**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)**

Can the Expectation Maximization (EM) approach be applied to link ecosystem impact to fish population dynamics with the goal of enhancing 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.

Eastern Georges Bank (EGB) haddock, a Canada/U.S.A. transboundary stock, have been one of the most commercially important fisheries species in both countries since prior to 1900. Recent research suggested the natural mortality rate (M) of this stock is affected strongly by compensatory density-dependence in response to a few extraordinary year classes (TRAC 2020, 2021; Kronlund et al., 2022). Quantifying the contribution of compensatory mechanisms would have implication for assessing the stock status and setting fishery management strategy. This highlights the need for ecosystem considerations in the evaluation of stock status and development of advice for subsequent decision-making.

The incorporation of ecological data and model structures into single-species assessments have traditionally been limited (Trites et al., 1999; Mace, 2001). Expectation Maximization (EM, Dempster et al. 1977; Sammaknejad et al. 2019) is an established approach for solving complex problems with latent variables that are not directly informed by data, such as density dependent survival. This project aims to develop a robust EM-Assessment tool so that ecosystem impacts are directly linked to population dynamic modelling, with the goal of improving the provision of catch advice for fisheries managers.

**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)**

M of a fish stock is typically highly influential on the outcome of age-structured stock assessment models, but at the same time almost always unobserved and extremely difficult to measure. Therefore, it is often treated as constant in stock assessments.

However, M of marine fish stocks is a dynamic parameter that will change with density-dependent competition for resources (food, habitat) or predators (Power 2014; Mannini et al., 2020). In the current EGB haddock assessment model, an ad hoc approach based on an estimation of averaging M during a high biomass period is used to account for density-dependent impacts of the strong year classes. As density-dependence M is not modelled explicitly, with recent strong year classes exit the biomass, concerns about how M should be adjusted and uncertainty in M in the projection period led to no consensus on science catch advice in the recent stock assessments (TRAC 2022, 2023), and 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).

Ecosystem models, while useful for characterizing hypotheses, have rarely been used to provide management advice because they rely on a large number of assumptions and struggle to pass peer review.

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 by simulation and then application to EGB haddock. The relationship between density and M is to be modelled explicitly, so the choice of M-scenario would be less ad-hoc and more ecologically plausible with the goal of improving the provision of catch advice for fisheries managers.

**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 two fishery case studies, with the goal of enhancing the ecological credibility in science advice and fishery management decisions.

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)**

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 EM-Assessment tool will be documented in a TRAC working paper and presented at TRAC meeting for review.

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 2 years.

Year 1:

* Hiring a BI-02 and signing a consulting service contract with Blue Matters Science Ltd.
* Establishing a working group of experts including scientists and managers.
* Compiling EGB Haddock data and fitting to stock assessment model.
* Developing the EM-Assessment tool and conducting simulation testing.
* 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.

Year 2:

* Applying the EM-Assessment tool to the EGB haddock real fishery data, with quarterly progress updates to the working group.
* 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 salary ($65,662) or Postdoc ($58,563) + $20,000 consultation fee with Blue Matter Science

**Reference**

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