



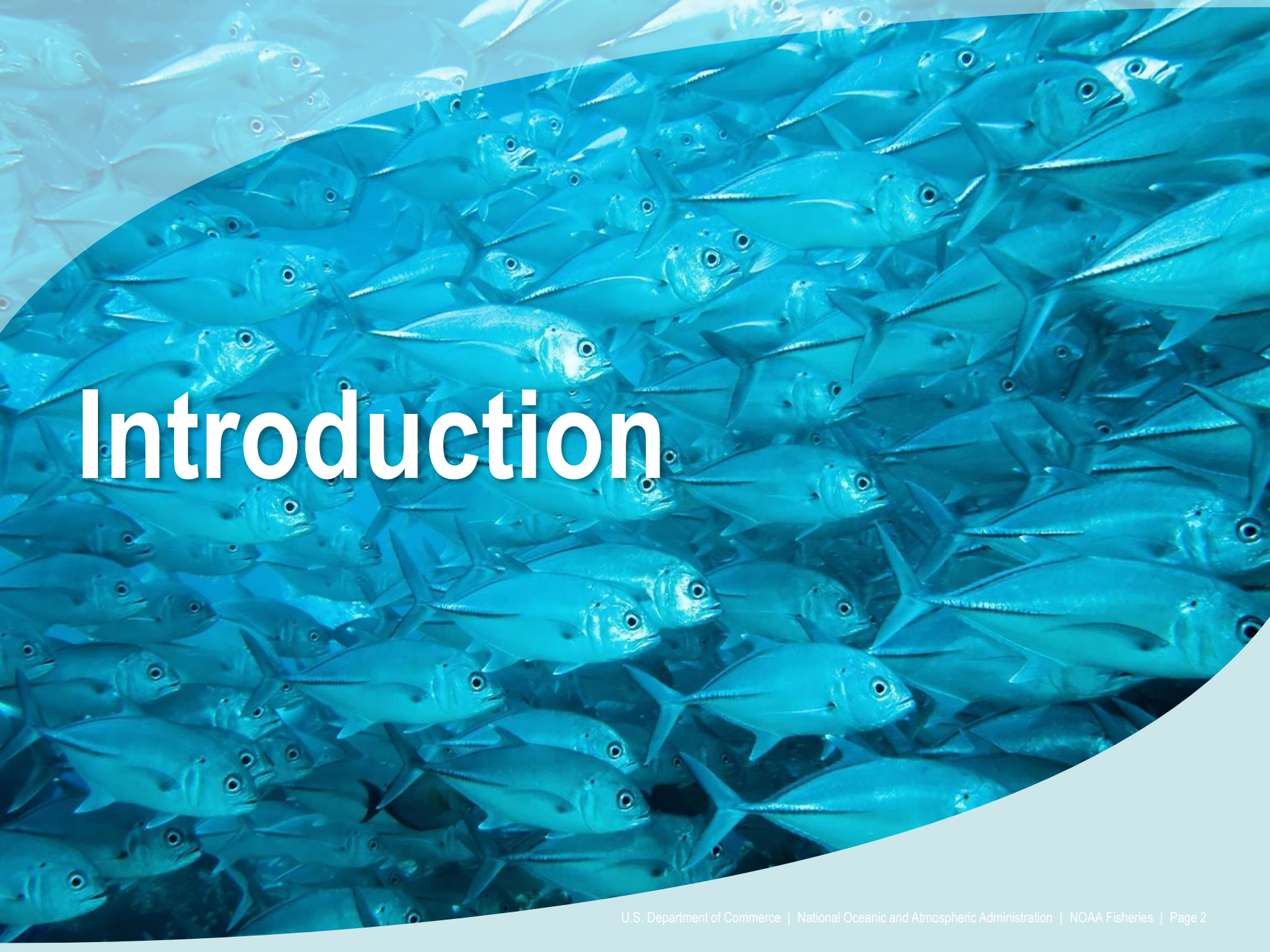
**NOAA  
FISHERIES**

# Climate Vulnerability Assessment 2.0 and the NEFMC Risk Policy

**Katherine Gallagher**

*IBSS in support of NOAA NEFSC*

Climate and Ecosystem Steering Committee  
July Meeting 2026



# Introduction

# Climate Change & Fisheries

- Fisheries impacts due to climate change
  - Distribution shifts
  - Fitness impacts
- Need for process-based (how) and mechanistic (why) understanding of responses to change



Figure 1 from [Melbourne-Thomas et al 2022](#)



# Climate Vulnerability Assessments (CVA)

- Evaluates marine species' vulnerability to climate change by combining trait-based and process-based approaches
- Experts rank life history trait sensitivities and exposure to future climate conditions
- Used by NOAA since 2016 for:
  - Regional and Individual Fish Stocks
  - Protected Species
  - Habitats
  - Fishing Communities

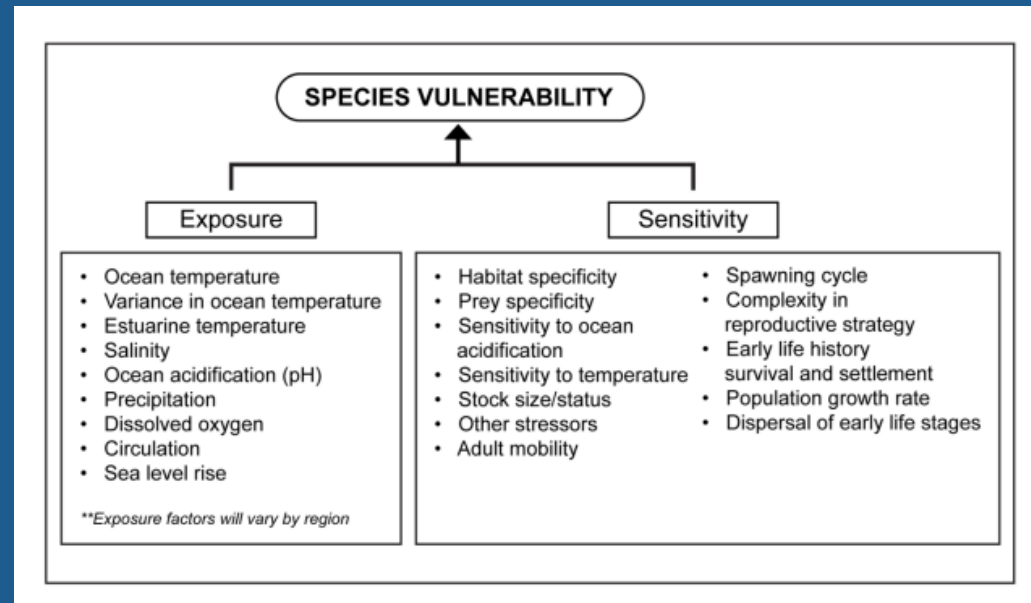


Figure 2 from [Morrison et al 2015](#)

# Climate Vulnerability Assessment Tool

This tool displays measurements for how vulnerable different species are to the effects of a changing climate. Scores are derived by experts to determine how much a particular species is exposed to a changing environment, and how sensitive it is to these changes. This can help broaden our understanding, which can be helpful in making decisions about how to protect them.

## Dataset

Northeast Fish and Shellfish ▾

## Functional Group

Groundfish ▾

## Common Name

Atlantic Cod ▾

## Legend

- Very High
- High
- Moderate
- Low

## Northeast Fish and Shellfish Climate Vulnerability Assessment Data Atlantic Cod

### Overall Vulnerability



### Sensitivity



### Exposure



| Sensitivity Attributes                                  | Mean | Data Quality | Expert Scores Plots                                                                   |
|---------------------------------------------------------|------|--------------|---------------------------------------------------------------------------------------|
| Adult Mobility                                          | 2.2  | 2.8          |   |
| Complexity in Reproductive Strategy                     | 2.4  | 2.9          |  |
| Dispersal of Early Life Stages                          | 1.44 | 2.8          |  |
| Early Life History Survival and Settlement Requirements | 2.76 | 2.8          |  |
| Habitat Specificity                                     | 1.76 | 3            |  |

# NEFMC Risk Assessment

Table 5. The scoring rubric for the **Climate Vulnerability** factor. Gray boxes within a numerical score column are unavailable to use when scoring Climate Vulnerability.

| Numerical score   | -4                                                                                  | -3                                                                                  | -2                                                                        | -1                                                                                                                                                          | 0                                                                | 1 | 2 | 3 | 4 |
|-------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|---|---|---|---|
| Categorical score | High Negative Direction                                                             | High                                                                                | Moderate, Negative Direction                                              | Moderate                                                                                                                                                    | Low                                                              |   |   |   |   |
| Description       | Climate vulnerability is high or very high, and the directional effect is negative. | Climate vulnerability is high or very high, ignoring the directional effect column. | Climate vulnerability is moderate and the directional effect is negative. | Climate vulnerability is moderate and ignoring the directional effect column; <u>OR</u> Climate vulnerability is low and the directional effect is negative | Climate vulnerability is low and ignoring the directional effect |   |   |   |   |

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This tool displays measurements for how vulnerable different species are to the effects of a changing climate. Scores are derived by experts to determine how much a particular species is exposed to a changing environment, and how sensitive it is to these changes. This can help broaden our understanding, which can be helpful in making decisions about how to protect them.

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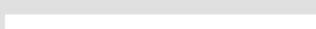


### Sensitivity



### Exposure



| Sensitivity Attributes                                  | Mean | Data Quality | Expert Scores Plots                                                                   |
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| Adult Mobility                                          | 2.2  | 2.8          |   |
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| Habitat Specificity                                     | 1.76 | 3            |  |

[Find A Species](#)
[About Us](#)

# Climate

This tool displays how much a particular species' distribution has changed, which can be helpful in making management decisions.

## Dataset

Northeast Fish

## Functional Group

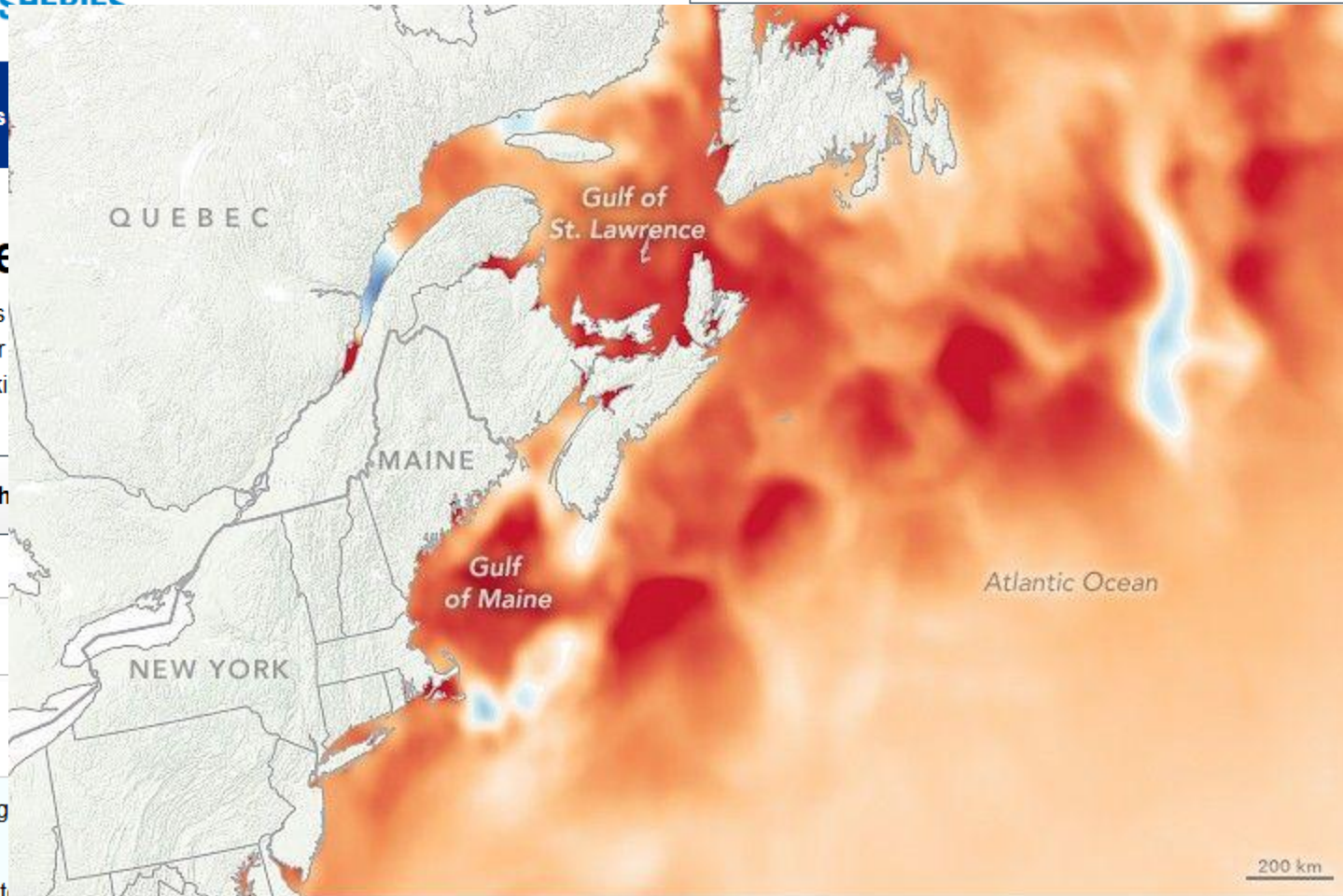
Groundfish

## Common Name

Atlantic Cod

## Legend

- Very High
- High
- Moderate
- Low



August Sea Surface Temperature Anomaly (difference from 1985-2012 average, °C)



Image by NASA from August 2018



# Spatially-Explicit CVAs

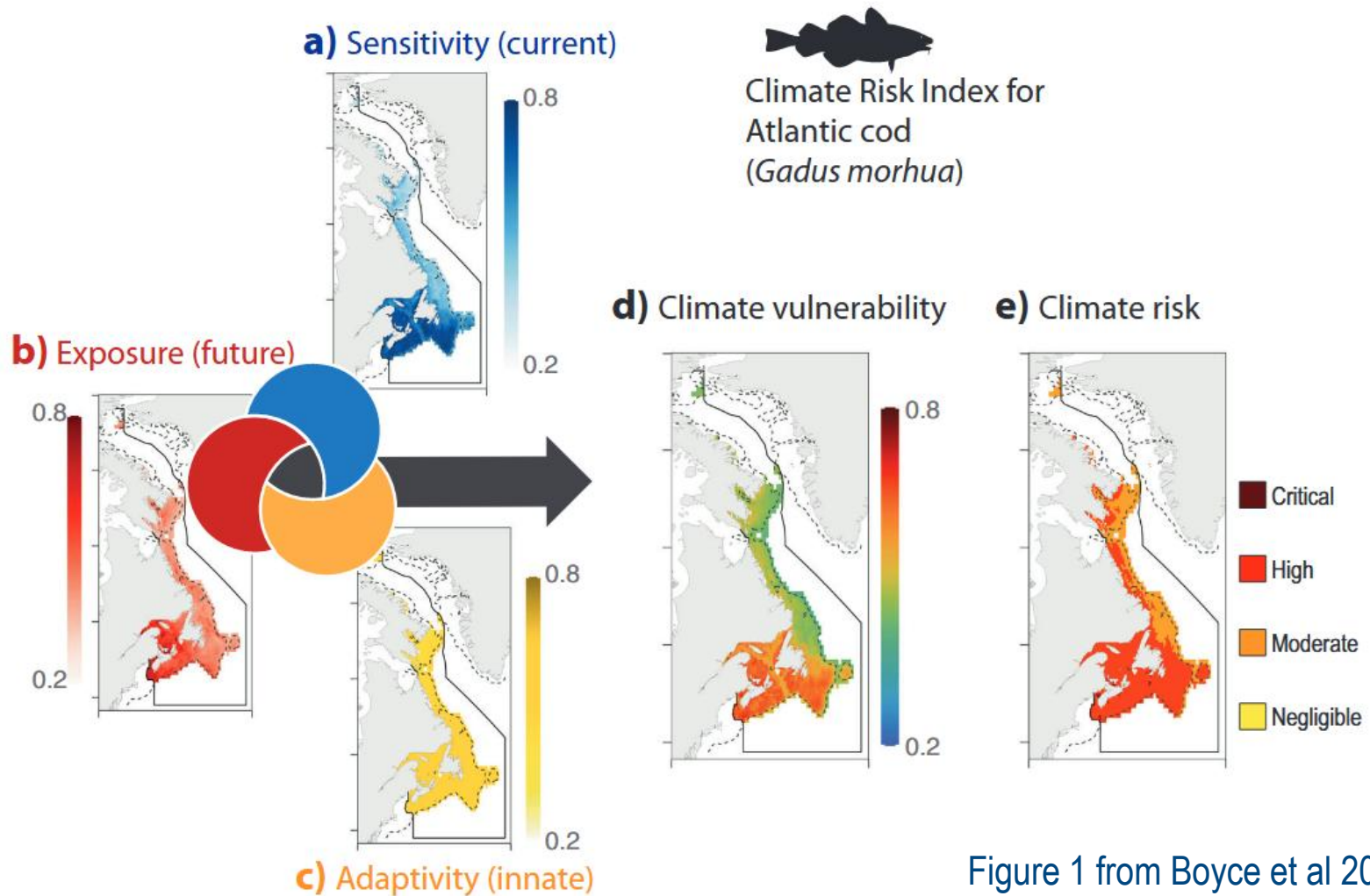
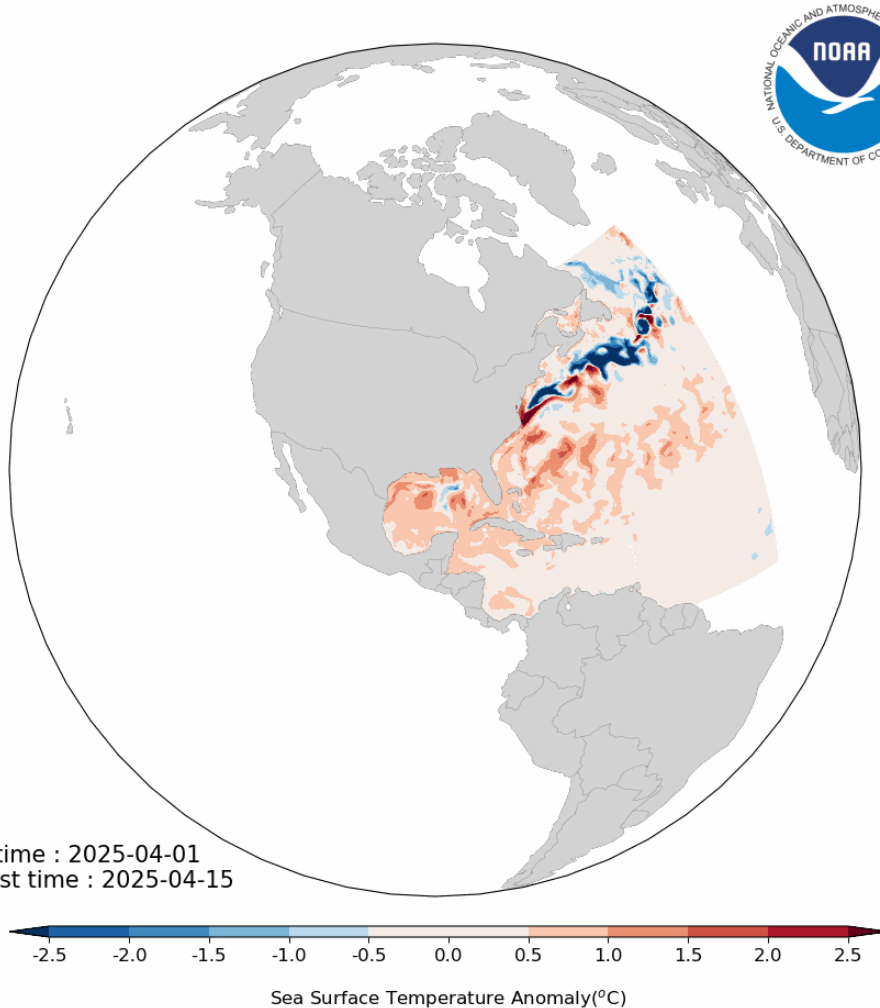


Figure 1 from Boyce et al 2024

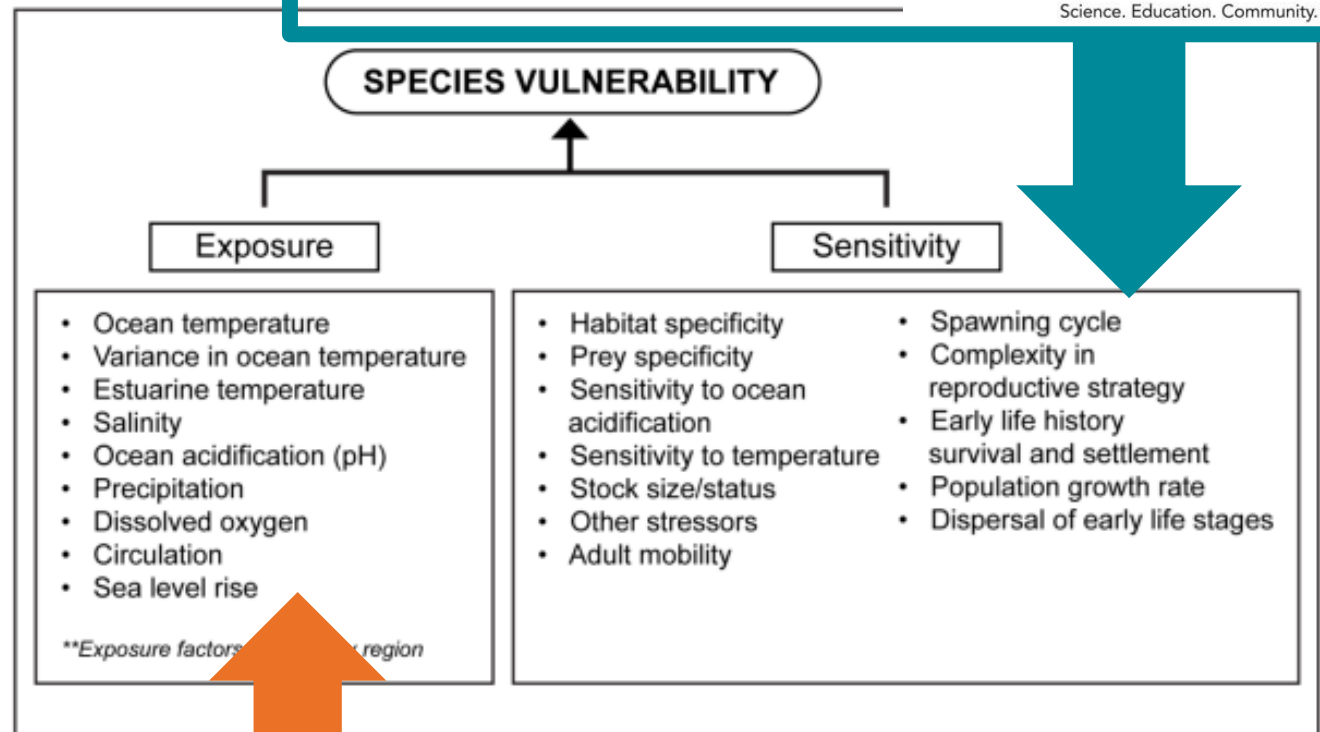
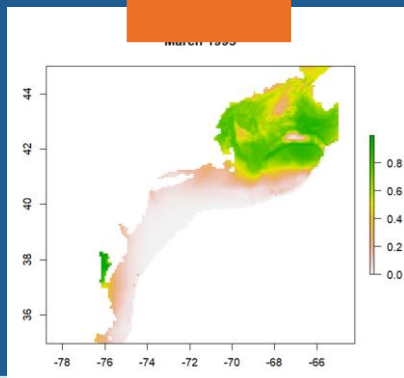
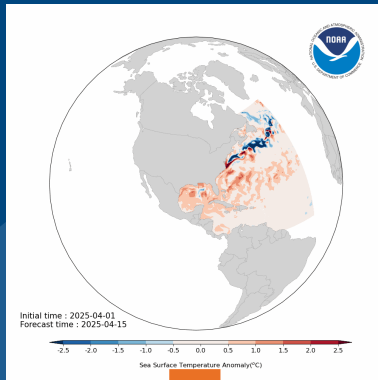
# More Dynamic CVAs



## Changing Ecosystems and Fisheries Initiative (CEFI) Modular Ocean Model (MOM) 6

- 1/12 degree resolution
- Physical Ocean Model + Biogeochemical Model
- Hindcasts
- Decadal forecasts
- Long term forecasts (out to 2100)

# CVA2.0



# Species List

|                                                                             |                                     |               |
|-----------------------------------------------------------------------------|-------------------------------------|---------------|
| 1. American Lobster (SS)                                                    | 15. Blueline tilefish               | 29. Scup (MA) |
| 2. <b>Atlantic cod (NE)</b> (MA)                                            | 30. Shortfin squid (MA)             |               |
| 3. Atlantic croaker (C)                                                     | 31. Smooth dogfish (HMS)            |               |
| 4. <b>Atlantic halibut (NE)</b>                                             | 32. Softshell clam (SS)             |               |
| 5. <b>Atlantic herring (NE)</b> (MA)                                        | 33. Spanish mackerel (MA, C)        |               |
| 6. Atlantic mackerel (MA)                                                   | 34. Spiny dogfish (MA)              |               |
| 7. Atlantic menhaden (SS) (SS)                                              | 35. Striped bass (C)                |               |
| 8. <b>Atlantic sea scallop (NE)</b>                                         | 36. Summer flounder (MA)            |               |
| 9. Atlantic surfclam (MA)                                                   | 37. Tautog (C)                      |               |
| 10. <b>Atlantic wolffish (NE)</b> (MA)                                      | 38. <b>White hake (NE)</b>          |               |
| 11. Black sea bass (MA, C)                                                  | 39. <b>Windowpane flounder</b>      |               |
| 12. Blue crab (SS)                                                          | 40. <b>Winter flounder (NE)</b>     |               |
| 13. Bluefin Tuna (HMS FMP) (MA)                                             | 41. <b>Witch flounder (NE)</b>      |               |
| 14. Bluefish (MA)                                                           | 42. <b>Yellowtail flounder (NE)</b> |               |
| NE, MA, C, HMS, SS - indicates who designated species as a priority         |                                     |               |
| (NEMFC, MAMFC, ASMFC, Highly Migratory Species FMP, Social Sciences Branch) |                                     |               |
| 25. Ocean pout (NE)                                                         |                                     |               |
| 26. Ocean quahog                                                            |                                     |               |



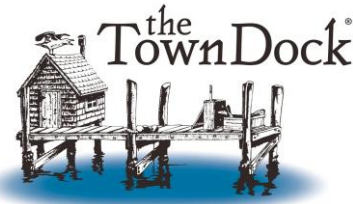


# Methods

# CVA2.0



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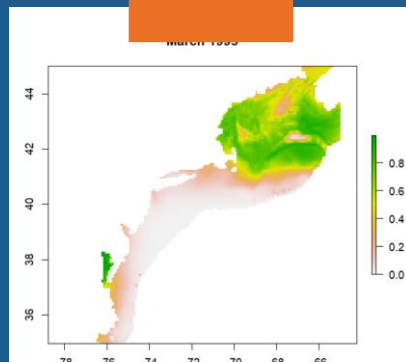
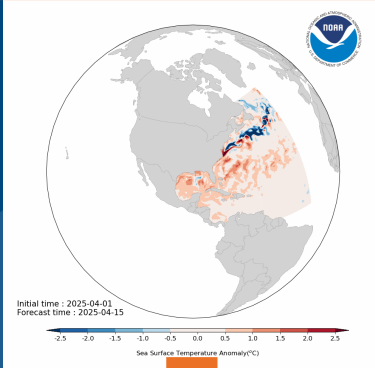
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Science. Education. Community.



## SPECIES VULNERABILITY

### Exposure

- Ocean temperature
- Variance in ocean temperature
- Estuarine temperature
- Salinity
- Ocean acidification (pH)
- Precipitation
- Dissolved oxygen
- Circulation
- Sea level rise

**\*\*Exposure factors** region

### Sensitivity

- Habitat specificity
- Prey specificity
- Sensitivity to ocean acidification
- Sensitivity to temperature
- Stock size/status
- Other stressors
- Adult mobility
- Spawning cycle
- Complexity in reproductive strategy
- Early life history survival and settlement
- Population growth rate
- Dispersal of early life stages



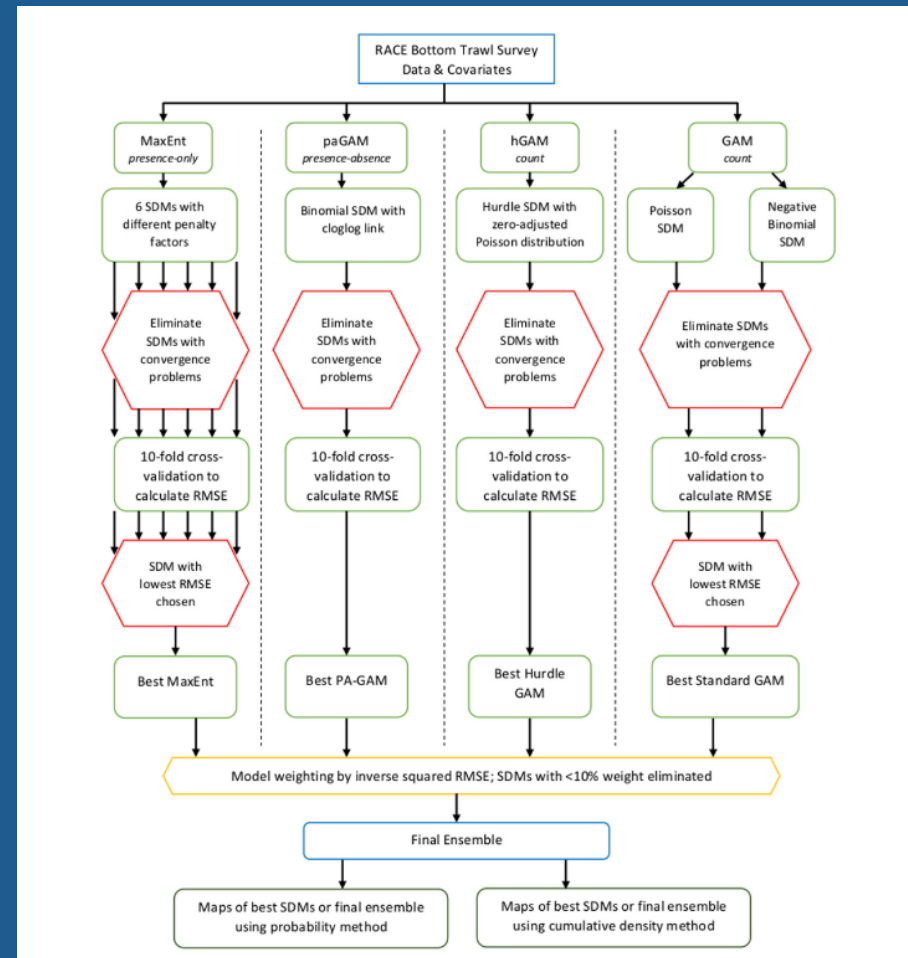


# Exposure

# Species Distribution Models

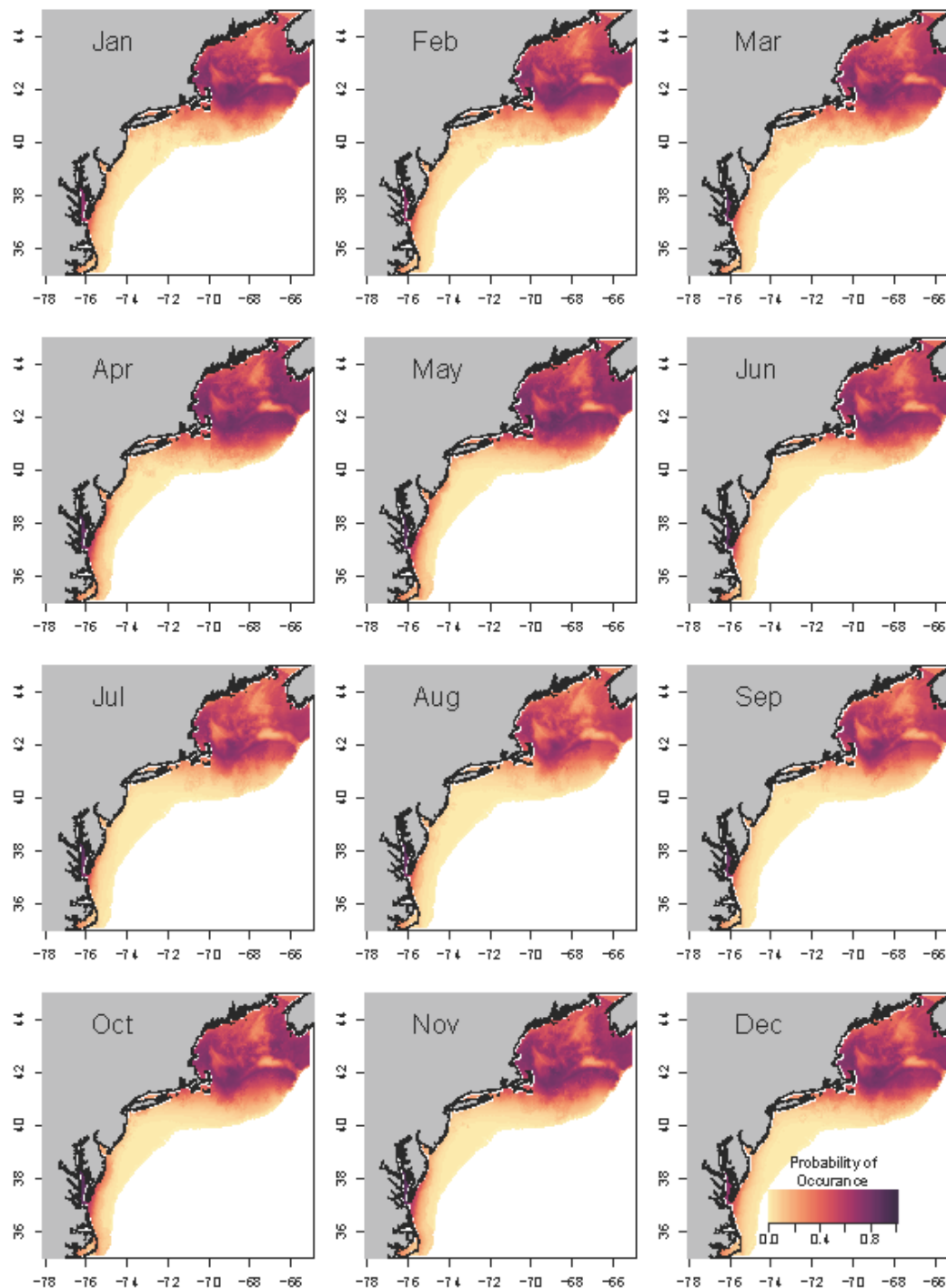
Figure 2 from [Harris et al 2023](#)

- Ensemble Model
  - GAM
  - MAXENT
  - Spatially Interpolated Random Forest
  - sdmTMB
  - Boosted Regression Trees
- Using 1993 - 2023 MOM6 hindcast to build & test models
  - Covariates specific to species
- Fisheries independent and dependent datasets
  - Presence-absence modeling
- Ensemble built with weighted average based on component performance





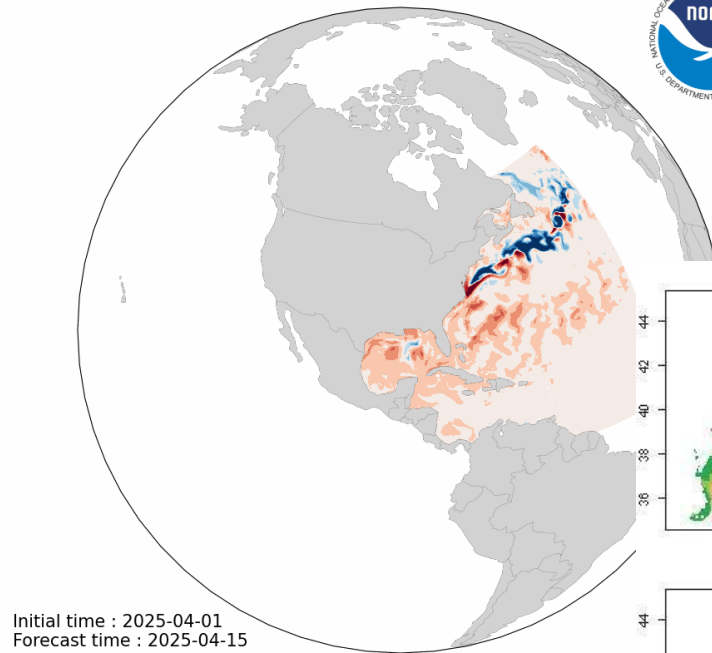
# Ensemble SDM



# Quantifying Exposure

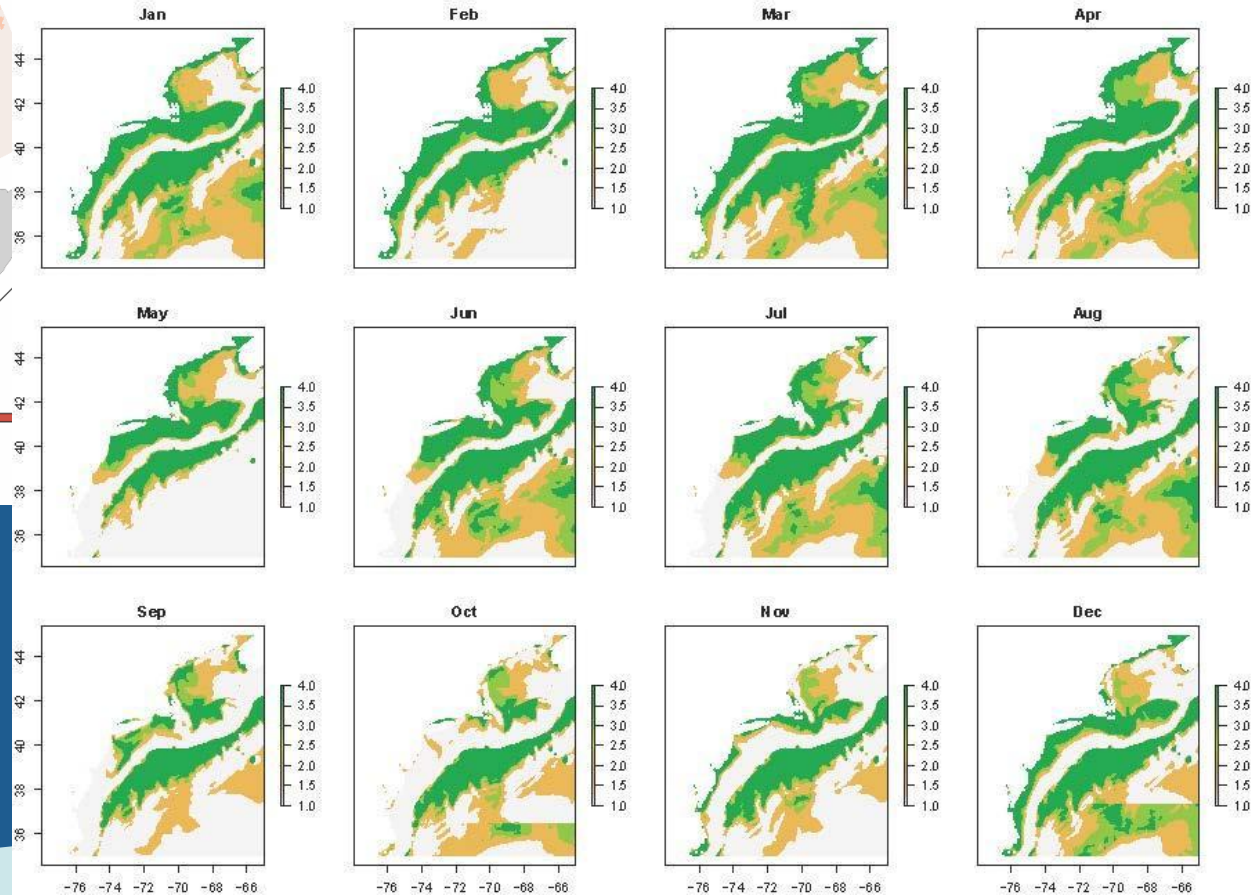


- Calculate a z-score from decadal MOM6 forecasts
- Z scores ranked from 1-4

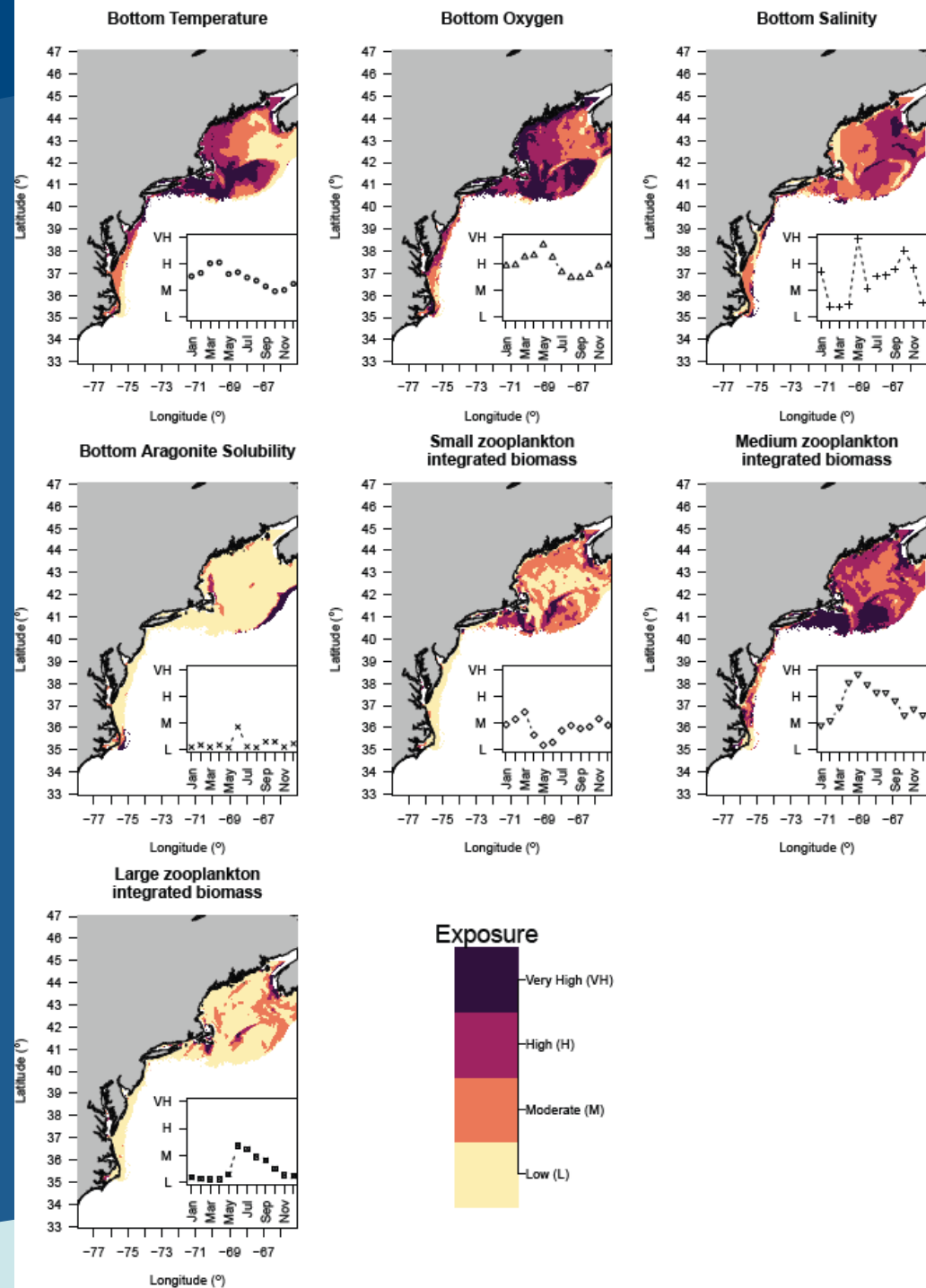


Initial time : 2025-04-01  
Forecast time : 2025-04-15

Sea Surface Temperature Anomaly(°C)



# Variable Exposure



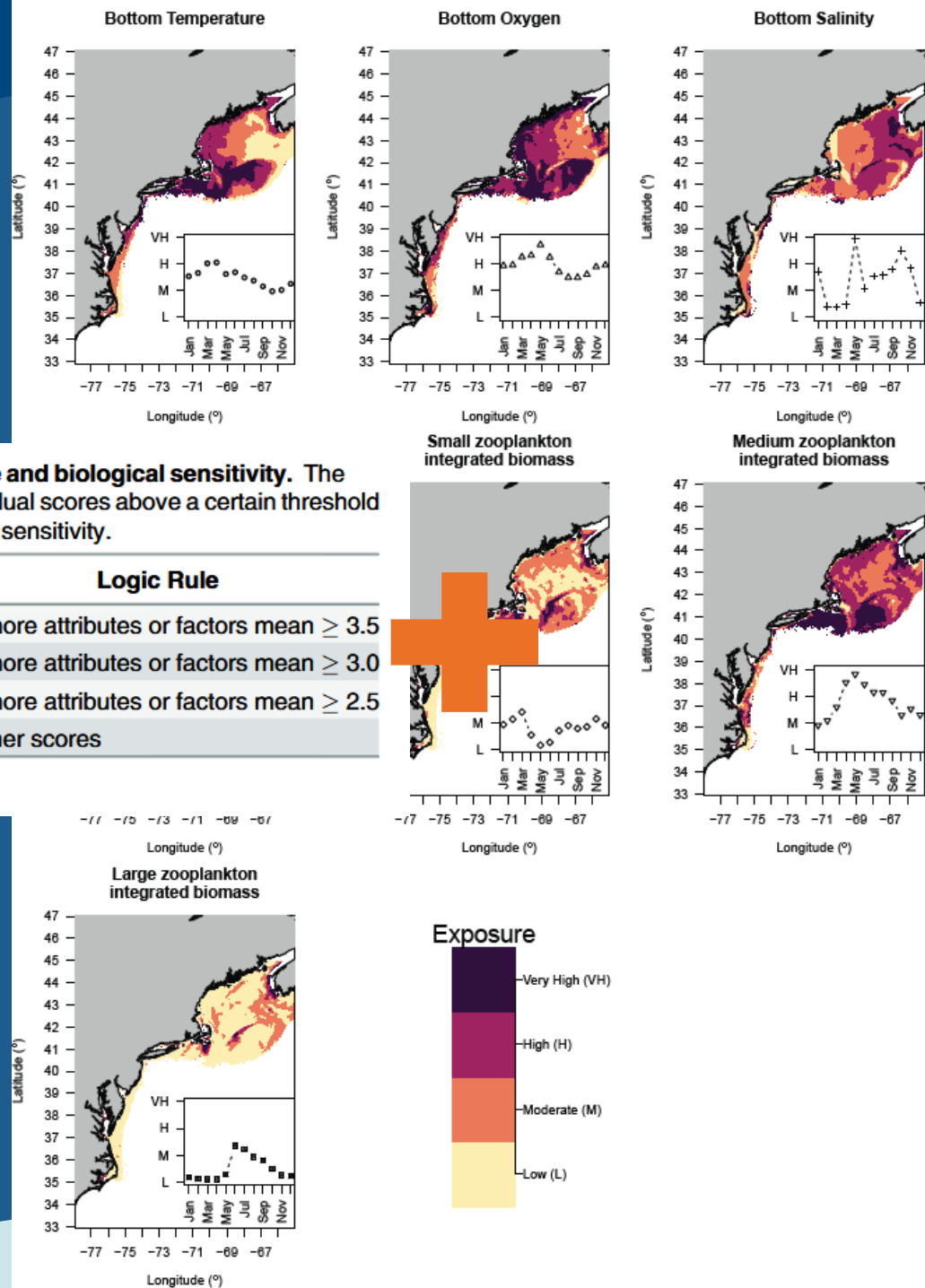


# Variable Exposure

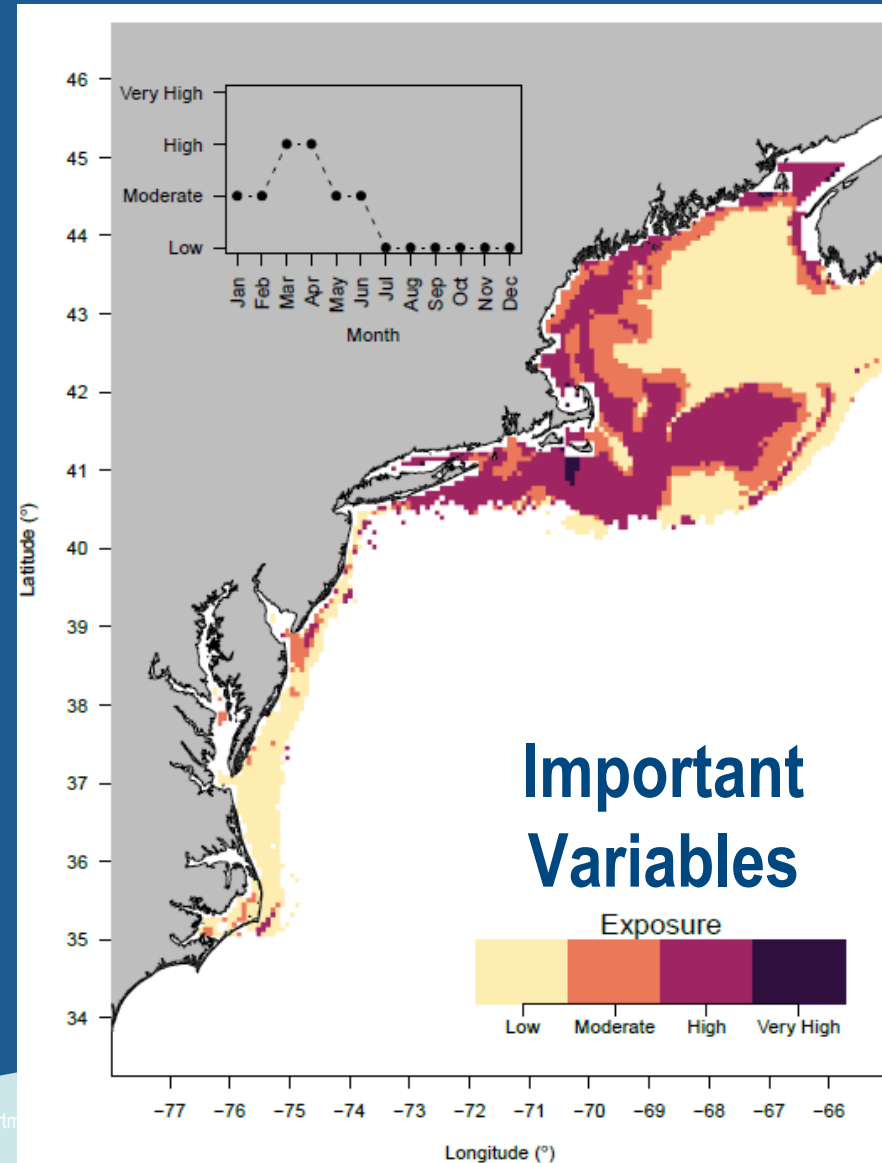
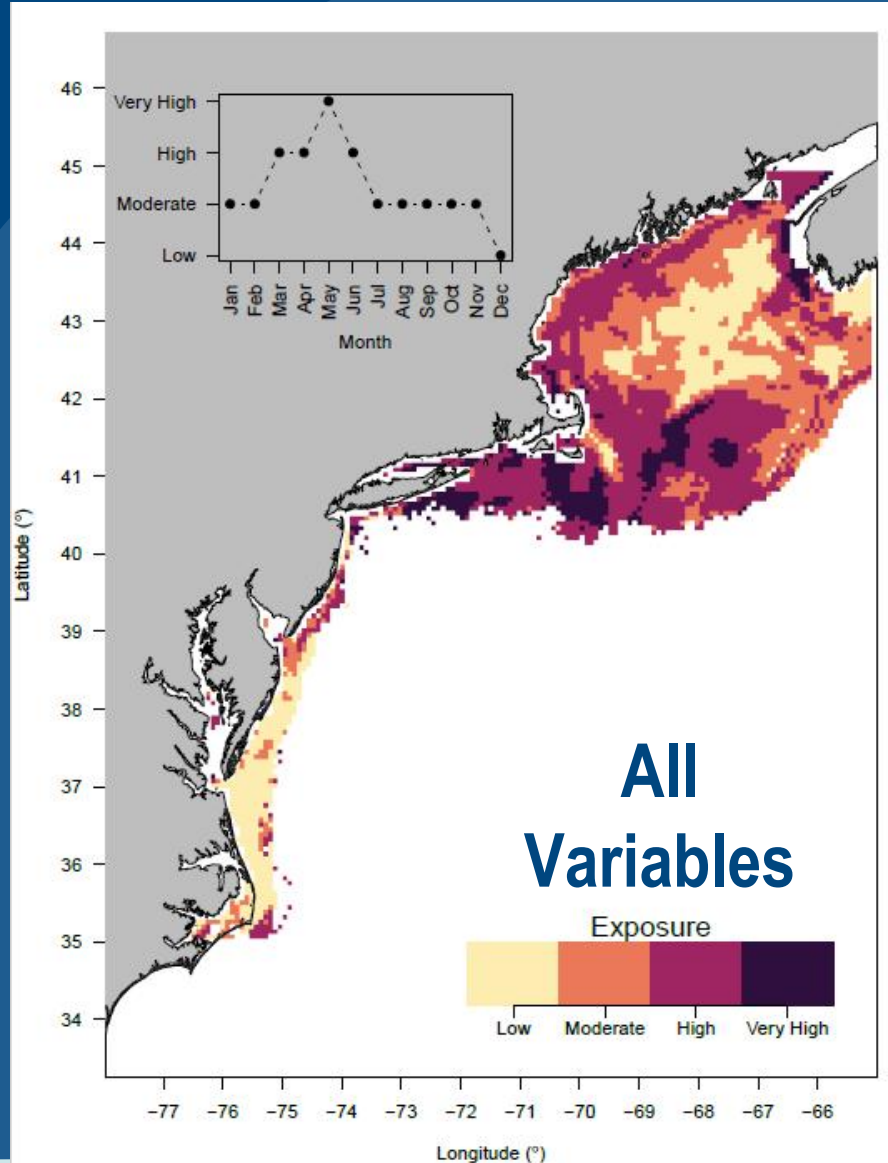
**Table 3. Logic rule for calculating overall species' climate exposure and biological sensitivity.** The scoring rubric is based on a logic model where a certain number of individual scores above a certain threshold are used to determine the overall climate exposure and overall biological sensitivity.

| Overall Sensitivity or Exposure Score | Numeric Score | Logic Rule                                      |
|---------------------------------------|---------------|-------------------------------------------------|
| Very High                             | 4             | 3 of more attributes or factors mean $\geq 3.5$ |
| High                                  | 3             | 2 of more attributes or factors mean $\geq 3.0$ |
| Moderate                              | 2             | 2 of more attributes or factors mean $\geq 2.5$ |
| Low                                   | 1             | All other scores                                |

doi:10.1371/journal.pone.0146756.t003

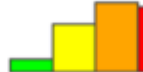


# Total Exposure



# Total Exposure

- Includes mean and standard deviation of values across space
- Averaging will occur across species ranges and within stock units

| Factor Name                                 | Space |      |                                                                                      |
|---------------------------------------------|-------|------|--------------------------------------------------------------------------------------|
|                                             | Mean  | SD   | Distribution                                                                         |
| <i>Bottom Temperature</i>                   | 2.48  | 1.00 |   |
| <i>Bottom Oxygen</i>                        | 2.96  | 0.83 |   |
| Bottom Salinity                             | 2.36  | 0.73 |   |
| <i>Bottom Aragonite Solubility</i>          | 1.24  | 0.64 |   |
| Small zooplankton integrated biomass        | 1.81  | 0.79 |   |
| Medium zooplankton integrated biomass       | 2.84  | 0.82 |   |
| <i>Large zooplankton integrated biomass</i> | 1.39  | 0.58 |   |
| Exposure - All Variables                    | 2.37  | 0.94 |   |
| <i>Exposure - Important Variables</i>       | 1.83  | 0.90 |  |

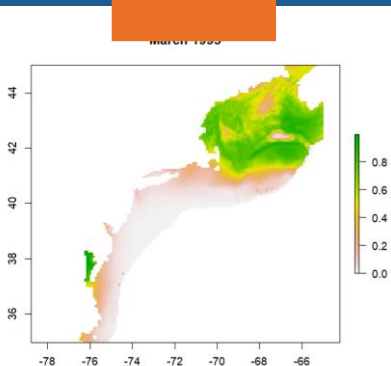
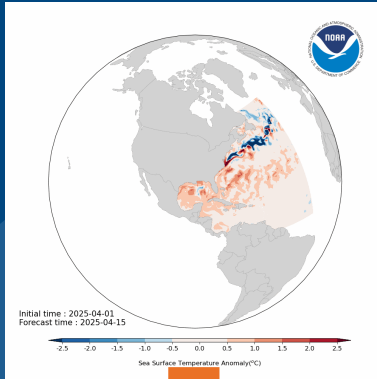




# Sensitivity



# CVA2.0



## SPECIES VULNERABILITY

### Exposure

- Ocean temperature
- Variance in ocean temperature
- Estuarine temperature
- Salinity
- Ocean acidification (pH)
- Precipitation
- Dissolved oxygen
- Circulation
- Sea level rise

\*\*Exposure factors for the region

### Sensitivity

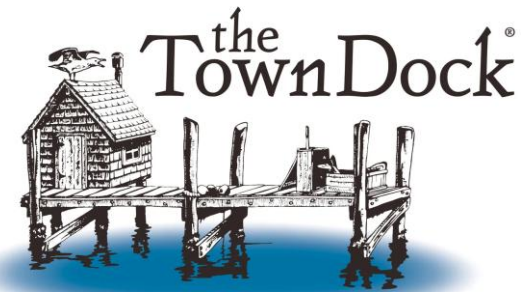
- Habitat specificity
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- Sensitivity to temperature
- Stock size/status
- Other stressors
- Adult mobility
- Spawning cycle
- Complexity in reproductive strategy
- Early life history survival and settlement
- Population growth rate
- Dispersal of early life stages

# Sensitivity



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& MARY**

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# Sensitivity Attributes

## Unchanged

- Prey Specificity
- Stock Size/Status
- Population Growth Rate
- Dispersal of Early Life Stages
- Adult Mobility
- Spawning Cycle

# Sensitivity Attributes

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- Prey Specificity
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## Minor Revisions - New Information

- Complexity in Reproductive Strategy
- Other Stressors



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- Spawning Cycle

## Minor Revisions - Name Changed

- Relationship to Calcified Organisms (due to impacts from Ocean Acidification)
- Historical Variability in Temperature
- Egg and Larval Survival and Settlement Requirements

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- Historical Variability in Temperature
- Egg and Larval Survival and Settlement Requirements

## Minor Revisions - New Information

- Complexity in Reproductive Strategy
- Other Stressors

## Major Revisions

- Juvenile Habitat Requirements

# Sensitivity Results

- Generated from expert scores using original methods
- Scored at stock level when appropriate

**Table 3. Logic rule for calculating overall species' climate exposure and biological sensitivity.** The scoring rubric is based on a logic model where a certain number of individual scores above a certain threshold are used to determine the overall climate exposure and overall biological sensitivity.

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| Low                                   | 1             | All other scores                                |

doi:10.1371/journal.pone.0146756.t003

| Sensitivity                                             |              |              |                    |
|---------------------------------------------------------|--------------|--------------|--------------------|
| Attribute Name                                          | Expert Score | Data Quality | Tally Distribution |
| Adult Mobility                                          | 2.40         | 2.75         |                    |
| Complexity in Reproductive Strategy                     | 2.35         | 3.00         |                    |
| Dispersal of Early Life Stages                          | 1.75         | 3.00         |                    |
| Early Life History Survival and Settlement Requirements | 2.55         | 3.00         |                    |
| Habitat Specificity                                     | 2.20         | 3.00         |                    |
| Other Stressors                                         | 2.15         | 2.75         |                    |
| Population Growth Rate                                  | 2.75         | 2.75         |                    |
| Prey Specificity                                        | 1.30         | 3.00         |                    |
| Sensitivity to Ocean Acidification                      | 1.15         | 2.00         |                    |
| Sensitivity to Temperature                              | 2.00         | 3.00         |                    |
| Spawning Cycle                                          | 1.85         | 3.00         |                    |
| Stock Size/Status                                       | 3.85         | 3.00         |                    |
| <b>Total Sensitivity: Moderate (2)   Certainty: 1</b>   |              |              |                    |

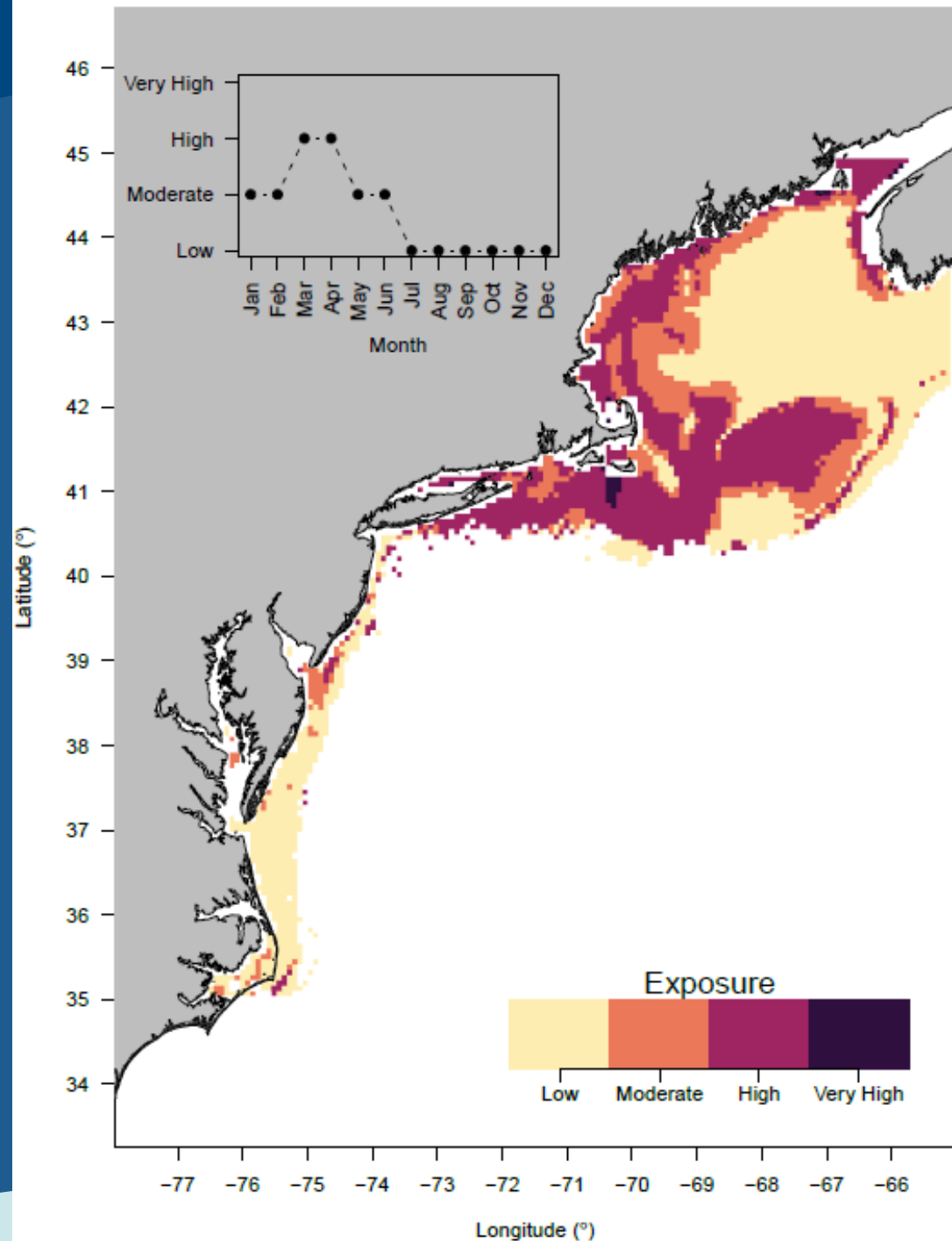


# Vulnerability & Additional Metrics



# Vulnerability

- Sensitivity x Exposure
  - Sensitivity will be single value per species/stock
  - Exposure will be spatially/temporally explicit
- Vulnerability will be mapped, then averaged
  - Within stock units & across range
  - Can provide for all exposure variables or just important variables



# Vulnerability Matrix



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**SENSITIVITY**

Very High

High

Moderate

Low

|   |   |    |    |
|---|---|----|----|
| 4 | 8 | 12 | 16 |
| 3 | 6 | 9  | 12 |
| 2 | 4 | 6  | 8  |
| 1 | 2 | 3  | 4  |

Low

Moderate

High

Very High

**EXPOSURE**

# Additional Metrics

## Unchanged Metrics

- Directional Effect
  - Experts ranked overall impacts of climate change on species (positive, negative, neutral)
- Data Quality
  - Quality of information available for scoring

## Revised Metrics

- Potential for Distribution Change
  - Use Ensemble SDM to calculate Center of Gravity and Change in Habitat Area across time in hindcast and forecasts
  - Will no longer use subset of expert scores

## New Metrics

- Model Confidence
  - Similar to Data Quality - Does SDM represent species distributions well?
  - In addition to AUC to quantify model performance

# Additional Metrics

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## Revised Metrics

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  - **Will no longer use subset of expert scores**

## New Metrics

- **Model Confidence**
  - **Similar to Data Quality - Does SDM represent species distributions well?**
  - **In addition to AUC to quantify model performance**





# Products & Future Work

# CVA2.0 Products

## Species Narratives

- Averaged & spatially-explicit exposure, sensitivity, vulnerability
  - Species and stock-level results as appropriate
- Summary statistics
  - Model Confidence
  - Model AUC
  - Data quality
- Directional effects
- Descriptions of known climate impacts
- Maps
  - Exposure, sensitivity, vulnerability
  - Potential for distribution change metrics
    - Centroid
    - Habitat Area change

## Species Distribution Models

- Hosted on DisMAP

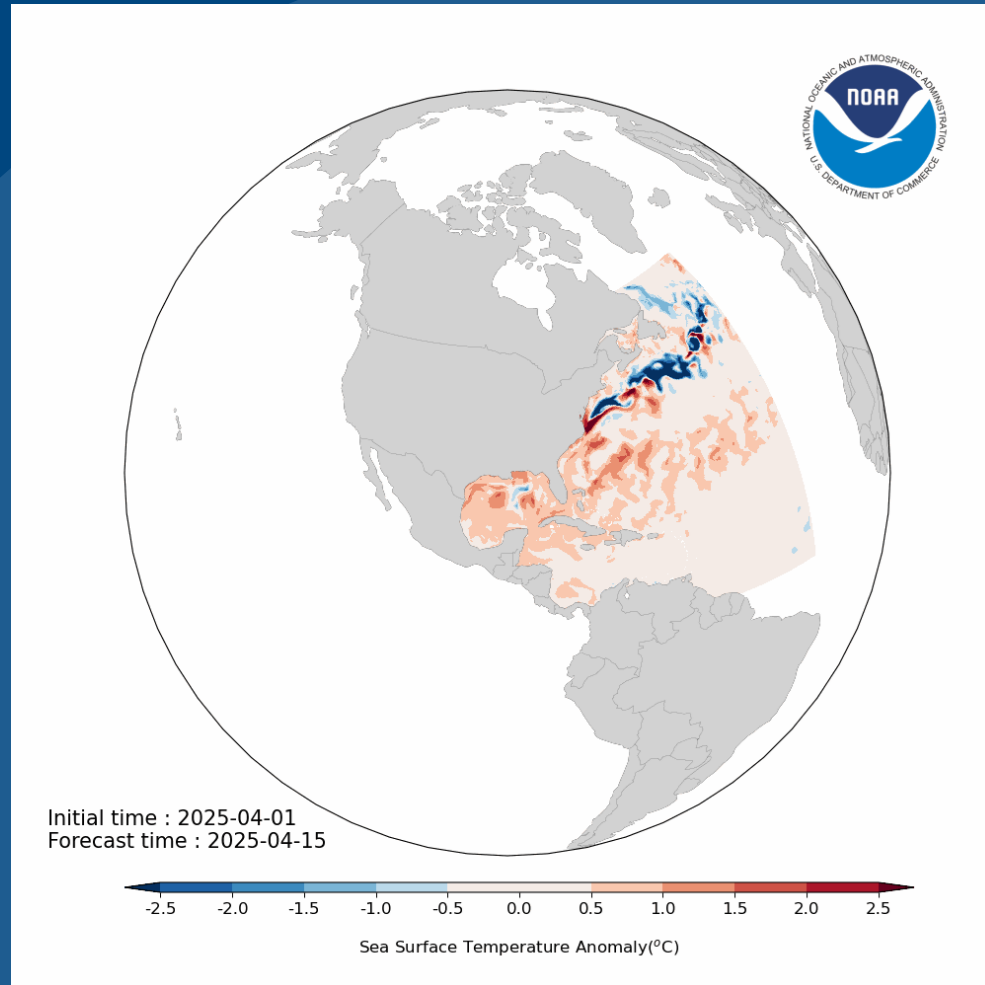
## *spatialcva* R Package

- Documenting workflows and methods
- Functions for MOM6 data pulls, ensemble SDM building, and exposure/sensitivity analysis

## CVA2.0 Website

- Webpage describing methods
- Potential host for narratives

# Future Work



- MOM6
  - Exposure can be updated annually with new decadal forecasts
  - Long term exposure can be calculated out to 2100 once data are available
- More Species/Regions
  - Developing R package/documentation to simplify expansion to more species/regions

# CVA2.0 & NEFMC Risk Policy

CVA2.0 will have

- Spatial, temporal, and **average vulnerabilities**
- **Directional effects (same as 1.0)**
- New distribution shift metrics

Table 5. The scoring rubric for the **Climate Vulnerability** factor. Gray boxes within a numerical score column are unavailable to use when scoring Climate Vulnerability.

| Numerical score   | -4                                                                                  | -3                                                                                  | -2                                                                        | -1                                                                                                                                                          | 0                                                                | 1 | 2 | 3 | 4 |
|-------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|---|---|---|---|
| Categorical score | High Negative Direction                                                             | High                                                                                | Moderate, Negative Direction                                              | Moderate                                                                                                                                                    | Low                                                              |   |   |   |   |
| Description       | Climate vulnerability is high or very high, and the directional effect is negative. | Climate vulnerability is high or very high, ignoring the directional effect column. | Climate vulnerability is moderate and the directional effect is negative. | Climate vulnerability is moderate and ignoring the directional effect column; <u>OR</u> Climate vulnerability is low and the directional effect is negative | Climate vulnerability is low and ignoring the directional effect |   |   |   |   |





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# Thank you for your attention!

Additional Thanks to:

- NEFSC and NOAA staff, the New England and Mid Atlantic Fisheries Management Councils, the Atlantic States Marine Fisheries Commission, and our research partners who provided valuable feedback and assistance in developing these methods
- Federal and state-run fisheries survey and the NOAA Observer programs for providing fisheries independent and dependent datasets
- Expert Sensitivity Scorers

**Questions?**

**Katherine Gallagher**

***katherine.gallagher@noaa.gov***

# Exposure

## Raw Climate Exposure

$$E = \frac{\overline{C_F} - \overline{C_P}}{\sigma_P}$$

F – 2025 - 2035

P – 2013 - 2023

$\overline{C}$  – mean climate factor

$\sigma$  – standard deviation climate factor

| Score         | E       | Rank |
|---------------|---------|------|
| Low           | <0.5    | 1    |
| Low-Moderate  | 0.5-1.5 | 2    |
| Moderate-High | 1.5-2   | 3    |
| High          | >2      | 4    |

