Mid-Atlantic Fishery Management Council
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MEMORANDUM

Date: March 22, 2023

To: Council

From: Brandon Muffley, Council staff

Subject: Short-Term Forecasts of Species Distributions for Fisheries Management Project: Meeting Materials

On Tuesday, April 4, 2023, the Mid-Atlantic Fishery Management Council (Council) will review the preliminary results of a collaborative research project between the Council and Rutgers University to develop a new and innovative modeling approach for short-term forecasts of climate-driven species distributions. The Council will also provide input on future considerations for continued model development and discuss potential opportunities for the Council to utilize and incorporate this information into different Council initiatives and actions.

Materials listed below are provided for Council consideration of this agenda item.

Materials behind the tab:
- Project Overview: Developing Models to Forecast Near-Term Species Distributions
- Meeting Summary: February 23, 2023 Ecosystem and Ocean Planning Committee and Advisory Panel Meeting
- SSC Input: Response to Short-Term Forecast Research Project Terms of Reference from March 7-8, 2023 SSC Meeting

LENFEST OCEAN PROGRAM

A scientific summary
March 2023

SUPPORTING SCIENCE AND COMMUNICATING RESULTS.

DEVELOPING MODELS TO FORECAST NEAR-TERM SPECIES DISTRIBUTIONS

A project examines dynamic range models as one method to predict economically important stock distributions over 1 – 10 years.

The 2022 Mid-Atlantic State of the Ecosystem Report indicated that the Mid-Atlantic Bight oceanography is changing, the cold pool is becoming warmer, and productivity is declining for many economically important fish species. As such, most research is currently focused on predicting where species will be over the rest of the century- but fisheries managers also need to know where and how fish are moving now.

Understanding short-term species distribution shifts (e.g., over 1-10 years) more closely aligns with management timelines and current stakeholder needs. A project led by Malin Pinsky and Alexa Fredston at Rutgers University and Brandon Muffley with the Mid-Atlantic Fishery Management Council (MAFMC), takes the first steps toward such an approach.

NUTS & BOLTS: HOW THE MODELS WORK

Researchers are taking a retrospective approach to develop these dynamic range models, meaning, they are using data from the past to test if the models can predict things we already know happened. Where they fall short, the researchers are then adjusting the models to better reflect the important biological processes. While not a current focus of this project, this lays the groundwork for developing models that can use projected oceanographic and climate information to make future short-term range forecasts.

IN BRIEF

Guided by priorities in the MAFMC Ecosystem Approach to Fisheries Management (EAFM) Guidance Document, this project aims to use historical data to develop and test a novel modeling method that can help inform near-term management approaches (e.g., 1-10 years) in response to species distribution shifts. Preliminary results show that these dynamic range models have the potential to predict species' ranges in response to changing ocean conditions a result of both climate change and natural variation.

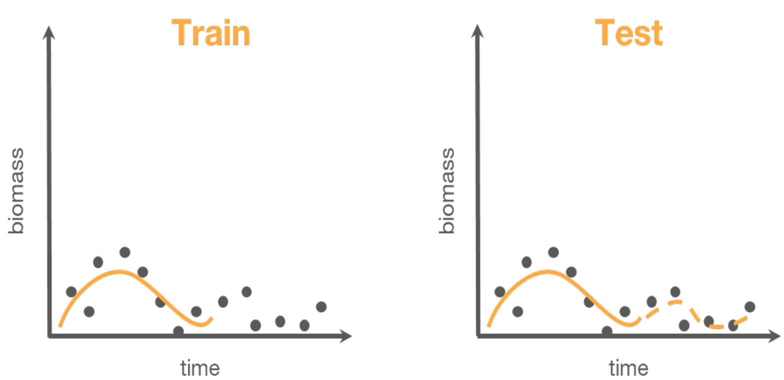


Figure 1

TRAINING VS. TESTING MODELS

A simplified example of how a model trained on data (black dots) from the past (left panel) can predict trends and patterns even in years that were not part of the training data (right panel, dotted line).

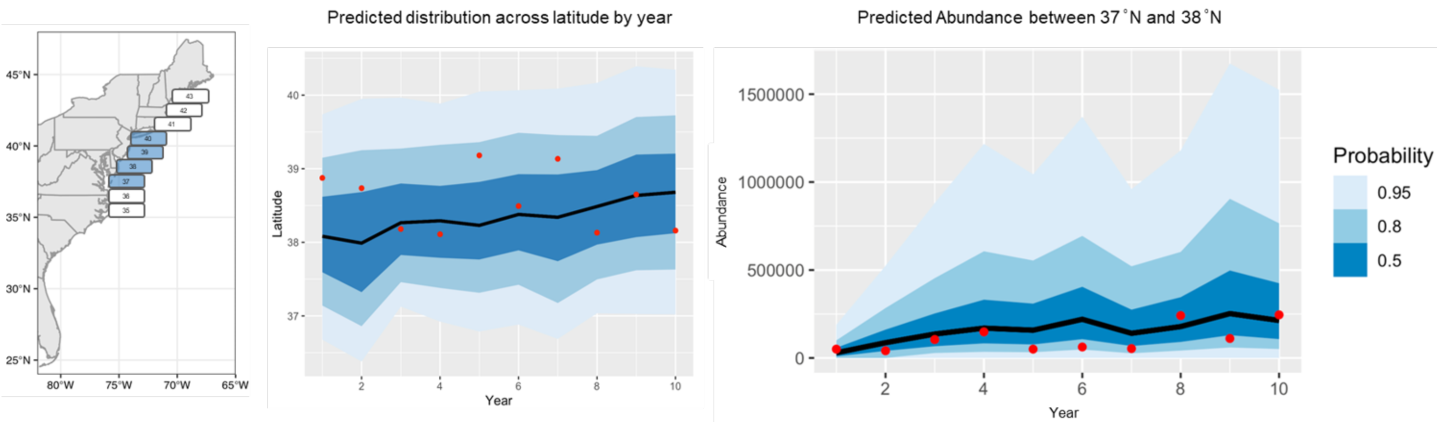
The team is using economically important fish species that exhibit a wide range of life history traits and predicted range shifts, including shortfin squid (short lifespan), spiny dogfish (long lifespan), summer flounder (past range shifts in the Mid-Atlantic), and gray triggerfish (potential shifts into the Mid-Atlantic). The model considers simple population dynamic variables such as recruitment, aging, and death, as well as spatially explicit information such as dispersal and non-biological parameters like fishing pressure.

Using data from the Northeast Fisheries Science Center fall bottom trawl survey during the years 1972-2006, researchers train the model. They then test the forecast accuracy by running the model between 2007-2016. Below are some examples of what the model can do for summer flounder.

Figure 2

EXAMPLE OF OUTPUTS FROM THE SUMMER FLOUNDER MODEL

Looking across certain latitudinal patches (shown on left), when applied to summer flounder, the model closely matched observed population distributions (center). For a specific latitudinal patch, the model also closely followed trends in abundance for that area (right).



PRELIMINARY FINDINGS

- Non-climate factors (e.g., fishing pressure and larval dispersal) influence species distribution.
- Species distributions are highly variable- they often move north to south, and they are not simply "marching up the coast."
- Dynamic range models have the ability to forecast changes in distribution shifts with some skill, meaning, when trained, they can forecast how populations are distributed from year to year.

UTILITY IN MANAGEMENT

The aim is for scientists to produce reliable predictions of species' distributions for management priorities and needs. Once the models are ready, managers can potentially use them in a variety of approaches and management applications, for example:

- Advance priorities outlined in the EAFM Guidance Document and Risk Assessment
- Evaluate future governance and management considerations developed from the East Coast Climate Scenario Planning
- Inform the Mid-Atlantic State of the Ecosystem Report
- Inform adaptive allocation strategies in the future

Developing confidence in these models requires continued feedback and input from managers, stakeholders, and scientists on what information they need and how the models could or could not be used. Thus, the research team has created and maintained open communication channels with the MAFMC Ecosystem and Ocean Planning (EOP) Committee and Advisory Panel, the Scientific and Statistical Committee, and other species distribution model experts to incorporate their feedback throughout the process. As the project nears its end, information gleaned from the Council will highlight opportunities for future research priorities on this topic.

Ecosystem and Ocean Planning Committee & Advisory Panel Meeting

February 23, 2023
Webinar Meeting Summary

The Mid-Atlantic Fishery Management Council's (Council) Ecosystem and Ocean Planning (EOP) Committee and Advisory Panel (AP) met on Thursday, February 23, 2023 from 1:00 p.m. to 3:00 p.m. The purpose of the meeting was for the EOP Committee and AP to provide feedback on the results and future application of a research project the Council is collaborating on with a research team from Rutgers University. The research team is developing forecast models for four economically important Mid and South Atlantic managed species (Summer Flounder, Spiny Dogfish, *Illex* Squid, and Gray Triggerfish) and is testing the forecasting skill of the models to predict short-term (1-10 years) climate-induced distribution changes. The forecast model has been developed, fully tested, and evaluated for summer flounder and will be fitted and applied to the other three focal species. The EOP Committee and AP provided feedback on the model results, potential model utility, and possible future science and management applications.

EOP Committee Attendees: A. Nowalsky, J. Cimino, M. Duval (Committee Chair), P. Geer, K. Kuhn, S. Lenox, T. Schlichter, S. Winslow (Committee Vice-Chair), D. Stormer, W. Townsend (Council Vice-Chair)

EOP Advisory Panel Attendees: W. Goldsmith, F. Hogan, M. Lapp, E. Bochenek, P. Himchak, P. Lyons Gromen, G. Topping, F. Akers, M. Binsted, B. Brady, J. Firestone, J. Hancher

Other Attendees: M. Pinsky, A. Fredston, C. Collier, E. Knight, S. Close, G. DiDomenico, K. Howington, K. Dancy, J. Curtis, K. Wilke, K. Ripple, M. Waine, B. Muffley, D. Potts, K. Almeida, E. Reid, J. Coakley

Dr. Michelle Duval, EOP Committee chair, started the meeting by welcoming everyone and noting this particular project is part of a larger suite of research projects funded by the Lenfest Ocean Program that seek to improve the scientific knowledge of climate-induced changes to stock distributions and help build climate resilience fisheries.

<u>Project overview and results discussion:</u>

Drs. Pinsky and Fredston provided an overview of the project scope, the development and structure of dynamic range models, and the preliminary retrospective forecast results for summer flounder. They are testing whether spatial population dynamic models that include a temperature effect on recruitment, mortality, or adult movement can predict near-term range shifts. The model has been fully developed and tested for summer flounder; though not all model combinations were able to be run and fully analyzed in time for the meeting. However, the results from a sub-set of summer flounder model runs indicate that 1) dynamic range models can forecast distribution changes with reasonable skill, 2) the interannual and short-term changes in distribution are highly variable, and 3) non-climate factors (e.g., fishing pressure and dispersal) have a substantial influence on short-term distribution changes.

All model combinations (temperature effects on recruitment / mortality / movement, and other model options) are currently being run on a supercomputer at Rutgers. Once these runs are complete, the research team will formally evaluate and compare the different combinations and also compare results with other species distribution models (SDM) and identify which model combination(s) have the best forecasting skill. The research team will also begin to identify and obtain relevant data sources for the other three species and begin to build out the models for spiny dogfish, *Illex* squid, and gray triggerfish. They emphasized that thus far, the model has not been used to create future forecasts (i.e., 2023 onward) of distribution; the team has only tested the ability of the model to accurately forecast summer flounder distributions from 2007-2016. Further model development, including the development of oceanographic condition forecasts, will also be needed.

Following the presentation, the EOP Committee and AP provided the following questions and input regarding the dynamic range modeling approach and initial results for summer flounder:

- The group asked for confirmation the model has not yet been developed and run for the other three target species and noted recent presentations to the Council regarding science advancements associated with *Illex* and spiny dogfish. It was recommended the research team connect and start a dialogue with those groups conducting relevant research (e.g., the Squid Squad) to learn about each other's activities and potentially help inform the development of these models.
    - The research team confirmed that the models have not yet been fitted to data for the other three target species. The plan is to complete the models later in 2023 but the timing is still uncertain given the need to use new datasets and adapt the model to different life histories. The research team also notes that model development will be a proof-of-concept application to test how they work for these other species.
- There were several comments regarding the appropriateness of this modeling approach for *Illex*. Some of the concerns raised included: using the NEFSC bottom trawl as the primary data source to train the model given its limited coverage of the *Illex* range, there is no stock-recruit relationship, and there is no approved stock assessment model given the complexities of *Illex* stock dynamics.
    - The research team acknowledged the potential challenges associated with *Illex* and noted that part of the project goals are to understand how well dynamic range models perform with different data limitations, stock dynamics and life history characteristics. In addition, the models don't necessarily need to capture or forecast the entire/global range of a stock and can capture some of local or regional dynamics to help understand how/what might be driving distribution changes.
- Many Committee members indicated that any final model needs to include distribution forecasts that can incorporate or respond to future temperature changes in either direction (i.e., warmer or cooler). This component will be critical should these models have any potential management application.

    - The research team agreed and noted the current model does not make any assumptions about future temperatures and uses existing temperature data from the NEFSC trawl survey to inform the model. There is a temperature dependence function (a bell curve) within the model to inform temperature effects on recruitment, mortality, and movement. The shape of this function allows the model to account for these temperature effects if temperature is warmer or colder.
- Other members of the group expressed concerns about NEFSC trawl data used to inform the model and identified additional data sources for consideration. For example, potential changes in the timing of when summer flounder might be available to the trawl survey due to earlier/delayed seasonal migration patterns may increase the variability in bottom trawl catch. Data from the for-hire sector and insights from fishermen observations should also be considered.
    - The research team did note that the model does account for uncertainty in the trawl survey data, but seasonal migration issues and other data sources could be areas of further exploration in the future.

Project application and utilization feedback:

Council staff then gave a presentation that identified a range of examples on the potential application and utilization of the research project's results in the Council's science and management processes. Potential areas include: EAFM guidance document and risk assessment, east coast climate change scenario planning, the Mid-Atlantic State of the Ecosystem report, dynamic allocation strategies, and marine spatial planning (e.g., offshore wind and aquaculture). Staff noted, however, that the potential application will likely be different across Council managed fisheries and there is no "one size fits all" approach to what information could be used and for what species.

Following the presentation, the EOP Committee and AP provided the following input regarding the potential future application and use of the model and its outputs by Council:

- Similar to comments raised above, the existing and/or future models need to ensure there is a bi-directional temperature component included in order to accommodate potential increase/decreases in temperature and associated stock distribution changes. Similar comments were made during the recent East Coast climate change scenario planning summit as managers consider information that could support management in 20 years.
    - The EOP Committee agreed with this suggestion given that changes in stock distribution can occur in both directions and may not just be a shift north (and/or east). **The Committee recommended a bi-directional temperature function be considered within the modeling framework.**
    - The Committee also wanted to highlight the need to consider these models and their development for South Atlantic stocks to help understand and prepare for continued and future availability within the Mid-Atlantic.
- Some members of the AP did not support the use of these models in management, particularly for any application associated with *Illex* management due to data limitations, model assumptions, and lack of a specific management need. Others expressed concern about the use of these models in spatial allocation considerations, regardless of species, which

would likely result in the loss of allocation to Mid-Atlantic states. In addition, some AP members felt the models need additional refinement and should consider migration/timing issues associated with the NEFSC trawl survey and include other data sources before management application.

- Some Committee and AP members supported the continued model development and indicated the types of information provided by these models are needed for management. Specific areas of potential application noted by members included the EAFM risk assessment and information on the sensitivity of leading/trailing edges of stock distribution changes (the latter was mentioned as an area of research/interest at the East Coast scenario planning summit).

A similar presentation will be given to the Scientific and Statistical Committee (SSC) during their March 7-8, 2023 meeting. The EOP Committee, AP, and SSC feedback will be provided to the Council for their consideration at the April Council meeting.

Mid-Atlantic Fishery Management Council
Scientific and Statistical Committee Meeting

Short-Term Forecast Research Project

Excerpt from the March 2023 SSC meeting report

Malin Pinsky and Alexa Fredston of Rutgers University presented a detailed overview of their project to develop dynamic models for predicting species distributions in response to climate change. Their models combine spatial analyses of historical bottom trawl data with age-based models to create simulated populations in multiple geographical areas or patches. Simulated populations within these geographical patches can migrate north and south in response to environmental gradients of temperature and randomly by using principles of particle diffusion. Incorporation of fishing mortality within the spatial units helps isolate the potentially confounding effects of spatially heterogeneous fishing mortality on the detection of migration in response to environmental change. Currently the geographical zones are based on one degree of latitude intervals. Input data include abundance, biomass, age, and length data from the fall NEFSC bottom trawl surveys, as well as temperature data from a variety sources. The Bayesian hierarchical state space model was fit initially to the 1972-2006 data.

The predictive skill of the Bayesian hierarchical state space model has been tested by comparing predictions for the 2007-2016 period with observations from the bottom trawl surveys. Various metrics of prediction for Summer Flounder suggest reasonably good correspondence with observed population trends and spatial patterns. As in all models, the variation of predictions increases with the length of the forecast. Model outputs of one to five years are most relevant to Council decisions regarding catch regulations. SSC decisions about appropriate levels of uncertainty in assessments and risk policies could also be informed by such forecasts. The authors noted that true forecasts will also require forecasts of oceanographic conditions on similar time scales.

Modeling efforts for *Illex* squid, Spiny Dogfish, and Gray Triggerfish are currently underway. These species were chosen to illustrate the range of possible applications.

The presentation generated considerable interest from the SSC. Questions of clarification included how the model handles observation error in the surveys, concerns about small area estimation, and effects of missing data. Members noted that distributions of most species have major seasonal shifts across depth gradients and inquired about how such changes are handled within the model. Discussions often simultaneously addressed potential applications of the dynamic range models and the need for future work. Conclusions drawn from those discussions are summarized under the Terms of Reference below.

Terms of Reference

For the short-term forecast research project, the SSC will provide a written report that identifies the following:

1) Comment on potential applicability of short-term forecasts of species distribution for stock assessment, science, and management purposes of Mid-Atlantic species. Consider potential implications for the SSC's OFL CV approach;

   - The SSC recognized the significant potential of the models for short-term forecasts for some species. Potential applications include:
     - Model forecasts could be linked to SOE indicators of vulnerability for coastal communities and various social and economic metrics. Investigations of linkages with other SOE indicators are encouraged. EAFM indicators of distributional shifts could be compared with dynamic range model forecasts.
     - Forecasts of distributional shifts could be useful for evaluating recreational fishing performance under various Harvest Control Rules.
     - Evaluation of the feasibility of catch advice relative to the historical distribution of resources.
     - The model could be used as a tool for allocation decisions, particularly if dynamic harvest allocation becomes a possibility.
     - The dynamic range model forecasts may be helpful for interpreting retrospective patterns observed in some species stock assessments.
     - Forecasts may be helpful for interpreting changes in species distributions within and around offshore wind energy areas.
   - The SSC expressed concerns that more validation studies are necessary.
     - Applicability will vary greatly among species depending on the spatial domain of the stock and the type of model being used to assess the stock. Currently there are no spatially explicit stock assessments in the Mid-Atlantic region.
     - The dynamic range models could assist with survey redesign, particularly if animals are leaving the defined stock areas.

2) Provide any research recommendations and inclusion of relevant data for future model development that could facilitate their consideration of factors influencing determination of ABCs.

   - Accommodate ontogenetic population dynamics, and, in particular, ontogeny as it relates to spatial distribution and habitat utilization.
   - Consider alternative patterns of spatial binning. Currently the bins are defined by North/South boundaries, but for many species, distributions along the East/West (or depth) axis may be more important. Thermal preferences of many species vary by age with cooler temperatures preferred by larger individuals. Such preferences often manifest as changes in depth distributions. Future model formulations may benefit by consideration of spatial units defined by both latitude and depth.

- Surveys occur over protracted time blocks and therefore might be considered as a slow-motion depiction of stock distributions rather than a snapshot. In most years, surveys have been conducted with sampling progressing from south to north. The timing and duration of surveys have also varied over time due to logistical and operational factors. Such changes could confound detectability of trends due to climatic change with those attributable to survey timing.
- General patterns of species distribution forecasts should be confirmed by simpler methods.
- Population patches are currently defined by one-degree latitudinal boundaries with no accounting for depth or temperature gradients within patches. Moreover, the width of the sampleable shelf areas, generally <300 m, varies along north-south direction. Accordingly, the number of samples per patch will also vary, resulting in varying levels of precision within the patches. Adjusting the latitudinal boundaries to achieve more even distribution of samples among patches may be useful.
- Consider potential use of spring bottom trawl surveys along with the fall surveys in the definition of dynamic range models.