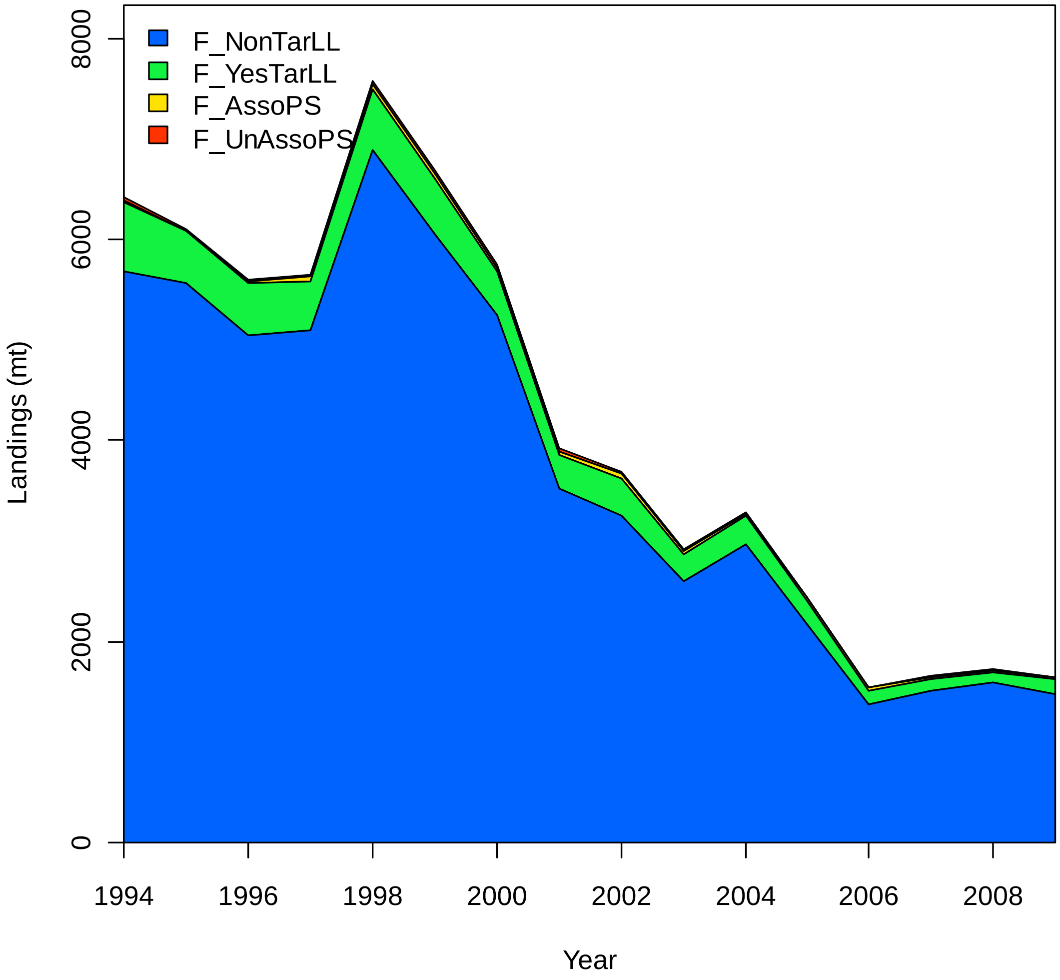


Figure 4. Annual estimated oceanic whitetip shark catch in the WCPO by fleet and fishing method, 1995-2009. Based on Lawson (2011) – see Figure 3.

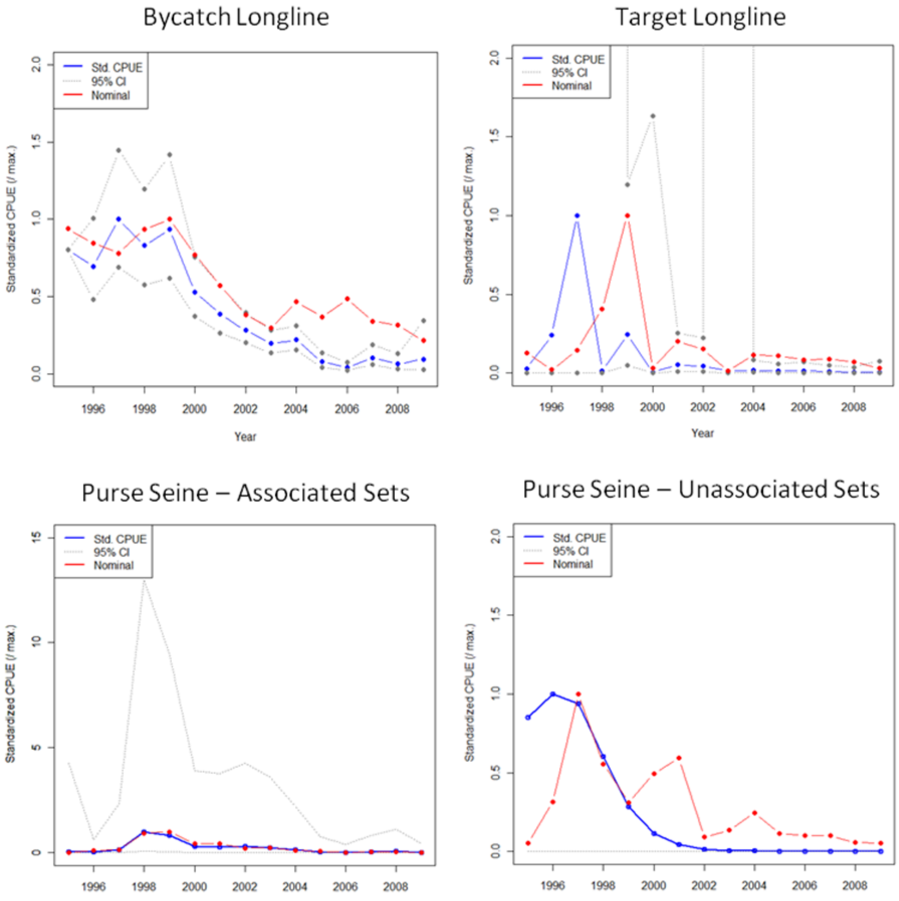
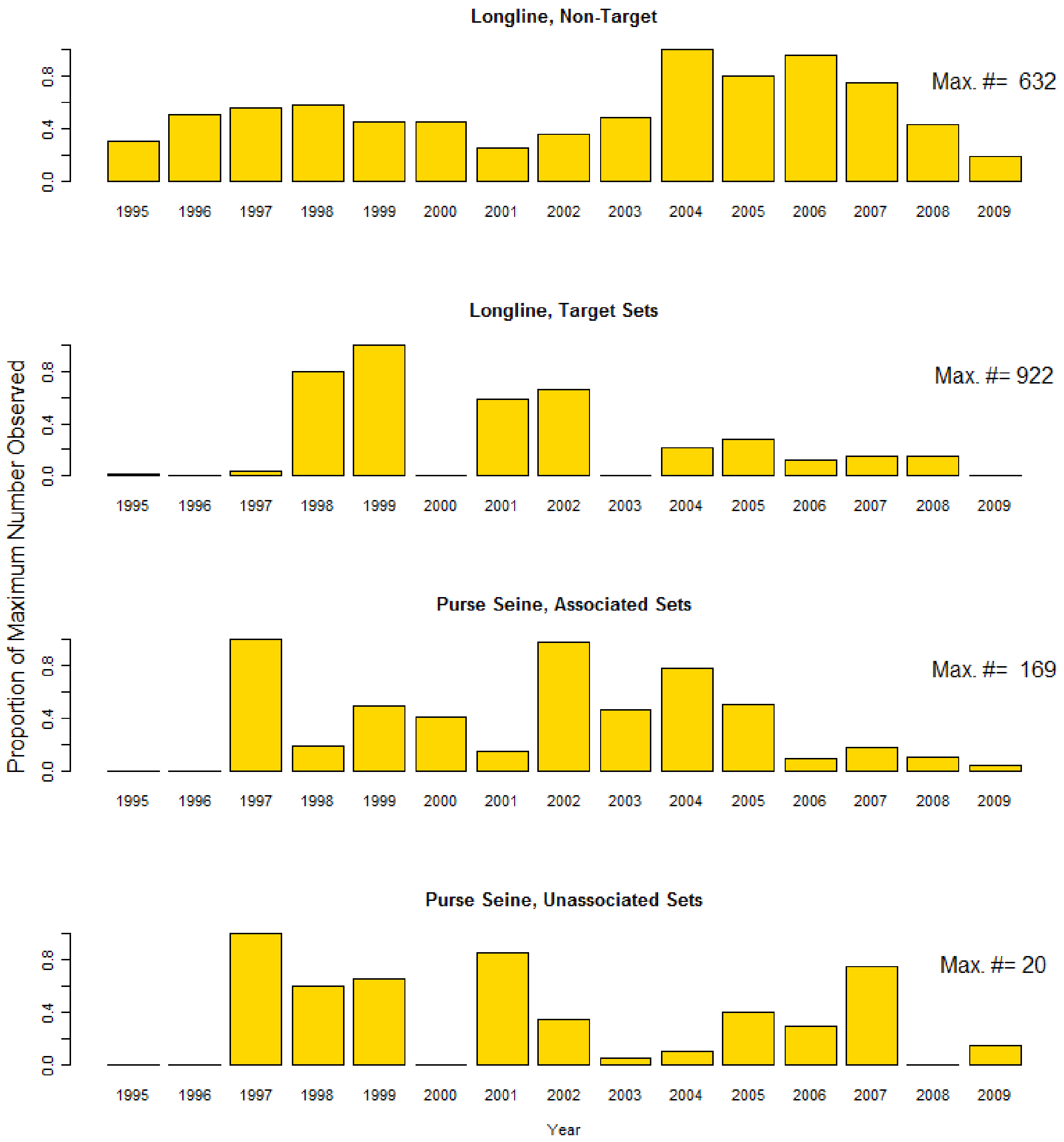


Figure 5. Standardized and nominal oceanic whitetip CPUE time series for each of the four fisheries



Longline, Non-Target

Longline, Target Sets

Purse Seine, Associated Sets

Purse Seine, Unassociated Sets

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).

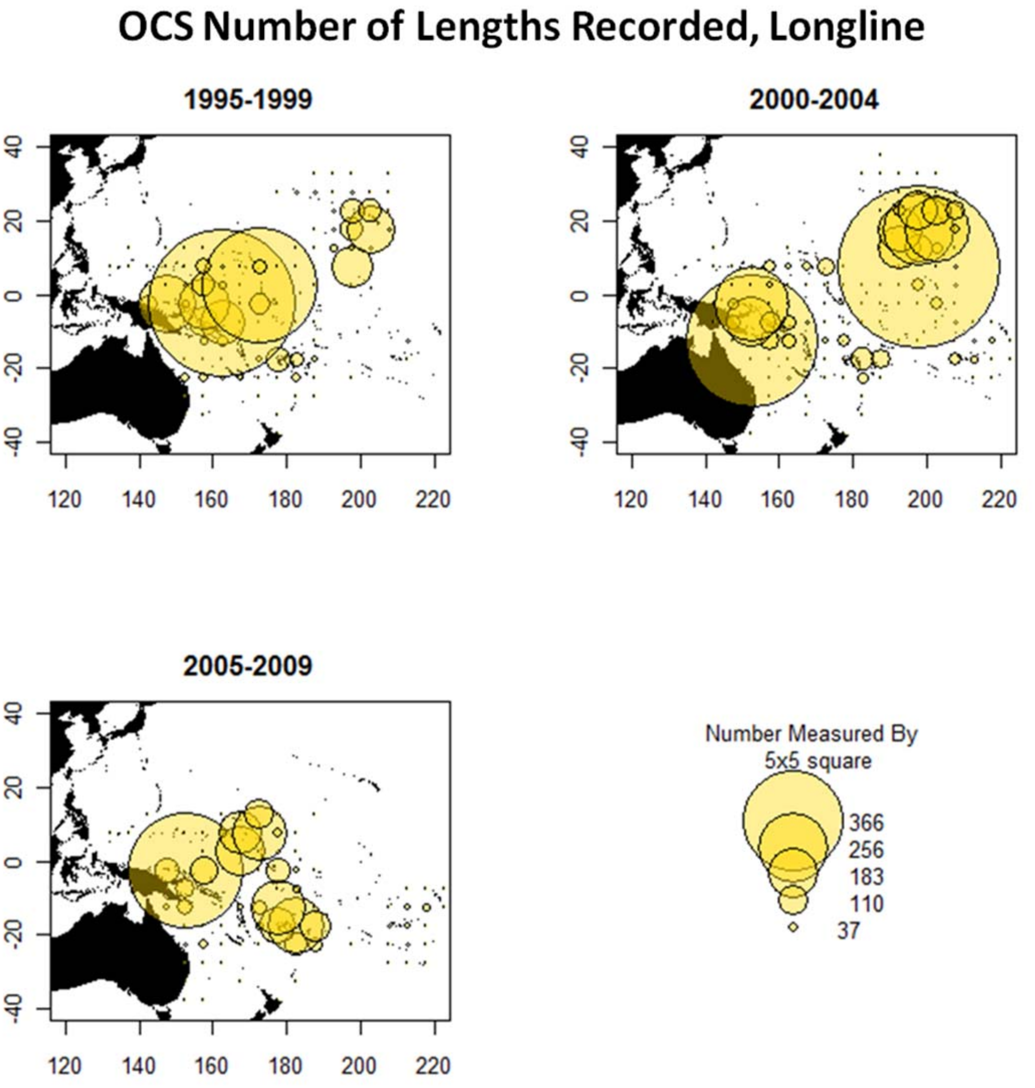


Figure 7. Number and location of oceanic whitetip sharks measured in the longline fishery (target and bycatch) by 5-year block in 5x5 degree squares.

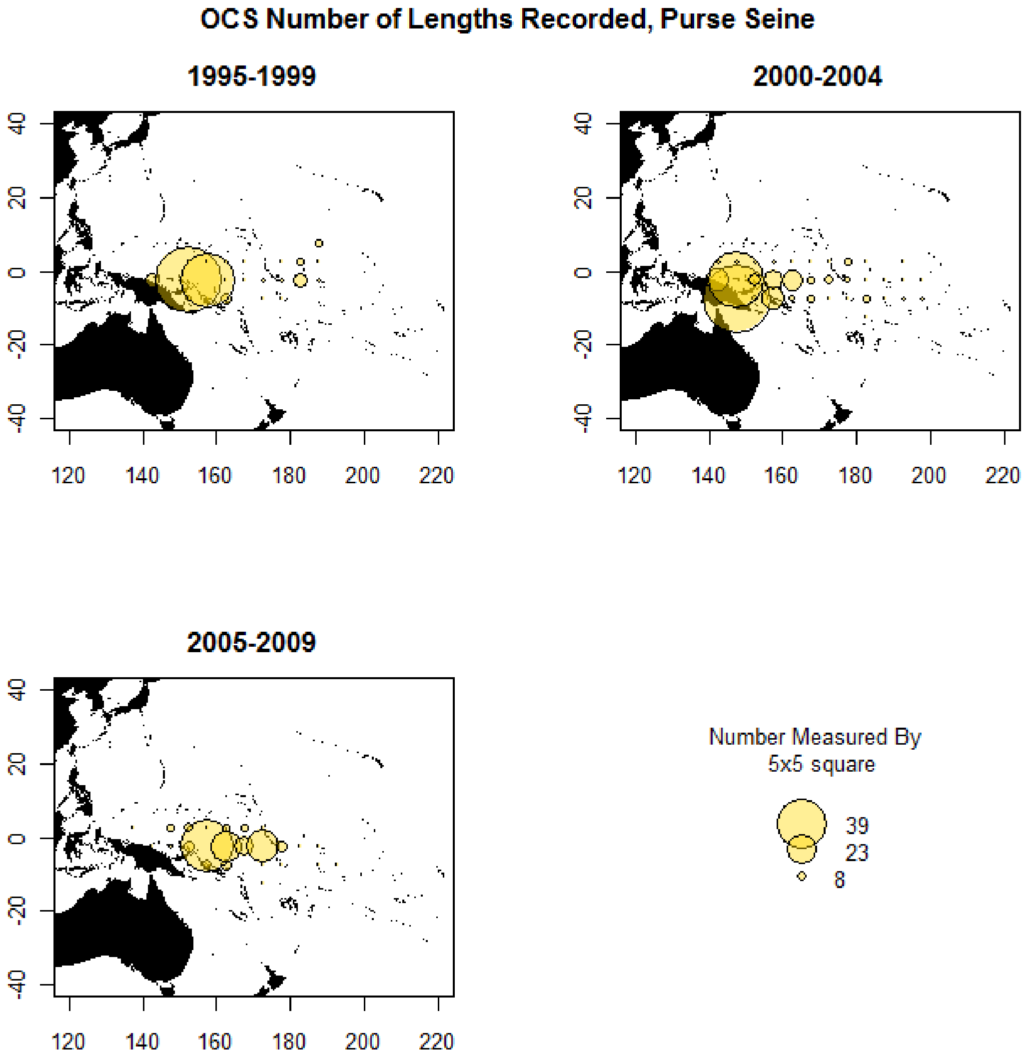


Figure 8. Number and location of oceanic whitetip sharks measured in the purse seine fishery by 5year block in 5x5 degree squares.

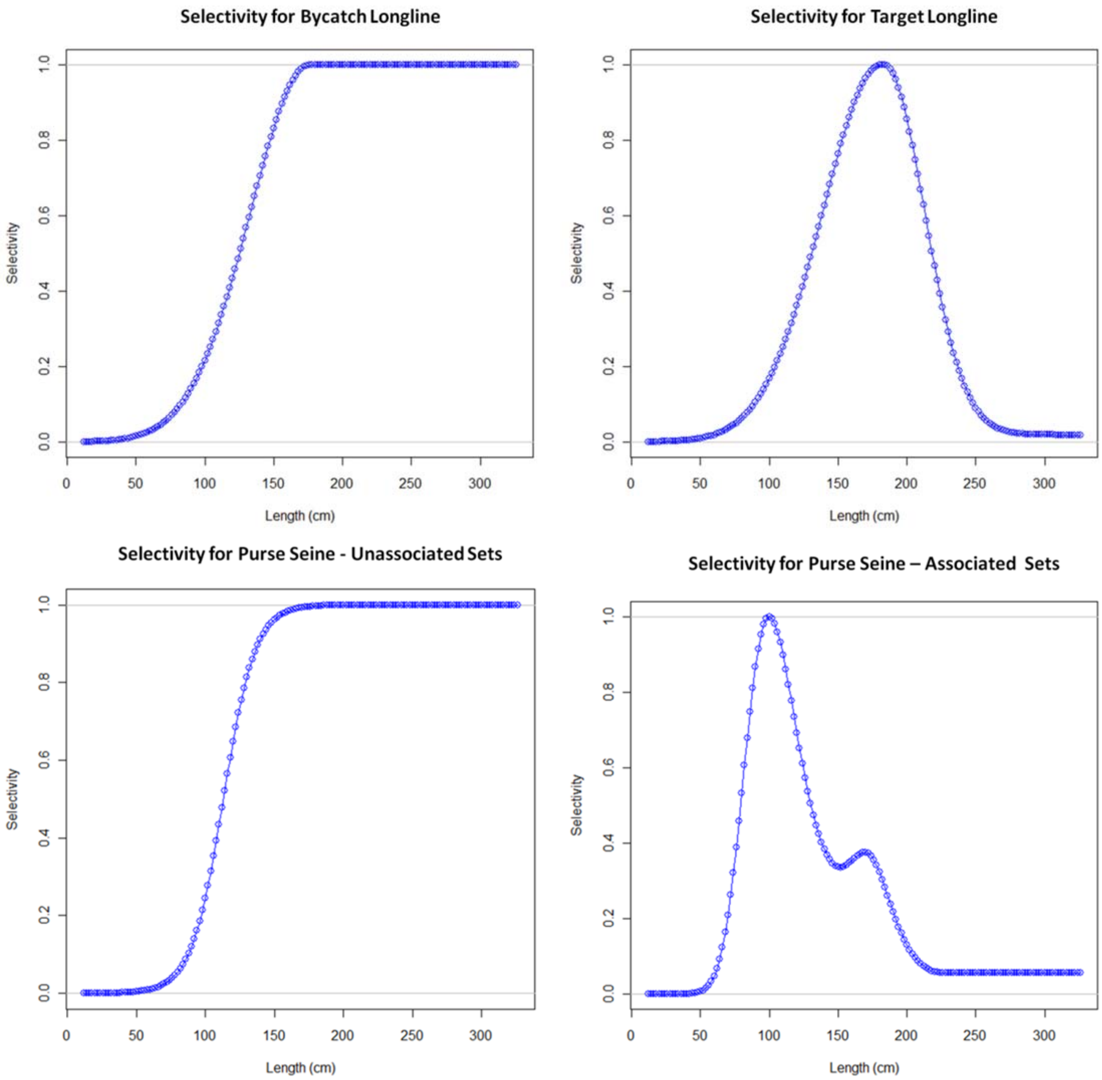


Figure 9. Selectivity by fleet (as estimated in the reference case). The top left is longline bycatch, top right is longline target, lower left is unassociated purse seine lower right is associated purse seine. Selectivity for males and females is the same.

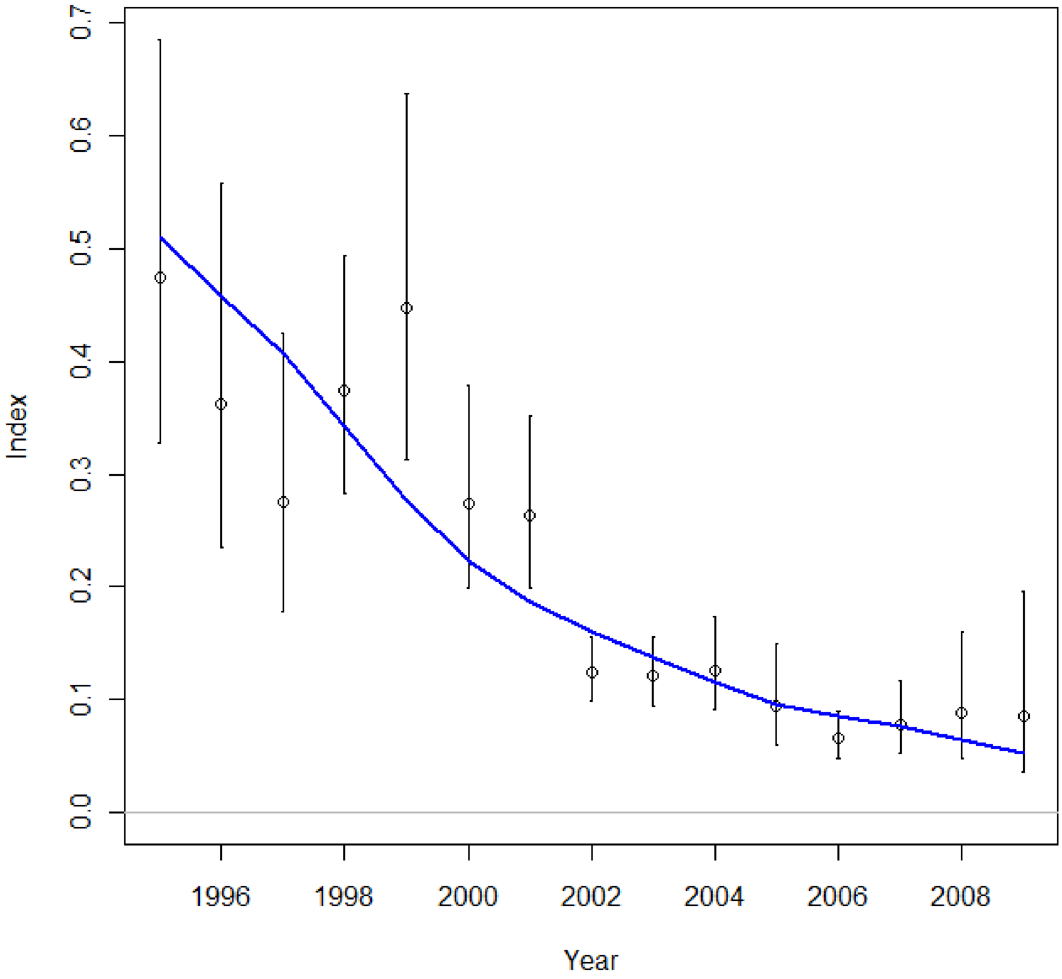


Figure 10. A comparison of the observed LL bycatch CPUE (empty circles with 95% confidence intervals) and model fit (blue solid line) for the reference case.

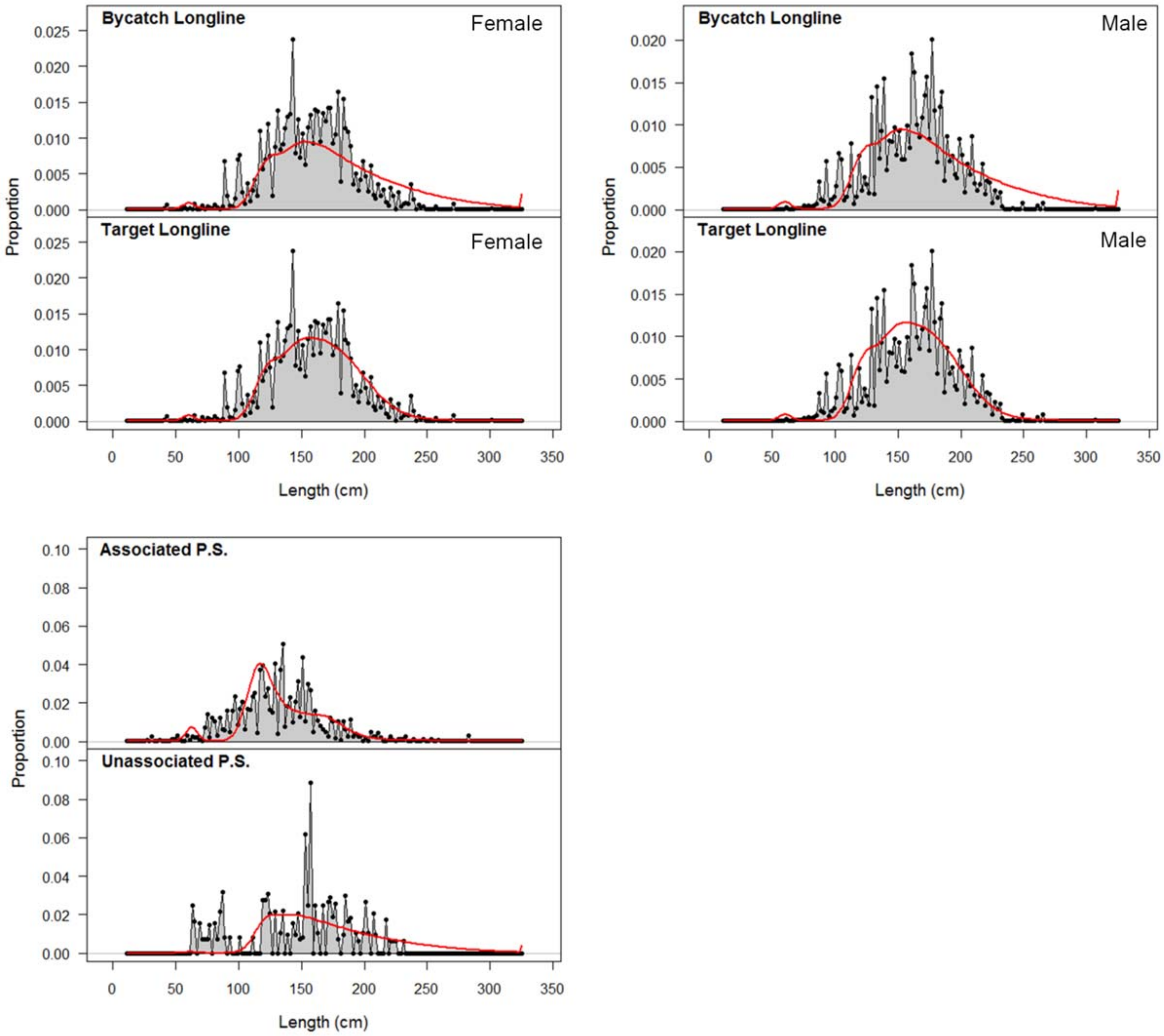


Figure 11. Predicted catch at length (red line) and observed lengths (black line and grey shaded area) in the longline fishery by fleet for the reference case model. Samples and predictions are pooled across all years. The top four panels are for the longline fisheries (males on the right and females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

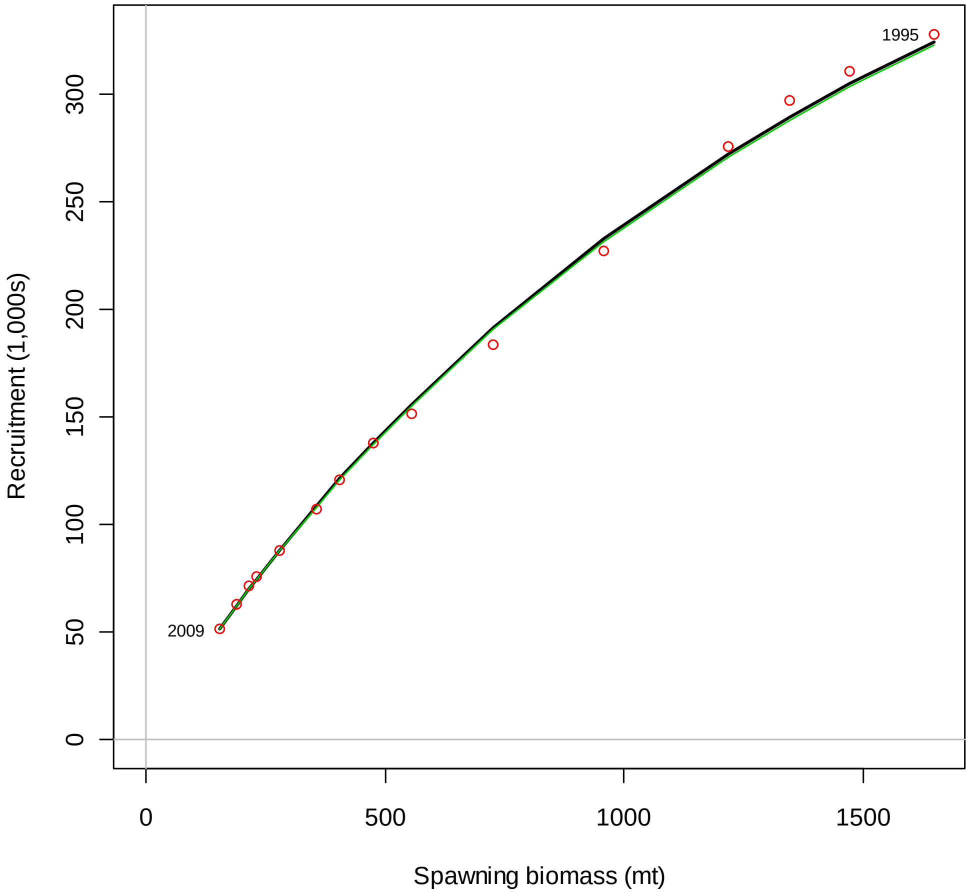


Figure 12 Spawning biomass per recruitment estimates and the assumed Beverton and Holt stock-recruitment relationship (SRR) assuming a steepness of 0.409.

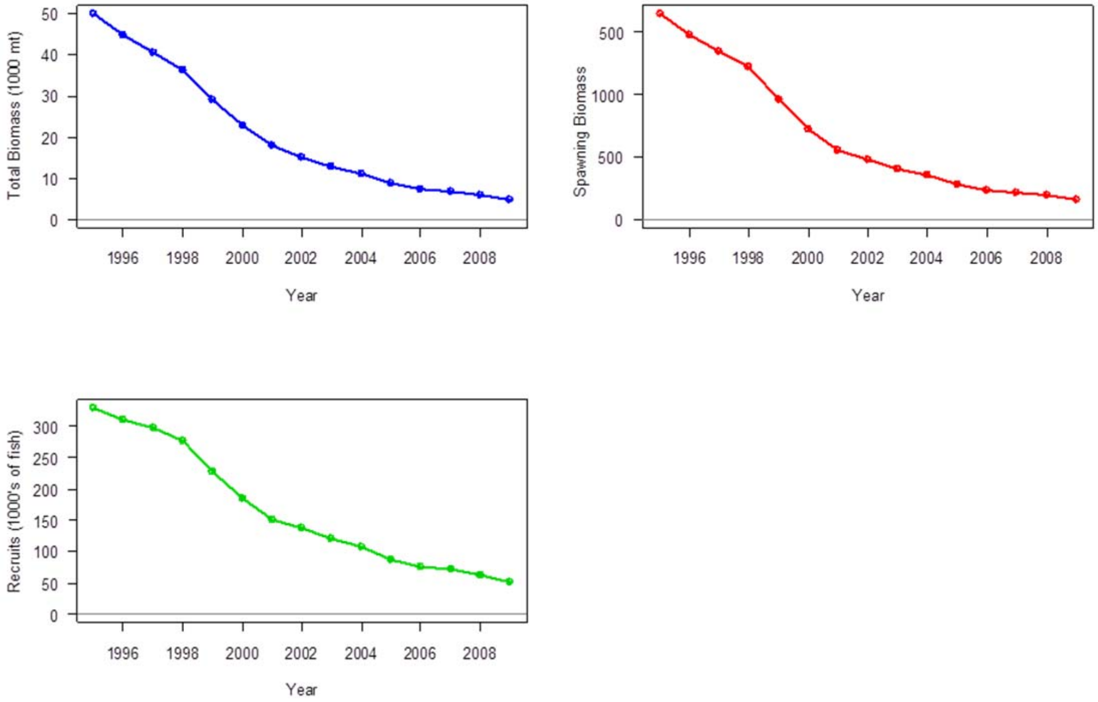


Figure 13. Estimated total biomass (top left, 1000 metric tons), estimated spawning biomass (top right) and estimated annual recruitment (1000's of fish) in the WCPO for the reference case.

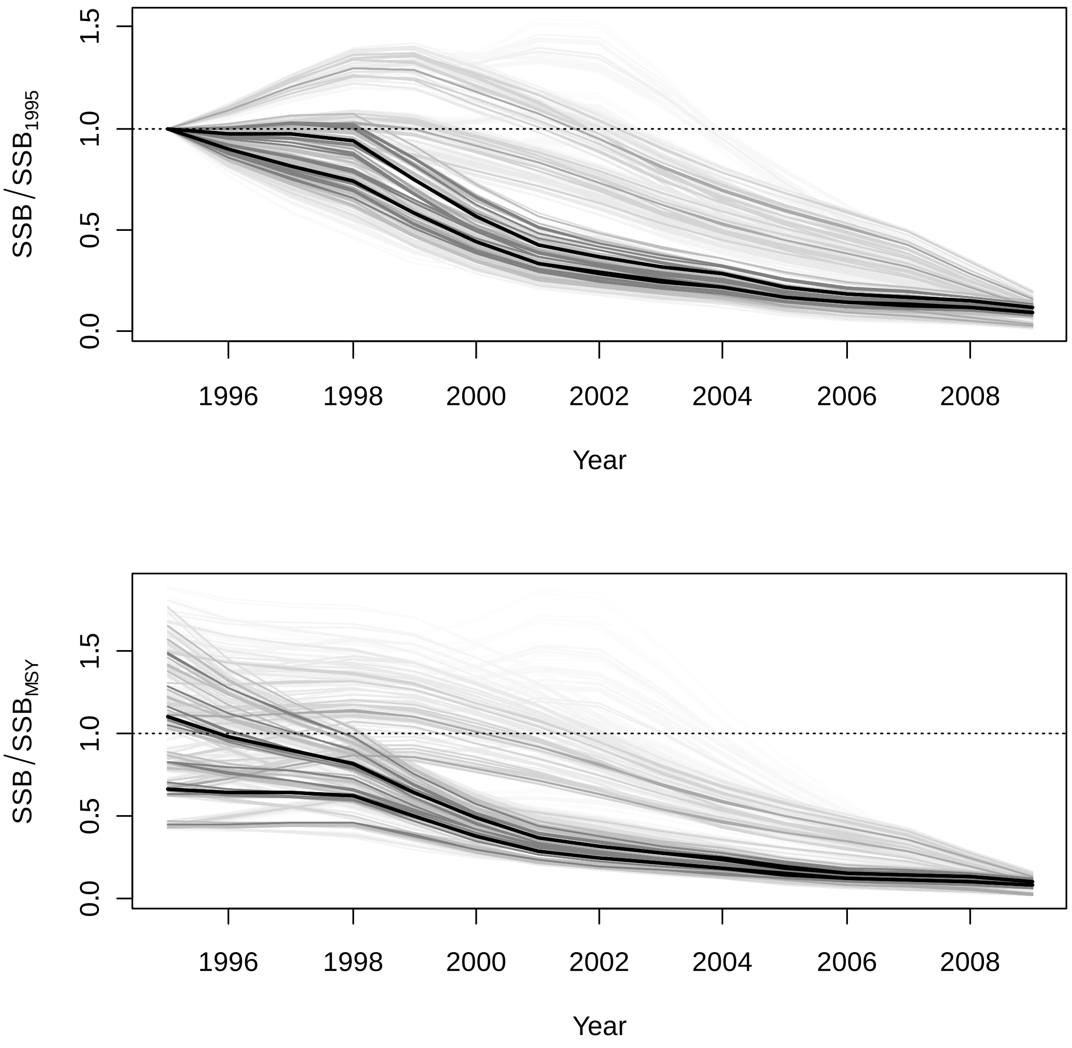


Figure 14. Changes in the spawning biomass relative to the first year of the model (1995 – top panel) and SB_{MSY} (bottom panel). Each line represents one of 648 runs from the grid and the darker the line, the higher the assigned weight (plausibility) for that model run.

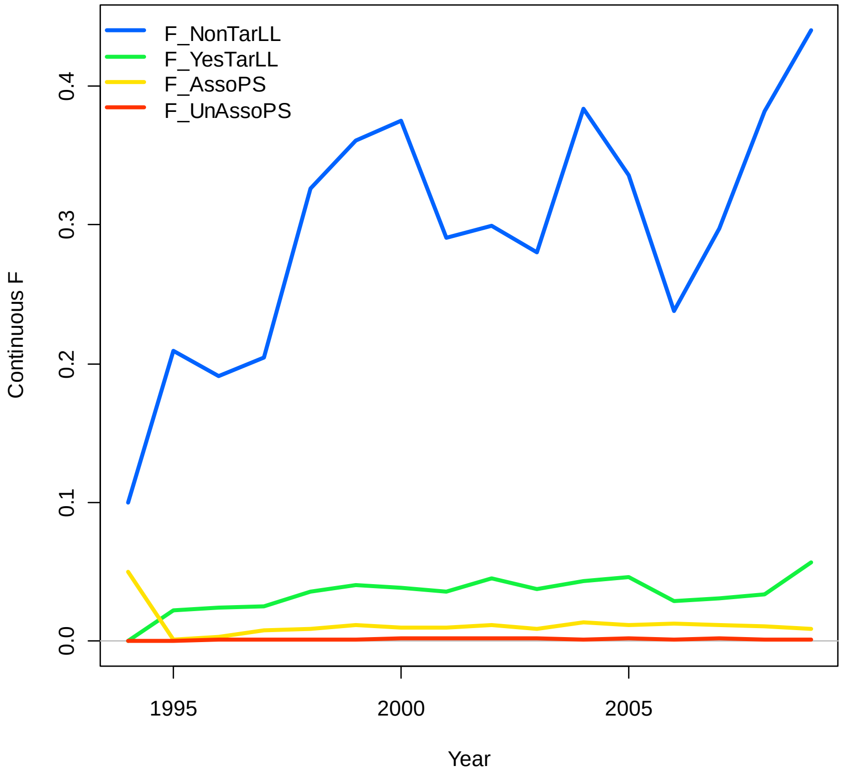


Figure 15. Estimated fishing mortality by fleet for the reference case over the model period.

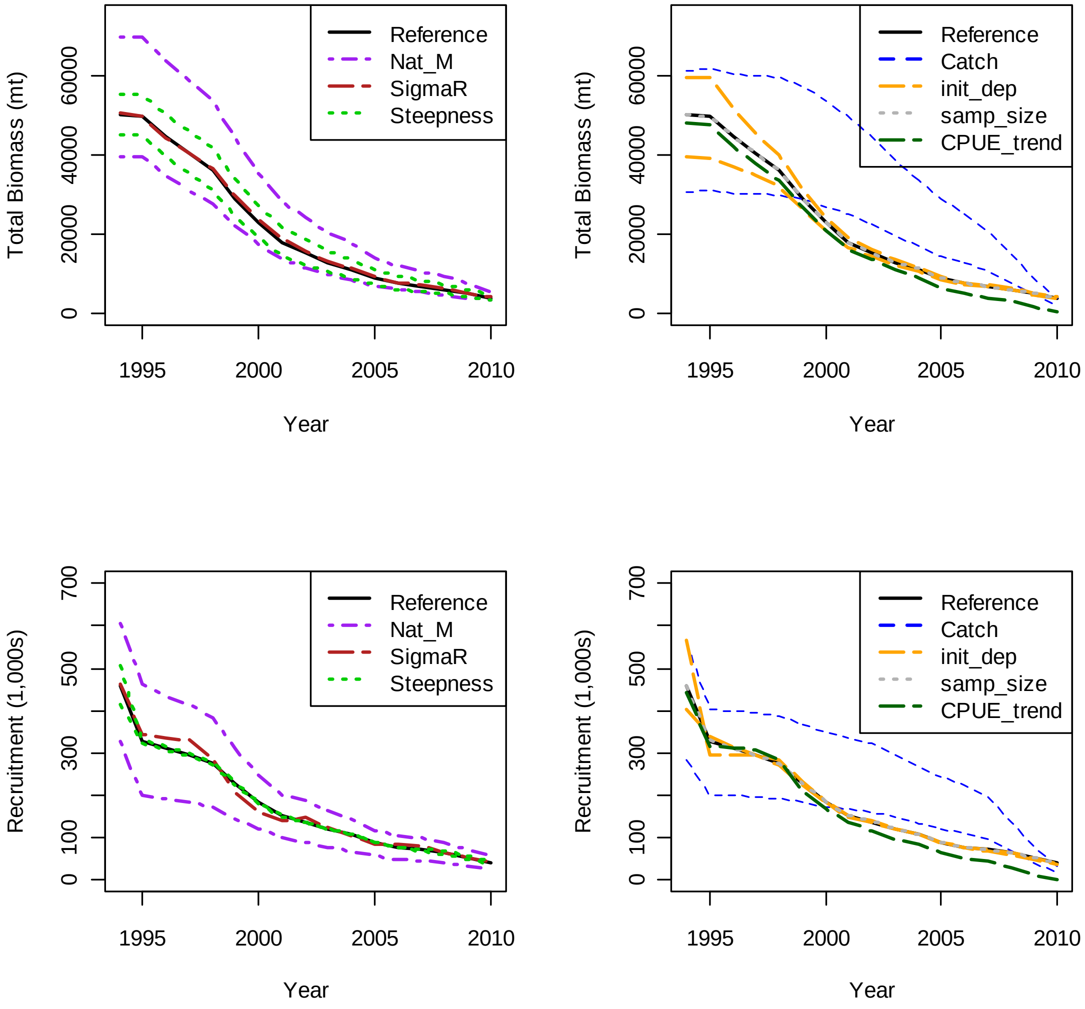


Figure 16. Sensitivity analysis effects on total biomass (top) and recruitment (bottom) of alternate variable levels on the reference case. The figures on the left show the effects of the natural mortality, SigmaR (the s.d. on the recruitment devs.), and the steepness. The figures on the right show the effects of changing the catch inputs, initial depletion, sample size down weighting, and the CPUE inputs.

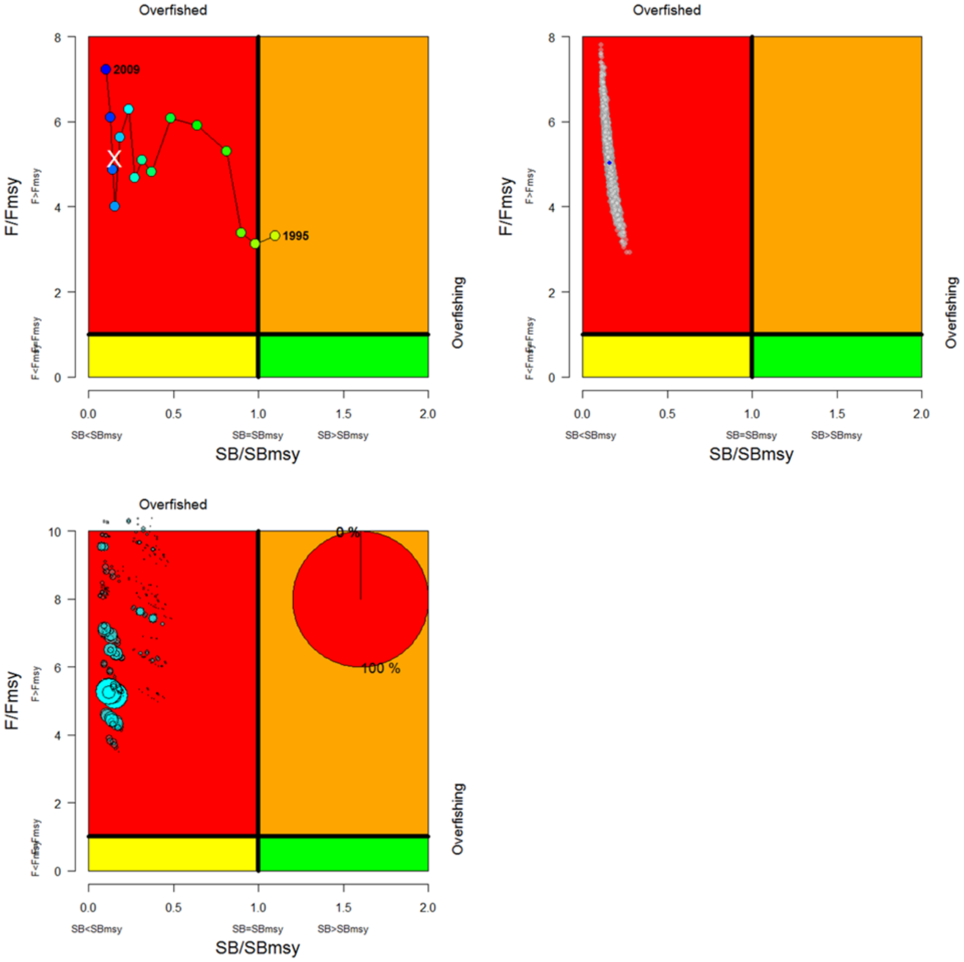


Figure 17. Kobe plots indicating annual stock status, relative to SB_{MSY} (x-axis) and F_{MSY} (y-axis) reference points. These present the reference model for the period 1995–2009 (top left panel), the statistical uncertainty based on the MCMC analysis for the current (average of 2005-2008) status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

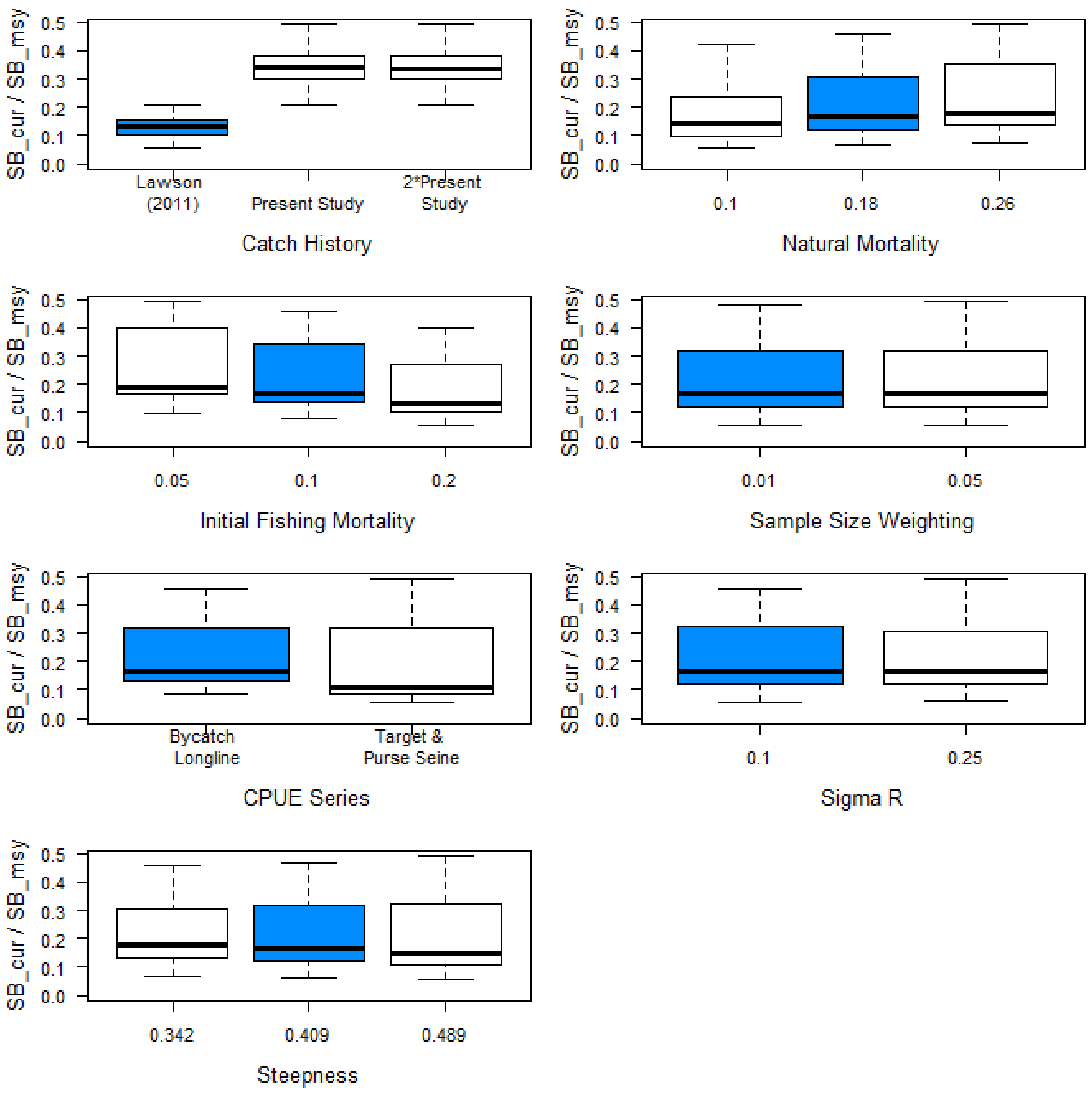


Figure 18. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter $SB_{CURRENT}/SB_{MSY}$.

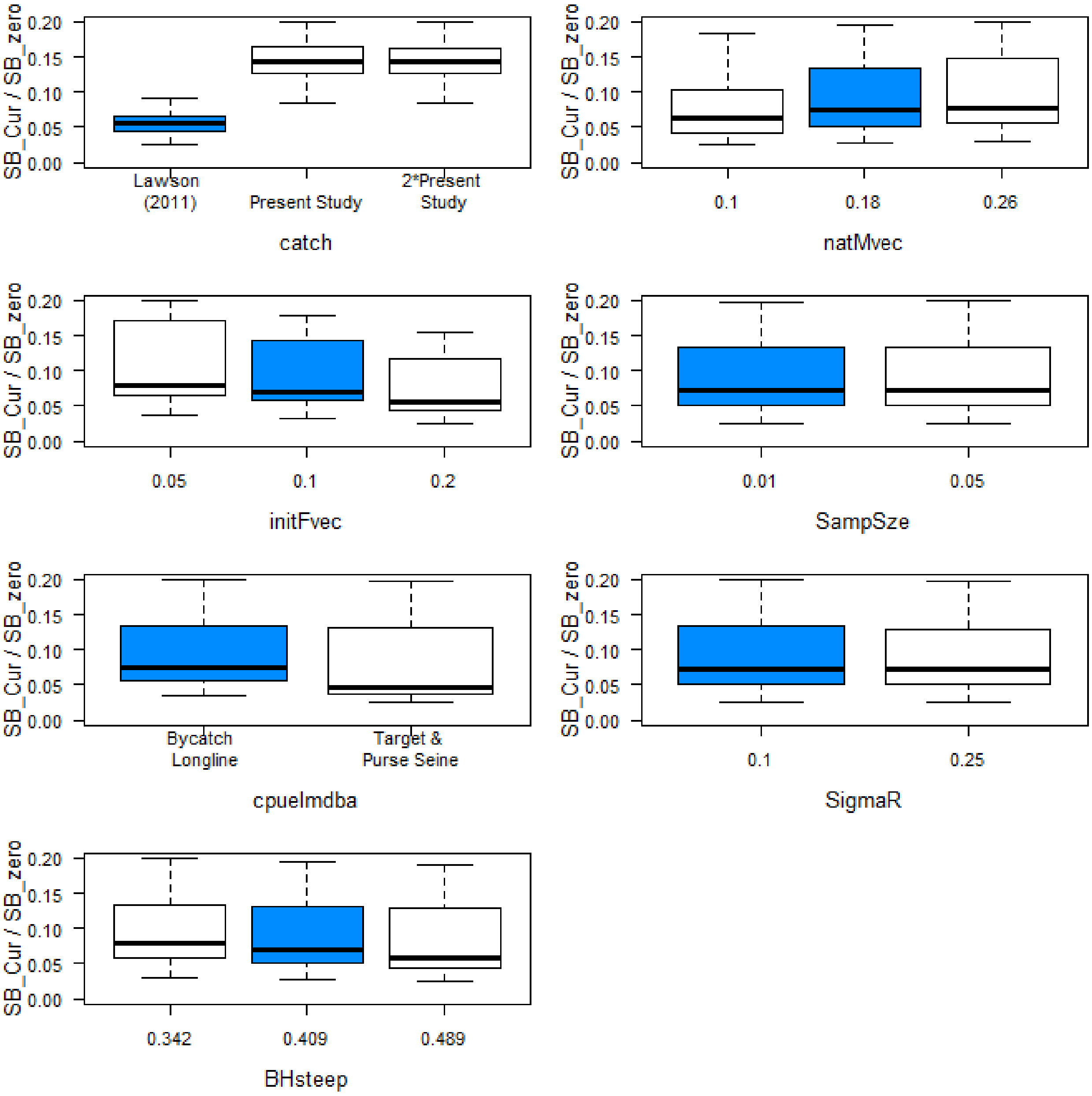


Figure 19. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter $SB_{CURRENT}/SB_0$.

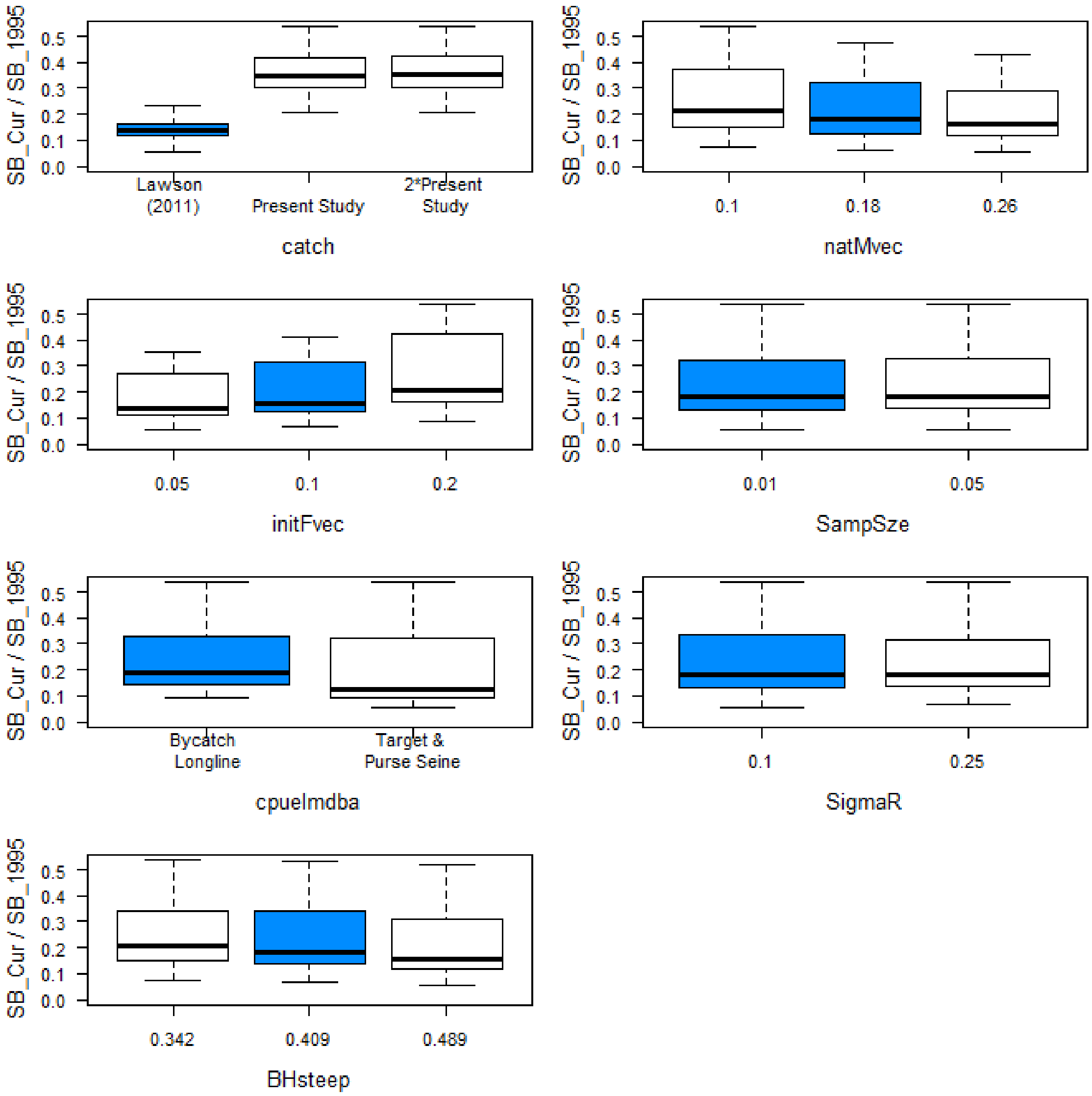


Figure 20. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter $SB_{CURRENT}/SB_{1995}$.

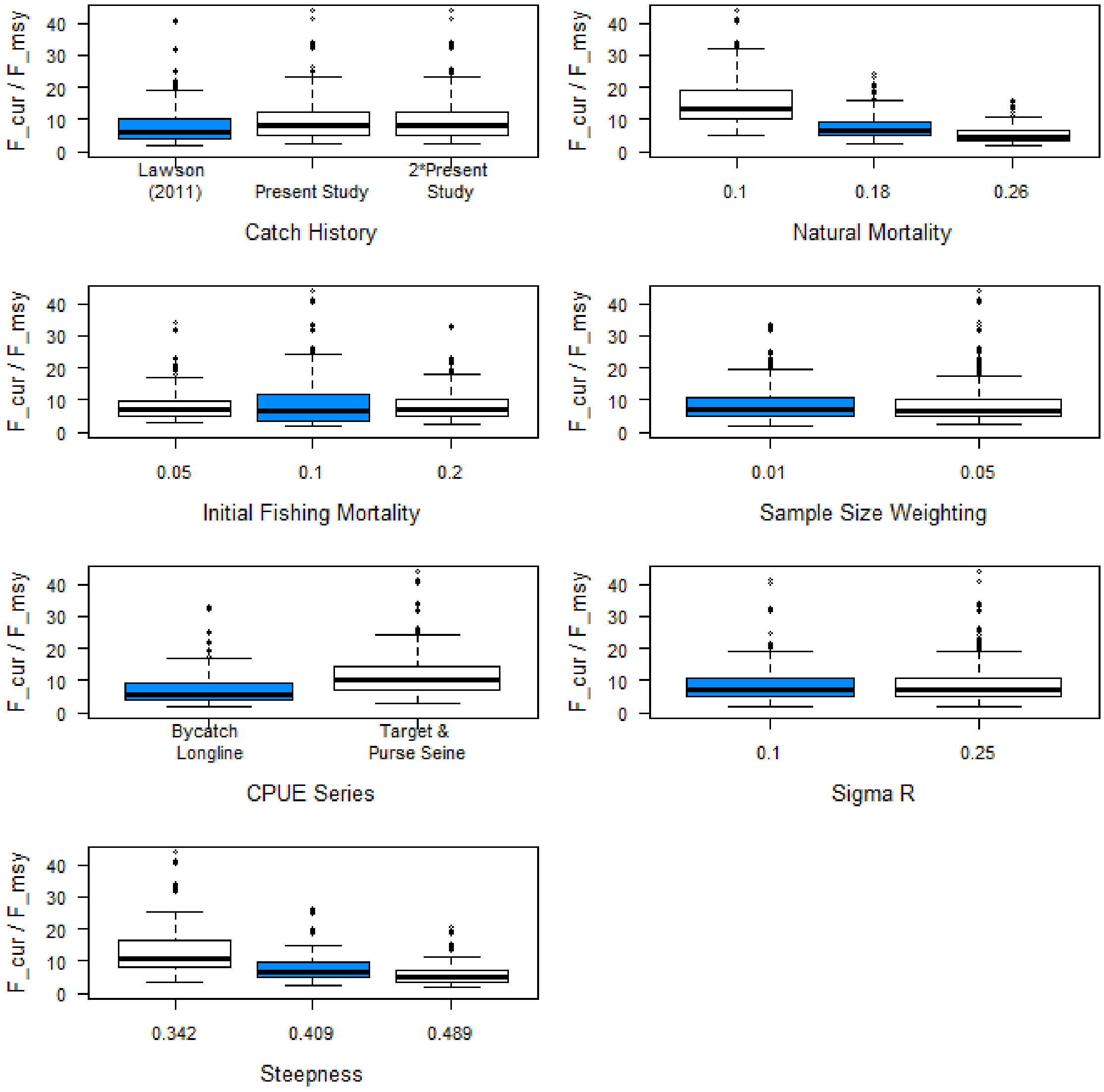


Figure 21. Box plots showing of the effects of the different values of the 7 grid parameters (catch, natural mortality, initial depletion, sample size weighting, CPUE, SigmaR and steepness) on the management parameter $F_{CURRENT}$ /F_{MSY}.

11 Appendix 1: Control File for SS3 model

```
# OCS-WCPO model. Developed by Joel Rice (joelr@spc.int)on 21/11/2011
#_data_and_control_files: OCS.dat // OCS.ctl
#_SS-V3.21d-win64-safe;_05/22/2011;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB
# FISHERY DEFINITIONS
# FisheryNum      FishSurvNum       FishSurvAlpha      Gear       SetType Years
#1         F1         F1-NonTar_LL      LL          1995-2009
#2         F2         F2-YesTar_LL      LL          1995-2009
#3         F3         F3-PS_Asso_PS     PS          1995-2009
#4         F4         F4-PS_UN-Asso_PS              PS          1995-2009
#5         S1         S1-NonTar_LL      LL 1995-2009
#6         S2         S2-YesTar_LL      LL 1995-2009
#7         S3         S3-PS_AssoPS      PS 1995-2009
#8         S4         S4-PS_UN-AssoPS PS 1995-2009
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
6 #_First_Mature_Age         # overwritten
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 0 # NatM_p_1_Fem_GP_1
 70 120 108.227 108.227 0 10 -4 0 0 0 0 0.5 0 0 # L_at_Amin_Fem_GP_1
 40 350 266.491 266.491 0 10 -2 0 0 0 0 0.5 0 0 # L_at_Amax_Fem_GP_1
 0.05 0.15 0.103 0.103 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 2.01667e-005 2.01667e-005 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_1_Fem
 -3 3.5 2.761 2.761 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_2_Fem
 -3 300 175 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 1.18268e-005 1.18268e-005 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_1_Mal
 -3 4 2.86 2.86 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 8 6.13005 4 0 10 2 # 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 -0.000615755 0 0 1 1 # SR_R1_offset
 0 0 0 0 -1 99 -99 # SR_autocorr
0 #_SR_env_link
1 #_SR_env_target_0=none;1=devs;_2=R0;_3=steepness
2 #do_recdev:  0=none; 1=devvector; 2=simple deviations
1995 # first year of main recr_devs; early devs can preceed this era
2009 # last year of main recr_devs; forecast devs start in following year
2 #_recdev phase
1 # (0/1) to read 13 advanced options
 -5 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
 2 #_recdev_early_phase
 0 #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
 1 #_lambda for Fcast_recr_like occurring before endyr+1
 -2 #_last_early_yr_nobias_adj_in_MPD
```

```
 -1 #_first_yr_fullbias_adj_in_MPD
 2006 #_last_yr_fullbias_adj_in_MPD
 2007 #_first_recent_yr_nobias_adj_in_MPD
 0.85 #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for all estimated recdevs)
 0 #_period of cycles in recruitment (N parms read below)
 -15 #min rec_dev
 15 #max rec_dev
 0 #_read_recdevs
#_end of advanced SR options
#
#_placeholder for full parameter lines for recruitment cycles
# read specified recr devs
#_Yr Input_value
#
#Fishing Mortality info
0.25 # 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
4  # N iterations for tuning F in hybrid method (recommend 3 to 7)
#
#_initial_F_parms
#_LO HI INIT PRIOR PR_type SD PHASE
 0 1 0.1 0.1 0 99 -1 # InitF_1F_NonTarLL
 0 1 0 0.01 0 99 -1 # InitF_2F_YesTarLL
 0.05 1 0.05 0.1 0 99 -1 # InitF_3F_AssoPS
 0 1 0 0.01 0 99 -1 # InitF_4F_UnAssoPS
#
#_Q_setup
 # Q_type options:  <0=mirror, 0=median_float, 1=mean_float, 2=parameter, 3=parm_w_random_dev,
4=parm_w_randwalk, 5=mean_unbiased_float_assign_to_parm
 #_Den-dep  env-var  extra_se  Q_type
 0 0 0 0 # 1 F_NonTarLL
 0 0 0 0 # 2 F_YesTarLL
 0 0 0 0 # 3 F_AssoPS
 0 0 0 0 # 4 F_UnAssoPS
 0 0 0 0 # 5 S_NonTarLL
 0 0 0 0 # 6 S_YesTarLL
 0 0 0 0 # 7 S_AssoPS
 0 0 0 0 # 8 S_UnAssoPS
#
#_Cond 0 #_If q has random component, then 0=read one parm for each fleet with random q; 1=read a parm for
each year of index
#_Q_parms(if_any)
#
#_size_selex_types
#_Pattern Discard Male Special
 24 0 0 0 # 1 F_NonTarLL
 24 0 0 0 # 2 F_YesTarLL
 27 0 0 4 # 3 F_AssoPS
 1 0 0 0 # 4 F_UnAssoPS
 5 0 0 1 # 5 S_NonTarLL
 5 0 0 2 # 6 S_YesTarLL
 5 0 0 3 # 7 S_AssoPS
 5 0 0 4 # 8 S_UnAssoPS
#
#_age_selex_types
```

```
#_Pattern ___ Male Special
 11 0 0 0 # 1 F_NonTarLL
 11 0 0 0 # 2 F_YesTarLL
 11 0 0 0 # 3 F_AssoPS
 11 0 0 0 # 4 F_UnAssoPS
 11 0 0 0 # 5 S_NonTarLL
 11 0 0 0 # 6 S_YesTarLL
 11 0 0 0 # 7 S_AssoPS
 11 0 0 0 # 8 S_UnAssoPS
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
 14 300 176.537 50 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_1P_1_F_NonTarLL
 -15 15 2.9745 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_1P_2_F_NonTarLL
 -15 15 8.24972 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_1P_3_F_NonTarLL
 -15 15 0.0945531 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_1P_4_F_NonTarLL
 -15 15 -9.55821 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_1P_5_F_NonTarLL
 -15 15 6.92325 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_1P_6_F_NonTarLL
 14 300 181.667 50 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_2P_1_F_YesTarLL
 -15 15 -7.82984 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_2P_2_F_YesTarLL
 -15 15 8.22461 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_2P_3_F_YesTarLL
 -15 15 7.42571 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_2P_4_F_YesTarLL
 -15 15 -9.6806 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_2P_5_F_YesTarLL
 -15 15 -3.97051 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 6.54609 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSpline_Val_1_F_AssoPS_3
 -15 15 5.45604 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSpline_Val_2_F_AssoPS_3
 -15 15 5.5292 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSpline_Val_3_F_AssoPS_3
 0 15 3.66482 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSpline_Val_4_F_AssoPS_3
 1 200 113 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_4P_1_F_UnAssoPS
 -200 200 34 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_4P_2_F_UnAssoPS
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_5P_1_S_NonTarLL
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_5P_2_S_NonTarLL
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_6P_1_S_YesTarLL
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_6P_2_S_YesTarLL
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_7P_1_S_AssoPS
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_7P_2_S_AssoPS
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_8P_1_S_UnAssoPS
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_8P_2_S_UnAssoPS
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_1P_1_F_NonTarLL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_1P_2_F_NonTarLL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_2P_1_F_YesTarLL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_2P_2_F_YesTarLL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_3P_1_F_AssoPS
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_3P_2_F_AssoPS
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_4P_1_F_UnAssoPS
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_4P_2_F_UnAssoPS
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_5P_1_S_NonTarLL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_5P_2_S_NonTarLL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_6P_1_S_YesTarLL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_6P_2_S_YesTarLL
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_7P_1_S_AssoPS
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_7P_2_S_AssoPS
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_8P_1_S_UnAssoPS
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_8P_2_S_UnAssoPS
```

```
#_Cond 0 #_custom_sel-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no enviro fxns
#_Cond 0 #_custom_sel-blk_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no block usage
#_Cond No selex parm trends
#_Cond -4 # placeholder for selparm_Dev_Phase
#_Cond 0 #_env/block/dev_adjust_method (1=standard; 2=logistic trans to keep in base parm bounds;
3=standard w/ no bound check)
#
# Tag loss and Tag reporting parameters go next
0  # TG_custom:  0=no read; 1=read if tags exist
#_Cond -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0  #_placeholder if no parameters
#
1 #_Variance_adjustments_to_input_values
#_fleet: 1 2 3 4 5 6 7 8
  0 0 0 0 0 0 0 0 #_add_to_survey_CV
  0 0 0 0 0 0 0 0 #_add_to_discard_stddev
  0 0 0 0 0 0 0 0 #_add_to_bodywt_CV
  0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 #_mult_by_lencomp_N
  1 1 1 1 1 1 1 1 #_mult_by_agecomp_N
  1 1 1 1 1 1 1 1 #_mult_by_size-at-age_N
#
1 #_maxlambdaphase
1 #_sd_offset
#
24 # number of changes to make to default Lambdas (default value is 1.0)
# Like_comp codes:  1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq; 7=sizeage; 8=catch;
# 9=init_equ_catch; 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp; 15=Tag-comp;
16=Tag-negbin
#like_comp fleet/survey  phase  value  sizefreq_method
 1 1 1 0 1
 1 2 1 0 1
 1 3 1 0 1
 1 4 1 0 1
 1 5 1 1 1
 1 6 1 0 1
 1 7 1 0 1
 1 8 1 0 1
 4 1 1 1 1
 4 2 1 1 1
 4 3 1 1 1
 4 4 1 1 1
 4 5 1 0 1
 4 6 1 0 1
 4 7 1 0 1
 4 8 1 0 1
 9 1 1 0 1
 9 2 1 0 1
 9 3 1 0 1
 9 4 1 0 1
 9 5 1 0 1
 9 6 1 0 1
 9 7 1 0 1
 9 8 1 0 1
#
# lambdas (for info only; columns are phases)
#  0 #_CPUE/survey:_1
#  0 #_CPUE/survey:_2
#  0 #_CPUE/survey:_3
#  0 #_CPUE/survey:_4
```

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