Design of alternative management procedures (MPs) for black grouper fisheries: An exploration of MP viability and data limitations

Vania Henriquez, Peyton Moore, William Harford

Nature Analytics

551 Lakeshore Rd E, Suite 105, Mississauga,
Ontario, L5G 0A8

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EXECUTIVE SUMMARY

In this report, we propose a foundation for designing management procedure (MP) options for black grouper fisheries in the U.S. Southeastern Region. MPs arise from a 'procedural' paradigm that aims to integrate data collection, data analysis, and decision rules into a holistic process to support provision of catch advice. Our proposed foundation for design of MPs for black grouper fisheries is presented as a five-part information synthesis. In part one, we discuss the established uncertainties in data inputs, and delineate the strengths and weaknesses of current data streams as it relates to MP design. While catch histories are complicated by high degree of uncertainty, fishery-dependent and fishery-independent indices and length composition of the catch could remain viable data streams for MP design. In parts two and three, we provide a theoretical overview of MP types followed by highlighting four examples (domestically from the northeast US, and three international examples) for fisheries facing similar challenges to the black grouper fishery. In part four, we discuss how MPs can be subjected to scientific scrutiny, including a primer on a simulation-based form of policy analysis known as management strategy evaluation (MSE). Design of MPs is largely intertwined with testing using MSE because the 'procedural' paradigm emphasizes examining how well the interconnected parts of an MP will perform in meeting fishery management objectives prior to real-world implementation. In part five, we present a stepwise approach for navigating the complexities of MP design and for prioritizing a pathway most suitable to the U.S. Gulf of Mexico and South Atlantic. We conclude by proposing a series of next steps for decision-makers and stakeholders to consider, which are centered on three themes: science communication of the MP design process, constructing a preferred pathway to designing realistic MP options for the black grouper fishery, and conducting scientifically defensible testing of MPs using MSE.

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INTRODUCTION

Many fish stocks lack adequate data to determine current biomass despite the importance of this information in supporting the long-term sustainability of fisheries (Cope et al. 2023). These data can include catch-time series, indices of abundance, length and age composition, and life history parameters, which contain key information needed to evaluate population status (e.g., overfishing, overfished; Carruthers et al. 2014). But where data limitations persist, fisheries worldwide must address these challenges to proceed with decision-making (Dowling et al. 2023). Such challenges can be addressed through design and implementation of management procedures (MPs). An MP has components of data collection, data analysis, and a decision rule that work together in the provision of catch advice. An MP exists at this interface of science and policy, where design must confront challenges related to data quality and availability, robustness to ecological uncertainties, and practicalities related to implementation. While stock assessment models offer a quantitative foundation for management advice, absence of stock assessment need not hinder innovation towards tactical decision-making through alternative approaches, such as data-limited assessment or multi-indicator MPs (Newman et al. 2014).

Management procedures (MPs) arise from a ‘procedural’ paradigm that aims to understand how data collection, data analysis, and decision rules work holistically as a tactical decision-making framework (Bentley and Stokes 2009). Elements of MP design exist along a spectrum of complexity and nuance, where severity of data limitations is likely to form the basis of proposed solutions (Harford et al. 2021). At one extreme, fisheries lacking any data may implement some form of ‘data-less’ management action and establish a monitoring program that could later become the basis on an MP (Prince and Hordyk 2019). At the other extreme, an MP can be centered around conventional, fully integrated stock assessment. In between, MPs of intermediate complexity can be based on observations of the fishery system that are qualitative (e.g., 'good' or 'poor'), model-free (derived more-or-less from raw data) or model-based (based on simple demographic models or analytical approaches). These MPs of intermediate complexity can also integrate multiple sources of information in support of structured decision-making (Harford et al. 2021).

In this report, we propose a foundation for designing MP options for management of black grouper fisheries in the U.S. Southeastern Region (South Atlantic and Gulf of Mexico). Management of black grouper fisheries is complicated by high degree of uncertainty in data inputs, such as accuracy and precision of landings, indices, and catch rates, which have previously hindered stock status determination using traditional stock assessment (SEDAR 2017). In 2017, the Florida Fish and Wildlife Conservation Commission (FWC) was working on a stock assessment using Stock Synthesis (Methot and Wetzel 2013), but the assessment was suspended due to high uncertainty in landing records. Accordingly, we view addressing the challenge of decision-making in the face of high uncertainty as a research priority.

Our proposed foundation for design of MPs for black grouper fisheries is presented as a five-part information synthesis. In part one, we discuss the established uncertainties in data inputs, noting that delineating the strengths and weaknesses of data and corresponding analytical methods are crucial to MP design. In part two, we provide a theoretical overview of MP types, with emphasis on those expected to be suitable for black grouper fisheries management. In part three, we shift from theoretical to practical and highlight example MPs that have been applied to fisheries facing similar challenges to the black grouper fishery. In part four, we discuss how MPs can be subjected to scientific scrutiny, including a primer on a simulation-based form of policy analysis known as management strategy evaluation (MSE; Punt et al. 2016). Finally, given MP design criteria and means of testing using MSE, we present a stepwise approach to examining viability of MPs based on their data inputs, complexity, and their inherent trade-offs in effectively guiding decision-making toward achievement of fishery management objectives. Together, this five-part synthesis is aimed at illuminating a pathway to viable MP options that can support well-informed decision-making for black grouper fisheries of the U.S. Gulf of Mexico and South Atlantic.

PART 1. KEY UNCERTAINTIES IN DATA INPUTS FOR BLACK GROUPER FISHERIES MANAGEMENT

Fisheries management objectives and regulations

Management regulations for the South Atlantic Fishery

In the South Atlantic region, the black grouper fishery is managed by the South Atlantic Fishery Management Council under the Snapper-Grouper Fishery Management Plan (FMP) implemented in 1983. The Snapper-Grouper FMP comprises four main goals and several fishery objectives (https://safmc.net/fishery-management-plans/snapper-grouper/) that align with the National Standards to ensure sustainable and responsible fishery management as mandated by the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

The fishery goals and objectives of the Snapper-Grouper FMP are:

Goal 1 (Science): Management decisions for the snapper grouper fishery rely on robust science, using both qualitative and quantitative data analyzed promptly and transparently to build stakeholder confidence. This goal involves objectives such as improving data quality to support management plans, enhancing stakeholder collaboration on research, deepening understanding of the socio-economic aspects of the South Atlantic red snapper fishery, and strengthening monitoring and ecosystem-oriented data efforts for this fishery.

Goal 2 (Management): Implement strategies for the snapper grouper fishery that focus on rebuilding and conserving fish stocks, considering regional differences in the fishery and fishing communities' social and economic needs. The specific objectives of this goal involve developing management measures for the snapper grouper fishery that consider sub-regional differences, promote equitable access, enhance socio-economic benefits for all sectors, minimize discards, consider ecosystem and habitat factors in management measures, and support optimal sector allocations.

Goal 3 (Communication): Use interactive outreach strategies to encourage continuous engagement and support two-way communication between managers and stakeholders of the snapper grouper fishery, enhancing understanding of the science and management involved. This goal involves developing effective communication methods to increase stakeholder awareness and engagement, promote interaction with diverse audiences, enhance understanding of fisheries science and its impact on management, and improve understanding between socio-economic issues and fisheries management.

Goal 4 (Governance): Adopt a transparent, balanced, expeditious decision-making process that includes flexible but transparent protocols and strategies for managing the snapper grouper fishery. The specific objectives of this goal involve establishing an accountable and adaptive decision-making process for developing and evaluating management measures, building capacity to streamline management efforts and coordination with partners, and improving communication with stakeholders to ensure their needs are incorporated into the Council process.

Commercial fishermen must have a permit to fish, land, or sell black grouper. Managers limit the number of available permits to control the number of fishermen harvesting black grouper. The commercial fishery is managed based on minimum size limits (24 inches in total length) to reduce harvest of immature black grouper and with a commercial annual catch limit (ACL), which for the year 2024 was set at 96,844 lbs. of whole weight. The fishing year is from January 1 to December 31, with a seasonal closure between January 1 and April 30 to protect black grouper during their peak spawning period. Gear restrictions have been implemented to reduce bycatch and protect habitat. Commercial gear permitted includes hand lines, long lines, and diving. There are eight deep-water marine protected areas (MPAs) and five spawning special management zones (SMZs) to protect habitats (fishing is prohibited year-round).

The recreational fishery is managed based on a minimum size limit (24 inches in total length), aggregate limit (3 fish), and bag limit (1 fish), and no more than one black or gag grouper per person per day (not both). The aggregate limit means other grouper species can be retained along black grouper or gag (not both). When fishing for snapper-grouper species in South Atlantic Federal waters, the permitted gear includes vertical hook and line, including hand line and bandit gear, and spearfishing gear without rebreathers. Regulations are as follows: 1) Anglers must use a dehooking tool. 2) Non-stainless-steel hooks are required when using natural bait with hook-and-line gear. North of 28° N, circle hooks must be non-offset and non-stainless steel when using hook-and-line gear with natural baits. 3) All vessels must have a descending device attached to a minimum of 16 ounces of weight and 60 feet of line. Like commercial fisheries, recreational fisheries are closed from January 1 to April 30 during the peak of the spawning season. Since 1988, several amendments affecting black grouper have been incorporated into the South Atlantic Fishery Management Council FMP, affecting both commercial and recreational fisheries. These amendments include the prohibition of some fishing gear (e.g., trawls), changes in the depth where some gears are allowed to operate, changes in bag limits for recreational fisheries, changes in the minimum size limit, closing areas for conservation, etc. Recent amendments to the FMP (Amendment 53, 2021) established a recreational vessel limit for both gag and black grouper of 2 fish per day or two fish per trip, not to exceed the daily bag limit of 1 fish (either gag or black grouper) per person per day, whichever is more restrictive. The amendment also prohibits black grouper retention by captain and crew. The sector allocation of landings is 63.12% to the recreational sector and 36.88% to the commercial sector.

Management regulations for the Gulf of Mexico

In the Gulf of Mexico, black grouper are managed under the Reef Fish Fishery Management Plan implemented in 1984 (GMFMC 1984). The FMP guides the management of reef fish resources under the authority of the Gulf of Mexico Fishery Management Council. The plan considers reef fish resources throughout their range from Florida to Texas. The area regulated by the federal government under this plan is limited to the waters of the Fishery Conservation Zone (FCZ). The

FMP aims to (1) rebuild declining reef fish stocks, (2) establish a reporting system for monitoring, (3) conserve and enhance reef fish habitats, and (4) minimize conflicts among resource user groups. The fishery is currently managed under an Individual Fishing Quota (IFQ) program. Anyone commercially fishing for this species must possess an IFQ allocation and a reef fish permit and follow established protocols. The IFQ program allocates the commercial catch limit among shareholders, with measures to prevent fishermen from harvesting more than their individual allocation. In the Gulf of Mexico, the ACL is allocated between the commercial (76 %) and recreational (24 %) fishing sectors. Accountability measures (AMs) are triggered if ACL is exceeded. The commercial fishery is also managed based on a minimum size limit (24 in total length) to protect immature black grouper. Also, there are year-round and/or seasonal area closures for commercial and recreational sectors to protect spawning groupers. The recreational fishery is managed based on size limits and bag limits. The daily bag limit is four per person within 4 grouper aggregate. This fishery is closed during the spawning season (from February 1 through March 31) in deep water (greater than 120 feet) to protect spawning aggregations. Several amendments affecting black grouper have been incorporated into the Gulf of Mexico FMP, including gear prohibitions, possession limits, area closures, etc.

General data reliability considerations

Understanding your data is a necessary prerequisite for planning of management options (Newman et al. 2014). We reviewed life history parameters and fishery-dependent and fishery-independent data for black grouper to assess quality and main limitations. The quality of each data source varies depending on several factors, such as monitoring program design, sampling coverage, data collection, species misidentification, statistical records, time gaps, etc. Despite the identified limitations, there are several data sets that could be considered in the design of MPs. The data characteristics and limitations are outlined in Appendix 1. As an initial assessment of data quality, we used a traffic light representation (Table 1; Figure 1), with red reflecting poor data quality, yellow reflecting medium quality, and green indicating acceptable or good data quality. The criteria used to assign the different colors to data sets were based on the data review performed by the working group in SEDAR 48 (SEDAR 2017) and some additional limitations identified in this report.

Understanding the informative nature of data is critical for informing management actions and for prioritization of cost-effective monitoring programs (Magnusson and Hilborn 2007). Fisheries with well-developed MPs that integrate data collection, stock assessment, and decision rules tend to meet management objectives better than fisheries lacking such systems (Hilborn et al. 2020). The information contained in typical datasets used in stock assessments provides insights into the scale of the fishery and fish stock, cohort size, and relative changes in abundance over time (Magnusson and Hilborn 2007). Typical data needs for fisheries management include: i) biological data to provide information on size, age, growth, maturity and movement; ii) abundance indices to provide information on absolute or relative stock abundance; and iii) catch data to provide information on fishery removals, exploitation patterns and effort levels.

Catch-at-age data are considered highly informative because they contain cohort-specific information (Deriso 1980; Sun et al. 2020). Long-term data on catch-at-age indices, especially those that show significant temporal patterns, are particularly valued because they reflect population dynamics under different stock status (Magnusson and Hilborn 2007) and can provide information about changes in natural mortality (Maunder et al. 2023). In addition, size composition and life history traits play a critical role in providing biological information on growth, mortality, selectivity, and stock response to exploitation (Jennings et al. 1998).

The use of indices can be informative but also require scrutiny of inherent assumptions prior to use in an MP. For example, when we assume that CPUE is proportional to abundance, we also assume that catchability is constant over time. Catchability is influenced by several factors, such as fleet efficiency and management measures (quotas, size limits, and gear restrictions). In addition, CPUE measures the component of the population vulnerable to fishing gear. It may be proportional to that component of the population but not to the total population (Harley et al. 2001). Where necessary, CPUE standardization should be reviewed prior to use in an MP.

Black grouper data reliability

Life history parameters such as growth, length-weight, and maturity seem acceptable to use in designing MPs (Table 1). Some limitations remain, for example, the number of age samples for estimating growth parameters is relatively small. Also, the accuracy of age determination in older groups was unknown. Estimates of maturity parameters are based on data from 1994-1996. No recent studies are available to update these parameters. In addition, there are uncertainties in determining the age at 50% transition from female to male, mainly due low sample size and potentially insufficient representation of males in the sample (Crabtree and Bullock 1998). Accordingly, a medium quality (yellow light) was assigned to age/length at 50% transition from female to male. Natural mortality was derived from empirical approaches. No experimental (i.e., mark-recapture) estimates of M have been conducted for black grouper in the southeastern US, and neither informative composition data is available to estimate this parameter within the stock assessment. Therefore, M is likely subject to high uncertainty.

Population indices also appear reasonably reliable for use in MP design. Despite some limitations, the Reef fish Visual Census (RVC) survey could have utility as an abundance indicator. While it is a sub-adult survey and occurs in the center of the distribution, and therefore could be subject to hyperstability, this issue could potentially be navigated in MP design. The coefficients of variation (CVs) of the RVC survey are reasonable and are in the range of 0.086 to 0.208.

Two fishery-dependent indices appear useful as indicators of abundance. First, catch rates from the Marine Recreational Information Program (MRIP) of South Florida are available from 1981 to the present. However, the methodology of this survey was improved in 1991, with better data collection and better training of field samplers, resulting in more accurate species identification. Catch and effort were appropriately standardized to produce an abundance index that better reflects relative abundance by considering the other factors influencing catch rates. MRIP annual CVs range from 0.12 to 0.30. Second, the Southeast Regional Headboat Survey (SRHS) can also be used as a fishery-dependent abundance index. However, this index was initially based only on trips that landed black grouper in their distribution center, perhaps raising concerns about hyperstability. Like the MRIP survey of South Florida, the Southeast Regional Headboat Survey was standardized into two generalized linear sub-models: one to predict the probability of catching a black grouper and another to estimate the number of black grouper caught on successful trips. The annual CVs for the SRHS survey are reasonable, ranging from 0.10 to 0.23, except for 1990 (2.75). In 1990, only three trips were included in the analysis.

The length composition data from commercial fishery, beginning in 1986, appear useful as length-based indicators (e.g., mean length in catches). Some exploration of representativeness may be required, given small annual sample sizes; however, sample sizes from handline and longline length composition may be suitable to provide information on selectivity, changes in length-frequency as it relates to fishing mortality (e.g., Gedamke and Hoenig 2006) and potentially recruitment pulses (Rudd and Thorson 2017).

Commercial (from 1986) and recreational (from 1981) landings of black grouper are highly uncertain due to the misidentification of black grouper and gag (SEDAR 2017). This is one of the main reasons that the stock assessment has not been updated since 2010 (SEDAR 2010). Several methods have been used to correct species misidentification in recreational and commercial landings, but these model-based methods may also introduce estimation errors in these estimates of black grouper landings. Several adjustments (calibrations) have also been applied to recreational landings, primarily to improve the accuracy and consistency of recreational catch estimates provided by MRIP and to correct for species misidentification. Given the identified limitations in commercial and recreational landings, we recommend caution before including these as an indicator in MPs. Catches are not an indicator of fish abundance; however, catches may provide valuable information about fishery removals and exploitation patterns. Species misidentification in catches may introduce considerable uncertainty to the stock assessment model; however, the impact of this uncertainty can be tested against different MPs.

PART 2. REVIEW OF DATA-LIMITED AND INDICATOR-BASED MPS

Many fisheries worldwide do not have enough historical data, or the available information is insufficient to conduct conventional stock assessments and generate management advice (Costello et al. 2012; Geromont and Butterworth 2015; Carruthers and Hordyk 2018). Even when stock assessments are conducted, there is, in many cases, considerable uncertainty over population status and trajectory (Carruthers and Hordyk 2018). In such situations, we must face questions about how to achieve sustainable management without complex stock assessment (e.g., Geromont and Butterworth 2015) and how to align decision-making based on MPs with sustainability guidelines that are historically developed under the ‘stock assessment paradigm’ (Bentley and Stokes 2009). With these questions in mind, we conducted a literature review of MPs that fit within the bounds of the data limitations for black grouper fishery management, as described in Part 1.

Given a variety of data limitations, our review of available MPs focuses on indicator-based MPs. In a data-limited context, indicators are observations or estimates of the state of the fishery resource that are typically proxies for variables of interest, rather than quantities like stock biomass obtained from data-rich stock assessment (Harford et al. 2021). In this section, we begin by providing an overview of the components of an MP, followed by a description of MP usage within the context of U.S. fisheries management. We conclude by presenting a synthesis of MP types and design considerations centered on the use of indicator-based MPs. While we focus on indicator-based MPs to overcome limitations associated with problematic catch histories, we have not dismissed the potential importance of quantitative stock assessment (e.g., data-rich approaches) in black grouper fishery management and return to stock assessment-based MPs in Part 5 of the report.

Components of a management procedure

An MP consists of three parts: a monitoring program for data collection, a method of analysis yielding values of indicators, and a harvest control rule (HCR; Sainsbury et al. 2000; Butterworth 2007). The HCR is a pre-agreed decision rule that produces a recommended adjustment to a management measure, such as catch or effort limits, or fishing season length (e.g., Cadrin 2016). Accordingly, an HCR determines the frequency and magnitude of management responsiveness. Together, the inter-connected components of an MP are designed with the aim of achieving specific management objectives (Miller et al. 2019; Walter III et al. 2023).

U.S. fisheries management context

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) mandates annual catch limits (ACLs) for most federally managed fish stocks to prevent overfishing and achieve Optimum Yield (OY) while accounting for scientific and management uncertainty (Reuter et al. 2010). A typical approach to setting an ACL, often corresponding to the availability of a stock assessment, involves a three-step process: establishing an Overfishing Limit (OFL) based on the maximum sustainable fishing mortality rate (F_{MSY} or proxy), determining the Acceptable Biological Catch (ABC) that accounts for scientific uncertainty in the OFL estimate, and setting the ACL at or below the ABC, considering additional ecological, social, and economic factors as well as management control uncertainties (National Standard 1 - Optimum Yield 2022).

Reference points

National Standard 1 – Optimum Yield (NS1) defines criteria and describes fishery management approaches to meet the objectives of National Standard 1, including definitions of key quantities (National Standard 1 - Optimum Yield 2022). Reference points collectively refer to: Status Determination Criteria (SDC), maximum sustainable yield (MSY), OY, ABC and ACL. SDC means the measurable and objective factors including maximum fishing mortality threshold (MFMT), OFL, and minimum stock size threshold (MSST), and their proxies. To address NS1, Fishery Management Councils must include in their fishery management plan(s) descriptions of MSY, SDC, OY, and ABC control rule(s), among other elements.

The South Atlantic Fishery Management Council adopted benchmark proxies for the snappers and groupers in 1998 (Amendment 11) (SEDAR 2010). The MSY proxy for black grouper was defined as 30% SPR (Spawning Potential Ratio), and the MFMT was defined as $F_{30\%SPR}$ (SEDAR 2010). The MSST is 75% of the spawning biomass the produces MSY (SSB_{MSY}), and the OY has been defined as OY = ACL = ABC. Accountability measures (AMs) are triggered if the ACL is exceeded (or when the ACL is projected to be exceeded).

The Gulf Council used the same proxies for MSY and the same definitions of MFMT and MSST as the South Atlantic Fishery Management Council (GMFMC 2021). Because the last SEDAR stock assessment for black grouper could not be completed (SEDAR 2017), stock status is considered “unknown” and the GMFMC Scientific and Statistical Committee (SSC) provided management advice based on Tier 3a of the GMFMC ABC Control Rule. Accordingly, black grouper has an OFL for the combined Gulf and South Atlantic jurisdictions as mean recent landings plus two standard deviations.

Data-limited considerations

Data-limited fisheries are those with limited or insufficient data to conduct a conventional stock assessment, like the circumstances facing management of black grouper fisheries. In their synthesis of data-limited assessment of U.S. fisheries, Newman et al. (2014) reviewed 47 fisheries management plans. At the time of their review, Newman et al. (2014) noted that development of data-limited assessment was rapidly advancing; however, an absence of reliable catch histories precluded applications to numerous fisheries in the Gulf of Mexico and South Atlantic regions. In a more recent review, Free et al. (2023) reported that where HCRs are established for data-limited fisheries in the Gulf of Mexico and South Atlantic, they tend to be applied to fisheries with catch histories. Thus, developing data-limited approaches for stocks without reliable catch histories remains an ongoing challenge because catch histories are typically needed to calculate reference points such MSY, OY and MSST. To address this challenge, Newman et al. (2014) suggests that stocks without reference points (e.g., those lacking.) are likely to be amenable to indicator-based MPs, which utilize changes in indicators to adjust current catch advice relative to previous catch advice.

Within the scope of NS1, reference point estimation for data-limited fisheries has sometimes been addressed using simple demographic models, where catch histories inform the absolute scaling of quantities of interest. Given a catch history, these quantities of interest can include MSY or the vulnerable biomass that must have been available to sustain observed catches (MacCall 2009; Thorson and Cope 2015). While fisheries without reliable catch histories preclude the use of such simple demographic models, NS1 addresses this complication by allowing for the provision of alternative types of SDC:

> *When data are not available to specify SDCs based on MSY or MSY proxies, alternative types of SDCs that promote sustainability of the stock or stock complex can be used. For example, SDC could be based on recent average catch, fish densities derived from visual census surveys, length/weight frequencies, or other methods. In specifying SDC, a Council must provide an analysis of how the SDC were chosen and how they relate to reproductive potential of stocks of fish within the fishery. If alternative types of SDCs are used, the Council should explain how the approach will promote sustainability of the stock or stock complex on a long term basis.* (National Standard 1 - Optimum Yield 2022)

Accordingly, NS1 offers an alternative pathway to ABC calculation without the need to calculate conventional SDC. Newman et al. (2014) point out that data-limited methods have already been used to directly produce an ABC without specification of an OFL (i.e., OFL is a conventional SDC). For example, the South Atlantic Fisheries Management Council specifies ABC control rules based on severity of scientific uncertainty, with some tiers used to calculate ABC directly (Free et al. 2023 supplementary information). Both the South Atlantic Fisheries Management

Council and Gulf of Mexico Fishery Management Council utilize scientific uncertainty in their tier-based ABC control rules, with black grouper currently associated with Level 4 (designated an 'Only Reliable Catch Stock') and Tier 3a (OFL and ABC based on recent landings), respectively (Free et al. 2023 supplementary information).

Indicator-based management procedures

Indicators are derived from observations of a fishery system. The information provided by indicators about prevailing conditions is used within a pre-agreed decision rule (i.e., an HCR) to recommend adjustments to management measures. While indicators can be obtained from a conventional stock assessment, they can also be proxies for variables of interest obtained in the absence of stock assessment (Harford et al. 2021). Sometimes, indicators are classified as qualitative (e.g., 'good' or 'poor'), model-free (derived more-or-less from raw data), or model-based (based on simple demographic models or analytical approaches). Each of these indicator types can be paired with an HCR to adjust input or output controls, depending on whether the decision is based on effort limits or catch limits, respectively (Prince et al. 2008; Carruthers et al. 2014; Dowling et al. 2015).

Motivating examples

As a set of motivating examples, several single-indicator approaches are described below with additional details in Table 2. In each example, an indicator is paired with an HCR to adjust allowable catches (e.g., Apostolaki and Hillary 2009). As a first example, decisions can be based on average catch trends, with declines in average catch triggering reductions in catch limit, while conversely, the opposite may occur with increases in average catch trends. In a second but related example, catch trends can be replaced with a survey index or fishery-dependent index (e.g., catch-per-unit effort (CPUE)), where increases or decreases in the most recent survey index or CPUE relative to previous year(s) can trigger corresponding increases or decreases in a catch limit. In a third example, average length in the catch can inform catch limit adjustments. The average length in the catch reflects a fish stock's size-frequency distribution and usually its exploitation status. As fishing mortality increases, fewer fish can grow to larger sizes, preventing fish from growing to their full potential and thus affecting the overall average size of the catch (Gedamke and Hoenig 2006). Decreases in average length result in lower catch limits to protect the population, while increases allow for higher catch limits (Bellquist et al. 2022). However, this can be counterintuitive, as anomalously large recruitment events introduce many small fish into the population, lowering the average length. Because indicators can sometimes provide conflicting information, it is possible to integrate multiple indicators to respond to conflicts that arise at key decision points.

Pairing indicators with harvest control rules

The following section describes several generic approaches for pairing indicators with HCRs.

Constant catch

This is the simplest form of indicator-based MP. It involves setting a fixed catch limit, as described by Geromont and Butterworth (2015), where the reference catch level (Cref) is a constant value, often determined by averaging catches from previous years. This fixed catch limit can be scaled using a multiplier and may be maintained in the future or periodically reviewed and adjusted based on recent catch data (Carruthers et al. 2014, 2015; Fischer 2022). However, this MP is typically not recommended because of the lack of a feedback control mechanism (Newman et al. 2014).

Indicator adjusted catch

When data on a fish stock is limited, a variety of indicators of the fishery system can be utilized to modify catch advice. Unlike the constant catch approach, the five approaches described above allow for adjustments in catch advice based on an observed indicator (Jardim et al. 2015).

1) Stepwise adjustment: The catch advice is “stepped” up or down based on specific indicator thresholds (Carruthers et al. 2015; Fischer 2022). The approach was introduced by Jardim et al. (2015) and Geromont and Butterworth (2015). The two versions differ, but both follow similar concepts. In the approach of Geromont and Butterworth (2015), the catch limit will vary depending on a recent indicator value (I) (e.g., survey or CPUE) and conditional on upper (Iu) and lower (Il) reference values. So, the catch limit will increase by a proportion based on the previous catch when $I>Iu$, keep the same when $Il \leq I \leq Iu$, and decrease when $I<Il$. In the approach of Jardim et al. (2015), incremental changes are made to the catch limit in relation to recent changes in an indicator, which, in this case, is the mean length in catches. This stepwise adjustment MP was simulation-tested using a variety of life histories (i.e., pelagic, demersal and deep-sea stocks) (Jardim et al. 2015).

This MP aims to keep the indicator (e.g., index biomass or mean length in catches) between two reference values. The catch advice will increase only when the indicator exceeds the upper reference value. Using simulation testing, Jardim et al. (2015) found that the stepwise adjustment MP may help recover stock biomass, depending on how the upper and lower reference values are defined and if some gain/loss parameters are used to limit the increase of catch and reduce catch more when the indicator decline.

2) Indicator trend: Rather than modifying catch advice solely when an indicator crosses a threshold, this empirical MP uses the trend of the indicator to adjust the catch advice. In this MP, the slope from a linear or log-linear regression of an indicator (usually an abundance index) for several recent years is calculated. This slope is then used to define the magnitude and direction of a catch limit multiplier (Geromont and Butterworth 2014; Carruthers et al. 2015; Fischer 2022; Mosqueira et al. 2023). Slope-based MPs utilize the trend in a limited subset of data (typically the most recent 4 or 5 years of the index) for input. The catch advice is adjusted relative to the previous year, depending on whether the trend is positive or negative and its magnitude.

As an example, an interim MP based on a recent trend of commercial catch rate and survey indices was applied to the Namibian hake (*Merluccius capensis* and *M. paradoxus*) fishery (Butterworth and Geromont 2001). Cox and Kronlund (2008) tested an indicator trend MP for Sablefish (*Anoplopoma fimbria*) in British Columbia that included parameters weighting the influence of the previous catch and the indicator trend. Kurota et al. (2010) and Hillary et al. (2016) applied an indicator trend MP based on an abundance index for Southern bluefin tuna. Plaganyi et al. (2018) applied this approach to the lobster (*Panulirus ornatus*) fishery in

Australia using multiple indices and additional parameters weighting the influence of previous catch and the indicator trend.

The objective of this MP is to adjust the catch advice based on the index change over time (usually the last 5 years). This MP has different variants, but most aim to keep a constant relative abundance index and relatively stable catches (Geromont and Butterworth 2015; Anderson 2021). Jardim et al. (2015) recommend caution when using this MP since this indicator trend MP by itself may not recover depleted stocks.

3) Indicator target: Catch advice can be adjusted based on indicator values to move the resource abundance toward a prespecified target level for some abundance index (Carruthers et al. 2015; Fischer 2022). For example, the catch limit is adjusted yearly depending on whether the average of recent survey index values is above or below the target index value (Geromont and Butterworth 2015). In many cases, an X% limitation on the extent of interannual change in catch limit is imposed. The indicator target can also be in terms of length. In this case, the MP adjusts the catch limit to reach a target mean length in catches. For example, Jardim et al. (2015) applied this MP using the mean length in the catch as an indicator and defined the reference length based on simple life-history considerations.

Geromont and Butterworth (2015) applied a more complex formulation, including a tuning parameter to control the catch limit depending on the index status. Hoshino et al. (2020) used a similar MP formulation for skipjack and yellowfin tropical tuna in Indonesian archipelagic waters. Instead of calculating a catch limit, they calculated effort levels. Each year, the effort was adjusted up or down or unchanged from the previous year based on the recently observed CPUE or mean length, target CPUE or target mean length, and limit CPUE or limit mean length (Mosqueira et al. 2023). This MP aims to move the population index toward a target reference level or maintain it at some reference level. Catch advice will increase only if the indicator's recent value exceeds the reference level. This MP may help recover stock biomass (Jardim et al. 2015).

4) Indicator trend + target: This MP is a combination of indicator trend (slope) and indicator target. The CPUE rule is based on the recent slope of the survey index and the distance to the target index value (Kolody and Jumppanen 2019). This MP was originally developed for application to commercial CPUE indices in tuna fisheries. The catch limit is calculated using the slope of the index (sl) over the last five years and the difference between the current index value and the target value (D). Relative weights are assigned to the sl and D. This MP has been simulation-tested on bigeye tuna stocks from the Indian Ocean (Kolody and Jumppanen 2019). This MP aims to achieve a target index reference level. The catch advice will only increase if the current index is above the target index reference level and the trend is increasing. This MP can be more robust than using the indicator trend MP alone.

5) *Indicator ratio*: This MP adjusts the catch recommendations based on survey index values. It calculates a ratio (a) by dividing the mean survey index from the last two years by the denominator, which is the mean index from the three (or five) years prior. This ratio indicates whether the survey index has increased or decreased. The resulting ratio is then multiplied by the previous year's catch to generate a new catch recommendation (ICES 2012; Jardim et al. 2015).

A demonstration of this management plan was simulated for Western Atlantic skipjack tuna (Huynh et al. 2020). We also provide an additional example based on rex sole from British Columbia (Anderson 2021). This MP aims to determine whether the index has increased or decreased and adjust changes in catch advice based on changes in the index over time. This MP seeks to keep biomass at stable levels.

Multi-indicator management procedures

Multi-indicator MPs are those where multiple sources of monitoring data (e.g., biomass survey index, CPUE, or even mean size) are interpreted together and integrated within a structured decision framework. They can be structured to use different indicators in aggregate (Caddy 1999, 2002) or sequentially (Wilson et al. 2010; Prince et al. 2011). Multi-indicator approaches may be recommended when individual indicators provide different information or contrasting signals so that various indicators may clarify the information provided by a primary indicator. For example, contrasting signals can occur when an increase in CPUE occurs (suggesting abundance increase or fishing power increase) along with a decrease in mean length (suggesting increased fishing mortality or strong recruitment pulse). A multi-indicator MP designed to respond to these circumstances could resolve decision paralysis. Likewise, moving beyond single-indicator approaches may be necessary to avoid overreliance on indicators that are weakly informative or limited in scope (Harford et al. 2021). Among the design consideration involved in developing multi-indicator MPs, stakeholders and decision-makers must confront information availability with respect to management objectives, funding, capability to obtain additional information, and research capacity (Harford et al. 2021). Additionally, multi-indicator MPs present opportunities to align decision-making frameworks with local and customary practices, including incorporation of local expert knowledge (Plagányi et al. 2020).

PART 3. EXAMPLE MANAGEMENT PROCEDURES FROM OTHER FISHERIES

This section presents case studies from the US, Europe, Australia, and Canada illustrating the application or proposed implementation of indicator-based MPs. The first example is Thorny Skate (*Amblyraja radiata*) from the Gulf of Maine, USA. The New England Fishery Management Council manages this species, which, due to data limitations, lacks a quantitative stock assessment. The index of relative abundance determines the stock status, and the ABC is set using an empirical catch-based rule adjusted to account for management risks and uncertainties (NEFMC 2022). See a detailed explanation in Figures 2 and 3.

The second example is Plaice (*Pleuronectes platessa*), managed by ICES divisions 7.h–k (Celtic Sea South, southwest of Ireland). This is a data-limited stock without stock assessment. There are significant data uncertainties, especially regarding discards before 2004. Catch advice for this stock is adjusted based on various factors, such as recent survey indices, changes in average catch length, and precautionary multipliers to ensure biomass sustainability (ICES 2022) (Figures 4 and 5).

The third example illustrates the management of the spanner crab (*Ranina ranina*) in Queensland, Australia (State of Queensland 2020). The spanner crab stock is data-limited and lacks sufficient data for a comprehensive stock assessment. Management relies on indicator-based rules to provide catch advice, using two main indicators: commercial CPUE and a fishery-independent survey. This MP has been subjected to Management Strategy Evaluation (MSE). Catch advice adjustments are based on a pooled index (CPUE and survey), with specific rules for increasing or decreasing catch advice based on year-over-year changes in the index. There are specific rules for area closures and maintaining current conditions (i.e., no change in catch advice). See a detailed explanation in Figures 6 and 7.

The last example is based on rex sole (*Glyptocephalus zachirus*) from British Columbia. Rex sole, like most stocks in the groundfish fishery, is considered data-limited, with significant uncertainties, especially regarding historical catches, before implementing the 100% at-sea observer program. This limits the ability to conduct traditional assessment methods. A simulation-tested management procedure framework has been tested for data-limited stocks like rex sole, focusing on maintaining stock levels above the Limit Reference Point (LRP) to ensure sustainability. The study explored several MPs, including indicator-based MPs such as index-ratio, index-slope, and index-target MPs (Anderson 2021). Although the MP approach has been demonstrated using rex sole as a case study, it has not yet been implemented to provide actual catch advice. This method aims to improve the ability of the Department of Fisheries and Oceans Canada (DFO) to offer evidence-based catch advice despite the prevalent data limitations. For details, see Figures 8 and 9.

PART 4. A PRIMER ON MANAGEMENT STRATEGY EVALUATION

What is Management Strategy Evaluation (MSE)?

Management Strategy Evaluation (MSE), also referred to as evaluation of Management Procedures (MPs) (Butterworth 2007, 2008), is a simulation testing process that mimics the dynamics of an exploited stock and the behavior of the fishery (including data collection and analysis). MSE is used to explore the effectiveness of various MPs in achieving fishery management objectives under different scenarios representing key uncertainties (Holland 2010; Punt et al. 2016). The MSE approach uses detailed fishery data to create various operating models (OMs) that simulate different plausible scenarios about the fishery and fish population dynamics. Robustness is an essential facet of interpreting performance of an MP. A simulated MP that produces satisfactory achievement of objectives across multiple scenarios is considered to be robust to key uncertainties and is preferable to an MP that produces optimal achievement of objectives if a particular scenario is true (Smith 1994; Rademeyer et al. 2007).

MSE facilitates management planning and enables a better understanding of the trade-offs and outcomes of different MPs, ideally leading to selection of an MP that suitably balances achievement of each fishery objective (Walter III et al. 2023). MSE allows MPs to be designed and tested before real-world implementation to ensure their effectiveness and mitigate potential risks. Also, MSE provides transparency in the management system because it involves dialogue between scientists, managers, and stakeholders, and because an MP is a pre-agreed process for decision-making, so stakeholders know what to expect (Butterworth 2007).

What are the steps involved in conducting MSE?

The guidelines for MSE best practices recommend taking the following steps (Figure 10) when conducting MSE and identifying a suitable MP for use in fishery management (modified from Punt et al. 2016):

1. Identification of objectives and performance metrics: Fishery management objectives and quantifiable performance metrics need to be defined before starting the MSE process. Objectives need to be made measurable, with timelines for achievement and stated levels of acceptable risk or performance. Example performance metrics include the probability of stock being overfished, the probability of avoiding the lower limit reference point, inter-annual variation in catch.

2. Identification of key uncertainties: Key uncertainties are those thought to have potentially important influences on the performance of MPs. For example, uncertainties in population dynamics and historical catch trends, bias and precision in monitoring data, uncertainties in management implementation, etc. MSE can be used to evaluate whether a reduction in uncertainties is useful, for instance, comparing high and low precision monitoring programs, and can help understand how to cope and make good decisions in the face of uncertainty.

3. Specification of operating models (OMs): OMs represent the fish population dynamics, fishery characteristics, data collection, and the precision with which management tactics are implemented.

4. Selection of parameters: These are the parameters used to parameterize the OMs. In this step, the task is to focus on the possible range of biological and fishery parameters (parameter distribution) and their representation in OMs. Some examples of parameters include growth parameters, natural mortality, catchability, etc.

5. Identification of candidate management procedures (MPs): MPs can be model-based or empirical. Model-based MPs incorporate stock assessment models that explicitly estimate population and fishing dynamics. Empirical MPs are simpler algorithms that provide management advice from streamlined data, such as a single index of abundance (Carruthers et al. 2023). MPs consist of two or three parts: the monitoring program (data generation from the OM), the estimation model (if model-based), and a Harvest Control Rule (HCR). Candidate MPs that could realistically be implemented should be identified in this step.

6. Simulation of the application of the MSE: An MSE can be conducted once OMs are designed and various candidate MPs are selected. Each OM configuration is simulated against each candidate MP.

7. Presentation of MPs: Results must be presented with graphics and tables summarizing the information clearly. This should enable stakeholders (particularly decision-makers) to compare the MPs and evaluate which one best balance management objectives. In this step, the performance of the MPs is compared against the different OM scenarios using the performance metrics.

8. Refinement, as needed, and selection of an MP: Conducting MSE in conjunction with engagement of interested parties like stakeholders and decision-makers can be an iterative process. That is, each of several MPs is typically contrasted against each of several OMs. While the purpose is to find (and hopefully implement) an MP that work acceptably across most OMs, performance differences between MPs can be nuanced and require trading-off between desirable outcomes of fishery management. Thus, refinement and further testing could be necessary. Alternatively, or following subsequent refinement, stakeholders and managers could select an

MP. Ideally, this selection is based on comparing performance metrics, defined in step 1, among the candidate MPs. The performance metrics used in these comparisons must be meaningful to all stakeholders to ensure that the selected MPs are well-suited to achieve fishery management goals.

9. Implementation of an MP: After selecting an MP, the process is followed by the practical application to provide catch advice for fishery management.

The somewhat technical details of MSE

Conducting an analysis using MSE typically consists of constructing several interconnected simulation components: population dynamics, data collection, data analysis and stock assessment (which can be present or not), an HCR or decision-rule that specifies management adjustment (e.g., catch advice), and imperfect implementation of that management action (Holland 2010). The approach simulates the fishery and stock condition, simulated sampling to mimic the imprecision and bias of catches and various data collection programs (fishery-dependent and fishery-independent data). These data are passed to the data analysis or assessment model, or directly to the HCR when there is no data analysis. The HCR is then used to calculate the catch advice. Importantly, MSE then simulates the implementation of the catch advice. The simulated fishery takes up this catch advice (either precisely or imprecisely), fishes accordingly during the next year of the simulation, thus creating a feedback loop between the catch advice and subsequent effects on fishery, stock condition, and observation of changes by way of simulated data collection.

Analysts involved in conducting MSE use a more technical set of descriptors of simulation components, with the most common components being operating model (OM), performance metrics, and the previously defined management procedure (MP) Figure 11. The OM is a mathematical model used to simulate and describe the biological and fishery components of the system in simulation trials. It represents the possible underlying dynamics of the resource (Butterworth et al. 2010). The OM simulates the main uncertainties in the system (e.g., growth, maturity, M, selectivity, etc.). Each OM represents a possible combination of hypotheses of how the real system works. During the MSE process, multiple OMs are typically considered to reflect the key uncertainties about the dynamic of the resource and the fishery, these OMs are called reference OMs (Rademeyer et al. 2007). In addition, OMs for robustness tests are designed to determine if the MPs behave as expected under scenarios that are unlikely but still plausible (Punt et al. 2016).

OMs can be data-conditioned (fitted to the data as an assessment model) or models that reconstruct observed population and fishery patterns (not fitted to the data) (Punt et al. 2016). Conditioning or reconstruction may be difficult for data limited MSE. Nevertheless, multiple plausible scenarios or potential states of nature must be constructed thoughtfully, facilitating understanding of the risks and probabilities of achieving management goals for various MPs despite incomplete knowledge of population dynamics or removal levels (Carruthers and Hordyk 2018; Goethel et al. 2019). MPs for data-limited fisheries should not be based only on expert judgment (Butterworth et al. 2010). Likewise, MSE can be used to inform improvement of data collection by helping to identify when and where data can be informative to support design of novel data collection initiatives linked to decision-rules (Harford and Babcock 2016; Carruthers et al. 2023).

An additional core subcomponent to an OM is called the observation model, which simulates imperfect resource monitoring data with the same error structure that would be available in practice (including the effect of measurement error). The data generated (fishery-dependent and/or fishery-independent monitoring data) by the observation model subcomponent are fed into the MP. The OM also has another subcomponent called the implementation model, which reflects the degree to which regulations are imperfectly implemented in practice (Rademeyer et al. 2007).

The performance of each MP is evaluated by simulation. This is accomplished by projecting biomass forward under the prescribed HCR over a defined period. Performance is evaluated by inspecting performance metrics (e.g., probability of overfishing, probability of overfished, annual variability in catch) developed as measurable criteria for the achievement of management objectives (Rademeyer et al. 2007). Importantly, because MSE is used to simulate the 'true' dynamics of a fishery, we know all the details about a fish stock even if we cannot, in reality, measure those details. Thus, performance metrics can pertain to quantities that cannot, in reality, be directly observed (or estimated in the absence of a stock assessment), such as status determination criteria (e.g., MFMT, OFL, MSST, MSY), stock biomass, or 'true' yields in the case of unknown catch histories.

Comparing MSE with traditional stock assessment projections

Stock assessment and MPs are crucial in fisheries management but play different roles (Table 3). They are sometimes referred to as different paradigms because they are different ways of *thinking* about decision-making in fisheries management (Bentley and Stokes 2009). Likewise, stock assessment and MPs have been described as differing "*in the way science advice is delivered"* (Anderson 2021). The stock assessment paradigm largely emphasizes tactical catch advice that is the *product* of estimation of stock status and corresponding reference points (Bentley and Stokes 2009). The MP paradigm, which is closely intertwined with the use of MSE, aims to identify MPs that are robust to key system uncertainties in achieving fisheries management objectives. Thus, the MP paradigm is not aimed at providing catch advice *per se*, but instead is focused on the *strategic process* of providing science advice with the product of a well-designed process being catch advice. The intertwined nature of the MP paradigm with the use of MSE is a principal reason that we provided a primer on MSE (see above).

Stock assessments typically produce catch advice in form of decision tables, where probabilities of compromising reference points are presented against alternative future catch levels (Anderson 2021). Uncertainty can be incorporated using a 'best assessment model' with inclusion of model parameters as random variables and/or considering multiple models along with sensitivity analyses (Anderson 2021). Consideration of risks occurs when decision-makers select among catch level options, based on their risk tolerances, sometimes without transparency about how the decision is related to agreed-upon objectives (Anderson 2021). Robustness to key system uncertainties of repeated tactical advice (e.g., catch advice provided annually or every few years) may remain unknown since there is no explicit testing of the recursive decision-making that occurs each time data sets and stock assessments are updated.

Conversely, the MP paradigm, especially when intertwined with testing via MSE, emphasizes the strategic process of decision-making (Bentley and Stokes 2009). Consideration of risk tolerance and probabilities of achieving management objectives are considered part of the process of designing an MP. Using MSE, the performance of MPs can be evaluated relative to any reference point that can be obtained or calculated from the ‘true’ simulated stock dynamics. Reference points and stock status remain integral to constructing an MP but are built into performance metrics that are calculated during testing using MSE. When an MP is selected and is implemented (in reality), provision of tactical catch advice does not explicitly require reporting probabilities of compromising reference points (Anderson 2021). Expected achievement of objectives over pre-defined time horizons are ‘baked-in’ to the tactical catch advice provided by the MP (Anderson 2021). We accept that expected achievement of objectives are ‘baked-in’ to the tactical catch because we have observed so through simulation testing. The MP paradigm leads to some important practicalities too, especially given that many reference points (e.g., MSY, OFL and MSST) cannot be reliably estimated for data-limited stocks. For example, MSE allows us to examine how the fishery system is expected to respond under a given MP even where quantities like MSY or OFL are not available during provision of catch advice.

PART 5. VIABLE PATHWAYS TOWARDS BLACK GROUPER MPS

Towards MP design

MPs depend and rely on the “best available information” for the provision of catch advice. Often, fisheries are classified depending on data availability; for example, many countries adopt a tiered approach (e.g., Australia, the US, and European countries) based on data availability and quality. The management strategy depends on the data's amount and reliability, which defines how precautionary the management decision should be.

We propose a stepwise approach structured into four progressive stages to consider a design pathway for MP evaluation across varying data availability and levels of analytical complexity (Figure 12). This framework starts with limited data at the initial level (top), illustrating the current management circumstances and progressively moves to alternative MP options (downward) using currently available data, improved data reliability, or combination thereof (bottom). The stepwise approach emphasizes indicators that could be used to transition away from status quo catch-only methods. A similar approach has been implemented for the sea cucumber fishery in Australia (Plagányi et al. 2020), which has motivated improvements in data collection to support fishery management.

The first box in Figure 12, at the top of the stepwise approach, represents the current approach for catch advice. At this level, there is no stock assessment, and no indicators are used in setting catch advice. Therefore, the MP relies on basic data such as previous catch advice, and expert judgement to set precautionary catch limits, in addition to size limits and gear restrictions.

The second box in Figure 12, titled "What can we achieve with current data?" is still a data-limited approach. However, it could be more robust than the status quo since it uses simple indicators already available to inform the decision rule and provide catch advice, rather than a catch only method (Sagarese et al. 2018). This strategy promotes enhancing MPs by making better use of available data. Several potential MPs can be tested and compared in this section.

For example, single-indicator or multi-indicator-based MPs, such as stepwise adjustment, indicator trend (slope), indicator target, and indicator target + trend, could be evaluated using information contained in the RVC, MRIP, and SRHS indices. Also, the mean length-in-catch data could be used as a proxy for fishing pressure. In this step, we mostly exclude model-based MPs since we assumed the information in catch data is still unreliable.

The third box in Figure 12, titled "What can we achieve with improved catch and indices' reliability?" could help the fishery move forward to a more sophisticated approach. In this section, indicator and multi-indicator MPs can still be tested, but improved data reliability in catch data and indices could support the use of simple demographic models or stock assessments and, therefore, move to a model-based MP, using a simple model such as a surplus production or stock reduction analysis.

The final box in Figure 12, titled "How do we design and prioritize a pathway forward"? expresses a framework of explicitly evaluating whether and how improvements in data collection and reliability could improve achievement of fishery management objectives. Improvement in data reliability, particularly composition data (ages and/or lengths), catch data, and abundance indices, would allow the implementation of age-structured assessment models and, therefore, the design and testing of several MPs, such as model-based or MPs-based on the stock assessment. This also could be an opportunity to evaluate the robustness of MPs by assessing how well MPs of varying complexity perform under alternative OMs. This approach involves simulation-testing under the MSE approach, promoting stakeholder engagement and adherence to management recommendations. This MSE approach also offers the advantage of assessing the value of information (VoI), evaluating the costs and benefits of new data collection, determining how improvement in data collection could be prioritized, and determining the benefit of improving data reliability. This structured, progressive approach could enhance fishery sustainable management and improve transparency in the decision rule and adaptability to new MPs as new or better information becomes available.

The Value of Information (VoI) quantifies the benefit of gaining specific new knowledge. It is commonly calculated in economic terms but also can encompass other quantitative metrics (Mäntyniemi et al. 2009). In fisheries management, particularly in MSE and structured decision analysis, the VoI can be used to evaluate the gains expected from having better information (Hilborn and Walters 1992). For example, the expected maximum increase in fisheries yields if we have better information and implement the best management action using it. Furthermore, the VoI can demonstrate the value of investing in research and adaptive policies. It shows how acting on new knowledge can be expected to yield benefits, thereby emphasizing the crucial role of research in improving decision-making in fisheries management.

The MSE approach allows us to evaluate how increasing data collection investments may increase the performance of candidate MPs. We can also evaluate which data sets are more valuable or whether we can achieve the same performance with a specific MP using fewer data. The previous statement applies equally to both data-limited MPs and data-rich MPs. It follows then, that data quantity and quality are interconnected with complexity of analysis or stock assessment. As we noted earlier, the MP paradigm and the stock assessment paradigm represent different ways in which scientific advice is delivered. However, there is a middle ground that consists of integrating both approaches. For example, when a conventional stock assessment forms a component of an MP, linked to the harvest control rule, such a data-rich MP can be subject to performance testing using MSE (Harford et al. 2018). Specifically, for black grouper fisheries, this means that testing the effect of more precise survey indices, the improvement in the reliability of catch data, or the value of length and/or age data collections allows comparisons of simpler indicator-based MPs to more complex MPs aligned with conventional stock assessment.

Organization and suitability of data inputs

In Part 1 of this report, a summary of uncertainties in data inputs was provided. We now return to these data inputs from the perspective of MP design. A series of steps for developing MPs based on indicators is outlined in Harford et al. (2021). Here, we focus on the first step from Harford et al. (2021): identifying indicators (including those used successfully in other fisheries), with emphasis on the sub-steps of *getting organized* and *confronting indicator suitability*. Getting organized refers to categorization of indicators according to elements of a fishery system, such as the fish stock, the fishery, and related socio-economic factors. Getting organized also promotes discussion about which indicators are likely most proximate to variables of direct interest (e.g., survey index as a proxy for spawning biomass) (Halliday et al. 2001). Confronting indicator suitability addresses the extent to which indicators can be linked to management objectives, and the extent to which the reliability of indictors can be validated. Below, we return to the data streams listed in Table 1 and provide a preliminary attempt at getting organized and confronting indicator suitability.

Life history

Where life history parameters are used in MPs, such as inputs to simple demographic models or conventional stock assessment, these inputs are clearly related to the fish stock. Our review did not reveal any substantive reasons to question life history reliability, although no recent studies are available to update life history parameters. Natural mortality and steepness of the stock-recruitment relationship are considered uncertain. As validation is unlikely, MSE can be used to create contrasts between the life history parameter values used in OMs and those specified (or misspecified) in MPs. Thus, robustness of MPs to poor reliability of life history parameters can be tested through simulation.

Catch

Catches are an element of the fishery and are the most uncertain data stream. Commercial and recreational landings of black grouper are highly uncertain because they are often misidentified as gag (SEDAR 2017). It appears highly unlikely that catch histories can be used in delineating reference points such as MSY, OY and OFL, given the importance of accurate catch histories as a scaling quantity needed for reference point estimation. Thus, by extension, the suitability of catches to inform management objectives is low. In terms of constructing more complex MPs that may require catch histories and/or recent catches, OM specification can focus on scenarios about the degree of bias in landings data to identify the potential extent to which landings accuracy needs to be improved before satisfactory management outcomes can be achieved.

Catch composition

Length composition of the catch is an element of the fishery, which can be used to infer rates of fishing mortality and spawning potential of the stock (Hordyk et al. 2016; Harford et al. 2016). Some challenges persist in the use of length composition for long-lived species, as length-frequency may lag behind more rapid changes in biomass and fishing mortality. Length composition may be better suited as a 'slow indicator' tracking longer-term trajectories towards target reference points (Hordyk et al. 2015; Harford 2020; ICES 2022). To the extent possible, validation should consider the spatial distribution of the fleet relative to the spatial distribution of the adult stock to ensure representative sampling of the adult stock.

Population indices

Population indices (fishery-independent and fishery-dependent indices) are an element of the fish stock. As proxies for a given sub-component of fish stock (e.g., adult or sub-adult components), all identified indices appear to have reasonable precision, but the possibility of hyperstability was identified given the geographic extent of sampling. While it is unlikely to validate questions about hyperstability, these limitations can be assessed by designing alternative OM scenarios about index hyperstability and evaluating the use of such indices in MPs. In terms of utilizing indices in MPs, the fact that the fishery-independent survey observes only a subadult component of the population could be addressed by incorporating a lag of *N* years to inform potential cohort size within the design of decision-rules. Further, the fishery-independent index and standardized CPUE time series can potentially be used as indicators in combination with other indicators that provide additional information. For example, length information can be used to improve the interpretation of indices.

NEXT STEPS

In this report, we propose a foundation for designing MP options for black grouper fisheries given the high degree of uncertainty in the accuracy of catches. By outlining examples of indicator-based MPs, highlighting MSE as a means of testing prior to real-world implementation, and providing a stepwise pathway to MP design, we have begun to address the challenges of decision-making for the black grouper fishery. A task remains to consider the most suitable next steps. Below we outline our view on possible next steps which center on three themes: science communication of MP framework and process, constructing a preferred pathway to designing realistic MP options, and conducting scientifically defensible testing of MPs using MSE.

We suggest that a logical next step is to encourage communication related to designing and testing of MPs. We have initiated this step by providing non-technical companion materials to supplement this report. Engaging with stakeholders and decision-makers is desirable for a variety of reasons, including the following two. First, MPs that rely on indicators must be understandable and designed to ensure that information is accessible to user groups involved in policy and decision-making (Garcia and Staples 2000). Second, testing of MPs through MSE creates an opportunity for transparency. Not all MPs will achieve the same balance between performance metrics, thus engagement provides a platform for discovering whether management options are palatable to stakeholders and decision-makers, and promotes dialogue with scientists (Cooke 1999; Cox et al. 2013; Pilling et al. 2016; Punt 2017).

We also suggest that dialogue related to a pathway towards MP design is a priority. In Part 5, we proposed a stepwise approach to considering MP design in relation to varying data availability and levels of analytical complexity (Figure 12). This approach identifies four progressive stages akin to entry points into discussion and design of MPs for black grouper. For example, prioritizing MP design under the theme of "What can we achieve with current data?" could promote exploration of MP options that make best use of currently available data. Conversely, prioritizing MP design under the theme of "What can we achieve with improved catch and indices' reliability?" could promote exploration of MP options that include demographic or conventional stock assessment models, possibly including analysis of value of information to understand expected gains (or not) from having better information (Hilborn and Walters 1992). None of these ideas are mutually exclusive, thus it is useful to prioritize a preferred entrée to MP design for black grouper. This 'next step' could serve as a valuable scoping exercise for scientists to better understand the priorities as directed by advisory bodies like Scientific and Statistical Committees (SSCs) and direction from the Councils themselves.

Finally, we suggest considering whether to conduct an MSE to examine MP options for the black grouper fisheries of the Gulf of Mexico and South Atlantic regions. Conducting MSE requires completing a complex set of tasks, thus we suggest compartmentalizing these tasks and recommend beginning with development of operating models (OMs). Developing OMs will require technical expertise in translating life history information, fishery characteristics, and monitoring programs into a suitable simulation of the fishery system. This task must emphasize translation of key uncertainties into discrete model configurations and parameter ranges, or likely, both. The expected outcome of developing OMs should be a reasonably realistic representation of the black grouper fishery system, including alternative OM configurations representing key uncertainties most likely to influence the performance of MP options.

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TABLES AND FIGURES

Table 1. Categorization and reliability of the available data. The green circle represents good or acceptable quality; the yellow circle represents medium quality, and the red circle represents bad quality. This classification is based on the information provided in the data review and limitation section.

Data	**Description**	**Data category**	**Data reliability**
A50%	Age at 50% maturity	Life history	green circle
L50%	Length at 50% maturity	Life history	green circle
M	Natural mortality	Life history	yellow circle
Linf	Asymptotic length in VBGF	Life history	green circle
K	Growth parameter in VBGF	Life history	green circle
t0	Age at zero length in VBGF	Life history	green circle
a	Parameter *a* in weight–length relationship	Life history	green circle
b	Parameter *b* in weight–length relationship	Life history	green circle
A50% transition	Age at 50% of transition	Life history	yellow circle
L50% transition	Length at 50% of transition	Life history	yellow circle
Ct	Commercial landings	Catch	red circle
Crt	Recreational landings	Catch	red circle
CAL	Commercial length samples	Catch composition	yellow circle
Reef Fish Visual Census (RVC)	Fishery independent survey (sub-adults)	Population indices	green circle
MRIP (South Atlantic)	Fishery dependent survey	Population indices	green circle
Southeast Regional Headboat Survey (SRHS)	Fishery dependent survey	Population indices	green circle

Table 2. Summary of the most typical indicators of fishery status used to inform indicator-based MPs.

Indicator of fishery status	Interpretation	Examples
Survey index	Increase or decrease in survey index may indicate an increase or decrease in fish abundance	-Australia sea cucumber fishery (Plagányi et al. 2020) -Sole (Solea solea) (ICES 2023)
Fishery catch rates (CPUE)	An increase or decrease in CPUE may indicate an increase or decrease in abundance or increase or decrease in fishing power	-Belize spiny lobster (*Panulirus argus*) and Queen conch (*Strombus gigas*) (Harford et al. 2016) -South Africa toothfish (*Dissostichus eleginoides*) (Brandao and Butterworth 2009) -Spanner crab (*Ranina ranina)* (State of Queensland 2020)
Average length in the catch	Decrease in mean length in the catch may indicate an increase in fishing mortality but also may indicate a strong recruitment	- Belize spiny (*Panulirus argus*) (Harford et al. 2016) -South Africa toothfish (*Dissostichus eleginoides*) (Brandao and Butterworth 2009) -Sub-Antarctic toothfish (*Dissotichus eleginoides*) (Butterworth et al. 2010) - Australia sea cucumber fishery (Plagányi et al. 2020)
Catches	Recent mean catch (last 5 years) or reference mean catch are used to achieve a stable catch or a historical target	-Belize spiny lobster (*Panulirus argus*) and Queen conch (*Strombus gigas*) (Harford et al 2016) -Thorny skate (*Amblyraja radiata*) (NEFMC 2022). - Australia sea cucumber fishery (Plagányi et al. 2020)
LBSPR (Length based spawning potential ratio)	Indicator of stock status (LBSPR < 0.4 indicates overfished status)	-California red abalone (*Haliotis rufescens*) (Hordyk et al. 2016; Harford 2020)
Pmat: Proportion of fish in catch that are mature Popt: Proportion of fish caught that are within 10% of Lopt Pmega: Proportion of fish caught that are mega-spawners Pobj: Sum of Pmat, Popt, and Pmega	Indicator of stock status - Pmat < 1 indicates immature fish being caught - Popt < 1 indicates potential growth overfishing - Popt < 0.2 indicates possible depletion of mega-spawners - Pobj used to distinguish selectivity patterns	(Froese 2004; Cope and Punt 2009)
Size-based catch rates and proportion of old fish in the catch	Indicator of stock status -Increase of small fish in catches can reflect overfishing or increase in recruitment. -Decrease of old fish in catches may indicate depletion of the adult population	-Australian eastern tuna and billfish (*Xiphias gladius, Thunnus obesus, Thunnus albacares*) (Davies et al. 2007; Prince et al. 2011)
L/Lm or L/Ltarget	Mean length relative to the length at maturity Lm or target length across all fish in the catch < 1 indicates overfishing.	-Plaice (*Pleuronectes platessa*) and sole (*Solea solea*) (ICES 2022, 2023)

Table 3. Summary of the main differences between MSE and stock assessment.

	MSE	Stock Assessment
Goal	Identify robust MPs) that allow the achievement of the pre-agreed objectives while considering the key uncertainties of the system.	Provide recommendations for management (e.g., TAC), but the reliability of these recommendations is not known.
Emphasis	To find an MP that is in accordance with the pre-agreed objectives and robust to different interpretations of the available data.	Provide recommendations for management (e.g., TAC) based on the single best possible interpretation ("best stock assessment") of the available data.
Performance	Tested with simulations and quantifiable using performance metrics.	Unknown (the assessment may be wrong; we will never know how well it will work).
Uncertainty	Uses multiple possible states of the fishery system (different OMs) to test management procedures. It focuses on the key uncertainties when setting management rules.	Uses sensitivity analysis to understand perceived system uncertainties with the stock assessment.
Robustness	Uses multiple scenarios (OMs) to test MPs, allowing evaluation of their strengths and weaknesses, which provides confidence in the chosen management approach.	Unknown robustness to uncertainties
Management recommendation	It can be derived from straightforward rules, promoting adherence to the recommendation.	It arises from complex models often difficult for stakeholders to interpret (limits adherence to the recommendation).
Complexity	More complex in terms of identifying OMs. However, how the TAC is calculated is usually easier to understand.	It depends on the data, the fishery and the assessment approach.
Participation	Stakeholder participation is fundamental for the MSE process. Since MPs are chosen based on the balance of pre-agreed objectives.	Stakeholders often feel that they are observers of the process and are unable to relate the stock assessment results to their objectives.
Transparency	At the end of the MSE process, it is clear why one MP is chosen and not another since it is known which procedure best balances the fishery's objectives.	It is not clear how decisions are made regarding models and data.

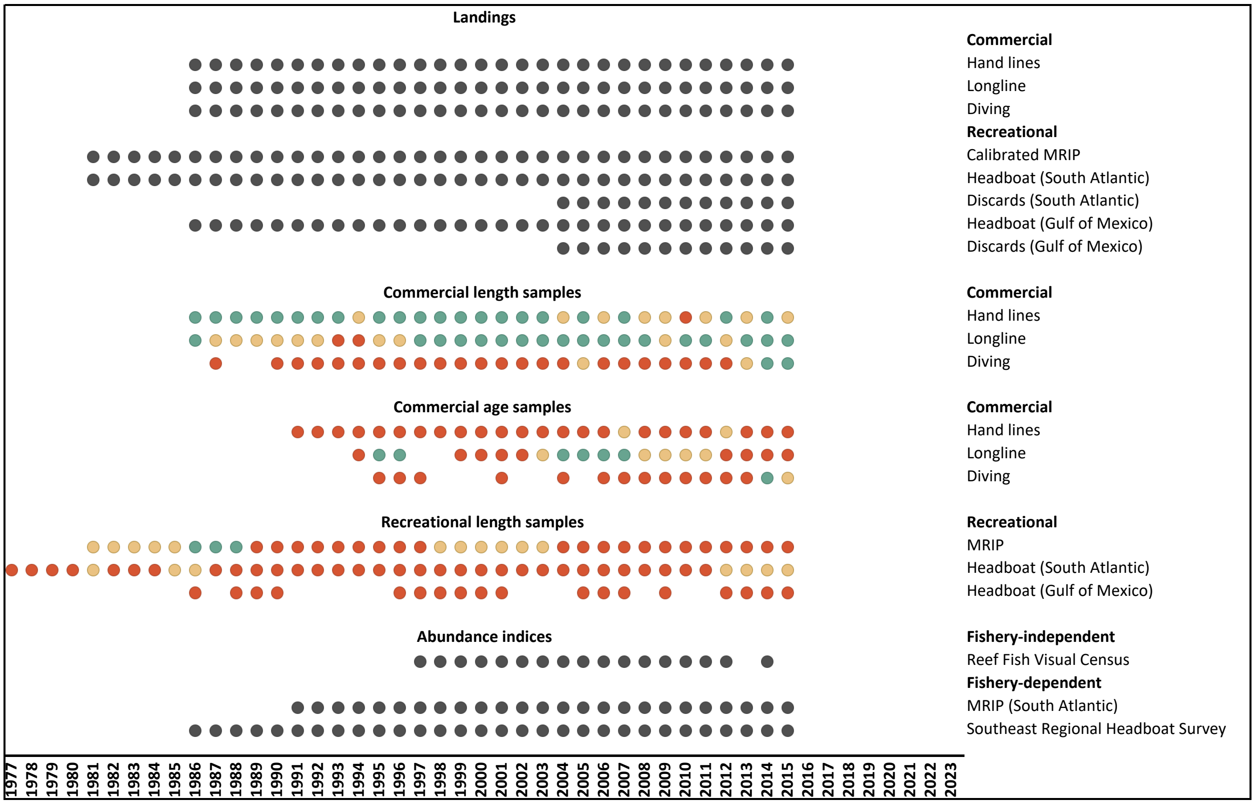

Figure 1. Available data for black grouper fishery. Grey dots represent available data, and green (N>100), yellow (N=50-100), and red (N<50) dots represent available data and sample size for age and length samples.

Figure 2. Description of the Management Procedure, decision rule visualization, and catch advice calculation for Thorny Skate (*Amblyraja radiata*) from the Gulf of Maine, USA.

TECHNICAL DETAILS

Data-Limited Management
Data-limited stock with no quantitative stock assessment.

Uncertainties in Historical Data
Historical data is characterized by high uncertainties, particularly in recorded catches and discards.

Management Proxies
Biomass target: As a proxy for BMSY, this target is calculated as the 75th percentile of the biomass index time series from 1963 to 2007 (e.g., 4.13 kg/tow for thorny skate).
Biomass threshold: As a proxy for determining overfished status is calculated as 1/2 of the biomass target (e.g., 2.06 kg/tow for thorny skate).

Decision Rule
Status determination is based on a three-year moving average of the biomass index.

Catch Advice Process
- The ABC (= ACL) is calculated using an empirical rule, based on the median ratio of catch to biomass index, adjusted by a three-year moving average.
- An annual Catch Target (ACT) is set to 90% of the ACL to incorporate a buffer for management uncertainties.
- This basic MP employs dynamic adjustments based on a biomass index (only indicator), facilitating responsive management.

Modified from: Northeast skate complex fishery management plan. Annual Monitoring Report for Fishing Year 2021. Prepared by the New England Fishery Management Council In consultation with the National Marine Fisheries Service.
Free, C. M., Mangin, T., Wiedenmann, J., Smith, C., McVeigh, H., & Gaines, S. D. (2023). Harvest control rules used in US federal fisheries management and implications for climate resilience. Fish and Fisheries, 24(2), 248-262.

Figure 3. Technical details of the Management Procedure, decision rule, and catch advice calculation for Thorny Skate (*Amblyraja radiata*) from the Gulf of Maine, USA.

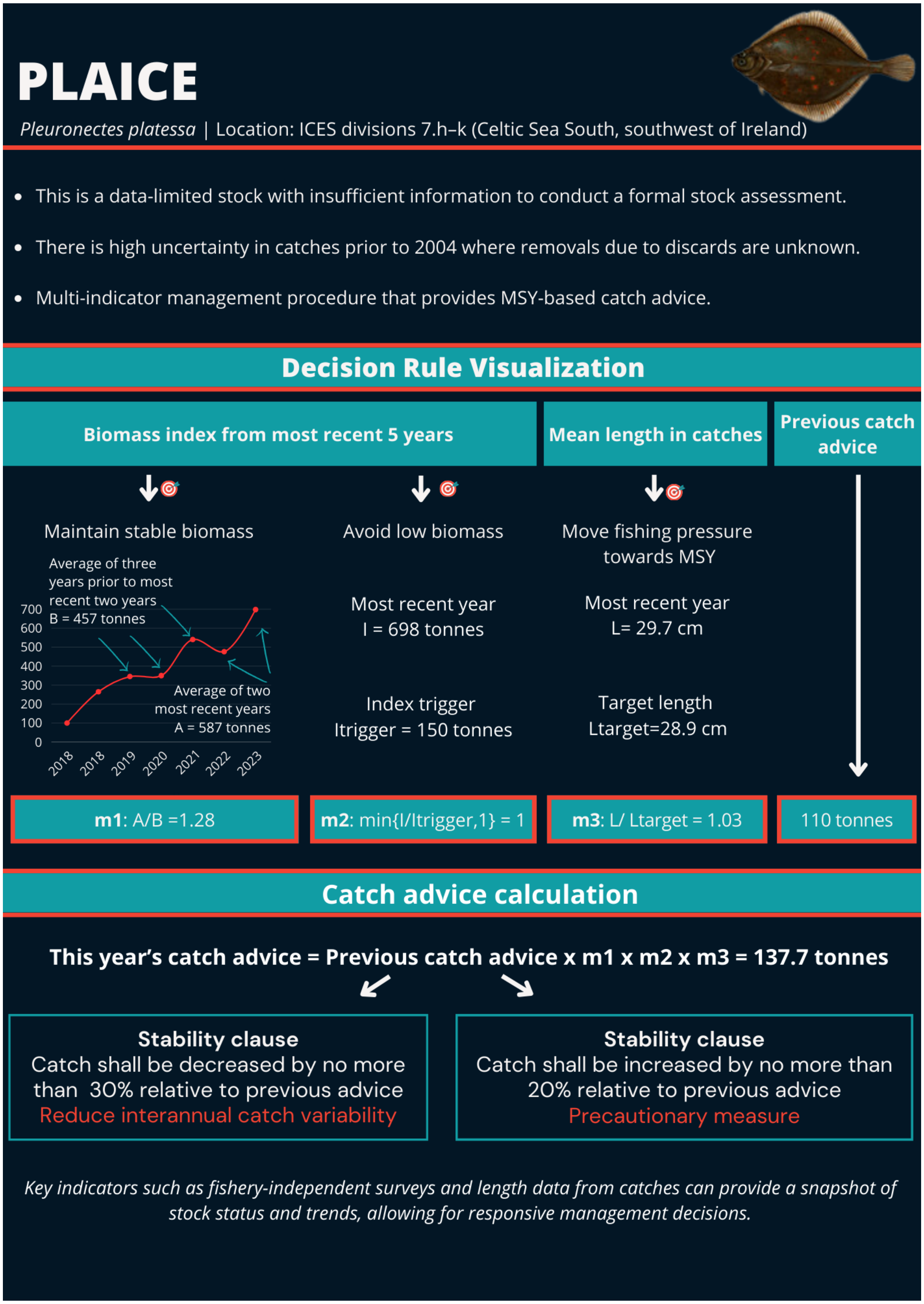

Figure 4. Description of the Management Procedure, decision rule visualization, and catch advice calculation for Plaice (*Pleuronectes platessa*), managed by ICES divisions 7.h–k (Celtic Sea South, southwest of Ireland).

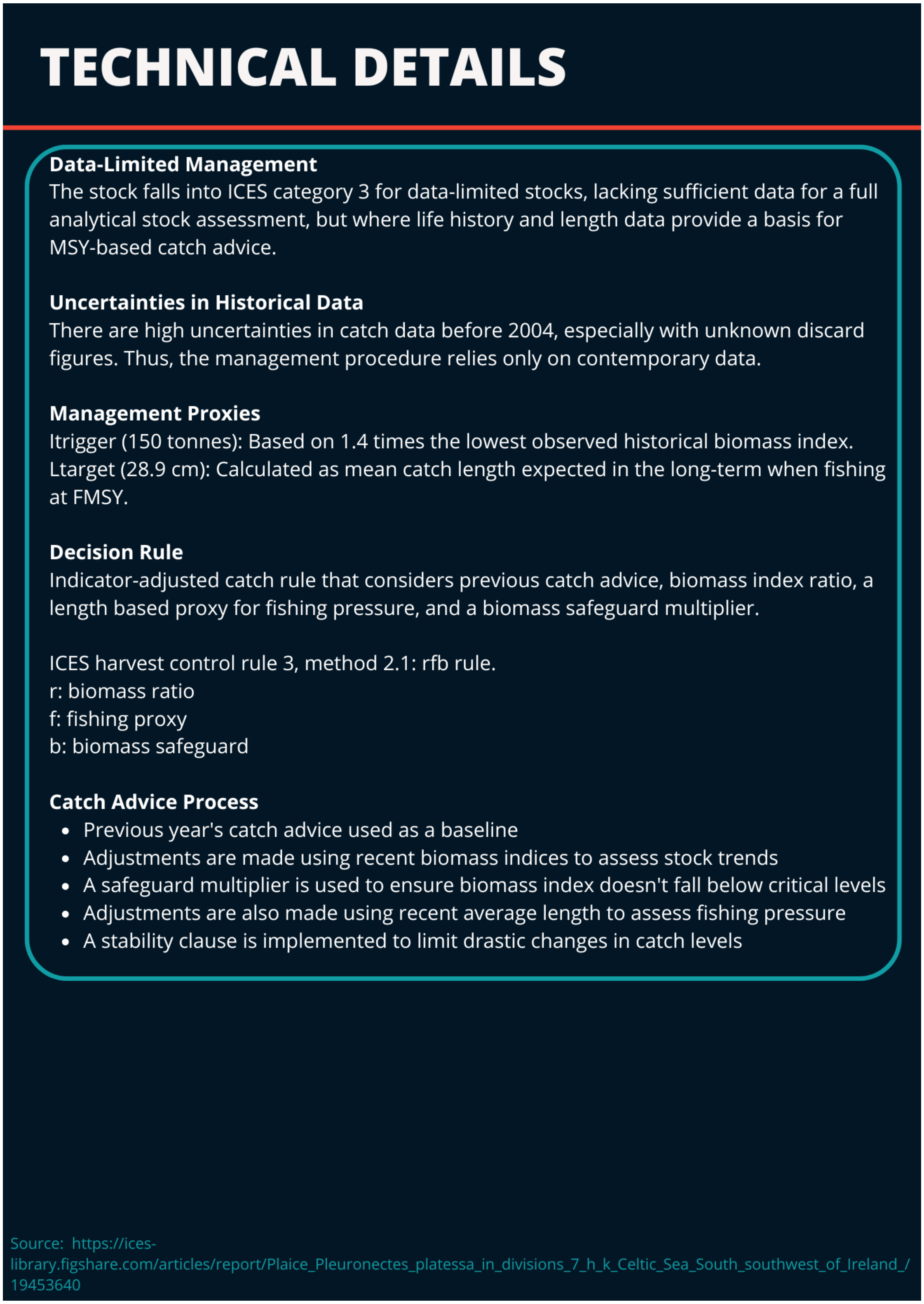

Figure 5. Technical details of the Management Procedure, decision rule, and catch advice calculation for Plaice (*Pleuronectes platessa*), managed by ICES divisions 7.h–k (Celtic Sea South, southwest of Ireland).

Figure 6. Description of the Management Procedure, decision rule visualization, and catch advice calculation for Spanner crab (*Ranina ranina*) in Queensland, Australia.

TECHNICAL DETAILS

Data-Limited Management
There is insufficient data to assess the status of the spanner crab stock.

Uncertainties in Historical Data
Uncertainties in growth rates, age at maturity, longevity and recruitment.

Management Proxies
Limit Reference Point (LRP): 0.5 kg per dilly lift (CPUE), which represents a proxy for approximately 20% of biomass in the fishery. LRP based only on the CPUE index to provide greater decision-making certainty in a declining resource.

Target Reference Point (TRP): Pooled index standardized to a reference period that reflects strong commercial catch rates and stable survey catch rates.

Decision Rule
The allowable commercial catch is adjusted based on a pooled index from CPUE and survey data. Changes in allowable commercial catch are proportional to year-over-year index comparisons, with set upper and lower limits.

Catch Advice Process

- Increase allowable commercial catch: If the pooled index shows improvement.
- Decrease allowable commercial catch: If the pooled index declines.
- Close fishery if CPUE is critically low.
- No change in catch advice if none of the conditions for a change are met.
- Additional criteria trigger review of catch advice under certain circumstances.
- Catch advice process can be modified through regulatory and non-regulatory options to address issues related to fishery profitability, social and economic considerations.

Modified from: State of Queensland 2020. Spanner crab fishery harvest strategy: 2020–2025. Queensland Government.

Figure 7. Technical details of the Management Procedure, decision rule, and catch advice calculation for Spanner crab (*Ranina ranina*) in Queensland, Australia.

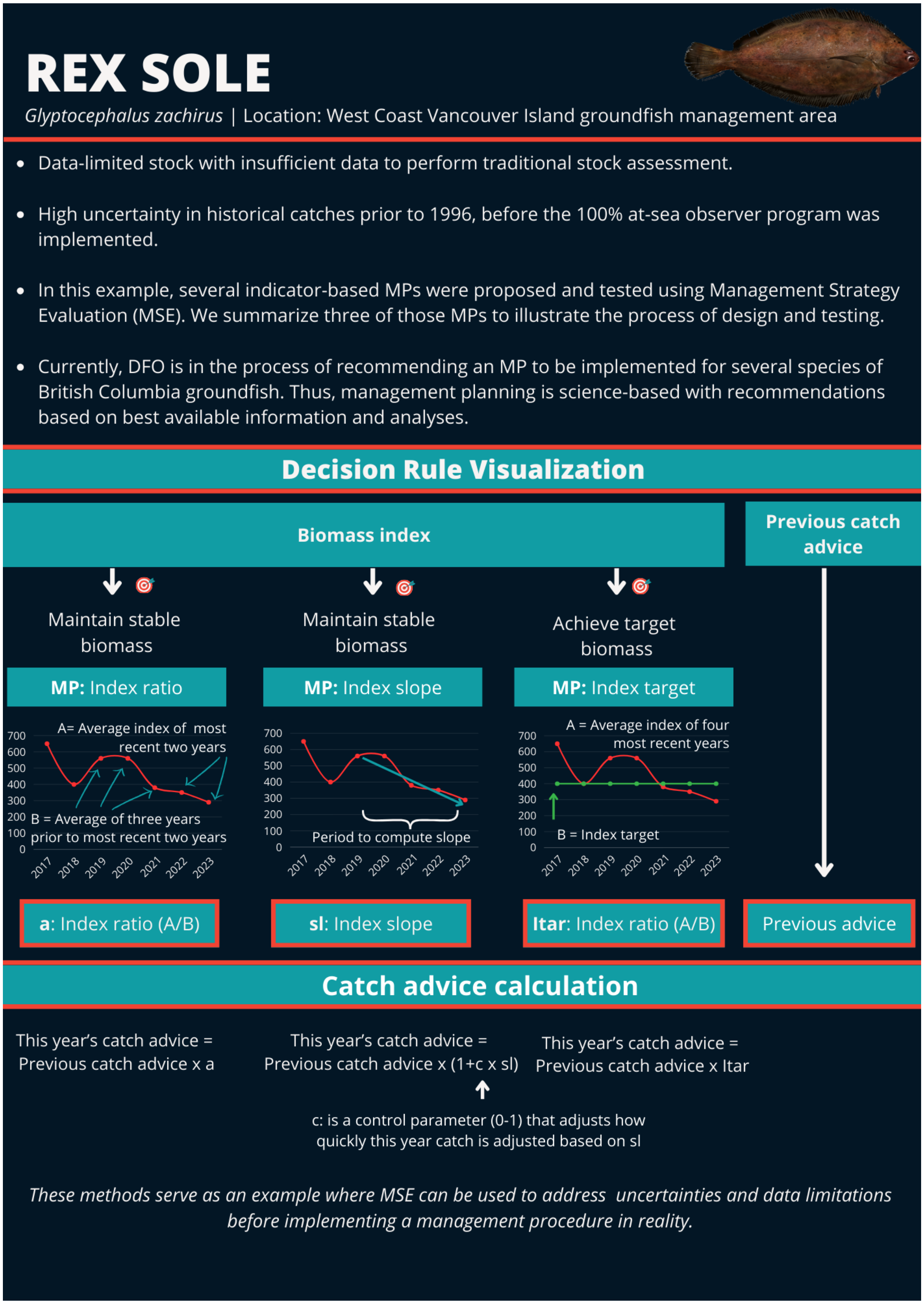

Figure 8. Description of the Management Procedure, decision rule visualization, and catch advice calculation for Rex sole (*Glyptocephalus zachirus*) from British Columbia.

TECHNICAL DETAILS

Data-Limited Management
Several groundfish species in the British Columbia integrated groundfish fishery are managed with insufficient data to perform traditional assessment methods.

Uncertainties in Historical Data
Significant uncertainties in catch data exist before the implementation of the at-sea observer program.

Management Proxies
A Limit Reference Point (LRP) is defined to ensure sustainability, regardless of data limitations.

Decision Rule
Indicator-based MPs are used to guide management decisions:

- *Index-ratio MPs:* Recommend catches by comparing recent population indices to those from a recent period.
- *Index-slope MPs:* Recommend catch based on the trend of population indices during a recent period.
- *Index-target MPs:* Recommend catch by comparing recent indices to a historical benchmark.

Catch Advice Process

- Simulation tests and performance metrics help guide selection of the most reliable MPs for providing evidence-based catch advice, ensuring sustainable management despite data limitations.

Source: Anderson S., Forrest, R., Huynh Q., and Kepper, E. 2021. A management procedure framework for groundfish in British Columbia. Fisheries and Ocenas Canada.

Figure 9. Technical details of the Management Procedure, decision rule, and catch advice calculation for Rex sole (*Glyptocephalus zachirus*) from British Columbia.

Figure 10. Description of the basic steps to follow when conducting a Management Strategy Evaluation (MSE) (modified from Punt et al. (2016)

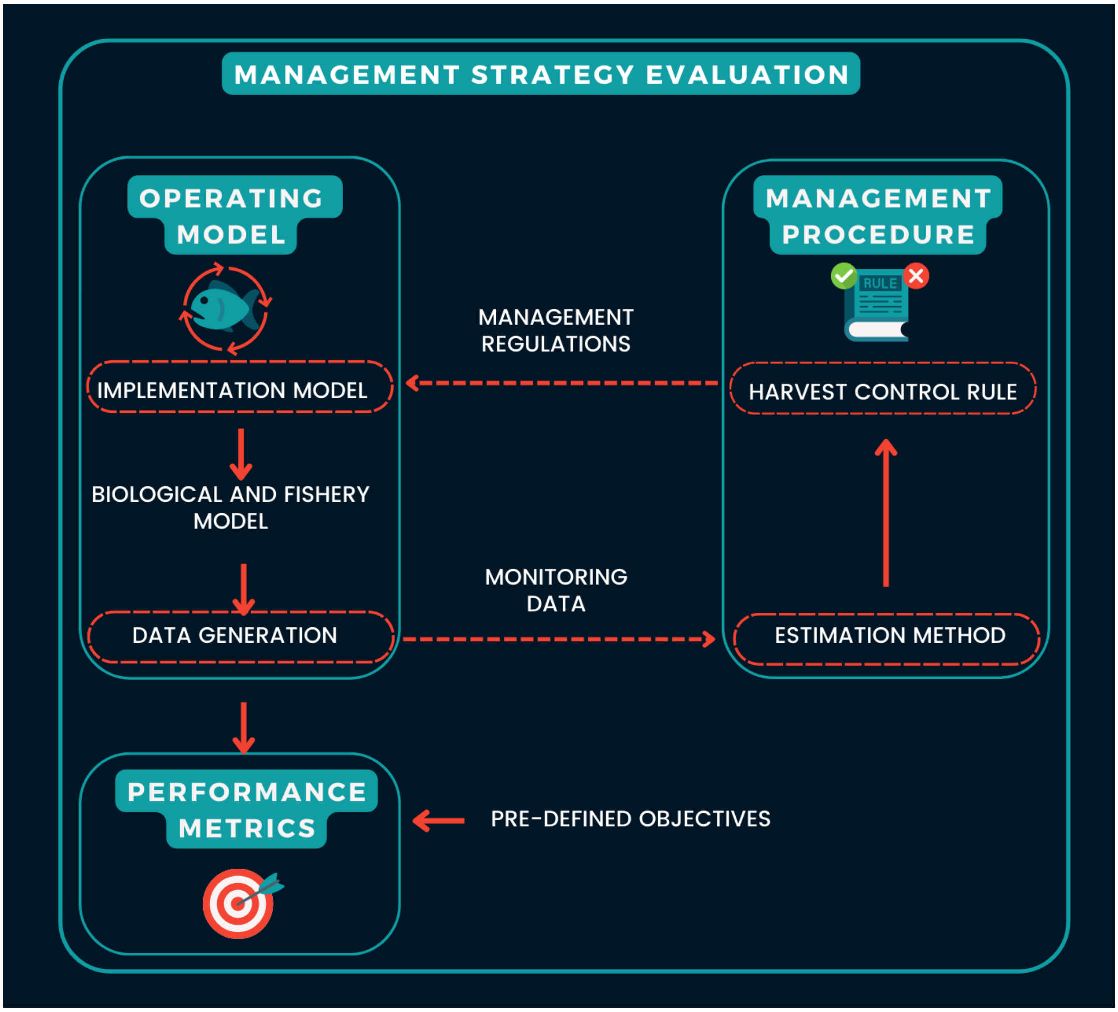

Figure 11. Conceptual overview of the MSE modeling process.

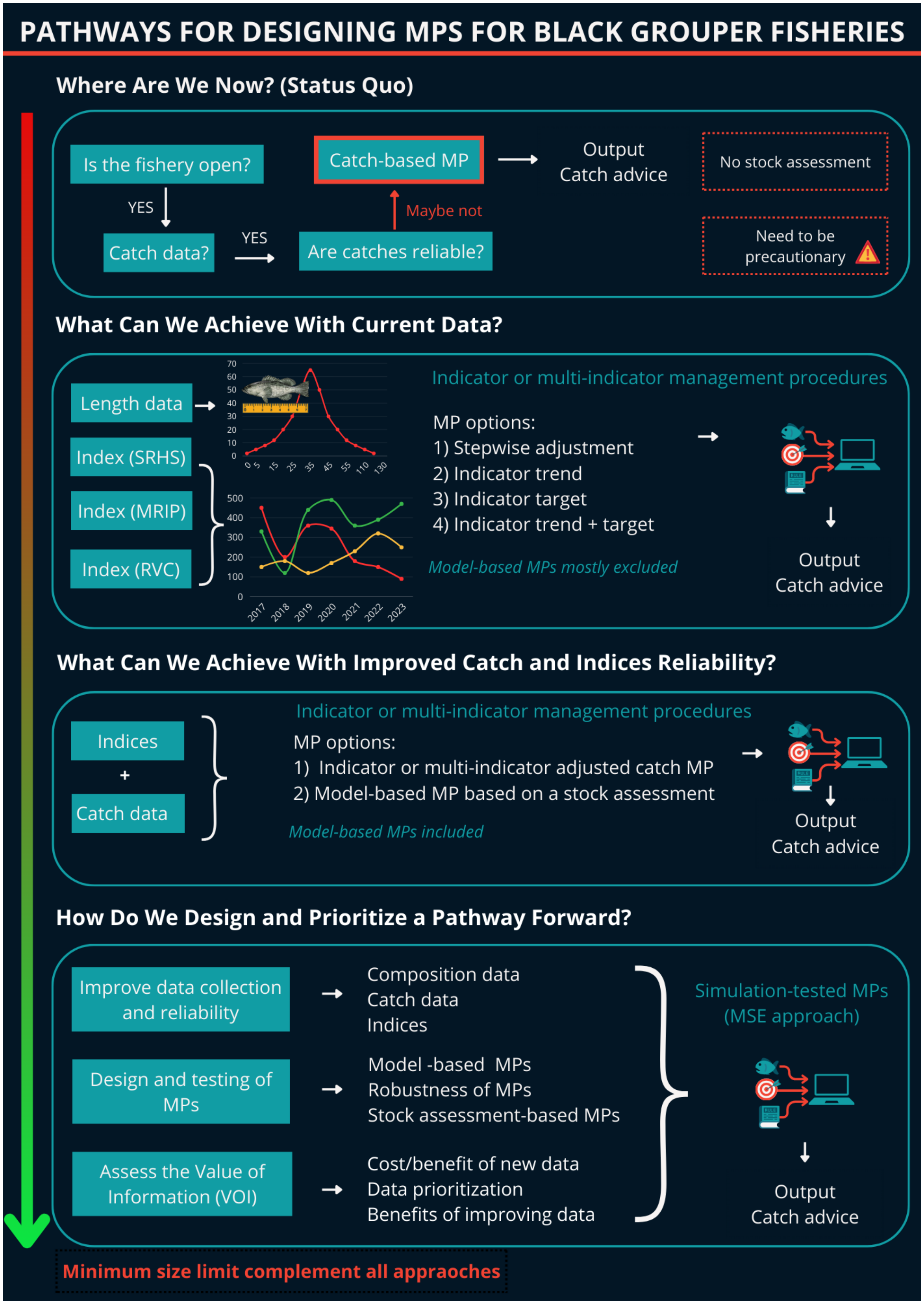

Figure 12. Proposed stepwise approach to explore a design pathway for MP evaluation for black grouper fisheries across varying data availability and analytical complexity.

APPENDIX 1. DATA BOUNDS AND LIMITATIONS

Life history

***Taxonomy and identification*:** The morphologic identification of the black grouper, *Mycteroperca bonaci* (Poey, 1860) is not difficult; however, its common name is shared with other groupers, causing confusion in the reporting of commercial and recreational landings. Gag (*M. microlepis*) has been historically reported as, or confounded with black grouper, especially in areas of Florida where black grouper are less common according to NMFS Marine Recreational Information Program (MRIP) and the NMFS Southeast Head Boat Survey (SRHS) (SEDAR 2017). Other species, such as scamp (*M. phenax*) and yellowfin grouper (*M. venenosa*), have also been reported as black grouper according to observations by port samplers (NMFS Trip Interview Program; TIP). TIP, MRIP, and SRHS programs rely on field observers to examine landed catch and generally provide reliable data on landed catch identification. However, the release of information from MRIP contains more uncertainty, particularly in the early years (1981 - 1991), due to less effective observation training.

Limitation: Confusion arises in reporting both commercial and recreational landings due to the misidentification of black groupers and unclassified landings, which may include several species.

Stock structure: Using microsatellite DNA, Zatcoff et al. (2002) examined genetic information (N=276) in the Southeastern United States and Caribbean region. The study found genetic homogeneity among samples from the Florida Keys, Mexico, and Belize, indicating that gene flow between those populations likely occurs and that these specimens belonged to a single stock of black grouper. This information supports the decision to assess black grouper as a single stock in the U.S. Southeastern Region (South Atlantic and Gulf of Mexico).

Limitation: Zatcoff et al. (2002) is the only study that we are aware of that evaluates the stock structure of black grouper in the Southeastern and Caribbean regions. Another study conducted on the northern coast of Yucatan (in three regions) revealed three genetically distinct subpopulations (González-Salas et al. 2020) in that area. Unlike the black grouper stock from the Southeastern and Caribbean regions, the black grouper population from the northern coast of Yucatan cannot be considered a panmictic population within the region.

Natural mortality (M): The M of black grouper has been derived using various empirical relationships based on its maximum age (t_{max} = 33 years) (Crabtree and Bullock 1998). In SEDAR 19 (SEDAR 2010), M was derived using the "$Hoenig_{lm}$" relationship (M~0.14 y^{-1}) (Hoenig 1983) and an age-specific M was developed based on the Lorenzen method (Lorenzen 2005) using body length rather than body weight. The SEDAR 19 (SEDAR 2010) working group recommended running an extensive sensitivity analysis of M when fitting assessment models. Catch curve analysis (using long line samples from the waters west of the Dry Tortugas) has also been used to estimate total mortality (Z), which can be used as an upper bound for M in assessment models (O'Hop and Beaver 2009). Values of Z ranged from 0.22 y^{-1} (ages 9-33) to 0.16 y^{-1} (ages 15-33).

Then et al. (2015) recommended employing the Hoenig nonlinear regression method ("Hoenig nls") as a new model to estimate M based on maximum age and compared this method with other empirical approaches based on growth parameters (Alverson and Carney 1975; Pauly 1980; Pauly and Binohlan 1996) to evaluate its performance. Both methods, Hoenig_{lm} and Hoenig_{nls}, were applied to black grouper, and the M estimates were 0.16 y^{-1} and 0.20 y^{-1}, respectively. These M values are within the range suggested for sensitivity analyses in SEDAR 19 (SEDAR 2010). The working group in SEDAR 48 (SEDAR 2017) suggested estimating M, when possible, in the assessment. If this is not possible, the working group suggested using Hoenig_{nls} estimator (Then et al. 2015) and constructing an age-specific M averaged over ages 3 to 33 (Lorenzen 2005). If priors are specified, the working group recommended using a bound between 0.1 – 0.2 or using Z estimates from catch curves to define an upper bound.

Hamel and Cope (2022) updated and corrected the work of Then et al. (2015). Hamel and Cope (2022) found two main problems with Then et al. (2015) analysis of the relationship between M and maximum age (Amax or Tmax). First, the lognormal transformation was not consistently applied when fitting the alternative model forms relating M to Amax. Secondly, the NLS models were fitted in real space, giving too much weight to short-lived species with high M, skewing the relationship. This biased the results, especially affecting the accuracy for species with longer lifespans. Hamel and Cope (2022) propose updated relationships between M and Amax that provide more accurate point estimates and priors for M. Based on the maximum reported age of 33 years, the Hamel and Cope (2022) estimator produces of 0.16 y^{-1} with log-normal 95% confidence interval of 0.09 to 0.30 y^{-1}.

Limitation: M is a difficult parameter to estimate and often highly uncertain. When evaluating MPs, alternative M values will need to be tested to assess the impact of the M assumption on their performance. No experimental or direct estimate (i.e., mark-recapture) of M for black grouper in the southeastern U.S. have been conducted. Catch curve estimates of Z (M+F) for black grouper are influenced by fishing mortality from long line gear and other fishing sectors (recreational and other commercial gears). Also, depending on the age range considered for analysis, Z could vary (younger fish in shallow water vs older fish in deeper water).

Discard mortality**:** Various studies have assessed discard mortality for shallow water groupers from the southeastern US Atlantic and Gulf of Mexico (Sauls and Cernak 2013). However, various methods (e.g., observational, mark-recapture) and fishing gears have been used, and these estimates were not standardized by method or gear. A meta-analysis was conducted to incorporate the effects of different methods and fishing gears. The model showed a positive correlation between capture depth and mortality. A mark-recapture model was also developed for gag discards (Sauls and Cernak 2013) based on data from recreational for-hire vessels, including headboats and charter vessels, in the Gulf of Mexico.

The SEDAR 33 (SEDAR 2014) Data Workshop Panel recommended using the depth-dependent discard mortality function (from the meta-analysis) for commercial longline fisheries and a mark-recapture model for recreational hook-and-line and commercial vertical line fisheries. Mean depths were used to assign overall discard mortality rates for each fishery during the assessment workshop (Table 2.2 in SEDAR 2017).

Since 2005, the state of Florida has collaborated with the for-hire industry to establish an observer program for charter and headboat fleets targeting federally managed reef fish stocks.

This program collects data on fish caught and released. Since 2009, tagging fish prior to release has been included in the program. This mark-recapture program has provided useful information about survival rates for gag. However, due to the low number of black groupers discarded, it has not provided enough information to quantify discarding mortality for black grouper. Therefore, the overall discard mortality (13.9%) assumed for black grouper is based on gag estimates (from charter and headboat trips).

Limitation: The lack of specific data on black grouper discard mortality has led to the use of proxy models and extrapolation from other species (such as gag). The low number of black grouper discards observed over time has hindered the development of a separate mark-recapture model for the species. Models developed for gag grouper and depth-dependent functions might not fully capture the characteristics of black grouper fisheries.

Age and growth**:** The study by Crabtree and Bullock (1998) is the only age and growth study conducted for black grouper in southeastern US waters (South Florida waters). The study used data from 1994 to 1996 and examined 1166 black grouper. These specimens were collected from various gear and fisheries (e.g., spear fishermen, commercial hook and line, and bottom long line). However, most of the age data were obtained from commercial vessels (Table 2.6 in SEDAR 2017).

The data collected by Crabtree and Bullock (1998) were re-examined and re-aged (SEDAR 19 DW 09) (O'Hop and Beaver 2009), and more recent data gathered by biological surveys in the southeastern United States were incorporated to update the estimation of growth parameters.

Two von Bertalanffy (VB) growth models were fitted to the data. A traditional VB model was applied in SEDAR 19 (SEDAR 2010), while a variation of the VB growth model was developed for SEDAR 2017. This variant incorporated the coefficient of variation (CV) of length at age, which was modeled as a decreasing linear function from ages 5 to 27 to account for length variability and to decrease the contribution of unusually small or large lengths for an age to the likelihood in the fitting process. However, this new growth model did not improve the model fit (Table 2.9 in SEDAR 2017). The working group in SEDAR 48 recommended using the traditional VB model where the following growth parameters were estimated: L_∞ (mm)=1366.6, K $(y^{-1)}$ = 0.1338, and t_0 (y)=-0.4568.

Limitation: The accuracy of age determination in older groups was unknown. Despite most age data were obtained from commercial vessels (Table 2.6 in SEDAR 2017), the annual collection of otoliths was relatively low.

Length-length and length-weight relationships**:** Parameters of the length-length and length-weight relationships have been estimated for Black grouper (Table 1 in Crabtree and Bullock 1998). For SEDAR 48, Black grouper Length and Weight Relationships for the South Atlantic and Gulf of Mexico regions were revised, and new data were included. The data underwent re-analysis, cross-checking, and outlier detection to ensure accuracy. Various sources were utilized to compile the data, including TIP, SRHS, MRIP, NCDMF, FDM Biostat, FIM, etc. Simple linear regressions were employed to analyze the length-length and length-weight relationships after log e-transformation. The study focused on developing conversion equations to standardize the observed information across surveys and prepare data for stock assessments. The table with all the estimated parameters, including those estimated by Crabtree and Bullock (1998), the respective sample size, and the goodness of fit of the models, are available in Table 2.12 in SEDAR 2017.

A more recent study (Velázquez-Abunader et al. 2021) also estimated the length-weight relationship of black grouper in the southern Gulf of Mexico (Yucatan Peninsula), using data (N= 572) from 1996 – 1999 and 2017 – 2018. The estimated parameters were a= 0.014 (cm, g) and b= 3.0902 (Table 1 in Velázquez-Abunader et al. 2021). However, we recommend using those estimates provided in SEDAR 2017, as that data underwent exhaustive revision, is more specific for the study area, and has a larger sample size.

Limitation: No limitations have been identified.

Maturity-at-age and length**:** Crabtree and Bullock (1998) estimated female maturity at length and age for M. bonaci based on histological analysis of specimens from various months of the year in South Florida waters. Brule et al. (2003) conducted a similar analysis for Southern Gulf of Mexico specimens. In SEDAR 19, maturity at age and length were estimated based on Crabtree and Bullock (1998) data. However, the analysis was restricted to data from January to March preceding peak spawning activity to assess maturity status better. Specimens in the "regenerating phase" were excluded due to challenges in distinguishing them from immature specimens. Limited additional research has been conducted in southeastern US waters using histological examinations. As a result, SEDAR 48 (SEDAR 2017) recommended using parameters presented in Table 2.10, which were estimated for Southeastern US waters using data from Crabtree and Bullock (1998), limited to January to March. A more recent study (Brulé and Colás-Marrufo 2013) estimated maturity-at-length based on histological samples from the Campeche Bank in the Gulf of Mexico. Their results differ from those reported in SEDAR 2017, indicating that fish from the southern Gulf of Mexico reach first maturity at smaller sizes.

Limitations: There have been no recent studies conducted in southeastern US waters. The maturity ogive is based on data collected from 1994 to 1996.

***Sexual transition*:** Black grouper display monandric protogynous hermaphroditism (Crabtree and Bullock 1998; Brulé et al. 2003). Initially born as females, mature females achieving larger sizes (and older ages) may undergo a transition to males. Overlaps in size and age exist between females and males of this species, suggesting that the triggers for sexual change are not solely size- or age-related (Brulé et al. 2003). Crabtree and Bullock (1998) and Brulé et al. (2003) estimated the proportion of males among their *M. bonaci* specimens using histological analyses. They noted significant differences in sex ratios across depths.

Crabtree and Bullock (1998) estimated that 50% of the females had transformed into males by a length of 1214 mm and an age of 15.5 years in Florida waters. Brulé et al. (2003) estimated the median size at sexual inversion was 1033 mm (fork length) in the southern Gulf of Mexico (Campeche Banks), indicating that the size at which 50% of the females transformed to males was lower from black grouper from the Campeche Bank than for those from Florida. In both studies, the overall sex ratio for the population could not be accurately described due to biases in sampling or catches. Still, the proportion of males in the sampling was very low in both studies.

For SEDAR 48 (SEDAR 2017), 55 more macroscopic sex determinations were conducted, resulting in a slight increase in the number of males available for analyzing male proportions by length and age. Differences between microscopic and macroscopic determination have been found in previous studies (García-Cagide and García 1996). Therefore, caution is needed when using macroscopic sex determinations. However, the inclusion of these new data to estimate length and age, where 50% of specimens are male, only produced minor differences compared to the estimate provided by Crabtree and Bullock (1998) (Table 2.11 in SEDAR 2017).

Limitations: There are challenges in accurately determining sex ratios due to biases in sampling methods and catches and the differences in sex ratios observed at various water depths. Also, there are some errors in macroscopic sex determinations.

***Movement and migrations*:** There is limited knowledge about larval transport and connectivity among different areas of the Gulf of Mexico and the South Atlantic where black grouper are known to spawn. Habitat requirements change as they grow. Larval black grouper may settle in estuarine habitats, indicating a preference for shallow, protected areas with suitable nursery conditions. Juveniles may be found in habitats that are challenging to sample using traditional fishery-independent gears, such as rocky areas with limestone outcrops or irregular hard bottoms. As *M. bonaci* matures, they move deeper, preferring high-relief areas (SEDAR 2017). Conventional tagging studies (Burns et al. 2006) have been conducted to track the movements of black grouper in specific regions, such as the Florida Keys. Studies have shown that black grouper movements can vary in distance and duration, with some individuals exhibiting relatively short-range movements, which may indicate site fidelity to specific areas. Also, acoustic tagging studies (Farmer 2009) have been conducted to monitor black grouper over short-term periods. The movements were relatively short (4 km or less), and site fidelity seemed relatively high (SEDAR 2017). These findings are supported by Keller et al. (2020). They used acoustic telemetry to describe the movement and habitat use of 10 subadult black grouper and the detection data of tagged grouper indicated high site fidelity and short distance movements in Western Dry Rocks in the Florida Keys.

Limitations: Small sample size (conventional tagging), and most tagged fish were caught in depths of less than 20 m. Due to the size of the acoustic-tagged fish (likely only immature females) and the brief observation period, these recorded movements are unlikely to be generalized to mature fish throughout the year.

Commercial data

Commercial Landings: In SEDAR 48 (SEDAR 2017), the discussion on southeastern U.S. black grouper commercial landings encompassed several critical issues. These included the duration of data for the stock assessment (the length of landing time-series), defining the geographical boundaries for the assessment with specific attention to the northern boundary in the South Atlantic and the western boundary in the Gulf of Mexico, and the methodology for allocating landings by region and gear. Additionally, the procedures for correcting misidentified black grouper, the uncertainty and error in black grouper landing estimates, commercial discards, and discard mortality were considered.

Databases containing information on commercial landings include the Accumulated Landings System (ALS, 1962-2015), General Canvass (1976-1996), and Coastal Logbook (1990-2015) (data provided by NOAA Fisheries SEFSC for all groupers). In addition, trip ticket data reported by the Florida Fish and Wildlife Conservation Commission (FWC) is available for all groupers from 1986 to 2015. The ALS and coastal logbook databases include landings from Florida, Georgia, South Carolina, North Carolina, Mississippi, Alabama, Louisiana, and Texas. Meanwhile, the canvass data and trip tickets only include Florida grouper data.

All data prior to 1986 are marked as unclassified grouper, except for Warsaw and Goliath. The most significant concern with commercial landings data is the historical misidentification of black grouper and gag, particularly in the southeastern United States, where "black grouper" was often used interchangeably with gag for marketing purposes. This situation had resulted in inflated reported landings of black grouper since 1986 when the two species were first distinguished in the landings data.

After SEDAR 19 (SEDAR 2010), it was recommended that data prior to 1986 be excluded from the landings dataset because of the need to apportion historical unclassified grouper landings. Regarding the geographic boundaries for the stock assessment, the Commercial Working Group recommended using the Florida/Georgia line as the northern boundary for the South Atlantic portion of the black grouper stock because, according to NOAA Fisheries (SEDAR 2010), black grouper was not reported north of North Carolina. North Carolina reported only gag grouper in their landings. The most recent data showed a ratio of 98% gag to 2% black grouper from Georgia to North Carolina, indicating that the reported black grouper are likely gag.

The Commercial Work Group in SEDAR 19 (SEDAR 2010) discussed allocating landings by MRIP regions rather than by South Atlantic and Gulf of Mexico waters due to the complexity of black grouper movements and due to the occurrence of black grouper and fishing behavior seem to differ by region. The group proposed using area or water body data to establish regions and recommended dividing landings into seven regions based on MRIP regions (1=Texas to Levy County, Florida (TX-FL Panhandle); 2=Citrus to Sarasota Counties (NW FL); 3=Charlotte to Collier Counties (SW FL); 4=Monroe County (FL Keys); 5=Miami-Dade to Indian River Counties (SE FL); 6=Brevard to Nassau Counties (NE FL); 7=Georgia to North Carolina (GA-NC)) (Table 3.1 in SEDAR 2017). Where water body information was not available, county or state landings were used to assign regions.

In addition, the Commercial Work Group decided to allocate landings based on gear assignment due to uncertainty in dealer-reported gear data. They decided to assign data to gear based on NMFS Florida General Canvass data for 1986-1992 and coastal logbook data for 1993-2015, considering that direct fisherman-reported logbook data are more accurate than dealer-reported data. The proportions of gear types for each year and region were calculated and applied to the total landings to determine landings by gear.

The rationale for assigning landings by MRIP rather than Council boundaries is that U.S. black grouper are all from a single stock with a primary nursery area in Florida Bay (partly state territorial waters and partly federal waters of the Gulf of Mexico). However, as black grouper age, some of them move into the reef environment that falls under the jurisdiction of the South Atlantic Federal Waters. In some areas, such as the Dry Tortugas, the movements of black grouper become more complex. Therefore, the Council's boundaries do not correspond to the species' movements.

The workgroup in SEDAR 48 (SEDAR 2017) discussed various approaches/methods to proportion black groupers from misidentified landings but focused primarily on Trip Interview Program (TIP) data. Unlike previous methods for proportioning gag, they needed to disaggregate data by gear, time, and region. Due to sparse TIP data, it was too difficult to calculate annual ratios, so they proposed dividing it into 5-year periods. The group calculated ratios of black grouper to black grouper + gag from TIP data by 5-year period, region, and gear. Due to the low sample sizes for some gears (traps, others), the group used only hand lines, long lines, and diving gears.

The workgroup in SEDAR 48 (SEDAR 2017) decided to proportion unclassified groupers into combined black + gag grouper landings for 1986-2015 from Florida to Texas, using annual ratios developed for each region. This proportion was determined by dividing the total black + gag grouper amount by the total identified groupers.

Finally, a correction for misidentification was implemented for the adjusted black + gag grouper landings. This correction was based on TIP ratios of black grouper to black + gag grouper, categorized by 5-year periods, regions, and gear types. The adjustments were derived from actual species compositions observed by trained samplers in the TIP program (methods are described in the working paper S48-DW-06). The resulting final adjusted black grouper landings are detailed in Table 3.2 in SEDAR 2017.

Limitations: The process of allocating unclassified grouper landings to black grouper, allocating by gear and area, and correcting for species misidentification introduces errors in the estimates of black grouper landings. This is the main reason for the lack of formal stock assessment for this species.

Commercial Discards**:** Discard calculations for black grouper from the Gulf of Mexico and the US South Atlantic were conducted using the methods outlined in SEDAR19 DW-15 (McCarthy 2009). Discard data from the Southeast Fisheries Science Center (SEFSC) coastal fisheries logbook program were used to calculate the number of black grouper discarded during the period January 1, 2002, through December 31, 2008.

Two sets of discard data were used to calculate black grouper discards. The first set included trips by vertical (handline and electric reel/bandit rig) line vessels that reported discards from 2002 to 2008 in the Gulf of Mexico and the US South Atlantic to 37°N (Texas-Mexico border). The second set was limited to longline vessels reporting discards in the Gulf of Mexico during the same period. Both handline and longline discards were included in the discard analyses, along with the effort reported through the logbook program.

GLM analyses were used to evaluate the influence of five factors (year, region, days at sea, quarter, and crew) on the discard rate and the proportion of trips with discards. The analysis was applied only to data from vertical line vessels. The available longline data were too limited to allow this analysis.

Once significant main effects were identified, the data were stratified by these factors and a mean discard rate was calculated for each stratum. These mean rate calculations included all vertical line discard trips within each stratum, i.e., the discard rate calculations included trips with no black grouper discards to produce a mean nominal discard rate. The total vertical line effort (hook hours) for each stratum was determined from coastal logbook data. Total discards for each stratum were then calculated as stratum mean discard rate x stratum total effort. For years before 2002, when there was no discard logbook program, the stratum mean discard rate was used for the yearly total effort reported to the coastal logbook program (McCarthy 2009). All available data were pooled to calculate the longline discard rate, and the mean discard rate across all years was calculated. This single mean discard rate was then applied to the yearly longline effort, defined as the number of hooks fished per year.

The calculated black grouper discards (in numbers) are presented in Table 3.13.5 in SEDAR 19 (SEDAR 2010). The estimated black grouper hand line discards and dead discards in numbers are converted to pounds of gutted weight using the TIP hand line mean weights for each year in Table 3.13.7 in SEDAR 19 (SEDAR 2010)

Table 3.13.6 in SEDAR 19 (SEDAR 2010) reports the release condition of discarded black grouper for handline and longline gear. Except for 2004 (86%), over 90% were reported alive or mostly alive at release. 82% were reported alive for longline gear, with no annual breakdown due to small sample sizes.

Before 2008, "regulatory restrictions" explained over 98% of black grouper discards for hand line gear and 85% for longline gear. After 2008, reporting distinguished between size limits and fishery closures, with approximately 68% of discards due to size limits and 19% due to unspecified regulatory restrictions.

Annual handline trips with discard reports ranged from 2,064 to 6,960. Since the implementation of the discard logbook program (2002), the percentage of handline trips reporting "no discards" increased from 25% to 55% (Gulf of Mexico and South Atlantic combined). Longline reporting trips in the Gulf of Mexico ranged from 100 to 280 per year, with 24% to 40% reporting "no discards," with no clear trend.

Limitations: Due to increasing "no discards" handline reporting trips and a small, long line sample, black grouper discards may be underreported and poorly characterized by available self-reported data. The working group in SEDAR 19 (SEDAR 2010) decided to accept the logbook estimates despite a potential decreasing trend in discard estimates, possibly indicating under-reporting. Additionally, misreporting gag grouper as black grouper complicated the discard calculations.

The Commercial Working Group in SEDAR 19 (SEDAR 2010) recommended that 20% be used as the point estimate for hook and line mortality of black grouper with a sensitivity range of 10-30 and a point estimate of 30% for black grouper long line release mortality with a sensitivity range of 25-35%.

Commercial Effort: The National Marine Fisheries Service (NMFS) monitors handline, electric reel, and longline landings and fishing effort of commercial vessels in the Gulf of Mexico and The US South Atlantic through the Coastal Fisheries Logbook Program (CFLP). The program collects landings and effort data by fishing trips from federally permitted vessels SEDAR19 DW13 (McCarthy 2009).

Black grouper trips were identified using a data subsetting technique modified from Stephens and MacCall (2004) to limit the dataset to trips with fishing effort in black grouper habitat. This approach was used because the fishing location was not reported to the CFLP at a spatial scale adequate to identify targeting based on the habitat where the fishing occurred. GLM analyses examined four factors for their potential influences on the proportion of trips landing black grouper and catch rate. Significant main effects were utilized to stratify available effort data for total catch calculations. Calculated black grouper effort and catch per unit effort (CPUE) are detailed in Table 3.9 for handline and Table 3.10 for longline in (SEDAR 2010).

Limitations: Expert input should be sought on the suitability of trends in effort as input to an MP.

Biological sampling: Biostatistical samples, including length, weight, sex, and otoliths, have been collected along the southeast US coast since 1981 by the Trip Interview Program (TIP) port agents and various state agencies. Samples are collected at docks where commercial catches are landed. A subset of these data consisting of commercial samples without sampling bias was selected for analysis. These data were limited to samples that could be assigned to specific years, gear types, and regions (SEDAR 2017).

Length samples and length distribution: Length data from the commercial fishery began in 1986 and extended through 2015, separated by fishing gear. Sample sizes vary between gear types and years. Overall, the sample size for each year is small, especially for the bottom trawl fishery. The handline and longline gears have larger sample sizes. From 1986 to 1997, most of the length data came from handline gear, and since 1998, sampling effort has increased in longline gear, generally resulting in larger sample sizes than handline gear. Only in a few years did sample sizes exceed 400 fish. From 1986 to 2015, handline gear sampled, on average, approximately 157 fish per year, while longline gear sampled approximately 176 fish per year (Table 3.3 in SEDAR 2017). Length data were converted to total length in centimeters and binned in two-centimeter increments ranging from 18 cm to 154 cm (SEDAR 2017).

Age samples and age distribution: The number of commercial age samples (otoliths) is minimal and varies by gear type. The range in the number of age samples collected was 0-64 for handline, 0-480 for longline, and 0-130 for dive (Table 3.4 in SEDAR 2017). Longline is the only gear where the number of commercial age samples exceeded 100 in some years (1995-1996, 2004-2007). Black grouper ages were organized into annual bins by gear. Across all gears, sampled ages ranged from 2 to 33 years. Specifically, ages by gear varied from 2 to 27 years for handlines, 3 to 33 years for longlines, and 2 to 27 years for diving.

Limitations: Due to data inconsistency and small sample sizes, composition data likely contain little information for estimating recruitment. However, the data may help estimate selectivity. The representativeness of composition data to characterize the length-structure in the catch should receive additional scrutiny, if this information is to be used in an MP.

Recreational data

Recreational landings: Recreational charter, private, and shore landings data for black grouper are collected from different sampling programs: i) Marine Recreational Information Program (MRIP); ii) Texas Parks and Wildlife Department (TPWD): Covers charter and private fishing; iii) State Reef Fish Survey (SRFS); and iv) Southeast Region Headboat Survey (SRHS) (SEDAR 2017).

MRIP, TPWD and SRFS programs

Since 1981, MRIP has provided estimates of catch per unit effort, total effort, landings, and discards for six two-month periods (waves) each year for three recreational fishing modes: shore-based fishing (SH), private and rental boat fishing (PR), and for-hire charter and guide fishing (CH). The MRIP survey covers coastal Atlantic states from Maine to Florida and coastal Gulf of Mexico states from Florida to Louisiana.

The TPWD Sport-boat Angling Survey, initiated in May 1983, samples sport-boat angler fishing trips in Texas marine waters, focusing on recreational boat access sites. Raw data include catch, effort, and length composition of the catch for the sampled trips, which TPWD uses to estimate recreational catch and effort. The survey is designed to estimate landings and effort by high-use (May 15 - November 20) and low-use (November 21-May 14) seasons. SEFSC staff disaggregates TPWD seasonal estimates into two-month periods (waves) to match the MRIP time series and ensure compatibility. The survey covers private and charter boat fishing trips, with most sampled trips associated with private boats in bay/pass areas, which account for most of fishing effort, while charter boat trips in ocean waters are less common.

Several adjustments have been made to the MRIP. The adjustments included using calibration factors, methodologies to separate landings by area, adjustments to correct misidentification of black grouper and gag grouper, corrections in calculating average weights, and adjustments to fill missing data. These adjustments aimed to improve the accuracy and consistency of recreational catch rate estimates provided by MRIP.

In 2015, a new program, Florida's Gulf Reef Fish Survey, was implemented to improve data from the private boat segment of the recreational reef fish fishery. This program underwent peer review and NOAA certification in 2018. The program was expanded statewide in 2020 and renamed the State Reef Fish Survey (SRFS) (SAFMC 2023). The SRFS provides information on the number of monthly recreational reef fish trips and the number of fish harvested and released (landings and discards). The program uses two components to collect information: Mail and Dockside Monitoring. The SRFS program runs concurrently with the MRIP and uses complementary survey methods to the MRIP. The program currently has three years of data.

Southeast Region Headboat Survey (SRHS)

The Southeast Region Headboat Survey estimates landings and effort for headboats in the South Atlantic and Gulf of Mexico. It began in 1972 in the South Atlantic, from the VA/NC border to Key West, FL. The Gulf of Mexico headboat survey began in 1986 and extends from Naples, FL to South Padre Island, TX. Typically, 70-80 vessels participate annually in each region's survey. The Headboat Survey uses two methods to estimate catch and effort: biological information and logbook information.

Biological information: Port samplers collect fish size and weight data during dockside sampling. These data are used to generate mean weights for all species by area and month. Otoliths are also collected for aging studies.

Logbook information: Vessel personnel complete logbooks with total catch and effort data for each trip. These logbooks are summarized by vessel to estimate landings by species, area, and time strata.

The SRHS experienced inconsistencies in LA from 2002 to 2005. In 2002, no trip reports were collected, so reports from 2001 were used as a proxy. In 2003, few trip reports were available, but they were still used to generate estimates. From 2004 to 2005, no trip reports or fish samples were collected due to funding issues and Hurricane Katrina, resulting in no estimates or samples for those years. However, the MRIP For-Hire Survey included LA headboats in their charter mode estimates for those years, filling the gap in headboat mode estimates.

There are no variance estimates available for the SRHS catch estimates. Estimated headboat landings of black grouper in the South Atlantic and Gulf of Mexico from 1981 to 2015 are reported in Table 5 (SEDAR 2017).

Limitations: The representativeness of information obtained from recreational catch should receive additional scrutiny, if this information is to be used in an MP.

Discards:

MRIP and TPWD Discard Estimates: Anglers interviewed by MRIP report discarded live fish, but their identities and quantities are not verified. MRIP estimates of released live fish are adjusted similarly to landed fish using calibration factors and adjustments. TPWD does not estimate discards and assumes zero discards for black grouper due to very low catches.

Headboat Logbook Discards: In 2004, the SRHS modified its logbook form to include a self-reported discard category that distinguished between fish released alive and dead. As of January 1, 2013, electronic data collection began, and the distinction between released alive and released dead was removed, with all discards reported as released alive. Discards of black grouper are reported by region for reasons of vessel confidentiality. Estimated headboat landings and discards of black grouper in the South Atlantic and the Gulf of Mexico from 1981 to 2015 are provided in Table 5 in SEDAR (2017).

Limitations: Discard mortality rates remain uncertain for black grouper and should be considered as a key source of uncertainty in MP design.

Effort: Catch and effort data are reported in logbooks provided to headboats and completed by captains or designated crew members after each trip. Effort data are reported as the number of anglers on a given trip. The number of anglers is standardized by trip type (length in hours) by converting the number of anglers to "angler days" (e.g., 40 anglers on a half-day trip would result in 40 * 0.5 = 20 angler days). Angler days are summed by month for individual vessels. Port agents collect these monthly logbook trip reports and check them for accuracy and completeness. Although logbook reporting is mandatory, compliance is not 100% and varies by location. Correction factors are applied to account for non-reporting. Headboat estimated angler days by year and state from 1981 to 2015 are provided in Table 8 (SEDAR 2017).

Limitations: Expert input should be sought on the suitability of trends in effort as input to an MP.

Biological sampling:

Private Recreational Fishery and Charter Fishery: From 1981 through 2015, MRIP samplers measured 1779 black grouper lengths in the Southeast US from charterboat and private/rental boat anglers. Before 1986, the charterboat mode was combined with the headboat mode, accounting for 155 fish. Sampler measurements are typically mid-line length or fork length in millimeters; whenever possible, the samplers obtain weight data. Otoliths are rarely collected under the current sample design.

Headboat Survey Biological Sampling: From 1972 to 2015, headboat dockside samplers initially collected lengths in North and South Carolina, expanding to Georgia and northeast Florida in 1976 and covering all Atlantic waters along the southeastern US by 1978. The Gulf of Mexico (excluding Mississippi) was included in 1986, and Mississippi was added in 2010. Weight and biological samples are routinely collected. Due to vessel confidentiality, the number of black grouper measurements and trips with measured fish are reported by region (Table 7 in SEDAR 2017).

Limitations: The annual number of black grouper measured by fishing mode is small. The average number per year is approximately 50 individuals (all fishing mode). Expert input should be sought on the suitability of using length data from the recreational fishery as input to an MP.

Population indices

Fishery-independent survey: The RVC survey is the only fishery-independent survey for black grouper. The RVC survey began in 1979 with SCUBA divers counting fish along the Florida reef track using a two-stage stratified random survey design. The Florida Fish and Wildlife Conservation Commission (FWC) initiated a similar survey in 1999 and merged with the RVC in 2009. Divers observe black grouper at depths ranging from 1 to 33 meters. Most fish are subadults, with only about 3% reaching adult size. Therefore, an index for this species should use a length-based dome-shaped selectivity curve. RVC does not collect age composition data, only length data since it is a non-destructive sampling method. Standardization of RVC was done using a hurdle approach, which splits the process into two generalized linear submodels (Lo et al. 1992); a submodel estimating the proportion of positive stations with a binomial distribution using a logit link and a submodel estimating the mean number of black grouper caught at a positive station with a gamma distribution using a log link. Standardized catch rates and CVs are presented in Table 5.8.1 and Figures 5.9.2 and 5.9.3 in SEDAR 2017.

Limitations: The survey primarily reflects subadult abundance and does not provide information on adult abundance or spawning biomass. Also, the survey is conducted in the center of the distribution of black grouper region; it does not cover the entire distribution of the stock. Therefore, the survey could be hyperstable, and expert input should be sought on how to address this issue in MP design.

Fishery-dependent indices*:* Two fishery-dependent indices were developed for black grouper: The Marine Recreational Information Program of South Florida and the Southeast Headboat Survey.

Marine Recreational Information Program of South Florida

Recreational anglers in southern Florida, from Tampa Bay to Cape Canaveral, primarily catch black grouper using private/rental and charter boats. The Marine Recreational Information Program (MRIP) provides fishery-dependent survey data, including total catch rates with discards reported in intercepts. These catch rates serve as indicators of population changes and are less affected by management regulations. In 1991, MRIP improved its survey methods by linking ancillary intercepts from the same trip, recording the total number of anglers in the group, and improving field sampler training, critical for accurate species identification.

Data analysis to estimate recreational CPUE indices for black grouper focused on MRIP intercepts from 1991-2015 in offshore waters from southern Florida to Cape Canaveral, focusing only on hook-and-line trips due to concerns about increased spearfishing activity in recent years. A methodology similar to that used in SEDAR 19 (SEDAR 2010) was used in SEDAR 48 (SEDAR 2017). Hierarchical cluster analysis was performed on the presence-absence data of landings (recreational landings in number) to identify those species caught in association with black grouper and include trips that could have caught black grouper. Species associated with black grouper were identified, and all relevant trips catching any of these species were extracted from Pinellas County on the Gulf Coast to Indian River County on the Atlantic Coast. This included charter and private/rental boat trips in inshore (state) and offshore (federal) waters. After extracting recreational trip data, a hurdle approach with two generalized linear submodels (binomial and gamma distributions) was used to develop an abundance time series index. This method, like that used in SEDAR 19 (SEDAR 2010), involved calculating the probability of catching black grouper on a recreational trip and the number of black grouper caught on positive trips.

The final dataset spanned from 1991 to 2015, comprising 13,443 trips. No size or age data are available; the analyses focused on harvested (legal-sized) catch. Standardized catch rates and CVs are presented in Table 5.8.2, Figures 5.9.4 and 5.9.5 in SEDAR 48 (SEDAR 2017).

Limitations: Expert input should be sought to assess the limitations of fishery-dependent indices and their suitability as input to an MP.

Southeast Regional Headboat Survey

The headboat captain logbook dataset was used, which includes trip details such as date, area, vessel, angler, species caught, and weight. Records from headboat trips in the black grouper distribution center from 1986 to 2015 were used to generate this index.

Constructing an index using only trips that landed black grouper underestimates the effort exerted for this species. Therefore, the challenge was identifying which additional headboat trips should be included in the analysis because they could catch black grouper. The multiple logistic regression technique of Stephens and MacCall (2004) was used to predict the probability of catching black grouper on a trip (SEDAR48-DW-01 Muller and O'Hop 2017). This approach calculates a probability for each trip based on the presence or absence of other species and compares it to a threshold (i.e., a value to determine the minimum difference between the observed number of positive trips and the predicted number of positive trips), optimizing the balance between observed and predicted catches of black grouper.

To simplify the analysis, species landed on less than 1% of trips were excluded from the regression calculations. Of the 69 species in the full model, coefficients were statistically significant for only 43 species. In evaluating thresholds between 0 and 1, a value of 0.263 was set to minimize false positives and negatives in predicting black grouper catch. Thus, trips with a probability greater than 0.263 were included in the standardization analysis (SEDAR 2017).

The standardized mean number of black grouper caught per fishing trip was estimated using a delta-gamma model (Lo et al. 1992). This model included two generalized linear sub-models: one to predict the probability of catching a black grouper using a binomial distribution and another to estimate the number of black grouper caught on successful trips using a gamma distribution.

No size or age data are available in the Southeast Regional Headboat Survey. Standardized catch rates and CVs are presented in Table 5.8.3, Figures 5.9.6 -5.9.7 in SEDAR 2017.

Limitations: Expert input should be sought to assess the limitations of fishery-dependent indices and their suitability as input to an MP.

Data Analysis (stock assessment)

The only formal stock assessment for black grouper was conducted in SEDAR 19 (SEDAR 2010). In 2017, the FWC was working on a stock assessment using SS3 (Methot and Wetzel 2013), but the assessment was suspended due to high uncertainty in landing records.
Three models were developed for black grouper in SEDAR 19 (SEDAR 2010). Catch curves were used to provide a reasonable scale for natural mortality; a non-equilibrium surplus production model was used to evaluate the information contained in abundance indices and landing data; and a Statistical Catch-at-Age model (ASAP2) (Legault and Restrepo 1998) was used as the base model to estimate stock status, benchmarks, and project the population under different harvest rates.

The assessment carried out in 2010 was configured with four fleets (headboat, general recreational (Marine Recreational Fisheries Statistic Survey (MRFSS)), commercial hook-and-line, and commercial longlines) and eight indices of abundance (four fishery-dependent indices and four fishery-independent indices) for the period of 1986 through 2008. These indices differ from those mentioned above since this assessment was performed in 2010, and the data inputs were revised again in 2017 in SEDAR 2017. Age compositions were also used in the assessments. Discard information for each fleet was included in the assessment model (and fitted in the model). The stock was modeled with an age-structured population dynamics model with fish ages 1 –20+ years from 1986 to 2008 using an exponential population dynamics model to project abundance for each age. Initial abundance deviations (year 1) were estimated, and recruitment at age 1 was assumed to follow a Beverton-Holt stock-recruitment relationship parameterized in terms of steepness.

The ASAP2 stock assessment modeled selectivity for each fleet in temporal blocks to account for changes in minimum size limits for each fleet. Selectivity was modeled as double logistic curves for recreational and commercial hook-and-line fleets and as a logistic curve for the longline fleet. Initial fishing mortality for each fleet and multiplicative fishing mortality deviations were modeled as free parameters (i.e., no Baranov equation). The model estimated 196 parameters, including initial condition deviations, recruitment deviations, fishing mortalities, catchability for each index, selectivity parameters, etc. The model predicted a decline in fishing mortality rates over time, which is consistent with those estimates from ASPIC (surplus production model), and predicted increases in spawning biomass over time and more or less stable recruitment.

Retrospective analyses and sensitivity analyses were carried out, for example, adding or removing some age compositions, removing some indices years because of trip limits, changing the weight of some indices, using a single selectivity block, alternative M and steepness values, etc. ASAP2 model provided estimates of commonly used reference points. The SAFMC and GMFMC adopted F30%SPR as their overfishing limit. In the base run, F30%SPR was 0.212 per year, with an associated spawning biomass of 7.11 million lb. In 2008, fishing mortality was 0.076 per year, below the limit, and spawning biomass was 12.2 million lb., indicating that black grouper was not overfished, and overfishing was not occurring. Several projections under different fishing mortality rates were conducted, for example, F = 0, current fishing mortality ($F_{current}$), $F_{30\%SPR}$ (the overfishing limit for both councils), $0.65F_{30\%SPR}$, $0.75F_{30\%SPR}$, $0.85F_{30\%SPR}$, $F_{40\%SPR}$, and $F_{45\%SPR}$ (the SAFMC optimum yield measure). The current fishing mortality rate was the lowest, while $F_{30\%SPR}$ was the highest.

Limitations: The model fit of biomass indices was poor, potentially due to the lack of contrast in indices and data sparsity. Some complications in modeling fitting included: the methodology to convert lengths into age composition introduced additional uncertainty into the analyses and the model may have been overparameterized. Importantly, the assessment was performed in 2010, and these data were revised in 2017 (SEDAR 2017), so most of the information contained in our data limitation review has been updated since this stock assessment occurred.