**Priority Table**

|  |  |  |
| --- | --- | --- |
| Develop analytical tools and methods to support stock assessment and science advice | What tools/methods could enhance the provision of science advice in stock assessment or rebuilding plans that consider effects of environmental variables (climate, freshwater, oceanographic and ecosystem factors) on stock dynamics, productivity or catchability (for example, development of ecosystem summaries based on transparent, traceable and transferable data for use in multiple stock assessments)? | 2024-25-17 |

**4.1 Project Title**

Establishing a Robust Approach to Adding Critical Ecological Credibility to Stock Assessments

**5. Research Team**

PI: Yanjun Wang

Collaborators: Tom Carruthers, Melanie Barrett, David Keith, Kathryn Cooper-MacDonald

**7.1 Project Research Question:** Clearly detail the question around which you are centering your research proposal. Ensure the question is focused and concise. **(60 words max)**

How to utilize Expectation Maximization (EM) approach to incorporate ecosystem considerations in stock assessment methods to inform science advice to fisheries management?

**7.2 Project Summary:** Summarize your project proposal. If the application is successful, this description will be posted to the DFO internal CSRF Funded Projects webpage. **(250 words max)**

The revised *Fisheries Act* in 2019 states that environmental conditions affecting the fishery stock shall be taken into account when maintaining and rebuilding stocks. To meet this obligation, Fisheries and Ocean’s Canada (DFO) initiates an Ecosystem Approach to Fishery Management (EAFM) for the development of single-stock advice.

A fundamental bottleneck in implementing EAFM is developing scientifically defensible stock assessment approaches that account for more complex ecosystem processes. Conventional stock assessments are poorly equipped to account for ecological processes outside of the single-stock paradigm (exceptions are Trites et al. 1999; and Mace 2001). Established techniques are however available that can incorporate additional complexity not reliably estimated from typical datasets, but these have not yet been developed for assessment models. The focus of this methodological study is Expectation Maximization (Dempster et al. 1977; Sammaknejad et al. 2019), an established algorithm for informing latent processes that are not directly observed using an iterative numerical approach.

We propose developing the EM-assessment approach for a high priority case study: Eastern Georges Bank (EGB) haddock. A Canada/U.S.A. transboundary stock, EGB haddock, has been among the most commercially important fisheries for both countries for over a century. Recent research suggests that the natural mortality (M) of haddock is strongly affected by density-dependence in response to extraordinary year classes (TRAC 2020, 2021; Kronlund et al., 2022). Quantifying the contribution of these processes that cannot currently be included in the assessment is vital for correctly evaluating stock status, forecasting the impact of fishery management options and designing management strategies.

**7.3 Addressing Knowledge Gaps:** Explain how this project would address the critical knowledge gap identified by the *Specific Question* in section 2. Clearly indicate how the research would advance scientific understanding beyond what is already available in the scientific literature, and how it would benefit the Department. **(300 words max)**

The project will address two important knowledge gaps: (1) the methodological gap in developing defensible stock assessments that can incorporate time-varying ecosystem dynamics and (2) empirical understanding of the time-varying density-dependent M for EGB haddock.

1. The methodological gap addressed by EM is large, important and pressing for the general discipline of stock assessment. It is particularly relevant to Canadian fisheries that are experiencing changing environmental conditions due to climate change and recovering populations of marine predators. Importantly the approach is broadly applicable to a range of assessment model platforms. Although M is typically among the most influential inputs determining the estimates and advice arising from a fishery stock assessment, it is generally unobserved and difficult to measure. Therefore, it is often treated as a constant in stock assessments, a clear case of model-misspecification for a dynamic parameter that changes with, for example, density-dependent competition for resources (food, habitat) or abundance of predators (Power 2014; Mannini et al., 2020).
2. Constrained by current assessment convention, the current EGB haddock assessment does not explicitly account for density-dependent M. Instead, an ad hoc approach is used to project M scenarios based on averaging M during a high biomass period. Concerns about how M should be adjusted as the recent strong cohorts leave the population, and uncertainty in M in the projection period led to no consensus on science catch advice in the recent stock assessments (TRAC 2022, 2023). Furthermore, the Transboundary Management Guidance Committee were unable to agree on the most appropriate combined Canada/U.S. TAC for EGB haddock for 2023 (TMGC, 2022). Gaining scientific knowledge of EGB haddock is vital to inform the current management decision making. Given the size of the fishery, the value of this empirical information may be very high and influence interpretations of precautionary management decision making given projections.

**7.4 Objectives:** State the objective(s) of the project. Point form is acceptable. **(200 words max)**

Stock assessments are the primary means of providing management advice for data-moderate and data-rich stocks in Canada. Stock assessments aim to characterize historical population and fishery dynamics to quantify stock status, reference points, and undertake projections of candidate management options.

To meet the requirement of EAFM, the overall objectives of this project is to establish a robust EM-Assessment approach to link ecosystem impacts in EGB haddock stock assessment, with better biomass estimates, improved understanding of processes for better predictions, and ecosystem based indicators we can use in science advice to inform fishery management.

This project will:

1. Establish plausible relationships between density and M for EGB Haddock with the EM-Assessment tool; improve the prediction of stock status and develop a robust approach to integrate density-dependent M in the development of catch advice of this important transboundary fishery stock relative to the current assessment model.
2. Build expertise in the technical aspects of EM, as this will be the first application of EM to stock assessment.
3. Define a reproducible framework for doing more complex assessments using any assessment model. For example, this tool can potentially be used to incorporate predator-prey relationship into stock assessment.

**7.5 Methodology:** Outline the methods you will use to achieve the objective(s) of the project. Ensure that concepts and terminology are clearly defined. Reviewers will not consult external resources. **(600 words max)**

EM is an established approach for solving complex problems with latent variables that are not directly informed by data (e.g., density dependence). However, EM has not yet been used in stock assessment to estimate ecosystem and biological phenomena despite the high degree of promise in the method. In this proposed study, we build an EM-Assessment tool, test it by simulation and then apply it to EGB haddock.

This project aims to develop a robust EM-Assessment framework that is applicable to a wide range of problems where ecosystem impacts are likely to be important but not easily accounted for in the single-stock paradigm, with the goal of improving the provision of advice for fisheries managers. The approach can be generalized to include other inter-dependent multi-stock dynamics such as those relating to time-dynamic somatic growth, recruitment regime shifts, simultaneous management of predator and prey species.

Step 1: Build an EM-Assessment tool. Applying EM in this context would use a conventional stock assessment model but place an ‘additional model’ (e.g., density dependence) between runs of the assessment model (Figure 1). Specifically, in the first step we use EGB haddock fishery data to fit a population dynamic model, then link it to the proposed density and M relationship to run the model. The iteratively to estimate parameters. After each iteration of the assessment model run, the input parameters are adjusted slightly according to the predictions of the additional model and the process continues until the method converges on a stable solution. The stable solution arising from this EM-Assessment approach can be subject to typical model diagnostics such as model selection criteria and profiling over the parameters of the additional model.

Step 2: Simulation test the EM-Assessment tool. We will simulate the EGB haddock fishery data to make sure the EM-Assessment tool correctly identifies the simulated relationships between density and M. In addition, the simulation tests will confirm the model selection criteria and likelihood profiling work. Because the EM approach is going to use a conventional stock assessment (e.g., WHAM (Woods Hole Assessment Model), RCM (Rapid Conditioning Model)), no changes to the conventional tools are required and there is unlimited flexibility in the specification of the additional model. Modern stock assessments also run sufficiently quickly (less than a few seconds) to make EM practically viable. Previous applications of EM (e.g., Carruthers et al. 2019) found highly complex models involving hundreds of populations could converge on a stable solution in less than 15 iterations (Figure 2).

Step 3: Apply the EM-Assessment tool to real EGB haddock fishery data. The stock assessment lead and resources managers are included in the research team. All data and code will be shared on an appropriate platform (e.g. GitHub), and progress of the project will be updated quarterly in MS team meetings for feedback among project team members. Considering the EGB Haddock case study is closely linked to the non-consensus in Science advice from the current EGB Haddock TRAC (Transboundary Resource Assessment Committee) assessment model, both Tom Caruthers who was the developer of the stock assessment model and David Keith who has recently reviewed the EGB Haddock stock assessments are included on the project team to provide their expertise on the proposed EM-Assessment tool. The final well defined EM-Assessment tool will be documented in a TRAC working paper and presented at TRAC meeting for review. With an explicitly built in density-dependent M relationship, this model will provide better biomass estimates and well-defined predictions with improved understanding of density-dependance processes, and the ecosystem based indicators we can use in TRAC science advice to inform TMGC fishery management.

Step 4: Write and document the EM-Assessment tool in an R package.

Step 5: Write up primary literature for peer review.

**8. Work Plan**

This project will be finished in 3 years.

Year 1:

* Hiring a BI-02.
* Establishing a working group of experts including scientists and managers.
* Compiling EGB Haddock data and fitting to stock assessment model.
* Establishing a data and code sharing platform (e.g. github) which will include links to resources and scheduling quarterly progress updates (virtual) among the working group members.
* Starting to develop EM-Assessment tool and conducting simulation testing.

Year 2:

* Singing a service contract with Blue Matters Science Ltd. for Tom Carruthers’ consultation role and help with building a EM-Assessment tool in a R package.
* Completing development of simulation testing.
* Applying the EM-Assessment tool to the EGB haddock real fishery data, with quarterly progress updates to the working group.

Year 3:

* Presenting the EM-Assessment model at the TRAC stock assessment meeting for peer review.
* Writing up and document EM-Assessment tool in a R package.
* Summarizing the approach in a draft paper for publication in the primary peer-review literature.
* Writing final report and plain language report.

**12. Budget**

Bi-02 ($58,563) + $20,000 consultation fee with Blue Matter Science

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