Evaluating the risks of misspecifying red tide mortality within Gulf grouper stock assessments

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Introduction

The most recent Gulf Gag (SEDAR 72) and Red Grouper (SEDAR 88) stock assessments use the by-catch fleet option in Stock Synthesis (SS) to model episodic red tide mortality. The by-catch fleet approach assumes a fixed selectivity pattern and a mortality rate of zero for all years except those selected for non-zero mortality by the analyst. The stock assessment model is allowed to freely estimate the magnitude of annual red tide mortality in the specified non-zero years. Previous simulation testing concluded that the by-catch fleet accurately estimates red tide mortality with low bias when it is designated in the correct years (Sagarese and Harford 2022). The specific red tide years used for the by-catch fleet have typically been determined using a combination of quantitative and qualitative information. Gulf Grouper assessments have recognized 2005 as the most extreme red tide event in recent history (SEDAR 33, 42). The severity of the 2005 red tide has been consistently supported by the binary index of red tide severity (Walter et al. 2013, Sagarese et al. 2018) and estimates of red tide mortality derived from the West-Florida Shelf (WFS) Ecospace model (Vilas et al. 2023). According to the Ecospace indices, none of the subsequent red tide events in 2014, 2018, and 2021 reached the severity of the 2005 event. However, results from Karnauskas et al.'s (SEDAR61-WP20) and Turley et al.'s (SEDAR72-WP-09) Local Ecological Knowledge (LEK) work showed that fishermen consistently identified 2005, 2014, and 2018 as major red tide events for red and gag grouper mortality. During the review of SEDAR 72 projections in 2021 (and later in 2022), 2021 was identified as a potentially important red tide year and was modeled as a "medium red tide" for projection purposes, largely informed by results from the WFS Ecospace model. In 2024, SEDAR 88 established 2021 as a fourth red tide event year based on Topical Working Group (TWG) discussions focused on red tide. However, no prior research has evaluated the impact of misspecifying the non-zero red tide mortality years selected in our stock assessments or measured the risk of omitting it altogether.

To address this gap, this study uses simulations to quantify the bias introduced by misspecifying red tide mortality settings in Gulf grouper stock assessments and the impact of that bias on fishery landings and population abundance. Specifically, we evaluate the consequences of incorrectly identifying event years and determine whether allowing SS to estimate red tide magnitude freely in all years serves as an improved alternative. We used the Management Strategy Evaluation for Stock Synthesis (SSMSE) r-package to conduct simulation tests on the SEDAR 61 Red Grouper stock assessment. Using this approach, a known population is simulated using an Operating Model (OM). This OM population is then sampled to produce simulated data sets that inform an Estimation Model (EM) that sets fishery landing targets which are then fed back into the OM in an iterative cycle. The OM parameters were conditioned on the original stock assessment to represent the historical period (1986–2017). The iterative MSE feedback period evaluated in the analyses presented herein spans a 30-year future simulation period (2018–2047). We conducted a series of experiments to explore how red tide parameter specifications influenced error and bias in stock assessments:

1. **Core**

Goal: Quantify the impacts associated with misspecifying the occurrence of red tide events in assessment models.
Method: A 2x2 factorial design where we evaluated two underlying red tide mortality realities (OMs) against two assessment assumptions (EMs)

- OMs: (1) No red tide and (2) red tide in 2018 and 2021
- EMs: (1) No red tide mortality estimated, and (2) red tide mortality estimated in 2018 and 2021.

2. **All years**
Goal: Evaluate whether simplifying the by-catch fleet approach by allowing SS to freely estimate red tide in all years rather than explicitly defining specific years serves as a robust alternative.
Method: A 3x1 design testing three different underlying realities (OMs) against a single assessment approach (EM).
    - OMs: (1) No red tide, (2) red tide in 2018 and 2021, and (3) red tide every 3 years
    - EM: Red tide mortality freely estimated in all simulated years

The matrices for each experiment are visualized in **Figure 1**. Collectively, these experiments aim to identify which year configurations result in the lowest error or bias from misspecification. By highlighting the potential risks of misspecification, this research will support management with the best available science on how to parameterize episodic mortality events in stock assessment models.

Methods

SSMSE and Residual Error

SSMSE is an R-package designed to test management strategies in SS before real-world implementation (Doering et al. 2023). It can utilize an existing SS model (such as a base model run from an accepted stock assessment) as the OM, which serves as the simulated truth. The OM consists of a fixed historic period conditioned on the original stock assessment as well as a future simulation period. During the future simulation period SSMSE iterates forward in 3 year steps, at each step:

1) Past data from the OM is sampled with error and fed into the EM (i.e. the simulated stock assessment model) that can be identical or differ in structure to the OM.
2) The EM is fit to this OM sampled data and used to estimate management targets (e.g. catch limits)
3) These management targets are then fed back into the OM as achieved landings to calculate the population structure for the next 3 years.

Throughout this paper, scenarios will be defined by the true OM settings crossed with the assumed EM settings (e.g. no_rt_x_no_rt). We will refer to the realized OMs (biological response after it has been subjected to the catch limits dictated by our EM) as the OM outcomes. While the EM outcomes show us what managers *think* is happening to the stock as a result of our assessment model, the OM outcomes show us what is *actually* happening to the stock. Changes to the EM can include: altering estimated or fixed parameters, and using different sampling structures. When an OM and an EM match, parameters and fishery reference points should be estimated with high mean accuracy and a precision subject to data sampling uncertainty. When they mismatch, we can quantify the mean bias or error that results from our assumptions not matching reality.

We used the SEDAR 61 Gulf Red Grouper SS model, refit to the expected data, as our base OM (SEDAR 2019). This model estimates red tide mortality in 2005 and 2014 during the historic modeled period (1986-2017). Red tide mortality is implemented as a by-catch fleet in SS with flat selectivity where all ages (including age-0) are equally vulnerable to red tide in all OMs and EMs. To follow current stock assessment methods, we fixed SigmaR to the value estimated in the stock assessment (0.811). This model was chosen over the Gulf Gag Grouper (SEDAR 72) and recently completed Gulf Red Grouper (SEDAR 88) models for its efficient runtime and relative simplicity (i.e. its use of a single bycatch fleet with flat selectivity).

To compare scenarios, we used the same error metrics for all experiments: Residual Error (RE), Percent Residual Error, and Total Removals as a percentage. Error was evaluated across three removal types – catches, discards, and environmental mortality–categorized into recreational, commercial, and red tide. The vertical line and longline fleets were summed to get the commercial fleet total removals; the trap fleet was closed in 2007 and was not relevant to our simulation period (2018-2047). We calculated the residual error (in million of tons, MT) for each removal type using the equation:

$$\text{Residual error} = OM_{removal\_type} - EM_{removal\_type}$$

Next we calculated the percent residual error, or percent bias using the equation:

$$\%\ \text{Residuals} = (OM_{removal\_type} - EM_{removal\_type}) / OM_{removal\_type} * 100$$

This equation works for the recreational and commercial removals, but did not work for the red tide removals because in the years where there were no red tides in the OM the result is undefined (infinity or NA). These instances are noted as “NA” in our results. To allow us to compare scenarios with all removals included in the % error, we used this equation:

$$\text{Total Removals \%: } \sum(OM_{removal\_type} - EM_{removal\_type}) / \sum OM_{removal\_type} * 100$$

All three error metrics were calculated over the 2018-2022 time period to demonstrate short term effects on the fishery. The percent bias equation was also used for evaluating bias in key derived quantities, including: Spawning Stock Biomass (SSB), and recruitment.

Core experiment

The goal of the core experiment was to identify the bias introduced by incorrect assumptions regarding red tide occurrences. We used a factorial design consisting of 4 scenarios characterized by either 2 red tide events (2018 and 2021) or no red tide events in the OM or EM throughout the simulation period (2018-2047). These scenarios were defined as scenarios 1-4 in **Table 1** and visualized in **Figure 1**. An incorrect assumption is represented by a scenario where the OM and EM are mismatched. We chose 2018 and 2021 as the two years with red tide mortality because they were red tide event years explicitly included in the SEDAR 88 model, which terminated in 2022 (terminal year of SEDAR 61 was 2017). The magnitude of the red tide mortality assumed in the OM was 0.1 which is considered a moderate red tide event (SEDAR 88). Red tide mortality magnitude was estimated by the EM but the years where red tide occurred were fixed.

All years experiment

The goal of the all years experiment was to evaluate whether allowing SS to freely estimate red tide mortality in all years would serve as a robust alternative to having to explicitly define specific event years. In practice, the true history of red tide events is uncertain. We therefore test how this single EM performs across three different versions of reality (OMs): no red tide events, 2 red tide events, and repeating red tide events every 3 years. These are scenarios 5-7 in **Table 1** and visualized in **Figure 1**. The red tide mortality in the OM is set to a magnitude of 0.1, and the first two red tide events were in 2018 and 2021, to match the core experiment.

Results

Core

The core experiment demonstrated that when the OM and EM match, red tide events are correctly estimated, and when the OM and EM mismatch, results are biased. **Figure 2** presents the average red tide mortality over time in the OM and EM, which highlights the differences between the scenarios. In the no_rt_x_rt_2 scenario where there are no red tides in the OM but the EM is allowed to estimate red tide events in 2018 and 2021, we see minimal (0.02) overestimation of red tide mortality. In the rt_2_x_no_rt scenario where there are red tide events in 2018 and 2021 in the OM and no events in the EM, the red tide mortality in the OM, is completely unaccounted for in the EM. Both the rt_2_x_rt_2 and no_rt_x_no_rt scenarios show the OM and EM matching with minimal difference in red tide mortality in 2018 and 2021.

The residual error of removals demonstrated that the matching scenarios had less error than the mismatching scenarios. The residual error percentages for each removal type, and the total removals are presented in **Table 2**. Commercial removals had the lowest range of error from -1.33 to 0.53 in the no_rt_x_rt_2 and rt_2_x_no_rt scenarios respectively. Recreational removals were always overestimated and ranged from 1.41 to 9.87 in the no_rt_x_rt_2 and rt_2_x_no_rt scenarios respectively. The only scenario that overestimated both the commercial and recreational removals was the scenario where there were red tide events in the OM and none in the EM (rt_2_x_no_rt). This scenario (rt_2_x_no_rt) also has the highest red tide removal error at -100% because there were red tide events in the OM that were not accounted for in the EM.

Total removals captured the error of all three types of mortality and allowed us to identify the worst and best case scenarios. The worst case scenario was rt_2_x_no_rt where red tide mortality was 100% underestimated and recreational removals were overestimated by 9.9% which contributed to a total underestimation of 10.3% total removals. In this case, the model underestimated the red tide mortality, so there were more fish available to increase commercial and recreational catch, but the trade-off between catch and red tide mortality was not 1-to-1. The model also reduced recruitment (**Figure 3**) and SSB

(**Figure 4**) to account for the extra mortality that was not estimated. The best case scenario was less clear, with both matching scenarios (no_rt_x_no_rt and rt_2_x_rt_2) having low total error (0.7% and -1.13%).

All years

When turning on red tide mortality in all years of the EM, SS was able to use the by-catch fleet as a "catch all" mortality fleet. **Figure 5** demonstrates the ability of the EM to capture trends in the OM by spreading the extra mortality across years which introduces a low level of extra mortality in non-red tide years. This resulted in less error in red tide mortality in the short term, while commercial and recreational removal errors were similar to the core experiments (**Table 3)**. The lowest total removal error occurred in the rep_3_x_all_years scenario at 0.63% error which is 0.07% less error than the perfect knowledge scenario from the core experiment. The highest error was in the no_rt_x_all_yrs scenario at 4.05% which is largely attributed to the overestimation of red tide and underestimation of commercial catch. Overall, none of these scenarios have an effect on commercial or recreational removals so there should be minimal foregone yield.

When checking for trade-offs, SSB and recruitment have minimal bias in the all years scenarios. **Figure 6** shows that the bias in SSB between the OM and EM in both scenarios with red tide events is close to zero and similar to rt_2_x_rt_2. **Figure 7** shows that the recruitment is very similar to the rt_2_x_rt_2 for both scenarios where red tide occurs.

Discussion

Simulation testing various red tide event frequencies should help us understand how our assessment models are performing by identifying any bias or risks of misspecification, ultimately improving management advice and fishery outcomes. Our first experiment concluded that excluding red tide events from the stock assessment model when they did in fact occur, introduced high bias to the SSB and recreational removals, which could put overly restrictive catch limits on recreational fishing. Similar trends were identified in Sagarese and Harford 2022, and our results emphasize the importance of accounting for red tide mortality in our Gulf grouper assessments. Excluding (i.e., ignoring) red tide mortality (rt_2_x_no_rt) within the assessment estimation model when it did actually occur was the worst case scenario for management because it had the highest recreational catch error and underestimated SSB, which could lead to overly restrictive catch limits on recreational fishing. This remained the worst scenario through all of the following experiments and is shown as the worst reference point in some of the figures. These results highlight incorrectly fixing red tide mortality at zero when it actually occurred as the largest risk evaluated in this study.

Allowing the estimation model to estimate red tide mortality freely in all years would therefore alleviate one of the biggest concerns with the current approach - the need to identify years where red tides were severe enough to cause mass mortality. When red tide was estimated in all years, the recreational removals, commercial removals, and total bias were consistent with the perfect knowledge scenario, and the red tide removals had 2% less bias. Red tide estimates were improved in the short-term, with more accurate estimates of the amount of fish removed by red tide events without having to designate the years. Additionally, the SSB had the same level of bias as the perfect knowledge (rt_2_x_rt_2) scenario, suggesting that estimating red tide mortality in all years does not significantly affect the SSB which would lead to similar management reference points. These results differ from the results of Sagarese and Harford, where their alternative historical model with estimated red tide mortality in all years (1986-2017) had highly biased estimates of terminal fishing mortality and SSB. The EMs in our simulation analysis only estimated red tide in the correct years during the historic conditioning period, the EM scenarios only differed in which years red tide mortality was estimated for during the simulation period (2018-2047). It is also possible that the SSMSE data sampling method may have made the EMs more robust at estimating the magnitude of the red tide mortality than could be expected in a real stock assessment due to increased contrast in the bootstrapped values that only included observation error in the data streams. It may be beneficial for SEDAR 105 to consider a sensitivity run where red tide mortality is estimated in all historical years to see whether the assessment model picks up on past red tide events, particularly in earlier years before satellite data were available to identify red tides (see Blake et al. 2022 for a reconstructed timeline).

While turning on the by-catch fleet in all years allows SS to account for red tide mortality, it also inherently accounts for any other source of episodic mortality currently unaccounted for in the stock assessment. This capacity may account for the past limitations observed in attempting to utilize externally derived red tide magnitude estimates directly within stock assessments (SEDAR 88). While active blooms produce toxins harmful to Gulf Groupers, the subsequent hypoxia associated with these events can also lead to mass mortality events. Turley et al. found that hypoxic conditions were seen in 2005, 2008-2011, 2014-2016, and 2019, in coastal regions that could affect Gulf Gag and Red Groupers (SEDAR 72-WP-10). Because previously mentioned indices and by-catch fleet configurations have focused exclusively on identifying severe red tide events, these hypoxic events, which occur in years without modeled red tide mortality, may remain entirely unrepresented in the stock assessment. Similarly, mass mortality events have been documented following cold snaps (e.g. 2010) for Goliath Groupers (SEDAR 47). If the red tide fleet is turned on in all years, it may be appropriate to call it an “extra mortality” fleet. Large mortality events estimated in future assessments using this extra mortality fleet would need to be validated from observations, an Ecospace model, or LEK.

Our tentative recommendations would be to consider running the Gag Grouper stock assessment with red tide turned on in all years and validate the red tide magnitude and frequency with external observation. This will allow SS to estimate external environmental mortality in all years and may capture die-offs that were not previously considered. The Ecospace index (Chagaris 2025) and LEK (Turley et al. 2021) could validate red tide events and be expanded to account for other episodic mortality to validate this method. Future analysis should focus on testing selectivity patterns and applying this work to a Gag Grouper SS model.

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Tables and Figures

Table 1. List of scenario names and descriptions. Scenarios 1-4 are considered the default presence/absence matrix of red tide mortality for the core experiment. Scenarios 5-7 explore how well an uninformed simulation predicts red tide events in the all years experiment.

Id #	Scenario	Description
1	no_rt_x_no_rt	No red tide events in the OM and EM
2	no_rt_x_rt_2	No red tide events in the OM, 2018 and 2021 in the EM
3	rt_2_x_no_rt	2018 and 2021 in the OM, no red tide in the EM
4	rt_2_x rt_2	2018 and 2021 red tide events in the OM and EM
5	no_rt_x_all_years	No red tide in the OM, all years in the EM
6	rt_2_x_all_years	2018 and 2021 in the OM, all years in the EM
7	rep_3_x_all_years	Repeating red tides every 3 years starting in 2018 in the OM, all years in the EM

Table 2. The proportional bias of commercial, recreational, and red tide removals from 2018-2022 for the core red tide scenarios. Each residual error percentage represents the proportional bias in a negative or positive direction when summed across the first 5 simulation years (2018-2022). The total removals present the residual error in Million Tons (MT) to put the tonnage in perspective. Finally, the total proportion of removals demonstrates that while the red tide removals have higher bias percentages, they make up very little of the total removals.

Scenario (OM x EM)	Commercial Removals (%)	Recreational Removals (%)	Red Tide Removals (%)	Total Removals (MT)	Total Removals (%)
no_rt_x_no_rt	-1.00	2.84	-	112.12	0.70
no_rt_x_rt_2	-1.33	1.41	-	558.56	3.52
rt_2_x_no_rt	0.53	9.87	-100.00	-1836.13	-10.31
rt_2_x_rt_2	-0.82	3.74	-14.86	-198.50	-1.13

Table 3. The proportional bias of commercial, recreational, and red tide removals from 2018-2022 for the all years experiment. Each residual error percentage represents the proportional bias in a negative or positive direction when summed across the first 5 simulation years (2018-2022). The total removals present the residual error in Million Tons (MT) to put the tonnage in perspective. Finally, the total proportion of removals demonstrates that while the red tide removals have higher bias percentages, they make up very little of the total removals.

Scenario (OM x EM)	Commercial Removals (%)	Recreational Removals (%)	Red Tide Removals (%)	Total Removals (MT)	Total Removals (%)
no_rt_x_all_yrs	-1.28	1.29	-	630.74	4.05
rep_3_x_all_yrs	-0.99	2.78	0.31	108.28	0.63
rt_2_x_all_yrs	-0.78	3.61	-12.70	-153.45	-0.89

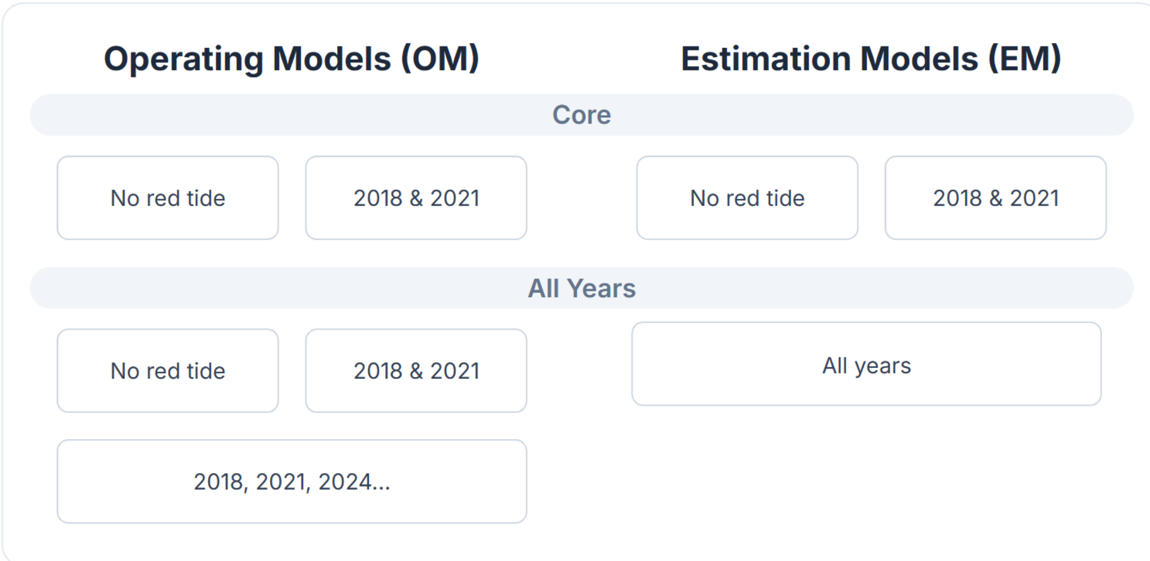

Figure 1. Diagram of the OMs and EMs included in each experiment. For the core experiment, there was the presence or absence of red tide events in 2018 and 2021. For the all years experiment there were 3 OM configurations with varying red tides, and one EM configuration applied to all of them.

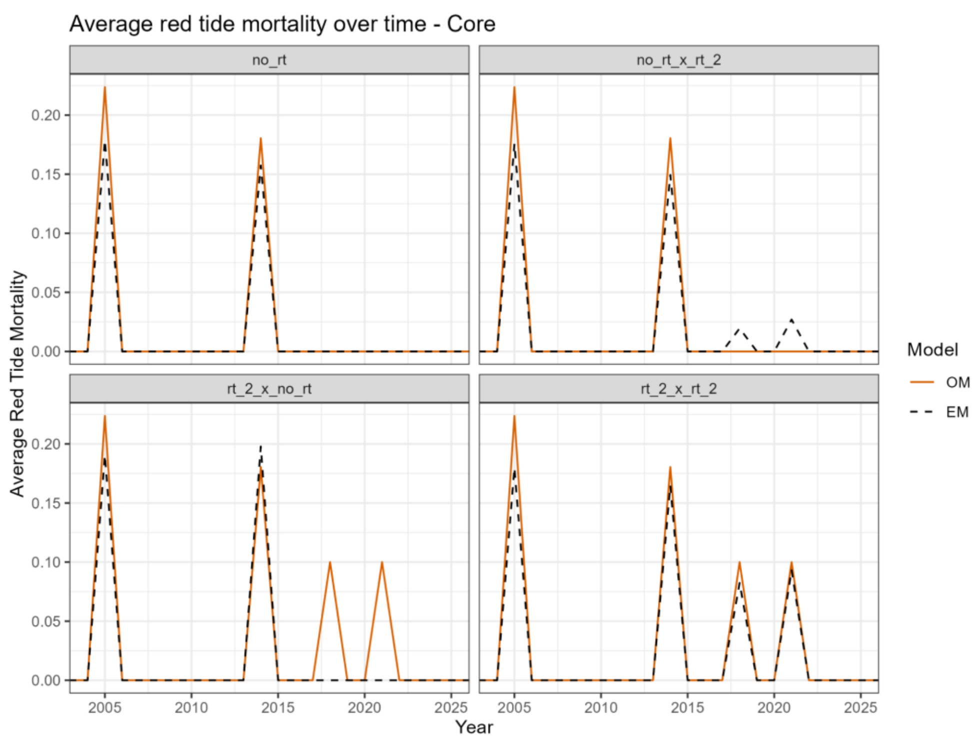

Figure 2. The average red tide mortality over time for the core experiment where the simulation period starts in 2018. This plot demonstrates that when the OM and the EM have matching initial settings, the lines match up, and when the settings mismatch, the red tide mortality is over or underestimated.

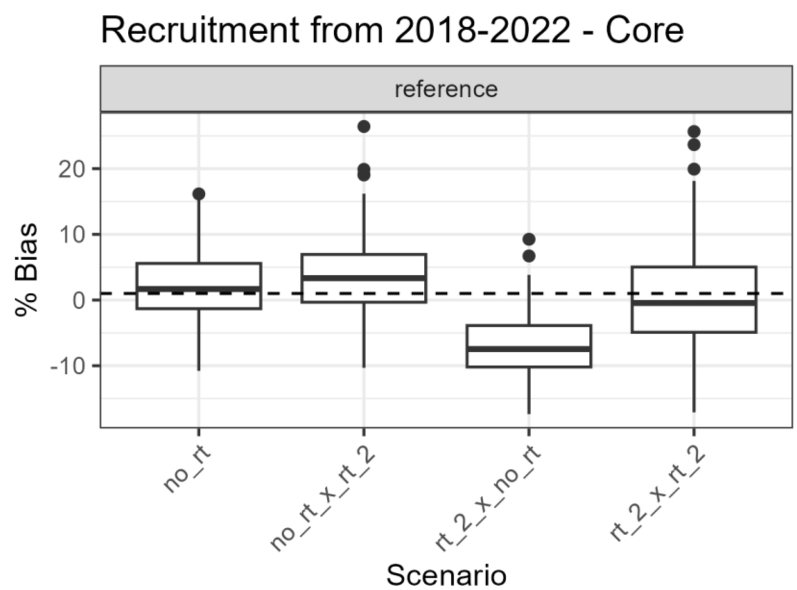

Figure 3. Percent bias of recruitment in the short-term for the core scenarios. Each boxplot represents the spread of bias in the 100 iterations for each scenario averaged across 2018-2022. The horizontal dashed line represents no bias so the median lines above or below the line represent when the EM results overestimated or underestimated recruitment relative to the OM.

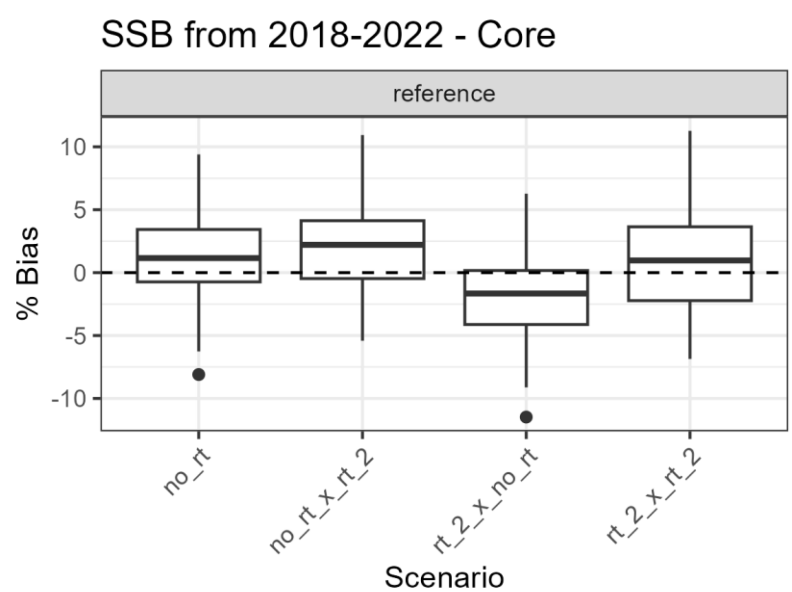

Figure 4. Percent bias of SSB in the short-term for the core 4 scenarios. Each boxplot represents the spread of bias in the 100 iterations for each scenario for each scenario averaged across 2018-2022. The horizontal dashed line represents no bias so the median lines above or below the line represent when the EM results overestimated or underestimated recruitment relative to the OM.

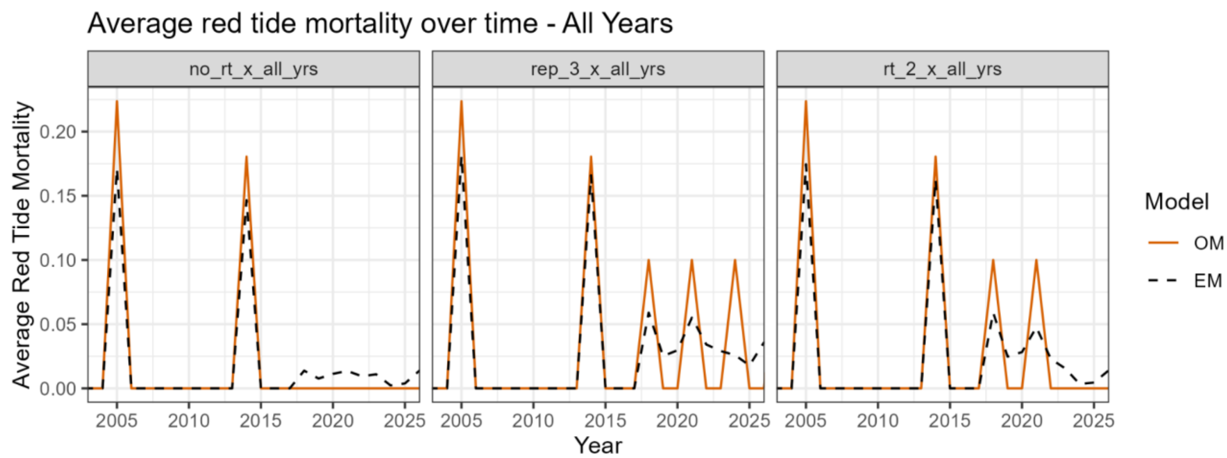

Figure 5. Average red tide mortality over time for the all years experiment where the simulation period starts in 2018. The EM line (black, dashed) demonstrates the estimated red tide over time when SS is allowed to estimate extra mortality from a by-catch fleet every year. The line overestimates in non-red tide years and underestimates in red tide years, spreading the mortality out but keeping the general trends of the OM line (orange, solid).

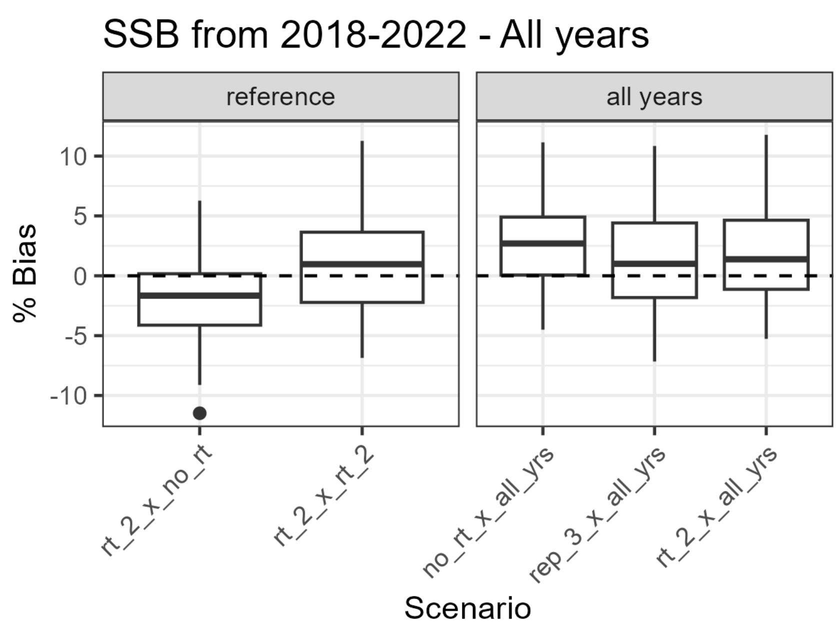

Figure 6. The percent bias of SSB in the short-term in the all years scenarios with reference scenarios. The rep_3 and rt_2 scenarios have the same amount of bias as the rt_2_x_rt_2 scenario. The no_rt_x_all_years scenario has the worst fit of the all years scenarios and overestimates the SSB.

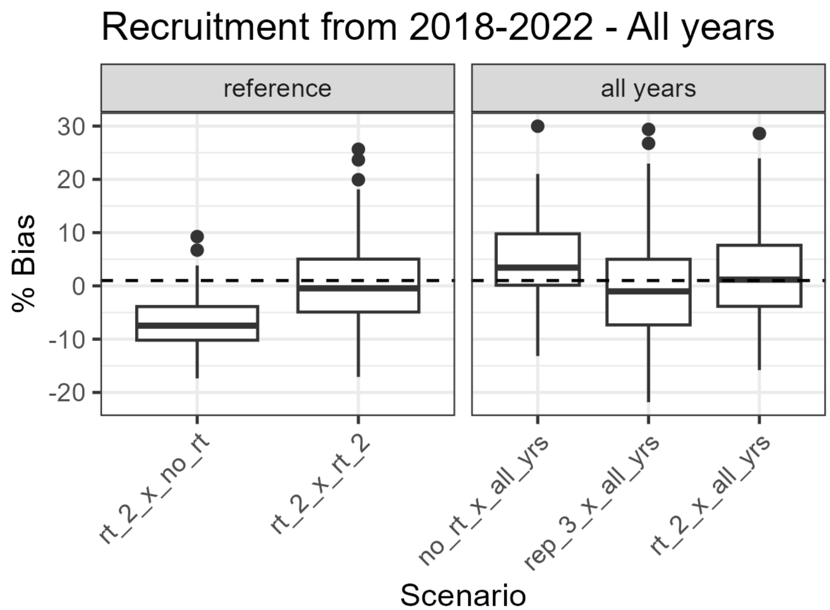

Figure 7. The percent bias of Recruitment in the short-term in the all years scenarios with reference scenarios. The rep_3 and rt_2 scenarios have the same amount of bias as the rt_2_x_rt_2 scenario. The no_rt_x_all_yrs scenario has overestimated recruitment most likely to account for additional mortality in the EM.