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.

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

<u>Performance Metrics</u>:
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

<u>Performance Metrics</u>:
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

<u>Performance Metrics</u>:
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

<u>Performance Metrics</u>:
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

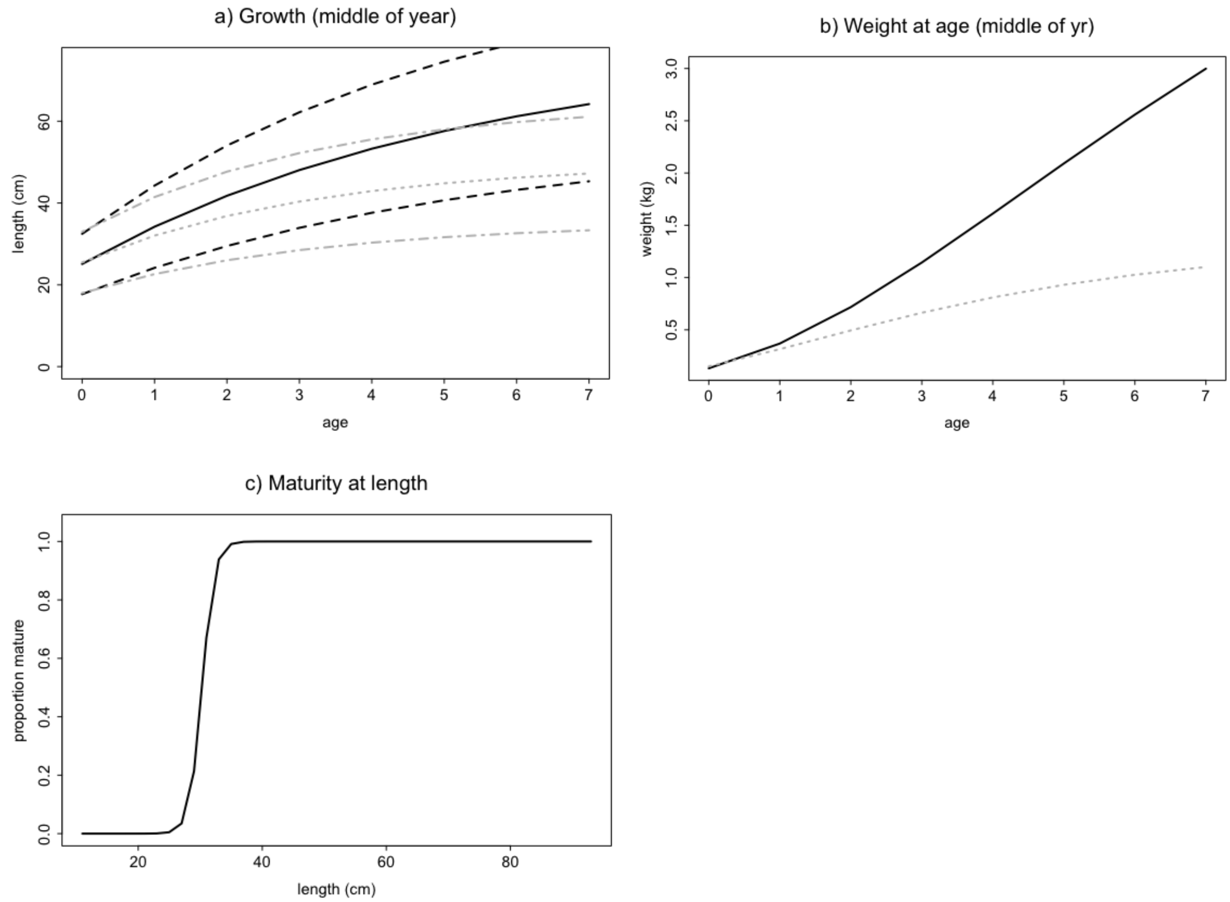

Figure 1. Operating model specifications for summer flounder showing a) mean (solid line) and standard deviation (dashed line) of length at age, b) weight at age (solid line females, dashed line males), c) maturity at length.

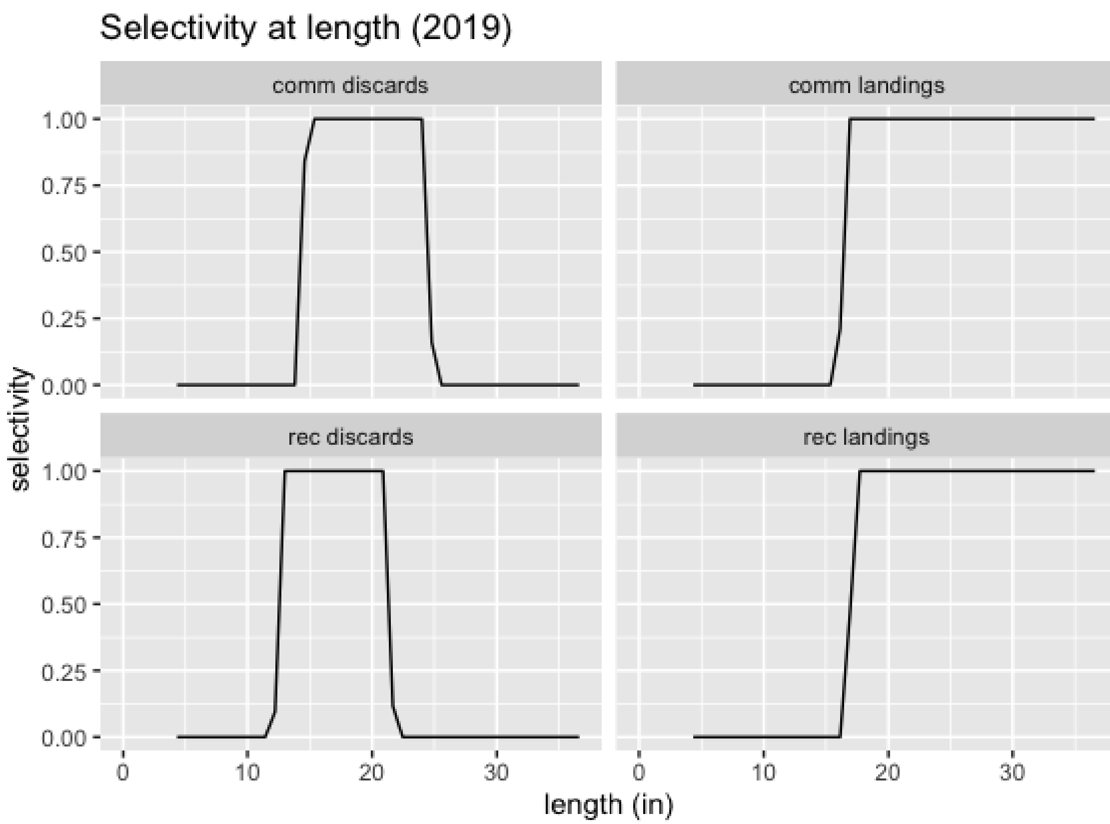

Figure 2. Operating model specifications for summer flounder showing selectivity at length for all years for the commercial fishing fleets and for the initial year for the recreational fleets.

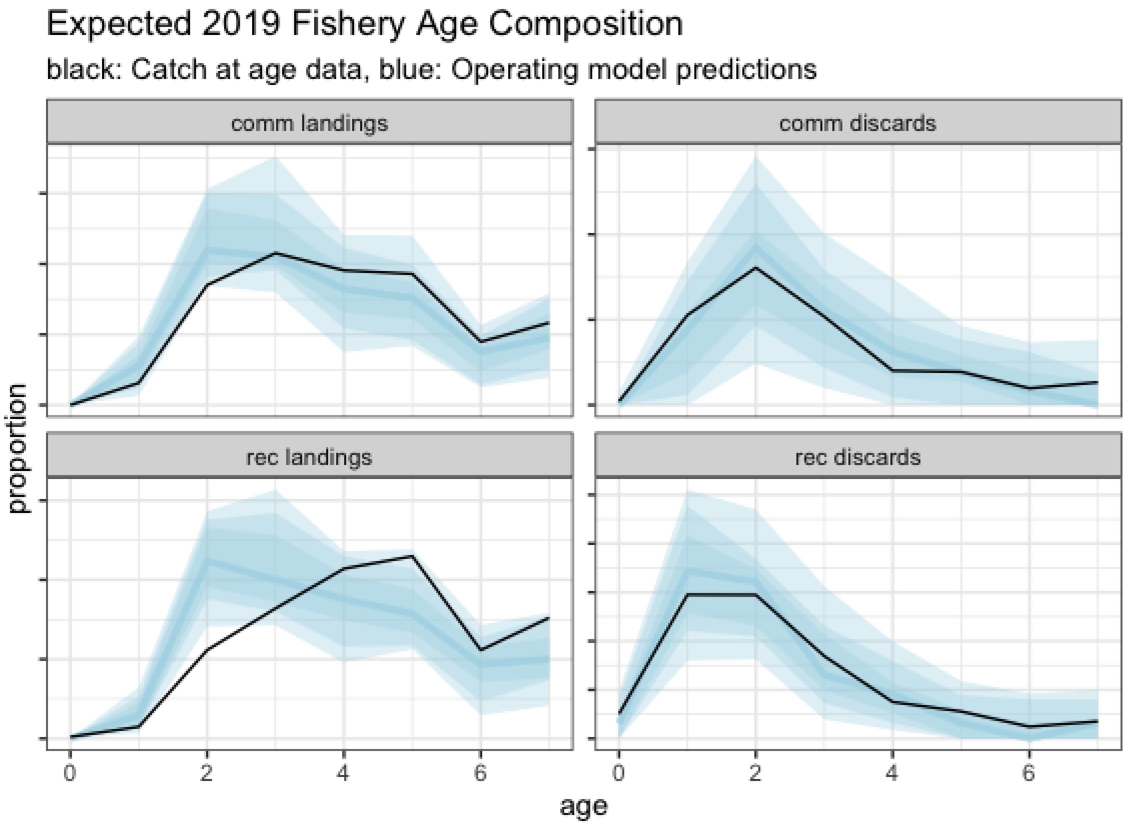

Figure 3. Operating model predictions for 2019 catch at age by fleet compared to the 2019 data.

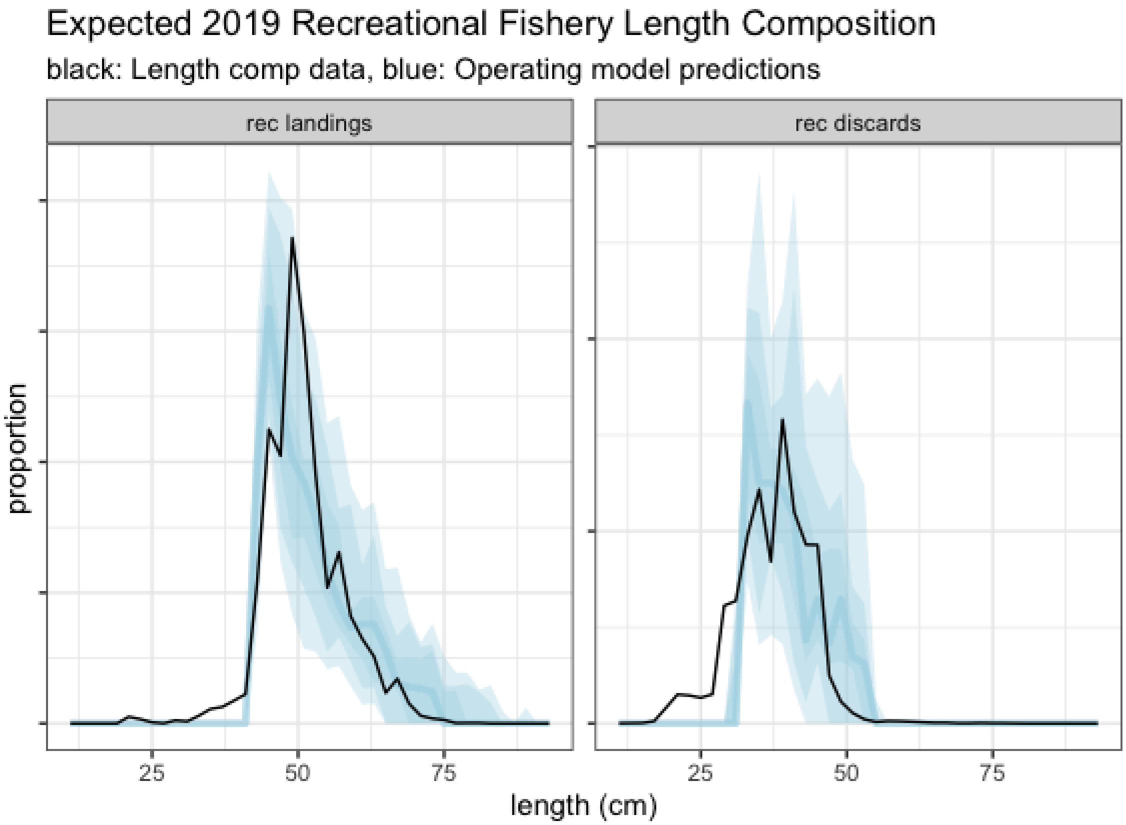

Figure 4. Operating model predictions for 2019 catch at length for the recreational fleets compared to the 2019 data.