Prototype Management Strategy Evaluation for Georges Bank Ecosystem-Based Fishery Management

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Overall Approach

The proposed prototype Management Strategy Evaluation (pMSE) modeling framework will use and link two existing regional modeling frameworks that have received broad attention and application. We will leverage a MSE framework developed for Northeast US groundfish (Kerr et al. 2020, Mazur et al. 2021), and the multispecies catch at length model Hydra (Gaichas et al. 2017), which was used as the basis for one of the worked examples in the NEFMC's eFEP (NEFMC 2019). We intend to link Hydra into the groundfish MSE framework (Phase 1), such that Hydra will swap in as the operating model dynamics, yet the existing data generation, management, and implementation modules, and MSE loop structure within the groundfish MSE framework can be utilized for the purposes of this project.

Building on these existing tools for this prototype, illustrative process will allow for more attention and time (both in software development and in stakeholder engagement) for defining the sets and steps associated with management alternatives. Analyses of Hydra and the groundfish MSE framework have been peer reviewed by the NEFMC's SSC and a panel from the Center for Independent Experts and there is already some familiarity with these models within the stakeholder groups as defined by the pMSE process. Given the illustrative and educational nature of the objectives for the pMSE, being able to direct stakeholder and technical time to research questions and process understanding rather than model development is advantageous. We realize some additional extension of these platforms will be needed to meet the objectives of the pMSE, thus our sequence of engagement activities (Phase 2) is set up to allow for iteration on the modeling tools and scenarios, but with the expectation that the range of these will be narrow to allow for focus on evaluating management alternatives and exploration of the implications of decision points via data visualization and communication tools (Phase 3).

Objectives

We propose to limit the scope of the technical analyses to address the following objectives, while embedding these in a mini-version of a full MSE process, to provide exposure to stakeholders and technical team members to the undertaking of an MSE aimed at understanding the performance of EBFM options including the ceilings and floors approach like those described in the eFEP (NEFMC 2019). Embracing the prototype nature of the project, a small number of scenarios will be evaluated.

- **Replicate in a short time frame the full MSE process**, including continued engagement and collaboration with a dedicated group of stakeholders and technical advising group, to inform and create understanding about the various roles and responsibilities within MSE and how this intersects with choices for EBFM.
- **Develop a linked MSE modeling platform** that is able to represent salient constraints to fisheries management, including the effects of environmental drivers, biological species

interactions and technical interactions, and the legal constraints imposed by governance and management.

- **Represent alternatives for ecosystem-based fisheries management procedures** that include the ceilings and floors approach to species group-based management as outlined in the eFEP.
- **Compare the performance of alternatives for EBFM including those described in the NEFMC's eFEP to the current approach to single-species fisheries management** given underlying time-varying ecosystem dynamics (trophic interactions and varying productivity) that result in dynamic reference points (whether or not those are accounted for in management advice).
- **Mapping of decision points for the management alternatives** to demonstrate potential gaps or areas of flexibility within the management process, and highlight areas that a full MSE process involving a broader set of public stakeholders would need to be able to include and address.
- **Evaluation of the performance of the tested alternative management procedures** for a set of metrics that reflect multiple management objectives, both derived through the engagement with stakeholders

Timeline and overview of work plan

We propose to conduct the work over the six month period 09/26/2022 - 03/31/2023. We also describe some places where additional resources beyond the six month period would allow for extensions of MSE scope if this is required. These additional resources and scope could include staff time for conducting additional scenarios or further developing an aspect of the pMSE.

Our work plan and timeline (Table 1) is based on continued engagement with the core stakeholder group as defined in the RFP (members of the EBFM committee, AP members, and additional advisors), as well as technical advisors (PDT) and the SSC. This is in addition to regular communication with Council staff. We propose a sequence of engagement throughout the project period to help the pMSE achieve the goals of both emulating a full MSE process with stakeholders and also to create sustained engagement on the topics addressed by the pMSE and improved community understanding about the roles of MSE and the likely decision points and needed activities involved in testing a FEP in a full MSE with a broader set of public stakeholders. Planned initial communications and conversations with Council staff and the EBFM PDT and Committee in the initial weeks of the project, as well as an initial scoping stakeholder workshop will provide opportunity to revise the proposed work plan and sequence of activities as needed, depending on feedback gained and needed development of existing software and alternative procedures. Additional modification may be needed to accommodate the timing of pMSE engagement with workload and availability of our stakeholder group given their involvement in other fishery management meetings and activities during the project period.

Table 1: Timeline and work plan of activities by Phase.

	Sep 26 - Oct 15	Oct 16-31	Nov 1-15	Nov 16-30	Dec 1-15	Dec 16-31	Jan 1-15	Jan 16-31	Feb 1-14	Feb 15-28	Mar 1-15	Mar 16-31
Phase 1 Technical Tasks												
Problem framing & research question scope		X										
Operating Model												
Scope OM development needs		X	X				X					
- Link Hydra into MSE framework		X	X									
- Generate age data from Hydra output	X											
- Integrate ecosystem drivers				X								
- Species selection & OM reparameterization			X									
- Fleet dynamics representation					X							
Assessment Models		X	X									
Scope development needs		X	X				X					
Add production model			X									
Management Procedures												
- Scope MP development needs		X	X		X							
- Code and implement MPs		X				X	X	X				
Performance metrics (code additional)					X							
Develop/refine experiment scenarios		X					X		X	X		
Conduct MSE simulations								X	X	X	X	
Phase 2 Facilitation & Coordination												
Engagement planning with Council staff	X											
Planning with EBFM PDT / Committee	X											
Present work plan to SSC			X									
Scoping stakeholder workshop		X										
Objectives & Performance Metrics workshop				X								
Management Procedure workshop					X							
Modeling workshop							X					
Preliminary results workshop									X			
Final results workshop												X
Present models/preliminary results to SSC											X	
Advisory discussions with PDT				X		X		X		X		X
Weekly meetings with Council staff	X	X	X	X	X	X	X	X	X	X	X	X

(Table 1 continued)

	Sep 26 - Oct 15	Oct 16-31	Nov 1-15	Nov 16-30	Dec 1-15	Dec 16-31	Jan 1-15	Jan 16-31	Feb 1-14	Feb 15-28	Mar 1-15	Mar 16-31
Phase 3: Presentation & Summary												
Identify communication tools & visuals												
Develop graphics/tables												
Develop shiny app for results												
Deliverables												
1. Develop workplan and calendar												
2. Participate in and lead discussions												
3. Meetings, PDT/Committee & stakeholders												
4. Weekly meetings with Council staff												
5. Make software available (github)												
6. Workshop summay reports												
7. Final report												

Phase 1: Development of software and closed loop simulation analysis

The software and tools development and technical analysis work will take place throughout the project period (Table 1). As early as possible during the project we will have a linked, functioning MSE loop, that has the minimal functionality of the final analyses to provide examples of what products may look like throughout the sequence of Phase 2 engagement activities. In addition to allowing the stakeholders to become familiar with the models, outcomes and what is feasible, this will also allow for iteration and improvement of the modeling based on discussions and feedback obtained during Phase 2 activities.

MSE software - extending the NE Groundfish MSE framework

In this study, we will leverage a previously developed MSE model framework to evaluate the performance of groundfish management in the context of changing ocean conditions (NOAA COCA # NA17OAR4310272) and choke species issues (NOAA SK #NA17NMF4270213). The MSE development was developed by a team of scientists from the Gulf of Maine Research Institute (L. Kerr, S. Truesdell, M. Mazur, A. Pershing, A. Weston, J. Jesse), University of Massachusetts Dartmouth, School for Marine Science and Technology (S.Cadrin, G. Fay, J. Cummings), and the NOAA Northeast Fisheries Science Center (S. Gaichas). Additional collaboration with economists Min-Yang Lee (NEFSC) and Anna Birkenbach (University of Delaware) has allowed for ongoing work to integrate a mechanistic fleet dynamics model into the MSE framework. This modeling framework was expanded through funding from the New England Fishery Management Council (NEFMC) for application of the Groundfish MSE framework to: 1) evaluate the implications of misreported catch on the performance of assessment and fisheries management, and 2) evaluate the performance of alternative harvest control rules for New England groundfish. This work provided the opportunity to present the details of the MSE model framework to the NEFMC groundfish PDT, groundfish Committee, SSC, and Council for feedback.

Overview of Modeling Framework

The MSE model framework consists of: 1) operating models designed to emulate population dynamics of groundfish stocks, and 2) a management procedure that includes an observation model (designed to emulate generation of survey and harvest data), a stock assessment fit to simulated fishery and survey data (including estimates of biological reference points), and a harvest control rule that determines catch advice (Figure 1). Our current framework includes operating models for five principal groundfish stocks, Gulf of Maine Atlantic cod, Georges Bank Atlantic cod, George Bank haddock, Georges Bank yellowtail flounder, and pollock. We simulate harvest of a stock by the fishery, as well as sampling through scientific surveys, and the simulated fishery independent and dependent data are used to assess the stocks in a stock assessment model (e.g., statistical catch at age model). We compare stock status estimates to biological reference points and apply harvest control rules to generate catch advice and then model the implementation of catch advice by the fishery. We can then quantify and compare a range of metrics (e.g., spawning stock biomass, probability of overfishing, stability in catch) to evaluate the performance of management strategies. This provides a comprehensive view of the risks and returns of the alternative fisheries management strategies. Models are written in the R statistical programming language (R Core Team, 2019) and code is stored and version controlled through a GitHub repository that includes technical documentation and is publicly available (https://github.com/lkerr/groundfish-MSE).

In the context of this proposal, we will leverage this pre-existing MSE framework and make several additions to our existing work that will add new components and functionality to this MSE framework. Additions will include development of compatibility of current framework, which relies on multiple single species models without biological interactions, to accommodate a multi-species operating model (ie. Hydra, detailed below), and management procedures that can accommodate both single-species and aggregate species (complexes) assessments and control rules (i.e. ceilings and floors concepts detailed in the eFEP, again, detailed below).

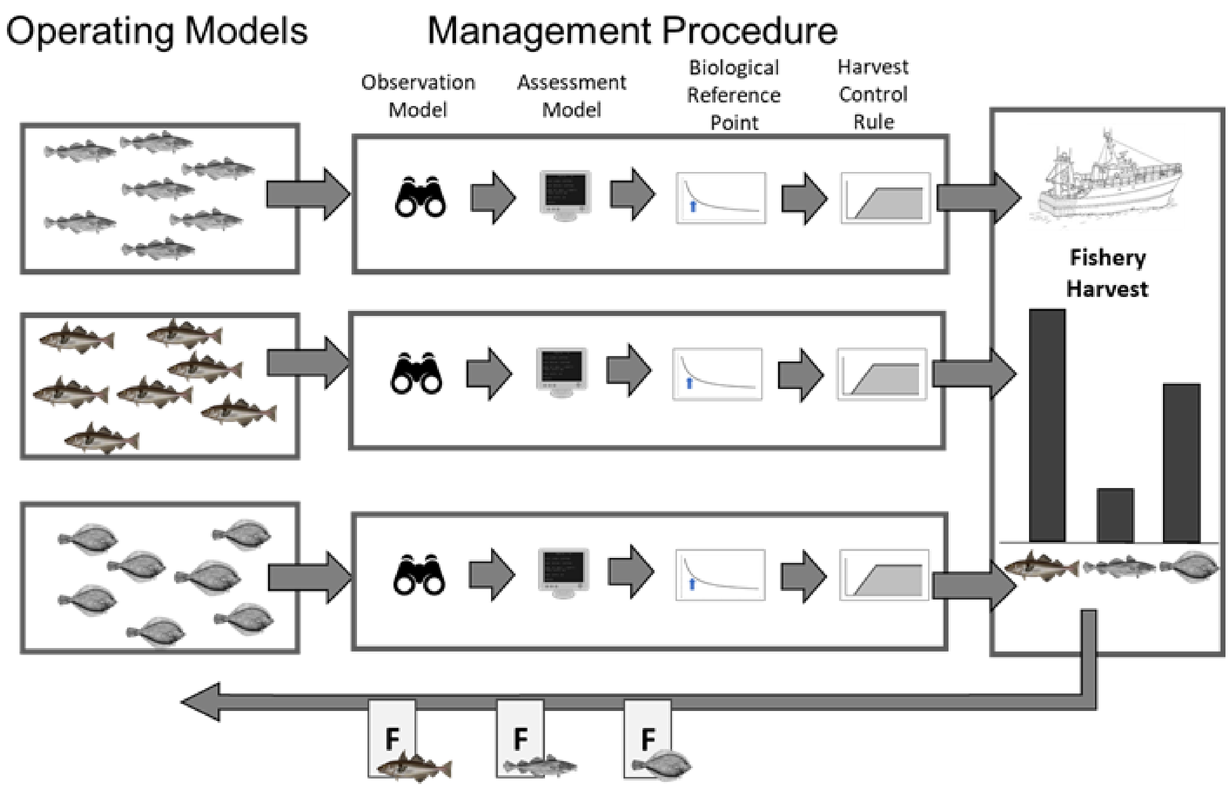

Figure 1. Illustration of the groundfish management strategy evaluation (MSE) model framework. The MSE model framework consists of: 1) operating models designed to emulate population dynamics of groundfish stocks, and 2) a management procedure that includes an observation model designed to emulate generation of survey and harvest data, a stock assessment fit to simulated fishery and survey data, biological reference points, and a harvest control rule that determines catch advice.

There are several features of the groundfish MSE model framework that make it suitable for this project:

- Implements a full MSE loop that can be run and parameterized for multiple species of interest
- Available assessment models include those currently used as the basis for management advice for New England managed stocks (e.g. statistical age-structured models, ASAP, index-based approaches), with ability to add additional assessment models.
- Management procedure model and structure is already designed to represent the timeline and processes typical of New England fisheries management.

- Multiple options for defining fisheries reference points and harvest control rules, including time-varying reference points.
- Multiple models for representing the effects of implementation error (realized catches differing from management advice)
- Performance metrics of the form that are familiar to assessment and management groups.
- The framework has general extensibility for future applications.
- Simulations are set up to be able to be run on High Performance Computing facilities through UMass Dartmouth's participation in the Mass Green High Performance Computing Center.
- Communication, visuals, and tutorial education materials describing the framework, its use, and outputs are already available.
- Code and development and diagnostics are publicly available on GitHub.

Operating Model - multispecies length structured model (Hydra)

Accounting for species interactions in both stock assessment modeling and fisheries management is of increasing interest, and has been identified through the NEFMC's EBFM process as a key element to capture in the dynamics of an operating model that can be used as the basis for the modeled truth in MSE simulations. Multispecies models "of intermediate complexity" between single population and full ecosystem models potentially combine the best aspects of current single species assessment models with key ecological linkages between species (e.g. Plaganyi et al. 2014). The Northeast Fisheries Science Center (NEFSC) is currently applying a suite of these models to New England and Mid-Atlantic managed fishery stocks and species. We aim to leverage work done using one of these models, Hydra, that has been used in the NEFMC EBFM eFEP worked example, as the basis for the operating model in this project.

Hydra is a length-based multispecies model that has been used as an operating model for multispecies simulation testing (Gaichas et al. 2017). As also demonstrated in the additional simulation analyses in the eFEP worked example (NEFMC 2019), Hydra has been parameterized to represent a ten-species fish community on Georges Bank. The model includes length-structured population dynamics and predation, and a flexible specification for fishing fleets that target one or more of the modeled species. Multiple forms for growth and recruitment are implemented and environmental covariates on these processes can be included, similar to modeled climate impacts in the groundfish MSE framework. Simulations presented in Gaichas et al. (2017) included temperature-dependent consumption for all species. Similar to many multispecies population dynamics and fishery assessment models, Hydra does not include a direct feedback between prey consumption and predator growth, but this can be represented via forcings on growth functions. In an ongoing project we are also currently converting Hydra from a simulation to an estimation model, statistically fitting the model to both fishery dependent and fishery independent data (CINAR/WHOI #A101442/37077405). Hydra is implemented in ADMB (Fournier et al., 2012) and the model code is publicly available on GitHub, as is a nascent diagnostics package to assess model behavior (https://github.com/NOAA-EDAB/hydra_sim & https://github.com/thefaylab/hydra_sim, https://github.com/thefaylab/hydra_diag).

There are several features of the Hydra model that make it suitable for this project:

- Multispecies length-structured model, includes trophic interactions among modeled species and size-based mortality (e.g. predation of smaller fish by larger fish)
- Already parameterized for a subset of stocks on Georges Bank
- Flexible fishing fleet implementation

- Ability for externally forced drivers of population productivity and growth
- Existing supporting diagnostics and data processing for input files
- Reviewed as part of the 2018 Center for Independent Experts review of the NEFSC Ecosystem-Based Fishery Management Strategy
- Familiarity of the model with the NEFMC EBFM committee through its use in the eFEP worked example simulation analyses
- Code and development and diagnostics publicly available on GitHub.

Our initial scoping and problem framing workshops and planning conversations with Council staff, the EBFM Committee and PDT, and the SSC (Phase 2) will provide an opportunity to refine and further develop the operating model. For the purposes of this project, these initial conversations will define a small set of operating model scenarios, limiting operating development according to our timeline to allow focus on MP development and MSE model results demonstration.

Key operating model development tasks and decision points that will form part of the project:

- **Embed Hydra as an operating model into the MSE loop within the MSE framework** software to allow updating of operating model population dynamics given output of management procedures and implementation models. Hydra is already set up to run in simulation mode with population dynamics responding to given input catches and/or effort. This functionality was used in the eFEP worked example analyses.
- **Write code to generate age composition data based on Hydra length composition output**. Hydra is a length-structured model, tracking length composition of each modeled fish population in a similar way that age-structured models track age composition. To support the use of age-structured models as assessment models within our pMSE (described below), we will write functions to translate the Hydra length structure to a simulated age composition, based on the Hydra growth functions (so as to be internally consistent). We will build on work we have performed with NEFSC as part of Key Runs analyses for the ICES Working Group for Multispecies Assessment Methods (WGSAM, https://www.ices.dk/community/groups/pages/wgsam.aspx) to translate model output between models and code we have developed as part of the `atlantisom` R package (https://github.com/r4atlantis/atlantisom) with Dr. Sarah Gaichas at NEFSC on preparing Hydra input files.
- **Include an environmental driver to link deviations in annual recruitments among species to reflect systemic changes in productivity**, emulating the effects of time-varying ecosystem productivity that leads to dynamic reference points (in addition to those resulting from trophic interactions). Hydra does not include phytoplankton forcing and so this functionality will emulate this desired property in the modeled ecosystem dynamics to understand the implications given options for management in the eFEP. Plausible alternatives for the parameterization of this driver will be based on existing work to correlate climate drivers and ecosystem indicators with recruitment of relevant stocks.
- **Species selection.** We propose to initially use the existing ten-species parameterization of Hydra, with some scope for expansion of species if needed based on our early engagement (Phase 2). Additional data and species information to support inclusion of additional stocks and their parameterization will come through application of functions that query the NEFSC bottom trawl survey database with the `survdat` R package (S. Lucey, NOAA NEFSC, pers. comm. https://noaa-edab.github.io/survdat/) and additional NEFSC MS-KeyRuns work (S. Gaichas, NOAA NEFSC, pers. comm). Our scope will aim to include the minimum number of species that can allow for illustrative exploration of the range of initial Management Procedures, Management Objectives, and Performance metrics intended for this prototype.

For this pMSE process, it will not be necessary to include every species in a given management plan or caught by a particular gear to understand performance and the needed decision points for how EBFM strategies might operate. Possibilities for including the impacts of fishing and consequences of management procedures for additional species that are not directly part of the operating model is to include them as part of the suite of performance metrics, given expectations for consumption requirements (e.g. energetic needs for top predators) or known technical interactions (e.g. quantifying removals for bycatch stocks).

- **Fishing fleet dynamics representation**. One additional advantage of using Hydra is that fishing can be modeled as size-based mortality process, with linkages among species due to size-based selectivity and relative catchababilities among stocks. This, coupled with several options for modeling implementation error (difference between advised and realized catches) within the groundfish MSE framework, provides the capability to include the effects of technical interactions that result in linked fishing mortality among stocks. We propose to use a simple fleet-based approach to modeling technical interactions but will discuss the feasibility of other simple approaches within the current software during initial problem framing and model scoping discussions. Extending the fishing fleet model to include dynamic representation of targeting behavior is beyond the scope of this project but our MSE framework does have the capability for extensibility to include this in additional future applications.
- **Initialization and Operating Model Scenarios.** The operating model will be conditioned to represent current conditions for the modeled stocks, based on the existing parameterization, current estimates of stock abundance, preliminary fits to data and estimated recruitment time series and growth. For this prototype MSE, a small set of operating model scenarios will be chosen in consultation with stakeholders, the technical advisors (PDT and SSC), and Council staff. These scenarios will be chosen to help meet the objectives of the analysis and to understand likely performance of selected management alternatives given key uncertainties and research questions, to be fully described during scoping and problem framing (Phase 2). We will frame the discussion of alternative operating model scenarios given alternative expectations for future stock productivity (which could include alternative initial stock status based on historical stock sizes), including climate change effects on future growth and recruitment, and alternatives for fishing fleet dynamics that vary the flexibility (or otherwise) of technical interactions among species, to understand how changes in the ability to target individual stocks/species may intersect with the various management alternatives. We will ensure at least one operating model scenario (if not the base case) will model one or more species in a depleted state to help achieve the goal in the RFP of understanding ecosystem-based management procedure performance relative to single-species management for responding to and recovering overfished stocks.

Assessment Models

Assessment models in the MSE will include single-species population dynamics models, aggregated complex population dynamics assessment models, and index-based methods, fit to the data generated from the operating model. This will enable emulation of both the current assessment and management basis (i.e. single-species), and procedures described in the eFEP that leverage stock complex estimates of productivity (e.g. assessment models fit to data aggregated over two or more species), and single-species abundance relative to thresholds (e.g. index-based methods).

- The groundfish MSE software has functionality to use (write input files for, run models, and incorporate output of) statistical age-structured assessment models that are predominantly the current basis for catch advice in the region. This includes ASAP (Legault and Restrepo 1998) and a generic, simpler statistical catch at age model. The state-space age-structured Woods Hole Assessment Model (WHAM, Stock and Miller 2021) is currently being added to the framework.

- Our index-based assessment method will compare survey abundance index (and/or its trend) with a reference point (described below in the MPs). This will be able to be applied at either the single species or aggregate species level. This type of assessment (similar to the 'planB smooth' method used for some New England stocks) will be used to provide the management procedures with information about stock status relative to floors. Alternative implementations for index-based methods are available via work we performed for the 2020 Index-Based Methods Research track stock assessment (NEFSC 2020), and via the R package DLMtool (Carruthers et al. 2018).
- We will add an additional assessment model, a surplus production model, to the MSE framework, to create functionality to fit aggregate stock complex models (e.g. Gaichas et al. 2012, Nesslage and Wilberg 2019, NEFMC 2019) to catch and abundance index information generated from the operating model. We will use existing state-space surplus production modeling software such as available functions in the MSEtool R package (Hordyk et al. 2022).

Our proposed project thus does not include an assessment model that is a multispecies population dynamics model (models multiple species simultaneously - the aggregate production model considers multiple species but does not model their individual dynamics). We feel that this complexity and the additional scope of decision points that applying them as an assessment model within an MSE creates is beyond the scope for the timeline and for the necessary demonstration of how the management procedure approaches described in the NEFMC's eFEP (NEFMC 2019) could operate. Consideration of the performance and benefits of using tactical multispecies models within EBFM procedures is a natural step for further development in a broader MSE process.

Management Procedures

The full set of management procedures that will be tested in the pMSE will be derived through engagement with stakeholders during the management procedure workshop component of the engagement activities (see Table 1 and Phase 2). A goal for the pMSE is to more clearly communicate and demonstrate the necessary steps associated with the approaches to EBFM outlined within the eFEP. The management procedure workshop will provide the opportunity to identify with stakeholders the decision points associated with a management procedure, which includes (but is not limited to) the type(s) of assessment methods, the aggregation (or not) of species in to species complexes, evaluation of individual and aggregate stocks to single-species and stock complex level reference points, the determination of those reference points, the functional forms for how catch advice is adjusted based on assessment results relative to reference points, and then rules for how advice and fishing mortality is realized given allocation to fishing fleets, stock complexes, and constraints imposed by technical interactions.

The NEFMC eFEP outlines a system of managing stocks via aggregates or stock complexes, with a system of ceilings placing limits on total and/or stock complex exploitation levels (or catch magnitude), and floors representing abundance levels (or proxies for them) at which management advice is triggered to reduce exploitation on vulnerable or depleted stocks (NEFMC 2019), an approach adapted from that described by Fogarty (2014).

A primary goal for the pMSE is to understand how management procedures based on the system of ceilings and floors outlined in the eFEP can be expected to perform compared to status quo management approaches (e.g. single-species management) and to demonstrate how these ecosystem-based approaches can provide flexibility in management thus improving performance while also ensuring the approaches satisfy the requirements for preventing overfishing and rebuilding depleted species as defined by the National Standard Guidelines.

Our linked MSE framework provides the platform for testing the performance of both status quo management approaches and the NEFMC eFEP approaches given the context of operating model system dynamics that include trophic interactions and ecosystem drivers that lead to time-varying dynamics reference points in the operating model dynamics, even if these are not accounted for in the management procedure (such as is typically done under single-species management). By including age-structured assessment models in the MSE framework we can compare the eFEP approach to the single-species tools that are currently applied in the region and compare their performance. To implement the ceilings and floors approach within our model framework we will adapt and expand on R code created for our worked example for catch advice under the ceilings and floors approach that was included as part of the draft eFEP (https://gavinfay.shinyapps.io/ebfm-ne-teaching-eg/).

The range of management procedures will include:

- Single-species assessment and management with no adjustment of reference points for underlying operating model dynamics (status quo)
- Single-species assessments and catch advice with dynamic reference points (building from the COCA-funded groundfish MSE work)
- Stock complex-based assessments with ceilings and floors based on abundance index thresholds
- Status quo assessment approaches with ceilings and floors
- Stock complex assessments with dynamic ceilings and floors, which will include rules for allocating catches to species/fishing fleets

These will be designed with our stakeholders and advisers to bound the range of possible options under the eFEP approach while providing a manageable number of procedures to compare and run during the project period.

Performance Metrics will be developed with stakeholders that address the ability to compare the performance of both status quo management approaches and the eFEP approaches. These metrics will include conservation status of individual stocks and stock complexes, and fishery and economic metrics. Stock status metrics will be calculated both from operating model quantities and the perceived status based on the results of the applied assessment methods within the management procedures.

Phase 2: Stakeholder interaction and facilitation

We plan a sequence of stakeholder engagement activities and interaction throughout the project period (Table 1). These engagement activities include a series of workshops with the Council-identified group of stakeholders (EBFM Committee members, Advisory Panel Chairs, and others), technical advisors (the members of the EBFM PDT and SSC), and frequent interaction with Council staff. The timeline of activities under Phase 1 is designed to support the Phase 2 activities, in that each opportunity for interaction with the stakeholder group will allow for update and review of work completed, direction of the modeling and simulations, and decision points for the software components, in addition to defining scope, objectives, performance metrics, and management procedure alternatives.

The stakeholder workshops will be a series of half-day meetings (sequence in Table 1), facilitated by a dedicated project staff member (UMassD-SMAST decision support specialist M.Guyant), who will prepare materials for distribution, lead discussions and group whiteboard activities, and assemble and distribute workshop summary reports following each workshop. We will make use of existing presentations, web applications, and tutorial materials on MSE and EBFM that we have already used in stakeholder processes for MSE, and also the EBFM education and outreach materials already prepared by the NEFMC. The stakeholder workshop meetings may be held in-person or online if required by COVID protections. Our team has extensive experience with holding and facilitating remote and in-person workshops and discussions. We envisage large parts of workshops being in active discussion and co-creation of MSE components, but will include time on agendas for updates and presentations from the project team on progress, which will allow for iteration and continued feedback and direction on MSE decision points and analyses. Our budget also includes hourly time for dedicated rapporteurs during these workshops, ensuring that the modeling staff and stakeholder group, including Council staff, can engage fully in the discussions and workshop activities. Primary topics and decision areas for each of the stakeholder workshops (Table 1) are:

- **Scoping workshop:** problem framing, review goals for the pMSE and determine research question scope, including the choices for modeling components to understand software development needs in the project (e.g. alternatives/extensions to the proposed framework), extent of operating model scenarios, species to include, and specific questions the pMSE analyses will be applied to.
- **Objectives and Performance metrics workshop:** identify the fundamental and means management objectives for the pMSE analyses, and develop a suite of quantitative performance metrics that can be calculated and used to assess how the chosen management procedures are able to meet the management objectives. Identification of visualization tools and summary graphics that can support interpretation of performance metrics.
- **Management Procedure workshop**: develop the set of management procedures (combinations of monitoring, species complex aggregations, assessment methods, and types of control rules) to be tested within the pMSE; outline and work through the needed steps and decision points associated with each management procedure, and identify gaps associated with implementation that can and can not be addressed within the pMSE analyses.
- **Modeling workshop:** overview, review, and discussion on the modeling software and model scenarios, including technical details of operating models, MSE closed-loop simulation structure, and management procedure implementations.
- **Preliminary results workshop**: walk-through of preliminary results for initial pMSE scenarios, with review of graphic and other presentations of results, including comparison among a subset of management procedures. Opportunity for stakeholder group to see a small version of the final results format, and for project team to learn and revise presentation/communication tools as well as identify needed changes for final analyses.
- **Final results workshop:** presentation of pMSE results including comparison of performance among management procedures and tradeoff analysis, supported by interactive Shiny application for results viewer. Identification of key pMSE outcomes, and recommendations for further model development, data synthesis, and exploration of alternative candidate management procedures that could be included in the next stage of the Council's EBFM MSE process (e.g. a broader public stakeholder-based MSE).

In addition to the sequence of workshops with the identified stakeholder group, we also include planning meetings with Council staff and the EBFM Committee and PDT in the initial stages of the project, continued dialogue with the technical advisors (PDT) during the project, and weekly meetings of (at least) the modeling postdoc and PIs with Council staff to review progress. We will also present workplan and the final results and report to meetings of the Council's Scientific and Statistical Committee (see Table 1 for timeline details). Given the extensive amount of engagement activities through the project period, we anticipate many of these meetings with PDT and Council staff to take place remotely via web conference call.

Documentation of meeting minutes and workshop outcomes will be curated through a Google Drive or similar file sharing method, ensuring that all participants in the pMSE have full access to materials and can review documents asynchronously in addition to during workshops and meetings. We will also make use of web surveys (e.g. via Google Forms) if it is necessary to generate additional discussion and response from the stakeholder group during the pMSE. Our workshop facilitator will also distribute a pre- and post- evaluation survey to the stakeholder group that the Council can use to assess the effectiveness of the pMSE in meeting the educational goals of providing the Council in gaining experience with the MSE process.

Phase 3: Presentation and summary of results

Through our stakeholder workshops we will identify and discuss options for summarizing and communicating results, this will be done in tandem with MSE component development and discussion. For example, during determination of the set of performance metrics we will also share options for how those performance metrics may be presented, for example in the form of graphics and tables. We will make use of existing code and visualizations from MSE applications conducted by our team, including those already developed as part of the groundfish MSE framework we propose to use. Examples of visualizations for model results will include decision tables, boxplot and tradeoff plot comparisons of management procedure performance for the different model scenarios, as well as interactive results viewer in a R Shiny application. Documentation of MSE process, project management, workflow, decision points, model technical specifications, and tutorials will be done through the GitHub repository via project board and wiki, ensuring that the materials are updated alongside the software development as part of the same consistent set of products. All code for the pMSE analyses will be posted and publicly available on GitHub. We will make use of flow diagrams and infographics to represent modeling structure and the sequence of decisions within each management procedure, as both a documentation and communication tool and also as a way of generating discussion during meetings and workshops about the necessary parameterization or choice of values for each decision point. We will also use simple Shiny applications in workshops that demonstrate one or more particular aspects of management procedure operation to help stakeholders understand and work through management procedure options, such as our worked example for catch advice under the ceilings and floors approach that was included as part of the draft eFEP (https://gavinfay.shinyapps.io/ebfm-ne-teaching-eg/).

For our results workshops, we will also develop a R Shiny web application results viewer that will allow users to explore modeling results and select alternative visualizations and comparisons for the range of performance metrics, management procedures, and operating model scenarios. Our team has experience creating R shiny applications and we will adapt applications that have already been used to show results for the groundfish MSE framework. Code for this results viewer shiny will also be made available on GitHub. As with the modeling components, the communication tools and materials, including shiny applications, will be shared with the stakeholder group as early as possible during the project period, both to familiarize stakeholders with them and how the results can be expected to be presented, and to allow for iteration on effective products based on feedback during workshops and meetings.

The short time-frame for the project period in the RFP necessarily limits the scope of analyses that can be performed within the pMSE. Although this is consistent with the illustrative, educational nature of this prototype MSE we recognize that the analyses and resources leveraged in our proposal may not cover the full suite of goals that a pMSE could explore. Potential amendments to the six month project period would allow for some additional model development, which could include additional complexity to one aspect of the operating model, or additional operating model scenarios, or additional flexibility and configuration associated with management procedures. We anticipate that this work would also require additional engagement with our stakeholder group and so include time for two additional meetings or workshops during this period.

Deliverables

Timeline for deliverables during the project period is included in Table 1.

1. *Develop an overall work plan and calendar for operating model development, MSE analysis, and stakeholder meetings;*

Our initial work plan calendar is described in Table 1. As outlined in the initial weeks we will work with Council staff, the EBFM committee and PDT to refine and adapt this schedule.

2. *Participate and lead discussions at stakeholder meetings;*

See Phase 2 description above and schedule of stakeholder meetings detailed in Table 1.

3. *Meet as needed with the EBFM PDT, the EBFM Committee, and selected stakeholders chosen by the Council;*

Our Phase 1 and Phase 2 descriptions of work includes our intended schedule for these interactions. We will aim to alternative engagement between the stakeholder workshops and the technical advisors (EBFM PDT, EBFM Committee) to allow for progression of the work (Table 1).

4. *On a weekly basis, discuss progress with Council staff to receive interim feedback and Guidance.*

The PIs and postdoc will set up a regularly scheduled weekly conference call with Council staff throughout the project to review progress and discuss needed directions for the work. Additional project team members may join these calls when this is necessary.

5. *Make programs and software developed for the pMSE available to the Council, including the parameterized operating models, the estimation model, the closed loop simulation programs, and the Shiny App.*

As detailed in Phase 1 and Phase 3 description above, all model code and documentation for its use and specification, as well as that for the Shiny application results viewer and other communication products, will be posted on GitHub, with collaborative development via GitHub during the project. At the end of the project a virtual container (e.g. Docker image) will be created with the final code, results, and versions of software used to generate them to enable future reproducibility of the pMSE analyses.

6. *Prepare a final report that analyzes and summarizes the MSE development, analyses, and results.*

A final report will be submitted at the end of the project period (03/31/2023), which will include full detail of the analyses, and engagement activities. We anticipate that additional changes may need to be made based on review feedback from the SSC depending on when it is possible to schedule presentations of results to these groups. As described in Phase 2 above, following each workshop a summary report will be produced and distributed documenting decisions, scope, and model structure choices. These will be included in the final report. A google drive (or similar) of the materials created during the project and used during engagement activities will also be included as part of the final report.

Senior Personnel

Dr. Gavin Fay (PI), Associate Professor of Fisheries Oceanography at the University of Massachusetts Dartmouth School for Marine Science and Technology (SMAST) has over 14 years experience with fisheries management and stock assessment modeling, including facilitating collaborative modeling groups, and performing Management Strategy Evaluation simulations and communicating results to decision-makers, including in the Northeast US and internationally. Dr. Fay is a member of the NEFMC's EBFM Plan Development Team (PDT), and he also serves on the MAFMC Scientific and Statistical Committee. In this latter role, he is working on the technical and modeling working group for the MAFMC's summer flounder recreational discards MSE, developing and running simulation models and presenting results. Dr. Fay will oversee project logistics, and manage project and budget administration, working with the available existing administrative support at the University of Massachusetts Dartmouth in SMAST and the Office of Research Administration. Dr. Fay will support work to couple the modeling frameworks and help develop the architecture for implementation of the EBFM management procedures. He will supervise work by the postdoc and workshop facilitator and participate in stakeholder meetings and will contribute to documentation of pMSE process and results in presentations and reports.

Dr. Lisa Kerr (co-PI), Research Scientist at GMRI, is an expert in simulation modeling and groundfish population dynamics. She has extensive experience in MSE and is actively involved in the fishery management process both regionally (New England Fishery Management Council's Scientific and Statistical Committee) and internationally (ICES Stock Identification Working Group and U.S. Delegate to ICCAT). She will support work to integrate the multispecies operating model into the existing Groundfish-MSE framework . She will supervise work by the quantitative research technician (J. Jerelle) and participate in stakeholder meeting and will contribute to the synthesis of results in presentations and reports.

Roles and responsibilities for additional project staff are detailed in the budget justification below.

Examples of relevant publications (detailed below) conducted by the PIs are attached following the CVs, relevant technical reports can be found at the following links (to preclude excessive file length):

Fay, G., J.S. Link, S.I. Large, and R.J. Gamble. 2015. Management performance of ecological indicators in the Georges Bank finfish fishery. ICES Journal of Marine Science 72: 1285-1296.

Fay, G. and G.N. Tuck. (eds.) 2011. Development of a multi-gear spatially explicit assessment and management strategy evaluation for the Macquarie Island Patagonian toothfish fishery. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 181p. https://www.afma.gov.au/sites/default/files/uploads/2010/06/rr2008_0873_toothfish2011.pdf?9370a8

Hart, A.R., G. Fay. 2020. Applying tree analysis to assess combinations of ecosystem-based fisheries management actions in Management Strategy Evaluation. Fisheries Research 225:105466

Hart, A.R., G. Fay, and D. Boelke. 2017. Draft impacts of Amendment 8 ABC control rule alternatives. Report to the September 2017 New England Fishery Management Council Atlantic Herring Advisory Panel and Herring Committee. 108 pp. https://s3.amazonaws.com/nefmc.org/7.Draft-impacts-of-A8-ABC-control-rule-alternatives.pdf

Kerr, L.A., Cadrin, S.X., Secor, D.H., Taylor, N.G. 2017. Modeling the implications of stock mixing and life history uncertainty of Atlantic bluefin tuna. Canadian Journal of Fisheries and Aquatic Sciences. 74(11): 1990–2004.

Kerr L.A., Weston A.E., Mazur, M.D., Cadrin S.X. 2020. Evaluating the Impact of Inaccurate Catch Information on New England Groundfish Management. Report to the New England Fishery Management Council. https://s3.amazonaws.com/nefmc.org/2.-Report_-Eval_of_Inaccurate-Catch_7.15.20.pdf

Mazur, M., Cadrin, S., Jesse, J., Kerr, L. 2021. Evaluation of Alternative Harvest Control Rules for New England Groundfish. Report to the New England Fishery Management Council. https://s3.amazonaws.com/nefmc.org/1aii_Summary_HCR_Evaluation_Report.pdf

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Fogarty, M.J., 2014. The art of ecosystem-based fishery management. Canadian Journal of Fisheries and Aquatic Sciences, 71(3), pp.479-490.

Fournier, D.A., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A. and Sibert, J., 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software, 27(2), pp.233-249.

Gaichas, S., Gamble, R., Fogarty, M., Benoît, H., Essington, T., Fu, C., Koen-Alonso, M. and Link, J., 2012. Assembly rules for aggregate-species production models: simulations in support of management strategy evaluation. Marine Ecology Progress Series, 459, pp.275-292.

Gaichas, S.K., Fogarty, M., Fay, G., Gamble, R., Lucey, S. and Smith, L., 2017. Combining stock, multispecies, and ecosystem level fishery objectives within an operational management procedure: simulations to start the conversation. ICES Journal of Marine Science, 74(2), pp.552-565.

Hordyk A, Huynh Q, Carruthers T (2022). MSEtool: Management Strategy Evaluation Toolkit. R package version 3.5.0, https://CRAN.R-project.org/package=MSEtool.

Kerr L.A., Weston A.E., Mazur, M.D., Cadrin S.X. 2020. Evaluating the Impact of Inaccurate Catch Information on New England Groundfish Management. Report to the New England Fishery Management Council. https://s3.amazonaws.com/nefmc.org/2.-Report_-Eval_of_Inaccurate-Catch_7.15.20.pdf

Legault, C.M. and Restrepo, V.R., 1998. A flexible forward age-structured assessment program. ICCAT. Col. Vol. Sci. Pap, 49, pp.246-253.

Mazur, M., Cadrin, S., Jesse, J., Kerr, L. 2021. Evaluation of Alternative Harvest Control Rules for New England Groundfish. Report to the New England Fishery Management Council. https://s3.amazonaws.com/nefmc.org/1aii_Summary_HCR_Evaluation_Report.pdf

NEFMC. 2019. Draft Example Fishery Ecosystem Plan for Georges Bank. Document prepared by the Ecosystem Based Fishery Management Plan Development Team, presented to the January 2019 meetings of the New England Fishery Management Council and Ecosystem-Based Fishery Management Committee. 83 p.

NEFSC. 2020. Draft Report of the Index-Based Methods Working Group. NOAA Fisheries / NRCC Research Track Stock Assessment CIE Review. 59p.

Nesslage, G.M. and Wilberg, M.J., 2019. A performance evaluation of surplus production models with time-varying intrinsic growth in dynamic ecosystems. Canadian Journal of Fisheries and Aquatic Sciences, 76(12), pp.2245-2255.

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Stock, B.C. and Miller, T.J., 2021. The Woods Hole Assessment Model (WHAM): a general state-space assessment framework that incorporates time-and age-varying processes via random effects and links to environmental covariates. Fisheries Research, 240, p.105967.