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

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1 Introduction

This document describes the data and methods underlying the summer flounder (fluke) recreational demand model (RDM). The RDM was built to predict the impact of stock conditions and management measures (bag, size, and season limits) on angler effort, angler welfare, the local economy, and recreational fishing mortality. As part of the fully integrated bio-economic model, it provides the key link between projected population abundances, regulations, and expected recreational fishing mortality. For an overview of the integrated bio-economic model, see _______________

The RDM is composed of three main components: an angler behavioral model, a calibration sub-model, and a projection sub-model, each of which are described in detail below. The angler behavioral model uses stated preference survey data to estimate angler preferences for harvesting and discarding fluke and other primary species. These results parameterize the calibration and projection sub-models. The calibration sub-model replicates coast-wide fishing activity in a baseline year using trip-level data in order to set the number of simulated fishing trips (choice occasions) entering the projection sub-model. The projection sub-model re-simulates the fishery conditional on the projected stock structure, i.e., the output from the biological operating model, and the management scenario of interest and computes expected impacts to angler effort, angler welfare, the local economy, and fishing mortality.

2 Choice experiment survey

The stated preference choice experiment (CE) data used to estimate angler preferences 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.[1]

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

[1] 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.

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.

4 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. Johnston et al. (2017) note that such choice patterns can be interpreted as scenario rejection whereby “respondents do not interpret scenarios as intended and thus value something different from the intended item or outcome."[2] We also excluded from 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. Therefore, anglers fishing from private access points were excluded from the sampling design. If these excluded anglers have different preferences than those who fish from

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

publicly accessible fishing sites, then the estimated choice model parameters would not represent the preferences of the population. To understand the extent to which each fishing mode is represented in our 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 the primary species by mode to the distribution of fishing effort indicated by our sample. Compared to the population, shore trips are underrepresented in the sample while party and charter boat trips are 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 does not mirror the population distribution of fishing effort by mode, it does 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.

5 Behavioral model framework

Choice experiment data can be used to evaluate consumer preferences for, behavioral response to, and welfare impacts from marginal changes in non-market goods or attributes (Louiviere, Hensher, and Swait 2000). The primary purpose of collecting our choice experiment data was to identify the relative importance to recreational anglers of keeping and releasing fluke such that economic and behavioral impacts of regulatory changes could be assessed.

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, Steinback, and Wallmo 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).

6 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 are generally of the expected sign. Across the regional models, the mean parameters on *trip cost*, the marginal utility of price, are negative and significant and intuitively suggest that higher trip costs reduce angler utility. Mean parameters on all keep variables are 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 the keep parameters on other primary species 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 vary by species and region. For example, only in the VA/NC model is 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 $\sqrt{WF\ released}$ is 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*, are negative and significant. This mean that, when given the option, anglers get 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, which 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.

7 Recreational demand model

7.1 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. 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 the Northeast U.S. recreational fluke fishery (Holzer and McConnell 2017) and for managing the recreational Gulf of Maine cod and haddock fishery (Lee, Steinback, and Wallmo 2017).

The RDM is multipart algorithm that simulates individual choice occasions mirroring those depicted in the CE survey. Each 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 and utility parameters and calculates the expected utility, probability, and willingness-to-pay of the three options. These metrics are calculated twice: first, in the baseline scenario under 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 stock conditions. Differences in expected utility, trip probability, and willingness-to-pay 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.

7.2 Calibration sub-model

The first of the two-part simulation algorithm involves calibrating the recreational demand model to a baseline year (Appendix Figure 1). In essence, we attempt to replicate observed state-level aggregate 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 a given 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 having bottom-dwelling natures that make them susceptible to similar fishing gears. We account for this catch-per-trip 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 are able to simulate catch data with a correlation structure approximating the observed correlation between the two series. This approach provides the flexibility to generate correlated catch-per-trip data with any specified correlation structure and marginal catch 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.[3]

The calibration sub-model then distributes catch into harvest and discard bins. 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.[4] These d^*_{fs} values, identified outside the simulation model, 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 that enter the ensuing projection sub-model.

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

[4] 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.

Therefore, approximating MRIP-based estimates of harvest in the baseline years 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. Simulated harvest statistics for a given species are available only for states in which that species' catch attributes entered the corresponding utility model.

The calibration sub-model was designed to approximate estimated actual harvest, and thus simulated harvest for each species-state combination approximate the MRIP-based estimates. Given that expected harvest is the key determinant of the probability of taking a fluke trip, this bolsters confidence that the calibration model generates an appropriate number of choice occasions to enter 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

7.3 Population adjustments to recreational catch-at-length and catch-per-trip

The RDM predicts fishery outcomes under new management measures and explicitly relates projected fluke population abundances from the biological operating model with numbers and sizes of fluke caught by recreational anglers. For example, greater numbers of fluke in the ocean should lead to higher catch-per-trip, holding all else constant. Similarly, if the size distribution of fluke changes, one would expect the size distribution of fish encountered by anglers to change as well. To account for these links, we incorporate in the RDM two approaches based on angler targeting behavior.

We determine 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 requires population numbers-at-length and recreational catch-at-length distributions, the latter of which we create using historical catch data adjusted by the d^*_{fs} values identified in the calibration sub-model model. The unadjusted catch-at-length distribution is:

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

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 in state s.[5]

Preliminary analysis revealed a divergence between the probability $f(m_s)$ at and above the 2019 minimum size limit while accounting for the possession limit and expected catch-per-trip, and MRIP-based estimates of the percent of fluke catch that was harvested. This discrepancy could be due to under- or over-sampling of fluke harvest- or discards-at-length in the available recreational catch data. We therefore adjust $f(m_s)$ based on the d^*_{fs} values for fluke calculated in the calibration sub-model. Using $f(m_s)$, we first compute the relative probability of

[5] 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.

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 distribute 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 $f(l_s)^*$ preserves the value of the catch-at-length cumulative distribution function that explains landings in the baseline year (d_{fs}^*) while redistributing the remaining probability in proportion to the observed catch-at-length probability. Using $f(l_s)^*$, we then compute 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 use $f(m_s)^*$ and estimated population numbers-at-length distribution from the stock assessment in the baseline year to compute recreational selectivity. Following Lee, Steinback, and Wallmo (2017), we rearrange the Schaefer (1954) catch equation and solve for recreational selectivity of length-l fluke in state s the baseline year:

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

where c_{ls}^* is adjusted catch of length-l fluke and N_l is estimated population numbers-at-length from the stock assessment. Stock assessment numbers-at-age estimates for 2019 were converted to numbers-at-length using commercial trawl survey age-length indices.

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 the projected size distribution of fluke in the ocean the size distribution of fluke caught by recreational anglers. In the fully integrated bio-economic model, $\widetilde{N}_l$ is output from the biological operating model and is incorporated into the projection sub-model via Equation (12).

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.

7.4 Projection sub-model

After the catch-per-trip and catch-at-length distributions are adjusted based on projected numbers-at-length from the biological operating model, the projection sub-model proceeds by re-simulating outcomes under the alternative management scenarios for each of the N_s^0 choice occasions. First, it assigns to each choice occasion the β_n', trip cost, and numbers of scup, red drum, or weakfish determined in the calibration sub-model. It then draws fluke and black sea bass catch-per-trip values from the population-adjusted catch-per-trip distributions. 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 re-drawn from population-adjusted catch-per-trip distributions, is allocated to the 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 from 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.

We measure 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.,

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

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.

8 Summary

To recap, the calibration sub-model uses angler utility parameters and historical catch, effort, and trip cost data to simulate a number of individual choice occasions that, when aggregated, approximate observed harvest in the baseline year. This number of choice remains fixed in the subsequent projection sub-model. The RDM then 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 catch outcomes and an alternative management scenario of interest, 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. Expected total harvest and discard values feed back into the operating model, which subsequently produces $\widetilde{N}_{lt+1}$, the input for the RDM in year $t+1$. This cycle continues for each year of the time horizon and over multiple iterations.

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Appendix

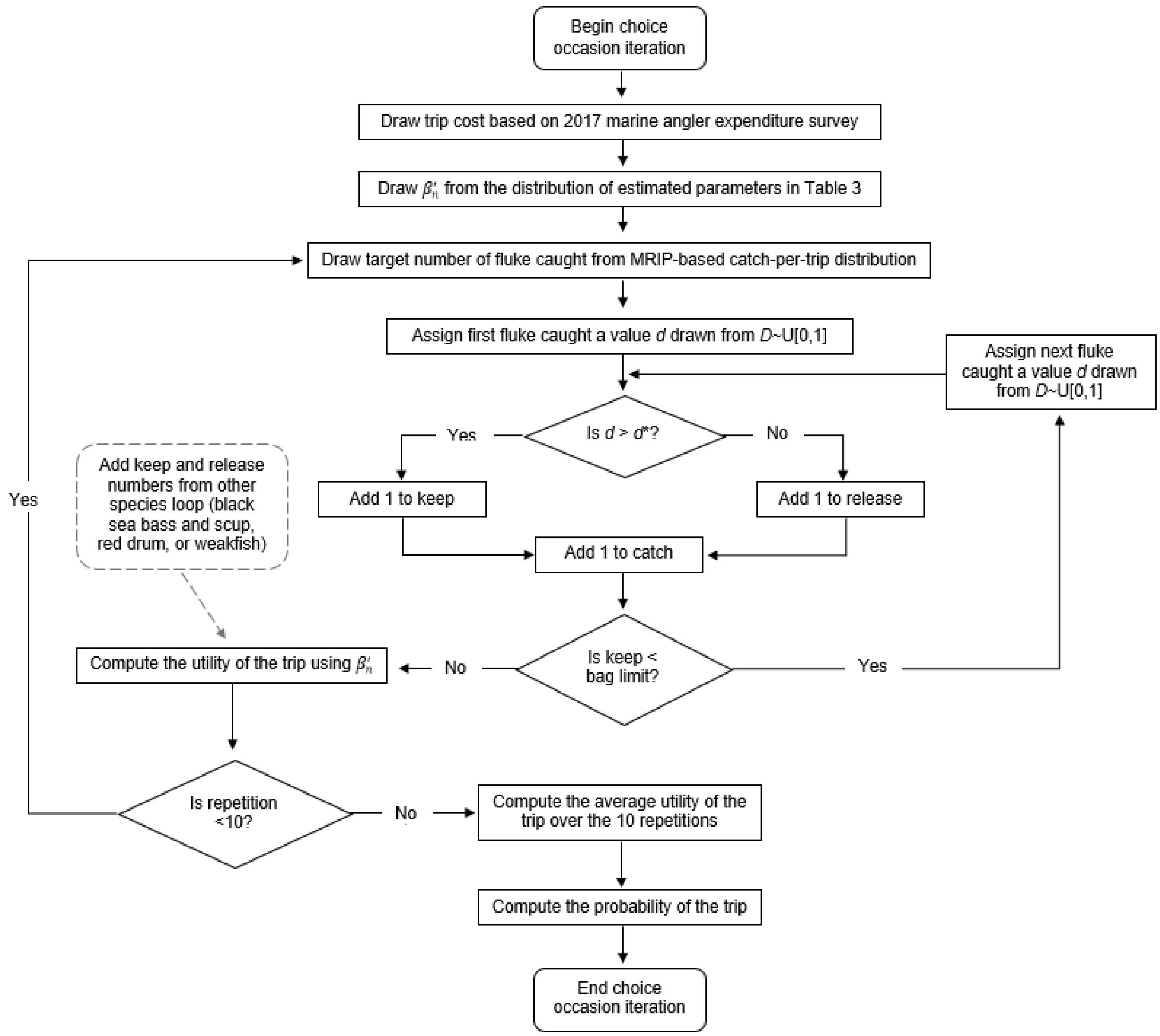

Figure A1. Calibration sub-model algorithm. Only the loop for summer flounder is shown in detail.

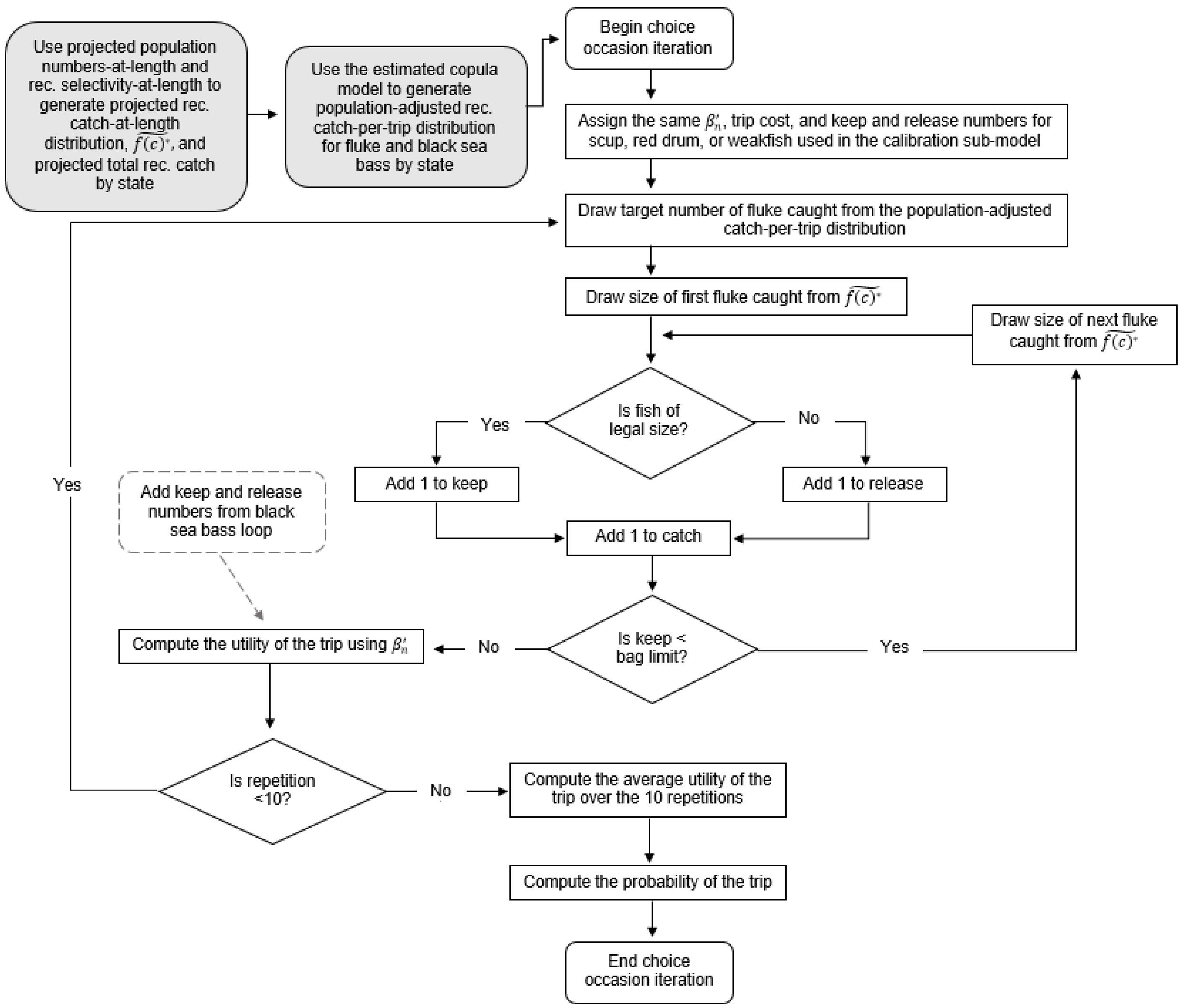

Figure A2. Projection sub-model algorithm. Only the loop for summer flounder is shown in detail.