SEDAR

Southeast Data, Assessment, and Review

SEDAR 29

HMS GOM Blacktip Shark

Post-Review Updates and Projections

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The first part of this document addresses the CIE peer reviews of the SEDAR 29 HMS Gulf of Mexico blacktip shark stock assessment report (here forth referred to as SAR). The document addresses only those comments that can be addressed by the assessment team and are thus related to the actual assessment (section 3 of the SAR) since other comments directed to data and analyses conducted by other participants and presented in SEDAR 29 working documents (section 2) would have to be addressed by the individual authors of those reports. The present document thus mostly includes more detail in the form of additional equations or explanations to help clarify several issues raised by the reviewers and in some cases misinterpretations of model functioning covered in section 3. Our responses to specific Terms of Reference (ToR) items also apply to the respective sections in the "Conclusions and recommendations" section of the reviews. We thank the reviewers for their thorough reviews and helpful suggestions for future work.

The second part of the document addresses the projections that, while not in the ToRs, were requested by NOAA's HMS division.

1. Reviews

1.1. Addressing Review of CIE reviewer N. Cadigan

The main conclusion from this reviewer was that the assessment provided evidence that the stock of GOM blacktip shark is not overfished, but that the status regarding overfishing is uncertain. The conclusion regarding overfishing was based on the reviewer's interpretation of the model being mis-specified. Next we will address this conclusion and other findings by this reviewer related to the stock assessment.

<u>ToR 1a: Age and growth datasets and decisions; natural mortality</u>

Issue: The reviewer wondered how the maximum observed age of 18 years was used in the assessment.

Response: Since the model (SSASPM) is an age-structured production model, all the population dynamics equations consider 18 age groups (a goes from 1 to 18 in all relevant equations: Equation 1, 3, 6, etc.) with the last age group being a plus group.

Issue: The reviewer noted that a text description of the demographic gamer Excel spreadsheet was not provided and that the sensitivity of M to deviations in maximum age should have been provided.

Response: The demographic gamer spreadsheet is intended to provide an easy interface precisely to evaluate the effect of multiple biological inputs, such as maximum age, fecundity, and von Bertalanffy growth function parameters, on estimates of M and by extension several population parameters of interest (maximum rate of increase, generation times, etc.) obtained through a straightforward life table approach. A brief description of the life history invariant methods used to generate estimates of M (all of which can be found in the literature) was included in the last paragraph of section 3.1.2 (page 56). Varying the value in cell P4 of the demographic gamer allows one to see the effect of considering different methods or sets of methods on estimates of M (expressed as annual survival in column S). Of the four life history methods used to estimate M, only Hoenig's (1983) method makes full use of longevity. By varying the value in cell C13 one can examine the effect of changing maximum age on the single (age-independent) value of M predicted by the Hoenig method. The magnitude of the difference in values of M obtained by considering alternative, reasonable values of longevity is less than that obtained in scenarios 11 and 12 (low and high productivity runs; page 64), which used the 95% CLs of the von Bertalanffy growth function parameters, which in turn affect the estimates of M obtained through the Chen and Watanabe (1989) method. Therefore the sensitivity of M values and assessment results to reasonable changes in longevity was indirectly included in the low and high productivity scenarios.

ToR 1c: Are data applied properly within the assessment model?

Issue: The reviewer noted that "the maturity schedule in the input data file did not appear to be sex-specific and was different from the values in Table 2.5.3 of the AR – for males or females. Fecundities in WP-24 were different from the values in Figure 2.6.5 of the AR… It seems that the standard errors derived from the index standardization models are not used in the stock assessment model. Methods to use this valuable information should be considered in future assessments – although I recognize that this methodological issue requires further investigation (see research recommendation in ToR6)."

Response: The ADMB input data file provided to the reviewers actually includes a maternity schedule (as described in the decision listed on page 14 of the SAR) and thus does not match the maturity schedule listed in Table 2.5.3. It corresponds to the maternity schedule listed in Table 2.5.4 for integer ages using the parameter values for *a* and *b* listed at the top of the table. Fecundities in the input data file do correspond to those depicted in Figure 2.6.5, divided by two to account for females only. The CVs derived from the statistical standardization of the relative abundance indices were included, but only in the inverse CV weighting scenarios. For the base model, indices were weighted by the inverse rankings and in the equal weighting (or no weighting) scenario, all indices were weighted by 1. This response also applies to items ToR2a and ToR5b.

ToR 1d: Are input data series reliable and sufficient to support the assessment approach and findings?

Issue: The reviewer felt that the sensitivity analyses using different catch streams may not have adequately reflected uncertainty in the catch data.

Response: As explained in the description of scenarios 9 and 10 on page 63, low and high catch scenarios were developed to attempt to incorporate uncertainty in the magnitude of catches, as recommended by previous CIE reviewers. We think that objective was reasonably met by applying the procedures described on page 63. Additionally, this assessment of GOM blacktip sharks incorporated sources of removals not contemplated in other shark assessments, specifically post-release live discard mortalities in the commercial and recreational fisheries and dead discards in commercial fisheries. However, we recognize that, as for other shark assessments, historical information on the level of removals, in this case prior to the beginning year of the model, 1981, is largely unknown and thus no reconstruction of catches prior to 1981 was attempted.

Issue: The reviewer indicated that while the assessment model was age-based, he thought the indices were not age-based and he was unsure about whether the catch data were disaggregated into ages.

Response: The indices used are not age-based per se, but age-specific selectivity and catches are used for their computation (Equation 9). Likewise, because no catch-at-age data are available, predicted age-*specific* catch by fleet is estimated by sequentially removing one *age-specific* catch series at a time (Equation 7). The sum of the predicted *age-specific* catches by fleet is then removed from the stock

(Equation 6). Predicted catch by fleet is then compared to observed catch by fleet in the objective function (as in Equation 12; line 871 of ADMB template file). Predicted catch by fleet is obtained as the sum of the predicted *age-specific* catch by fleet (line 740 of ADMB template file):

$$\hat{C}_{y,m,i} = \sum_{a} \hat{C}_{a,y,m,i}$$

Issue: The reviewer questioned whether this implementation of SSASPM could estimate both fishery and index selectivities and also that he suspected that the approach used to estimate selectivities externally to the model was based on the assumption that recruitment and F for fully recruited ages are constant for the cohorts represented in the age-compositions.

Response: Although SSASPM can in theory estimate selectivities for both indices of relative abundance and fisheries (fleets) when age compositions are available, the general lack of such data is the reason why selectivities were fixed, i.e., they were not estimated by the model but rather fitted externally to the model based on age frequency distributions obtained from length frequency distributions. This procedure, while not ideal, as recognized in several parts of the assessment report (section 3.1.2.2. and 3.3), was the only one available given early unsuccessful attempts at estimating selectivities within the model based on the few and incomplete age compositions available. We also recognize that the ad-hoc approach used to estimate selectivities relies on the assumption of constant recruitment and F, as pointed out by the reviewer. If this modeling platform continues to be used in the future, the sensitivity of the model to changes in fleet and index selectivities will have to be explored.

ToR 2a: Are methods scientifically sound and robust?

Issue: The reviewer indicated that Equations 6 and 7 in the report indicate the model is age-based but the age compositions of catch were not provided and that while he saw where they were read by the ADMB code, he could not find the inputs. The reviewer also did not understand the τ_i parameter in Equation 7 and noted that Equation 13 suggested that data were weighted by annual CVs but he could not see where these were read in the ADMB code.

Response: As mentioned above, because no catch-at-age data are available, predicted *age-specific* catch by fleet is estimated by sequentially removing one *age-specific* catch series at a time (Equation 7). The sum of the predicted *age-specific* catches by fleet is then removed from the stock (Equation 6). Predicted catch by fleet is then compared to observed catch by fleet in the objective function (as in Equation 12; line 871 of ADMB template file). Predicted catch by fleet is obtained as the sum of the predicted *age-specific* catch by fleet (line 740 of ADMB template file and see equation at the top of this page). The τ_i parameter denotes the duration (in years) of the fishing season for each fleet, which is imputed in the ADMB data file in the form of a month when the fishery begins and a month when it ends. In this application, τ_i = 12 months or 1 year, and the δ parameter in Equation 7 (fraction of the year elapsed) is also 1, thus Equation 7 is unaffected by the ratio. The annual index CVs are imputed in the ADMB data file as annual scaling factors for observation variance. In the case of equal weighting all values are 1; for inverse CV weighting each value is 1/CV; and for rank weighting, each value is 1/rank.

Issue: The reviewer indicated he could not evaluate the Bayesian Surplus Production (BSP) model because there was little information.

Response: The BSP, which is part of the ICCAT software library, is fully described in several publications (e.g., McAllister and Babcock 2004). It was included by the analysts to provide some contrast to SSASPM and because it had been previously used in 2002 and 2006 and is easily implemented (section 3.2.9).

Issue: The reviewer indicated that in Equation 12, the whole equation is multiplied by 0.5, which is what the ADMB code does.

Response: This is correct and Equation 12 *does show* the whole term multiplied by 0.5.

ToR 2b: Are assessment models configured properly and used consistent with standard practices?

Issue: The reviewer had some concerns with the specific implementation: 1) that the population was assumed to be in virgin conditions in 1981, when the model started, which may not have been the case, and 2) that no process error in recruitment (i.e., recruitment deviations) was included in the model

Response: 1) As described in section 3.1.1, SSASPM has the ability to estimate a population trajectory from virgin conditions back through a more data-poor historic period when only catch or effort data are available. Because no historic information (i.e., prior to the starting year of the model, 1981) on catch or effort was available for this standard assessment, this implementation of SSASPM only considered the modern period. Other assessments with SSASPM (e.g. SEDAR 21) have considered a historic period because catches or effort series were derived by the Catch Working Group during the Data Workshop. This was not the case for the present assessment. As noted in the Discussion, the alternative to considering virgin conditions in 1981 was to reconstruct catches back in time, but there was no basis for doing so given the lack of available information. Note that the age distribution at the start of the model *is* at equilibrium (Equation 1).

2) Regarding process error in recruitment, SSASPM *includes it*. The inputs can be found in the "process error" section at the end of the ADMB parameter input file. The same Equation (5) as for fleet-specific effort is used for recruitment, i.e., it follows a first-order lognormal autoregressive process (see also Equation 10). In this case, the correlation coefficient ρ was set to 0.5, and η is a normally distributed random error with mean=0 and variance=0.15. These choices reflect a high level of autocorrelation in process error and a low level of process error in recruitment, which is compatible with the life history of sharks, where interannual variation in recruitment is expected to be low. What likely confused the reviewer is that this was not mentioned in the report and because process error in recruitment was fixed (not estimated) it did not show up in the figures depicting the contribution to relative likelihood by category. Additionally, recruitment is taken into account in the model through the reparameterization of the Beverton-Holt curve (Equations 2 and 3), whereby the virgin number of recruits (R_0) and pup survival (S_0) were given prior pdfs and estimated in a Bayesian framework, making full use of all relevant biological information available.

ToR 2c: Are the methods appropriate for the available data?

Issue: The reviewer concluded that the current model configuration was not appropriate for the stock based on his misgivings about recruitment detailed above.

Response: Since we showed that process error in recruitment was fully considered, this conclusion would therefore be invalidated. This response also applies to item ToR5b.

ToR 3a: Are abundance, exploitation, and biomass estimates reliable, consistent with input data and population biological characteristics, and useful to support status inferences?

Issue: The reviewer was concerned that the low Fs and constant recruitment implied by the model led to poor model fit and indicated that a somewhat consistent pattern in 4 of the 6 indices was not picked up by the model.

Response: We showed above that process error in recruitment was considered and thus it would not be one of the factors contributing to the poor fit. The flat trend fitted by the model is likely a reflection of the flat trend in the two indices available prior to the mid-1990s (ENP and TEXAS) combined with an early increase (1981 to early 1990s) and subsequent decrease (early 1990s to 2010) in catches. A possible explanation of why the increase in 4 of the 6 indices from the mid-1990s to the mid-2000s noted by the reviewer is not picked up by the model is that the ENP index remained rather flat during that period and 3 of the indices showed a decline from the mid-2000s to 2010 (PCL+MML+MS GN, BLLOP and MS+MS-LA+AL LL) while the TEXAS index showed a steep increase from the mid-2000s to 2010.

ToR 3c: Is the stock undergoing overfishing? What information helps you reach this conclusion?

Issue: The reviewer was not confident about the conclusion of "no overfishing" reached in the assessment because 3 of the indices had declined in the last 5 years and because F_{msy} was low, a model with reasonable variation in recruitment could indicate a current F more similar to F_{msy} and thus the stock approaching an overfishing condition.

Response: We have already shown that the recruitment considered in the model was reasonable and thus the low current F value is too. The low value of F_{msy} is consistent with what is expected from the biology of sharks. Of the 3 indices mentioned by the reviewer that showed a decline since the mid-2000s, two actually show an increase in the terminal year, 2010 (PC+MML+MS GN and MS+MS-LA+AL LL), and of the remaining 3 indices used in the base model, one also shows an increase in 2010 (ENP) and another is almost flat (NMFSLLSE). Given this, we believe the assessment conclusion of no overfishing is warranted. This response also applies to item ToR3e.

1.2.Addressing Review of CIE reviewer S.J. Smith

The main conclusion from this reviewer was that it was hard to argue against the results of the assessment given the lack of any data pointing to a large effect of the fishery on this stock of blacktip sharks. The two major recommendations from this review for future assessment of this stock were to evaluate the usefulness of the indices of relative abundance and the impact of process errors in the model on MSY reference points.

The reviewer referred to a paper by Bousquet et al. (2008) (ToR3b) which found that deterministic estimates of MSY and F_{MSY} in a traditional Schaefer production model may defer substantially from stochastic estimates of these quantities when process error is included. The reviewer further stated that this finding may also apply to the age-structured production model used (SSASPM) in the blacktip assessment. This caveat was prompted by the lack of explanation in the assessment of how MSY and F_{MSY} were calculated, and the possibility that if these quantities had been calculated in a deterministic framework then current stock status may be less optimistic than found in the assessment.

In response to this comment, we clarify that F_{MSY} and MSY are obtained stochastically in SSASPM. While process error is not directly incorporated into the calculation of reference points, F_{MSY} is obtained at each iteration by solving for the value of F that maximizes equilibrium yield (Y), calculated as $Y=YPR(F)\cdot S(F)/\varphi(F)$ where

$$YPR(F) = \sum_{a=1}^{A-1} w_a F s_a \frac{(1-\exp(-M-Fs_a))}{(M+Fs_a)} \prod_{j=1}^{a-1} \exp(-M-Fs_j)$$

$$+ \frac{w_A F s_A}{(M+Fs_A)} \prod_{j=1}^{A-1} \exp(-M-Fs_j)$$

$$\varphi(F) = \sum_{a=1}^{A-1} \mu_a E_a \prod_{j=1}^{a-1} \exp(-M-Fs_j) + \frac{\mu_A}{(1-\exp(-M-Fs_A))} \prod_{j=1}^{A} \exp(-M-Fs_j)$$

$$\breve{S}(F) = \frac{R_0\hat{\alpha}\varphi(F) - R_0\varphi_0}{\hat{\alpha}-1} = \frac{4hR_0\varphi(F) - R_0\varphi_0(1-h)}{5h-1}$$

In the above equations, A is maximum age, w_a is weight at age, s_a is selectivity at age, μ_a is the proportion mature at age, E_a is fecundity at age, R_0 is virgin recruitment, $\hat{\alpha}$ is the maximum lifetime reproductive rate, φ_0 is unexploited spawners per recruit, h is steepness, $\breve{S}(F)$ is the equilibrium spawning biomass for a given F and $\varphi(F)$ is the lifetime production of spawners per recruit for a given F (Brooks et al. 2010).

Therefore the calculation of F_{MSY} and MSY takes into account variability in life history parameters, more specifically S_0 (survivorship of age-0s, which is part of $\hat{\alpha}$ and h) and R_0 (virgin number of recruits), both of which are given prior pdfs. The only other process error that was included in the assessment was in the annual deviations in fishing effort (Equation 14). Process error in recruitment and catchability coefficients was also included (Equation 10), but held constant (not estimated), thus it was not part of the objective function for this implementation of the model.

Literature cited

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2. Projections

This section summarizes projections conducted for the final state-spaced, age-structured production model (SSASPM) from the SEDAR 29 Gulf of Mexico blacktip shark SAR. These projections were conducted after the stock assessment workshop in response to a request made by NOAA Highly Migratory Species (HMS) staff during the stock assessment workshop and post assessment webinars (Table 2.1). Projections were conducted for the base model configuration and six alternative model configurations of SSASPM included in the SAR: 01-Base, 02-Low Productivity, 03-High Productivity, 04-Low Catch, 05-High Catch, 06-Prior on R_0, and 07-NMFS Longline (LL) Southeast (SE). The base model and the range of alternatives were considered representative of the range of alternative states of nature evaluated in the SEDAR 29 SAR (Table 3.5.19).

Projections were not requested in the terms of reference included in the SEDAR 29 SAR. As a result, this addendum responds to the terms of reference from the most recent full stock assessment for HMS sharks assessed under the SEDAR process (SEDAR 21) (e.g., NMFS 2011a, 2011b, 2011c, 2011d) which include the following:

1. "Project future stock conditions (biomass, abundance, and exploitation) and develop rebuilding schedules, if warranted. Provide the estimated generation time for each unit stock. Stock projections shall be developed in accordance with the following:
   A) If stock is overfished:
      F=0, F=Fcurrent, F=Fmsy, Ftarget (OY),
      F=Frebuild (max that rebuild in allowed time)
   B) If stock is undergoing overfishing:
      F=0, F=Fcurrent, F=Fmsy, F= Ftarget (OY),
      F=Freduce (different reductions in F that could prevent overfishing, as appropriate)
   C) If stock is neither overfished nor undergoing overfishing:
      F=Fcurrent, F=Fmsy, F=Ftarget (OY)"

The base as well as alternative model configurations of SSASPM in the SEDAR 29 SAR indicated that the GOM blacktip shark stock is most likely neither overfished nor undergoing overfishing. As a result, and in order to be consistent with the terms of reference of previous HMS shark assessments conducted under the SEDAR process, projections were conducted here for F=Fcurrent, F=Fmsy, and F=Ftarget (OY). In addition, projections were conducted for a Fixed Removals scenario in response to a specific request by NOAA HMS staff during the stock assessment workshop and post assessment webinars (Table 2.1).

2.1 Projection Methods

Projection methods followed those developed during SEDAR 21 for an age-structured catch-free model (ASCFM) for HMS dusky sharks (NMFS 2011b), except that the projection methodology was adapted to the SSASPM used for the SEDAR 29 SAR. Projections were governed with the same set of population dynamics equations as the original assessment model, but allowed for uncertainty in initial conditions at the beginning of the time series (2010) as well as in underlying productivity. Projections were run using

Monte Carlo bootstrap simulation, where initial numbers (N_{2010}^{boot}), fishing mortality (F_{2010}^{boot}), and pup survival at low biomass ($e^{-M_0}{}_{2010}^{boot}$) were sampled from a multivariate normal distribution with expectations equivalent to posterior modes from SSASPM, and standard deviations set to the posterior standard deviation (obtained numerically by rejection sampling of the "profile likelihood" posterior approximation). Covariance values were obtained from the Hessian approximation of the variance-covariance matrix at the posterior mode. The multivariate normal approximation was chosen because it reduced the probability of selecting values of the different parameters that were unlikely to have generated the data (for instance, high fishing mortality and low pup survival).

Projections were started in 2010, the first full projection year was 2011, and projections were run until the year 2040 (30 years). As a result, the projection interval included more than two generations (generation time is cf., 11.5 years; SEDAR 29 SAR, Section 3.1.7). Projections were implemented with current fishing mortality (F_{2010}^{boot}) during the first four years (2010, 2011, 2012, 2013) and then with the fishing mortality rate evaluated for the projection scenario during the remaining years (2014-2040). Projections used the same selectivity as used in SSASPM. Thus, the anticipated allocation of effort within the fishery (between fleets) was assumed to remain the same. Projected total removals due to fishing included commercial + unreported catches, recreational catches, Mexican catches, and menhaden fishery discards (e.g., SEDAR 29 SAR, Table 3.5.1B). All projections used 10,000 Monte Carlo bootstrap simulations. Moments of the bootstrap runs were summarized using quantiles, with median used for the central tendency, and 30th percentile used as the criterion for whether a projection had a 70% chance of being above anticipated MSY levels in 2040. Each projection was summarized with respect to mature spawning stock fecundity (SSF in numbers), recruitment (numbers), and landings (numbers and lbs dressed weight) relative to anticipated MSY levels. All projections were conducted with R statistical software.

The following projection scenarios were evaluated:

- *Fcurrent*: Fishing mortality constant at 2010 levels
- *Fmsy*: Fishing mortality constant at MSY levels
- *Ftarget* (OY): Fishing mortality set with pseudo P* approach (cf., Prager *et al*. 2003)
- *Fixed Removals:* Fishing mortality at a fixed level of total removals due to fishing

Most of these projection scenarios are self-explanatory, but some require more elaboration:

Fmsy projection—The *Fmsy* projection scenario was implemented by modeling fishing mortality beginning in year 2014 as

$$F_{MSY}^{boot} = F_{2010}^{boot} \times \frac{\hat{F}_{MSY}}{\hat{F}_{2010}},$$

where uncertainty was included in the estimate of fishing mortality in 2010 (F_{2010}^{boot}); $\hat{F}_{MSY}$ was the estimated fishing mortality at MSY from SSASPM, and $\hat{F}_{2010}$ was the estimated fishing mortality in the current year (2010) from SSASPM (e.g., NMFS 2011b; their section 3.1.7.).

Ftarget projection—The *Ftarget* projection scenario was implemented by modeling fishing mortality beginning in year 2014 as

$F_{target}^{boot} = c \times F_{2010}^{boot}$,

where uncertainty was included in the estimate of fishing mortality in 2010 (F_{2010}^{boot}), and *c* was the constant scalar ($F = c\hat{F}_{2010}$) which resulted in the highest fishing mortality rate F_{target} that achieved a probability of overfishing in 2010 of 0.3 (e.g., NMFS 2011b; their section 3.1.7.). To determine the highest fishing mortality rate that achieved this goal, a profile likelihood approximation to the posterior distribution for $\hat{F}_{2010}$ was obtained (defined here as $\hat{P}(F_{2010})$). The profile likelihood approximation to the posterior distribution for $\hat{F}_{2010}$ was used as an approximation of the posterior distribution for $\hat{F}_{MSY}$ defined here as $\hat{P}(F_{MSY})$ [Both a normal approximation and a profile likelihood approximation failed for the posterior distribution of $\hat{F}_{MSY}$]. To generate samples from candidate $F = c\hat{F}_{2010}$ values, distributions for projections were sampled from $\hat{P}(F_{2010})$ and then multiplied by the fixed constant *c*; in this manner, candidate *F* values were drawn from a distribution with the same shape as $\hat{P}(F_{2010})$, but with reduced variance owing to the identity $\mathrm{Var}(aX) = a^2\mathrm{Var}(X)$. The resulting distribution was defined here as $\hat{P}(F_{trial})$. An iterative solution was then found with Microsoft Excel for the highest F_{trial} value that resulted in

$$\Pr(F_{trial} \geq F_{MSY}) = \int_0^{\infty} \left[\int_{F_{trial}}^{\infty} \hat{P}(F_{trial}) dF_{trial} \right] \hat{P}(F_{MSY}) dF_{MSY} \geq 0.3 \text{ (cf., Prager et al. 2003).}$$

Projections were then conducted with R statistical software at $F_{target} = c \times \hat{F}_{2010}$ using the fixed constant *c* from the iterative solution for F_{trial} (e.g., NMFS 2011b; their Section 3.1.7.). Using this approach, F_{target} ranged from 0.018 to 0.119 and the constant *c* ranged from 2.3 to 10.4, which can be interpreted as a 2.3-fold to 10.4-fold increase in effort over that at $\hat{F}_{2010}$ (Table 2.2).

Fixed Removals—The *Fixed Removals* projection scenario was implemented by iteratively solving for an annual fishing mortality rate within the projection equations in R statistical software beginning in year 2010 and ending in year 2040 at a fixed level of removals equal to an estimate of the average total removals due to fishing during the years 2009 and 2010 (Table 2.1).

Average total removals due to fishing during the years 2009 and 2010 was estimated here as 418 mt dw (which is equal to 922,515 lb dw) from the total anticipated mortality (removals) due to fishing from commercial + unreported catches, recreational catches, Mexican catches, and menhaden fishery discards during the years 2009 and 2010 (SEDAR 29 SAR, Table 3.5.1B).

Year	Removals (mt dw)	Removals (lb dw)
2009	389	858,000
2010	448	987,031
Average (2009, 2010)	418	922,515

Projections were conducted with R statistical software with simulated fishing mortality set equal to the annual fishing mortality rates from the iterative solution.

2.2 Projection Results

Projected SSF values in the year 2040 were above anticipated MSY values in the *Fcurrent*, *Ftarget*, and *Fixed Removals* projection scenarios for all SSASPM model configurations where results were available (Figures 2.1 –2.7).

In contrast, projected SSF values in the year 2040 were below anticipated MSY values in the *Fmsy* projection scenario for the base (01-Base) and high productivity (03-High Productivity) SSASPM model configurations (Figures 2.1 and 2.3).

Projected SSF values were not available (NA) from either the *Fcurrent*, *Ftarget*, or *Fmsy* projection scenarios for the low catch (04-Low Catch) SSASPM model configuration (Figure 2.4), because these projection scenarios produced unrealistic values of SSF, recruitment, and total removals.

The results obtained from the projection scenarios should be interpreted cautiously. First, the parameter estimates of initial numbers ($\hat{N}_{2010}$), fishing mortality ($\hat{F}_{2010}$), and pup survival at low biomass ($e^{-\hat{M}_0}{}_{2010}$) obtained from the SSASPM model configurations were highly uncertain, and, as a result, the frequency distributions of 10,000 Monte Carlo bootstrap simulations sampled from the multivariate normal distribution for these parameter estimates were uninformative in some model configurations. For example, frequency distributions of initial numbers (N_{2010}^{boot}) and fishing mortality (F_{2010}^{boot}) from the base model configuration (01- Base) exhibited essentially uniform (uninformative) distributions (Figure 2.8). Second, the uncertainty in $\hat{F}_{MSY}$ used for the *Ftarget* projection scenarios was approximated here from the posterior distribution for $\hat{F}_{2010}$ [*i.e.*, both a normal approximation and a profile likelihood approximation failed for the posterior distribution of $\hat{F}_{MSY}$]. Third, because the *Fcurrent*, *Ftarget*, and *Fmsy* projection scenarios were not applied to the full range of alternative SSASPM model configurations, the results may not be representative of the range of alternative states of nature evaluated in the SEDAR 29 SAR (Table 3.5.19). Finally, the *Ftarget* projection scenario implemented here approximates a P* approach (c.f., Prager et al. 2003); however, additional research may be required to verify that the approach implemented here adequately accounts for uncertainty as outlined in more recent implementations of the P* approach (e.g., Prager *et al.* 2010).

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Table 2.1. Stock projection information requested for the Gulf of Mexico blacktip shark stock by NOAA Highly Migratory Species (HMS) staff during the stock assessment workshop and post assessment webinars.

Requested Information	Value
First projection year	2011
End projection year	2040 (30 years) (one generation is cf., 11.5 years)
First year of management based on this assessment	2014
Projection criteria	Fixed Removals (Iteratively solve for annual fishing mortality at a fixed level of total removals due to fishing)
Projection values (interim years 2011, 2012, 2013)	Average removals 2009, 2010

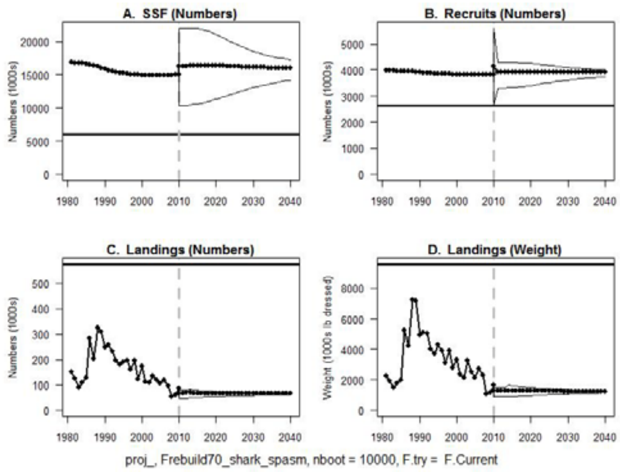
Table 2.2. Fishing mortality rates applied in the *Fmsy* ($\hat{F}_{MSY}$), *Fcurrent* ($\hat{F}_{2010}$), and *Ftarget* ($F_{target} = c \times \hat{F}_{2010}$) projection scenarios for each model configuration of SSASPM (SEDAR 29 SAR, Table 3.5.19).

SSASPM Model Configuration (Table 3.5.19)	Projection Scenario					
		Description	$\hat{F}_{MSY}$ [1]	$\hat{F}_{2010}$ [1]	c	$F_{target} = c \times \hat{F}_{2010}$
Base	01	Base	0.082	0.0062	8.0	0.050
S11	02	Low Productivity	0.021	0.0026	6.8	0.018
S12	03	High Productivity	0.154	0.0410	2.9	0.119
S9	04	Low Catch	0.069	0.0038	10.4	0.039
S10	05	High Catch	0.094	0.0110	5.2	0.058
S6	06	Prior on R_0	0.088	0.0126	5.8	0.073
S8	07	NMFS LL SE	0.107	0.0292	2.3	0.067

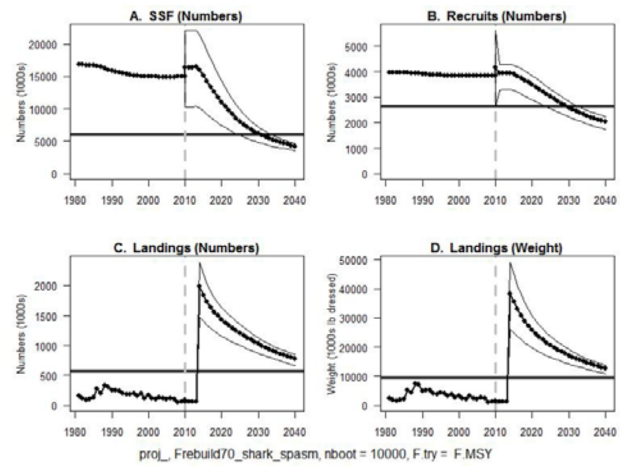
[1] $\hat{F}_{MSY}$ was the estimated fishing mortality at MSY, and $\hat{F}_{2010}$ was the estimated fishing mortality in the current year (2010) from SSASPM (e.g., NMFS 2011b; their section 3.1.7.).

Figure 2.1. Projection results for the base model configuration of SSASPM (01- Base) including SSF, recruits, and total removals due to fishing (landings) from 10,000 Monte Carlo bootstrap simulations for the *Fcurrent*, *Fmsy*, *Ftarget*, and *Fixed Removals* projection scenarios; Median (diamonds), 30^{th} percentile (lower solid line), and 70^{th} percentile (upper solid line) relative to the anticipated MSY values (heavy horizontal line).

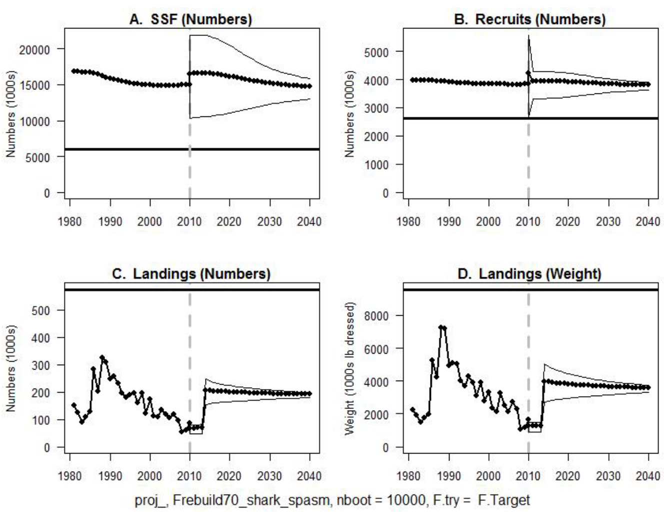
Fcurrent



Fmsy



Ftarget



Fixed Removals

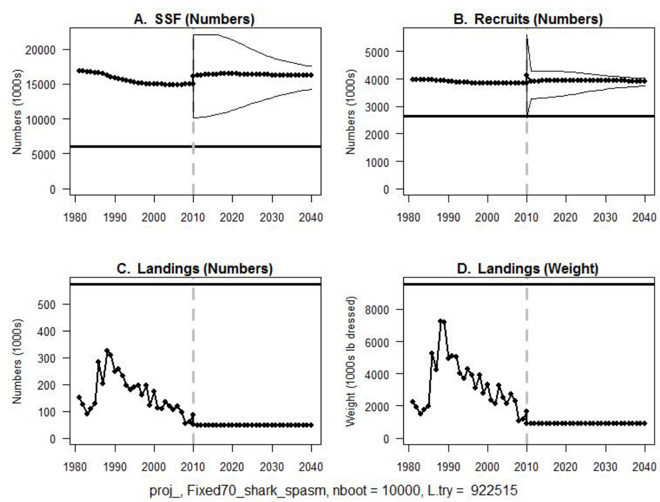


Figure 2.2. Projection results for the low productivity model configuration of SSASPM (02- Low Productivity) including SSF, recruits, and total removals due to fishing (landings) from 10,000 Monte Carlo bootstrap simulations for the *Fcurrent*, *Fmsy*, *Ftarget*, and *Fixed Removals* projection scenarios; Median (diamonds), 30th percentile (lower solid line), and 70th percentile (upper solid line) relative to the anticipated MSY values (heavy horizontal line).

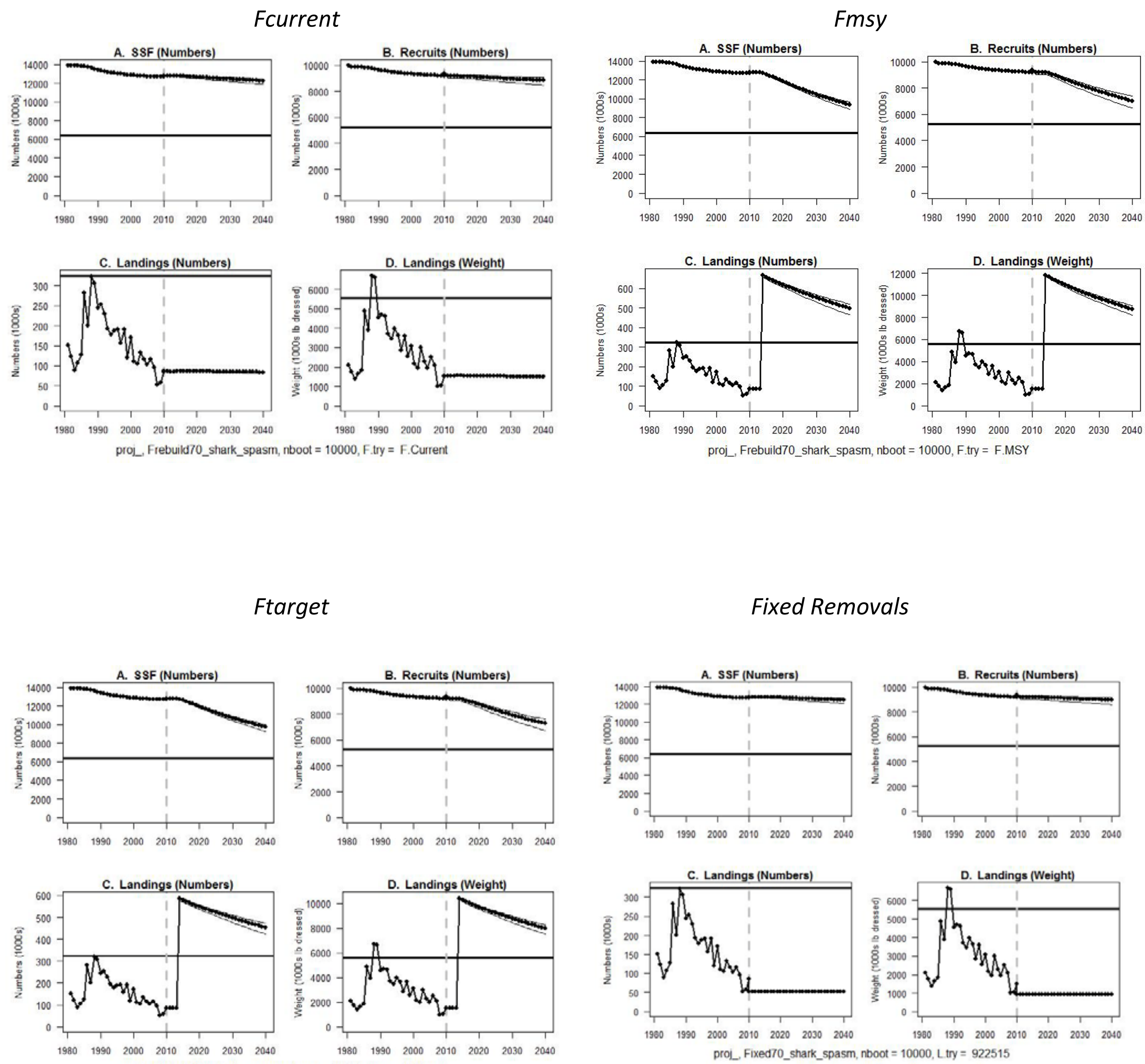
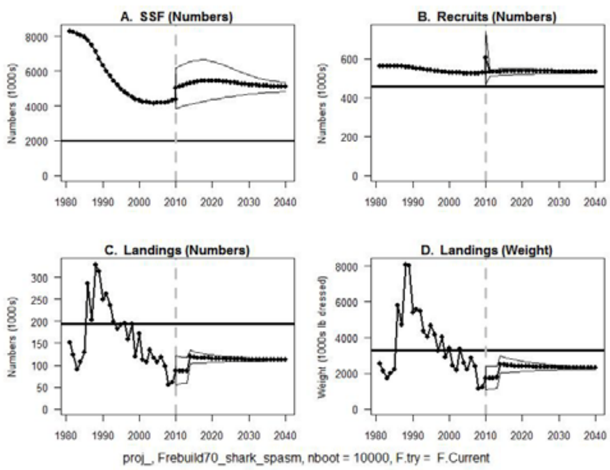
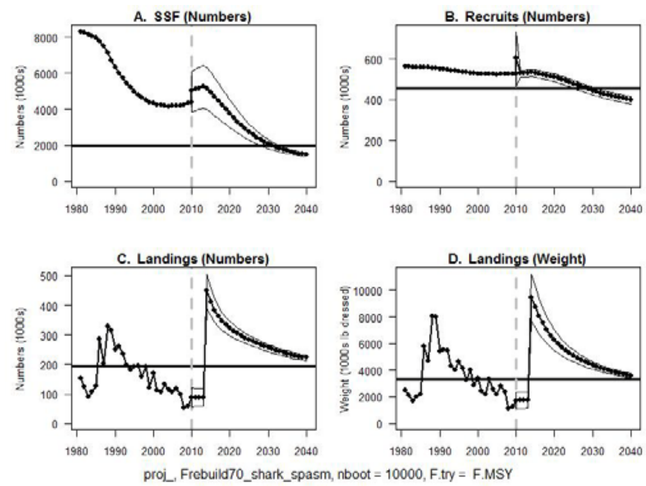


Figure 2.3. Projection results for the high productivity model configuration of SSASPM (03-High Productivity) including SSF, recruits, and total removals due to fishing (landings) from 10,000 Monte Carlo bootstrap simulations for the *Fcurrent*, *Fmsy*, *Ftarget*, and *Fixed Removals* projection scenarios; Median (diamonds), 30th percentile (lower solid line), and 70th percentile (upper solid line) relative to the anticipated MSY values (heavy horizontal line).

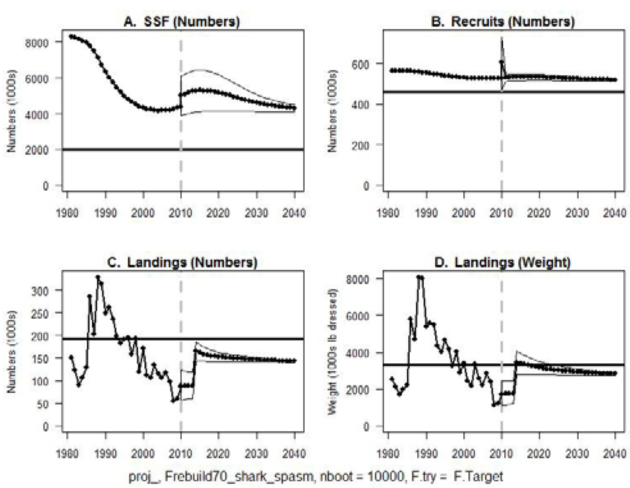
Fcurrent



Fmsy



Ftarget



Fixed Removals

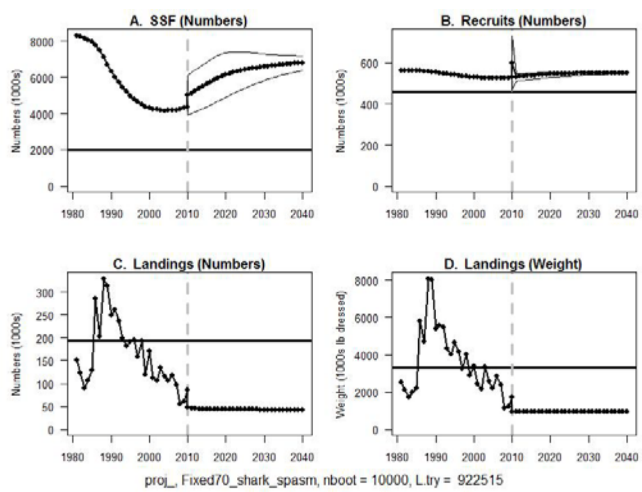


Figure 2.4. Projection results for the low catch model configuration of SSASPM (04-Low Catch) including SSF, recruits, and total removals due to fishing (landings) from 10,000 Monte Carlo bootstrap simulations for the *Fcurrent*, *Fmsy, Ftarget,* and *Fixed Removals* projection scenarios; Median (diamonds), 30th percentile (lower solid line), and 70th percentile (upper solid line) relative to the anticipated MSY values (heavy horizontal line).

Fcurrent

NA

Fmsy

NA

Ftarget

NA

Fixed Removals

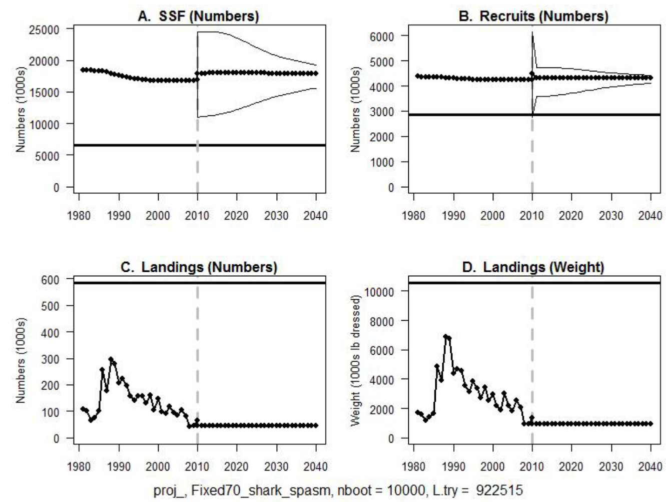
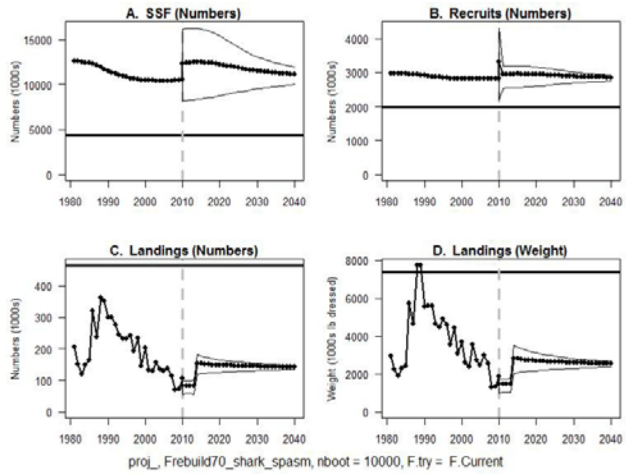
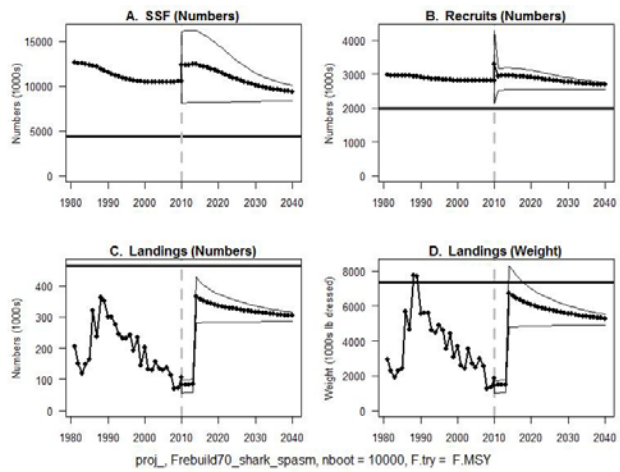


Figure 2.5. Projection results for the high catch model configuration of SSASPM (05-High Catch) including SSF, recruits, and total removals due to fishing (landings) from 10,000 Monte Carlo bootstrap simulations for the *Fcurrent*, *Fmsy, Ftarget,* and *Fixed Removals* projection scenarios; Median (diamonds), 30th percentile (lower solid line), and 70th percentile (upper solid line) relative to the anticipated MSY values (heavy horizontal line).

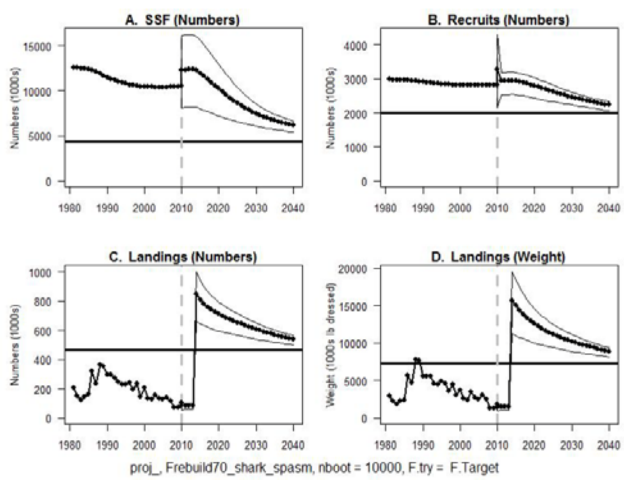
Fcurrent



Fmsy



Ftarget



Fixed Removals

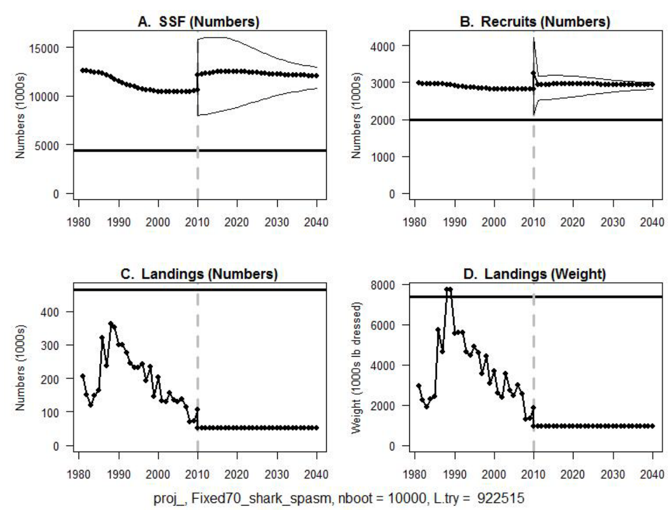
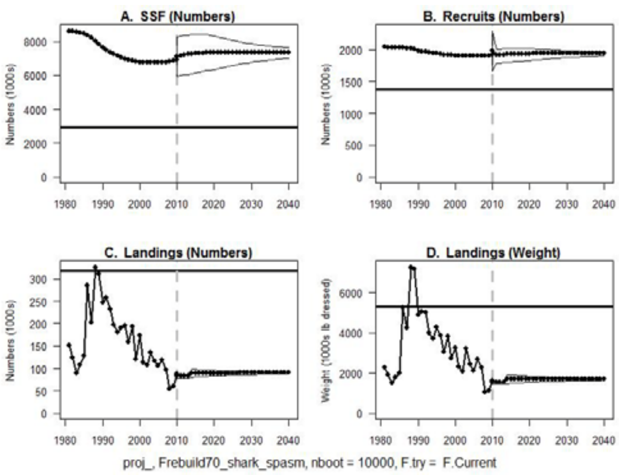
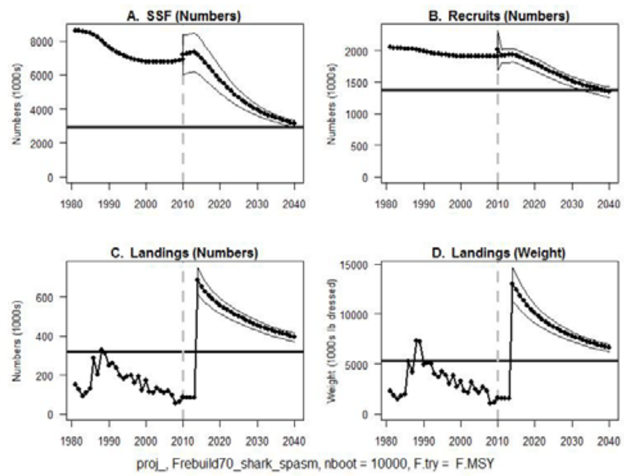


Figure 2.6 Projection results for the prior on R_0 model configuration of SSASPM (06-Prior on R_0) including SSF, recruits, and total removals due to fishing (landings) from 10,000 Monte Carlo bootstrap simulations for the *Fcurrent*, *Fmsy, Ftarget,* and *Fixed Removals* projection scenarios; Median (diamonds), 30^{th} percentile (lower solid line), and 70^{th} percentile (upper solid line) relative to the anticipated MSY values (heavy horizontal line).

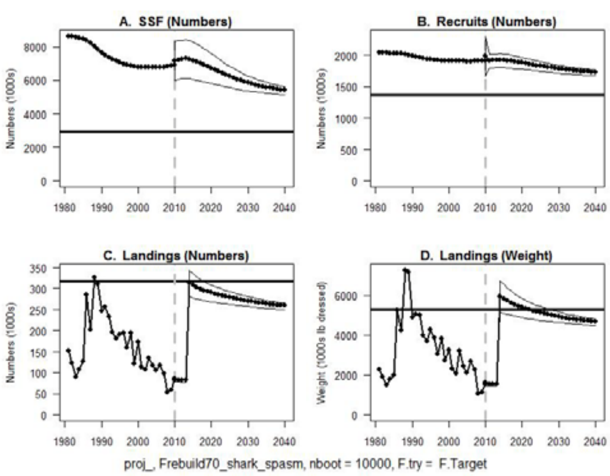
Fcurrent



Fmsy



Ftarget



Fixed Removals

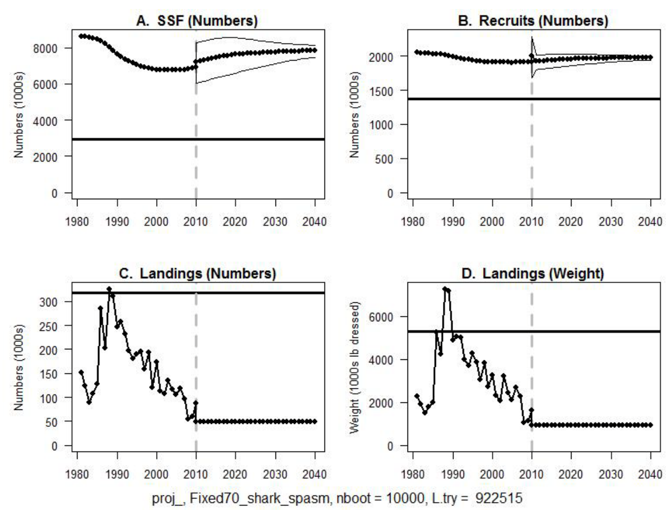
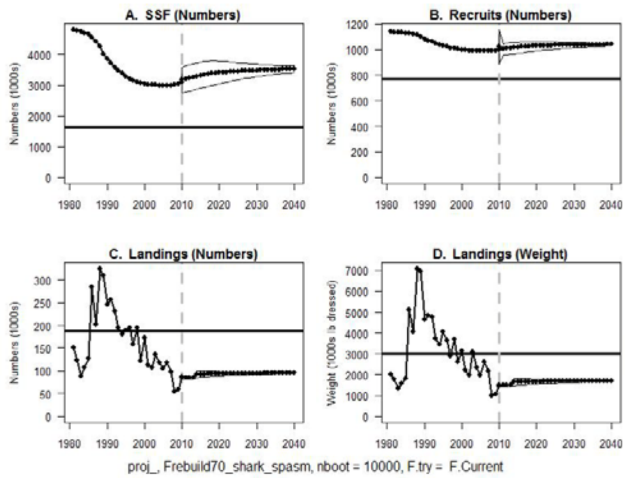
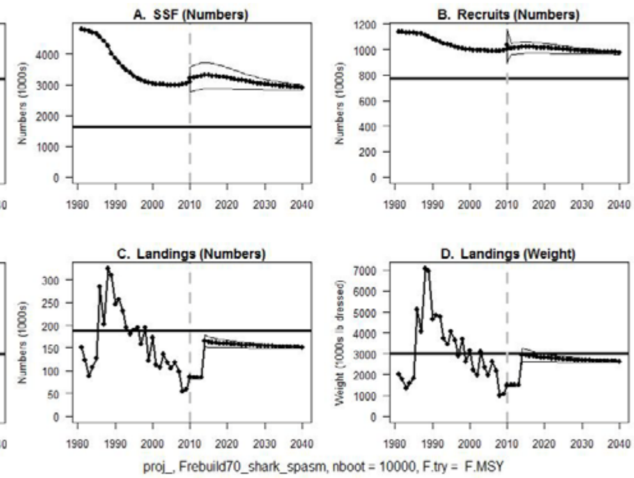


Figure 2.7. Projection results for the NMFS LL SE model configuration of SSASPM (07-NMFS LL SE) including SSF, recruits, and total removals due to fishing (landings) from 10,000 Monte Carlo bootstrap simulations for the *Fcurrent*, *Fmsy, Ftarget,* and *Fixed Removals* projection scenarios; Median (diamonds), 30th percentile (lower solid line), and 70th percentile (upper solid line) relative to the anticipated MSY values (heavy horizontal line).

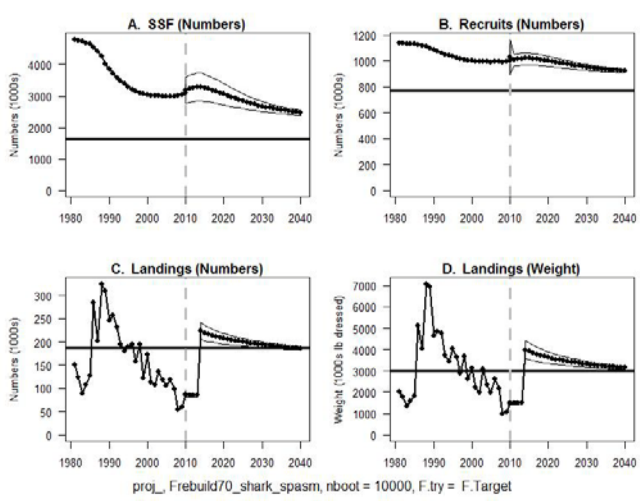
Fcurrent



Fmsy



Ftarget



Fixed Removals

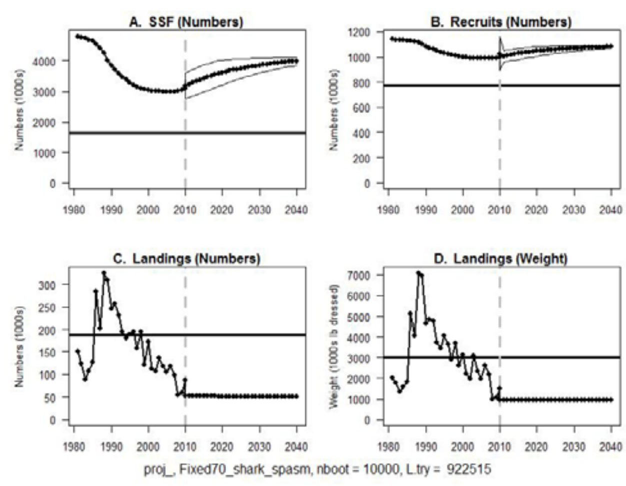


Figure 2.8. Frequency distributions from 10,000 Monte Carlo bootstrap simulations (random draws) from a multivariate normal distribution of initial numbers (N_{2010}^{boot}), fishing mortality (F_{2010}^{boot}), and pup survival at low biomass ($e^{-M_0}{}_{2010}^{boot}$) for the base SSASPM model configuration (01- Base) along with the corresponding parameter estimates from SSASPM (dashed lines) and the medians of the 10,000 Monte Carlo bootstrap simulations for each parameter (solid lines) used for projections in the *Fcurrent*, *Fmsy*, and *Ftarget* projection scenarios.