Mid-Atlantic Fishery Management Council
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Michael P. Luisi, Chairman | P. Weston Townsend, Vice Chairman
Christopher M. Moore, Ph.D., Executive Director

MEMORANDUM

Date: July 29, 2022

To: Council

From: Brandon Muffley, Council staff

Subject: Summer Flounder Management Strategy Evaluation: Meeting Materials

On Tuesday, August 9, 2022, the Mid-Atlantic Fishery Management Council (Council) and the Atlantic States Marine Fisheries Commission Summer Flounder, Scup, and Black Sea Bass Board (Board) will review the final results and outcomes from the EAFM recreational summer flounder management strategy evaluation (MSE).

Materials listed below are provided for Council and Board consideration of this agenda item.

Materials behind the tab:
- Staff Memo: Overview of MSE Process, Outcomes, and Potential Application
- Executive Summary and Overview of MSE Results
- Updated: Overview of the Summer Flounder MSE Simulation Model Specifications (by G. Fay)
- Updated: Overview of the Summer Flounder Recreational Demand Model (by A. Carr-Harris)
- All MSE model outputs (by performance metric, operating model alternative, and state) can be found here - https://bit.ly/fluke-mse-metrics.

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EAFM Recreational Summer Flounder Management Strategy Evaluation

Summary of Process, Outcomes, and Potential Application

August 2022 Council Meeting

Prepared By: Brandon Muffley, Council Staff

July 29, 2022

Background

This briefing document provides a summary on the overall process, general outcomes, and potential application regarding the recreational summer flounder management strategy evaluation (MSE)[1]. Development of this MSE is part of the continued implementation of the Mid-Atlantic Fishery Management Council's (Council) Ecosystem Approach to Fisheries Management (EAFM) structured framework process. Through the EAFM process, the Council identified summer flounder as a high-risk stock and agreed to conduct an MSE that would focus on discards in the recreational fishery. The overall objectives of this MSE are to (1) evaluate the biological and economic benefits of minimizing discards and converting discards into landings in the recreational summer flounder fishery, and (2) identify management procedures to effectively realize these benefits.

A technical work group and core stakeholder group worked collaboratively to complete this task and the MSE successfully met the objectives identified by the Council and Atlantic States Marine Fisheries Commission's Summer Flounder, Scup, and Black Seas Bass Management Board (Board). The performance of eight different management procedures under three different states of the world (scenarios) were assessed using a suite of biological, social, and economic performance metrics (e.g., stock biomass and fishing mortality as well as angler welfare and ability to keep a fish). Results from the MSE suggest there are management procedures that outperform status quo management at reducing discards and converting those discards into harvest while limiting risk to the summer flounder stock.

At the August meeting, the Council and Board will be presented with the model outcomes, trade-off analysis results, and broader MSE project takeaways. Staff will then offer potential next steps and opportunities to utilize the results of the MSE, the MSE simulation models, and general framework developed through the MSE process. Given the results of the MSE, the Council and Board should be prepared to offer feedback and direction regarding interest in additional analyses to be considered and the anticipated

[1] To find more information about the entire summer flounder MSE project, please see: https://www.mafmc.org/actions/summer-flounder-mse.

timeline for potential application (e.g., to help inform and identify potential recreational summer flounder regulations in 2023 or future).

Why an MSE?

MSE’s are a tool that allows scientists, managers, and stakeholders to identify and test different management strategies and their ability to achieve desired, and often conflicting, management objectives before implementation. By utilizing an MSE to evaluate the objectives associated with this project, the Council and Board can consider new and more comprehensive information regarding the performance of traditional recreational management strategies within an ecosystem context and align the EAFM process and the typical recreational management process.

Two models were developed as part of this project, an operating/biological model and an implementation/recreational demand model, which are coupled within an MSE simulation framework that is designed to emulate summer flounder stock dynamics, both commercial and recreational fisheries, and the management system. Together these models and the MSE framework simulate the summer flounder population, its ecosystem, and different management procedures of interest while also considering key uncertainties and ecosystem drivers. This MSE won’t specify a single outcome or strategy that will solve and address all management issues or concerns associated with recreational summer flounder discards. It will, however, provide the Council and Board an opportunity to evaluate and balance different management procedures and their associated biological, social, and economic trade-offs that best address their management objectives.

The Recreational Summer Flounder MSE Process

This MSE was structured into two different phases – a public scoping and stakeholder engagement phase, followed by a management considerations and model development phase – each lasting about one year. Stakeholder participation and input is a critical component of a successful MSE and since the MSE process was relatively new to the Mid-Atlantic, an extensive and inclusive stakeholder process was developed as part of phase 1 for this project (Figure 1). A variety of scoping and outreach initiatives were conducted covering a range of targeted audiences that offered different levels of engagement for input. The goal of this approach was to invest a significant amount of time early in the process on education and outreach and then continued, targeted feedback throughout the process to ensure better outcomes at the end of the project. The public response and interest, in terms of the total number of participants and the diversity of feedback, was very high for all steps in phase 1.

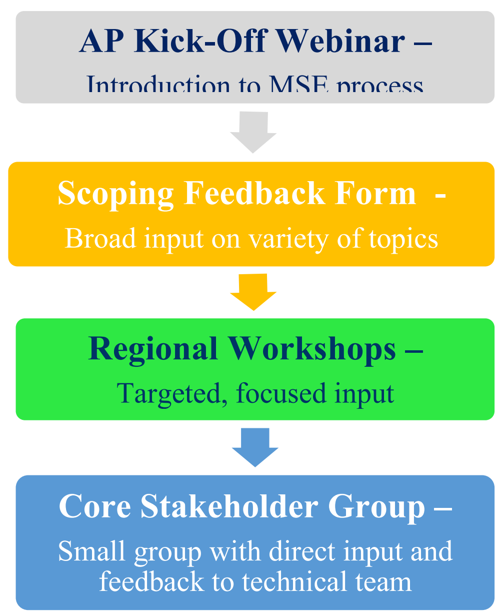

Figure 1. Process and approach to Phase 1 (public scoping and stakeholder engagement) of the

All of the input received in phase 1 was synthesized and used as a starting point and idea generator for the second phase of the project. Through a series of five webinar and in-person workshops, a small core group of diverse stakeholders collaborated with an MSE technical work group (Table 1) to identify the different management considerations and priorities and develop the decision tools and modeling framework necessary to address the management interests. Each workshop would build off the work conducted at the previous workshop as the core stakeholder group members would identify, refine, and prioritize management objectives, performance metrics, management procedures, management tradeoffs, key uncertainties and assumptions, data considerations, and model outputs. Following each workshop, the technical work group would then work to incorporate this feedback into the development of the biological and recreational demand models given the model structure, capabilities and limitations, the availability and uncertainty of the data elements, and the overall project focus and deadlines. This collaborative and iterative process between the two groups was a positive experience that worked very well to help ensure a common understanding, general agreement, and support for the process and project outcomes.

Management and Modeling Considerations

Here we describe the rationale by the core group and technical work group for the development and prioritization of the different management components and model alternatives that comprised the simulation experimental design that were evaluated within the MSE framework.

Management Objectives

While the Council identified the overall project objectives when originally agreeing to conduct an MSE, they are quite broad and don't explicitly provide direction or guidance for other important management considerations. For example, management may also be interested in a goal to ensure that any management alternatives developed to address recreational discards don't significantly disadvantage one state, region, or sector. To help identify additional management objectives to be considered by the MSE, potential management objective themes or categories were identified during public scoping and were then refined by the core group and approved by the Council and Board. These expanded management objectives, listed below, are intended to help us define and understand what a successful recreational fishery would look like that minimizes discards and discard mortality.

1. Improve the quality of the angler experience
2. Maximize the equity of anglers' experience
3. Maximize stock sustainability
4. Maximize the socio-economic sustainability of the fishery

Management procedures

Management procedures represent example recreational management regulations (i.e., size, season, and possession limits) to be evaluated relative to different performance metrics (details below) and identify which procedures best meet the four different management objectives. The management procedures considered here are not intended to specify an exact set of recreational regulations that would be implemented in 2023 or future date. Rather, these management procedures are examples intended to represent the range and scope of regulations the fishery is likely to operate in and are of interest to management and stakeholders. In addition, it was important to consider management procedures that were different enough from one another in order to evaluate the relative differences in performance. Should the Council and Board express interest in certain management procedures or particular procedure categories (e.g., current regions, new regions, coastwide, slot limits), more refined alternatives would be developed and analyzed for consideration and potential implementation in 2023 or beyond.

The management procedures consider different size limits, including slots, season length adjustments, coastwide options, and existing and different regional configurations. Other management tools or actions (e.g., reporting requirements, hook/terminal tackle) were discussed and proposed by stakeholders but not included in the analysis because there was either a lack of data to inform the impact of those regulations or not enough time for them to accurately and appropriately be modeled.

The same management procedure was implemented for an entire 26-year projection period (13 new/updated stock assessments and specification cycles). This was done for a few reasons. First, given the time scales at which summer flounder stock dynamics operate (e.g., growth, recruitment, sex ratios, generation time), it would be difficult to evaluate the benefits and/or effects on the summer flounder stock under continually changing regulations. In addition, the goal of the MSE is to provide strategic advice and information regarding the "long-term" performance of different management procedures on both the stock and fishery.

There were seven different alternative management procedures evaluated that were grouped into four different categories based on similar configurations. Details on each management procedure alternative are provided below and the management procedure number and shorthand description in parentheses is the same in all of the background materials included behind Tab 2.

Status Quo/Current Region Breakdown Alternatives

The 2019 regional regulations were specified as status quo and are the baseline regulations which other alternative management procedures are compared and evaluated against. The 2019 regulations were selected as the status quo/baseline regulations for a variety of reasons. First, regulations remained relatively unchanged from 2019 – 2021 and managers and stakeholders likely have a good understanding of management performance and angler satisfaction with these regulations. In addition, when model development was started in 2020 and into 2021, the 2019 recreational data was the most complete dataset available. The 2020 data includes imputed data because of the loss of sampling due to COVID-19 and the 2021 data was not available until the spring of 2022. Regulations for many states changed in 2022 and the technical work group did not want to use 2022 regulations given the lack of data on their performance and to minimize conflating the MSE project goals and the desire to predict 2022 harvest.

Management procedure alternatives #2 and #3 would retain the existing regional configuration but consider the implications of a reduction in the minimum size for all states or, for many states, extending the open season. Under management procedure #2, states/regions would retain their existing regulations but the minimum size within each state/region would be dropped by 1 inch in an effort to increase angler retention, reduce discards, and lower the proportion of female harvest. Management procedure #3 would retain the same size and possession limits for each state/region but would extend the season length, for most states, into April and October. This would allow for greater overlap in season with other fisheries and hopefully minimize discards of summer flounder when other fisheries are open and summer flounder are available.

Management Procedure #	Procedure Explanation
1 (status quo)	Status Quo - 2019 regulations
2 (minsize-1)	2019 regulations except for a 1 inch decrease in minimum size within each state, but not to go below a minimum of 16 inches
3 (season)	2019 regulations except season of April 1 - Oct 31 for all states

Modified Regional Breakdown Alternative

Management procedure #4 would consider a different regional breakdown and each state within a region would have the same management measures. The same regional breakdown as currently implemented for black sea bass was considered here. This alternative was developed to address feedback received from stakeholders interested in reducing regulatory complexity and increasing state angler equity while also allowing for some modifications and liberalizations from the current regulations.

Management Procedure #	Procedure Explanation
4 (region)	**New Regional Breakdown:** **MA - NY:** 5 fish possession, 18 inch minimum size, season of May 1 - Sept 31 **NJ:** 4 fish possession, 17 inch minimum size, season of May 1 - Sept 31 **DE - NC:** 4 fish possession, 16 inch minimum size, season of May 1 - Sept 31

Coastwide Alternatives

Historically, the recreational summer flounder fishery was managed under coastwide regulations with one set of regulations for all states. There was a lot of stakeholder interest in considering coastwide measures again given real or perceived inequities in regulations between the states and different sectors. Coastwide management measures would reduce management complexity, make enforcement easier, and may provide for more predictable stock responses to regulations.

Management procedure #5 was initially considered by the core group as a potential lower bound option that would greatly minimize the possession and size limit in order to increase the potential that trips, for any sector, would produce a fish to take home. The 14 inch minimum size limit would align with the commercial minimum size for consistency across sectors and potentially reduce the harvest of female summer flounder. After reviewing the initial model results for this alternative, the core group agreed to remove this alternative given the extremely low possession limit and the likelihood that this option may lead to increased discards as anglers are likely to continue fishing despite catching a 14 inch in the hopes of retaining larger fish.

Management procedure #6 represented a coastwide option that was generally in the middle of all the existing state regulations (pre-2022) with components in some states more liberal and some more restrictive. This option is also generally within the range of recent options considered for non-preferred coastwide measures.

Management Procedure #	Procedure Explanation
5	1 fish possession limit, 14 inch minimum size, May 15 - Sept 15 – removed
6 (c3@17)	3 fish possession limit, 17 inch minimum size, May 1 - Sept 30

Slot Limit Alternatives

Slot limits within the recreational summer flounder fishery have been considered and analyzed on several occasions and a maximum size limit for federal waters was recently added to the FMP so that slot limits could be implemented if there was an interest from management. Many stakeholders expressed a lot of interest in considering slot limits and noted the successful use of slot limits in other recreational fisheries. Two different types of slot limit options were developed for this MSE and these options were modeled and considered to be implemented at the coastwide level.

Management procedure #7 is based on management measures implemented in 2022 by New Jersey and modified based on feedback from the core group and comments made by the ASMFC Technical Committee when they reviewed New Jersey's proposal. This alternative would allow for one smaller fish between 16 and 19 inches and then two fish greater than 19 inches. Allowing for one small fish is intended to provide for increased opportunities for anglers to take home one fish across modes and states while retaining a two fish possession at a larger size could constrain harvest yet allow anglers the ability to take home a trophy fish.

Management procedure #8 would implement a true slot and would not allow for the harvest of summer flounder greater than 20 inches. This alternative is intended to provide for greater opportunities to retain a fish across states and modes, while also reducing the amount of larger female harvest.

Management Procedure #	Procedure Explanation
7 (c1@16-19)	**Modified slot:** 1 fish from 16 inches - 19 inches, 2 fish 19 inches and greater, May 1 - Sept 31
8 (slot)	**True slot limit**: 3 fish possession limit between 16 inches and 20 inches, May 1 - Sept 31

Performance Metrics

Quantifiable performance metrics are used to evaluate the success of a particular management procedure in achieving the desired management objectives. The metrics considered here were compiled from survey responses, refined and prioritized by the core group, turned into measurable units by the technical work group, and calculated using the outputs from the different MSE models. Different metrics were specified for each of the four management objectives and calculated at either the trip, state/region, or coastwide level. In addition, several metrics are calculated relative to the modeled baseline or *status quo* (i.e., 2019 recreational) regulations to determine if an alternative management procedure represented an improvement or a less favorable outcome. In addition, these performance metrics were calculated across three different operating model configurations (more information below) to test how robust the performance of these different management procedures will be under different ecosystem conditions and management drivers.

The core group expressed a lot of interest in calculating performance metrics by mode given the differential impacts changing regulations, particularly minimum size limits, are likely to have by mode. However, the technical work group expressed concerns given the limited and variable recreational data by mode, particularly at the state, wave, or trip level needed for some of the metric calculations at the mode level. In addition, the technical work group noted the significant amount of information and outcomes already being generated from the MSE model outputs (17 metrics by state or region, across 7 management procedures, for 3 different operating models) could make interpretation and summarizing difficult. However, the technical work group did indicate the modeling framework is built in a way that it could be adapted to evaluate mode specific outcomes and this may be an area of future exploration. The core group and technical work group also discussed a number of other metrics that might evaluate changes in non-compliance rates, changes in discard mortality rates, and regulatory complexity. However, given time constraints, data availability, output complexity, and modeling assumptions, as well as the relative importance of those metrics to the stakeholders, these metrics were considered a lower priority and removed from consideration in the results presented here.

Listed below are the 17 final performance metrics, by management objective, that were prioritized by the core group and calculated by the technical work group:

<u>Management Objective 1: Improve the quality of the angler experience</u>

1. Percent of trips that harvest one fish
2. Average number of harvested fish per trip
3. Consumer surplus* per trip
4. Percent of trips harvesting a trophy fish (>28 inches)

* Consumer surplus – a measure of the amount of money anglers would be willing to pay to see a management procedure implemented. An economic calculation of angler satisfaction.

<u>Management Objective 2: Maximize the equity of anglers' experience</u>

5. Percent change in chance of a trip with a harvested fish
6. Percent difference across states in chance of a trip with a harvested fish
7. Change in retention rate (harvested:discarded)
8. Change in retention rate across states

<u>Management Objective 3: Maximize stock sustainability</u>

9. Percent chance the stock is overfished
10. Percent chance of overfishing

11. Total spawning stock biomass (mature males and females)
12. Average number of discards per trip
13. Change in recreational removals (harvest and dead discards)
14. Percent of harvest that are female

Management Objective 4: Maximize the socio-economic sustainability of fishery

15. Total number (millions) of summer flounder trips
16. Percent change in consumer surplus (angler satisfaction) by state (across all trips)
17. Percent change in fishery investment (e.g., sales, income, employment)

These metrics, and the four management objectives, were also used in a trade-off based decision analysis designed to evaluate how well each management procedure achieves the stated management goals for the project. To determine the overall performance of a particular management procedure, an overall score for each management procedure was calculated by having core group members rank and weight the objectives and associated metrics to understand their overall relative importance. Objectives and metrics that were weighted more heavily (i.e., more important) contributed more to the overall score than those that were considered less important. The final score for each management procedure can then be used to evaluate the relative performance and associated trade-offs a management procedure may have in meeting the overall management objectives. More information regarding the trade-off analysis can be found in the Summer Flounder MSE Final Report behind Tab 2.

Alternative Operating Model Scenarios

Three different operating model scenarios were developed for this MSE, 1) a baseline model, 2) an MRIP bias model and, 3) a stock distribution change model. These different model configurations incorporate some of the critical uncertainties (e.g., data, biology, climate, etc.) identified through stakeholder scoping and by the technical work group. They are intended to evaluate how different management procedures perform under these different assumptions about the "true" summer flounder population. All seven management procedures were run under each operating model scenario and the same 17 performance metrics were produced for each management procedure to allow for comparisons across the different operating model scenarios.

MRIP bias alternative

Stakeholders and the core group consistently raised concerns about Marine Recreational Information Program (MRIP) data and their belief that MRIP overestimates the total number of summer flounder trips, catch, and harvest. The MRIP bias model scenario was developed to understand the potential management and fishery implications under different recreational catch and effort assumptions. This scenario was not an evaluation of the MRIP program or the accuracy and reliability of the data. For model runs in this scenario, instead of using the catch and effort point estimate, the lower bound of the 95% confidence interval of the MRIP estimates were used. These lower catch and effort estimates were used to calibrate the recreational demand model and to adjust the stock dynamics in the biological model to account for the lower recreational catch history.

Stock distribution change alternative

As mentioned earlier, this MSE is part of the Council's implementation of its EAFM guidance document. Prior to initiating the MSE, the Council developed a conceptual model that considered risk factors and ecosystem elements affecting summer flounder and its fisheries[2]. The conceptual model identified stock distribution changes as the most linked risk factor with potential implications across the summer flounder ecosystem (e.g., stock productivity, science, and management). Historical stock distribution information by region was used to inform future potential changes in the spatial distribution of the stock over time and the implications for future availability of summer flounder to recreational anglers along the coast (Figure 2). This scenario provides an opportunity to evaluate if changes in summer flounder availability could undermine the effectiveness of implemented management measures.

Additional details and information on the model structure, data elements, and assumptions of the operating model scenario configurations can be found in the model reports by Dr. Fay and Dr. Carr-Harris behind Tab 2.

Overview of MSE Outcomes

Listed below are some of the key findings and outcomes from the MSE. Additional results, including details explaining the outcomes, can be found in the MSE Results Summary document behind Tab 2.

- Under the baseline operating model scenario, all management procedure alternatives, except for one, outperformed the status quo alternative (MP#1) across a majority of performance metrics including those that reduce recreational discards and provide for increased harvest opportunities (Figure 3 and Table 2).
- No management procedure resulted in the stock becoming overfished. Most had low risk of overfishing, while two had increased risk of overfishing (Figure 3).
- Under different states of the world (scenarios), relative performance of the different management procedures are the same as those observed under the baseline, but outcomes are slightly degraded with the MRIP bias scenario and more degraded with the distribution shift scenario (Figure 4).
- All management procedures, except for one, reduce the proportion of females in the recreational harvest when compared to the status quo. However, reducing the harvest of females does not appear to result in increases to the overall population spawning stock biomass (Figure 5a-b)
- All management procedures, except for one, resulted in higher levels of angler welfare relative to the status quo. Angler welfare is measured by changes in consumer surplus, or the amount of money anglers would be willing to pay for a fishing trip under a given management procedure (Figure 6).
- According to trade-off analysis, relative to the performance of the status quo, the overall satisfaction provided by the fishery is expected to increase by 4 to 106% by implementing MP #2-8, respectively (Figures 7a-b).
    - This result is highly robust to both the range of weightings provided by stakeholders and the set of scenarios evaluated.

[2] For more information about the summer flounder EAFM conceptual model, please visit: https://www.mafmc.org/eafm.

- The relative performance of a management procedure, particularly when comparing to the status quo, is highly variable at the state or regional level.
- Management procedures assessed season length, bag limit, and size limit; size and bag limit were most influential on performance.
- Due to priorities, data availability, and time constraints, not all areas of interest raised by stakeholders were able to be considered in the project.
- Overall, the core stakeholder group found the process to be very informative, appreciated their ability to participate and contribute, and believe the results and outcomes will be useful for management. They also identified and suggested a number of areas of improvement for any future MSE project.

Results from the MSE suggest there are opportunities to make management adjustments that can reduce the overall number of recreational discards, increase recreational opportunities, minimize risk to the stock, and provide for greater equity and access across states and likely fishing modes. The technical work group does note that there are a range of uncertainties and variabilities in the modeling framework that could have an affect the model outputs. In addition, some management procedures considered here have never been implemented, or there is limited experience with their implementation, and our understanding of how the stock, reference points, or angler behavior may change in response to new management measures is uncertain. However, the incorporation of the recreational demand model to capture angler behavior in response to changing regulations and stock conditions should help account for these changes and reduce uncertainty.

Future Direction and Meeting Goals

Potential Application of MSE Process and Results

As mentioned earlier, this MSE is designed to provide strategic advice to the Council and Board regarding a range of management procedures and their overall performance relative to priority management objectives intended to address discards in the recreational summer flounder fishery. Through a very collaborative process, drive both by stakeholder input and scientific rigor, this MSE has developed a novel, forward-thinking, and robust modeling framework unique to the Mid-Atlantic region that integrates a full summer flounder population dynamics model with an angler economic behavior model to understand how recreational behavior responds to changing regulations and stock availability. Results from the MSE demonstrate that there are different management procedures and management procedure categories, particularly when compared to status quo regulations, that achieve the overall management goals of reducing discards and converting discards to increased harvest opportunities, while maintaining stock biomass above the threshold and limiting risk to overfishing. In addition, the results suggest these same management procedures also increase angler welfare, result in more fishing trips and higher expenditures on fishing, reduce female harvest and keep total catch (commercial and recreational) relatively constant. However, as the trade-off analysis indicates, no management procedure achieves all of the management goals and procedures are likely to have differential effects across regions, states, and modes. The MSE is a different approach that has provided the Council and Board with a comprehensive understanding of how traditional management tools (e.g., size, season, and possession limits), within an ecosystem context, may perform over the long term and what the potential implications and associated trade-offs might be for the stock and fishery.

In addition, the MSE successfully developed new tools that can also provide tactical advice to management. While the MSE developed a simulation framework designed at evaluating the long-term performance of different management procedures relative to B_{MSY} and F_{MSY}, the quantitative models developed within the framework can provide short-term (annual) recreational catch and harvest estimates for a given stock size and length structure. These estimates could then be compared to recreational catch (ACL) or harvest limits (RHL) and we can evaluate the overall effectiveness and response to different management measures. While the simulation framework and specific models are currently built for summer flounder, the overall application and approach could be applied to other recreational species.

While the MSE was not able to address all stakeholder and management interests raised throughout the process, the foundation and modeling framework is set up to investigate these other issues should there be interest from management, and given there are appropriate data sources and resources that are made available to conduct the necessary analyses. Topics such as alternative recreational management strategies (e.g., education, terminal tackle, changes in discard mortality, compliance, and enforcement), allocations, the interaction between commercial and recreational harvest strategies, mode specific considerations, habitat management, and additional uncertainties (e.g., changes in stock productivity, environmental drivers) were all identified as other areas of interest. Some core group members also expressed interest in conducting a similar MSE for other recreational species like scup and black sea bass. Lastly, there may also be a need/interest to update the analysis with the results of the 2022 discrete choice experiment survey. The 2010 survey served as the foundation to developing the angler preferences used in the recreational demand model. It is anticipated the results and information from the 2022 survey will be available this fall and evaluating and comparing how potential changes in angler preferences for popular recreational species may affect the results of this MSE is likely worth considering.

Council and Board Direction in August

Given the range in the potential utilization and applications of the MSE results, the Council and Board will need to offer the technical work group feedback and direction on next steps – focusing on any additional analysis and timing for implementation. If the Council and Board are interested in potentially implementing management procedures that reduce discards in the recreational summer flounder fishery, input on refining individual management procedures and/or categories with guidance on specific alternatives should be provided. In addition, direction on the priority management objectives and metrics will be needed to ensure any analysis and evaluation of the management procedures is focused on the most important considerations for management. Any additional analysis would retain the existing modeling framework, data elements, and assumptions. The only modifications, if desired, could include revising the performance metrics to be estimated and evaluated or their weights, the management procedures to be tested and, if available, possibly incorporating the 2022 discrete choice experiment results.

The Council and Board will also need to provide feedback regarding the potential timing for future implementation of the MSE results – 2023 specifications or sometime later. If there is interest in utilizing the results of the MSE for 2023 recreational management considerations and specifications, the technical work group will take the feedback from the Council and Board and work with the Monitoring Committee as part of their recreational process. Coordinating with the Monitoring Committee will also allow for considerations as to how to integrate the results and management procedures from the MSE and the application and development of recreational management measures as part of the recently approved recreational harvest control rule.

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Table 1. Members of the Mid-Atlantic Council's EAFM management strategy evaluation technical work group. * Denotes members that were independent contract facilitators to help support core group work and decision analysis.

Name	Affiliation	Name	Affiliation
Andrew (Lou) Carr-Harris	NEFSC	Jorge Holzer	SSC/Univ. of Maryland
Dustin Colson-Leaning	ASMFC	Emily Keiley	GARFO
Jonathan Cummings*	UMass Dartmouth/USFWS	Jeff Kipp	ASMFC
Kiley Dancy	MAFMC staff	Doug Lipton	NOAA Fisheries
Geret DePiper	SSC/NEFSC	Brandon Muffley	MAFMC staff
Jon Deroba	NEFSC	Annabelle Stanley*	Cornell Univ.
Gavin Fay	SSC/UMass Dartmouth	Mark Terceiro	NEFSC
Sarah Gaichas	SSC/NEFSC	Mike Wilberg	SSC/Univ. of Maryland
Kaili Gregory*	Cornell Univ.	Greg Wojcik	CT DEEP/ASMFC TC chair

Table 2. Summary of model outputs for select performance metrics across the seven different management procedures under the baselines operating model configuration. MP#1 – 2019 regs; MP#2 – 2019 regs with 1 inch decrease in minimum size; MP#3 – 2019 regs with a standard season of April 1- Oct 31; MP#4 – new regional configuration; MP#6 – coastwide measures; MP#7 – modified slot; MP#8 – true slot.

Performance Metric	MP#1	MP#2	MP#3	MP#4	MP#6	MP#7	MP#8
Percent of trips that harvest one fish	0.193	0.284	0.197	0.279	0.301	0.350	0.357
Average number of harvested fish per trip	0.274	0.471	0.279	0.478	0.504	0.458	0.642
Harvest:Discards	0.102	0.207	0.104	0.202	0.240	0.189	0.390
Average number of discards per trip	2.91	2.45	2.89	2.55	2.29	2.58	1.84
Consumer surplus (angler satisfaction) per trip	3.703	12.896	4.001	13.100	13.502	14.352	19.873
Total recreational expenses (millions of $)	470.9	492.3	474.5	492.6	495.7	499.3	513.0
Total Spawning Stock Biomass (mature male & female) in metric tons	67,514	60,504	67,291	59,795	59,372	61,088	56,554
Percent of female harvest	0.676	0.607	0.677	0.608	0.591	0.602	0.49
Total catch (recreational+commercial) in metric tons	15,935	16,468	15,986	16,526	16,460	16,031	15,834
Total recreational removals (harvest+dead discards) in metric tons	6,331	8,157	6,498	8,337	8,263	7,685	8,085
Total number of recreational trips (millions)	11.22	11.72	11.31	11.74	11.82	11.91	12.22
Percent of trips harvesting a trophy fish (>28 inches)	0.017	0.008	0.018	0.008	0.007	0.008	0.000

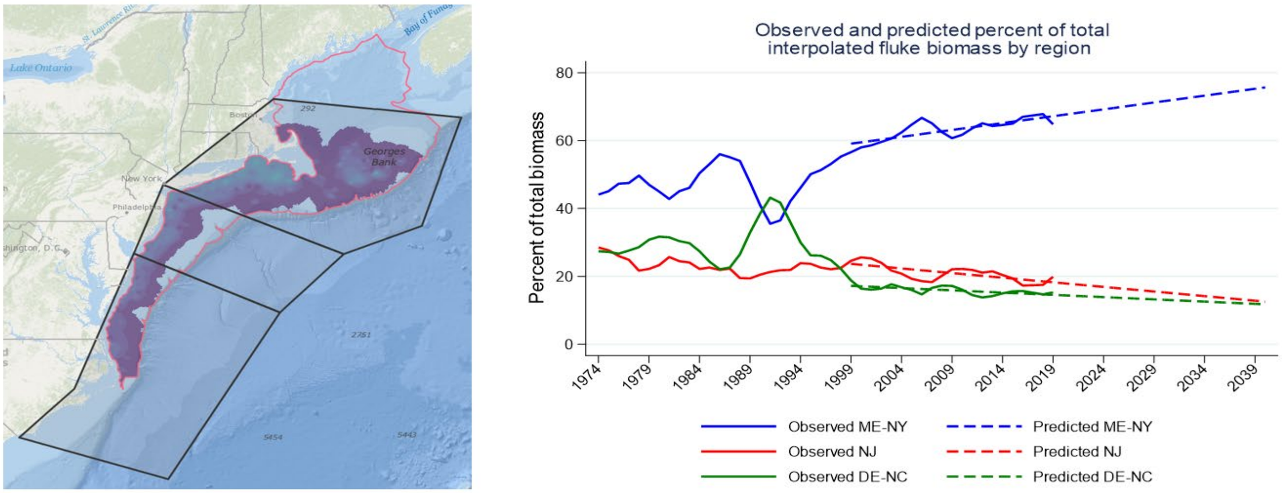


Figure 2. Proportion of observed and projected summer flounder stock biomass by region (ME-NY, NJ, DE-NC) based on the NEFSC fall bottom trawl survey used for an alternative MSE operating model to reflect potential changes in future stock distribution and availability to recreational anglers. Source: NOAA Fisheries. 2022. DisMAP data records. Retrieved from apps-st.fisheries.noaa.gov/dismap/DisMAP.html. Accessed 7/14/2022.

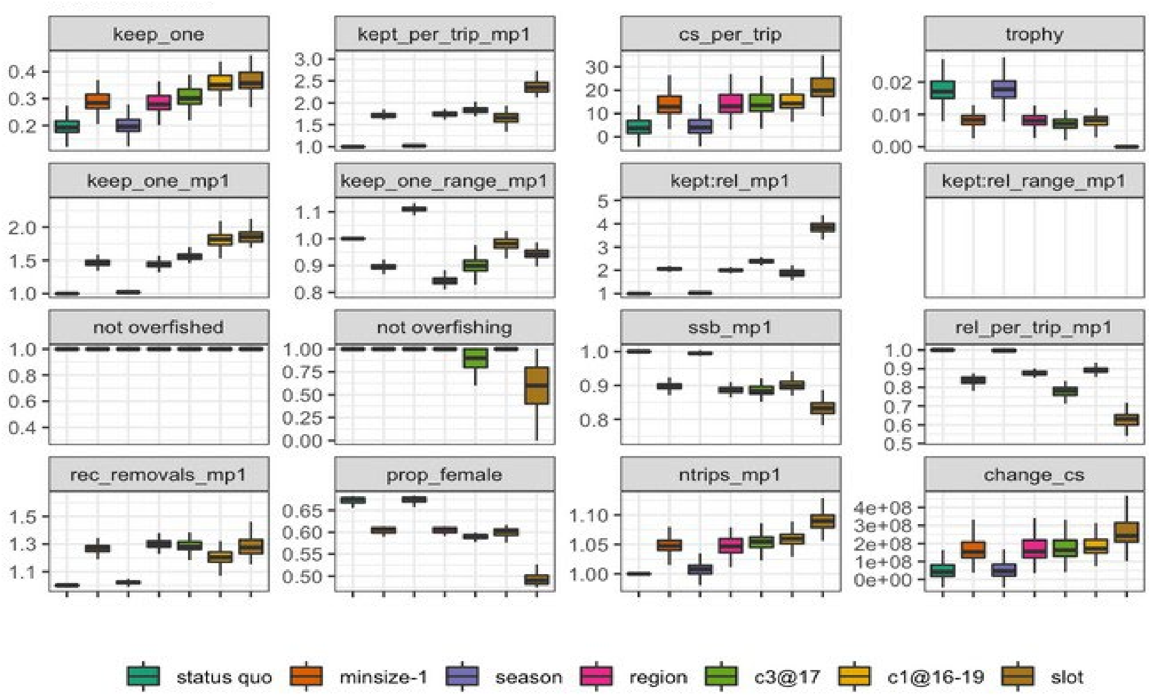


Figure 3. Coastwide results for a suite of biological, social, and economic performance metrics for seven different management procedures under the baseline operating model configuration.

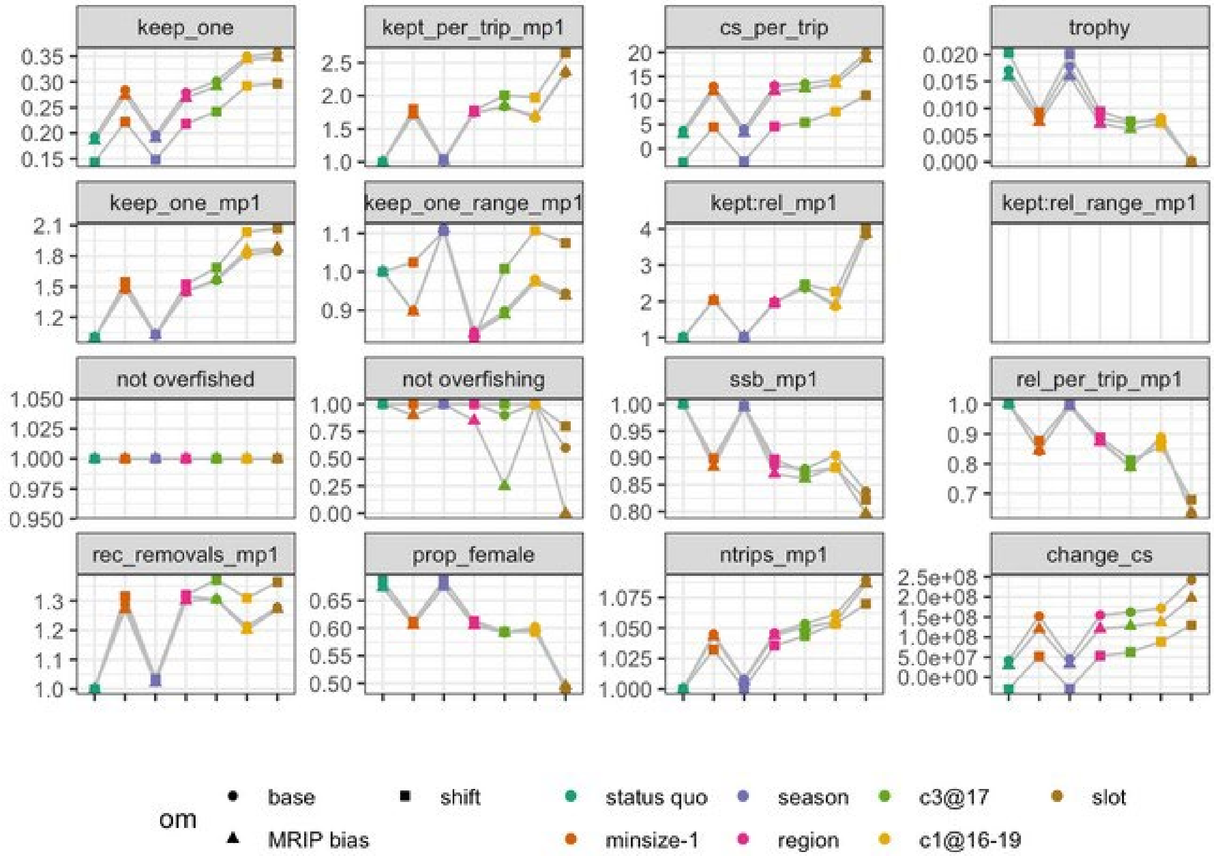


Figure 4. Comparison of the relative performance of seven different management procedures across a suite of biological, social, and economic performance metrics and three different operating model scenarios (baseline, MRIP bias, and stock distribution shift).

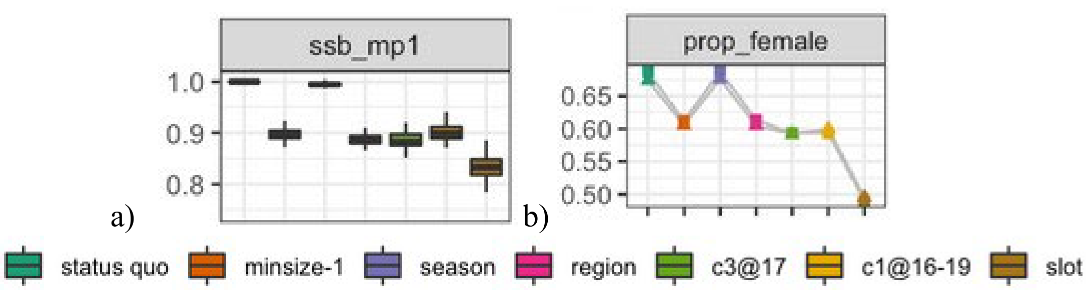


Figure 5 a) The relative difference in total spawning stock biomass (SSB) for the different management procedures compared to the status quo. SSB includes both mature male and female summer flounder. **b)** The average percentage of the recreational summer flounder harvest is female across the seven different management procedures.

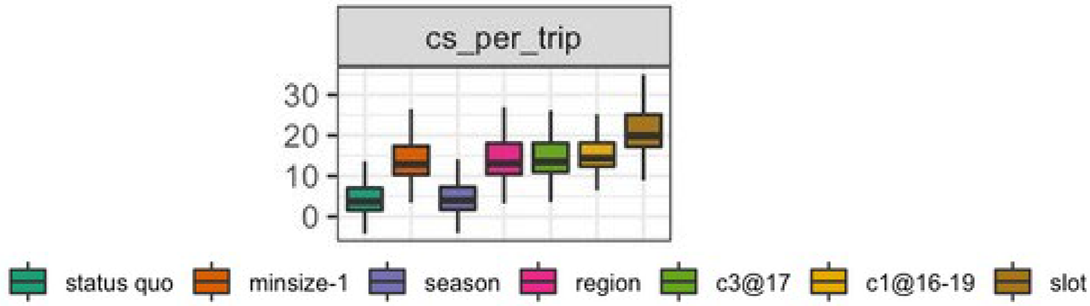


Figure 6. The differences in angler welfare measured by changes in consumer surplus, or the amount of money anglers would be willing to pay for a fishing trip under a given management procedure.

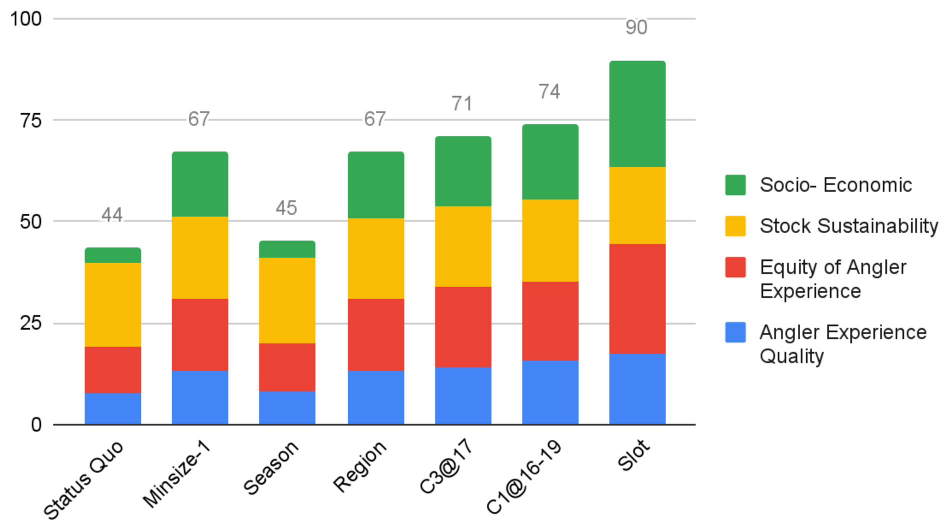


Figure 7a. Total Performance of each management procedure. Management procedures are listed across the bottom axis and the total performance score is displayed by the height of the stacked bar on the vertical axis. Scores reflect the expected degree of satisfaction provided by a management procedure, such that a doubling of the score indicates the average stakeholder expects to be twice as satisfied by the change in management procedure. The four colored regions of each bar show the degree of contribution each management objective provides to the total score.

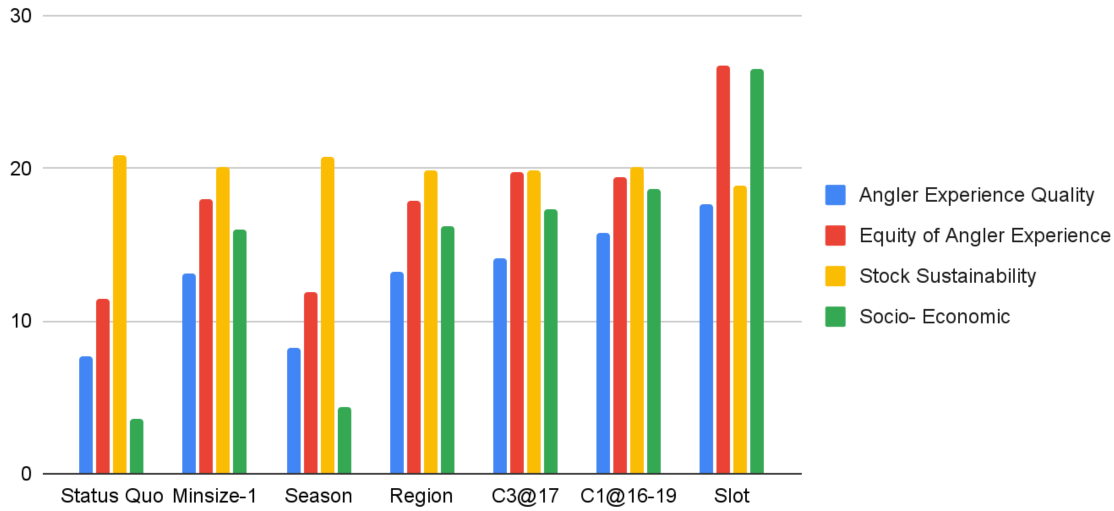


Figure 7b. Performance of each management procedure by management objective. Management procedures (MP) are listed across the bottom axis and the total performance score is displayed by the height of the stacked bar on the vertical axis. Looking only at a single color bar shows the relative performance of a MP for that objective (e.g., the blue bars display the relative performance of the MP for the Angler Experience Quality objective).

EAFM Recreational Summer Flounder Management Strategy Evaluation

Summary of MSE Results and Findings

Executive Summary

The Mid-Atlantic Fishery Management Council's (Council) Ecosystem Approach to Fisheries Management (EAFM) guidance document established a structured framework and process to incorporate ecosystem considerations into the evaluation of policy choices and trade-offs as they affect Council-managed species and the broader ecosystem. As part of this process, the Council requested a Management Strategy Evaluation (MSE) to "Evaluate the biological and economic benefits of minimizing discards and converting discards into landings in the recreational sector. Identify management strategies to realize these benefits."

Through a collaborative, stakeholder, and science driven process, the MSE successfully met its objectives and developed a modeling framework unique to the Mid-Atlantic region integrating a full summer flounder population dynamics model with an angler economic behavior model to understand how recreational behavior responds to changing regulations and stock availability. The performance of eight management procedures (MPs) were tested under three different states of the world (scenarios). A core group of stakeholders outlined objectives, developed performance metrics, and identified key uncertainties to test procedures against. The benefits of each management procedure were assessed using a suite of biological, social, and economic performance metrics (e.g. stock biomass and fishing mortality as well as angler welfare and ability to keep a fish) across four different management objectives.

Results from the MSE suggest there are management procedures that outperform status quo management at reducing discards and converting those discards into harvest while limiting risk to the summer flounder stock. In addition, the simulation framework and individual models developed as part of the MSE can help provide both strategic and tactical advice for a variety of potential management priorities. These models and results can be used to directly inform recreational management, through recreational harvest control rules and annual specifications, to achieve a range of Council objectives.

This document describes how the work undertaken achieved this task and summarizes the key outcomes and findings. The accompanying briefing memo outlines the details of the process itself.

Summary of key findings and outcomes

- Under the baseline operating model state of the world (scenario, all management procedures, except for one, outperformed the status quo alternative across a majority of performance metrics, including those that reduce recreational discards and provide for increased harvest opportunities.

- No management procedure resulted in the stock becoming overfished. Most had low risk of overfishing, while two had an increased risk of overfishing.
- Under different states of the world (scenarios), the performance of the management procedures relative to one another is the same as we observed under the baseline.
    - Relative to the outcomes from the baseline scenario a given management procedure's performance will be slightly degraded with the MRIP bias scenario and more degraded with the distribution shift scenario.
- All management procedures, except for one, reduce the proportion of females in the recreational harvest when compared to the status quo. However, reducing the harvest of females does not appear to result in increases to the overall population spawning stock biomass.
- All management procedures, except for one, resulted in higher levels of angler welfare relative to the status quo. Angler welfare is measured by changes in consumer surplus, or the amount of money anglers would be willing to pay for a fishing trip under a given management procedure.
- According to trade-off analysis, relative to the performance of the status quo, the overall satisfaction provided by the fishery is expected to increase by 4 to 106% by implementing alternative management procedures.
    - This result is highly robust to both the range of weightings provided by stakeholders and the set of scenarios evaluated.
- The relative performance of a management procedure, particularly when comparing to the status quo, is highly variable at the state or regional level.
- Management procedures assessed season length, bag limit, and size limit; of these, size and bag limit were most influential on performance.
- Due to stakeholder and technical team priorities, data availability, and time constraints, not all areas of interest raised by stakeholders were able to be considered within the timeline for this project.
- Overall, the core stakeholder group found the process to be very informative and positive, appreciated their ability to participate and contribute, and believe the results and outcomes will be useful for management. They also identified and suggested a number areas of improvement for any future MSE project.

Overview of MSE Results

Here we present additional details regarding the key project results and outcomes and offer insight as to why these results may have occurred. Given the significant amount of information produced and the nuance in interpreting outcomes for the different management procedures and performance metrics across regions and states, not all of the results are provided here. The results presented below focus on the priority project areas requested by the Council and ASMFC Summer Flounder, Scup, and Black Sea Bass Board. For those interested, all MSE results and outputs can be found at: https://bit.ly/fluke-mse-metrics. Here you can review results by performance metric, operating model scenario, and by state.

Harvest and Discard Outcomes

As requested by the Council, the primary objective of the MSE was to evaluate management procedures that reduce the number of recreational discards and develop strategies that convert discards into increased harvest and recreational opportunities. This section provides an overview of the outcomes that provide insight on addressing this primary objective.

For reference, Table 1 provides a summary of the seven different management procedures included in the results below. An additional management procedure was evaluated (coastwide, 1 fish possession limit, 14 inch minimum size, and a season of May 15 - September 15) but removed by the core stakeholder group and those results are not included.

Table 1. Summary of the seven different management procedures tested as part of the EAFM recreational summer flounder MSE.

Management Procedure #	Procedure Explanation
1 (status quo)	Status Quo - 2019 regulations
2 (minsize-1)	2019 regulations but a 1 inch decrease in minimum size within each state to a minimum of 16 inches
3 (season)	2019 regulations but season of April 1 - Oct 31 for all states
4 (region)	**Modified regions:** MA-NY - 5 fish, 18 inch min, May 1 - Sept 31 NJ - 3 fish, 17 inch minimum, May 1 - Sept 31 DE-NC - 3 fish, 16 inch minimum, May 1 - Sept 31
6 (c3@17)	3 fish possession limit, 17 inch minimum size, May 1 - Sept 30
7 (c1@16-19)	**Modified slot:** 1 fish from 16 inches - 19 inches, 2 fish 19 inches and greater, May 1 - Sept 31
8 (slot)	**True slot limit:** 3 fish possession limit between 16 inches and 20 inches, May 1 - Sept 31

Overall/coastwide results

Results demonstrate there are management tools and different management procedures that can reduce the number of discards, increase the keeper:discard ratio, and promote recreational opportunities that would convert discards into landings (Figure 1, Table 2). Nearly all of the management procedures tested performed better across the discard related performance metrics when compared to the status quo (MP#1).

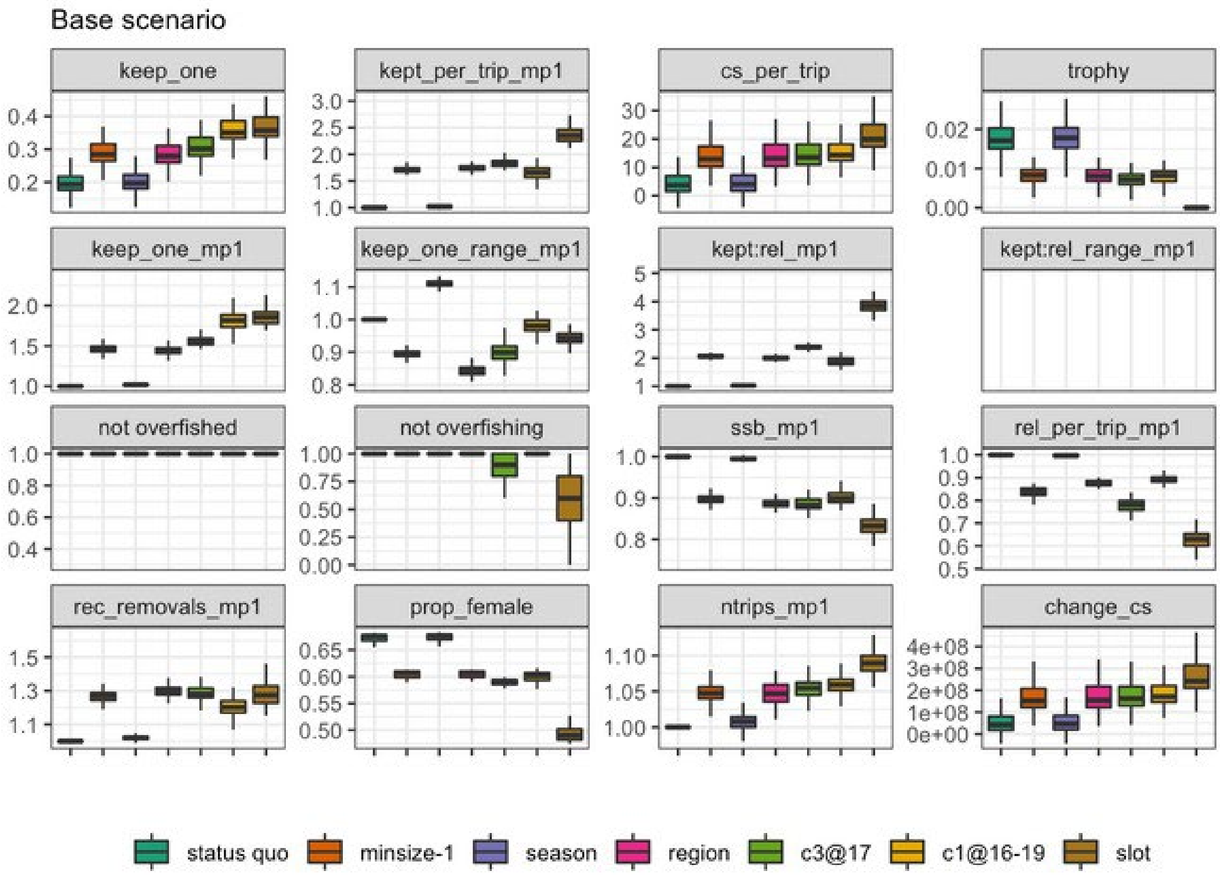


Figure 1. Coastwide results for a suite of biological, social, and economic performance metrics for seven different management procedures under the baseline operating model configuration.

- Kept:Discard ratio
    - MP#1 and #3 result, on average, in one keeper for every 10 fish caught.
    - MP #2, 4, and 7 double the keeper ratio with 2 fish kept for every 10 caught.
    - MP#6 was slightly better with 2.5 fish kept for every 10 caught.
    - MP#8 was nearly 4 times higher than status quo MP with 3.9 fish kept for every 10 caught.
- Percent of trips that keep a fish
    - MP#1 and #3 result, on average, in 19 percent of all trips keep a fish.

- o MP#2, 4, and 6 result in an approximately 29 percent of all trips keep a fish.
  - o MP #7 and #8 result in substantially higher success rate with 46 percent and 64 percent of all trips keeping a fish, respectively.
- Average # of fish kept per trip
  - MP #1 and #3 result in an average of 0.27 fish kept per trip.
  - MP #2,4,6 and 7 are nearly double with close to a half fish (0.5) kept per trip.
  - MP #8 has the highest average number of fish kept per trip and more than double MP #1 and #3 with 0.64.
- Average # of discards per trip
  - MP #1 and #3 had the highest discard per trip with just under three (2.9) summer flounder released per trip.
  - MP #2, #4, and #7 had similar discards per trip with an average of 2.5 summer flounder discarded each trip. This is a 16 percent reduction in the number of discards.
  - MP #6 had the second fewest discards per trip with an average of 2.29 summer flounder discarded per trip or a 24 percent reduction compared to the status quo.
  - MP #8 had the lowest discards per trip with 1.84 summer flounder discarded on average. This is slightly more than one fewer fish released than under the status quo alternative, or a 38 percent reduction in discards.

Table 2. Summary of model outputs for select performance metrics across the seven different management procedures under the baselines operating model configuration.

Performance Metric	MP#1	MP#2	MP#3	MP#4	MP#6	MP#7	MP#8
Percent of trips that harvest one fish	0.193	0.284	0.197	0.279	0.301	0.350	0.357
Average number of harvested fish per trip	0.274	0.471	0.279	0.478	0.504	0.458	0.642
Harvest:Discards	0.102	0.207	0.104	0.202	0.240	0.189	0.390
Average number of discards per trip	2.91	2.45	2.89	2.55	2.29	2.58	1.84
Consumer surplus (angler satisfaction) per trip	3.703	12.896	4.001	13.100	13.502	14.352	19.873
Total recreational expenses (millions of $)	470.9	492.3	474.5	492.6	495.7	499.3	513.0
Total Spawning Stock Biomass (mature male & female) in metric tons	67,514	60,504	67,291	59,795	59,372	61,088	56,554
Percent of female harvest	0.676	0.607	0.677	0.608	0.591	0.602	0.49
Total catch (recreational+commercial) in metric tons	15,935	16,468	15,986	16,526	16,460	16,031	15,834
Total recreational removals (harvest+dead discards) in metric tons	6,331	8,157	6,498	8,337	8,263	7,685	8,085
Total number of recreational trips (millions)	11.22	11.72	11.31	11.74	11.82	11.91	12.22
Percent of trips harvesting a trophy fish (>28 inches)	0.017	0.008	0.018	0.008	0.007	0.008	0.000

While not specific performance metrics, the core group was interested in how the different management procedures might result in changes to the average length of harvested fish and how those would compare to the status quo (Figure 2). This information is an additional piece of information to demonstrate how the different management procedures reduce discards and allow for increased harvest opportunities. The results show that most management procedures resulted in a noticeable decrease in the average size of harvested fish compared to the status quo.

- The average length of a harvested summer flounder under MP #1 and #3 was 19.8 inches.
- MP #2, #4, and #6 resulted in a decline in the average size by nearly 1.5 inches down to 18.4 inches.
- MP #7 reduced the average size of a harvested fish by nearly 2 inches down to 18.0 inches.
- MP #8 reduced the minimum size even further with the average size of a harvested summer flounder of 17.0 inches, nearly 3 inches smaller than the status quo measures.

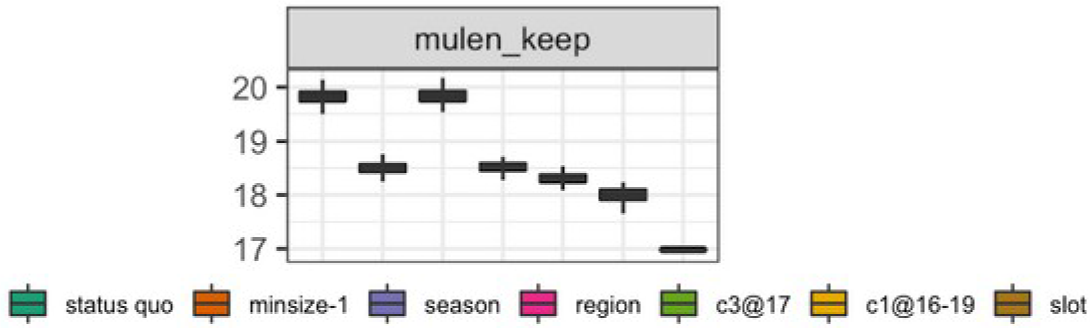


Figure 2. The average size (inches) of summer flounder harvested for the entire coast under the seven different management procedures.

The results also suggest that even with increasing total recreational removals, the total fishery removals, both commercial and recreational harvest and discards, are not very different across all management procedures (Figure 1, Table 2).

- For example, MP #2, #4, #6, #7, and #8 result in a 29% increase in total recreational removals, but there is only 2% difference across all management scenarios when looking at total catch (commercial and recreational).

State specific results

Overall, the relative performance of a particular management procedure, particularly when comparing to status quo (MP#1) is highly dependent upon the state/region (Figure 3). For states New Jersey and north, MP#1 (and #3) performed much worse (significantly worse in some cases) across most metrics compared to all other management procedures; while MP#1 (and #3) performed better, or as well as, the other management procedures for the states Delaware and south.

- This result is somewhat to be expected given that the states of DE through NC currently have more liberal measures (those associated with MP#1) compared to the states of NJ through MA and some management procedure alternatives would be more restrictive for certain measures compared to MP#1. Although MP#1 performed better for this region, there are a number of other management procedure alternatives that performed equally well, presenting possible opportunities to adjust management measures to meet other management objectives for this region.

There was also a difference in the relative consistency or variability in performance across management procedures across states (Figure 3).

- For example, when evaluating the percentage of trips that keep one summer flounder, in CT, NY, and NJ there was a similar pattern with MP #1 and #3 performing the worst with about 20% of all trips keeping one summer flounder. There was a general increasing pattern in the percentage of trips keeping one summer flounder across the remaining management procedures with MP #2 and #4 twice as high as MP #1 and 2.5 times higher for MP #7 and #8. MA had the same range (i.e., 2.5 times) in the differences between the worst performing and best performing management procedure for this metric, but MP #2 performed the best and MP #4 and #6 performed the worst. In contrast, in VA there was only a 6 percent difference in the percent of trips with a keeper summer flounder between the worst performing MP (#6) and the best performing MP (#2 and #4).

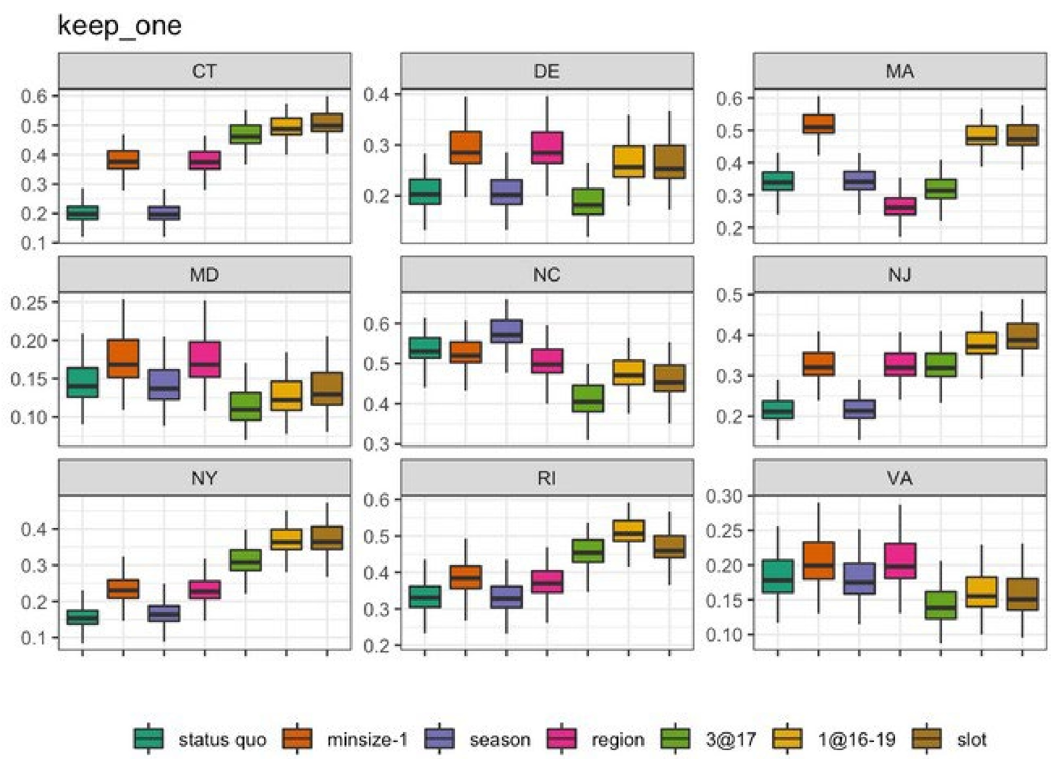


Figure 3. Comparison of the average number of trips where one summer flounder was kept across the seven different management procedures for each state under the baseline operating model.

We can also take a broader look at the performance of each management procedure at the state level by determining the number of states where a management procedure performed better/worse than the status quo (MP#1) for a particular metric. This type of evaluation allows us to determine if a particular management procedure benefited/disadvantaged a majority of states. It is worth noting that this evaluation does not consider the magnitude of improvement/decline.

- The results indicate that MP #2 performed better for 8 of the 9 states across several metrics (Figure 4). This was followed by MP #4, #7, and #8 that performed better for a majority of states. MP #3 and #6 did not perform better for a majority of states for the metrics considered.

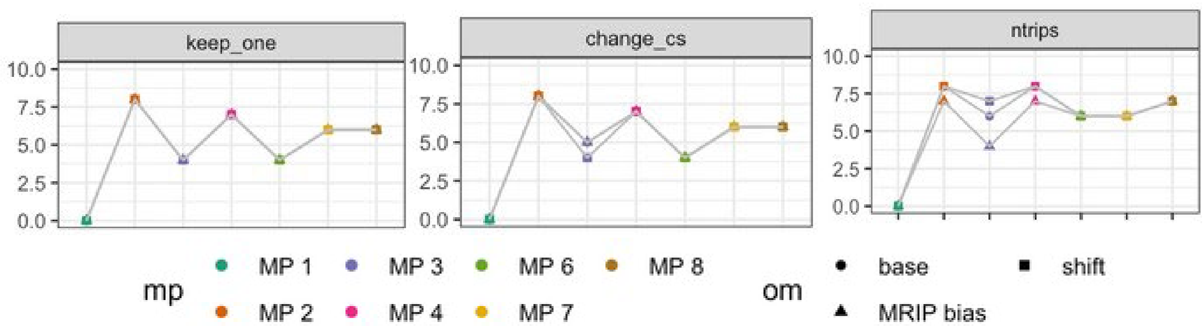


Figure 4. The number of states that perform better under different management procedures compared to status quo measures for three different metrics (keep_one is the percent of trips that keep at least one summer flounder; change_cs is the change in consumer surplus across all trips within state; ntrips is the total number of recreational summer flounder trips). This evaluation was also conducted across three different operating model configurations (baseline, MRIP bias, and stock distribution shift).

Biological Outcomes

Evaluating the biological impacts of implementing different management procedures was also a management objective of the MSE. Here we included metrics that focused on the Council's legal mandate under the Magnuson-Stevens Act (MSA) to prevent overfishing and a stock from becoming overfished. Other priority areas of interest from stakeholders included the proportion of female harvest and opportunities to catch and retain trophy summer flounder.

The results indicate that the risk of the stock becoming overfished during the last 10 years of the projection period (26 years) is very low regardless of the management procedure implemented (Figure 5). Results also indicate there is low risk of overfishing occurring across the different management procedures (Figure 5). It's worth noting that the fishing mortality estimated to determine the stock status metrics includes the removals of both the recreational and commercial sectors.

- MP #8 did result in the highest risk of overfishing, but below the 50% threshold, followed by a slight increase in risk associated with MP #6.

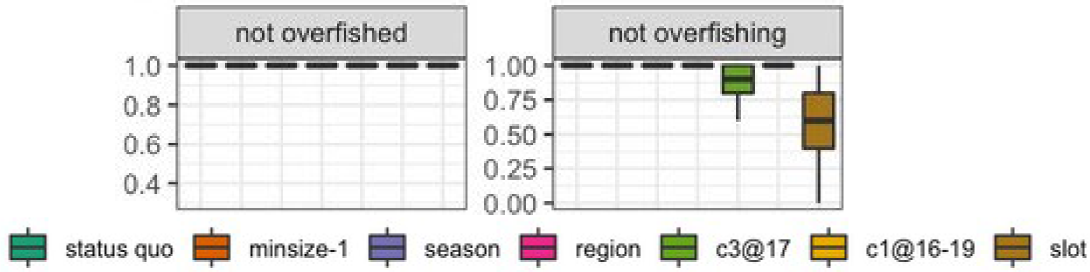


Figure 5. The percent chance that a particular management procedure results in the summer flounder stock not being overfished or not overfishing over the final 10 years of a 26 year projection period.

While there is little risk to the overall stock, there are differences across the different management procedures when evaluating the average total spawning stock biomass (SSB) over the last 10 years of the 26 year projection period (Figure 6, Table 2). Consistent with the stock assessment, total SSB is calculated as mature male and female summer flounder. MP #1 and #3 resulted in the highest average total SSB of approximately 67,400 metric tons (Table 1). These two management procedures resulted in total SSB that was about 10% higher than MP #2, #4, #6, and #7 and was about 16% higher than MP #8 with an average total SSB of 56,500 metric tons.

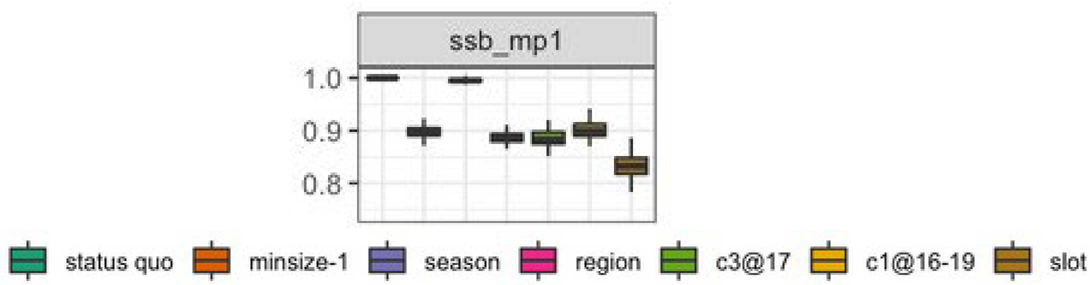


Figure 6. The relative difference in total spawning stock biomass (SSB) for the different management procedures compared to the status quo. SSB includes both mature male and female summer flounder.

There are management procedures that can reduce the percentage of females in the recreational harvest, some by as much as 33 percent (Figure 7, Table 2). Nearly 69 percent of the recreational harvest is comprised of females under MP #1 and #3. MP #2, #4, #6 and #7 reduce the proportion of female harvest to about 60 percent. MP #8 is the only alternative that reduces the proportion of female harvest to just below 50 percent. However, as discussed above, reducing the harvest of females does not appear to have much effect on increasing the total population SSB. In fact, MP #8 which had the lowest proportion of females in the harvest also had the lowest average total SSB.

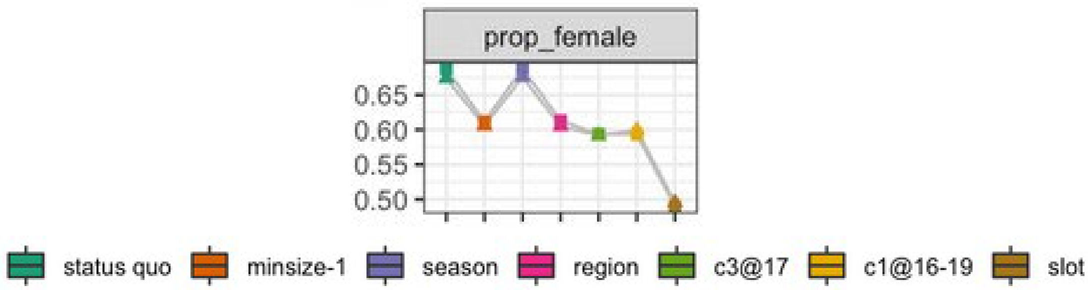


Figure 7. The average percentage of the recreational summer flounder harvest is female across the seven different management procedures.

While these results may seem counterintuitive, there are likely a number of reasons for this outcome and is consistent with previous analyses and with a review of the sex structure during the 2018 benchmark stock assessment. Many of the different management procedures, like MP #8 reduce the minimum size limit, which increases the harvest and fishing mortality rate on smaller male and female summer flounder. This results in removing more smaller and younger fish before they become a greater proportion of the total SSB. In addition, as recent management actions have set lower catches and reduced the total fishing mortality on the stock, sex ratios within the population are changing and more males are surviving to larger sizes and older ages and represent a greater contribution to the SSB. Lastly, consistent with the stock assessment, the operating model used for the MSE does not have a stock-recruit relationship, so there is no direct link between total SSB and stock productivity/recruitment.

Social and Economic Related Outcomes

One of the most significant advances associated with this MSE was the development and integration of the recreational demand model within the simulation framework. Not only did this advancement allow for the consideration of angler behavior in response to management and stock changes, but it also provided the opportunity to estimate the social and economic benefits associated with different management procedures. This was critical to ensure we could address the economic management objectives requested by the Council and Board.

Overall/coastwide results

In general, the economic metrics display a very similar pattern, at the individual trip level or across all trips, as the harvest and discard related metrics discussed earlier. Those management procedures with a higher percentage of trips with a keeper summer flounder, a greater the number of summer flounder kept per trip, and the higher harvest:discard ratio also had greater economic benefits (Figures 8 and 9).

- Angler welfare (consumer surplus) is a measure of an angler's willingness to pay for a fishing trip under a given set of regulations and generally reflects angler satisfaction. MP #1 and #3 had the lowest angler welfare across all seven management procedures evaluated. MP #2, #4, #6, and #7 performed equally well and increased angler welfare 3 times higher than the status quo (MP #1). MP #8 had the highest angler welfare and was nearly 5 times higher than MP #1. These results intuitively make sense, as angler welfare/satisfaction is positively and significantly related to harvest according to the analysis of angler preferences.

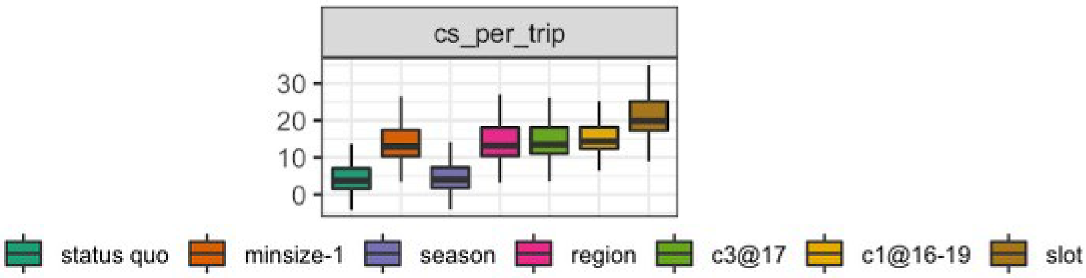


Figure 8. The estimated angler welfare (consumer surplus) per trip across all seven management procedures under the baseline operating model.

- Number of summer flounder recreational fishing trips is included as an economic metric because the more trips taken, the higher the angler welfare and the greater the economic benefit.
    - MP #1 and MP #3 resulted, on average, in 11.25 million directed summer flounder fishing trips per year.
    - MP #2, #4, #6, and #7 were all similar and resulted in approximately 11.8 million trips per year, which is a 5 percent increase over the status quo (Figure 9).
    - MP #8 resulted in the highest number of directed summer flounder tips at 12.22 million trips, or nearly a 9 percent increase compared to MP #1 (Figure 9).

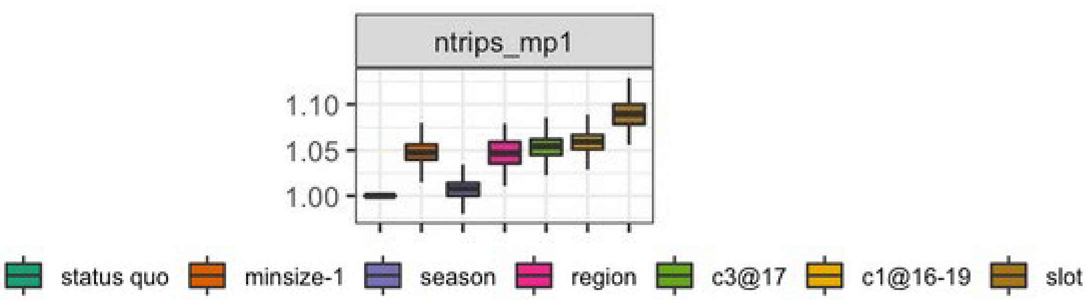


Figure 9. The change in the average total number of directed summer flounder fishing trips per year for all management procedures compared to the status quo (MP#1) under the baseline operating model.

- Fishery investment/expenses is closely linked to the total number of recreational trips and, therefore, the general pattern across the different management procedures is similar, particularly at the coastwide level with the status quo alternative (MP#1) performing the worst. The more trips taken, the more economic activity and greater investment and expenses. For reference, marine angler expenditures on fishing trips for all species totaled $3.6B across the study region in 2017.

- MP #1 resulted in the lowest fishery investment and expenses due to summer flounder activity totaling $470.9 million. This was followed by MP #3 with total fishery expenses estimated to be $474.4 million.
- MP #2, #4, #6 resulted in a 5 percent increase in total summer flounder expenses totaling $493.5 million, or $23 million more per year than the status quo.
- MP#7 had the second highest fishery investment totaling $499.3 million.
- MP#8 had the greatest economic impact with a total fishery investment of $513.0 million, a 9 percent increase compared to MP #1 or nearly $43 million more per year.

State specific results

- Angler welfare
    - State-level angler welfare generally follows the same trends in state-level numbers of trips; both of these metrics are driven by changes in expected harvest, which varies with regulations and state-specific catch-per-trip and catch-at-length distributions. Similar to the harvest and discard metrics, angler welfare is much more variable at the state or regional level with the states of NJ through MA displaying different patterns than those found in the states of DE through NC (Figure 10).

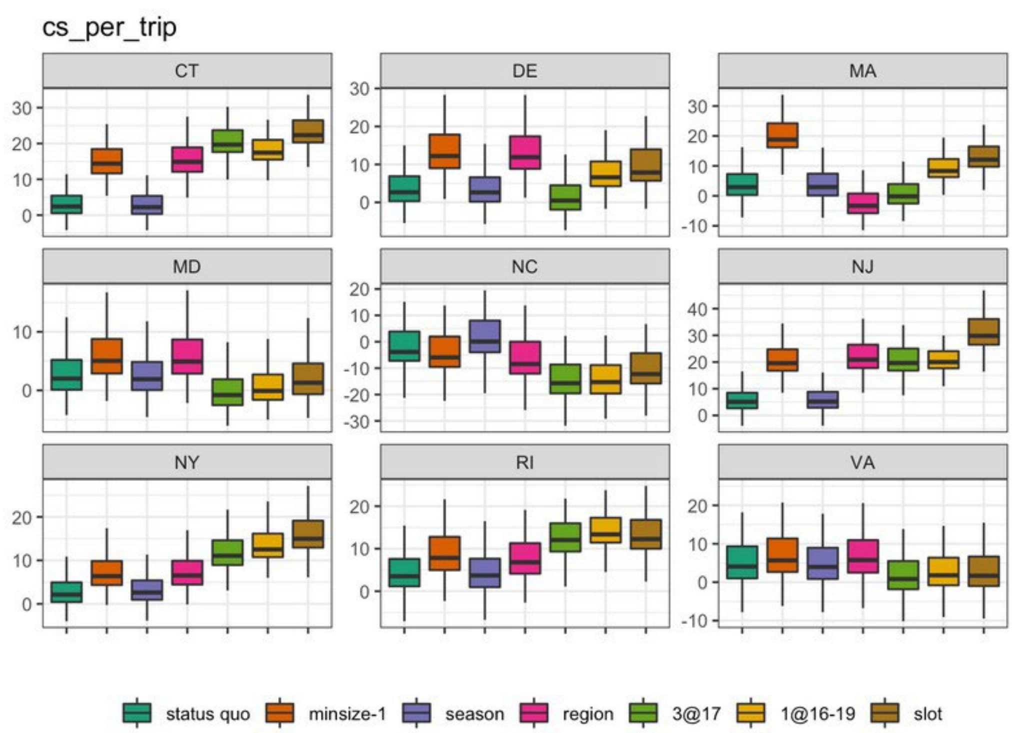


Figure 10. The estimated angler welfare (consumer surplus) per trip for each state across all seven management procedures under the baseline operating model.

- Fishery investment/expenses

- Total fishery investment/expenses are more variable than the angler welfare at the state level and across the different management scenarios than at the coastwide level (Figure 11). For example, in Massachusetts MP #3 results in significantly higher fishery expenses but is one of the lowest performing management procedures when considering angler welfare. This is due to more variability between the combination of total number of recreational trips and the trip expenses at the state level (e.g, average trip expenses range from $22 per trip in RI to $70 per trip in NC).

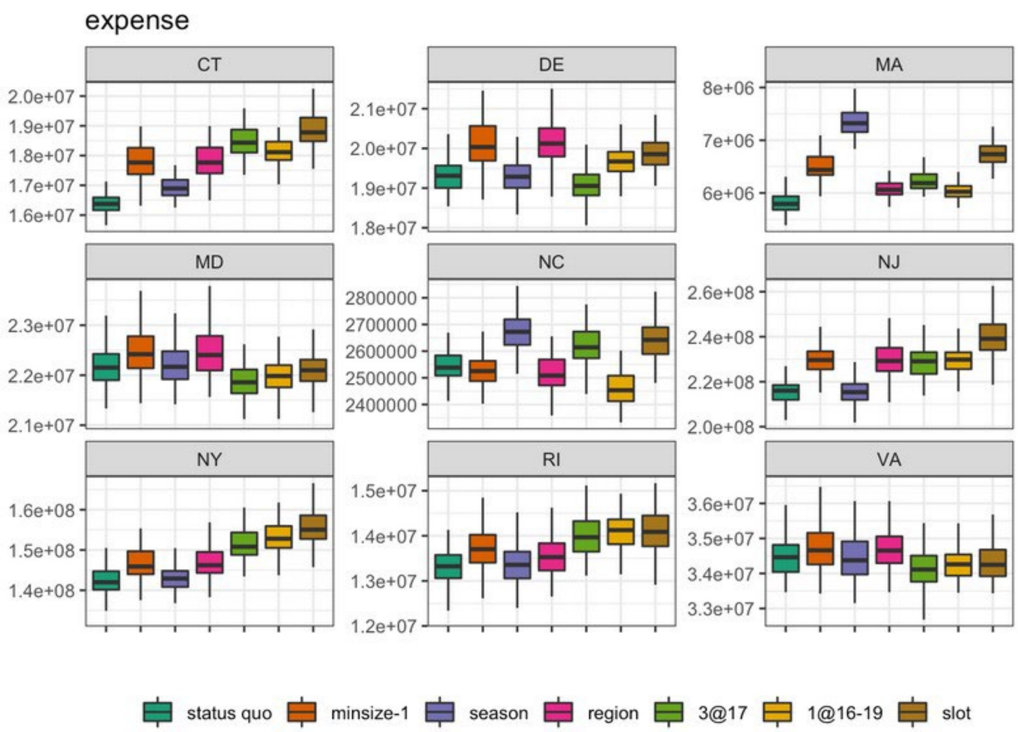


Figure 11. Total summer flounder fishery investment/expenses by state for each management procedure under the baseline operating model.

Outputs/results across operating model alternatives

A benefit of conducting an MSE is the ability to evaluate the performance of management procedures across different unknowns and uncertainties within the biological, fishery, or management system. Here we evaluate the relative performance of the same seven management procedures across two different states of the world (scenarios). One scenario assumes the Marine Recreational Information Program (MRIP) estimates of summer flounder effort and catch are lower than the point estimate used as the official measure. The second scenario considers the anticipated changes in the spatial distribution and availability of summer flounder along the Atlantic coast.

The results suggest that all seven of the management procedures are fairly robust and the relative performance was similar across the different operating model uncertainties (MRIP bias and stock distribution shifts). Those management procedures that performed better under baseline model also performed better under two operating model alternatives (Figure 12).

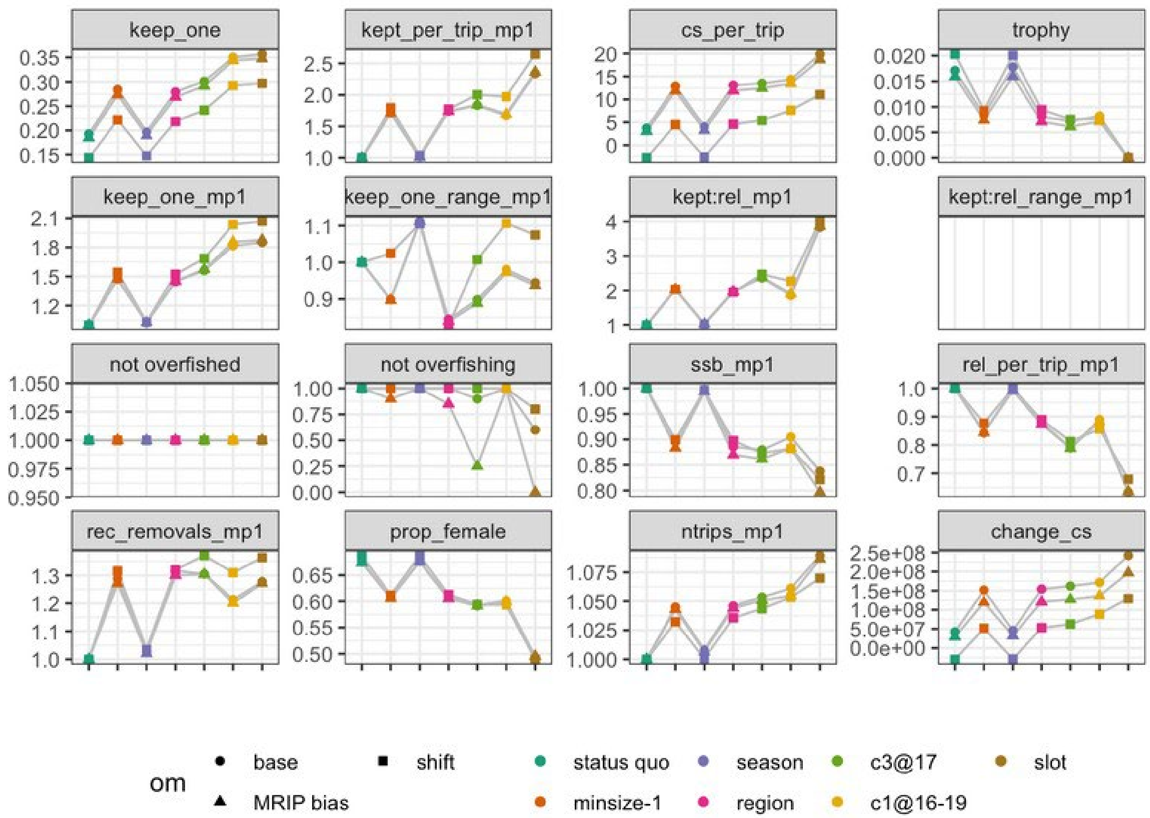


Figure 12. Comparison of the relative performance of seven different management procedures across a suite of biological, social, and economic performance metrics and three different operating model scenarios (baseline, MRIP bias, and stock distribution shift).

The MRIP bias operating model runs do show a slightly higher risk of overfishing across many management procedure alternatives. MP#6 and #8 result in significantly higher risk of overfishing under these scenarios with overfishing occurring 75 percent of the time under MP #6 and in most years for MP #8. While MP #6 and #8 do result in fishing mortality rates higher than F_{MSY} threshold, they are not significantly higher and, while they result in lower stock biomass, it never falls below the overfished threshold.

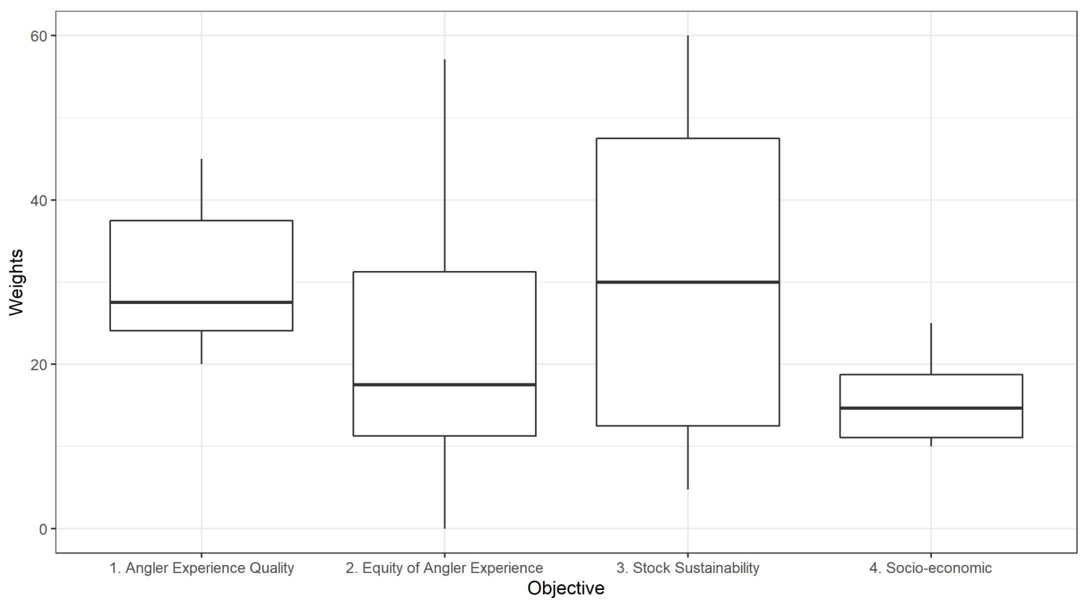
The distribution shift operating model results in poorer performance across all management scenarios for several metrics: percent of trips that kept 1 fish, consumer surplus per trip, and total number of recreational trips (Figure 13). When first considering the MRIP bias results, they may seem counterintuitive since this operating model includes much lower effort and catch estimates; however, the lower recreational catch estimates also change our understanding of stock productivity when compared to the baseline and distribution change operating model scenarios.

With the lower MRIP catch estimates being used, the total stock size is estimated to be lower and reference points would change given the changes in stock productivity.

In addition, the number of states where a metric performed better than MP #1 was also fairly robust and consistent across operating model alternatives (Figure 5). The exception was the MRIP bias alternative resulted in fewer recreational trips and recreational expenses under MP #3 and therefore, fewer states saw an improvement for those metrics compared to the status quo alternative.

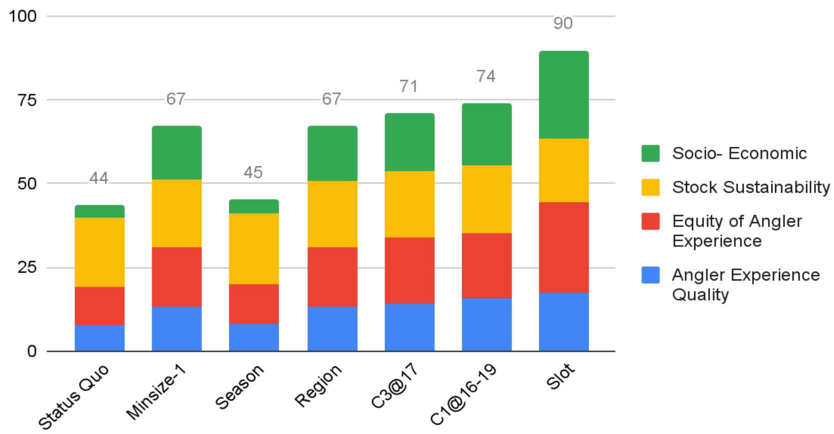
Tradeoff outputs/results

- Core group members have a diversity of preferences in terms of how important each objective and performance metric is, with the most agreement about the socio-economic objective's importance and a wide range of preferences in terms of the angler equity and stock sustainability objective. These preferences were captured through weights across objectives.
- On average core group members consider the Stock Sustainability and Quality of Angler Experience objectives as the highest priority. Equity of Angler Experience was third (quite a bit lower than stock sustainability) and lastly the Socio-Economic Sustainability objective was fourth.



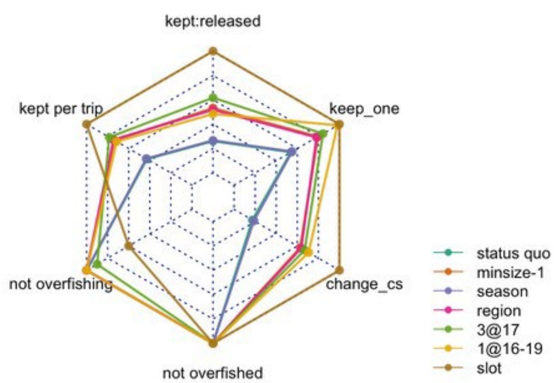
- Management procedures are fairly robust and relative performance was similar across the different weightings provided by the core group.
  - The relative ranking of the management procedures was consistent across the range of relative importance placed on each objective by the stakeholders.
- MP #8 had the highest score across weighting schemes, producing the greatest expected value for the management objectives considered.
  - MP #7, then MP #6, #2, and #4 had similar scores and MP #1 and #3 produced the lowest scores.

- Relative to the status quo (MP #1), MP #8 represented an 106% increase in degree to which satisfaction is produced by these management objectives.



Another way to visualize tradeoffs is using a spider plot where the greater the area enclosed by a management procedure the better it performs. Note that the performance here is unweighted (i.e., the raw model outputs).

- This also shows that MP #8 performs best on most of the metrics (not overfishing is the exception).
- We can see there isn't any difference between the management procedures in terms of their performance at avoiding an overfished stock while the consumer surplus and kept:released ratios exhibit the greatest difference in performance across the management procedures.



EAFM summer flounder recreational discards Management Strategy Evaluation: Simulation modeling specifications

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1. Purpose

This document provides description of the technical specifications and experimental design for the simulation framework employed as part of the MAFMC's Management Strategy Evaluation (MSE, e.g. Bunnefeld et al. 2009) for discarding in the summer flounder recreational fishery.

2. Simulation framework overview

The MSE simulation framework consists of a set of coupled model systems to emulate *in silico* the dynamics of the fishery and fishery management system for summer flounder, with a focus on the regulations for and response of the recreational fishery, as an experimental design to assess likely consequences of a set of management alternatives (here, different specifications for recreational fishing regulations, including bag limits, minimum size, and season length) for a set of performance metrics that address a range of social, economic, and conservation management objectives, given uncertainties in summer flounder population dynamics, scientific estimates of stock status, and the response of recreational fishers to changing conditions in summer flounder availability and regulations. The purpose of the MSE is to compare the relative performance of these alternatives against the stated objectives, and quantify the tradeoffs among objectives that arise for the different cases considered.

The set of management alternatives, performance metrics, and scenarios considered were developed through the Council's stakeholder engagement process for the project, with both a core group of stakeholders and guidance from a technical working group. These processes resulted in selection of 3 scenarios, and 7 management alternatives to be tested for each of those scenarios. A set of 100 simulations were conducted for each combination of scenario and management alternative. In each simulation, an **operating model**, representing the population dynamics of the summer flounder stock, its response to fishing, and the dynamics of the recreational fishery, was projected forwards in time by applying a **management model** that emulates the results of scientific stock assessments, applies management buffers in advice for scientific uncertainty, and allocates allowable catch to both commercial and recreational fishing sectors. The behavior of recreational fisheries in response to the chosen management alternative at the state level given the operating model stock size and length structure is then derived using a **recreational demand model**, and then the summer flounder population dynamics are updated via recruitment, growth, natural and fishing mortality based on the predicted levels of removals from both the commercial and recreational fishing fleets. More details on the sequence of model time steps are provided below following description of each model component. This feedback loop procedure is applied repeatedly over the course of the simulation, to reflect the influence of management decisions on the stock dynamics. At the end of each projection period, results are summarized for both the summer flounder stock and the fishery performance, and a set of performance metrics is calculated from the 100 simulations for the particular combination of scenario and management alternative.

During projections we distinguish between advice time steps and model time steps (annual) to reflect the fact that the management advice is not updated each year, the management advice (ABC) is updated every 2 years. In reality, the MAFMC's Scientific and Statistical Committee updates ABC recommendations every year, however these recommendations usually follow the results of ABC calculations determined from projections that were conducted at the time of the last stock assessment. For ease of implementation in the MSE the ABC for all years within an advice time step (2 years) was set at the same level.

In a given simulation, at each advice time step the following sequence of operations is implemented:

1. Calculate the current true operating model OFL based on the most recent year's fishing pattern
2. Apply the management model to:
   a. Generate the result of a new stock assessment in the form of an estimated OFL
   b. Calculate the ABC based on the estimated OFL and application of the MAFMC's risk policy.
   c. Determine the magnitude of commercial landings and discards given the current allocation to each sector (55% of ABC to commercial, then split according to current [2019] proportion by landings and discards)
3. For each year within the advice time step:
   a. Calculate the expected operating model vulnerable biomass and operating model size structure for the next year.
   b. Apply the recreational demand model given the recreational regulations in the management alternative being applied, and the current operating model population size structure to generate the values for that year's number of trips by state, and total numbers of fish released and kept by the recreational fishery.
   c. Update the operating model population dynamics to calculate the following year's numbers at age given the commercial allocation of the ABC and the realized recreational landings and discards at length from the output of the recreational demand model.

d. Increment the year by 1.

3. Operating model

The operating model represents the 'truth' in the simulation, in that it describes the dynamics and behavior of the summer flounder population and the fishery in response to changing management advice through the course of the simulation. Unlike a stock assessment projection, the MSE operating model framework thus allows for evaluation of management performance against a known population, rather than an estimated one that is subject to uncertainty and incomplete observation.

Three operating model scenarios were considered, 1) a 'base-case' scenario described below, and two alternatives reflecting key uncertainties that were identified as being important to understand behavior of management against. These focused on: 2) uncertainty in the MRIP estimates of the magnitude of recreational catch and its implications for understanding of stock size (and sustainable yield), and 3) changes over time in the regional availability of summer flounder to the recreational fishing sector.

The operating model consists of both a population dynamics model, and a fishing model. The fishing model includes both commercial and recreational fishing, but as the focus of the project is on the recreational component, the commercial fishing dynamics were modeled very simply to allow for more focus on the project objectives. The recreational fishing dynamics were driven by an economic model of recreational demand fit to angling preference data from a choice experiment. Details of how the models were coupled and description of the inputs and the outputs of the recreational demand model are provided below, the technical specifications are more fully described in the accompanying recreational demand technical document (Carr-Harris 2022).

3.1. Population Dynamics Model

The operating model population dynamics model consisted of an age- length- and sex-structured model, conditioned on the avaulable information for summer flounder to emulate summer flounder population and fishery dynamics. Full technical specifications for the generalized version of the model are detailed in Fay et al. (2011) and (Wayte et al. 2009). This operating model has been used extensively to evaluate the performance of assessment methods and management strategies (e.g. Fay et al. 2011; Little et al. 2014; Klaer et al. 2012; Fay and Tuck 2011, Fay 2018), including a previous application to summer flounder (MAFMC 2018). Advantages of adapting this existing software for the project included the explicit accounting of length based fishing mortality, to be able to represent the way in which the recreational fishery is managed, the ease of conditioning to available stock-specific information (being able to leverage results of summer flounder stock assessments). Using an existing, already-tested tool also allowed for project resources to be more efficiently allocated to the aspects of the summer flounder recreational fishing dynamics that were the focus of the research questions rather than in software development.

Where possible, life history and stock-recruitment parameter values were taken from the most recent summer flounder stock assessment report (NEFSC 2019) and in consultation with the technical working group. Specific operating model details are outlined below, and summarized in Figure 1.

3.1.1. Age and length structure

Age classes 0-7 were modeled for each sex, with age 7s as a plus group. A sex ratio at recruitment (age 0's) of 50% females and 50% males was assumed. 2cm length bins, from 10cm to 92cm.

3.1.2. Natural mortality

Age-specific, time-invariant values for the rate of natural mortality (*M*) were specified according to the most recent stock assessment (averaging $0.25yr^{-1}$). The same natural mortality at age schedule was applied to both males and females.

3.1.3. Growth

Growth of summer flounder was assumed to follow von Bertalanffy growth equations using schedules developed for SAW66 (NEFSC 2019), with separate growth patterns for males and females (Figure 1). Length at age was calculated at both the beginning of the year and mid-year, for summary statistics and vulnerable biomass calculations respectively. A single weight-at-length relationship (Lux and Porter 1996) was used to determine weights at age, as was calculated in the most recent summer flounder assessment (NEFSC 2021). Growth curve parameters and weight-at-length relationships were combined with estimates of population age structure and values for fishery selectivity (see below) to ensure the operating model dynamics produced expected size and age compositions for 2019 that are consistent with recent observations from the system. Figure 2.

3.1.4. Maturity

A logistic maturity at length relationship for both females and males was estimated, to determine a derived maturity at age schedule that matched that used in the 2021 assessment. Maturity at length was modeled as invariant over time. Figure 1.

3.1.5. Stock-Recruitment

To replicate the stock-recruit dynamics of the current assessment for summer flounder, which assumes deviations from an annual average recruitment, an average recruitment (R_0) for the population was set based on the median of the posterior distribution from the current assessment, with the steepness parameter *h* of the Beverton-Holt stock-recruit relationship set to 1.0. Annual recruitment deviations were modeled assuming a log-standard deviation of 0.8, matching that in the 2021 summer flounder stock assessment. Recruitment deviations during MSE projections were assumed to be uncorrelated over time (e.g. annual recruitments are random draws from the distribution and not related to previous year's recruitment).

3.1.6. Fleet structure

Four fishing fleets were modeled: 1) commercial landings, 2) commercial discards, 3) recreational landings, and 4) recreational discards. As mortality from discarded fish were modeled as separate fleets, all fishing fleets were modeled with full retention (retention = 1 across all size classes). Selectivity at length for the commercial fleets in all years, and for the recreational fleets in the initial year were derived based on logistic (landings fleets) and double-logistic (discard fleets) curves fit to emulate the selectivity at age schedules from the 2021 stock assessment to approximate the general behavior of the fishery. As with the growth parameters, the selectivity estimates were used in the model to predict the catch at age and catch at length distributions for 2019 given the 2019 age structure, to validate the operating model with a goal of producing catch at length and catch at age distributions that were similar to the true data for summer flounder from 2019.

Recreational selectivity for projection years other than in the first year were derived from the output of the recreational demand model, which simulates outcomes for the size distributions of kept and released fish. Selectivity in these years therefore was computed by dividing the catch at length from the recreational demand model by the numbers at length available to the recreational fishing fleets. derived from the operating model prediction for next year, given the expected commercial catches. An assumed discard mortality rate is applied to the recreational demand model output of the numbers of released fish, to compute the recreational discard fleet catch.

This mortality level was fixed at 10% (i.e. the recreational discard removals (catch) at length was 10% of the number of releases).

3.1.7. Initial conditions

The numbers-at-age in the first year of the projection (2019) were determined from the available draws from the posterior distribution from the most recent (2021) summer flounder stock assessment. The 2019 catch data by fleet from the 2021 summer flounder stock assessment were used to generate the operating model predictions for the first year of simulation projections. Catches in subsequent years during MSE projections were based on the output of the management and recreational demand models within the MSE closed loop simulations.

3.1.8. Biological reference points

At each time step, the recreational fishing selectivity and the relative magnitude of catches across fishing fleets varies. Thus, annual values for the true population dynamics model reference points were calculated (biomass at maximum sustainable yield, maximum sustainable yield, , as the basis for application of the management model and for performance metric summaries. These reference points were calculated based on the current Fishing Mortality reference point proxy of $F_{35\%}$, the fishing mortality level resulting in spawning biomass per recruit 35% of that with no fishing. These quantities were calculated based on equilibrium assumptions rather than the results of a population projection. In each year, a true value for the population dynamics model OFL was calculated based on applying the true fishing mortality target to the expected population age structure in the subsequent model year based on the most recent model year's fishing pattern. This true OFL was thus the basis for the calculation of the estimated OFL in the management model (see Section 4 below).

3.2. Recreational demand model

The operating model population length structure (sex aggregated) was passed to the recreational demand predictive model, which was calibrated to the number of fishing choice occasions in 2019. This model (full details in Carr-Harris 2022) uses estimates of angler preferences by state and region, expectations for catch per trip (based on the operating model population stock size relative to 2019), the size structure of the population, and a set of recreational fishing regulations for each state (as defined by the management alternatives) to simulate values for the number of summer flounder fishing trips in a given year, the expected numbers of fish kept and released during these trips, and their size structure. The output of the recreational demand prediction model includes the numbers at length of fish kept and released for the year - these are fed back to the population dynamics model (thus including both changes in total catch and time-varying selectivity for the recreational fishing fleets). As detailed above, the recreational demand model was run in each year of the projections to obtain a new estimate of recreational catches, even when the management advice (ABC) was not updated.

3.4. Alternative operating model scenarios

Two alternative operating model scenarios to the base-case described above were considered. These were chosen by the core stakeholder working group and technical working group to represent hypotheses for a particular aspect of uncertainty for the summer flounder fishery, to investigate the robustness of the chosen management alternatives to these properties. They do not thus represent a full suite of uncertainties for the system but rather represent a targeted approach to understanding how the likely management outcomes may vary given these assumptions thought to be important system drivers.

3.4.1. Magnitude of MRIP catch estimates
To understand the implications of bias in the MRIP estimates of recreational catch, the lower bounds of the 95% confidence intervals for MRIP estimates of catch by state and wave were used as the basis for calibrating the recreational demand model rather than the point estimates. The population dynamics model was also adjusted in this scenario to reflect the expectations for stock size given a lower magnitude of historical recreational catches. The initial (2019) numbers at age and average recruitment were scaled based on the results of sensitivity analyses conducted during the 2019 benchmark assessment for summer flounder (NEFSC 2019).

3.4.2. Changes in spatial availability
This scenario reflects expected changes over time in the spatial distribution of summer flounder, which could result in further changes to the availability of fish to anglers in each state. This scenario adjusted the expected catch per trip by geographic region during application of the recreational demand model, based on projected proportions of summer flounder biomass by region from the NOAA Fisheries bottom trawl survey. This scenario thus allows for both the annual change in expected catch per trip as a result of variations in stock size, and a gradual shift northward of the stock, resulting in the northern regions having progressively more fish available on average over time and the southern region having fewer fish available over time. While a simplistic implementation, this scenario does allow for the general effect and consequent interactions with management performance that a shifting stock could likely induce. No adjustment was made to the relative availability by region of individual length classes.

4. Management Model
The management model emulates results of the scientific stock assessment process and the determination of ABCs, and was designed to reflect the believed scientific uncertainty associated with OFLs for summer flounder. At each advice time step, an estimated OFL is generated from the operating model based on the operating model true OFL that would be obtained based on applying the target fishing mortality to the modeled population vulnerable biomass given perfect knowledge of the current fishing pattern among fleets. The estimated OFL was generated from the true value assuming lognormal random variation with CV 60% (which reflects the value used by the SSC as representing the degree of scientific uncertainty associated with the OFL), and autocorrelation in OFL estimation errors (differences between the true OFL value and the estimated value) over advice time steps to reflect the tendency for stock assessments close in time to have similar results (e.g. Wiedenmann et al. 2015). This approach simplifies the modeling of the monitoring and assessment process, and thus does not capture everything associated with the assessment procedure. However, it is difficult to replicate in simulation the decision process associated with conducting a stock assessment, and the technical working group decided this simpler approach both allowed for appropriate capture of the general properties of an assessment (estimation error) with rationale for agreed-upon magnitude of uncertainty in assessment results (by using the uncertainty in OFL that the SSC uses for actual decision-making for summer flounder), and meant that differences in model behavior among management alternatives could be better ascribed to the different management specifications rather than additional interactions among the monitoring data and assessment process.

We distinguish between advice time steps and model time steps (annual) to reflect the fact that the management advice is not updated each year (i.e. a full assessment is not conducted every year). In reality, the MAFMC's Scientific and Statistical Committee updates ABC recommendations every year, however these recommendations usually follow the results of ABC calculations determined from projections that were conducted at the time of the last stock assessment. For ease of implementation in the MSE the ABC for all years within an advice time step (2 years) was set at the same level. Following calculation of the estimated OFL, the ABC was calculated by applying the Council's risk policy assuming the current SSC OFL CV determination of 60%. As the output of the modeled assessment process only constitutes an estimated OFL and not an estimate of stock status relative to the B_{MSY} reference point, a P^* value of 0.4 was applied to the estimated OFL to derive the ABC in all advice years. This approach approximates the application of the MAFMC risk policy but does not account for changing perceived tolerance in risk of exceeding the OFL based on estimates of stock size.

Following calculation of the ABCs, the magnitude of commercial catches were determined based on the current implementation of allocation between commercial and recreational sectors. The MSE simulations assumed that the commercial fishery always utilized its quota during the simulations, so the calculated commercial catch was input directly into the operating model population update. This is in contrast to the recreational catches, which were input based on the application and output of the recreational demand model.

5. Projections

The operating models were projected forward in time over a 26 year period. 100 simulations / realizations were conducted for each combination of operating model scenario and management alternative, with each of the 100 simulations differing based on: 1) the starting age structure (different draw from the posterior); 2) sequence of annual recruitment deviations; 3) observation/estimation errors for the OFL and resulting consequences for management advice; 4) simulated outcomes for angler behavior based on recreational regulations; and 5) a small amount if implementation error in the magnitude of catches among fleets. As the effects of these differences are linked through the coupled model structure and feedback loops, each of the 100 simulations represents a different realization of possible outcomes for the stock and fishery given a particular management specification. The same 100 set of draws from the 2019 age structure and time series of recruitment deviations were used in each scenario. At the conclusion of the 26 year projection period, a set of quantities are saved for the simulation, to be used to calculate performance metrics.

6. Management alternatives

Seven management alternatives were considered, each corresponding to a specification for the set of recreational regulations in place for the simulations. These alternatives were considered fixed over time - simulations used the same settings for the recreational regulations throughout the projection period. Thus there was no feedback from the assessment and monitoring components (management model) of the MSE to decisions regarding the recreational regulations to put in place in a given year (i.e. simulated managers did not update regulations based on information from the simulated fishery). Thus the simulations evaluated the general expectations for managing a certain way, rather than the efficacy or ability of the recreational fishery management system to respond to uncertain information, and the ability to make robust decisions based on this information. Alternatives considered included changes to size limits, bag limits, and season lengths, and are summarized in Table 1.

7. Performance metrics

We calculated a set of performance metrics, based on those specified by both the core stakeholder group and the technical advisory group. Calculations of these relied on information derived from the population dynamics model, the recreational demand model, and the management model. For magnitude-based metrics, these were calculated using the average over time for the projection period in a given simulation. For frequency-based metrics (e.g. proportion of years in which F is above F_{MSY}, a single value for each simulation was calculated given the realized time series. Performance metrics were summarized as the distribution over simulations for a given scenario/management alternative combination, and also as values across simulations to obtain a single value for each metric. These two methods of summarizing the results allow for different treatments when visualizing outputs and performing tradeoff analyses. Performance metrics calculated are summarized in Table 2, most quantities were calculated as:

$$\mathbf{X_{s,m}} = \mathbf{median}\left(X_{s,m,i=1}, X_{s,m,i=2}, \ldots, X_{s,m,i=100}\right)$$

$$X_{s,m,i} = \frac{1}{10}\sum_{2036}^{2045} X'_{s,m,i,t}$$

That is, the median (over simulations) of the average annual value for a quantity, and

$$X_{s,m,i} = \frac{1}{10}\sum_{2036}^{2045} \text{if}(X'_{s,m,i,t} = Z_X, 1, 0)$$

where Z_X is some threshold or condition associated with metric *X*. In this case, the metric is the median (over simulations) number of years in which a quantity is true.

The performance metrics were associated with each of the four management objectives:

7.1. Management Objective 1: Improve the quality of the angler experience

1. Percent of trips taken where the number of kept fish is greater than or equal to one.

$$X'_{s,m,i,t} = \frac{1}{N^T_{s,m,i,t}} \sum_{j=1}^{N^T_{s,m,i,t}} \text{if}(N^{keep}_{s,m,i,t,j} \geq 1, 1, 0)$$

2. Relative change in average annual numbers of kept fish per trip compared to that in management alternative 1.

$$X_{s,m,i} = \frac{\frac{1}{10}\sum_{2036}^{2045} X'_{s,m,i,t}}{\frac{1}{10}\sum_{2036}^{2045} X'_{s,1,i,t}}$$

$$X'_{s,m,i,t} = \frac{\sum(N^{keep}_{s,m,i,t})}{N^{T}_{s,m,i,t}}$$

3. Expected change in consumer surplus from 2019 expectation per trip

$$X'_{s,m,i,t} = \frac{\sum(\Delta CS_{s,m,i,t})}{N^{T}_{s,m,i,t}}$$

4. Proportion/number of fish caught greater than 28 inches

$$X'_{s,m,i,t} = \frac{\sum(N^{keep}_{s,m,i,t,l=28+})}{\sum(N^{keep}_{s,m,i,t})}$$

7.2. Management Objective 2: Maximize the equity of anglers' experience

5. ability to retain a fish 1.
   a. Relative change in the proportion of trips in each state that catch at least one fish compared to the baseline (status quo management alternative) for that state. (state subscripts not shown)

$$X_{s,m,i} = \frac{\frac{1}{10}\sum_{2036}^{2045} X'_{s,m,i,t}}{\frac{1}{10}\sum_{2036}^{2045} X'_{s,1,i,t}}$$

$$X'_{s,m,i,t} = \frac{1}{N^{T}_{s,m,i,t}} \sum_{j=1}^{N^{T}_{s,m,i,t}} \text{if}(N^{keep}_{s,m,i,t,j} \geq 1, 1, 0)$$

6. ability to retain a fish 2.
   a. Range (over states) in the proportion of trips in each state that catch at least one fish compared to the baseline (status quo management alternative) range over states.

$$X_{s,m,i} = \frac{\max_{state}(5_{s,m,i}) - \min_{state}(5_{s,m,i})}{\max_{state}(5_{s,1,i}) - \min_{state}(5_{s,1,i})}$$

7. retention rate 1.
   a. Relative change in the proportion kept:(kept+released) fish in each state compared to the baseline (status quo management alternative) for that state. (state subscript not shown)

$$X_{s,m,i} = \frac{\frac{1}{10}\sum_{2036}^{2045} X'_{s,m,i,t}}{\frac{1}{10}\sum_{2036}^{2045} X'_{s,1,i,t}}$$

$$X'_{s,m,i,t} = \frac{1}{N^{keep}_{s,m,i,t}} N^{keep}_{s,m,i,t} + N^{release}_{s,m,i,t}$$

8. retention rate 2.

a. Range (over states) in the proportion kept:(kept+released) fish in each state compared to the baseline (status quo management alternative) range over states.

$$X_{s,m,i} = \frac{\max_{state}(7_{s,m,i}) - \min_{state}(7_{s,m,i})}{\max_{state}(7_{s,1,i}) - \min_{state}(7_{s,1,i})}$$

7.3. Management Objective 3: Maximize stock sustainability

9. Proportion of years where SSB is less than 0.5 BMSY.

$$X_{s,m,i} = \frac{1}{10}\sum_{2036}^{2045} \text{if}(SSB_{s,m,i,t} < 0.5BMSY_{s,m,i,t}, 1, 0)$$

10. Proportion of years where F is greater than FMSY.

$$X_{s,m,i} = \frac{1}{10}\sum_{2036}^{2045} \text{if}(F_{s,m,i,t} > FMSY_{s,m,i,t}, 1, 0)$$

11. Relative change in average annual SSB compared to the average annual SSB under management alternative 1.

$$X_{s,m,i} = \frac{\frac{1}{10}\sum_{2036}^{2045} SSB_{s,m,i,t}}{\frac{1}{10}\sum_{2036}^{2045} SSB_{s,1,i,t}}$$

12. Relative change in average annual numbers of released fish per trip compared to that in management alternative 1, calculated for each state and region (state/region subscripts not shown)

$$X_{s,m,i} = \frac{\frac{1}{10}\sum_{2036}^{2045} X'_{s,m,i,t}}{\frac{1}{10}\sum_{2036}^{2045} X'_{s,1,i,t}}$$

$$X'_{s,m,i,t} = \frac{\sum(N^{release}_{s,m,i,t})}{N^{T}_{s,m,i,t}}$$

13. Relative change in average annual biomass of removals (retained and dead discard) compared to that in management alternative 1

$$X_{s,m,i} = \frac{\frac{1}{10}\sum_{2036}^{2045} X'_{s,m,i,t}}{\frac{1}{10}\sum_{2036}^{2045} X'_{s,1,i,t}}$$

$$X'_{s,m,i,t} = B^{keep}_{s,m,i,t} + B^{deaddiscard}_{s,m,i,t}$$

14. Proportion by numbers of the recreational removals (retained and dead discards) that are made up of female fish.

$$X^{'}_{s,m,i,t} = \frac{C^{female}_{s,m,i,t}}{C^{female}_{s,m,i,t} + C^{male}_{s,m,i,t}}$$

where $C_{\{s,m,i,t\}}^{female}$ is the recreational removals (catch) in numbers for females.

7.4. Management Objective 4: Maximize the socio-economic sustainability of fishery

15. Relative change in the average annual number of trips compared to management alternative 1, for each state and region (state and region subscripts not shown).

$$X_{s,m,i} = \frac{\frac{1}{10}\sum_{2036}^{2045} N^T_{s,m,i,t}}{\frac{1}{10}\sum_{2036}^{2045} N^T_{s,1,i,t}}$$

16. Average annual change in consumer surplus compared to 2019 expectation, for each state and region (state and region subscripts not shown).

$$X_{s,m,i} = \frac{1}{10}\sum_{t=2036}^{2045} \Delta CS_{s,m,i,t}$$

17. Relative change in annual average sales/income/employment/GDP compared to management alternative 1, by state/region/coast. (state/region subscripts not shown)

8. References

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Table 1. Management alternatives considered in the MSE, consisting of sets of regulations applied in the recreational fishery. Alternatives vary with respect to bag limit, size limit(s), and season length.

Options with Current Regional Breakdown
1. Status quo – using 2019 regs as baseline (regs essentially same in 2019-2021)
2. Size limit change – status quo regulations (possession and season) for each state, but drop the minimum size by 1 inch (not going lower than 16 inches) within each state
3. Season change - status quo regulations for each state (possession and size) but open season for all states of April 1-Oct 31
Options with Different Regional Breakdown
4. 3 region option (MA-NY, NJ, DE-NC – same as regions used in black sea bass) a. MA-NY: 5 fish @ 18" May 1-Sept 30 b. NJ: 4 fish @ 17" May 1-Sept 30 c. DE-NC: 4 fish @16" All year
Coastwide Options
5. 3 fish @ 17" and season from May 1-Sept 30
6. 1 fish @ 16"-19" (ie., up to 18.99 inches) and 2 @ 19" and greater and season from May 1-Sept 30
Slot Limit Option
7. 3 fish at 16"-20" with season of May 1-Sept 30

Table 2. Performance metrics calculated in the MSE corresponding to specified management objectives

Management Objective 1: Improve the quality of the angler experience

Performance Metrics:

1) Ability to retain a fish
    a. Percent of trips that harvest at least one fish
    b. Change from baseline (ie., status quo) in harvest per trip
2) Angler welfare
    a. Changes in consumer surplus/angler satisfaction at the trip/individual level
3) Ability to retain a trophy fish
    a. Proportion/number of fish caught greater than 28 inches

Management Objective 2: Maximize the equity of anglers' experience

Performance Metrics:

1) Ability to retain a fish
    a. Change in percent chance of retaining a fish, by state/region
    b. Difference in percent chance of retaining a fish, by state/region
2) Retention rate
    a. Change in ratio of landed : discarded fish, by state/region
    b. Difference in ratio of landed : discarded fish, by state/region

Management Objective 3: Maximize stock sustainability

Performance Metrics:

1) Stock status: Reference points
    a. % chance of stock is overfished relative to spawning stock biomass (SSB) target (note: SSB reference point includes both male and female biomass)
    b. % chance of overfishing relative to Fmsy threshold
2) Stock status: Overall population
    a. Change in SSB relative to status quo (i.e., stock grow, decline compared to status quo)
    b. Discard mortality
        i. # of discards per trip, by state/region
    c. Change in total removals (harvest and dead discards) compared to status quo
3) Stock status: Female spawning stock biomass
    a. % of female catch

Management Objective 4: Maximize the socio-economic sustainability of fishery

Performance Metrics:

1) Fishing effort
    - # of trips relative to status quo (increase or decrease in trips), by state/region
2) Angler welfare
    - Changes in consumer surplus/angler satisfaction at the state/region level
3) Fishery investment
    - Changes in fishery investment measured by: sales, income, employment, and GDP produced by supporting businesses at the state-level or higher

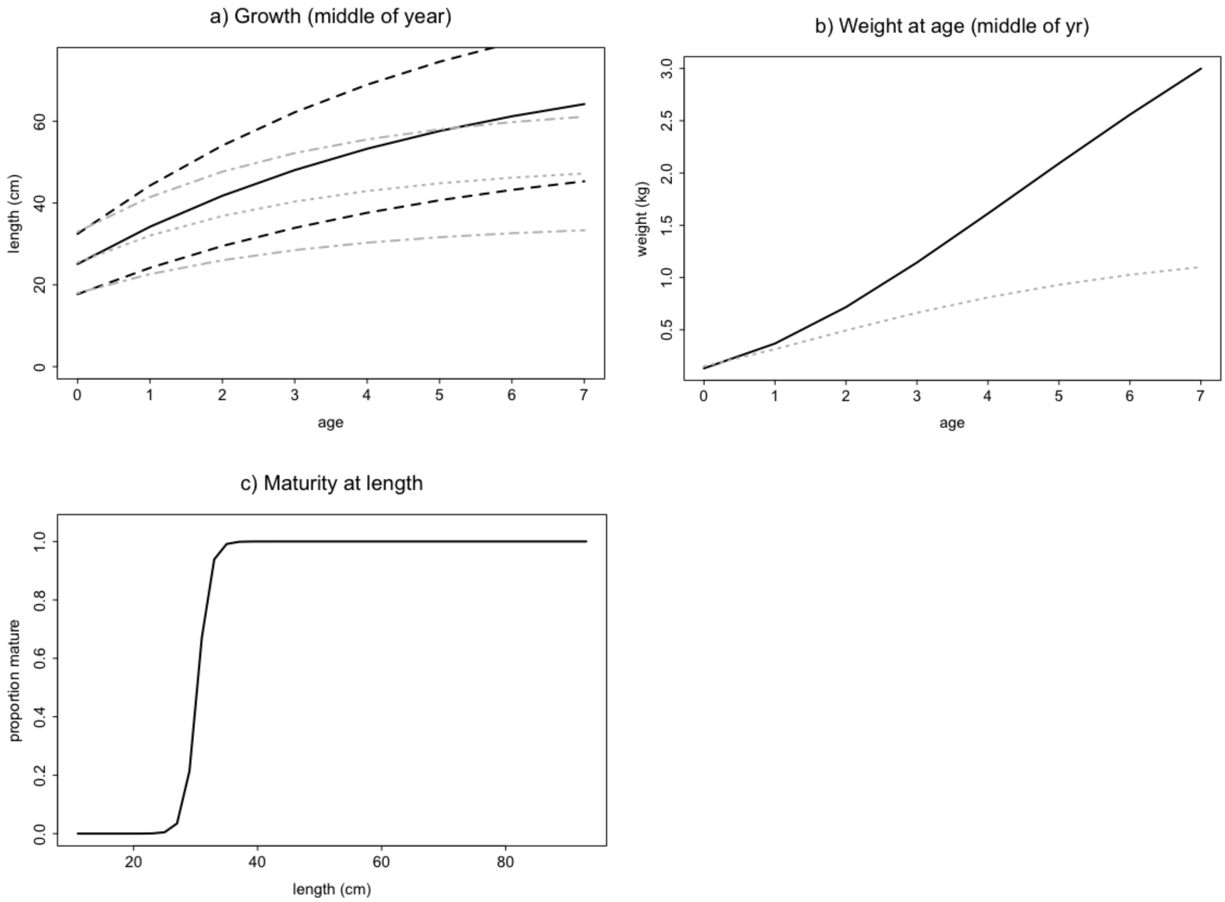

Figure 1. Operating model specifications for summer flounder showing a) mean (solid line) and standard deviation (dashed line) of length at age, b) weight at age (solid line females, dashed line males), c) maturity at length.

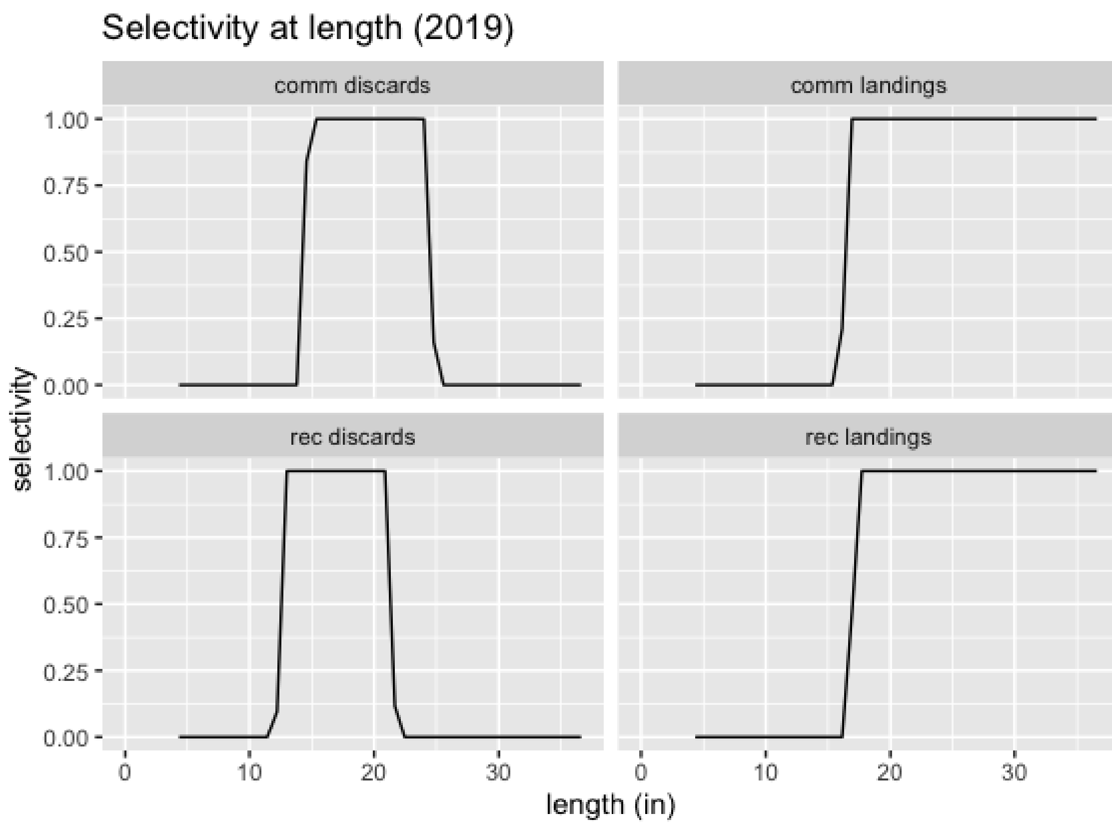

Figure 2. Operating model specifications for summer flounder showing selectivity at length for all years for the commercial fishing fleets and for the initial year for the recreational fleets.

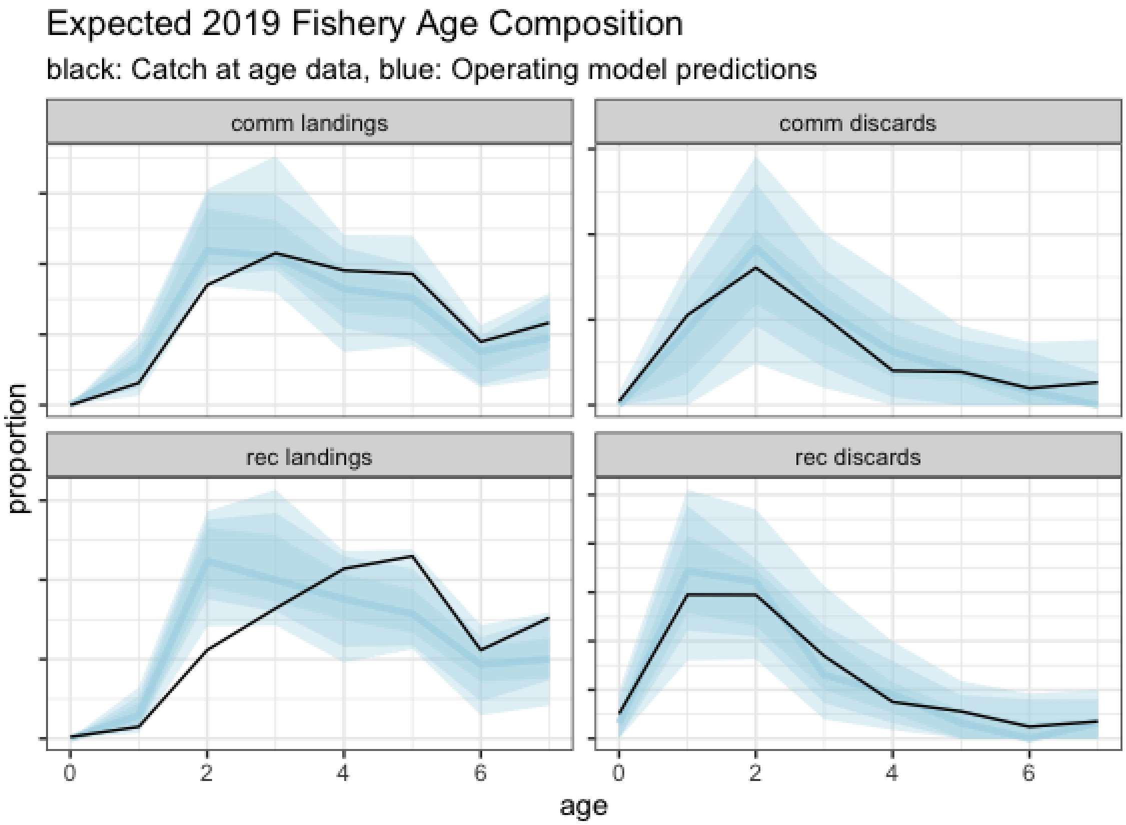

Figure 3. Operating model predictions for 2019 catch at age by fleet compared to the 2019 data.

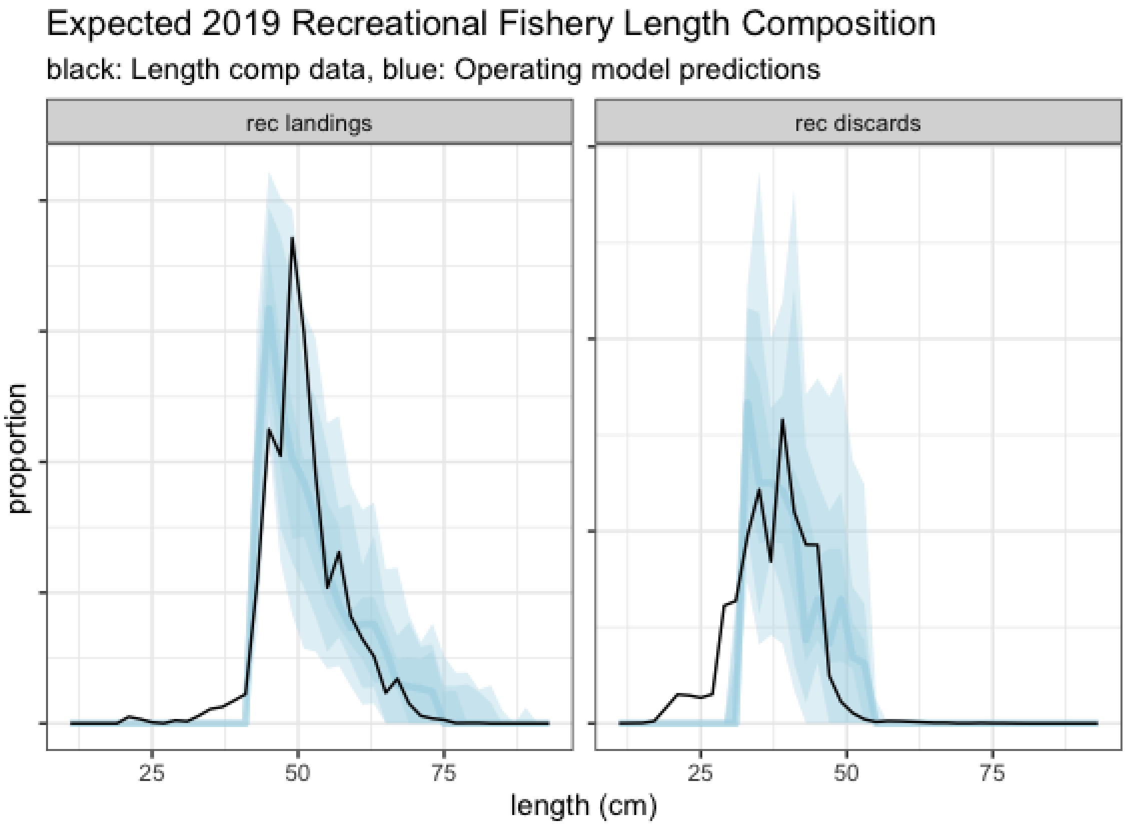

Figure 4. Operating model predictions for 2019 catch at length for the recreational fleets compared to the 2019 data.

Summer Flounder Recreational Demand Model: Overview, Data, and Methods

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1 Introduction

This document describes the data and methods underlying the recreational demand model (RDM) component of the MAFMC's Management Strategy Evaluation (MSE) of the recreational summer flounder (fluke) fishery. As part of a fully integrated bio-economic model,[1] the RDM provides the key link between projected fluke population abundances, regulations, and expected recreational fishing mortality.

The RDM is a unique approach to evaluating the potential impact of alternative fluke management strategies on fishery-wide outcomes because it explicitly models the relationship between policy- or stock-induced changes in trip outcomes and angler behavior. As Fenichel et al (2013) note, angler behavior has important consequences on several aspects of the recreational fishing system, including the cumulative effect on fishing mortality and subsequent impacts to biomass. However, angler behavior is often neglected in the policymaking process (Beard et al. 2011), which may lead to regulations that ineffectively meet management goals. In addition to measuring the likely effect of regulations on angler behavior and recreational fishing mortality, the RDM captures the economic implications of regulations in terms of changes in angler welfare and fishing trip expenditures, allowing for these metrics to be considered in the MSE.

There are three main components of the RDM: an angler behavioral model, a calibration sub-model, and a projection sub-model. Each component is described in detail below. The angler behavioral model uses choice experiment survey data (Sections 2) to estimate angler preferences for harvesting and discarding fluke and other primary species (Sections 3 and 4). These estimates parameterize the calibration and projection sub-models and are also used to calculate behavioral and welfare responses to regulations (Section 5). The calibration sub-model, discussed in Section 6, emulates coast-wide fishing activity in a baseline year using trip-level data and serves as a baseline to which we compare alternative management scenarios. The link between projected stock structures and angler catch is described in Section 7. The projection sub-model, described in Section 8, simulates the fishery conditional on a projected stock structure and management scenario and computes expected impacts to angler effort, angler welfare, the local economy, and recreational fishing mortality. Section 8.1 discusses the economic metrics captured by the RDM and Section 8.2 provides information about how alternative operating model assumptions enter

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[1] For an overview of the integrated bio-economic model, please see the August 2022 Council meeting briefing book materials at: https://www.mafmc.org/briefing/august-2022.

the RDM. We also the evaluate the out-of-sample predictive power of the RDM and provide these results in Section 8.3.

2 Choice experiment survey

Choice experiments (CEs) are a common stated-preference approach to non-market valuation and provide a means to estimate the value of goods and attributes that are not traded explicitly in a market and therefore lack prices to signal value (Adamowicz et al. 1998). Like other types of stated preferences methods, CEs rely on individuals' responses to hypothetical questions and are particularly useful when revealed preference, i.e., observational data on actual human behavior is inadequate or non-existent. In the case of the summer flounder MSE, the CE approach allowed us to derive the marginal value of harvesting and discarding fluke and therefore estimate the economic implications of current and previously unobserved management scenarios that might affect angler harvest and discards.

In a typical CE, respondents are presented with two or more hypothetical multi-attribute goods and asked to compare and choose their most preferred good. It is common for one attribute to represent the "price" of the good, defined in monetary (e.g., annual tax or one-time trip cost) or non-monetary units that can be monetized (e.g., travel distance) that provide a budget constraint to individuals' purchasing decisions. Individuals are assumed to choose a good only when its benefit outweighs its cost and it provides maximum utility overall all available goods in a given choice scenario. The resulting data on individual purchasing decisions can be used to evaluate consumer preferences for, behavioral response to, and welfare impacts of marginal changes in attribute levels (Louiviere et al. 2000). In recreational fishing contexts, there have been numerous applications of CEs and other types of stated preference surveys seeking to evaluate the influence of catch and non-catch related attributes on angler choices (Hunt et al. 2019).

Our CE data come from an angler survey administered in 2010 as a follow-up to the Access Point Angler Intercept Survey (APAIS), an in-person survey that collects information from anglers at publicly accessible fishing sites as they complete their fishing trips. The APAIS is one of several surveys used by the Marine Recreational Information Program (MRIP) to produce catch and effort estimates for recreational marine species across the United States. Anglers who participated in the APAIS in coastal states from Maine to North Carolina during

2010 were asked to participate in the voluntary follow-up CE survey. Those willing to participate were sent CE survey materials via mail or email shortly after the intercept interview. A total of 10,244 choice experiment surveys were distributed, of which 3,234 were returned for an overall response rate of 31.5%.

The survey instrument contained three sections. Section (A) collected information about respondents' fishing experiences in the past year and species preferences, as well as the factors that influence their decision to fish. Section (B) contained a set of choice experiment questions (Figure 1). In these questions, respondents were presented with three hypothetical multi-attribute fishing trip options. Trip A and Trip B varied and contained different species-specific bag and size limits, catch and keep of fluke and other primary species, and total trip costs. Trip A provided a range for numbers of fluke caught and kept rather than single value as in Trip B. Trip C was an option to go fishing for other species and was added as an attempt to capture target species substitution. Respondents were asked to compare and choose their favorite among the three trip options or opt to not saltwater fish. Lastly, section (C) gathered demographic information including gender, birth year, education, ethnicity, and income. Given regional differences in species availability, survey versions were developed for four sub-regions: (i) coastal states from Maine through New York, (ii) New Jersey, (iii) Delaware and Maryland, and (iv) Virginia and North Carolina. The four survey versions differed in the species other than fluke and black sea bass included in Sections A and B.[2]

2.1 Experimental design

For each regional version of the survey, multiple sub-versions that differed in levels of the trip attributes shown within and across choice questions were administered. Trip attribute levels were chosen based on historical catch and trip expenditure data and corroborated with focus group feedback. They were then randomized across choice questions using an experimental design that sought to maximize the statistical efficiency of the ensuing model parameters. Each experimental design was specified to produce a total 128 choice questions. Because 128 is too many questions

[2] In terms of the CE attributes in Section B, the Maine to New York version included fluke, black sea bass, and scup; the New Jersey version included fluke, black sea bass, scup, and weakfish; the Delaware and Maryland version included fluke, black sea bass, and weakfish; and the Virginia and North Carolina version included fluke, black sea bass, weakfish, and red drum.

for a single respondent to answer, questions were randomly allocated into 16 subsets such that each respondent was presented with eight choice questions.

SECTION B: SALTWATER FISHING TRIPS

The following questions help us understand tradeoffs made by anglers when they go fishing.
Compare Trip A, Trip B, and Trip C in the table below, then **answer** questions **1A** and **1B**.
Compare only the trips on this page. Do **not** compare these trips to trips on other pages in this survey.

Trip Features		Trip A	Trip B	Trip C
Summer Flounder (Fluke)	Regulations	1 Fluke, 16" or larger	3 Fluke, 18" or larger	Go fishing for striped bass or bluefish
	Fish Caught	3 to 13 Fluke, 22" TL	1 Fluke, 15" TL	
	Fish Kept	1 Fluke	0 Fluke	
Black Sea Bass	Regulations	20 Bl. S. Bass, 14" or larger	30 Bl. S. Bass, 9" or larger	
	Fish Caught	30 Bl. S. Bass, 12" TL	10 Bl. S. Bass, 9" TL	
	Fish Kept	0 Black Sea Bass	10 Black Sea Bass	
Scup (Porgy)	Regulations	20 Scup, 12.5" or larger	5 Scup, 13" or larger	
	Fish Caught	3 Scup, 16" TL or larger	40 Scup, 6" TL or smaller	
	Fish Kept	3 Scup	0 Scup	
Weakfish	Regulations	0 Weakfish of any size	5 Weakfish, 12" or larger	
	Fish Caught	7 Weakfish, 15" TL	1 Weakfish, 18" TL	
	Fish Kept	0 Weakfish	1 Weakfish	
Total Trip Cost		$160	$160	$45

Definitions:
- **Regulations:** The legal minimum size restriction and bag limit for this trip.
- **Fish caught:** The number of fish caught on this trip and the total length (TL) of those fish.
- **Fish kept:** The number of fish you can legally keep on this trip.
- **Total trip cost:** ***Your portion*** of the costs associated with this trip, including bait, ice, fishing equipment purchase or rental, daily license fees, boat rental fees, boat fuel, trip fees, and round trip transportation costs associated with traveling to and from the fishing location. Travel costs may include vehicle fuel, car rental, tolls, airfare, and parking.

1A Choose your favorite trip. (Please mark only **one** trip with a ☑ or a ☒.)

Trip A ☐
Trip B ☐
Trip C ☐
I would not go saltwater fishing ☐

Figure 1. Example choice experiment question from the New Jersey survey version.

2.2 Choice experiment sample

A total of 3,234 people completed or partially completed the mail or web version of the survey. Of these respondents, 2,941 answered at least one of the eight choice experiment questions. We removed from the sample respondents who universally choose the zero-cost, “Do not go saltwater fishing” option or the pelagic trip (Trip C) as their favorite trip following recommended best practices in Johnston et al. (2017).[3] We also excluded from the analysis respondents who indicated that the survey was not completed by the person to whom it was addressed. The remaining sample consisted of 2,448 anglers.

Table 1 displays some demographic characteristics of sample anglers by region. Sample anglers were predominantly male (90-93% across regions) and Caucasian (94-96% across regions). The average age was just under 53. Roughly one quarter to one third of the sample in each region attained a bachelor's degree or higher. Between 60% and 70% of the sample in each region had household incomes ranging from $20,000 to $100,000, while between 26% and 30% had household incomes above $100,000. Lastly, the average number of days spent fishing during the previous calendar year (2009) varied from 20 to 28 across regions, with New Jersey anglers fishing considerably more frequently in the past year than anglers in other regions.

Table 1. Demographic characteristics of choice experiment sample.

Characteristic	ME-NY	NJ	DE/MD	VA/NC
% male	92.7	93.2	91.0	90.0
% Caucasian	95.6	95.7	94.5	94.5
Mean age	52.8	52.8	52.9	52.2
Education				
% with high school graduate or GED	33.1	42.4	43.7	28.8
% with some college but no degree or associate's degree	34.7	30.5	28.0	36.8
% with bachelor's degree or higher	32.1	27.0	28.2	34.2
Household income				
% less than $20,000	6.9	2.0	7.1	4.6
% between $20,000 and $100,000	62.7	69.5	67.0	69.0
% over $100,000	30.3	28.4	25.7	26.3
Mean # fishing trips taken during 2009	21.1	27.7	18.6	20.1

Sample anglers were recruited from the APAIS, which occurs at publicly accessible fishing sites only. Anglers fishing from private access points were therefore excluded from the sampling design. To understand the extent to which each fishing mode is represented in our

[3] Key parameter estimates from choice models that included these participants were similar in sign, significance, and magnitude to those presented in this document.

sample and how the distribution of fishing effort by mode aligns with the distribution of fishing effort in the population, Table 2 compares MRIP estimates of fishing effort for primary species by mode to the distribution of fishing effort indicated by our sample.[4] Compared to the population, shore trips were underrepresented in the sample while party and charter boat trips were overrepresented. The percent of private boat trips in the sample closely matches the population and in both cases and accounts for the lion's share of all trips. So while the sample did not mirror the population distribution of fishing effort by mode in 2009, it did encompass directed effort from all four fishing modes.

Table 2. Percent of trips taken for primary species by mode during 2009.

	MRIP	CE sample
ME-NY		
Shore	40.3	16.7
Party boat	2.0	24.0
Charter boat	1.5	4.0
Private boat	56.2	55.3
NJ		
Shore	34.9	22.6
Party boat	2.1	21.8
Charter boat	1.3	3.9
Private boat	61.6	51.7
DE/MD		
Shore	37.8	28.6
Party boat	1.3	11.6
Charter boat	0.9	4.4
Private boat	60.0	55.4
VA/NC		
Shore	46.4	30.6
Party boat	0.1	3.6
Charter boat	0.2	3.5
Private boat	53.3	62.4

Notes: Primary species include fluke and black sea and other species that varied by survey version: the ME-NY survey also included scup, the NJ version also included scup and weakfish, the DE/MD version also included weakfish, and the VA/NC also included weakfish and red drum. The MRIP columns shows percentages of all trips taken for the primary species, while the CE sample column shows percentages of all trips taken for the primary species as indicated by sample respondents.

[4] The survey asked anglers how many trips they took in 2009 for fluke, black sea bass, and either scup, weakfish, and/or red drum depending on the survey version.

3 Behavioral model framework

We analyzed our CE data using random utility models (McFadden 1973) , which decompose the overall utility angler n receives from trip alternative j ($j = A, B, C, or\ no\ trip$) into two components: V_{nj}, a function that relates observed fishing trip attributes x_{nj} to utility, and ε_{nj}, a random component capturing the influence of all unobserved factors on utility. Angler utility can be expressed as

$$\begin{aligned} U_{nj} &= V_{nj} + \varepsilon_{nj} \\ &= \beta_n' x_{nj} + \varepsilon_{nj}, \end{aligned} \tag{1}$$

where β_n' is a vector of preference parameters measuring the part-worth contribution of trip attributes x to angler n's utility, and ε_{nj} is an independent and identically distributed Type I extreme value error term. Under the random utility framework, an angler will select alternative i if it provides maximum utility over all alternatives available to him or her in a given choice occasion, i.e.

$$U_{ni} > U_{nj}\ \forall\ j \neq i. \tag{2}$$

We estimated panel mixed logit models, which allow for unobserved preference heterogeneity—a recommended best-practice for stated preference analysis (Johnston et al. 2017)—through estimation of parameter distributions for the attributes specified as random. Allowing preferences to vary across individuals is the primary advantage of the mixed logit over the basic multinomial logit (MNL) model, which assumes that individuals have the same preferences. Panel mixed logit estimation also resolves some behavioral limitations of the MNL model, including the independence of irrelevant alternatives property and the assumption that unobserved factors that influence decisions are uncorrelated over repeated choice situations (Hensher and Greene 2003). The probability that angler n chooses alternative i is obtained by integrating the logit formula over the density of β (Train 2003):

$$P_{ni} = \int \frac{e^{\beta' x_{ni}}}{\sum_{j=1}^{J} e^{\beta' x_{nj}}} f(\beta) d\beta. \tag{3}$$

These probabilities are approximated via simulation in which repeated draws of β are taken from $f(\beta|\theta)$, where θ refers to the mean and covariance of this distribution. For each draw, the logit formula is calculated for all choice scenarios (up to eight) faced by individual n. Then, the product of these calculations is taken, giving the joint probability of observing individual n's sequence of choices. The average of these calculations over all draws is the simulated choice probability, $\check{P}_{ni}$. The estimated parameters are the values of θ that maximize the simulated log likelihood function,

$$LL = \sum_{n=1}^{N} \sum_{t=1}^{T} \sum_{j=1}^{J} d_{ntj} \ln(\check{P}_{ntj}), \tag{4}$$

where $d_{njt} = 1$ if individual n chose alternative j in choice scenario t and zero otherwise.

We specified the utility associated with fishing trip alternatives A and B as a linear additive function of the number of fish kept and released by species and the trip cost. For Trip A, the midpoint of the range of fluke catch depicted in the choice experiment was used to calculate numbers of fluke kept and released. The utility associated with Trip C, a fishing trip for other species, was specified as a function of the trip cost and a constant term (*fish for other species*) that measures the utility of a pelagic trip relative to the utility from the other alternatives. The utility associated with the non-fishing, "I would not go saltwater fishing" alternative (alternative D), was specified as a function of a constant term (*do not fish*) that captures preferences for not fishing. To allow for diminishing marginal utility of catch (Lee et al. 2017), keep and release attributes entered the model as their square root. The estimated models assumed that all non-cost parameters were normally distributed, while the cost parameter was treated as fixed to facilitate welfare calculations (Revelt and Train 2000).

4 Behavioral model results

Results from the panel mixed logit model, estimated separately for each regional survey sub-version, are shown in Table 3. Mean parameters measure the relative importance of each trip attribute on overall angler utility, while standard deviation parameters measure the extent to which preferences vary across the sampled population.

The estimated mean parameters were generally of the expected sign. Across the regional models, the mean parameters on *trip cost*, the marginal utility of price, were negative and significant and intuitively suggest that higher trip costs reduce angler utility. Mean parameters on all keep variables were positive, significant, and higher in magnitude than their corresponding release parameter. This means that each species is predominantly targeted for consumption rather than sport, which aligns with input from recreational fishery stakeholders. The magnitude of the summer flounder keep parameters relative to other primary species' keep parameters suggests that anglers value keeping fluke more than they value keeping black sea bass, scup, weakfish, or red drum.

The signs and significance of the release parameters varied by species and region. For example, only in the VA/NC model was the mean parameter on $\sqrt{SF\ released}$ positive and significant, suggesting that anglers in this region value catching and releasing summer flounder. Additionally, in two of the three regional models, the parameter on $\sqrt{WF\ released}$ was positive and significant. Catching and releasing scup reduces utility for anglers in New Jersey according to the parameter on $\sqrt{scup\ released}$. Perhaps these anglers perceive catching and having to release scup as a nuisance when fishing for larger and more valuable target species.

Baseline levels of non-fishing utilities, captured by the parameters on *do not fish*, were negative and significant. This mean that, when given the option, anglers derive more utility from fishing than not fishing. In contrast, the parameters on *fish for other species* suggest that anglers place a relatively high value on trips for striped bass and bluefish (or striped bass, bluefish, cobia, and Spanish mackerel in the VA/NC model). This follows from Trip C being most frequently selected as the favorite trip and aligns with the fact that striped bass are the most heavily targeted recreational species in the region. Lastly, with the exception of $\sqrt{BSB\ released}$ in the ME-NY and NJ models, the significance of standard deviations parameters confirms that preferences for keeping and releasing fish vary across the population, i.e., that marginal changes in catch will affect different anglers differently.

Table 3. Estimated utility parameters from mixed logit models.

	ME-NY		NJ		DE/MD		VA/NC	
Mean parameters	*Estimate*	*St. Err.*	*Estimate*	*St. Err.*	*Estimate*	*St. Err.*	*Estimate*	*St. Err.*
trip cost	-0.012***	0.000	-0.008***	0.000	-0.009***	0.000	-0.007***	0.000
$\sqrt{\text{SF kept}}$	0.535***	0.061	0.721***	0.064	0.776***	0.048	0.507***	0.031
$\sqrt{\text{SF released}}$	-0.068	0.045	0.007	0.041	0.043	0.033	0.105***	0.021
$\sqrt{\text{BSB kept}}$	0.273***	0.033	0.175***	0.032	0.239***	0.027	0.178***	0.018
$\sqrt{\text{BSB released}}$	-0.021	0.024	0.010	0.024	-0.009	0.019	0.025**	0.013
$\sqrt{\text{scup kept}}$	0.078***	0.020	0.096***	0.021				
$\sqrt{\text{scup released}}$	-0.015	0.015	-0.033**	0.016				
$\sqrt{\text{WF kept}}$			0.367***	0.055	0.360***	0.042	0.231***	0.029
$\sqrt{\text{WF released}}$			0.096**	0.043	0.061*	0.035	0.034	0.023
$\sqrt{\text{RD kept}}$							0.428***	0.036
$\sqrt{\text{RD released}}$							0.081***	0.023
do not fish	-2.398***	0.233	-1.877***	0.257	-2.838***	0.231	-3.573***	0.231
fish for other species	1.272***	0.172	1.049***	0.198	0.606***	0.151	0.493***	0.116
St. dev. parameters								
$\sqrt{\text{SF kept}}$	0.692***	0.079	0.630***	0.079	0.516***	0.061	0.457***	0.043
$\sqrt{\text{SF released}}$	0.358***	0.058	0.125	0.104	0.258***	0.047	0.230***	0.034
$\sqrt{\text{BSB kept}}$	0.245***	0.048	0.283***	0.048	0.311***	0.037	0.189***	0.031
$\sqrt{\text{BSB released}}$	0.080	0.058	0.053	0.051	0.139***	0.029	0.087***	0.031
$\sqrt{\text{scup kept}}$	0.096*	0.058	0.128***	0.040		0.000		0.000
$\sqrt{\text{scup released}}$	0.077***	0.028	0.120***	0.027		0.000		0.000
$\sqrt{\text{WF kept}}$			0.220**	0.111	0.251***	0.094	0.283***	0.058
$\sqrt{\text{WF released}}$			0.223***	0.081	0.220***	0.052	0.142***	0.046
$\sqrt{\text{RD kept}}$				0.000		0.000	0.472***	0.062
$\sqrt{\text{RD released}}$				0.000		0.000	0.324***	0.033
do not fish	2.193***	0.198	1.969***	0.173	2.246***	0.164	2.676***	0.181
fish for other species	1.652***	0.129	1.799***	0.144	1.752***	0.114	1.839***	0.090
No. anglers	443		357		581		1067	
No. choices	3451		2764		4494		8332	
LL	-3221.809		-2797.016		-4227.267		-8051.496	
LL(0)	-3753.301		-3203.314		-4814.363		-9215.204	
Pseudo R^2	0.327		0.270		0.321		0.303	
AIC/n	1.877		2.039		1.889		1.938	
BIC/n	1.914		2.095		1.918		1.959	

Notes: *,**, and *** represent significance at the 10%, 5%, and 1% level of significance, respectively. SF = summer flounder, BSB = black sea bass, WF = weakfish, RD = red drum.

5 Simulation modeling overview

To assess the effect of alternative fluke management measures and stock conditions on fishing effort, angler welfare, the local economy, and fishing mortality, we integrate the utility parameters in Table 3 with historical catch, effort, and trip expenditure data to create the recreational demand model (RDM). The RDM measures behavioral and economic responses to changes in fishing conditions through simulation of individual choice occasions, i.e., sets of fishing and non-fishing opportunities for hypothetical decision makers. Similar models have been developed for Northeast U.S. recreational fluke (Holzer and McConnell 2017) and striped bass (Carr-Harris and Steinback 2020) fisheries, and for managing the recreational Gulf of Maine cod and haddock fishery (Lee et al. 2017).

The RDM is multipart algorithm that simulates individual choice occasions mirroring those depicted in the CE survey. Each simulated choice occasion consists of three multi-attribute options: a fluke trip, a pelagic trip, and an option of not going saltwater fishing. The algorithm assigns to each choice occasion attribute levels based on historical and projected catch and effort data and utility parameters from the angler behavioral model. It then calculates the expected utility of each multi-attribute option, from which it derives the probability an angler would select that option and the associated consumer surplus. Expected utilities are calculated twice: first, in the baseline scenario in which harvest, discards, and trip cost per choice occasion reflect fishery conditions in the baseline year; and then again in subsequent projection scenarios when harvest and discards per choice occasion reflect alternative management measures and projected stock conditions. Differences in expected utilities between baseline and projection scenarios form the basis for determining the impact of alternative management and stock conditions on fishing effort, angler welfare, the local economy, and fishing mortality.

6 Calibration sub-model

The first of the two-part simulation algorithm, visually depicted in Appendix Figure 1, involves calibrating the recreational demand model to a baseline year. In essence, we attempted to replicate observed state-level outcomes, i.e., harvest and discards, using trip-level data. We calibrate the model to 2019 because it was the most recent year in which input recreational data was unaffected by COVID-related sampling limitations and because management measures remained relatively consistent across all states from 2019-2021.

The calibration sub-model begins by assigning choice occasions a trip costs drawn at random from state-level distributions. Cost distributions were created from recent trip expenditure survey data (Lovell et al. 2020) and weighted in proportion to the estimated number of directed fluke trips taken from shore, private boats, and for-hire boats in each state in 2019.

Choice occasion are then assigned numbers of fish caught by species drawn at random from baseline-year catch-per-trip distributions. According to MRIP data, directed trips for fluke also tend to catch black sea bass, as the correlation in catch-per-trip between the two species is positive and significant across the study area. This is likely due to the two species cohabitating similar fishing grounds and sharing a bottom-dwelling nature that makes them susceptible to similar fishing gears. We account for this correlation through copula modeling. Copulas are functions that describe the dependency among random variables and allow us to simulate correlated multivariate catch data that enter the demand model. We fit negative binomial distributions to each catch series (Terceiro 2003) and enter the estimated mean and dispersion parameters into a t-copula function. With this function we simulate catch data with a correlation structure approximating the observed correlation between the two series. This copula modeling approach provides the flexibility to generate multivariate catch-per-trip data with any specified correlation structure and distributional parameterization. Catch-per-trip of other species included in the model is assumed independent and these distributions are fitted (negative binomial) to MRIP catch data.[5]

The calibration sub-model then allocates catch as harvest and discards. To do so, it draws a value d_{fs} from $D \sim U[0,1]$ for every fish species f caught in state s on a given choice occasion. Fish are harvested (discarded) if d_{fs} is higher (lower) than d^*_{fs}, where d^*_{fs} is the value for which simulated harvest-per-choice occasion of species f in state s approximates the MRIP-based estimate of harvest-per-trip in the baseline year.[6] These d^*_{fs} values, identified outside the simulation algorithm, are the value of the catch-at-length cumulative distribution function evaluated at the minimum size limit. We implemented this method because harvest is the key determinant of the probability a choice occasion results in a fluke trip, and these probabilities in aggregate determine the number of choice occasions entering the ensuing projection sub-model.

[5] Catch-per-trip data for all species included in the simulation are based on recreational fishing trips that caught or primarily targeted fluke.

[6] Fluke fishing is assumed to stop once the bag limit is reached, i.e., there are no additional discards after a choice occasion reaches the limit.

Approximating MRIP-based estimates of harvest in the baseline years therefore ensures that the calibration sub-model generates an appropriate number of choice occasions. The whole process up to this point is repeated 10 times, providing multiple draws per choice occasion that reflect angler expectations about catch and trip cost.

Having a vector of attributes x_{ni} anchored on 2019 catch and recent trip expenditure data, we then assign to each choice occasion n a draw from the distribution of estimated utility parameters in Table 3 and calculate the utility of option i as $\beta_n' x_{ni}$. Expected utility is taken as $\beta_n' x_{ni}$ averaged over the 10 draws of catch and costs and is used to calculate choice probabilities conditional on β_n:

$$p_{ni} = \frac{e^{\beta_n' x_{ni}}}{\sum_{j=1}^{J} e^{\beta_n' x_{nj}}}. \tag{5}$$

The calibration model generates N_s^0 choice occasion for each state s, where the sum of the conditional probabilities of taking a fluke trip over the N_s^0 choice occasions equals the MRIP-based estimate of total directed fluke trips in state s during 2019. The number of choice occasions N_s^0 remains fixed throughout subsequent projection sub-model iterations. Expected total harvest and discards is computed as the sum of probability-weighted harvest and discards over the N_s^0 choice occasions.

Output from the calibration sub-model and MRIP-based estimates of harvest in 2019 are displayed in Table 4. Calibration statistics come from re-running the model 30 times, generating and drawing from new fluke and black sea bass catch-per-trip and utility parameter distributions at each iteration. MRIP point estimates and variance statistics are based on the weighting, clustering, and stratification of the survey design. Given the relative importance of harvest and the general insignificance of discards on angler utility, Table 4 compares simulated and MRIP-based estimates of harvest on directed summer flounder trips in numbers of fish for each state and species and omits discards.[7]

The calibration sub-model was designed to approximate estimated actual harvest, and thus simulated harvest for each species-state combination approximates the MRIP-based

[7] Catch statistics were only calculated in the model for state-species combinations in which a species' catch attributes entered the corresponding regional utility model.

estimates. Given that expected harvest is a key determinant of the probability of taking a fluke trip, this bolsters confidence that the calibration model generates an appropriate number of choice occasions for the ensuing projection sub-model.

Table 4. Harvest in numbers of fish on directed fluke trips from the calibration sub-model and MRIP. 95% confidence intervals in brackets.

State	Calibration sub-model	MRIP 2019
	Summer flounder harvest	
Massachusetts	54,896 [54615, 55177]	55,386 [23325, 87447]
Rhode Island	220,799 [219764, 221834]	213,592 [51594, 375590]
Connecticut	92,581 [91951, 93211]	89,843 [54911, 124776]
New York	563,376 [559579, 567173]	561,173 [318178, 804167]
New Jersey	1,075,530 [1069815, 1081245]	1,108,158 [736178, 1480138]
Delaware	89,045 [88593, 89497]	91,025 [56129, 125921]
Maryland	77,650 [77195, 78105]	79,371 [25346, 133396]
Virginia	150,361 [149794, 150928]	149,785 [66148, 233423]
North Carolina	33,391 [33280, 33502]	34,895 [13536, 56253]
	Black sea bass harvest	
Massachusetts	52,917 [52587, 53247]	54,178 [20329, 88028]
Rhode Island	207,900 [206767, 209032]	214,471 [118736, 310206]
Connecticut	157,294 [156091, 15849]	153,564 [84144, 222985]
New York	567,622 [562454, 572790]	556,955 [349796, 764115]
New Jersey	123,443 [121616, 125270]	123,860 [65887, 181833]
Delaware	13,672 [13469, 13875]	14,348 [4518, 24178]
Maryland	12,515 [12311, 12718]	13,272 [2407, 24136]
Virginia	32,112 [31675, 32549]	31,597 [-11867, 75062]
North Carolina	0	0
	Scup harvest	
Massachusetts	31,467 [31247, 31687]	31,515 [9304, 53726]
Rhode Island	368,228 [365533, 370923]	366,744 [72937, 660551]
Connecticut	355,442 [352371, 35851]	439,359 [-65705, 944423]
New York	1,074,804 [1067309, 1082300]	1,085,926 [687,805, 1,484,048]
New Jersey	3,452 [3090, 3815]	2,458 [-524, 5440]
	Weakfish harvest	
New Jersey	33,540 [32687, 34393]	32,668 [-10985, 76322]
Delaware	3,162 [3107, 3216]	3,185 [52, 6317]
Maryland	0	20 [-19, 60]
Virginia	6,903 [6790, 7015]	6,765 [158, 13372]
North Carolina	350 [344, 355]	682 [-594, 1958]
	Red drum harvest	
Virginia	0	0
North Carolina	0	0

7 Population-based adjustments to recreational catch

Built into the RDM is an explicit relationship between the projected fluke population abundance and size distribution with the numbers and sizes of fluke caught by recreational anglers. For example, we assume that greater numbers of fluke in the ocean will lead to greater catch-per-trip, holding all else constant. Similarly, if the size distribution of fluke changes, so too will the size distribution of fish encountered by anglers. To account for these two links, we incorporated into the RDM two approaches based on angler targeting behavior.

We determined state-level angler targeting behavior for fluke by computing recreational selectivity-at-length, or the proportion of the fluke population by length class caught by anglers. This metric required a recreational catch-at-length and population numbers-at-length distribution, the former of which we created using historical catch data adjusted by the d_{fs}^{*} values identified in the calibration sub-model model. The original catch-at-length distribution is:

$$f(m_s) = \frac{c_{ms}}{\sum_1^L c_{ls}} \; \forall \; m \in 1 \dots L, \tag{6}$$

where $\sum_1^L c_{ls}$ the MRIP-based estimate of total fluke catch and c_{ms} is the sum of fluke harvested and discarded within a length bin for state s.[8]

If $f(m_s)$ accurately represented the true catch-at-length distribution, we could for each simulated trip's draw of catch up to the bag limit, draw from $f(m_s)$, impose a size limit, and compute total harvest and discards overall all trips. However, we compared results from this method against MRIP estimates in a baseline year and found considerable differences in harvest and discards. The differences occurred because $f(m_s)$ does not represent the true catch-at-length distribution and is derived from available catch data that perhaps over- or under-samples fluke harvest- or discards-at-lengths. Left unaccounted for, this discrepancy would in some cases project shifts in harvest that move in a direction opposite to what we would expect under a given change in size limits. To ensure that hypothetical changes in size limits affect harvest in ways

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[8] Numbers of fluke harvested by length are computed by multiplying estimated proportions of harvest-at-length, derived from 2018 and 2019 MRIP estimates, by the MRIP-based of estimate of total harvest in 2019. Numbers of fluke discarded by length are computed similarly; however, we calculate proportions fluke discarded-at-length in 2018 and 2019 using raw MRIP data supplemented by volunteer angler logbook data on discard lengths. The resulting proportions fluke discarded-at-length are multiplied by the MRIP-based estimate of total discards in 2019 to arrive at 2019 fluke discards-at-length.

that follow *a priori* expectations (e.g., decreasing the minimum size limit relative to 2019 and holding all else constant will lead to increased harvest) we adjusted $f(m_s)$ based on the d^*_{fs} values for fluke attained in the calibration sub-model.

We did this by first using $f(m_s)$ to compute the relative probability of catching a length-m fluke among fluke shorter than, and equal to or longer than the 2019 minimum size limit in state s, respectively:

$$f_{\underline{l}}(m_s) = \frac{f(m_s)}{\sum_{l=1}^{min.size-1} f(l_s)} \forall\ m \in 1 \dots min.size - 1, \tag{7}$$

$$f_{\bar{l}}(m_s) = \frac{f(m_s)}{\sum_{l=min.size}^{L} f(l_s)} \forall\, m \in min.size \dots L. \tag{8}$$

We then distributed d^*_{fs} and $(1 - d^*_{fs})$ across the relative probability weights assigned to the corresponding sizes by the unadjusted catch-at-length size distribution to create $F(l_s)^*$:

$$F(l_s)^* = \begin{cases} \sum_{l=1}^{m} f_{\underline{l}}(m_s)\, d^*_{fs} & : m < min.size\ limit \\ d^*_{fs} & : m = min.size\ limit \\ \sum_{l=min.size+1}^{m} f_{\bar{l}}(m_s)\,(1 - d^*_{fs}) & : m > min.size\ limit \end{cases} \tag{9}$$

The resulting probability distribution $f(l_s)^*$ preserved the value of the catch-at-length cumulative distribution function evaluated at the minimum size limit which explains harvest in the baseline year (d^*_{fs}) and redistributed the remaining probability in proportion to the original catch-at-length probability distribution. Using $f(l_s)^*$, we computed an adjusted catch-at-length distribution:

$$f(m_s)^* = \sum_1^L c_{ls}\, f(l_s)^* = \frac{c^*_{ls}}{\sum_1^L c_{ls}}\ \forall\ c \in 1 \dots L, \tag{10}$$

We then used c_{ls}^*, the adjusted catch of length-l fluke, and median population numbers-at-age in the baseline year, N_a, from the Monte Carlo Markov Chain resampling procedure implemented in the fluke age-structured assessment program (NEFSC 2019) to compute recreational selectivity-at-length. After converting median population numbers-at-age to numbers-at-length using commercial trawl survey age-length indices, we followed Lee et al. (2017) and rearranged the Schaefer (1954) catch equation to solve for recreational selectivity of length-l fluke in state s:

$$q_{ls} = \frac{c_{ls}^*}{N_l}. \tag{11}$$

Having computed q_{ls} for a representative year, c_{ls}^* can be computed for any stock structure $\widetilde{N}_l$. Rearranging Equation (11) and dividing c_{ls}^* by total catch gives the probability of catching a length-l fluke conditional on the projected stock structure $\widetilde{N}_l$:

$$\widetilde{f(c_s)}^* = \frac{q_{ls}\widetilde{N}_l}{\sum_l^L q_{ls}\widetilde{N}_l} = \frac{\tilde{c}_{ls}^*}{\sum_l^L \tilde{c}_{ls}^*}. \tag{12}$$

Assuming constant q_{ls}, Equation (12) shows the relationship between any projected size distribution of fluke in the ocean and the size distribution of fluke caught by recreational anglers.

In addition to population-adjusted recreational catch-at-length distributions by state, Equation (12) provides total expected recreational catch by state, $\sum_l^L \tilde{c}_{ls}^*$, which we use to generate population-adjusted fluke catch-per-trip distributions. For each state s we scale the estimated mean parameters from the baseline-year fluke catch-per-trip distributions by $\sum_l^L \tilde{c}_{ls}^* / \sum_1^L c_{ls}$, where $\sum_1^L c_{ls}$ is the MRIP-based estimate of total fluke catch in the baseline year. The adjusted mean catch-per-trip parameters therefore reflect expected trip-level changes in fluke catch brought on by changes in population abundance. We also adjust the dispersion parameter of the projected fluke catch-per-trip distributions such that their coefficients of variation remain at baseline-year levels. These adjusted marginal catch-per-trip parameters are combined with baseline-year black sea bass marginal parameters and integrated into the estimated copula function to create new, population-adjusted joint catch-per-trip distributions from which we draw in the projection sub-model.

8 Projection sub-model

After adjusting the catch-per-trip and catch-at-length distributions based on projected numbers-at-length, the projection sub-model proceeds by re-simulating outcomes under the alternative management scenarios for each of the N_s^0 choice occasions. The projection sub-model, depicted in Figure A2, begins by assigning to each choice occasion β_n', trip costs, and numbers of scup, red drum, or weakfish harvest and discards from the calibration sub-model. It then draws fluke and black sea bass catch-per-trip values from the population-adjusted catch-per-trip distribution. Fluke harvest and discards per choice occasion are determined by drawing lengths from $\widetilde{f(c_s)}^*$ and checking them against the alternative size and bag limit. Black sea bass catch, also drawn from the population-adjusted catch-per-trip distribution, is allocated to a harvest or discard bin based on the d_{fs}^* approach from the calibration sub-model. The process up to this point is repeated 10 times and utilities are calculated at each iteration. Expected utility is taken as the average utility over the 10 draws and choice occasion probabilities are calculated using Equation (5). As in the calibration sub-model, projected total numbers of directed fluke trips is the sum of the probability of taking a fluke trip over the N_s^0 choice occasions and expected total harvest and discards is the sum of probability-weighted harvest and discards over the N_s^0 choice occasions.

8.1 Economic impacts

We measured both market and non-market values of changes in fishery conditions. The market value of recreational marine fishing is in part generated by angler trip expenditures filtering though the regional economy. Angler expenditures spur direct, indirect, and induced effects, which together represent the total contribution of marine angler expenditures on the regional economy. Direct effects occur as angler spend money at retail and service industries in support of their trip. In turn, angler spending produces indirect effects as retail and service industries pay operating expenses and purchase supplies from wholesalers and manufacturers. The cycle of secondary industry-to-industry spending continues until all indirect effects occur outside the region. Induced effects occur as employees in direct and indirect sectors make household consumption purchases from retailers and services industries. We measure the total contribution of marine angler expenditures on the regional economy using economic multipliers from the Northeast U.S. marine fishing input-output model (Lovell et al. 2020). Specifically, we measure the effect of changes in aggregate angler expenditures on (i) the gross value of sales by affected businesses, (ii) labor income, (iii) contribution to region GDP, and (iv) employment in recreational fishing-related industries. The first three metrics are measures in dollars, whereas the latter is measured in numbers of jobs. We compute these metrics on a state-by-state basis and assume that spending on durable fishing equipment, i.e., equipment that is not purchased on a trip-by-trip basis like boats, insurance, rods, or reels, which also contributes to the local economy, remains constant. When fishing conditions become more attractive to anglers, perhaps due to a relaxation of regulations, our model will predict an increase in overall angler expenditures that stems from an overall increase in directed fishing trips. Aggregate angler expenditures are computed in the projection sub-model as the probability-weighted sum of trip costs across choice occasions.

The non-market value of changes in recreational fluke fishery conditions occurs through trip-level changes in expected harvest and discards, attributes of which lack explicit markets that directly reveal their value. We measure these angler welfare impacts by computing the change in consumer surplus (CS), or the difference in expected utility in dollar terms between the baseline management scenario (scenario 0) and the alternative management scenario (scenario 1) (Hoyos 2010), i.e.,

$$\Delta E(CS_n) = \frac{\ln\left(\sum_{j=1}^{J} e^{V_{nj}^{1}}\right) - \ln\left(\sum_{j=1}^{J} e^{V_{nj}^{0}}\right)}{-\beta_{trip\ cost}} \qquad (13)$$

where V_{nj}^{1} and V_{nj}^{o} are expected utilities in the baseline and alternative scenarios and $\beta_{trip\ cost}$ is the marginal utility of price. Positive $\Delta E(CS_n)$ signifies angler welfare loss and is the amount of money needed to offset decreased angler utility from scenario 1 relative to scenario 0, thus maintaining scenario 0 utility. Conversely, negative $\Delta E(CS_n)$ signifies angler welfare gain and is the amount of money anglers would be willing to forego in scenario 1 to maintain scenario 0 utility. To ease the interpretation of our results, we multiply $\Delta E(CS_n)$ by -1 so that positive (negative) values of $\Delta E(CS_n)$ signify angler welfare gains (losses).

8.2 Alternative operating model assumptions

Two alternative operating model assumptions were considered in the MSE based on stakeholder and technical working group input that represent hypotheses about particular aspects of uncertainty in the summer flounder fishery. The first was that MRIP point estimates of recreational summer flounder effort are biased upward. We incorporated this scenario in the RDM by calibrating the model to the lower bounds of the 95% confidence intervals on MRIP estimates of effort, rather than the point estimates. Additionally, recreational selectivity-at-length in the baseline year was re-calculated from Equation 11 using (i) initial (2019) numbers-at-age data that was scaled down in proportion to the scaling of the MRIP effort data and (ii) MRIP catch estimates evaluated the lower 95% confidence interval.

The second assumption considered the expected northward shift of fluke biomass over time (Perretti and Thorson 2019) that may differentially affect recreational catch in different regions. To model these expectations, we first predicted future percentages of fluke biomass in three regions (Massachusetts to New York, New Jersey, and Delaware to North Carolina) using historical interpolated fluke biomass data downloaded from the Area Analysis Tool in the NOAA Fisheries Distribution Mapping and Analysis Portal (NOAA Fisheries, 2022). These data were derived from the NMFS Northeast U.S. fall trawl survey dataset and predictions were based on the most recent 10 years of available data. Percent total biomass by region was modeled as a function of a linear time trend and predicted values were obtained for the out-of-sample years. The left panel in Figure 2 shows the regional delineations, while the right panel shows observed and predicted percentages of interpolated fluke biomass by region.

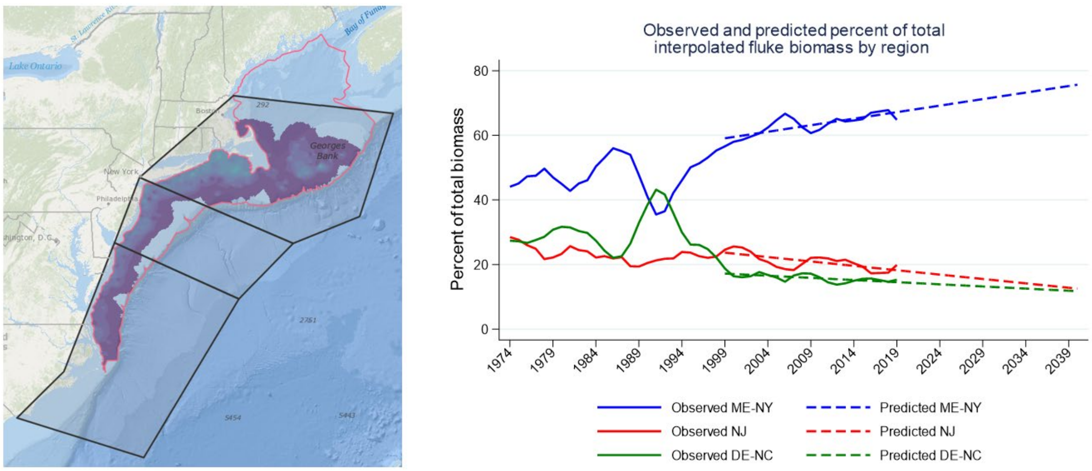

Figure 2. Left: regional delineations of interpolated biomass data. Right: observed and predicted percent of total biomass by region.

Predicted changes in the distribution of fluke biomass across the region entered the RDM through changes in mean catch-per-trip. For each year of the projection time horizon, we calculated state-level total catch relative to 2019 assuming differentiated biomass accessibility across states. After adjusting and rearranging and Equation (12) to reflect this assumption, total expected catch during projection year y for state s was calculated as:

$$\tilde{C}_{lsy} = \sum_{l}^{L} q_{ls} \tilde{p}_{sy} N_l. \tag{14}$$

where $\tilde{p}_{sy}$ was the predicted percent of total fluke biomass available to state s in projection year y. Note that in this formulation there is no distinction in availability across length classes. The ratio $\tilde{C}_{lsy}/C_{ls}$, where C_{ls} is total fluke catch in the baseline year for state s, was then computed for each year of the projection time horizon. During projection simulations, state-level mean parameters characterizing the catch-per-trip distribution were multiplied by $\tilde{C}_{lsy}/C_{ls}$, thus capturing a potential recreational catch response to the northward shifting biomass distribution.

This scenario results in a progressive increase in recreational summer flounder catch in the northern states with a concurrent decrease in catch in New Jersey and the southern region.

8.3 Out-of-sample predictions

We assessed the predictive accuracy of the RDM by comparing out-of-sample model forecasts of total fluke catch and harvest to MRIP-based estimates. After calibrating the model to 2019, forecasts were made for 2015, 2016, 2017, 2018, 2020, and 2021 conditional on state-specific recreational fishing regulations and distributions of stock sizes from the summer flounder management track 2021 assessment model in those years. We performed 30 iterations of the RDM to produce confidence bounds around the mean estimates. MRIP- and RDM-based estimates are shown in Figure 3.

Of important note is that 2020 and 2021 were both years in which COVID-19 induced substantial changes in recreational activities, including fishing behavior (e.g. Midway et al. 2021). Despite the massive disruption of a pandemic, the RDM does reasonably well at predicting fluke catch and harvest in 2018, 2020, and 2021, as mean projections fall within 95% confidence intervals of the MRIP estimates. However, the model consistently under-predicts total fluke catch and harvest in 2015, 2016, and 2017, as mean projections fall outside or just inside the MRIP confidence intervals. Given the good performance of the model during known behavioral shifts due to the COVID pandemic, the discrepancies in 2015, 2016, and 2017 could be an artifact of the MRIP's transition from the Coastal Household Telephone Survey (CHTS) to the Fishing Effort Survey (FES) in 2018 and the resulting calibration of its entire time series of catch and effort estimates through 2017.[9] Official MRIP estimates through 2017 are now based on calibrated CHTS data, while official MRIP estimates for 2018 and after are based on the FES data only. By conditioning the RDM to FES-based estimates in 2019 and comparing our projections to re-calibrated CHTS-based estimates in 2015 through 2017, we may be

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[9] Prior to 2018, the CHTS collected data about recreational fishing effort through a random digit dialing sampling approach. Due largely to a decline in the use of landlines over time, between 2007 and 2017 the MRIP developed the FES, a mail survey that is sent to randomly sampled residential households in coastal states. Compared to the CHTS, the FES was found to be more representative sample of angler population and less susceptible to non-response and non-coverage bias. The FES was peered review in 2014 and certified as a scientifically sound replacement for the CHTS in 2015. For more information see https://www.fisheries.noaa.gov/recreational-fishing-data/effort-survey-improvements.

confounding model performance with differences in MRIP estimates driven by the alternative data collection methods used to generate the estimates.[10]

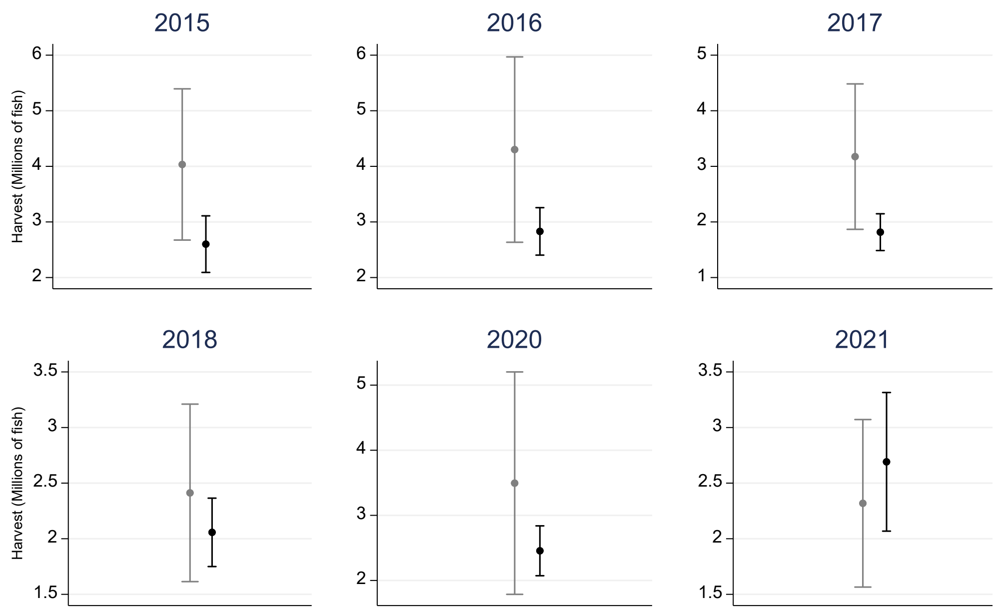
In an attempt to eliminate the possible effect of alternative MRIP data collection methods on our assessment of the RDM's predicative performance, we calibrated the RDM to 2017 (rather than 2019) and projected outcomes for 2015 and 2016. These three years share the same underlying data generating process by which recreational fishery statistics are estimated and so provide a consistent baseline to assess the predictive accuracy of the RDM for the period prior to the changes in the MRIP methodology. Comparisons of coast-wide output from the 2017-calibrated RDM to MRIP estimates are shown in Figure 4.

Figure 4 shows that calibrating the RDM to 2017 leads to more accurate predictions of total fluke harvest and catch in 2015 and 2016. While the model over-predicts coast-wide harvest in both years, mean estimates fall well within the MRIP-based confidence intervals. The RDM over-predicts total fluke catch in 2015 and under-predicts total fluke catch in 2016 but predicted means are similar to the MRIP-based point estimates. Furthermore, the predicted 95% confidence intervals for total catch in both years are nested within the MRIP-based confidence intervals.

Results in Figures 3 and 4 suggest the RDM is capable of making projections that fall within MRIP-based ranges of estimated outcomes. However, they also suggest that the baseline year used to calibrate the RDM is important and can affect the accuracy of model predictions. As a best practice when making projections for management purposes, the RDM should be calibrated to the most recent year of data and projections should be limited to a short, one- or two-year time horizon.

[10] Recreational harvest weight for all species in the Mid-Atlantic region dropped by roughly 50% from 2017 to a historic low in 2018 (NOAA Fisheries 2022), which may also be indicative of the alternative survey instruments used to generate these estimates.

Total fluke harvest



Total fluke catch

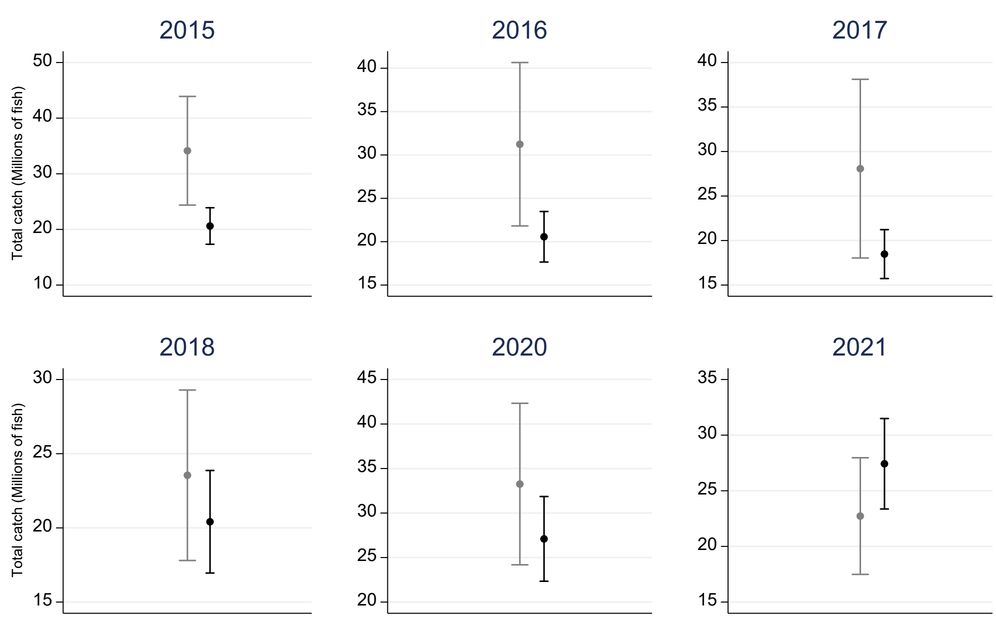


Figure 3. MRIP vs. model projections of coast-wide fluke catch (top) and harvest (bottom) in numbers of fish and 95% confidence intervals. Model calibrated to baseline year 2019. Gray = MRIP, black = model.

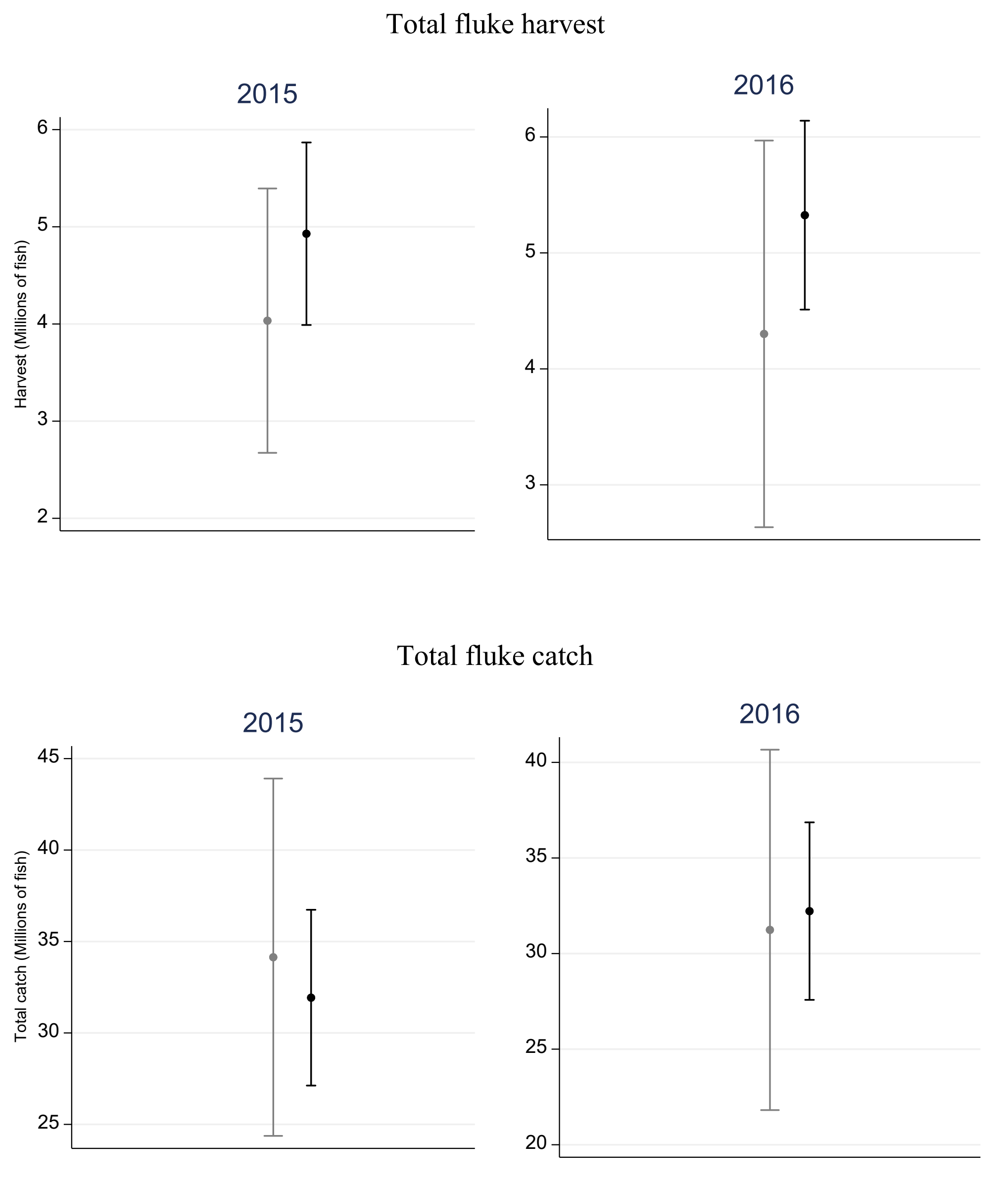


Figure 4. MRIP vs. model projections of coast-wide fluke catch (top) and harvest (bottom) in numbers of fish and 95% confidence intervals. Model calibrated to baseline year 2017. Gray = MRIP, black = model.

9 Summary

To recap, the RDM uses estimated preference parameters from the angler behavioral model to estimate changes in angler welfare and effort (fishing trips) conditional on expected harvest and discards. These estimates parameterize the ensuing calibration- and projection sub-models. Along with the behavioral parameters, the calibration sub-model uses historical catch, effort, and trip cost data to simulate fishing trips that emulate fishery conditions in the baseline year (2019). The calibration sub-model generates a number of fishing trips that enter and remain fixed in the subsequent projection sub-model.

Prior to the projection sub-model routine, the RDM takes projected numbers-at-length in year t from the operating model, $\widetilde{N}_{lt}$, and adjusts the catch-per-trip and catch-at-length distributions via Equation (12). Conditional on these population-adjusted trip-level distributions and a given management scenario, the projection sub-model re-simulates the fishery and computes expected angler effort, angler welfare, impacts to the local economy, and total harvest and discards. Predicted total harvest and discards feed back into the operating model, which subsequently produces $\widetilde{N}_{lt+1}$, the input for the RDM in year $t+1$. This recursive cycle continues for each year of the time horizon and over multiple iterations.

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Appendix

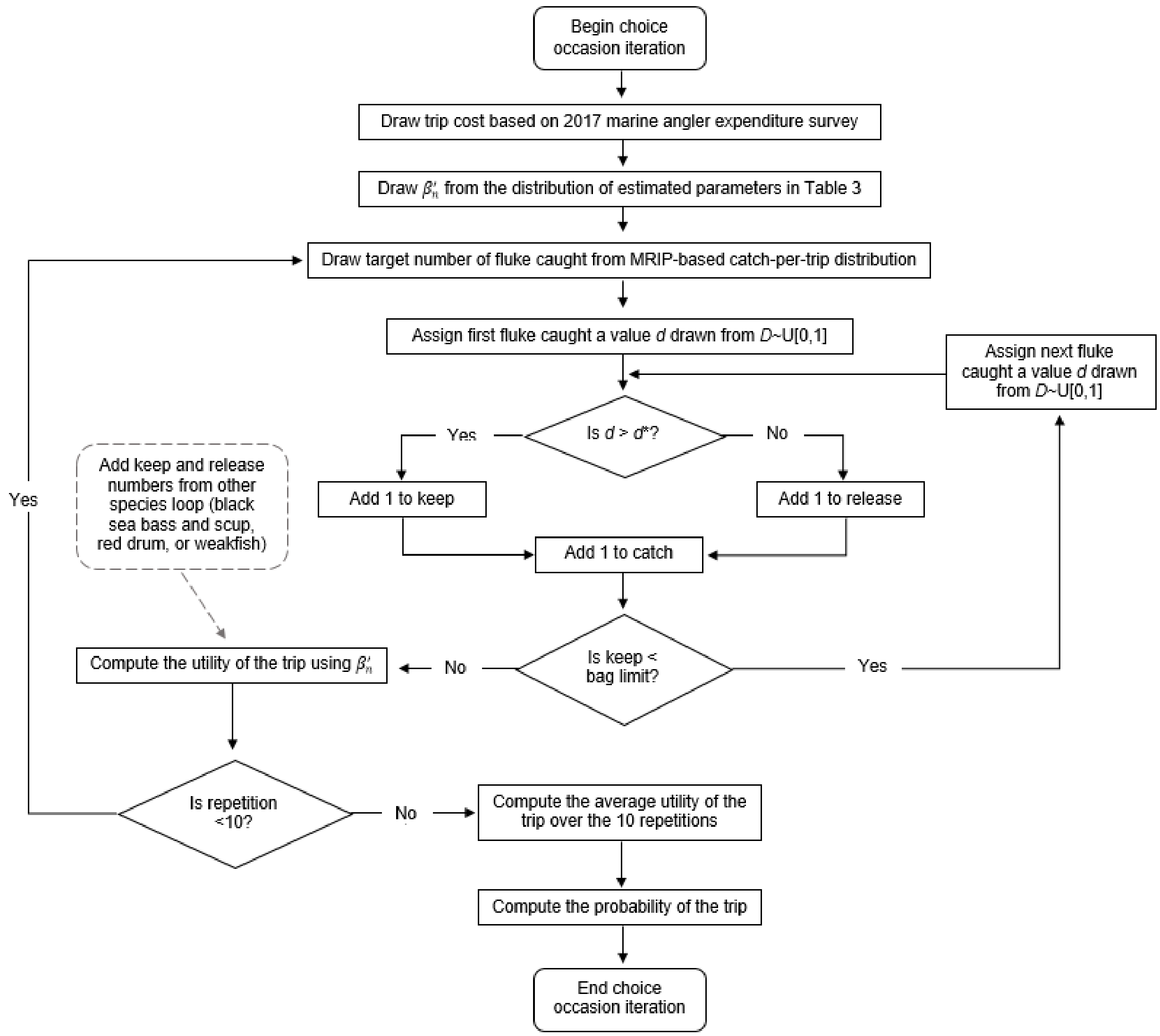

Figure A1. Calibration sub-model algorithm. Only the loop for summer flounder is shown in detail.

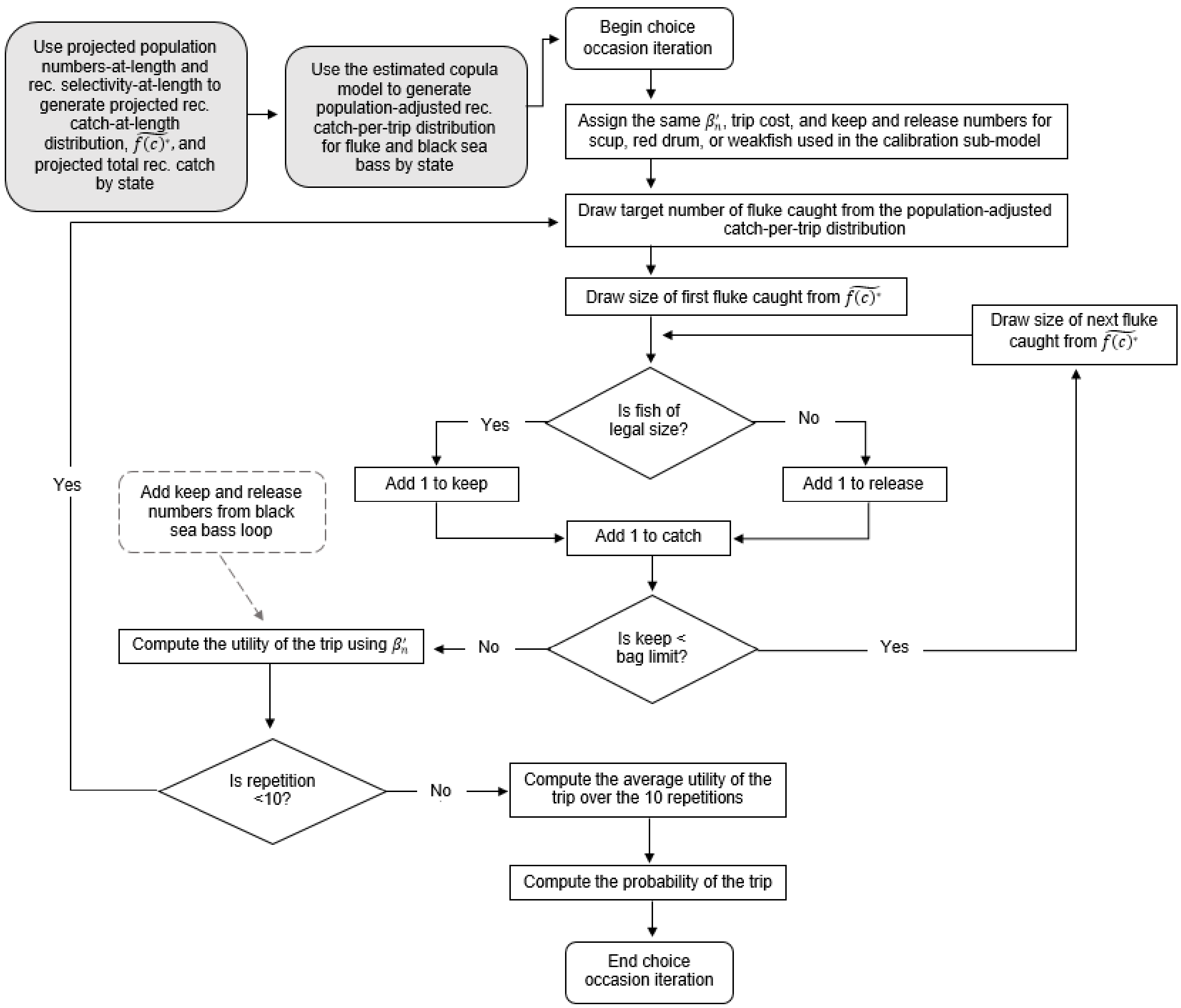

Figure A2. Projection sub-model algorithm. Only the loop for summer flounder is shown in detail.