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Exploring tradeoffs in Southeast United States marine fisheries management using management strategy evaluation

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Abstract

Recreational fishing is the fastest growing sector in industrialized nations and can have substantial impacts on marine fish populations and ecosystems. Commercial objectives are typically characterized by maximizing yield and fishery stability whereas recreational anglers generally prefer sustained access to fishing and the availability of larger fish. Achieving these objectives while balancing tradeoffs between recreational and commercial fishing is essential to effective recreational and mixed-use fisheries management. Balancing multiple sector objectives is of particular concern in the southeast United States (US), where recreational fishing is the dominant source of mortality for marine fish stocks. We developed and applied a size-structured management strategy evaluation (MSE) tool, individually, to two stocks in southeast US Atlantic waters, black sea bass (*Centropristis striata*), a sedentary reef fish in overfished condition, and cobia (*Rachycentron canadum*), a migratory coastal pelagic fish, to evaluate the performance and tradeoffs of mixed management procedures against a variety of objectives. Several recreational and commercial objectives were aligned: fishers sought to conserve the stock and maximize catch, which simplified the evaluation of tradeoffs. We tested management procedures over alternate states of recruitment for black sea bass, and natural mortality for cobia. Management procedures that allowed harvest for black sea bass resulted in or risked an overfished status if the current weak recruitment regime continues, but could rebuild with no fishing regardless of recruitment state. Although results were sensitive to uncertainty in recruitment, no management procedures could achieve historic landings for either sector, and only management procedures that reduced effort consistently resulted in a reduced number of dead discards. No management procedures resulted in an overfished status for cobia. Management procedures for cobia generally achieved objectives and were robust to uncertainty in natural mortality. In both case studies, tradeoffs occurred between maximizing catch and season length and maintaining a stronger size structure in the population. This study resulted in a flexible MSE tool with strong potential utility for scoping management procedures that explicitly consider recreational fishing objectives.

Keywords: management strategy evaluation, recreational fisheries, stock assessment, marine fisheries, management procedures

1. Introduction

Recreational fishing is the fastest growing sector in industrialized nations (Abbott et al. 2022, Arlinghaus et al. 2019) and can have substantial impacts on marine fish populations and ecosystems (Cooke and Cowx 2004, Lewin et al. 2019, Holder et al. 2020, Hyder et al. 2020). The United States (US) was recently ranked among the countries with more successful governance of recreational fisheries (Potts et al. 2020). However, both historically and presently, US marine fisheries management is largely accomplished via management procedures (MP), also known as management or "harvest" strategies, that are based on the theory of maximum sustainable yield (MSY) (Schaefer 1991, Mace 2001): a concept designed to ensure that fishers maximize the weight of their catch in the long-term (Kell and Fromentin 2007). Although achieving MSY may be an ideal management objective for commercial fishing, it is not necessarily the most desired objective for recreational fishing (Idhe et al. 2011), where recreational anglers increasingly prefer sustained access to fishing, longer seasons, and availability of larger fish (Pitcher and Hollingworth 2008, Hyder et al. 2020, Melnychuk et al. 2021, Damiano et al. 2022). As recreational fishing continues to grow, successful management will require understanding these drivers of recreational angler satisfaction (Birdsong et al. 2021) and determining the extent to which the MSY-based MPs can effectively achieve recreational fishing objectives. Addressing recreational objectives and balancing tradeoffs with commercial objectives is essential to effective recreational fisheries management (Hyder et al. 2020) and mixed-use fisheries management in general. This is of particular concern in the Southeast US Atlantic (SE US), where recreational fishing often comprises the majority of landings (Coleman et al. 2004) and is the dominant source of mortality for marine fish stocks (Shertzer et al. 2019).

There is a growing recognition that recreational fishing objectives should be integrated into MPs (Fowler et al. 2022). Adopting an untested MP can lead to ineffective management (Beddington et al. 2007). Therefore, a simulation approach that allows managers to examine the outcomes of proposed management procedures against a variety of objectives would greatly increase the likelihood of effective and successful management. Simulation approaches are being employed with increasing frequency to explicitly develop and evaluate MPs and policies geared toward meeting recreational fishing, management, and conservation objectives (van Poorten and MacKenzie 2019, Melnychuk et al. 2021, Bohaboy et al. 2022, Shertzer et al. 2023). However, few studies have analyzed the performance of MPs with explicit consideration of recreational objectives using a management strategy evaluation (MSE) framework (Mapstone et al. 2008, Pascoe et al. 2019), and fewer have tested such strategies using model-based reference points (Zhang 2018, MAFMC 2022). MSE is used to evaluate the outcomes of MPs against objectives given various sources of uncertainty (Smith et al. 1999; Bunnefeld et al. 2011; Punt et al. 2016; Ono et al. 2017). A complete MSE is a closed-loop simulation framework that attempts to model the entire management system (Punt et al. 2016), including an operating model to simulate stock dynamics (i.e., biological and fishery processes), a stock assessment model to estimate stock size and biological reference points (BRPs) used in a MP, a management implementation model that feeds back to affect the stock, and stakeholder input and feedback throughout the process (Feeney et al. 2019, Goethel et al. 2019). MSEs have been used to examine various aspects of the management system, e.g., performance of the stock assessment model, uncertainties, and alternative management measures (Punt and Donovan 2007; Punt and Hobday 2009). One of the key features of MSE is the ability to identify tradeoffs associated with each MP (Bunnefeld et al. 2011, Punt et al. 2016).

In the SE US, the South Atlantic Fishery Management Council (SAFMC) is responsible for the management of over 64 federal marine fisheries from North Carolina to eastern Florida. The majority (55) of these stocks are managed under the Snapper Grouper Fishery Management Plan (FMP): a mixed-stock fishery in which several species have a large degree of spatiotemporal overlap in habitat (Cao et al. *In Review*). MPs applied to marine fisheries in the SE US are generally comprised of two components: a harvest control rule (HCR) that is based on an acceptable biological catch (ABC) control rule derived from an estimated rate of constant fishing mortality (*F*) that produces an acceptable catch limit (ACL) designed not to exceed some spawning stock biomass (*SSB*) threshold, and management measures, i.e., output controls, which include minimum size limits, recreational bag limits, and trip/vessel limits, that are used to manage the landings of the commercial and recreational fisheries. Several challenges to this management paradigm have emerged during the last two decades: recruitment failure has occurred for multiple reef fish stocks (Wade et al. 2023); participation within the private recreational fleet, which consists of individually-owned "private" fishing vessels, has increased (Figueira and Coleman 2010); and the subsequent increase in fishing effort on stocks that overlap in habitat has combined with restrictive harvest limits for overfished stocks such as red snapper (*Lutjanus campechanus*), resulting in an increase in the number of dead discards for several species (Runde et al. 2021, SEDAR 2023). In cases such as red snapper, recreational dead discards have become the dominant source of mortality (SEDAR 2021). The synergistic effect of these pressures has also resulted in the overfished status of black sea bass (*Centropristis striata*) (SEDAR 2023), and the emergence of inter-sector conflicts (SAFMC Snapper Grouper Advisory Panel, personal communication 2020). This raises two important questions: can the combination of threshold HCRs and management measures meet commercial and recreational fishing objectives while also satisfying the conservation-related requirements of the Magnusson-Stevens Fishery Conservation and Management Act in the long term, and if so, are they robust to uncertainty in alternate states of nature in variable biological processes such recruitment or natural mortality? Although work has begun on a multi-species MSE to analyze tradeoffs in the Snapper Grouper fishery, there are no generalized or operational single-species MSE frameworks currently available to evaluate the long-term performance of management strategies employed by the SAFMC against commercial and recreational objectives.

We developed and applied a size-structured MSE tool to two SE US marine fisheries: black sea bass and cobia (*Rachycentron canadum*). The application resulted in two separate MSEs: one for each stock. We pursued an intermediate approach between a desk-based MSE, i.e., an exercise conducted by an analyst with no stakeholder input, and an MSE that integrates stakeholder feedback (Walter et al. 2023) using information obtained from semi-structured interviews with commercial and recreational participants in black sea bass and cobia fisheries (Damiano et al. 2022). We chose black sea bass and cobia as case studies to compare the performance of generalized SE US MPs applied to stocks with different life histories, different fishery compositions, and stock status. Black sea bass are a largely sedentary reef fish, a protogynous hermaphrodite, have a maximum life span of approximately 25 years, are distributed within the SE US from Cape Hatteras, North Carolina to Southeast Florida, and are managed under the Snapper Grouper FMP by the SAFMC (SEDAR 2023). Cobia are a migratory coastal pelagic species distributed from Chesapeake Bay waters in Virginia to the southern Georgia border, live to a maximum of 12 years, and though historically managed by the SAMFC, have been managed by the Atlantic States Marine Fisheries Commission (ASMFC) as of 2020 (Gallagher 2020, SEDAR 2020). Recreational sectors for both black sea bass and cobia are made up of private recreational anglers and the for-hire recreational fleet, i.e., charter vessels and headboats; commercial sectors fish using hook-and-line gear for both species and trap gear for black sea bass (SEDAR 2020, SEDAR 2023). Management measures for black sea bass fisheries include an 11-inch size limit and vessel limits for the commercial sector, and a 13-inch size limit and combination of bag limits and trip limits for the recreational sector, respectively (SEDAR 2023). The ACL, which is allocated based on past catch by sector, has historically been allocated to commercial and recreational black sea bass fisheries nearly equally, but in recent years, commercial fisheries have not caught their allocation, and private recreational fishing has become the dominant source of mortality (SEDAR 2023). Due to the low availability of legal-sized fish, the magnitude of dead discarded fish from the private recreational fleet has greatly increased (Rudershausen et al. 2014, SEDAR 2023). Black sea bass are currently overfished and overfishing is occurring, and short-term projections suggest a rebuilding time of approximately 6-10 years under long-term average recruitment conditions (SEDAR 2023). The cobia fishery has one incidental commercial gillnet fishery, is managed using a 33-inch size limit and vessel limits, while the recreational fishery is managed using a 36-inch size limit and bag limit (SEDAR 2020). As of the 2019 stock assessment, the commercial fleet was allocated less than 8% of the ACL, and the recreational fleets over 92% (SEDAR 2020). During the past 10 years however, the recreational fleets have landed more than 95% of the cobia ACL (SEDAR 2020). As of the terminal year of the last assessment, the Atlantic cobia stock was not overfished and overfishing was not occurring, but results were highly sensitive to estimates of natural mortality (SEDAR 2020).

The first goal of this study was to develop an MSE tool that is sufficiently general for application to a wide range of stocks and systems with size-structured dynamics. The second goal was to apply the MSE tool to black sea bass and cobia in the SE US. These applications were used to 1) evaluate the performance of multiple MPs against a variety of management objectives, with explicit consideration of recreational fishing objectives, 2) evaluate tradeoffs between recreational and commercial objectives where they occur, and 3) project changes in the fishery, i.e., catch by fleet, stock abundance, recruitment, and *SSB*.

2. Methods

2.1 MSE Framework Overview

The MSE used operating models (OM) to simulate size-structured population dynamics, fisheries processes, and data generation during 1990-2021 for black sea bass and 1986-2017 for cobia. These historic periods represented the most recent stock assessments for each species. Each OM was projected forward from the historic period 10 times at five-year assessment intervals, totaling 50 years. During each assessment interval, a size-structured estimation model (EM) was fitted to the historical and projected data to estimate fishing mortality (*F*)-based reference points that form the model-based HCRs used for management. Each MP was comprised of an EM, HCR, and management measure. We explored two recreational minimum size limit management measures for each species. We simulation-tested five MPs for black sea bass, including *F0* (no fishing) to simulate rebuilding, and six MPs for cobia. Each OM was projected under three alternative states of nature to account for population process error: black sea bass OMs were projected under alternate recruitment states, and cobia OMs were projected with alternate rates of natural mortality (*M*), i.e., *M* "states". We specifically explored these states of nature to encompass the scope of process uncertainty from the most recent stock assessments. This resulted in a total of 33 unique OMs: 15 for black sea bass, and 18 for cobia. Stochasticity for both species was included in simulations using randomly-generated lognormal deviations in mean recruitment during projections. Observation error was included in catch data, the index of relative abundance, and length composition data. Sampling error was included by simulating 200 iterations of each MSE. For each species, stochastic deviations in mean recruitment were saved from the first 200 iterations, i.e., replicates, and applied during subsequent MP-testing to ensure a balanced study design. During each assessment cycle, if the EM failed to achieve convergence (non-invertible Hessian matrix), the replicate was discarded and the OM re-fitted until convergence was achieved. Only replicates that converged were used in analysis. No post-hoc statistical tests were conducted on results.

2.2. Operating Models

2.2.1 General Structure and Parameterization

All OMs were written in R Statistical Software (R Core Team, 2021), and designed to simulate single-sex, size-structured population dynamics over a user-specified number of years and size bins (see Supplemental Material for details). Abundance-at-size for each year was calculated as a function of abundance-at-size that survived total mortality (*M* and *F*) and grew, and new fish recruited to the stock during the previous year. Mortality was assumed to occur instantaneously throughout the year. Natural mortality was assumed constant and time-invariant, and we provided a matrix of *F* values by fleet. Fishery selectivity for each fleet was assumed to be either logistic (asymptotic) or double-logistic (dome-shaped); a minimum of two fleets were included in each OM. Growth was modeled using a growth transition matrix that models growth increments using von Bertalanffy growth function (VBGF) parameters to generate an upper triangular matrix describing the probabilities of fish in one size bin transitioning to a different size bin (Chen et al. 2003, Cao et al. 2017a); only positive growth was allowed, i.e., no shrinkage. We assumed no functional stock-recruitment relationship, i.e., we used the mean recruitment model, which requires a single mean recruitment parameter and a vector of annual deviations from mean recruitment. *SSB* was calculated as a function of the simulated abundance-at-size that experienced total mortality up to the month of peak spawning, and multiplied by an exponential weight function and logistic maturity function. For observation models, we used the Baranov catch equation (Baranov 1918) to calculate the time series of catch-at-size for each fleet from the simulated abundance-at-size. A single unitless index of abundance was calculated for each OM as a function of fishery-independent survey catchability, simulated abundance-at-size, total mortality up to the month of sampling, and asymptotic survey selectivity. Each OM for black sea bass and cobia was parameterized to reflect the life history strategies, population dynamics, and exploitation history by fishery sector estimated in the most recent respective stock assessment (SEDAR 2020, SEDAR 2023). Parameterization was accomplished by borrowing values of parameters provided to or estimated by the most recent assessment. During the historical period, vectors of annual fishing mortality were summed by sector to parameterize fleets at the sector level, e.g., commercial, recreational, and a vector of estimated deviations from mean recruitment was used to parameterize the recruitment dynamics. See the Supplemental Material for a complete description of OM functionality.

2.2.2 OM Dynamics

Black sea bass OMs simulated data during 1990-2021 for the historical period over 22 size bins delineated by 30 mm growth increments. Catch-at-size was simulated for three fishery fleets: a general commercial fleet with logistic selectivity, a general recreational fleet with logistic selectivity, and a recreational dead discard fleet with dome-shaped selectivity. Catches were assumed to be approximately known without error; observation error was included with a small coefficient of variation (cv) set to 0.05. The index data were simulated to reflect the Reef

Fish Survey (SERFS) integrated chevron trap and video camera (CVID) index (Bacheler and Ballenger 2018). The index was parameterized using the estimated SERFS catchability coefficient, and observation error was assumed to be lognormal with a cv set to 0.27 (SEDAR 2023). We chose 1990-2021 as the historical period to begin at the same time as the CVID index; this allowed the use of a single set of logistic selectivity parameters for the index. Error in length composition data for catches and the index were assumed to be multinomially distributed with an effective sample size (*ESS*) set to 100. Cobia OMs simulated data during 1986-2017 for the historical period, the complete time series of data used in the assessment, and the population was modeled using 26 size bins separated by 50 mm growth increments. Two fishery fleets were simulated: a general commercial fleet with logistic selectivity, and a general recreational fleet with logistic selectivity. Bycatch and the magnitude of dead discards remain a concern for cobia at multiple spatial and temporal scales (Aspinwall et al. 2019, Carlson and McCarthy 2019), but the most recent stock assessment did not model dead cobia discards (SEDAR 2020), therefore we did not include them in OMs. Catches were assumed to be approximately known with cv set to 0.05. One survey index was simulated to model the NOAA Southeast Region Headboat Survey with logistic selectivity. Cobia length compositions in catches and the index were assumed to be multinomially distributed with an effective sample size (*ESS*) set to 100.

2.3 Management Procedures

2.3.1 Estimation Model

We used an integrated size-structured assessment model developed by Cao et al. (2017a) in AD Model Builder software (Fournier et al. 2012) as the EM to fit to the data generated by each OM. The size-structured assessment model is a flexible framework that has been peer-reviewed, simulation tested (Cao et al. 2017b), and applied to both invertebrate (Cao et al.

2017a) and finfish populations (North Carolina Division of Marine Fisheries, 2022); it is, however, not the model used in current management of either species. The previous assessments for black sea bass and cobia were conducted using the Beaufort Assessment Model (BAM), an integrated statistical catch-at-age formulation (Williams and Shertzer 2015), to generate reference points for management advice. The size-structured EM, however, is similar to statistical catch-at-age models, using nearly identical population sub-models with the exception of the growth transition matrix, and penalized maximum likelihood estimation to derive MSY-based BRPs, e.g., F_{msy}, SSB_{msy}, and proxies, e.g., $F_{\%SPR}$. We used the size-structured EM primarily because it is highly generalized (Cao et al. 2017a), whereas the BAM utilizes bespoke model code for assessment by species. This would have required using two separate, albeit similar EMs for each species. Additionally, we chose a size-structured EM to reduce uncertainty in EM estimates by avoiding age-length conversion (Quinn and Deriso 1999, Cao et al. 2017a), because several stakeholder objectives and challenges in recreational fisheries in general relate to size (Holder et al. 2020, Damiano et al. 2022). OM and EM population dynamics were represented in exactly the same way, i.e., using identical data types and parameters. Parameters were estimated by minimizing the negative log-likelihood. We enabled estimation of the initial *F, F* deviations by fleet, selectivity parameters, the initial population size, mean recruitment, and deviations from mean recruitment using penalized maximum likelihood. All other model parameters were fixed at the values borrowed from the stock assessments. A complete description of the EM methods, estimable quantities, and likelihood functions is provided in Cao et al. (2017a). The EM fishery sub-model can only accept a single set of selectivity parameters per pattern, i.e., one set for asymptotic and one set for dome-shaped, therefore, fleets with asymptotic selectivities were forced to share the same set of parameters; ascending limbs of asymptotic fleet and index selectivities in the most recent assessments were, however, generally similar (SEDAR 2020, SEDAR 2023). Additionally, because the BAM is age-structured, certain age to length conversions were required to parameterize the size-structured OMs. When size-based estimates or information were not available, the VBGF used in the assessment and estimates of abundance at size were used to inform parameterization. Additionally, although minimum size limits are measured in inches for management, size bins were measured in millimeters (mm) for consistency with the VBGF.

2.3.2 HCRs and Management Measures

In order to generate an HCR, the EM estimates a rate of *F* associated with MSY, e.g., F_{msy}, or, when using the mean recruitment model, a proxy based on the rate of *F* associated with some level of spawning potential reduction (*SPR*), e.g., $F_{\%SPR}$. The assessments that were conducted using the BAM use these proxies to calculate an ACL that is translated into total allowable catches (TAC) by sector for use in management. The EM framework does not include an ACL calculation, and consequently, we did not calculate sector-specific TACs during projections. Instead, these processes were approximated: once a new assessment cycle begins, the BRP, $F_{\%SPR}$, is multiplied by a vector of allocation proportions by fleet, $\bar{A}_f$, to produce estimated *F* by fleet, $\bar{F}_{f,y}$, to calculate projected catches using the Baranov catch equation up to the next assessment cycle (Supplementary Material, equation 18) (1):

$$F_{\%SPR} * \bar{A}_f = \bar{F}_{f,y} \qquad (1).$$

Management implementation error is included during projections by drawing from $\bar{A}_f$ from a normal distribution using the mean and standard deviation of fractions of *F* that each fleet was responsible for during the last 10 years.

All HCRs were modeled to approximate SE US threshold HCRs, i.e., allow for some constant rate of *F* until a *SSB* threshold is reached, e.g., minimum stock size threshold (MSST) (Figure 1). We selected three rates of *F* for black sea bass HCRs: $F_{40\%SPR}$ and $75\%F_{40\%SPR}$, which are common reference points tested in SE US marine stock assessment projections (Damiano et al. 2022), and *F0*, to simulate rebuilding (SEDAR 2023). In the EM, $F_{40\%SPR}$ is calculated as the rate of *F* achieved when *SPR* is reduced to 40% of its unfished size:

$$F_{40\%SPR} = 0.4SPR = \frac{\frac{SSB}{R}_{F=x}}{\frac{SSB}{R}_{F=0}} \qquad (2),$$

where *SPR* is defined as the *SSB* per recruit (R) at some level (*x*) of *F* divided by the SSB per recruit in an unfished condition. The exact value of $F_{40\%SPR}$ is found by the EM via a numerical search within an *SPR* function that calculates *SSB* per recruit based on estimated population dynamics, total *F*, and using a single selectivity averaged over fleets (Cao et al. 2017a). For cobia HCRs, we selected $F_{40\%SPR}$, $75\%F_{\%40SPR}$ for the same reasons as black sea bass, and $50\%F_{40\%SPR}$ to explore the potential effects of further reducing *F* (Damiano et al. 2022). We also considered two alternative minimum size limits as additional management measures within each MP for black sea bass and cobia, with the exception of *F0.* For black sea bass, $F_{40\%SPR}$ and $75\%F_{40\%SPR}$ HCRs were combined with the status quo 13-inch recreational minimum size limit, or an 11-inch recreational minimum size limit. This resulted in a total of five MPs for black sea bass. For cobia, all three HCRs were combined with either the status quo 36-inch recreational minimum size limit, or a 33-inch recreational minimum size limit. This resulted in a total of six MPs for cobia. Alternate size limits were identified during semi-structured interviews with recreational fishers as a preferred management measure for simulation testing within the MSEs (Damiano et al. 2022). Size limits were implemented by changing the fishery selectivity patterns during both the historic period and projections. For simplicity, time blocks for selectivity were not used, therefore, the same selectivity parameters were used during both the historic and projection periods; without time blocks, the EM requires this for internal consistency (Figure 1). For black sea bass, to this required changing both the asymptotic pattern for commercial and recreational fleets, and dome-shaped pattern for the dead discard fleet (Figure 1).

2.3.3 States of Nature

We explored three alternate states of process uncertainty for each species and MP. For black sea bass, we explored three alternative states of recruitment: an average recruitment based on the long-term mean estimated in the most recent assessment (SEDAR 2023), a recent recruitment state based on the average recruitment during 2012-2021, and a low recruitment state based on a period of declining mean recruitment during 2014-2019. We chose recruitment to represent process uncertainty in the black sea bass MSE due to the concern regarding recruitment failure in the SE US black sea bass stock (Wade et al. 2023) to which the recent overfished status was largely attributed (SEDAR 2023). For cobia, we explored three fixed rates of M: 0.3, 0.4, and 0.5 to represent alternative M states. We chose M to represent process uncertainty in the cobia MSE due to the strong influence of M on previous assessment results (SEDAR 2013, SEDAR 2020). The five MPs for black sea bass and six MPs for cobia across three alternate states of nature resulted in 15 and 18 unique OMs, respectively, totaling 33 unique OMs (Table 1). The *FSPR40* MP represents the status quo management approach for black sea bass prior to its overfished status, and the low recruitment state of nature represents the current recruitment regime (SEDAR 2023) (Table 1). The *FSPR40* MP also represents the status quo management approach for cobia, and the $M = 0.4$ state was assumed to represent average M conditions (Table 1).

2.3.4 Objectives and Performance Metrics

We pursued an intermediate approach to stakeholder engagement for the MSEs. Conceptual objectives were identified by Damiano et al. (2022) through semi-structured interviews with commercial and recreational fishers from the SE US conducted during summer, 2020 (Table 1). In brief summation: fishers from both sectors identified conservation of the resource as an objective for each species; commercial and recreational black sea bass fishers identified catching the greatest number of fish and reducing the number of dead discards as objectives for the fishery; recreational black sea bass and cobia fishers identified maximizing season length, and catching the largest fish possible as objectives for the fishery; and commercial cobia fishers also identified maximizing the season length as an objective (Damiano et al. 2022). Other objectives were identified during semi-structured interviews (Damiano et al. 2022), but only those with high rank were prioritized so as to avoid an excessive number of performance metrics (Punt 2017).

We developed performance metrics (PM) for each objective. However, because there was no additional stakeholder engagement following the semi-structured interviews, conceptual objectives were only partially operationalized, i.e., no thresholds were established for probabilistic PMs (Table 1). The purpose of the study was to test the MSE tool's ability to identify tradeoffs, not to provide advice for management, and therefore designed PMs to be interpreted in a relativistic manner, i.e., there was no weighting scheme to assign scores to MPs (Table 2). All PMs were calculated using median values over 200 iterations of each year during the last 40 years of projections. 90th and 10th quantiles were calculated to capture variation across iterations. We chose this period based on a visual analysis; PMs stabilized during this period. The PM for the conservation objective, i.e., preventing overfished status, was measured as proportion of years when median *SSB* dropped below the MSST each year. The MSST was calculated based on the equation from the most recent assessments for black sea bass and cobia: (1-*M*) $SSB_{40\%SPR}$ (SEDAR 2020, SEDAR 2023). The MSST was calculated using the underlying population dynamics from the OM and using the same fleet-averaged selectivity as the EM. MSSTs were the same across all states of nature. When computing the MSST for black sea bass, the average recruitment state was assumed for consistency with the assessment (SEDAR 2023), and for cobia, *M* was assumed equal to the average of the three alternate states of *M*, i.e., 0.4. We note that all other PMs relate to removals, e.g., landings, dead discards, and therefore, the *F0* MP for black sea bass is only evaluated against the conservation objective. The PM for the objective to maximize catch was measured using the median commercial and recreational landings (catch) in numbers of fish. Similarly, the PM for reducing the number of dead discards was measured using the median number of dead discards each year. The PM for the objective to maximize season length was measured in the median catch per unit effort (CPUE) relative to the CPUE obtained from the status quo MP and states of nature, which was *FSPR40* for both species with average recruitment and *M*=0.4, respectively, as a proxy for season length. The assumption is that CPUE will be inversely proportional to the length of the season, or in other words, the more fish caught per unit of effort, the sooner the sector will attain its ACL. If we hold that *F* is equal to catchability (q) multiplied by effort (E) and assume that q is constant over recruitment or natural mortality conditions, respectively, rearrange the equation such that E is equal to $\frac{F}{q}$, divide CPUE for a given MP, $CPUE_{MP}$, by the CPUE from the status quo MP, $CPUE_{SQ}$, then multiplying by q will yield a relative measure of CPUE, $CPUE_{rel}$:

$$CPUE_{rel} = \frac{CPUE_{MP}}{CPUE_{SQ}} = \frac{\frac{C_{MP}}{F_{MP}}}{\frac{C_{SQ}}{F_{SQ}}} \qquad (3).$$

We considered treating exploitation rate as a unitless proxy for season length (Bohaboy et al. 2022), but concluded that the relationship would not hold for a fishery with year-round season length. The PM for the objective to increase the availability of larger fish was measured as the proportion of the median population (out of 1.0) each year that was at least as large as the recreational minimum size limit.

3. Results

3.1 Black sea bass

3.1.2 Vital Rates

The magnitude of black sea bass vital rates, i.e., recruitment, abundance, and *SSB* depended on the state of recruitment (Figure 2). Differences in median recruitment across MPs was due to the stochasticity in the recruitment deviations, however, MP performance with respect to median abundance and median *SSB* was consistent across recruitment states. In all recruitment states, the *F0* MP achieved the greatest median abundance, while all other MPs achieved similar, lower levels of median abundance (Figure 2). In the average recruitment state, *F0* was the only MP to achieve a level of median abundance consistent with early years of the historical period; all MPs under recent and low recruitment states resulted in median abundance that was substantially less than the historic period (Figure 2). In all recruitment states, *F0* achieved the greatest median *SSB* while *75FSPR40* and *75FSPR40_SL* MPs achieved slightly greater median *SSB* than *FSPR40* and *FSPR40_SL* MPs (Figure 2). Differences in the magnitude of median abundance and *SSB* during the historic period were the result of implementing the different sets of selectivity patterns (Figure 1); the EM was not configured for time-varying selectivity, therefore, the selectivity parameters needed to be consistent during EM fitting during the historic and projection periods.

3.1.3. Performance Metrics

As with vital rates, the relative magnitude of recreational landings, commercial landings, and dead discards depended on the recruitment state (Figure 3). Generally, *FSPR40_SL* achieved the highest number of recreational and commercial landings regardless of recruitment state (Figure 3). The *75FSPR40_SL* MP achieved the second-highest number of recreational and commercial landings followed by the *FSPR40* and *75FSPR40* MPs, which achieved similarly lower landings across recruitment states (Figure 3). No MP, regardless of recruitment condition, achieved a level of commercial or recreational landings greater than the first few years of the historic period (Supplemental Figure 1). *FSPR40* resulted in the highest number of dead discards, followed by *75FSPR40_SL* and *FSPR40_SL*, which reduced the number of dead discards by approximately 500,000 (Figure 3). *75FSPR40* resulted in the largest reduction in dead discards (Figure 3). Reduced recruitment states generally resulted in fewer dead discards (Figure 3), but in the average recruitment state, only *75FSPR40* reduced the number of dead discards to near-historic lows (Supplemental Figure 1). Overall, the *75FSPR40_SL* MP achieved the highest stock status relative to the MSST, maintaining *SSB* at a level above the MSST 100% of the time across all recruitment states (Figure 3). In the average and recent recruitment states, no MP resulted in a stock status below the MSST (Figure 3). However, stock status relative to the MSST is substantially reduced in the recent recruitment state, and in the low recruitment state, *75FSPR40* is above the MSST 98% of the time, and *FSPR40* and *FSPR40_SL* are below the MSST 100% of the time (Figure 3). The *75SPR40_SL MP* resulted in the longest recreational season length relative to the status quo (*FSPR40*) followed *FSPR40_SL*, with *75FSPR40* achieving the shortest season length (Figure 3). *75FSPR40* and *75SPR40_SL* MPs resulted in the highest proportion of fish that were as larger or larger than the recreational minimum size limit

(Figure 3). Although the median proportion achieved by the *FSPR40_SL* MP was slightly greater than *FSPR40*, there was large overlap in interannual variability in medians (Figure 3). We note that estimated selectivities did not differ from those in the OM (Figure 1).

3.1.3 Summary of MP Tradeoffs

Excluding *F0*, *75FSPR40_SL* resulted in the highest stock status, longest recreational season length, lowest number of dead discards, and high proportion of large fish, while resulting in reduced recreational and commercial landings (Figure 4). The 75*FSPR40* MP resulted in a similarly high stock status, with lower recreational and commercial landings, the second-lowest recreational season length, and the second-highest number of dead discards (Figure 4). The *FSPR40_SL* MP resulted in the highest recreational and commercial landings, second-highest recreational season length and number of dead discards, and second-lowest stock status. The *FSPR40* MP resulted in recreational and commercial landings that were comparably low with the *75FSPR40* MP, lowest recreational season length and proportion of large fish, the lowest stock status and highest number of dead discards (Figure 4). Similar proportions of large fish were attained under each MP (Figure 4, Figure 5). These patterns were consistent in all recruitment states (Figure 5).

3.2 Cobia

3.2.1 Vital Rates

The magnitude of cobia vital rates, i.e., recruitment, abundance, and *SSB* depended on the state of *M* (Figure 5). Differences in median recruitment across MPs was due to the stochasticity in the recruitment deviations; we note that the final recruitment deviation was not estimable, and while it was included in Figure 5, it was removed from PM calculations. MPs generally resulted in similar levels of abundance across *M* states, with magnitude generally consistent with the historic period (Figure 6). In all *M* states, *50FSPR40* resulted in the highest *SSB*, followed very closely by *50FSPR40_SL*; *75FSPR40* and *75FSPR40_SL* performed similarly relative to one another with lower *SSB* overall; and *FSPR40* and *FSPR40_SL* resulted in the lowest *SSB* (Figure 4). No MP resulted in *SSB* at or below the MSST regardless of *M* state (Figure 5, Figure 6).

3.2.2 Performance Metrics

The pattern in the number recreational landings achieved by each MP closely matched that of abundance (Figure 4, Figure 5). Commercial landings followed a similar pattern with more variability: under the $M = 0.3$ state, *FSPR40_SL* and *FSPR40* MPs achieved a nearly identical median number of landings across the last 40 years of the projection period (Figure 5); and under the $M = 0.4$ state, the *FSPR40* MP resulted in a smaller median number of landings than the *75FSPR40_SL* MP (Figure 5). The *FSPR40_SL* MP resulted in the largest median number of landings, commercial and recreational, compared to the historic period, while *FSPR40* and *75FSPR40_SL* MPs achieved median landings that were generally consistent with the average landings during the historic period (Supplemental Figure 2). All MPs resulted in a stock status larger than the MSST 100% of the time, with MPs following a pattern similar to that of *SSB*, i.e., MPs with lower *F* HCRs resulted in a larger stock status relative to the MSST and vice versa (Figure 5). Patterns in MP performance with respect to both recreational and commercial season lengths relative to the status quo (*FSPR40*) were nearly identical (Figure 5). The *50FSPR_SL* MP consistently resulted in the longest season length across *M* states, followed by *75FSPR40_SL*; in the $M = 0.3$ state, *75FSPR40_SL* and 50FSPR40 MPs performed comparably, whereas 50FSPR40 resulted in a shorter season length in $M = 0.4$ and 0.5 states (Figure 6). The *FSPR40_SL* and *75FSPR40* MPs resulted in the shortest season lengths, respectively (Figure 6). The pattern in MP performance with respect to the proportion of fish as large or larger than the recreational minimum size limit also mirrored the pattern in *SSB*, i.e., *50FSPR40* resulted in the largest proportion, and *FSPR40_SL* the smallest (Figure 6). We note that estimated selectivities did not differ from those in the OM (Figure 1).

3.2.3 Summary of MP Tradeoffs

The *50FSPR40* MP resulted in the largest stock status relative to the MSST, the lowest number of recreational and commercial landings, second-highest proportion of large fish, and longest commercial and recreational season lengths (Figure 7). The *50FSPR* MP resulted in a similarly high stock status with lower recreational and commercial season lengths, the highest proportion of large fish, and the lowest number of recreational and commercial landings (Figure 7). The *FSPR40* MP generally resulted in the highest recreational and commercial landings, although commercial landings were comparable to *FSPR40_SL* when $M = 0.3$, the second-lowest stock status and proportion of large fish, and shortest season lengths (Figure 7). The *FSPR40_SL* MP resulted in the highest number of recreational and commercial landings, third-shortest corresponding season lengths, lowest stock status and smallest proportion of large fish (Figure 7). *75FSPR40* and *75FSPR40_SL* MPs performed similarly, achieving results between the other two sets of MPs: reduced landings from *FSPR40* and *FSPR40_SL* but with a higher stock status and number of large fish, and shorter seasons than *50FSPR40* and *50FSPR40_SL* (Figure 7). Patterns were similar over all *M* states.

4. Discussion

Using black sea bass and cobia as case studies, we demonstrated the utility of a size-structured MSE tool for evaluating MPs employed in SE US marine fisheries to achieve commercial and recreational objectives. By integrating recreational objectives with the MSE framework, we were able to evaluate tradeoffs among MPs using recreational performance metrics, including a proxy for season length, and the proportion of fish that are as large or larger than the recreational minimum size limit in the population. Several objectives were shared among fishers in both commercial and recreational sectors. The primary objective among both commercial and recreational black sea bass fishers was to catch the most fish, an objective that generally aligns with achieving MSY, and the primary objective for cobia fishers, both commercial and recreational, was to maximize season length (Damiano et al. 2022). This aspect simplified the evaluation in the sense that commercial and recreational objectives were not in competition.

Black sea bass MP simulation results were consistent with short-term projections from the most recent stock assessment: in a low recruitment state, i.e., productivity regime, *SSB* would remain below the MSST, i.e., in an overfished condition under the status quo MP, *FSPR40*, and in an average recruitment state, the stock would rebuild within ten years under *F0* (SEDAR 2023). Results also suggested that rebuilding under *F0* is possible within a similar timeframe in the recent and low recruitment states that are likely to be more reflective of the current productivity regime (Wade et al. 2023). Should the productivity regime remain in a low recruitment state, MPs that allow harvest will either failed to meet or risked failure to meet the objective to prevent an overfished stock status (Figure 3); this effect is mitigated somewhat in a recent recruitment state (Figure 3). Cobia MP simulation results were consistent with the effects of *M* on productivity (SEDAR 2013, SEDAR 2020), and suggested that all MPs met the objective to prevent an overfished status in all *M* states (Figure 4). Differences in the effects of fishing on productivity among the two species were likely due to selectivity patterns: black sea bass were subject to a broader range of selectivity over size bins than cobia due to the additional discard fleet (Figure 1), which, due to black sea bass protogyny, likely resulted in the removal of more mature fish compared to cobia.

We observed a general tradeoff in the ability of MPs to meet the objective to maximize catch and to increase the number of large fish in the population; this is both intuitive in that increased exploitation under the selectivity assumptions will remove more large fish, and consistent with past studies, which determined that lower rates of *F* improve the potential for catching larger fish at the expense of magnitude of catch (Hilborn 2007, Gwinn et al. 2015). Similarly, MPs that lowered the recreational minimum size limit generally resulted in more landings, which was expected given that length-based regulations, including minimum size limits, are tools designed to achieve MSY (Gwinn et al. 2015, Maggs et al. 2016). MPs with reduced recreational minimum size limits generally resulted in longer season lengths, presumably because making more fish available to the fishery increases catch under a constant rate of *F*, and therefore CPUE relative to the status quo.

Reducing the recreational minimum size limits resulted in some case-specific tradeoffs. For black sea bass, MPs that lowered the recreational size limit to 11 inches met the objective to maximize catch, and resulted in fewer dead discards: expanding the asymptotic selectivity pattern to fully select 11-inch fish was accompanied by a truncated dome, which selects fish in those size bins to be discarded dead (Figure 1). Consequently, this did not result in any change to the size structure of population abundance (Supplemental Figure 3) because the size at first capture did not change (Froese et al. 2016). Lowering effort through *F* consistently reduced the number of dead discards (Figure 3). Although black sea bass are relatively robust to discard mortality (Rudershausen et al. 2014), and current discarding practices such as venting, or recompression can have strong positive effects on post-release survival (Collins et al. 1999, Zemeckis et al. 2020), black sea bass discard mortality varies over their geographic range (Bugley and Shepherd 1991, Schweitzer et al. 2020), and results of the most recent stock assessment suggest that discarding occurs at such a magnitude that improved discarding practices alone cannot reduce the number of dead discards. Therefore, to fully satisfy the objective to reduce the magnitude of dead discards, effort would have to be curtailed via input controls (Bellido et al. 2020). Our approach to simulating projected catch controls F instead of a TAC, which, although a shortcut, demonstrates the effect of controlling effort on the magnitude of dead black sea bass discards. For cobia, MPs that reduced the recreational minimum size limit to 33 inches resulted in fewer large fish in the population, and consequently a small truncation to the size structure of population abundance (Supplemental Figure 4). The size-structured MSE framework did not include a mechanism to model evolutionary responses to fishing pressure, therefore, the benefits of reducing minimum size limits should be carefully considered against the effects of a truncated size (or age) structure, other associated effects, e.g., earlier size at maturity, that can reduce population stability and resilience (Hard et al. 2008, Kuparinen et al. 2016).

This project has resulted in several important contributions to MSE and ecosystem-based fisheries management. It is one of the few examples of an MSE that explicitly integrated recreational objectives into the simulation testing of management strategies. While the recreational objectives do not specifically measure social utility, measuring quantities such as the season length, and the ability to catch larger fish, both of which can be used as proxies for increased angler satisfaction, are steps forward toward operationalizing frameworks capable of evaluating so-called “triple bottom-line” management strategies, i.e., those that address conservation, economic, and social objectives (Dowling and Mangel 2016, Dichmont et al.

2021). MSE can also be an effective tool for establishing rebuilding plans for overfished stocks (Holland 2010, Deith et al. 2021), and by using black sea bass as a case study, we provide an example for future efforts to address management of overfished Snapper Grouper stocks in the SE US. This project has also resulted in a fully operational example of integrating stakeholder feedback via an intermediate approach, i.e., some degree of stakeholder engagement (Walter et al. 2023), within an MSE framework (Damiano et al. 2022). This was also the first MSE conducted for SE US marine fisheries, and in the case of black sea bass, an example of MSE occurring in lockstep with stock assessment - the black sea bass OMs were parameterized to account for the estimates of population dynamics from the recent stock assessment so as to capture the pronounced decline in abundance of black sea bass (Bacheler and Cheshire 2022, Bubley and Willis 2022) and weaker recruitment since 2017 (SEDAR 2018, SEDAR 2023).

The EM we selected to estimate reference points for MPs, and decisions relating to OM design imposed some constraints on the scope of this study. The EM developed by Cao et al. (2017a) is not a spatially explicit model, therefore, we could not model management measures such as timed area closures, which are used in the management of certain areas and sectors of black sea bass and cobia fisheries (SEDAR 2020, SEDAR 2023). Although the EM can accommodate a seasonal timestep, we followed the BAM implementations and used an annual time step, which precluded our ability to model temporal closures at a seasonal scale. Seasonal closures were cited by both recreational black sea bass and cobia anglers as a preferred management alternative during semi-structured interviews (Damiano et al. 2022), although they were ranked lower than the measures considered in this study. We acknowledge that the assumption of constant q among uncertainty conditions in the calculation of relative CPUE may be violated depending on changes in abundance. We experimented with using one minus the exploitation rate as a proxy for season length to model depletion of the ACL. However, given the low rates of F in projections relative to the historic period, these results suggested a much smaller effect of F on the population than is likely reasonable, therefore we maintain that the relative CPUE proxy is a more intuitive and appropriate measure when using a non-seasonal model for stocks with a year-round fishing season. Other size-based management measures such as slot limits have shown promise as a tool for achieving recreational fishing and conservation objectives (Gwinn et al. 2015, Bohaboy et al. 2022). We did not model slot limits, but should the SAFMC consider them, the effectiveness of that approach could be evaluated with the MSE tool presented in this study. The sharing of logistic selectivity parameters among both commercial and recreational fleets precluded our ability to evaluate the effects of changes to minimum size limits in commercial fisheries; for example, lowering the recreational size limit for cobia from 36 to 33 inches essentially assumed the status quo 33-inch commercial size limit. We could not explicitly simulate management measures such as bag limits because neither the BAM or the size-structured EM model effort, e.g. trips. Doing so would require stock-specific effort data for the private recreational fishery, which are not currently available from the Marine Recreational Information Program (NMFS, Fisheries Statistics Division, personal communication 2023). Choosing to use the mean recruitment model, though consistent with the stock assessments (SEDAR 2020, SEDAR 2023), also imposed some limitations: the stock could only be crashed at very low mean recruitment with enough sufficiently broad deviations for multiple years in a row. Relatedly, because the EM currently lacks the capacity to calculate an ACL from proxies, controlling F was a short-cut approach to input controls in MPs, i.e., in reality, management is not (currently) controlling F itself, but instead setting acceptable numbers/weight of landings. Finally, we acknowledge that recruitment and natural mortality had the greatest effects on the performance of MPs. Recruitment is highly variable in marine populations (Thorson, Rudd, and Winker 2019), and natural mortality is notoriously difficult to estimate (Punt et al. 2021), but testing a range of uncertainty across those processes may serve as a first step towards developing MPs that are robust to non-stationarity, thereby contributing to the development of climate-ready fisheries (Wilson et al. 2018, Grafton et al. 2023).

We anticipate that the size-structured MSE framework presented in this study will provide a useful tool for managers at state and federal levels to select a robust MP, particularly when competing social, economic, and conservation objectives need to be balanced. The size-structured MSE tool is highly flexible, and can be parameterized to approximate the dynamics of most age-structured stock assessments for marine fisheries currently used within the US. Testing the MSE tool using the black sea bass and cobia case studies has provided insights into the tradeoffs inherent to SE US marine fisheries and provided a foundation for exploring how MPs that include size-based management measures perform given a range of management and process uncertainty. The performance of cobia MPs were relatively robust to uncertainty, suggesting that the current SE US MP approach may be sufficient for managing certain recreational fisheries. Indeed, the $F_{SPR40\%}$ HCR and its variants should be robust in general given that they are designed to reduce the population to a certain level at a sustainable rate. That robustness held for black sea bass across recruitment states in that fishing at some constant F given a change in mean recruitment achieved the expected reduction in SSB (Figure 2). Although there have been no mechanistic relationships established between the “South Atlantic” black sea bass stock productivity and environmental variables to date (Wade et al. 2023), if the recruitment failure is the result of negative climate impacts, then the status quo SE US MP approaches used in this study may be more appropriate than those that would attempt to adapt to a new recruitment regime (Szuwalski et al. 2023); this would also hinge on whether the equilibrium recruitment assumption for MSST calculation was revisited, which is beyond the scope of this study. The additional challenge facing black sea bass management is that it is fished as part of a multi-species complex; black sea bass are essentially an incidental (although desirable) member of the Snapper Grouper recreational bottom fishery, i.e., they are sought, but not targeted. Our simulations demonstrated that even without further growth in the recreational sectors, no MPs will achieve historic levels of abundance or landings without strong recruitment, and dead discards are likely to be reduced more effectively by reducing *F*. This draws into question whether the open-access nature of the recreational Snapper Grouper bottom fishery is tenable in the long term, especially as many other stocks managed within the complex are experiencing recruitment failure (Wade et al. 2023).

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References

Abbott, J. K., Lew, D. K., Whitehead, J. C., & Woodward, R. T. (2022). The Future of Fishing for Fun: The Economics and Sustainable Management of Recreational Fisheries. *Review* *of Environmental Economics and Policy*, *16*(2), 262–281. https://doi.org/10.1086/720987

Arlinghaus, R., Abbott, J. K., Fenichel, E. P., Carpenter, S. R., Hunt, L. M., Alós, J., Klefoth, T., Cooke, S. J., Hilborn, R., Jensen, O. P., Wilberg, M. J., Post, J. R., & Manfredo, M. J. (2019). Opinion: Governing the recreational dimension of global fisheries. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(12), 5209–5213. https://doi.org/10.1073/pnas.1902796116

Aspinwall, A., Perkinson, M., Krause, J., Buckel, J., Gorham, B., Blow, W., Kalinowsky, C., McCarthy, K., & Markwith, A. (2019). *SEDAR 58 Discard mortality ad-hoc group working paper* (No. SEDAR58-WP04). SEDAR.

Bacheler, N. M., & Ballenger, J. C. (2018). Decadal-scale decline of scamp (Mycteroperca phenax) abundance along the southeast United States Atlantic coast. *Fisheries Research*, *204*, 74–87. https://doi.org/10.1016/j.fishres.2018.02.006

Bacheler, N. M., & Cheshire, R. (2022). *Standardized video counts of southeast US Atlantic black sea bass (Centropristis striata) from the Southeast Reef Fish Survey* (No. SEDAR76-WP02; p. 16). SEDAR.

Baranov, F. I. (1918). *On the question of the biological basis of fisheries*.

Beddington, J. R., Agnew, D. J., & Clark, C. W. (2007). Current Problems in the Management of Marine Fisheries. *Science*, *316*(5832), 1713–1716. https://doi.org/10.1126/science.1137362

Bellido, J. M., Sumaila, U. R., Sánchez-Lizaso, J. L., Palomares, M. L., & Pauly, D. (2020). Input versus output controls as instruments for fisheries management with a focus on Mediterranean fisheries. *Marine Policy*, *118*, 103786. https://doi.org/10.1016/j.marpol.2019.103786

Birdsong, M., Hunt, L. M., & Arlinghaus, R. (2021). Recreational angler satisfaction: What drives it? *Fish and Fisheries*, *22*(4), 682–706. https://doi.org/10.1111/faf.12545

Bohaboy, E. C., Goethel, D. R., Cass-Calay, S. L., & Patterson, W. F. (2022). A simulation framework to assess management trade-offs associated with recreational harvest slots, discard mortality reduction, and bycatch accountability in a multi-sector fishery. *Fisheries Research*, *250*, 106268. https://doi.org/10.1016/j.fishres.2022.106268

Bubley, W. J., & Willis, M. (2022). *Black sea bass fishery-independent index of abundance and age/length composition in US South Atlantic waters based on a chevron trap survey (1990-2021)* (No. SEDAR76-WP03; p. 20). SEDAR.

Bugley, K., & Shepherd, G. (1991). Management Briefs: Effect of Catch-and-Release Angling on the Survival of Black Sea Bass. *North American Journal of Fisheries Management*, *11*(3), 468–471. https://doi.org/10.1577/1548-8675(1991)011<0468:MBEOCA>2.3.CO;2

Bunnefeld, N., Hoshino, E., & Milner-Gulland, E. J. (2011). Management strategy evaluation: A powerful tool for conservation? *Trends in Ecology & Evolution*, *26*(9), 441–447. https://doi.org/10.1016/j.tree.2011.05.003

Cao, J., Chen, Y., & Richards, R. A. (2017a). Improving assessment of Pandalus stocks using a seasonal, size-structured assessment model with environmental variables. Part I: Model description and application. *Canadian Journal of Fisheries and Aquatic Sciences*, *74*(3), 349–362. https://doi.org/10.1139/cjfas-2016-0020

Cao, J., Chen, Y., & Richards, R. A. (2017b). Improving assessment of Pandalus stocks using a seasonal, size-structured assessment model with environmental variables. Part II: Model evaluation and simulation. *Canadian Journal of Fisheries and Aquatic Sciences*, *74*(3), 363–376. https://doi.org/10.1139/cjfas-2016-0021

Carlson, J., & McCarthy, K. (2019). *Bycatch of cobia, Rachycentron canadum, in the Atlantic coastal gillnet fishery* (No. SEDAR58-DW08). SEDAR.

Chen, Y., Hunter, M., Vadas, S., Robert, & Beal, B. (2003). Developing a growth-transition matrix for the stock assessment of the green sea urchin (Strongylocentrotus droebachiensis) off Maine. *Fishery Bulletin*, *101*, 737–744.

Coleman, F. C., Figueira, W. F., Ueland, J. S., & Crowder, L. B. (2004). The impact of United States recreational fisheries on marine fish populations. *science*, *305*(5692), 1958-1960.

Collins, M. R., McGovern, J. C., Sedberry, G. R., Meister, H. S., & Pardieck, R. (1999). Swim Bladder Deflation in Black Sea Bass and Vermilion Snapper: Potential for Increasing Postrelease Survival. *North American Journal of Fisheries Management*, *19*(3), 828–832. https://doi.org/10.1577/1548-8675(1999)019<0828:SBDIBS>2.0.CO;2

Cooke, S. J., & Cowx, I. G. (2004). The Role of Recreational Fishing in Global Fish Crises. *BioScience*, *54*(9), 857–859.

Damiano, M., Wager, B., Rocco, A., Shertzer, K. W., Murray, G. D., & Cao, J. (2022). Integrating information from semi-structured interviews into management strategy evaluation: A case study for Southeast United States marine fisheries. *Frontiers in Marine Science*, *9*. https://www.frontiersin.org/articles/10.3389/fmars.2022.1063260

Deith, M. C. M., Skerritt, D. J., Licandeo, R., Duplisea, D. E., Senay, C., Varkey, D. A., & McAllister, M. K. (2021). Lessons learned for collaborative approaches to management when faced with diverse stakeholder groups in a rebuilding fishery. *Marine Policy*, *130*, 104555. https://doi.org/10.1016/j.marpol.2021.104555

Dichmont, C. M., Dowling, N. A., Pascoe, S., Cannard, T., Pears, R. J., Breen, S., Roberts, T., Leigh, G. M., & Mangel, M. (2021). Operationalizing triple bottom line harvest strategies. *ICES Journal of Marine Science*, *78*(2), 731–742. https://doi.org/10.1093/icesjms/fsaa033

Figueira, W. F., & Coleman, F. C. (2010). Comparing landings of United States recreational fishery sectors. *Bulletin of Marine Science*, *86*(3), 499–514.

Fournier, D. A., Skaug, H. J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M. N., Nielsen, A., & Sibert, J. (2012). AD Model Builder: Using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optimization Methods and Software*, *27*(2), 233–249. https://doi.org/10.1080/10556788.2011.597854

Fowler, A. M., Ochwada-Doyle, F. A., Dowling, N. A., Folpp, H., Hughes, J. M., Lowry, M. B., Lyle, J. M., Lynch, T. P., Miles, N. G., & Chick, R. C. (2022). Integrating recreational fishing into harvest strategies: Linking data with objectives. *ICES Journal of Marine Science*, *79*(2), 285–307. https://doi.org/10.1093/icesjms/fsab270

Froese, R., Winker, H., Gascuel, D., Sumaila, U. R., & Pauly, D. (2016). Minimizing the impact of fishing. *Fish and Fisheries*, *17*(3), 785–802. https://doi.org/10.1111/faf.12146

Gallagher, R. (2020). *Using Acoustic Telemetry and Population Genetics to Investigate Cobia Stock Structure in the Southeast U.S* [M.Sc., North Carolina State University]. https://www.proquest.com/docview/2477957533/abstract/DAE4DF26EE8A4C83PQ/1

Goethel, D. R., Lucey, S. M., Berger, A. M., Gaichas, S. K., Karp, M. A., Lynch, P. D., Walter, J. F., Deroba, J. J., Miller, S., & Wilberg, M. J. (2019). Closing the feedback loop: On stakeholder participation in management strategy evaluation. *Under Pressure: Addressing Fisheries Challenges with Management Strategy Evaluation*, *01*(01), 1895–1913.

Grafton, R. Q., Squires, D., & Steinshamn, S. I. (2023). Towards resilience-based management of marine capture fisheries. *Economic Analysis and Policy*, *77*, 231–238. https://doi.org/10.1016/j.eap.2022.11.012

Gwinn, D. C., Allen, M. S., Johnston, F. D., Brown, P., Todd, C. R., & Arlinghaus, R. (2015). Rethinking length-based fisheries regulations: The value of protecting old and large fish with harvest slots. *Fish and Fisheries*, *16*(2), 259–281. https://doi.org/10.1111/faf.12053

Hard, J. J., Gross, M. R., Heino, M., Hilborn, R., Kope, R. G., Law, R., & Reynolds, J. D. (2008). Evolutionary consequences of fishing and their implications for salmon. *Evolutionary Applications*, *1*(2), 388–408. https://doi.org/10.1111/j.1752-4571.2008.00020.x

Hilborn, R. (2007). Defining success in fisheries and conflicts in objectives. *Marine Policy*, *31*(2), 153–158. https://doi.org/10.1016/j.marpol.2006.05.014

Holder, P. E., Jeanson, A. L., Lennox, R. J., Brownscombe, J. W., Arlinghaus, R., Danylchuk, A. J., Bower, S. D., Hyder, K., Hunt, L. M., Fenichel, E. P., Venturelli, P. A., Thorstad, E. B., Allen, M. S., Potts, W. M., Clark-Danylchuk, S., Claussen, J. E., Lyle, J. M., Tsuboi, J., Brummett, R., … Cooke, S. J. (2020). Preparing for a changing future in recreational fisheries: 100 research questions for global consideration emerging from a horizon scan. *Reviews in Fish Biology and Fisheries*, *30*(1), 137–151. https://doi.org/10.1007/s11160-020-09595-y

Holland, D. S. (2010). Management Strategy Evaluation and Management Procedures: Tools for Rebuilding and Sustaining Fisheries", OECD Food, Agriculture and Fisheries Working Papers, No. 25, OECD Publishing. doi: 10.1787/5kmd77jhvkjf-en

Hyder, K., Maravelias, C. D., Kraan, M., Radford, Z., & Prellezo, R. (2020). Marine recreational fisheries—Current state and future opportunities. *ICES Journal of Marine Science*, *77*(6), 2171–2180. https://doi.org/10.1093/icesjms/fsaa147

Ihde, T. F., Wilberg, M. J., Loewensteiner, D. A., Secor, D. H., & Miller, T. J. (2011). The increasing importance of marine recreational fishing in the US: Challenges for management. *Fisheries Research*, *108*(2), 268–276. https://doi.org/10.1016/j.fishres.2010.12.016

Kell, L. T., & Fromentin, J.-M. (2007). Evaluation of the robustness of maximum sustainable yield based management strategies to variations in carrying capacity or migration pattern of Atlantic bluefin tuna (Thunnus thynnus). *Canadian Journal of Fisheries and Aquatic Sciences*, *64*(5), 837–847. https://doi.org/10.1139/f07-051

Kuparinen, A., Boit, A., Valdovinos, F. S., Lassaux, H., & Martinez, N. D. (2016). Fishing-induced life-history changes degrade and destabilize harvested ecosystems. *Scientific Reports*, *6*(1), 22245. https://doi.org/10.1038/srep22245

Lewin, W.-C., Weltersbach, M. S., Haase, K., Arlinghaus, R., & Strehlow, H. V. (2023). Change points in marine recreational fisheries – The impact of stock status and fisheries regulations: A case from the western Baltic Sea. *Fisheries Research*, *258*, 106548. https://doi.org/10.1016/j.fishres.2022.106548

Mace. (2001). A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish and Fisheries*, *2*(1), 2–32. https://doi.org/10.1046/j.1467-2979.2001.00033.x

MAFMC (2022). EAFM Recreational Summer Flounder Management Strategy Evaluation [summary document]. NOAA.

Maggs, J. Q., Mann, B. Q., Potts, W. M., & Dunlop, S. W. (2016). Traditional management strategies fail to arrest a decline in the catch-per-unit-effort of an iconic marine recreational fishery species with evidence of hyperstability. *Fisheries Management and Ecology*, *23*(3–4), 187–199. https://doi.org/10.1111/fme.12125

Mangel, M., & Dowling, N. A. (2016). Reference Points for Optimal Yield: A Framework for Assessing Economic, Conservation, and Sociocultural Tradeoffs in Ecosystem-Based Fishery Management. *Coastal Management*, *44*(5), 517–528. https://doi.org/10.1080/08920753.2016.1208884

Mapstone, B. D., Little, L. R., Punt, A. E., Davies, C. R., Smith, A. D. M., Pantus, F., McDonald, A. D., Williams, A. J., & Jones, A. (2008). Management strategy evaluation for line fishing in the Great Barrier Reef: Balancing conservation and multi-sector fishery objectives. *Fisheries Research*, *94*(3), 315–329. https://doi.org/10.1016/j.fishres.2008.07.013

Melnychuk, M. C., Young, E. G., Anderson, L. E., & Hilborn, R. (2021). Trading off retained daily catch for longer seasons to maximize angler benefits in recreational fisheries management. *ICES Journal of Marine Science*, fsab049. https://doi.org/10.1093/icesjms/fsab049

NCDMF (North Carolina Division of Marine Fisheries). 2022. Stock Assessment of Spotted Seatrout, Cynoscion nebulosus, in Virginia and North Carolina waters, 1991–2019. North Carolina Division of Marine Fisheries, NCDMF SAP-SAR-2022-02, Morehead City, North Carolina. 137 p.

Ono, K., Haynie, A. C., Hollowed, A. B., Ianelli, J. N., McGilliard, C. R., & Punt, A. E. (2017). Management strategy analysis for multispecies fisheries, including technical interactions and human behavior in modelling management decisions and fishing. *Canadian Journal of Fisheries and Aquatic Sciences*, *75*(8), 1185–1202.

https://doi.org/10.1139/cjfas-2017-0135

Pascoe, S., Cannard, T., Dowling, N. A., Dichmont, C. M., Breen, S., Roberts, T., Pears, R. J., & Leigh, G. M. (2019). Developing Harvest Strategies to Achieve Ecological, Economic and Social Sustainability in Multi-Sector Fisheries. *Sustainability*, *11*(3), Article 3. https://doi.org/10.3390/su11030644

Pitcher, T. J., & Hollingworth, C. (Eds.). (2008). *Recreational fisheries: ecological, economic and social evaluation*. John Wiley & Sons.

Potts, W. M., Downey-Breedt, N., Obregon, P., Hyder, K., Bealey, R., & Sauer, W. H. H. (2020). What constitutes effective governance of recreational fisheries?—A global review. *Fish and Fisheries*, *21*(1), 91–103. https://doi.org/10.1111/faf.12417

Punt, A. E., & Donovan, G. P. (2007). Developing management procedures that are robust to uncertainty: Lessons from the International Whaling Commission. *ICES Journal of Marine Science*, *64*(4), 603–612. https://doi.org/10.1093/icesjms/fsm035

Punt, A. E., & Hobday, D. (2009). Management strategy evaluation for rock lobster, Jasus edwardsii, off Victoria, Australia: Accounting for uncertainty in stock structure. *New Zealand Journal of Marine and Freshwater Research*, *43*(1), 485–509. https://doi.org/10.1080/00288330909510017

Punt, A. E., Butterworth, D. S., Moor, C. L. de, Oliveira, J. A. A. D., & Haddon, M. (2016). Management strategy evaluation: Best practices. *Fish and Fisheries*, *17*(2), 303–334. https://doi.org/10.1111/faf.12104

Punt, A. E. (2017). Strategic management decision-making in a complex world: Quantifying, understanding, and using trade-offs. *ICES Journal of Marine Science*, *74*(2), 499–510. https://doi.org/10.1093/icesjms/fsv193

Punt, A. E., Castillo-Jordán, C., Hamel, O. S., Cope, J. M., Maunder, M. N., & Ianelli, J. N. (2021). Consequences of error in natural mortality and its estimation in stock assessment models. *Fisheries Research*, *233*, 105759. https://doi.org/10.1016/j.fishres.2020.105759

Quinn, T. J., & Deriso, R. B. (1999). *Quantitative Fish Dynamics*. Oxford University Press

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rudershausen, P. J., Buckel, J. A., & Hightower, J. E. (2014). Estimating reef fish discard mortality using surface and bottom tagging: Effects of hook injury and barotrauma. *Canadian Journal of Fisheries and Aquatic Sciences*, *71*(4), 514–520. https://doi.org/10.1139/cjfas-2013-0337

Runde, B. J., Bacheler, N. M., Shertzer, K. W., Rudershausen, P. J., Sauls, B., & Buckel, J. A. (2021). Discard Mortality of Red Snapper Released with Descender Devices in the U.S. South Atlantic. *Marine and Coastal Fisheries*, *13*(5), 478–495. https://doi.org/10.1002/mcf2.10175

Schaefer, M. B. (1991). Some aspects of the dynamics of populations important to the management of the commercial Marine fisheries. *Bulletin of Mathematical Biology*, *53*(1), 253–279. https://doi.org/10.1007/BF02464432

Schweitzer, C. C., Horodysky, A. Z., Price, A. L., & Stevens, B. G. (2020). Impairment indicators for predicting delayed mortality in black sea bass (Centropristis striata) discards within the commercial trap fishery. *Conservation Physiology*, *8*(1), coaa068. https://doi.org/10.1093/conphys/coaa068

SEDAR. 2013. SEDAR 28 – South Atlantic Cobia Stock Assessment Report. SEDAR, North Charleston SC. 420 pp. available online at:

http://www.sefsc.noaa.gov/sedar/Sedar_Workshops.jsp?WorkshopNum=28

SEDAR. 2018. SEDAR 56 – South Atlantic Black Seabass Assessment Report. SEDAR, North Charleston SC. 164 pp. available online at: http://sedarweb.org/sedar-56.

SEDAR. 2020. SEDAR 58 – Atlantic Cobia Stock Assessment Report. SEDAR, North Charleston SC. 500 pp. available online at: http://sedarweb.org/sedar-58

SEDAR. 2021. SEDAR 73 South Atlantic Red Snapper Stock Assessment Report. SEDAR, North Charleston SC. 194 pp. available online at: http://sedarweb.org/sedar-73

SEDAR. 2023. SEDAR 76 South Atlantic Black Sea Bass Stock Assessment Report. SEDAR, North Charleston SC. 182 pp. available online at: https://sedarweb.org/assessments/sedar-76/

Shertzer, K. W., Williams, E. H., Craig, J. K., Fitzpatrick, E. E., Klibansky, N., & Siegfried, K. I. (2019). Recreational sector is the dominant source of fishing mortality for oceanic fishes in the Southeast United States Atlantic Ocean. *Fisheries Management and Ecology*, *26*(6), 621–629. https://doi.org/10.1111/fme.12371

Shertzer, K. W., Crosson, S., Williams, E., Cao, J., DeVictor, R., Dumas, C., Nesslage, G. (In Press). Fishery management strategies for Red Snapper (*Lutjanus campechanus*) in the southeast United States Atlantic: a spatial population model to compare approaches. *North American Journal of Fisheries Management*.

Smith, A. D. M., Sainsbury, K. J., & Stevens, R. A. (1999). Implementing effective fisheries-management systems – management strategy evaluation and the Australian partnership approach. *ICES Journal of Marine Science*, *56*(6), 967–979. https://doi.org/10.1006/jmsc.1999.0540

South Atlantic Fishery Management Council. (2006). Snapper Grouper Amendment 13C.

[online]. https://safmc.net/fishery-management-plans/snapper-grouper/

Szuwalski, C. S., Hollowed, A. B., Holsman, K. K., Ianelli, J. N., Legault, C. M., Melnychuk, M. C., Ovando, D., & Punt, A. E. (2023). Unintended consequences of climate-adaptive fisheries management targets. *Fish and Fisheries*, *24*(3), 439–453. https://doi.org/10.1111/faf.12737

Thorson, J. T., Rudd, M. B., & Winker, H. (2019). The case for estimating recruitment variation in data-moderate and data-poor age-structured models. *Fisheries Research*, *217*, 87–97. https://doi.org/10.1016/j.fishres.2018.07.007

van Poorten, B. T., & MacKenzie, C. J. A. (2020). Using Decision Analysis to Balance Angler Utility and Conservation in a Recreational Fishery. *North American Journal of Fisheries Management*, *40*(1), 29–47. https://doi.org/10.1002/nafm.10377

Wade, K. J., Shertzer, K. W., Craig, J. K., & Williams, E. H. (2023). Correlations in recruitment patterns of Atlantic reef fishes off the southeastern United States based on multi-decadal estimates from stock assessments. *Regional Studies in Marine Science*, *57*, 102736. https://doi.org/10.1016/j.rsma.2022.102736

Williams, E. H., & Shertzer, K. W. (2015). *Technical documentation of the Beaufort Assessment Model (BAM)*. https://doi.org/10.7289/V57M05W6

Wilson, J. R., Lomonico, S., Bradley, D., Sievanen, L., Dempsey, T., Bell, M., ... & Gleason, M. (2018). Adaptive comanagement to achieve climate-ready fisheries. *Conservation Letters*, *11*(6), e12452.

Zemeckis, D. R., Kneebone, J., Capizzano, C. W., Bochenek, E. A., Hoffman, W. S., Grothues, T. M., Mandelman, J. W., & Jensen, O. P. (2020). Discard mortality of black sea bass (Centropristis striata) in a deepwater recreational fishery off New Jersey: Role of swim bladder venting in reducing mortality. *Fishery Bulletin*, *118*(2), 105–119. https://doi.org/10.7755/FB.118.2.1

Zhang, Y., Goethel, D., Chen, Y. 2018. Welcome to the GoMRedSnapperMSE Project [online]. http://gomredsnappermsetool.fiu.edu

Tables

Table 1. Management procedure (MP) listed by name (left), species: black sea bass or cobia (center left), state of nature (center right), and description. The " under MP and Species columns indicates the same entry for subsequent cells below. Similarly, "…" indicates that the description is the same as above up to the additional language included.

Management Procedure	Species	State of Nature	Description
FSPR40	Black sea bass	Average recruitment	$F_{SPR40\%}$ with 13-inch rec. size limit (Figure 1) and average recruitment conditions
"	"	Recent recruitment	... recent recruitment conditions
"	"	Low recruitment	... low recruitment conditions
75FSPR40	"	Average recruitment	75% $F_{SPR40\%}$ with 13-inch recreational size limit (Figure 1) and average recruitment conditions
"	"	Recent recruitment	… recent recruitment conditions
"	"	Low recruitment	… low recruitment conditions
F0	"	Average recruitment	No fishing under average recruitment conditions
"	"	Recent recruitment	… recent recruitment conditions
"	"	Low recruitment	… low recruitment conditions
FSPR40_SL	"	Average recruitment	$F_{SPR40\%}$ with 11-inch rec. size limit (Figure 1) and average recruitment conditions
"	"	Recent recruitment	… recent recruitment conditions
"	"	Low recruitment	… low recruitment conditions
75FSPR40_SL	"	Average recruitment	75% $F_{SPR40\%}$ with 11-inch recreational size limit (Figure 1) and average recruitment conditions
"	"	Recent recruitment	… recent recruitment conditions

“	“	Low recruitment	…and low recruitment conditions
FSPR40	Cobia	M = 0.3	$F_{SPR40\%}$ with 36-inch recreational size limit (Figure 1) and M = 0.3
“	“	M = 0.4	…and M = 0.4
“	“	M = 0.5	…and M = 0.5
75FSPR40	“	M = 0.3	75% $F_{SPR40\%}$ with 36-inch recreational size limit (Figure 1) and M = 0.3
“	“	M = 0.4	…and M = 0.4
“	“	M = 0.5	…and M = 0.5
50FSPR40		M = 0.3	50% $F_{SPR40\%}$ with 36-inch recreational size limit (Figure 1) and M = 0.3
“	“	M = 0.4	…and M = 0.4
“	“	M = 0.5	…and M = 0.5
FSPR40_SL		M = 0.3	$F_{SPR40\%}$ with 33-inch recreational size limit (Figure 1) and M = 0.3
“	“	M = 0.4	…and M = 0.4
“	“	M = 0.5	…and M = 0.5
75FSPR40_SL		M = 0.3	75% $F_{SPR40\%}$ with 33-inch recreational size limit (Figure 1) and M = 0.3
“	“	M = 0.4	…and M = 0.4
“	“	M = 0.5	…and M = 0.5
50FSPR40_SL		M = 0.3	50% $F_{SPR40\%}$with 33-inch recreational size limit (Figure 1) and M = 0.3
“	“	M = 0.4	…and M = 0.4
“	“	M = 0.5	…and M = 0.5

Table 2. Table of partially operationalized objectives by stock: black sea bass and/or cobia; type of objective: conservation, commercial, and/or recreational; performance metric (PM), and equation by which the PM is obtained. All medians refer to the median value each year over 200 iterations. All PMs are relative, i.e., no weights were assigned in order to produce scores for each management procedure.

Objective	**Stock(s)**	**Type(s)**	**Performance metric**	**Equation**
Prevent overfished status	Black sea bass; Cobia	Conservation	Proportion of the median *SSB* that is greater than the MSST during the last 40 years of projections	$P(Median(SSB_y) > MSST)$
Maximize catch	Black sea bass; Cobia	Recreational (black sea bass; cobia); Commercial (cobia)	Median annual number of fish landed (catch) by fleet during the last 40 years of projections	$Median(C_{y,f})$
Reduce the number of dead discards	Black sea bass	Commercial; Recreational	Median annual number of fish discarded dead during the last 40 years of projections	$Median(D_y)$
Maximize season length	Black sea bass; Cobia	Recreational (black sea bass; cobia); Commercial (cobia)	Median annual relative CPUE by fleet during the last 40 years of projections	$Median(CPUE_{rel_{y,f}})$
Increase availability of large fish	Black sea bass; Cobia	Recreational	Proportion of the median annual population abundance that is larger than or equal to the minimum size limit (*MSL*) during the last 40 years of projections	$P(Median(N_y) \geq MSL)$

Figure Legends

Figure 1. Harvest control rule (HCR) and operating model (OM) selectivities. The HCR (left) is a visual representation of a control rule that allows a constant rate of fishing mortality (F) to continue up to some stock size (x-axis) threshold past which no fishing may occur. The OM selectivities for black sea bass (center) correspond to the logistic (asymptotic) or double-logistic (dome) selectivity patterns associated with the recreational minimum size limit: 13-inches (status quo) or 11-inches. The OM selectivities for cobia (right) correspond to the logistic (asymptotic) patterns associated with the recreational minimum size limit: 36-inches (status quo) or 33-inches.

Figure 2. Line plots of vital rates for black sea bass by state of nature (columns) and management procedure (lines)(MP) during the historical period (1990-2021) and projection period (2022-2071): median annual recruitment in numbers of fish (top), median annual abundance in numbers of fish (middle), and median annual spawning stock biomass in kilograms of mature weight (*SSB*) (low). The black line in *SSB* plots represents the minimum stock size threshold (MSST). States of nature include average recruitment (left), recent recruitment (center), and low recruitment (right). Uncertainty bands (grey) during the projection period (2022-2071) represent the 90th and 10th percentiles of results from 200 iterations of each operating model (OM) simulation. See Table 1 for a MP definitions.

Figure 3. Box plots for performance metrics (PM) for black sea bass by MP (boxes) and state of nature (x-axis): median recreational landings in numbers of fish over the last 40 years of the projection period (2032-2071) (top left); median commercial landings in numbers of fish over the last 40 years of the projection period (top center); median dead discards in numbers of fish over the last 40 years of the projection period (top right); median stock status relative to the minimum stock size threshold (MSST) during the last 40 years of the projection period (bottom left); median recreational relative catch per unit effort (CPUE) during the last 40 years of the projection period as a proxy for season length (bottom center); and the median proportion of fish as large or larger than the recreational minimum size limit in the population out of a total 1.0 during the last 40 years of the projection period (bottom right). The *F0* MP is not included in this plot because PMs are based on removals. See Table 1 for a MP definitions.

Figure 4. Spider plots of all black sea bass performance metrics (PM) by management procedure (MP) and state of nature. In a clockwise direction, PMs include recreational landings (RL), the proportion of abundance as larger or larger than the minimum size limit, i.e., “legal” (PL), the recreational season limit (RSL), stock status relative to the minimum stock size threshold (STST), the number of dead discards (DD), and commercial landings (CL). States of nature are average recruitment (left), recent recruitment (center), and low recruitment (right). The values represented by lines on each spider plot are the median of median values over 200 iterations of the last 40 years of the projection period (2032-2071). Percentages represent the fraction of the maximum median value of the MP over 200 iterations of the last 40 years of the projection period. See Table 1 for a MP definitions.

Figure 5. Line plots of vital rates for cobia by state of nature (columns) and management procedure (lines)(MP) during the historical period (1986-2017) and projection period (2018-2067): median annual recruitment in numbers of fish (top), median annual abundance in numbers

of fish (middle), and median annual spawning stock biomass in kilograms of mature weight (*SSB*) (low). The black line in *SSB* plots represents the minimum stock size threshold (MSST). States of nature include natural mortality (M) = 0.3 (left), 0.4 (center), and 0.5 (right). Uncertainty bands (grey) during the projection period represent the 90th and 10th percentiles of results from 200 iterations of each operating model (OM) simulation. See Table 1 for a MP definitions.

Figure 6. Box plots for performance metrics for cobia by MP (boxes) and state of nature (x-axis): median recreational landings in numbers of fish over the last 40 years of the projection period (2028-2067) (top left); median commercial landings in numbers of fish over the last 40 years of the projection period (top center); median stock status relative to the minimum stock size threshold (MSST) during the last 40 years of the projection period (top right); median recreational relative catch per unit effort (CPUE) during the last 40 years of the projection period as a proxy for season length (bottom left); median commercial relative CPUE during the last 40 years of the projection period as a proxy for season length (bottom center); and the median proportion of fish as large or larger than the recreational minimum size limit in the population out of a total 1.0 during the last 40 years of the projection period (bottom right). See Table 1 for a MP definitions.

Figure 7. Spider plots of all cobia performance metrics (PM) by management procedure (MP) and state of nature. In a clockwise direction, PMs include recreational landings (RL), the proportion of abundance as larger or larger than the minimum size limit, i.e., "legal" (PL), the commercial season length (CSL); the recreational season limit (RSL), stock status relative to the minimum stock size threshold (STST), and commercial landings (CL). States of nature are natural mortality (M) = 0.3 (left), 0.4 (center), and 0.5 (right). The values represented by lines on each spider plot are the median of median values over 200 iterations of the last 40 years of the projection period (2028-2067). Percentages represent the fraction of the maximum median value of the MP over 200 iterations of the last 40 years of the projection period. See Table 1 for a MP definitions.