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Attachment 1
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Evaluating alternative rebuilding strategies to meet management goals for rebuilding overfished U.S. West Coast groundfish stocks

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Introduction

Federal fisheries within the U.S. are mandated by the Magnuson-Stevens Fishery Conservation and Management Act (MSA) and the Sustainable Fisheries Act (SFA) to be managed in a sustainable manner that optimizes yield, while preventing overfishing, rebuilding overfished stocks to target levels, and preventing stocks from falling into overfished states (to the extent that is possible). Fishery managers are required to set sustainable target stock abundances to manage to, along with stock abundance limits below which the stock would be determined to be overfished. Overfished stocks are required to be rebuilt to the target stock size within 10 years, except in cases when life-history or environmental conditions prevent rebuilding within that timeframe (SFA 1996).

The U.S. west coast has a high diversity of groundfish life-history characteristics, ranging from shorter-lived flatfish species to long-lived rockfish species that can live 100+ years. The Pacific Fishery Management Council (PFMC) is tasked with managing the diverse federal fisheries off the U.S. west coast. The groundfish fishery management plan (FMP) includes 90+ species (PFMC 2011) that are primarily comprised of flatfish, roundfish, and rockfish species. Currently, seven stocks within the West Coast groundfish FMP are declared overfished (PFMC 2014a). The SFA mandates that a rebuilding plan be implemented for each of these overfished stocks, allowing for recovery to the level of spawning biomass that results in maximum sustainable yield (B_{MSY}).

The National Marine Fisheries Service provided guidelines for rebuilding overfished stocks (Federal Register 1998). A rebuilding plan is required to define the following components for rebuilding; the target year for rebuilding (T_{TARGET}), the minimum amount of time that would allow rebuilding in the absence of fishing (T_{MIN}), and the maximum amount of time allowed for rebuilding the stock (T_{MAX}). The guidelines dictate that if T_{MIN} is less than 10 years, then the stock must be rebuilt within 10 years (e.g. $T_{\mathrm{MAX}} \leq 10$ years), but if the stock is unable to rebuild within 10 years (e.g. $T_{\mathrm{MIN}} > 10$ years) then the upper limit for rebuilding (T_{MAX}) may not be more than T_{MIN} plus one mean generation time. The target year for rebuilding (T_{TARGET}) must fall between T_{MIN} and T_{MAX}.

Projections are conducted based on a range of fishing mortality rates expressed in terms of Spawning Potential Ratios (SPR) to determine a T_{TARGET} for rebuilding which reflects a probability of rebuilding (P_{INIT}) by T_{MAX}. The probability value for the rebuilding plan is selected by the PFMC. However, the value should be ≥ 0.50, indicating a selected SPR value that would result in at least a 50% probability of rebuilding by T_{TARGET}. The results from the projections over a range of harvest rates and realized stock dynamics (process error modeled using recruitment deviations, although other sources of uncertainty could be considered) represent a “rebuilding analysis”. The rebuilding analysis provides the scientific guidance for the targets and the harvest rates for the rebuilding plan.

During rebuilding managers generally prefer a strategy allowing for minimal revisions to the rebuilding plan (for ease of application), while still meeting the rebuilding targets. Continuity between rebuilding analyses also allows fishery stakeholders to plan accordingly during the rebuilding period. Punt and Ralston (2007) conducted a Management Strategy Evaluation (MSE) that evaluated the performance of several alternative Rebuilding Revision Rules, the method for assessing rebuilding progress and guideline for adjusting rebuilding plans based upon changes in stock status. While this analysis was useful for managers, it evaluated rebuilding only for overfished rockfish. This work provides an updated MSE that considers some of the life-history types that are encountered on the West Coast. Four alternative rebuilding strategies are presented here (which include the current status quo rebuilding approach) along with model runs that explore sensitivity to specific assumptions. The performance of each strategy was evaluated relative to the goals of rebuilding the stock with minimal changes during the rebuilding period, of rebuilding by T_{MAX}, and the average catch obtained over a fixed portion of the rebuilding period.

Materials and Methods

General approach

Four life-history types that are common to U.S. west coast groundfish were simulated; a short-lived flatfish, a short-lived roundfish, a medium-lived rockfish and a long-lived rockfish (Table 1). Each simulated population was modeled using an age-structured model. An annual index of abundance was observed with error, and age composition data were collected for selected years, and used to estimate population size and catch. If a stock was estimated to be below the corresponding Minimum Stock Size Threshold (MSST) as defined given its life-history for the first time (not currently under a rebuilding plan), the estimated catch was modified to reflect a rebuilding plan which estimates an SPR rate that results in a probability of recovery at a specific future point in time. The catches were then applied to the simulated stock. The data generation, catch estimation and stock updating were conducted in an iterative fashion for a specified number of years based on life-history that would allow for recovery to target biomass levels under a variety of conditions (flatfish and roundfish, 50 years; medium-lived rockfish, 75 years; long-lived rockfish, 125 years) (Fig. 1).

The operating model

The numbers-at-age at the start of the year are computed as:

$$N_{t+1,\gamma,a} = \begin{cases} 0.5R_t & \text{if } a = 1 \\ N_{t,\gamma,a-1} e^{-\left(M_\gamma + S_{\gamma,a} F_t\right)} & \text{if } 1 \le a < A-1 \\ N_{t,\gamma,A-1} e^{-\left(M_\gamma + S_{\gamma,A-1} F_t\right)} + N_{t,\gamma,A} e^{-\left(M_\gamma + S_{\gamma,A} F_t\right)} & \text{if } a = A \end{cases} \tag{1}$$

where $N_{t+1,\gamma,a}$ is the number of fish of gender γ and age *a* for year *t*, R_t is the number of age-0 animals at the start of year *t*, $S_{\gamma,a}$ is the selectivity by gender and age, *A* is the plus group, F_t is the instantaneous fishing mortality rate during year *t*, and M_γ is the instantaneous rate of natural mortality of gender γ.

The number of age-0 fish is related to spawning biomass according to the Beverton-Holt stock recruitment relationship:

$$R_t = \frac{4hR_0 SB_t}{SB_0\left(1-h\right) + SB_t\left(5h-1\right)} e^{-0.5\sigma_R^2 + \tilde{R}_t} \qquad \tilde{R}_t \sim N\left(0;\sigma_R^2\right) \tag{2}$$

where SB_t is the spawning biomass at the start of the spawning season in year *t*, σ_R is the standard deviation of recruitment in log space, and *h* is the recruitment compensation (also known as steepness).

A non-equilibrium starting condition was created by applying equations (1) and (2) for the number of years equal to the maximum age for each life-history prior to the start of fishing with variation in recruitment and $F = 0$. The initial period of the fishery operated for 50 years, with the catch of fish of gender γ and age a during year t in numbers determined by:

$$C_{t,\gamma,a} = \frac{S_{\gamma,a} F_t}{M_\gamma + S_{\gamma,a} F_t} N_{t,\gamma,a} \left(1 - e^{-M_\gamma - S_{\gamma,a} F_t}\right) \quad (3)$$

A linearly increasing historical (years 1-50) fishing mortality was applied such that the populations were in an overfished state, based on the corresponding PFMC minimum biomass threshold levels for each life-history type, at the time of the first assessment in year 50. The depletion levels for each of the life-histories in year 50 are given in Table 1.

Each population was assessed for the first time at the start of year 50. An annual survey index of abundance and age-composition data (N = 100) from the survey and the fishery were available for 20 years prior to the first assessment and catches were known without error for all years. The relative stock size was estimated and the resulting catches (determined by the estimation method or the rebuilding plan depending upon the estimated stock status) were removed from the population, and an index of abundance along with age composition data were generated until the next assessment.

The estimation method

Stock Synthesis (SS) (Methot and Wetzel 2013), an integrated statistical catch-at-age model, was applied to assess the simulated stocks. Growth, natural mortality, and steepness of the Beverton-Holt stock recruit relationship in each assessment were taken from the simulation model (i.e. known without error). R_0, annual recruitment deviations, initial age-structure deviations, and the selectivity parameters for both the survey and the fishery were estimated. The relative stock status and the forecasted catches were also estimated according to the West Coast groundfish harvest control rule (rockfish and roundfish 40-10; flatfish 25-5).

Based on the estimated relative stock status, one of a possible three actions was performed; 1) if the relative stock status was estimated to be below the MSST as defined by the PFMC by life-history type (flatfish 0.125; rockfish and roundfish 0.25) for the first time, a rebuilding analysis was performed which defined the initial rebuilding plan for the stock, setting a rebuilding harvest level associated with the pre-defined probability of rebuilding by a target year, 2) if the stock was already under a rebuilding plan and estimated to not yet be rebuilt, a rebuilding analysis was conducted to evaluate the current probability of rebuilding by a pre-specified year, or 3) if the stock was under a rebuilding plan and the relative stock status was estimated above the biomass target level, the stock was declared rebuilt and catches were determined by SS under the default harvest control rule.

Data generation

The observation model was used to generate an index of abundance. The expected biomass available for observation during each year t is:

$$\tilde{B}_t = \sum_\gamma \sum_{a=1}^{A} w_{\gamma,\mathrm{a}} S_{s,\gamma,\mathrm{a}} N_{t,\gamma,a} e^{-0.5\left(M_\gamma + S_{f,\gamma,a} F_t\right)} \quad (4)$$

where $w_{\gamma,a}$ is the average weight by sex at age *a*, and $S_{s,\gamma,a}$ is the selectivity for the survey or fishery (*f* fishery and *s* survey) by sex and age *a*. The observed survey biomass is related to the available population according to:

$$I_t = Q\tilde{B}_t e^{\varepsilon_t^s - \frac{\sigma_s^2}{2}} \quad \varepsilon_t^s \sim N\left(0, \sigma_s^2\right) \tag{5}$$

where Q is the catchability coefficient for the survey (equal to 1), and σ_s is the standard deviation of the survey catchability in log space (see Table 1). The observed age composition data for the fishery and survey catch were assumed to be multinomially distributed and were sampled without error.

Rebuilding Analyses

The approach to rebuilding analyses can vary by region (National Research Council 2013). The process implemented here was based on the current practice for rebuilding plans and analyses for U.S west coast groundfish initially described by Punt and Ralston (2007):

1. The virgin biomass level, B_0, was calculated by multiplying the virgin recruitment (R_0) from the assessment.

2. Future recruitment was generated based using a Beverton-Holt stock-recruitment relationship.

3. The minimum time to rebuild (T_{MIN}) to the management target relative stock size with pre-defined probability of recovery (P_{INIT}) in the absence of fishing was determined by projecting forward the population from the estimated age-structure from the year the stock was declared overfished 100 times. T_{MIN} was defined as the year the median of the distribution for the relative stock size was greater than the management target (flatfish: $0.25B_0$, rockfish and roundfish: $0.40\ B_0$).

4. The maximum time to rebuild (T_{MAX}) was defined relative to T_{MIN}. If T_{MIN} was less 10 years then T_{MAX} equals 10 years. However, if T_{MIN} was great than 10 years then T_{MAX} was defined as T_{MIN} plus one mean generation.

5. The target year to rebuild (T_{TARGET}) was determined by a pre-specified probability (P_{INIT}) of recovery based on projecting the population forward 100 times with alternative SPR values from the age-structure of the population from the current year.

The first time a stock was estimated to be below the MSST, the stock was declared overfished and a rebuilding analysis was performed. The initial rebuilding analysis determined the parameters for the Rebuilding Plan (T_{MIN}, T_{MAX}, T_{TARGET}, and SPR harvest rate). The subsequent year's catches were determined by the SPR value that corresponded with the selected probability of recovery by T_{MAX}. The simulated stock was then projected forward for a set number of years, reassessed, and if the stock was estimated to not be rebuilt, a new rebuilding analysis was performed (Fig 2).

The subsequent rebuilding analysis evaluated four questions; 1) would the stock rebuild by T_{TARGET} with a probability greater than a pre-specified minimum probability by applying the

Rebuilding Plan SPR harvest rate, 2) if no, was there a SPR harvest rate that would result in rebuilding by T_{TARGET}, 3) if no, was the stock able to rebuild if T_{TARGET} was changed to equal T_{MAX} with any SPR harvest rate, and 4) if there was an SPR harvest rate that met one of the above conditions, was the resulting catch greater than 50% of the previous year's catch? When none of the first three criteria could be met, or when the fourth criterion was not met, the Rebuilding Plan was determined to be insufficient to rebuild the stock and the Rebuilding Plan was 'rebooted' were a new analysis estimated new T_{MIN}, T_{MAX}, T_{TARGET}, and SPR harvest rate values. Additionally, the SPR harvest rate was not allowed to decrease (representing a more aggressive harvest strategy) between analyses and the potential reboots.

Rebuilding revision rules

The value for the probability of recovery by T_{TARGET} is selected by the PFMC. The current guideline from the council is that the initial rebuilding plan will select an SPR harvest rate that results in probability of recovery by $T_{TARGET} \geq 50\%$ (P_{INIT}, although it has often been set much higher [PFMC 2014b]). The subsequent rebuilding analyses conducted during rebuilding evaluate whether the current SPR harvest rate is predicted to result in at least a 50% probability (P_{TARGET}) of rebuilding by T_{TARGET}. If the probability of recovery to T_{TARGET} with the current SPR harvest rate falls below 50%, the current council guidelines require that the SPR harvest rate be adjusted to a value that corresponds to a 50% probability of recovery. This work evaluated alternative threshold probability values for rebuilding revisions (See *Alternative Rebuilding Rules*).

Alternative Rebuilding Rules

The following scenarios were simulated to examine the performance of alternative rebuilding rules:

1. "Status Quo" – The status quo scenario assumed the current rebuilding rules as applied by the PFMC for rebuilding West Coast groundfish stocks. The initial rebuilding plan SPR harvest rate determined based on the calculated T_{TARGET} given P_{INIT} = 0.60 for rebuilding and the estimated SPR harvest rate was adjusted in the subsequent analyses while the stock was rebuilding if the probability of rebuilding fell below 0.50 (P_{TARGET}). The stock was projected 4 years, assessed and if the stock was still below B_{MSY} a new rebuilding analysis was performed. Depending upon rebuilding progress predicted catches could change substantially between analyses. The lower and upper limits of the change to catches were 50% and 120% of the previous analyses' last catch. This was done by either lowering the future catches produced by the new rebuilding analyses when predicted catches exceeded the upper bound or changing the T_{TARGET} to T_{MAX} or 'rebooting' the rebuilding plan (calculate new T_{TARGET} and T_{MAX}) when the lower bound was not met.

2. "Flexible Rebuilding" – The initial rebuilding plan SPR harvest rate determined based on the calculated T_{TARGET} given P_{INIT} = 0.60. The estimated SPR harvest rate was adjusted (upwards) in the subsequent analyses to a SPR harvest rate that would rebuild by T_{TARGET} given a P_{TARGET} = 0.50 if the probability of rebuilding fell below 0.40 (P_{TARGET}).

3. "Risk Averse Rebuilding" – The initial rebuilding plan SPR harvest rate was determined based on P_{INIT} = 0.75 for rebuilding by T_{MAX}. The estimated SPR harvest rate was adjusted (upwards) in the subsequent analyses to a SPR harvest rate that would rebuild by T_{TARGET} give a P_{TARGET} = 0.60 if the probability of rebuilding fell below 0.60 (P_{TARGET}).

4. "Fixed Rebuilding" – The initial rebuilding plan SPR harvest rate was determined based on P_{INIT} = 0.60 for rebuilding by T_{TMAX}. The SPR harvest rate was not updated while the stock was under rebuilding prior to T_{TARGET}. If the stock had failed to rebuild by T_{TARGET} the SPR harvest rate was set equal to either 75% of the SPR_{PROXY} value (flatfish: $SPR_{30\%}$, roundfish and rockfish: $SPR_{50\%}$) or remained at the rebuilding SPR harvest rate depending on which value was higher until the stock rebuilt.

Sensitivities

A number of alternative sensitivities were performed to evaluate the performance rebuilding strategies to specific assumptions. All scenarios below retain the specifications of the "Status Quo" scenario (except the 2.a "Flexible Rebuilding –Assessment Frequency" scenario), except for the listed revisions:

1.a "Natural Mortality" – The natural mortality rate was misspecified in the first assessment and for subsequent assessment years that were less than half the estimated time to rebuild the stock determined by the initial rebuilding plan. The natural mortality rate was set to 10% higher than the true value. The natural mortality value was updated to the true value for assessments that occurred after half of the timeframe to the T_{TARGET} estimated by the initial rebuilding plan.

1.b "Steepness" – The steepness parameter was misspecified in the first assessment and for subsequent assessment years that were less than half the estimated time to rebuild the stock determined by the initial rebuilding plan. The steepness parameter was set to 10% higher than the true value. The steepness parameter was updated to the true operating model value for assessments that occurred after half of the timeframe to the T_{TARGET} estimated by the initial rebuilding plan.

1.c "Underestimation of Historical Catch" – The historical catch prior to the stock being declared overfished was underestimated. The assessment method assumed only 80% of the true removals of the historical catch for years 1-49 for the entire rebuilding period. All catches during rebuilding were known without error.

1.d "No Rebuilding Catch Restrictions" – The limitations applied to the upward or downward change in catches between rebuilding plans were eliminated. The catch was set equal to the amount set by the rebuilding analyses.

1.e "Status Quo – Assessment Frequency" - The initial rebuilding plan SPR harvest rate determined based on P_{INIT} = 0.60 for rebuilding by T_{MAX}. The estimated SPR harvest rate was adjusted (upwards) in the subsequent analyses to a SPR harvest rate that would rebuild by T_{TARGET} give a P_{TARGET} = 0.50 if the probability of rebuilding fell below 0.50 (P_{TARGET}). The stock was projected either 2 or 8 years (2; flatfish and roundfish, 8; medium-lived rockfish and long-lived rockfish), assessed, and if the stock was still overfished, a new rebuilding analysis performed

2.a "Flexible Rebuilding – Assessment Frequency" – The initial rebuilding plan SPR harvest rate determined based on P_{INIT} = 0.60 for rebuilding by T_{MAX}. The estimated SPR harvest rate was adjusted (upwards) in the subsequent analyses to a SPR harvest rate that would rebuild by T_{TARGET} give a P_{TARGET} = 0.50 if the probability of rebuilding fell below 0.40 (P_{TARGET}). The stock was projected either 2 or 8 years (2; flatfish and roundfish, 8; medium-lived rockfish and long-lived rockfish), assessed, and if the stock was still overfished, a new rebuilding analysis performed

Performance measures

The following seven performance metrics were used to evaluate each alternative rebuilding strategy:

1. The number of SPR harvest rate changes during rebuilding,
2. The number of times the T_{TARGET} value was changed,
3. The number of times a rebuilding plan failed to recover the stock, requiring a new rebuilding plan (termed "reboot"),
4. A measure of the variability of the catches (abbreviation AAV), defined as:

$$AAV = 100\frac{\sum_y |C_y - C_{y+1}|}{\sum_y C_y} \qquad (6)$$

   where C_y is the catch during year *y*,

5. The average catch during a set number of years when the resource was under a rebuilding plan (flatfish 5, roundfish 10, medium-lived rockfish 25, and long-lived rockfish 50 years),
6. The "rebuilding ratio", the ratio of the number of years before the stock was assessed to be rebuilt divided by the number of years that it was expected that rebuilding would take place by the original rebuilding plan, and
7. The relative error about the number of years to rebuild the stock and the rebuilding ratio. The relative error was calculated as:

$$\text{RE} = \frac{E - T}{T} \qquad (7)$$

   where *E* is the estimated number of years to rebuild the stock from the assessment model and *T* is the true number of years it took the stock to rebuild the population based on the operating model. The relative error of the rebuilding ratio was calculated in a similar fashion using the estimated rebuilding ratio relative to the true rebuilding ratio from the operating model.

Results

Each of the four rebuilding strategies evaluated led to rebuilt stocks for all life-histories (Fig. 3-10). However, there were differences observed in the performance metrics across the strategies by life-history type. The performance metrics for the Status Quo and the Flexible rebuilding strategy were nearly identical for the flatfish and roundfish life-histories (Tables 2-5). The shorter rebuilding times based upon the faster dynamics of each of these life-histories allowed only limited frequency of the lower P_{TARGET} associated with the Flexible strategy being applied. However, the slower dynamics and longer rebuilding periods associated with rockfishes led to differences in results between the Status Quo and the Flexible rebuilding strategies (Tables 6-9). Implementing a lower threshold P_{TARGET} resulted in fewer SPR updates during rebuilding for the two rockfishes (median SPR changes - Status Quo: 3, Flexible: 1). The average catch across simulations did not vary greatly between strategies and the Status Quo and Flexible rebuilding strategies resulted in nearly identical rebuilding times for the medium- and long-lived rockfish life-histories.

The Risk Averse rebuilding strategy resulted in approximately a 10% faster rebuilding time relative to the Status Quo strategy for each of the life-history types (Tables 2-9). However, the average catch over the fixed period for each life-history was approximately 10% lower than the average catches from the Status Quo rebuilding strategy. The higher P_{TARGET} value resulted in an increased number of SPR changes for both the rockfish life-histories, but did not result in a median increase in the number of SPR changes for the flatfish or roundfish life-histories for the Risk Averse strategy.

The Fixed rebuilding strategy resulted in a slightly lower average catch but stocks rebuilt quicker relative to the Status Quo strategy for the rockfish and the roundfish life-histories (Tables 4-9). Across life-histories, the Fixed rebuilding strategy, rebuilt the stock by T_{TARGET} or earlier in the majority of simulations, with only 7% (flatfish), 27% (roundfish), 18% (medium-lived rockfish), and 3% (long-lived rockfish) of the simulations requiring adjustments to the SPR harvest rate due to not rebuilding by the initial target year.

The sensitivity runs that examined assessment frequency for the Status Quo and the Flexible rebuilding strategy resulted in similar median rebuilding times with either the same or fewer changes to the SPR harvest rate during rebuilding relative to the base strategies (Status Quo or Flexible, with assessments every 4^{th} year) for the medium- and long-lived rockfish life-histories (Tables 6-9). Reducing the frequency of assessment for the rockfishes from every 4^{th} to 8^{th} year also resulted in a higher average catch for the first 25 years of rebuilding for the medium-lived rockfish. However, increasing the assessment frequency for the fast dynamic life-histories (flatfish and roundfish) from every 4^{th} to every 2^{nd} year resulted in lower average catches during rebuilding with a larger range of SPR changes, and did not rebuild in shorter periods relative to each of the base strategies (Tables 2-5).

Both sensitivities that examined the impact of parameter misspecification, natural mortality (Error in M) and steepness (Error in h), resulted in an increase in the median times the SPR harvest rate needed to be changed to attempt to rebuild by T_{TARGET} for all life-histories relative to the Status Quo strategy (Tables 2, 4, 6, and 8). Across life-histories each of these sensitivities resulted in rebuilding plans that on average required adjustments to T_{TARGET}, and ultimately a median behavior of failing to rebuild the stock by T_{MAX} (Tables 2, 4, 6, and 8). However, the median time to rebuild did not differ greatly from the Status Quo median times (Tables 3, 5, 7, and 9). This unexpected result occurred due to the constraint preventing a decrease in the SPR harvest rate (an increase in harvest) between the failed and the new rebuilding plans. This constraint ensured that although the stock was allowed to have an extended period to rebuild the harvest could not increase, and led to similar rebuilding times relative to the Status Quo strategy.

Underestimating historical catch (Error in Historical Catch) resulted in negatively biased estimates of SB_0 and spawning biomass for all life-histories (Figs 3, 5, 7, and 9). The assessment method estimated lower stock sizes given the underestimated removals from the stock in order to fit the index of abundance used to inform relative stock status. The underestimation of SB_0 impacted the rebuilding plan projections, resulting in lower average harvest during rebuilding relative to the Status Quo strategy (Tables 2, 4, 6, and 8). Also, the negatively biased estimates of

SB_0 resulted in underestimation of the harvest at the proxy reference points by life-history which led to an under-utilization of the simulated stocks once rebuilt (Figs 3, 5, 7, and 9).

Removing the catch constraints (catch cannot increase by more than 120% or reduced by greater than 50% between rebuilding analyses) imposed on the Status Quo strategy did not generally impact the results across all life-histories (Table 2-9).

Discussions with advisory groups

The life-history types, the alternative rebuilding strategies, and sensitivities have been developed based upon multiple discussions with the Groundfish Management Team (GMT). The initial results were presented to the GMT in February 2015.

Presented and received feedback from the Groundfish Advisory Panel (GAP) and the Scientific and Statistical Committee (SSC) at the April 2015 council meeting in Rohnert Park, California. The following suggestions were made by the SSC:

- *The fixed rebuilding plan alternative is similar to the guidance on revising rebuilding plans in the draft National Standard One (NS1) guidelines (Agenda Item F.2, Attachment 1). The NS1 guidelines recommend changing to the maximum of rebuild fishing mortality and 75% of F_{MSY} (or its proxy) if the stock has not rebuilt by T_{target}, while the fixed rebuilding plan alternative increases the SPR by 25% in the same situation. This alternative should use the NS1 guidelines approach except that the harvest rate should be held constant if 75% of F_{MSY} is a higher harvest rate than the rebuilding SPR rate. The draft NS1 guidelines should be checked to evaluate whether other alternatives could be usefully added to MSE.*
  Response: The fixed rebuilding strategy was updated to match this suggestion.

- *Consider adding an alternative that decouples the timing for stock assessments and revising rebuilding plans. One possibility is a fixed, but infrequent, schedule for application of the rebuilding revision rules (an example is 16 years or ½ of T_{target} whichever is smaller) along with more frequent assessments.*
  Response: Due to time constraints this alternative to the fixed rebuilding plan has not been simulated at this point.

- *Provide an alternative that evaluates sensitivity to an incorrect value of stock-recruit steepness.*
  Response: A sensitivity run where steepness was misspecified for half of the rebuilding period has been conducted.

- *Currently there is constraint that catches cannot increase by more than 1.2 x current catch, or decrease by more than 0.5 x current catch. Sensitivity to this constraint should be evaluated. For example, drop the constraints altogether or constrain the catch to be no greater than the ABC.*
  Response: A sensitivity run that eliminates the constraints for changing catches between rebuilding analyses has been conducted.

- *Develop a graphic that depicts the hierarchical process whereby rebuilding plan parameters are adjusted to improve rebuilding probabilities (i.e., first SPR is adjusted, then T_{target} is adjusted, and finally the entire rebuilding plan is reset).*

Response: This has been done and is given in Figure 2.

- *Add spawning biomass plots to the figures for each alternative. Include both median and 95% simulation intervals as well as plots of individual simulations.*
  Response: The "true" spawning biomass has been plot for each alternative rebuilding strategy and sensitivity for each life-history.

- *Develop plots that summarize the standardized error rate, (estimated – true)/true.*
  Response: The standardized error rate (aka relative error) has been calculated for the rebuilding ratios and the time for rebuilding.

- *Develop a plot that displays results for multiple alternatives in a single plot, such as a Zeh plot (multiple box and whisker plots) or violin plot. Generally for these kinds of displays, provide results in one plot for rebuilding plan revision alternatives, and results in another plot for scenarios that evaluate sensitivity to parameter uncertainty (i.e., uncertainty in M, historical catches, steepness)*
  Response: Box and whisker plots have been made to visualize the results for each alternative rebuilding strategy and sensitivity, and can be located in Appendix A. The information provided in the box and whisker plots can also be located in Tables 2-9.

- *Consider adding a performance metric that evaluates the predictability of rebuilding plans. An example is the absolute average variation in catch (*AAV*).*
  Response: The average annual variation (AAV) performance metric has been added for each alternative rebuilding strategy and sensitivity.

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Tables

Table 1. Life-history parameters used in the operating model.

Parameter	Flatfish	Roundfish	Medium-Lived Rockfish	Long-Lived Rockfish
Natural mortality (M_γ)	M_{female} = 0.15 (yr^{-1}) M_{male} = 0.17 (yr^{-1})	M_{female} = 0.20 (yr^{-1}) M_{male} = 0.20 (yr^{-1})	M_{female} = 0.08 (yr^{-1}) M_{male} = 0.09 (yr^{-1})	M_{female} = 0.05 (yr^{-1}) M_{male} = 0.06 (yr^{-1})
Steepness (h)	h = 0.85	h = 0.70	h = 0.65	h = 0.50
Mean length at a_3 (L_1)[&]	L_1 = 16 (cm) a_3 = 1 yr	L_1 = 12 (cm) a_3 = 1 yr	L_1 = 10 (cm) a_3 = 2 yr	L_1 = 18 (cm) a_3 = 2 yr
Mean length at a_4 ($L_{2\gamma}$)	$L_{2,female}$ = 55 (cm) $L_{2,male}$ = 55 (cm) a_4 = 20 yr	$L_{2,female}$ = 60 (cm) $L_{2,male}$ = 55 (cm) a_4 = 20 yr	$L_{2,female}$ = 34 (cm) $L_{2,male}$ = 32 (cm) a_4 = 50 yr	$L_{2,female}$ = 63 (cm) $L_{2,male}$ = 65 (cm) a_4 = 80 yr
Growth coefficient (K_γ)	K_{female} = 0.133 (yr^{-1}) K_{male} = 0.213 (yr^{-1})	K_{female} = 0.120 (yr^{-1}) K_{male} = 0.150 (yr^{-1})	K_{female} = 0.115 (yr^{-1}) K_{male} = 0.153 (yr^{-1})	K_{female} = 0.047 (yr^{-1}) K_{male} = 0.047 (yr^{-1})
Body weight ($w_{l,\gamma}$)	$\Omega_{1,female}$ = 2.08x10^{-6} $\Omega_{2,female}$ = 3.50 $\Omega_{1,male}$ = 3.05x10^{-6} $\Omega_{2,male}$ = 3.40	$\Omega_{1,female}$ = 8.50x10^{-6} $\Omega_{2,female}$ = 3.10 $\Omega_{1,male}$ = 7.70x10^{-6} $\Omega_{2,male}$ = 3.05	$\Omega_{1,female}$ = 7.40x10^{-6} $\Omega_{2,female}$ = 3.17 $\Omega_{1,male}$ = 8.30x10^{-6} $\Omega_{2,male}$ = 3.13	$\Omega_{1,female}$ = 9.76x10^{-6} $\Omega_{2,female}$ = 3.17 $\Omega_{1,male}$ = 8.70x10^{-6} $\Omega_{2,male}$ = 3.10
Maturity slope (Ω_3)	Ω_3 = -0.75 (yr^{-1})	Ω_3 = -0.70 (yr^{-1})	Ω_3 = -0.67 (yr^{-1})	Ω_3 = -0.44 (yr^{-1})
Length at 50% maturity (Ω_4)	Ω_4 = 33 (cm)	Ω_4 = 35 (cm)	Ω_4 = 21 (cm)	Ω_4 = 38 (cm)
Mean Generation Time	mg = 23 yrs	mg = 23 yrs	mg = 40 yrs	mg = 70 yrs
Fishery Selectivity	Logistic	Logistic	Logistic	Logistic
Survey Selectivity	Logistic	Logistic	Logistic	Logistic
Recruitment variation	$\sigma_R = 0.60$	$\sigma_R = 0.60$	$\sigma_R = 0.60$	$\sigma_R = 0.60$
Catchability Coefficient (Q)	Q = 1	Q = 1	Q = 1	Q = 1
Survey Standard Error	σ_s = 0.20	σ_s = 0.20	σ_s = 0.20	σ_s = 0.20
Relative Depletion (year 50)	$SB_{t=50}/SB_0$ = 0.05	$SB_{t=50}/SB_0$ = 0.10	$SB_{t=50}/SB_0$ = 0.10	$SB_{t=50}/SB_0$ = 0.10

& See Methot and Wetzel (2013) for the parameterization of growth.

Table 2: The flatfish life-history median values and 95% simulation intervals for the number of SPR changes, number of changes to T_{TARGET}, the number of failed rebuilding plans, the average annual variation in catch(AAV), and the average catch over the first 5 years of the rebuilding period.

Flatfish	# SPR Changes	95% SI	# T_{TARGET} Changes	95% SI	# Failed Rebuilding Plan	95% SI	Median AAV	95% SI	Average Catch - 5 years	95% SI
Alternative Strategy										
Status Quo	0	(0 - 1.52)	0	(0 - 1.52)	0	(0 - 1)	18	(9.91 - 30.54)	160	(83 - 278)
Flexible Rebuilding	0	(0 - 1.52)	0	(0 - 1.52)	0	(0 - 1)	18	(9.91 - 30.54)	160	(83 - 278)
Risk Averse Rebuilding	0	(0 - 2)	0	(0 – 2.00)	0	(0 - 1.52)	18	(11.59 - 30.17)	144	(59 - 262)
Fixed Rebuilding Plan	0	(0 - 1)	0	(0 - 0.52)	0	(0 - 0.52)	17	(8.66 - 26.19)	159	(77 - 293)
Sensitivity										
Error in M - Status Quo	0	(0 - 1.52)	1	(0 - 2.52)	1	(0 - 2.52)	13	(8.65 - 23.95)	253	(149 - 399)
Error in h - Status Quo	1	(0 - 2)	2	(1.48 - 4.52)	2	(1 - 4)	12	(6.83 - 20.51)	288	(183 - 439)
Error in Historical Catch - Status Quo	0	(0 - 1)	0	(0 – 2.00)	0	(0 - 1.52)	17	(9.76 - 28.7)	149	(60 - 267)
No Restriction on Catch Changes - Status Quo	0	(0 - 2)	1	(1 - 2.52)	1	(1 - 2.52)	17	(10.36 - 26.75)	162	(78 - 295)
Assessment Frequency - Status Quo	1	(0 - 3)	0	(0 - 1)	0	(0 - 1)	24	(16.02 - 39.97)	132	(60 - 232)
Assessment Frequency - Flexible	0	(0 - 3)	0	(0 - 1)	0	(0 - 1)	24	(16.02 - 39.97)	132	(61 - 232)

Table 3: The flatfish life-history median values and 95% simulation intervals for the rebuild ratio, the time to rebuild the stock, and the relative error of the rebuilding ratio and the rebuilding time.

Flatfish	Rebuild Ratio	95% SI	Rebuild Time	95% SI	RE Rebuild Ratio	95% SI	RE Rebuild Time	95% SI
Alternative Strategy								
Status Quo	1.00	(0.7 - 1.6)	10	(7 - 17)	-0.01	(-0.36 - 0.34)	-0.08	(-0.71 - 0.16)
Flexible Rebuilding	1.00	(0.7 - 1.6)	10	(7 - 17)	-0.01	(-0.36 - 0.34)	-0.08	(-0.71 - 0.16)
Risk Averse Rebuilding	0.90	(0.67 - 1.47)	9	(6 - 20)	-0.08	(-0.39 - 0.29)	-0.09	(-0.79 - 0.20)
Fixed Rebuilding Plan	1.00	(0.29 - 1.3)	10	(3 - 16)	-0.08	(-0.75 - 0.25)	-0.08	(-0.92 - 0.19)
Sensitivity								
Error in M - Status Quo	1.30	(0.8 - 2.1)	13	(8 - 21)	0.20	(-0.27 - 0.85)	-0.06	(-0.75 - 0.21)
Error in h - Status Quo	1.40	(0.9 - 2.6)	14	(9 - 26)	0.33	(-0.16 - 1.18)	-0.05	(-0.74 - 0.19)
Error in Historical Catch - Status Quo	1.00	(0.65 - 1.7)	10	(6 - 17)	-0.02	(-0.38 - 0.58)	-0.08	(-0.56 - 0.21)
No Restriction on Catch Changes - Status Quo	1.00	(0.29 - 1.25)	10	(3 - 16)	-0.07	(-0.76 - 0.17)	-0.08	(-0.88 - 0.24)
Assessment Frequency - Status Quo	1.00	(0.69 - 1.2)	10	(7 - 16)	-0.09	(-0.40 - 0.15)	-0.08	(-0.78 - 0.17)
Assessment Frequency - Flexible	1.00	(0.69 - 1.2)	10	(7 - 16)	-0.09	(-0.40 - 0.15)	-0.08	(-0.78 - 0.17)

Table 4: The roundfish life-history median values and 95% simulation intervals for the number of SPR changes, number of changes to T_{TARGET}, the number of failed rebuilding plans, the average annual variation in catch (AAV), and the average catch over the first 10 of the rebuilding period.

Roundfish	# SPR Changes	95% SI	# T_{TARGET} Changes	95% SI	# Failed Rebuilding Plans	95% SI	Median AAV	95% SI	Average Catch -10 years	95% SI
Alternative Strategy										
Status Quo	1	(0 - 4)	0	(0 - 2)	0	(0 - 1.52)	10.23	(5.59 - 22.96)	173	(42 - 271)
Flexible Rebuilding	1	(0 - 3)	0	(0 - 2)	0	(0 - 1.52)	10.27	(5.79 - 22.96)	173	(42 - 271)
Risk Averse Rebuilding	1	(0 - 3.52)	0	(0 - 2)	0	(0 - 1)	11.43	(6.5 - 20.83)	158	(17 - 273)
Fixed Rebuilding Plan	0	(0 - 1)	0	(0 - 0)	0	(0 - 0)	11.56	(5.6 - 18.92)	158	(35 - 246)
Sensitivity										
Error in M - Status Quo	0	(0 - 3)	1	(0 - 3)	1	(0 - 2)	9.64	(6.42 - 16.87)	162	(53 - 324)
Error in h - Status Quo	0.5	(0 - 4)	2	(1 - 4)	2	(1 - 3)	11.52	(6.31 - 21.43)	151	(42 - 287)
Error in Historical Catch - Status Quo	1	(0 - 3)	0	(0 - 3)	0	(0 - 2)	11.07	(5.63 - 22.17)	162	(45 - 242)
No Restriction on Catch Changes - Status Quo	1	(0 - 4)	1	(1 - 3)	1	(1 - 2)	10.75	(6.35 - 19.13)	169	(36 - 275)
Assessment Frequency - Status Quo	1	(0 - 6.52)	0	(0 - 2)	0	(0 - 1.52)	13.7	(8.63 - 25.31)	155	(28 - 249)
Assessment Frequency - Flexible	1	(0 - 5)	0	(0 - 2)	0	(0 - 1.52)	13.81	(8.68 - 25.31)	155	(28 - 249)

Table 5: The roundfish life-history median values and 95% simulation intervals for the rebuild ratio, the time to rebuild the stock, and the relative error of the rebuilding ratio and the rebuilding time.

Roundfish	Rebuild Ratio	95% SI	Rebuild Time	95% SI	RE Rebuild Ratio	95% SI	RE Rebuild Time	95% SI
Alternative Strategy								
Status Quo	0.92	(0.6 - 1.45)	20	(8 - 34)	-0.04	(-0.39 - 0.44)	0.00	(-0.59 - 0.82)
Flexible Rebuilding	0.94	(0.6 - 1.45)	20	(8 - 34)	-0.04	(-0.39 - 0.44)	0.00	(-0.59 - 0.82)
Risk Averse Rebuilding	0.95	(0.59 - 1.43)	18	(9 - 30)	-0.06	(-0.43 - 0.40)	0.00	(-0.66 - 0.78)
Fixed Rebuilding Plan	0.90	(0.51 - 1.36)	18	(8 - 34)	-0.08	(-0.47 - 0.47)	0.00	(-0.65 - 1.31)
Sensitivity								
Error in M - Status Quo	1.40	(0.83 - 2)	16	(10 - 29)	0.34	(-0.24 - 0.72)	0.00	(-0.58 - 0.41)
Error in h - Status Quo	1.20	(0.74 - 1.79)	14	(9 - 32)	0.13	(-0.22 - 0.61)	-0.03	(-0.69 - 0.33)
Error in Historical Catch - Status Quo	0.87	(0.5 - 1.52)	20	(9 - 35)	-0.10	(-0.44 - 0.55)	0.00	(-0.33 - 1.69)
No Restriction on Catch Changes - Status Quo	0.92	(0.54 - 1.35)	19	(8 - 29)	-0.05	(-0.43 - 0.32)	0.00	(-0.62 - 0.62)
Assessment Frequency - Status Quo	0.93	(0.51 - 1.31)	20	(8 - 32)	-0.05	(-0.47 - 0.34)	0.00	(-0.74 - 0.73)
Assessment Frequency - Flexible	0.96	(0.54 - 1.31)	20	(9 - 32)	-0.05	(-0.45 - 0.34)	0.00	(-0.71 - 0.73)

Table 6: The medium-lived rockfish life-history median values and 95% simulation intervals for the number of SPR changes, number of changes to T_{TARGET}, the number of failed rebuilding plans, the average annual variation in catch(AAV), and the average catch over the first 25 years of the rebuilding period.

Medium Lived Rockfish	# SPR Changes	95% SI	# T_{TARGET} Changes	95% SI	# Failed Rebuilding Plans	95% SI	Median AAV	95% SI	Average Catch - 25 years	95% SI
Alternative Strategy										
Status Quo	3	(0 - 7)	0	(0 - 2.52)	0	(0 - 1)	5.21	(3.61 - 8.16)	517	(410 - 630)
Flexible Rebuilding	1	(0 - 4)	0	(0 - 2.52)	0	(0 - 1)	5.22	(3.73 - 7.79)	522	(416 - 627)
Risk Averse Rebuilding	2	(1 - 7)	0	(0 - 1)	0	(0 - 0)	5.94	(4.25 - 8.54)	465	(373 - 562)
Fixed Rebuilding Plan	0	(0 - 1)	0	(0 - 0)	0	(0 - 0)	6.56	(3.91 – 10.00)	463	(366 - 571)
Sensitivity										
Error in M - Status Quo	3.5	(1 - 6.52)	1	(0 - 2)	0	(0 - 1)	5.31	(3.96 - 6.73)	587	(475 - 712)
Error in h - Status Quo	4	(2 - 8)	1	(1 - 3)	1	(1 - 2)	5.08	(3.84 - 7.10)	577	(471 - 690)
Error in Historical Catch - Status Quo	1	(0 - 5.52)	0	(0 - 1)	0	(0 - 1)	5.96	(4.11 - 8.56)	440	(353 - 534)
No Restriction on Catch Changes - Status Quo	2	(0 - 7)	1	(1 - 2.52)	1	(1 - 1.52)	5.56	(3.88 - 8.45)	503	(408 - 604)
Assessment Frequency - Status Quo	2	(0 - 5)	0	(0 - 2.52)	0	(0 - 1.52)	4.20	(3.04 - 6.51)	548	(444 - 665)
Assessment Frequency - Flexible	1	(0 - 3)	0	(0 - 2)	0	(0 - 1.52)	4.13	(2.96 - 6.63)	553	(446 - 666)

Table 7: The medium-lived rockfish life-history median values and 95% simulation intervals for the rebuild ratio, the time to rebuild the stock, and the relative error of the rebuilding ratio and the rebuilding time.

Medium Lived Rockfish	Rebuild Ratio	95% SI	Rebuild Time	95% SI	RE Rebuild Ratio	95% SI	RE Rebuild Time	95% SI
Alternative Strategy								
Status Quo	0.92	(0.66 - 1.17)	41	(30 - 57)	-0.07	(-0.32 - 0.18)	0.04	(-0.43 - 0.58)
Flexible Rebuilding	0.92	(0.68 - 1.15)	41	(30 - 54)	-0.06	(-0.27 - 0.14)	0.03	(-0.40 - 0.58)
Risk Averse Rebuilding	0.88	(0.68 - 1.05)	36	(26 - 45)	-0.1	(-0.3 - 0.07)	0.03	(-0.46 - 0.47)
Fixed Rebuilding Plan	0.82	(0.6 - 1.18)	37	(27 - 54)	-0.14	(-0.36 - 0.21)	0.05	(-0.45 - 0.6)
Sensitivity								
Error in M - Status Quo	1	(0.83 - 1.37)	38	(31 - 48)	-0.01	(-0.18 - 0.16)	0.03	(-0.47 - 0.30)
Error in h - Status Quo	0.96	(0.78 - 1.13)	40	(33 - 48)	-0.03	(-0.21 - 0.08)	0.02	(-0.45 - 0.32)
Error in Historical Catch - Status Quo	0.8	(0.6 - 1.03)	37	(27 - 51)	-0.13	(-0.33 - 0.12)	0.11	(-0.34 - 0.65)
No Restriction on Catch Changes - Status Quo	0.89	(0.65 - 1.12)	40	(29 - 51)	-0.08	(-0.31 - 0.13)	0.03	(-0.44 - 0.64)
Assessment Frequency - Status Quo	0.93	(0.68 - 1.25)	41	(31 - 57)	-0.07	(-0.26 - 0.24)	0.03	(-0.42 - 0.63)
Assessment Frequency - Flexible	0.93	(0.68 - 1.24)	41	(31 - 56)	-0.05	(-0.29 - 0.24)	0.03	(-0.42 - 0.64)

Table 8: The long-lived rockfish life-history median values and 95% simulation intervals for the number of SPR changes, number of changes to T_{TARGET}, the number of failed rebuilding plans, the average annual variation in catch(AAV), and the average catch over the first 50 years of the rebuilding period.

Long-Lived Rockfish	# SPR Changes	95% SI	# T_{TARGET} Changes	95% SI	# Failed Rebuilding Plans	95% SI	Median AAV	95% SI	Average Catch - 50 years	95% SI
Alternative Strategy										
Status Quo	3	(0 - 11.05)	0	(0 - 2)	0	(0 - 1)	2.7	(2.12 - 4.16)	16	(14 - 19)
Flexible Rebuilding	1	(0 - 5)	0	(0 - 2)	0	(0 - 1)	2.7	(2.11 - 4.16)	16	(14 - 19)
Risk Averse Rebuilding	3	(0.48 - 10)	0	(0 - 2)	0	(0 - 2)	2.92	(2.14 - 5.04)	15	(12 - 17)
Fixed Rebuilding Plan	0	(0 – 0.52)	0	(0 - 0)	0	(0 - 0)	3.91	(2.87 - 6.82)	13	(10 - 16)
Sensitivity										
Error in M - Status Quo	4	(0.48 - 8.52)	1	(0 - 2)	1	(0 - 1)	2.65	(1.83 - 3.51)	19	(17 - 22)
Error in h - Status Quo	5	(1 - 11.52)	1	(1 - 3)	1	(1 - 2)	2.83	(2.21 - 3.55)	19	(16 - 23)
Error in Historical Catch - Status Quo	1	(0 - 7.52)	0	(0 - 1)	0	(0 - 0)	2.98	(2.23 - 3.74)	14	(12 - 16)
No Restriction on Catch Changes - Status Quo	3	(0 - 10.52)	1	(1 - 3)	1	(1 - 2)	2.78	(2.19 - 9.4)	15	(3 - 19)
Assessment Frequency - Status Quo	2	(0 - 7.52)	0	(0 - 2)	0	(0 - 1)	2.39	(1.85 - 3.34)	16	(14 - 19)
Assessment Frequency - Flexible	1	(0 - 4)	0	(0 - 1)	0	(0 - 1)	2.39	(1.8 - 3.14)	17	(15 - 19)

Table 9: The long-lived rockfish life-history median values and 95% simulation intervals for the rebuild ratio, the time to rebuild the stock, and the relative error of the rebuilding ratio and the rebuilding time.

Long Lived Rockfish	Rebuild Ratio	95% SI	Rebuild Time	95% SI	RE Rebuild Ratio	95% SI	RE Rebuild Time	95% SI
Alternative Strategy								
Status Quo	0.90	(0.7 - 1.05)	87	(65 - 100)	-0.04	(-0.25 - 0.09)	0.07	(-0.06 - 0.32)
Flexible Rebuilding	0.91	(0.74 - 1.06)	87.5	(68 - 101)	-0.04	(-0.26 - 0.1)	0.07	(-0.22 - 0.33)
Risk Averse Rebuilding	0.88	(0.76 - 1.04)	80	(68 - 95)	-0.06	(-0.24 - 0.04)	0.06	(-0.29 - 0.34)
Fixed Rebuilding Plan	0.82	(0.7 - 1.04)	80.5	(66 - 98)	-0.09	(-0.28 - 0.08)	0.06	(-0.33 - 0.42)
Sensitivity								
Error in M - Status Quo	1.14	(0.88 - 1.45)	88	(69 - 113)	0.04	(-0.15 - 0.26)	0.07	(-0.26 - 0.27)
Error in h - Status Quo	0.95	(0.84 - 1.11)	84	(71 - 100)	-0.02	(-0.17 - 0.1)	0.05	(-0.29 - 0.22)
Error in Historical Catch - Status Quo	0.84	(0.74 - 1.02)	83	(69 - 100)	-0.07	(-0.21 - 0.04)	0.09	(-0.26 - 0.36)
No Restriction on Catch Changes - Status Quo	0.90	(0 - 1.03)	85	(51 - 99)	-0.04	(-0.34 - 0.1)	0.06	(-0.19 - 0.34)
Assessment Frequency - Status Quo	0.91	(0.77 - 1.08)	88	(69 - 100)	-0.04	(-0.18 - 0.09)	0.05	(-0.10 - 0.36)
Assessment Frequency - Flexible	0.91	(0.77 - 1.06)	88.5	(72 - 100)	-0.04	(-0.18 - 0.08)	0.06	(-0.07 - 0.39)

Figures

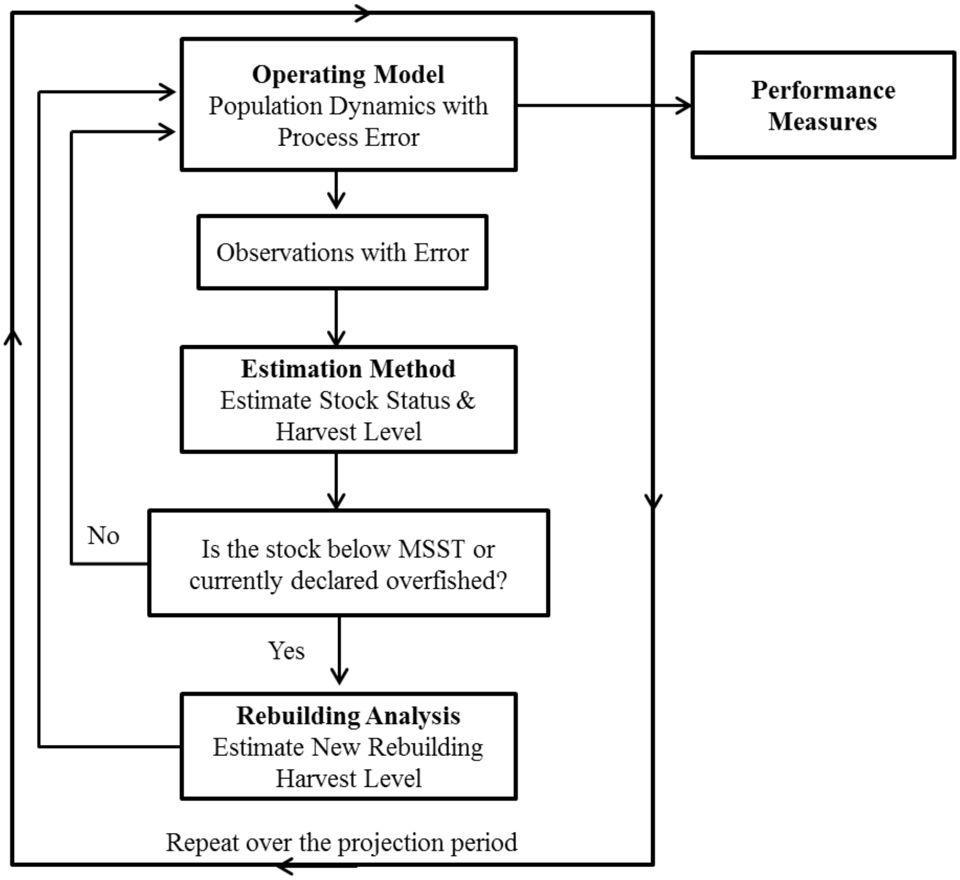

Figure 1. The process and order of operations for the MSE.

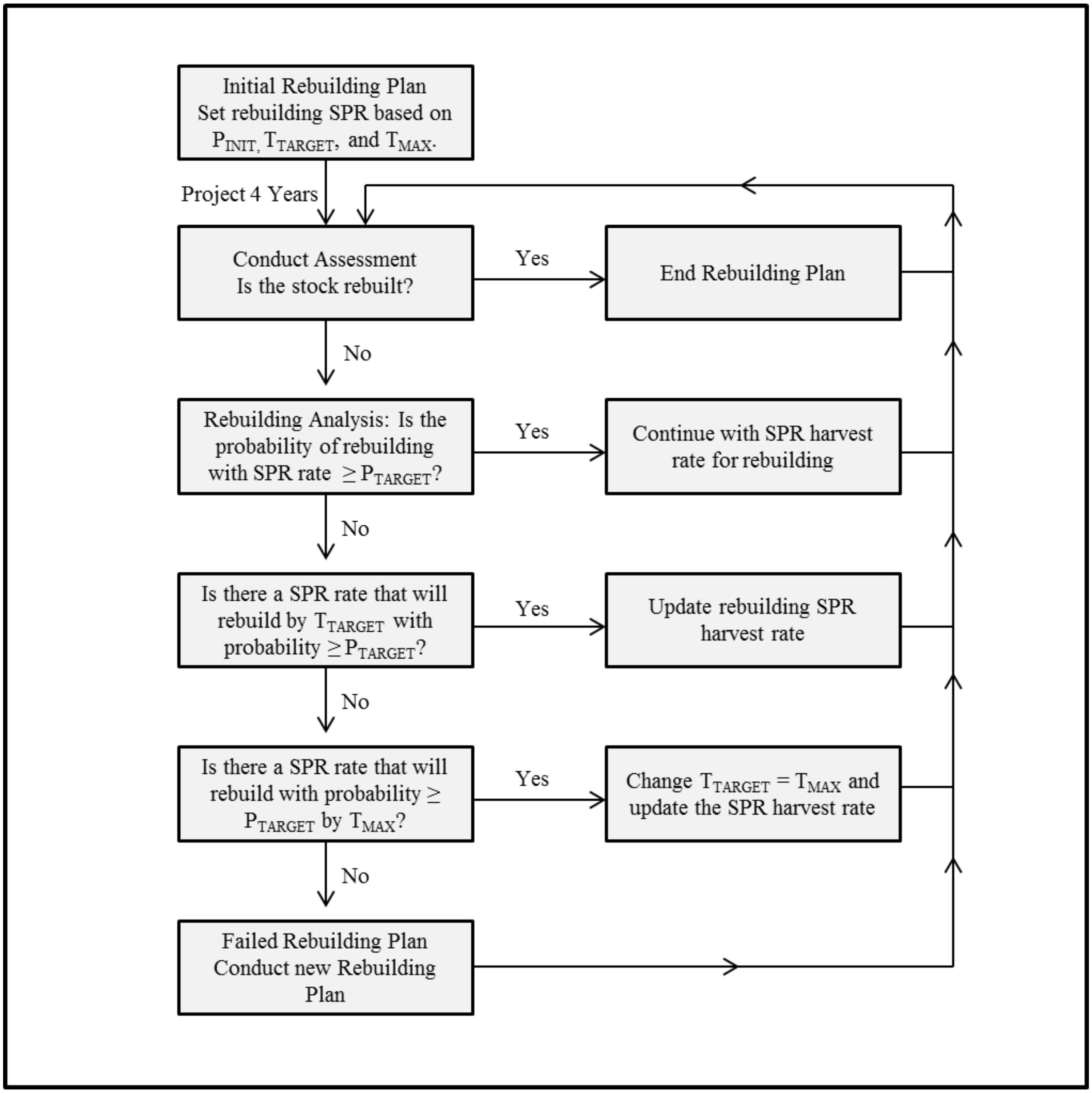

Figure 2. The process followed for updating targets and harvest rates during rebuilding.

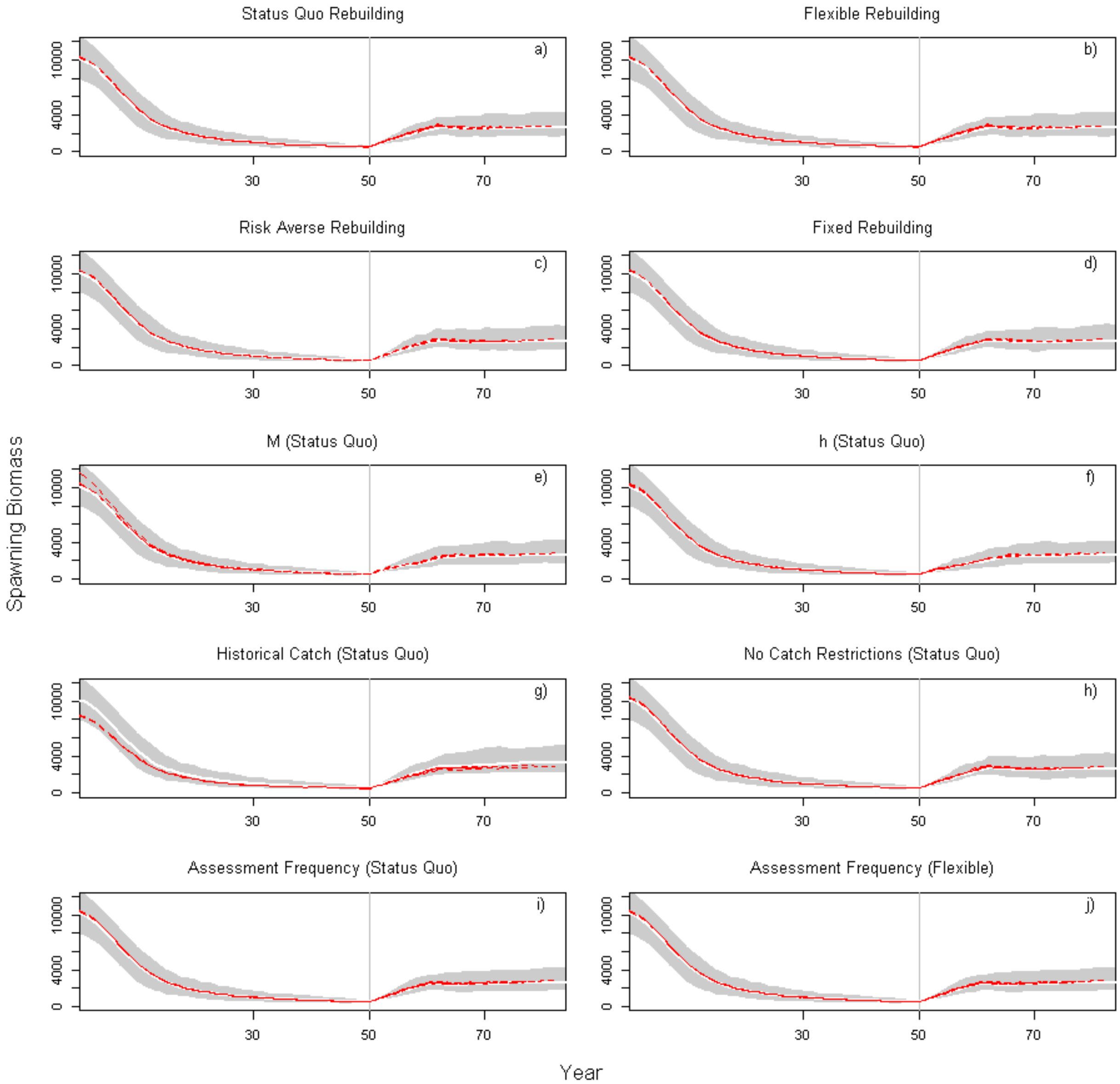

Figure 3: The median time-trajectories of spawning biomass for the operating model (black line) for the flatfish population with 95% simulation intervals (grey area) for each alternative rebuilding strategy and sensitivity. The median spawning biomass estimate across the simulations for each assessment is given by the red dashed lines. The vertical dotted line indicates the start of the projection period.

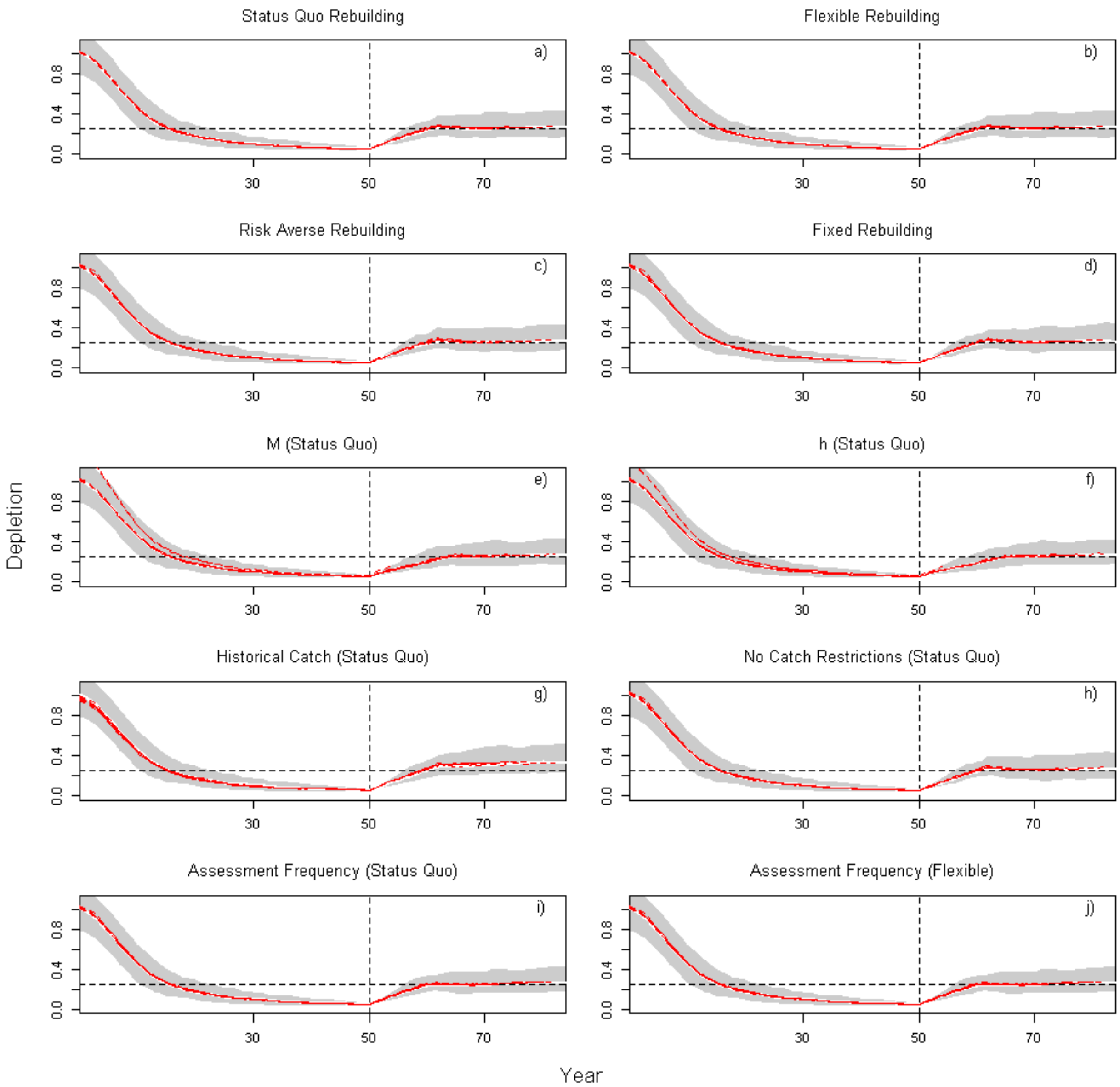

Figure 4: The median time-trajectories of relative stock size for the operating model (black line) for the flatfish population with 95% simulation intervals (grey area) for each alternative rebuilding strategy and sensitivity. The median relative stock size estimate across the simulations for each assessment is given by the red dashed lines. The vertical dotted line indicates the start of the projection period and the horizontal dotted line indicates the target value for flatfish stocks set by the PFMC.

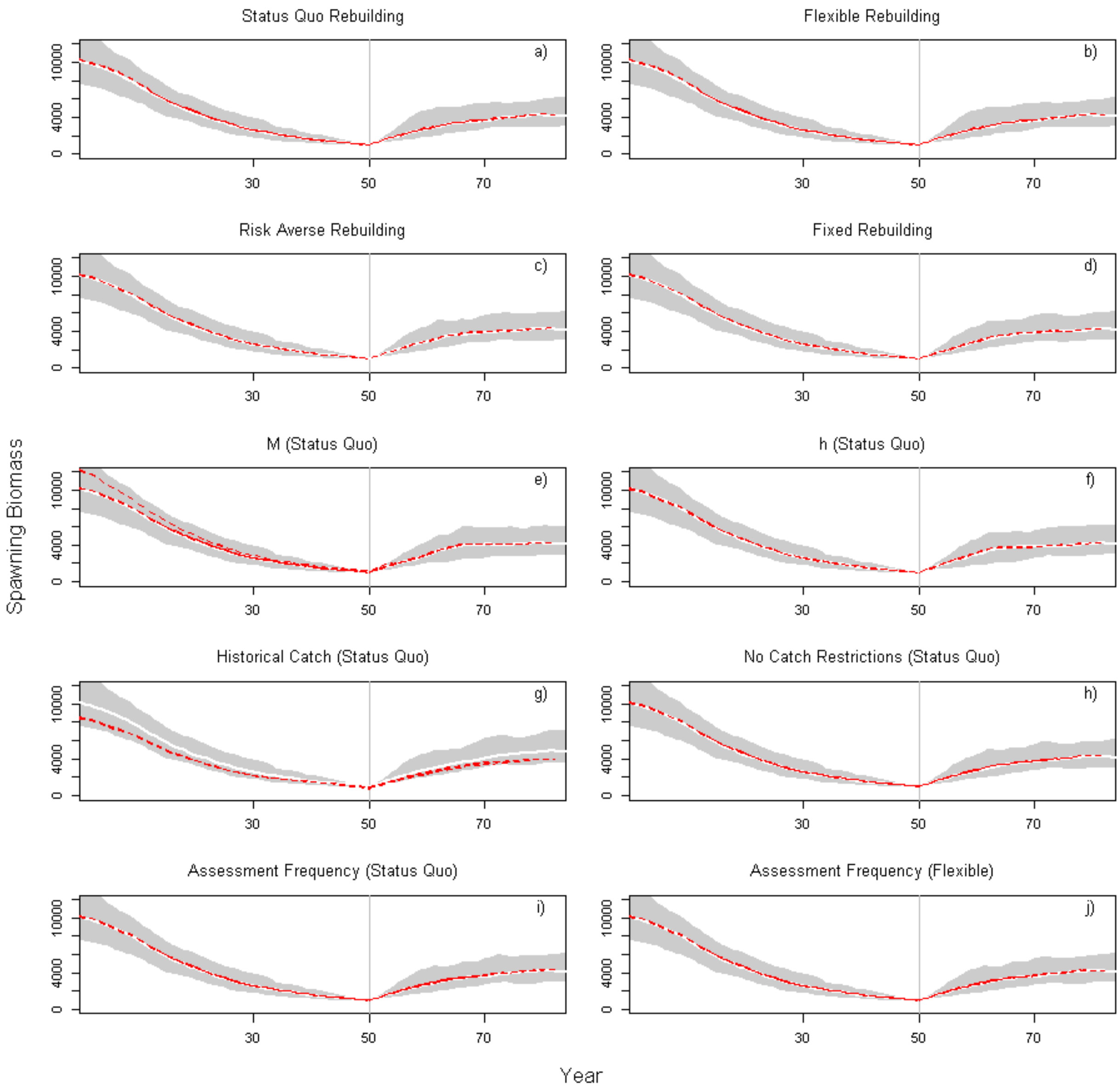

Figure 5: The median time-trajectories of spawning biomass for the operating model (black line) for the roundfish population with 95% simulation intervals (grey area) for each alternative rebuilding strategy and sensitivity. The median spawning biomass estimate across the simulations for each assessment is given by the red dashed lines. The vertical dotted line indicates the start of the projection period.

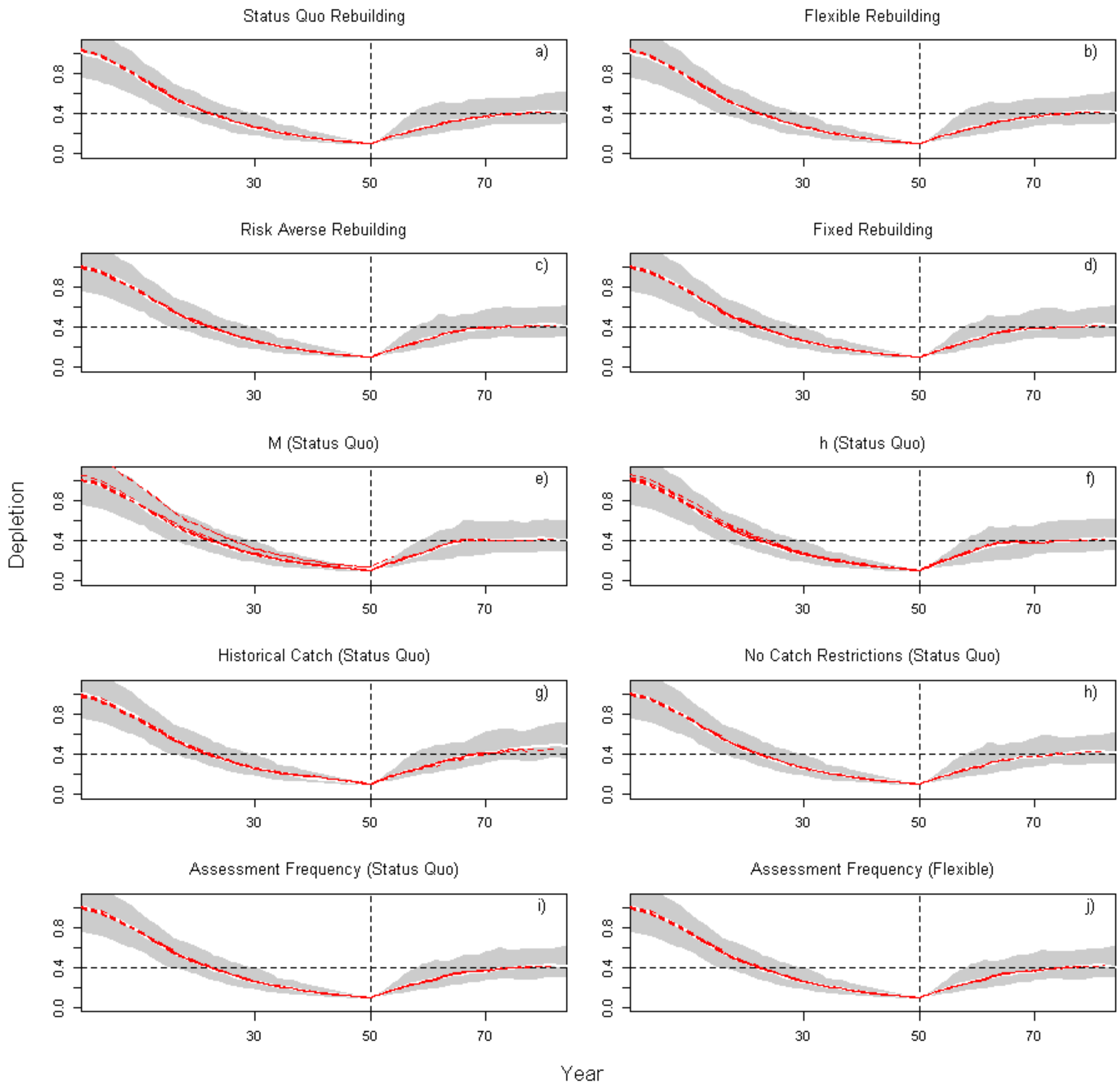

Figure 6: The median time-trajectories of relative stock size for the operating model (black line) for the roundfish population with 95% simulation intervals (grey area) for each alternative rebuilding strategy and sensitivity. The median relative stock size estimate across the simulations for each assessment is given by the red dashed lines. The vertical dotted line indicates the start of the projection period and the horizontal dotted line indicates the target value for roundfish stocks set by the PFMC.

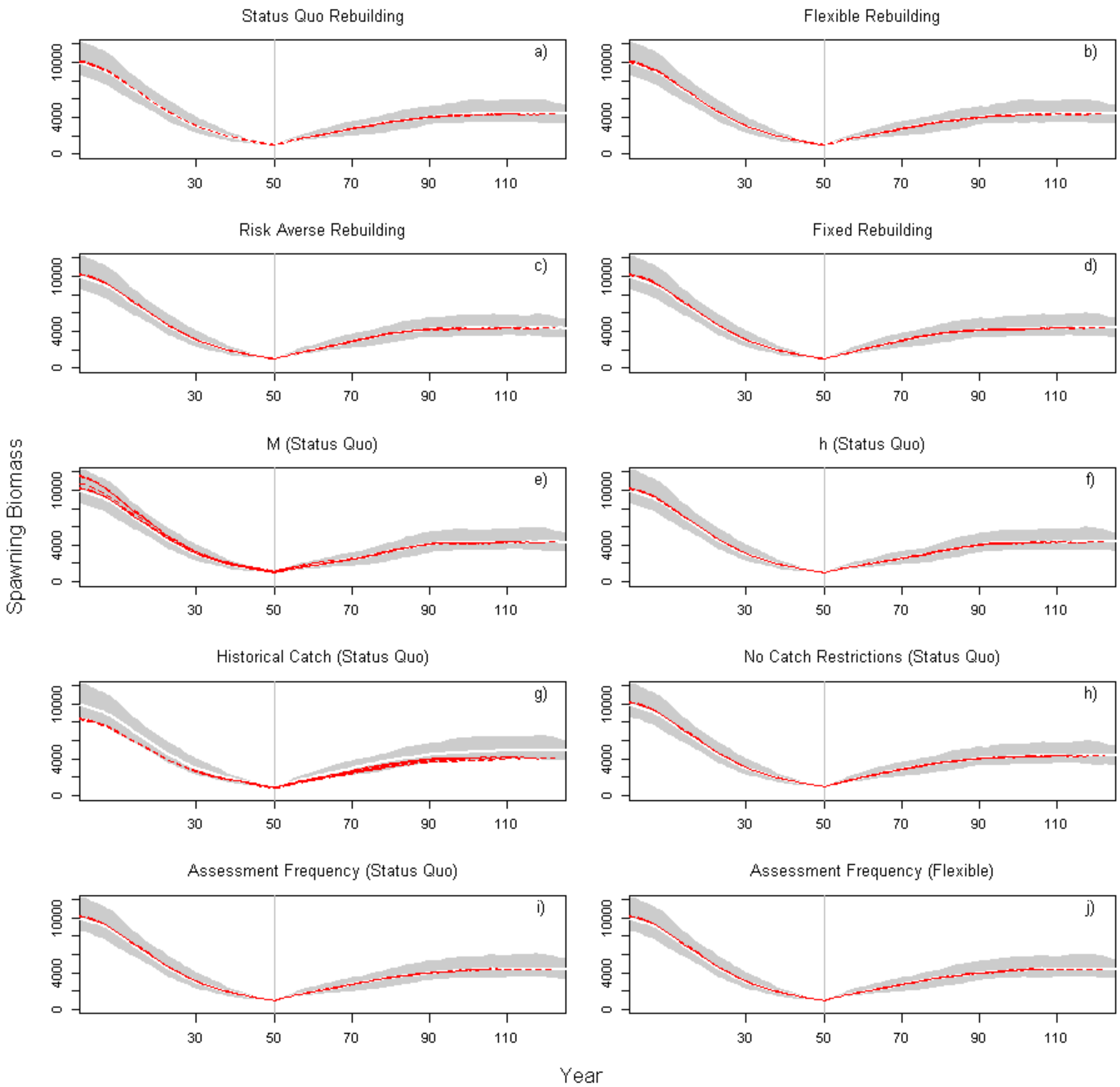

Figure 7: The median time-trajectories of spawning biomass for the operating model (black line) for the medium-lived rockfish population with 95% simulation intervals (grey area) for each alternative rebuilding strategy and sensitivity. The median spawning biomass estimate across the simulations for each assessment is given by the red dashed lines. The vertical dotted line indicates the start of the projection period.

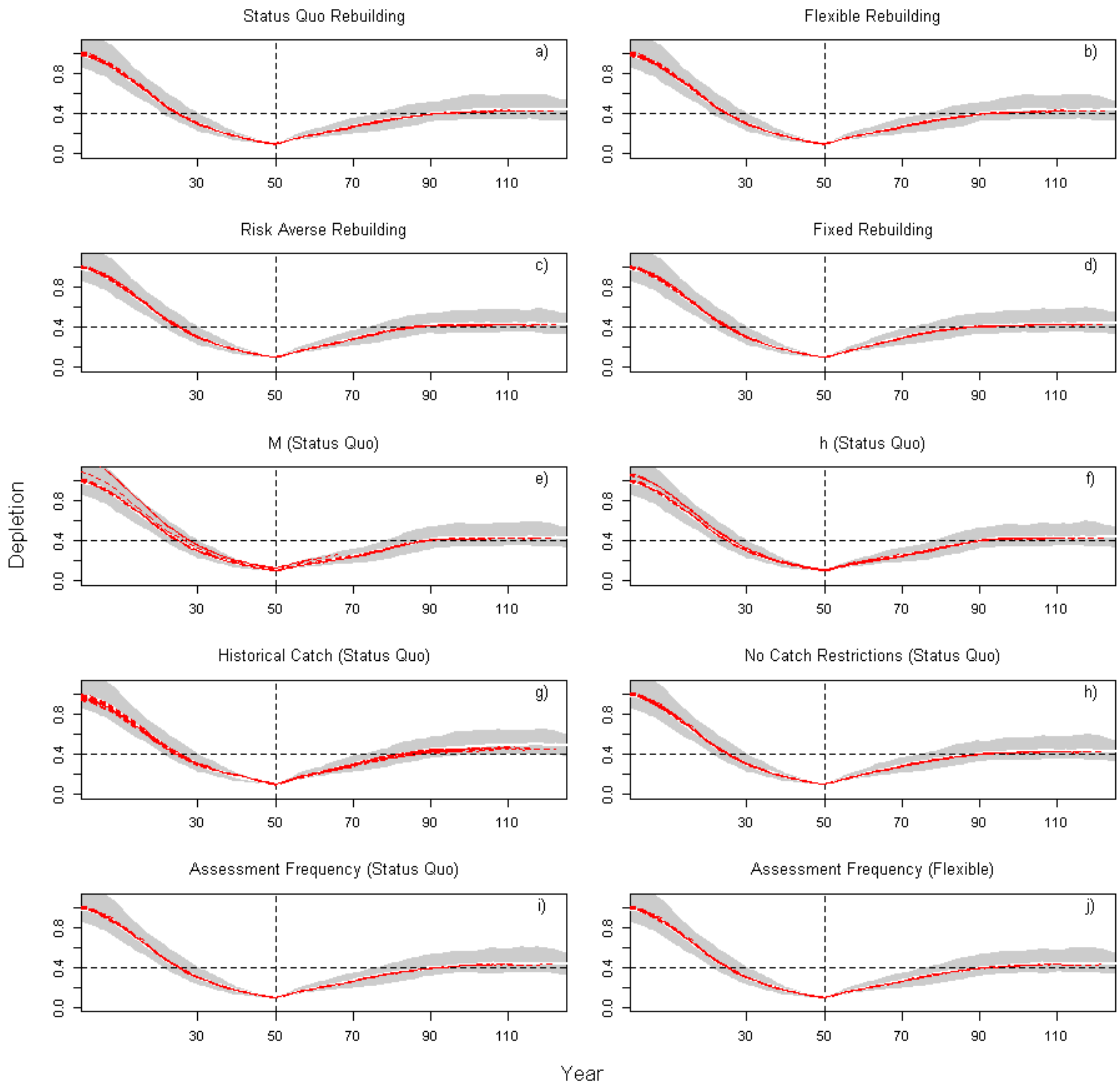

Figure 8: The median time-trajectories of relative stock size for the operating model (black line) for the medium-lived rockfish population with 95% simulation intervals (grey area) for each alternative rebuilding strategy and sensitivity. The median relative stock size estimate across the simulations for each assessment is given by the red dashed lines. The vertical dotted line indicates the start of the projection period and the horizontal dotted line indicates the target value for rockfish stocks set by the PFMC.

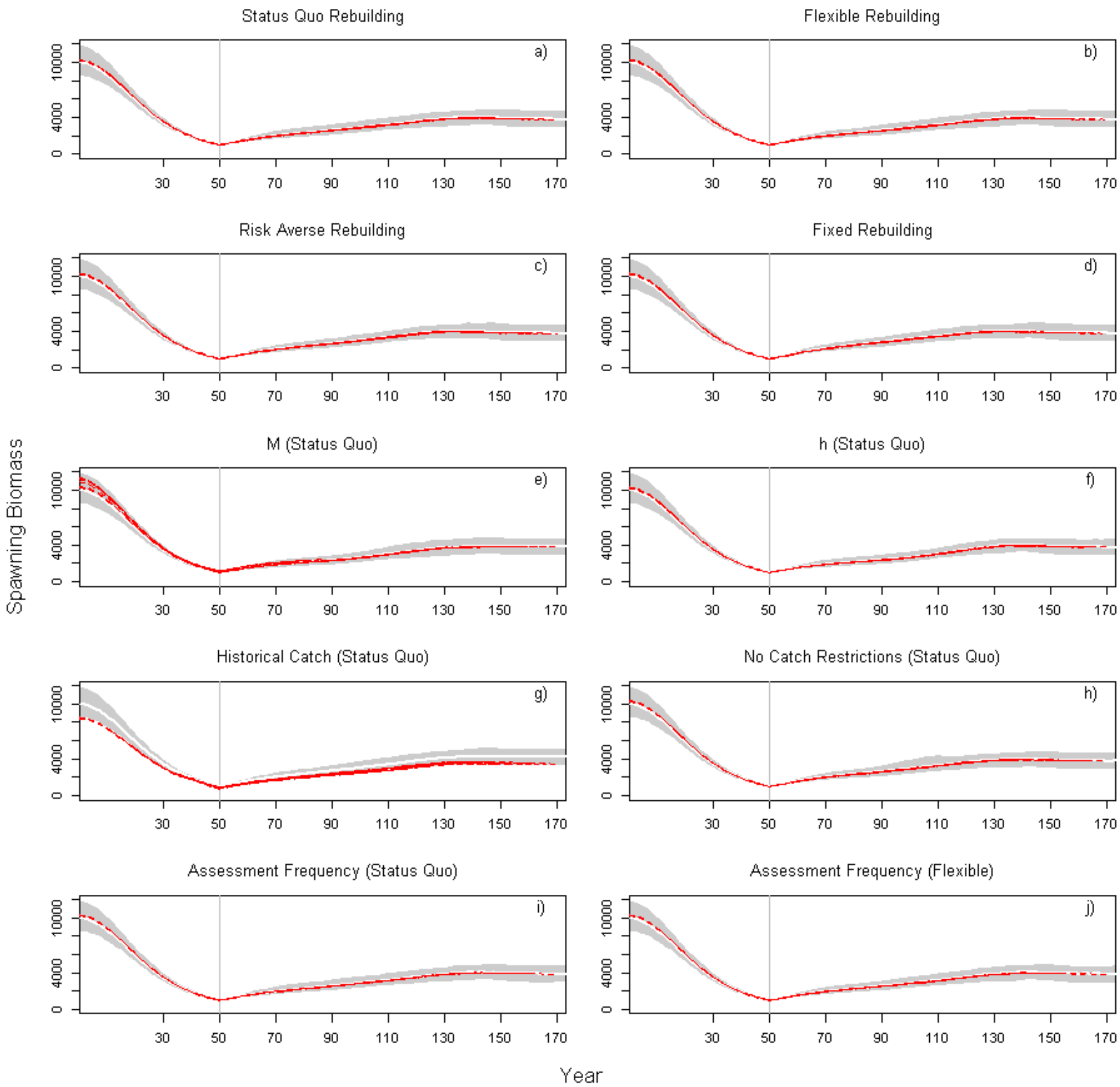

Figure 9: The median time-trajectories of spawning biomass for the operating model (black line) for the long-lived rockfish population with 95% simulation intervals (grey area) for each alternative rebuilding strategy and sensitivity. The median spawning biomass estimate across the simulations for each assessment is given by the red dashed lines. The vertical dotted line indicates the start of the projection period.

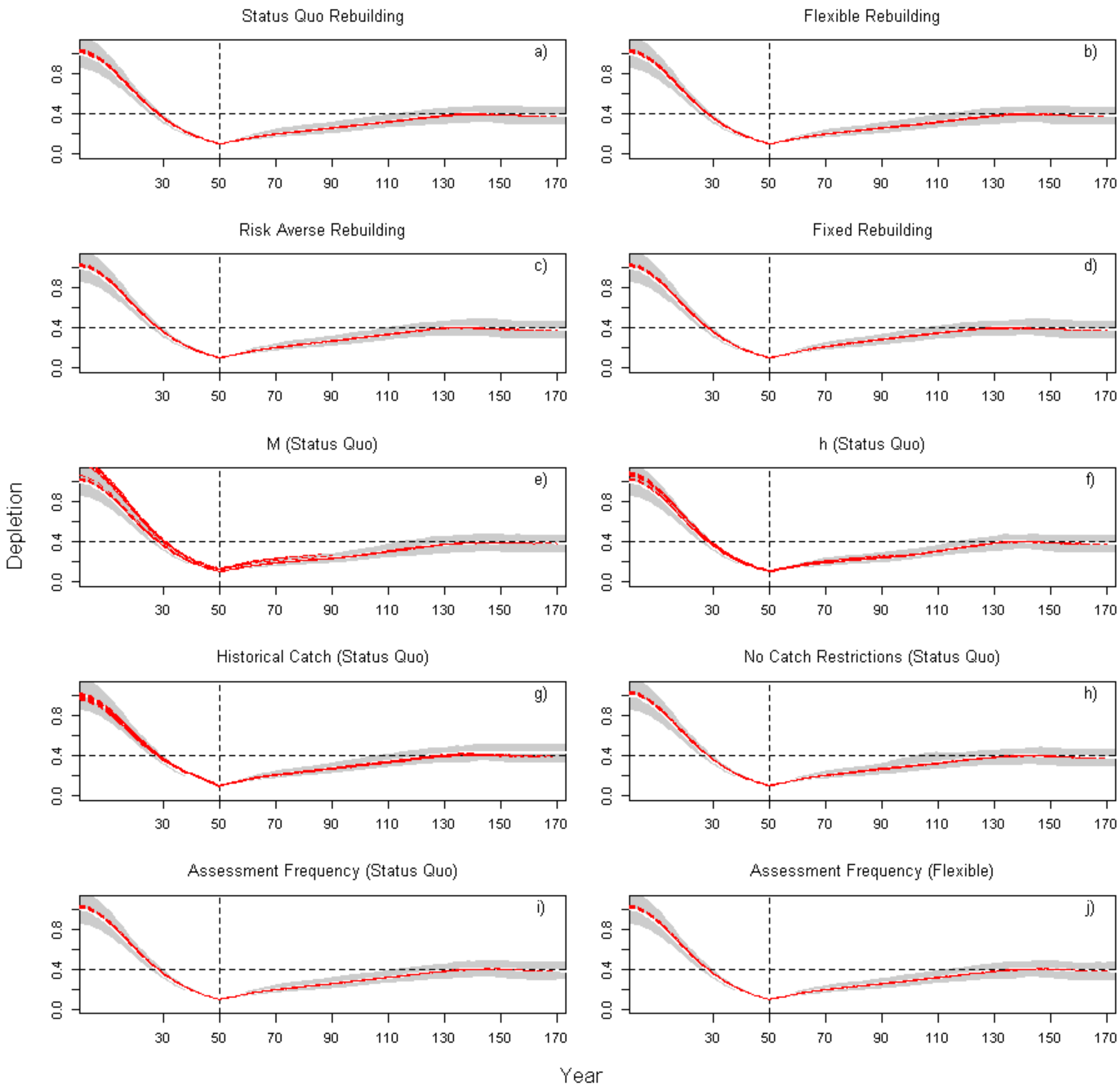

Figure 10: The median time-trajectories of relative stock size for the operating model (black line) for the long-lived rockfish population with 95% simulation intervals (grey area) for each alternative rebuilding strategy and sensitivity. The median relative stock size estimate across the simulations for each assessment is given by the red dashed lines. The vertical dotted line indicates the start of the projection period and the horizontal dotted line indicates the target value for rockfish stocks set by the PFMC.

Appendix 1: Box and whisker plots

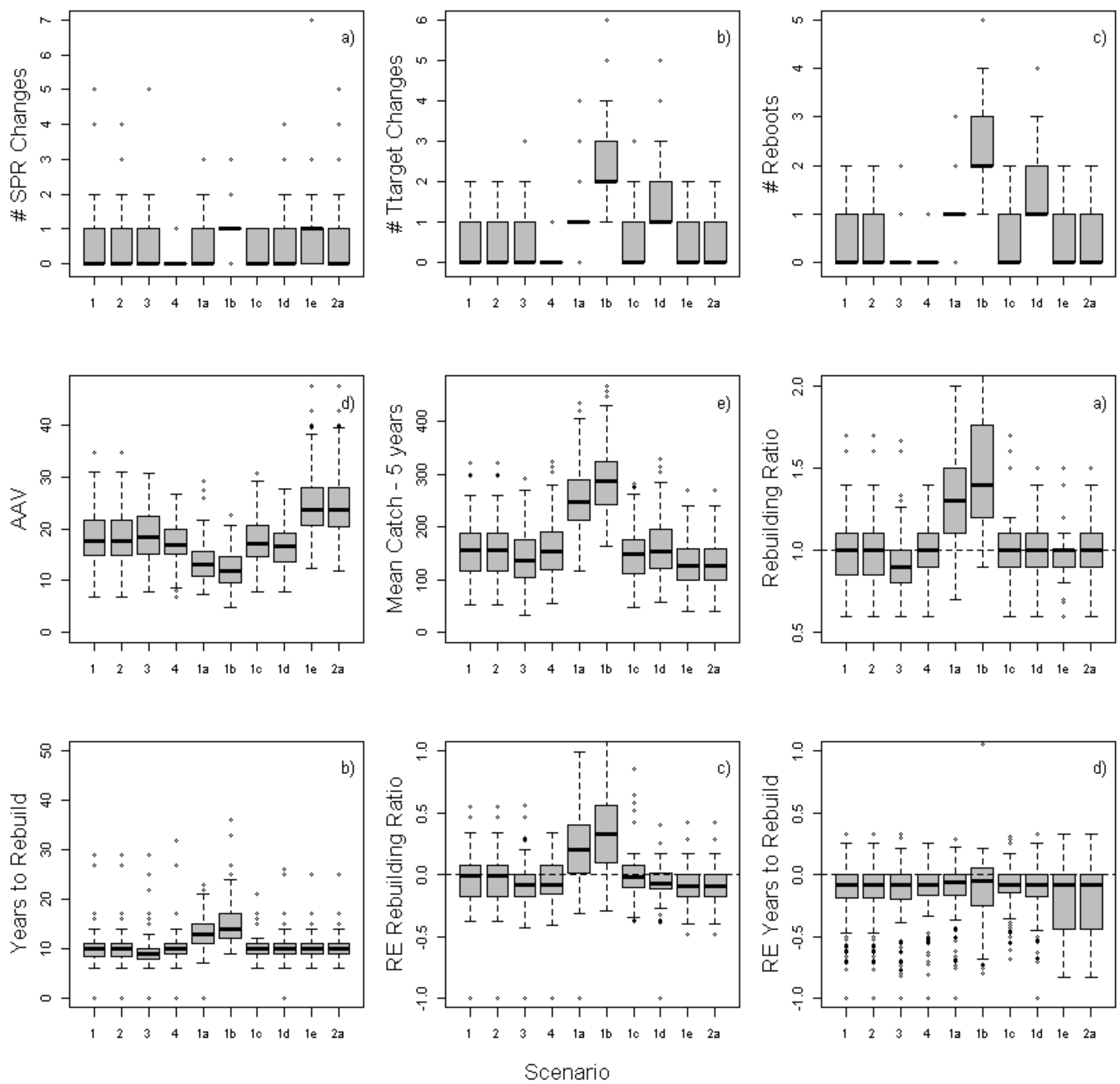

Figure A.1 The flatfish life-history median values and 95% simulation intervals for the number of SPR changes, number of changes to T_{TARGET}, the number of failed rebuilding plans, the average annual variation in catch (AAV), the average catch over the first 5 of the rebuilding period, estimated rebuilding ratio, estimated rebuilding time, relative error of the rebuilding time, and the relative error of the rebuilding ratio. The strategies are 1) Status Quo, 2) Flexible, 3) Risk Averse, 4) Fixed, 1a) Error in Natural Mortality, 1b) Error in Steepness, 1c) Underestimation of Historical Catch, 1d) No Restriction on Catch Restriction, 1e) Assessment Frequency – Status Quo, and 2a) Assessment Frequency – Flexible.

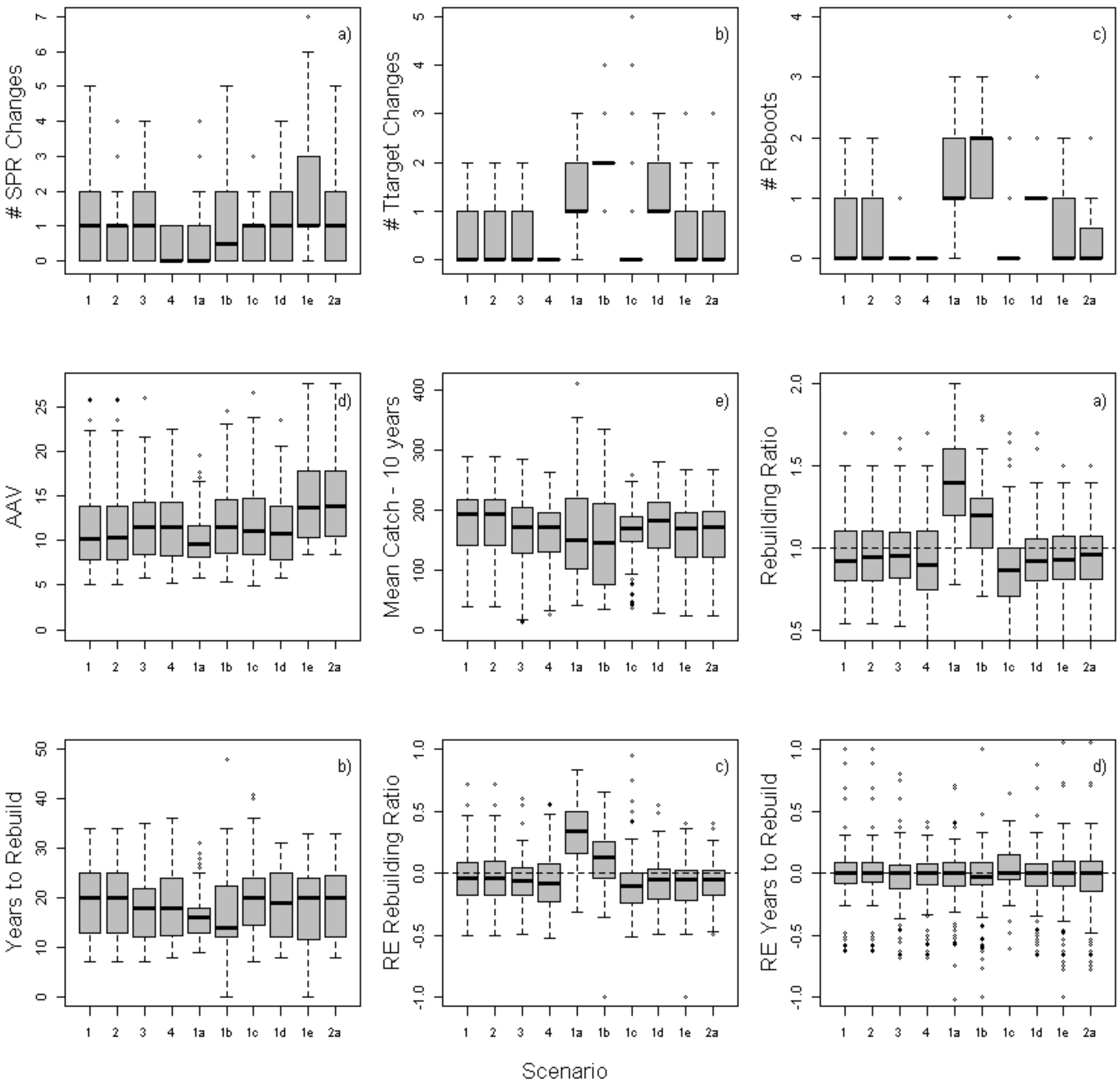

Figure A.2 The roundfish life-history median values and 95% simulation intervals for the number of SPR changes, number of changes to T_{TARGET}, the number of failed rebuilding plans, the average annual variation in catch (AAV), the average catch over the first 10 of the rebuilding period, estimated rebuilding ratio, estimated rebuilding time, relative error of the rebuilding time, and the relative error of the rebuilding ratio. The strategies are 1) Status Quo, 2) Flexible, 3) Risk Averse, 4) Fixed, 1a) Error in Natural Mortality, 1b) Error in Steepness, 1c) Underestimation of Historical Catch, 1d) No Restriction on Catch Restriction, 1e) Assessment Frequency – Status Quo, and 2a) Assessment Frequency – Flexible.

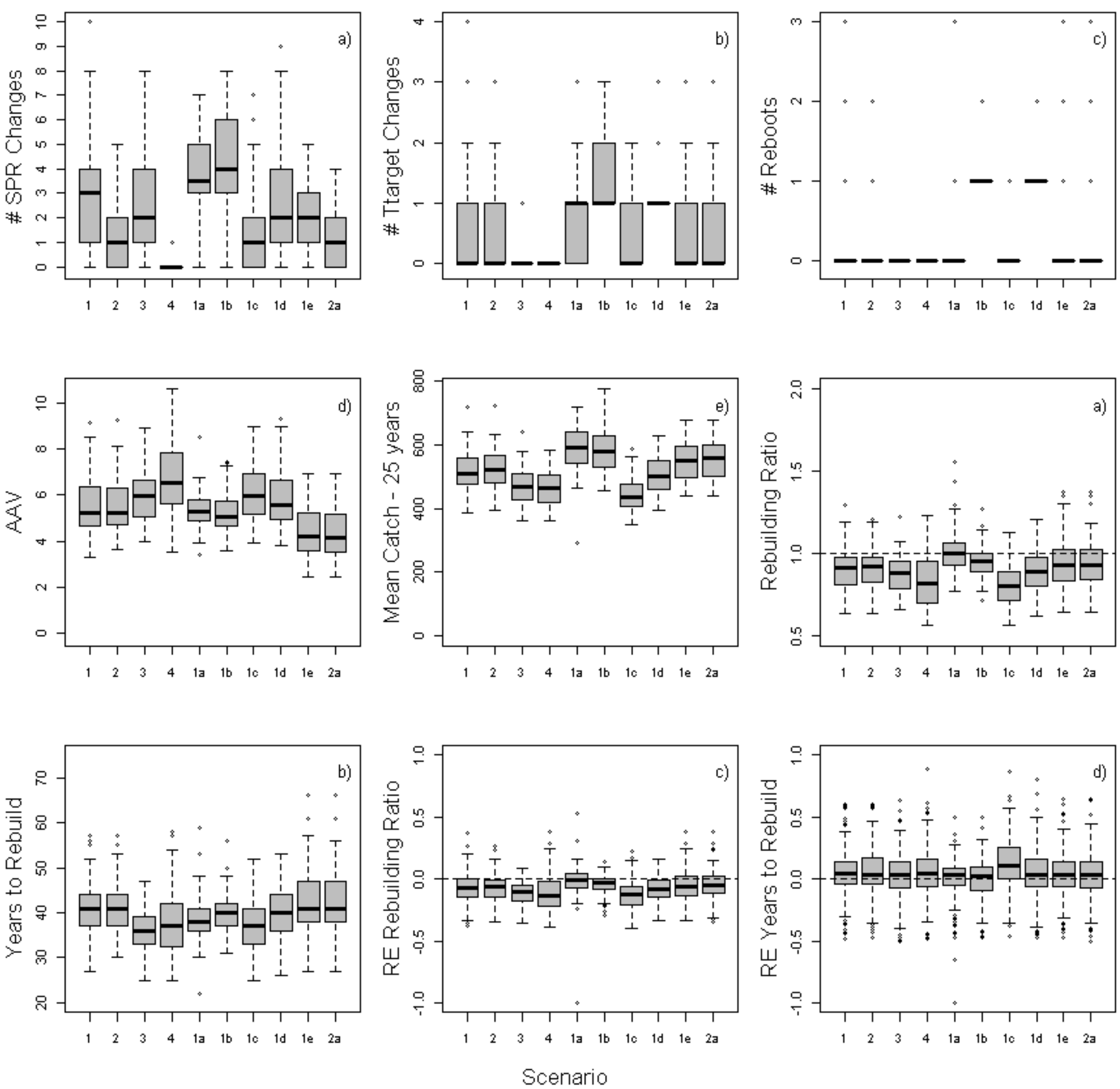

Figure A.3 The medium-lived rockfish life-history median values and 95% simulation intervals for the number of SPR changes, number of changes to T_{TARGET}, the number of failed rebuilding plans, the average annual variation in catch (AAV), the average catch over the first 25 of the rebuilding period, estimated rebuilding ratio, estimated rebuilding time, relative error of the rebuilding time, and the relative error of the rebuilding ratio. The strategies are 1) Status Quo, 2) Flexible, 3) Risk Averse, 4) Fixed, 1a) Error in Natural Mortality, 1b) Error in Steepness, 1c) Underestimation of Historical Catch, 1d) No Restriction on Catch Restriction, 1e) Assessment Frequency – Status Quo, and 2a) Assessment Frequency – Flexible.

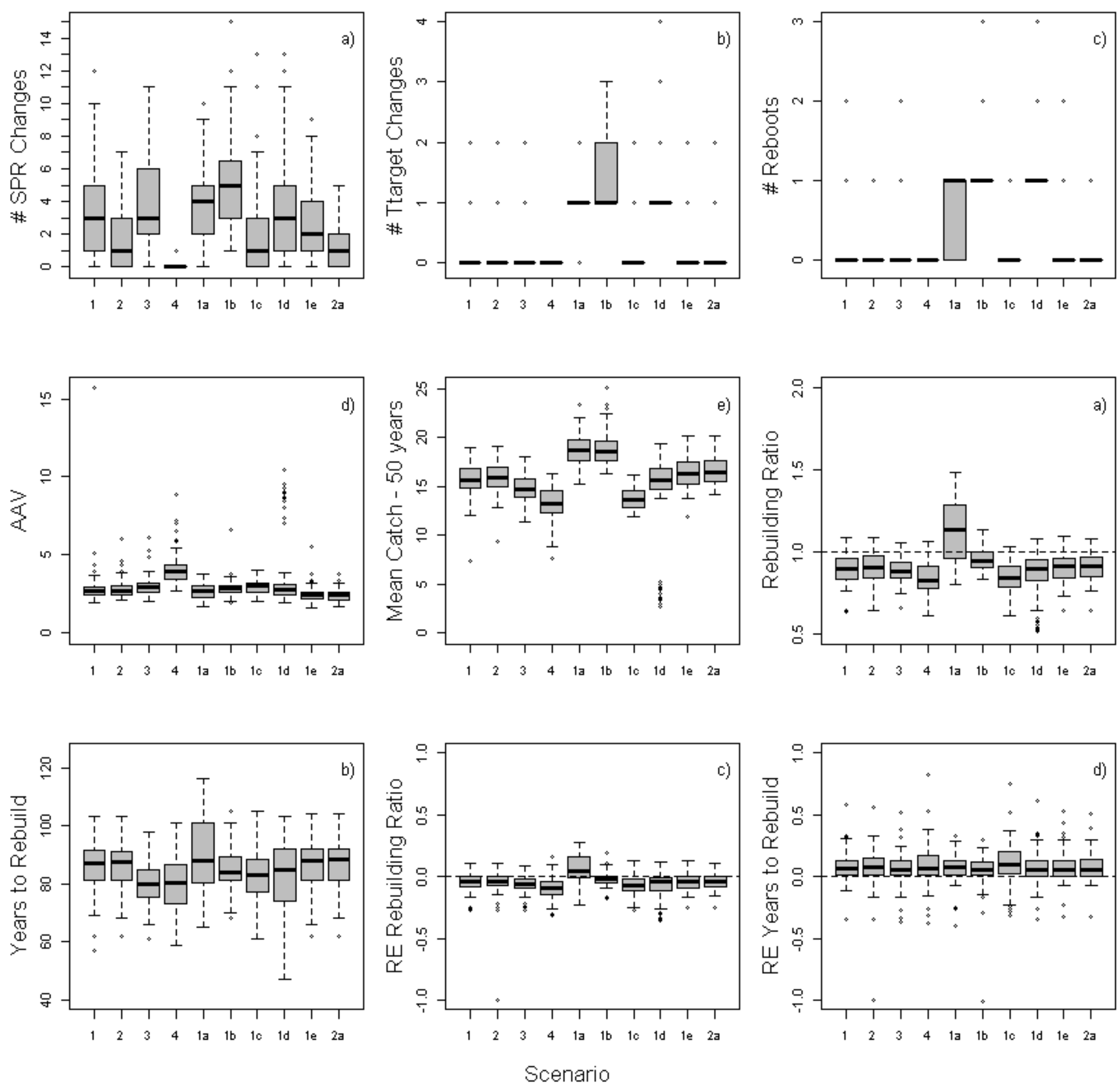

Figure A.4 The long-lived rockfish life-history median values and 95% simulation intervals for the number of SPR changes, number of changes to T_{TARGET}, the number of failed rebuilding plans, the average annual variation in catch (AAV), the average catch over the first 50 of the rebuilding period, estimated rebuilding ratio, estimated rebuilding time, relative error of the rebuilding time, and the relative error of the rebuilding ratio. The strategies are 1) Status Quo, 2) Flexible, 3) Risk Averse, 4) Fixed, 1a) Error in Natural Mortality, 1b) Error in Steepness, 1c) Underestimation of Historical Catch, 1d) No Restriction on Catch Restriction, 1e) Assessment Frequency – Status Quo, and 2a) Assessment Frequency – Flexible.