Assessing the Vulnerability of Fish Stocks to Climate Change

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PLoS One: A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf

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Goal and Objectives

Goal:

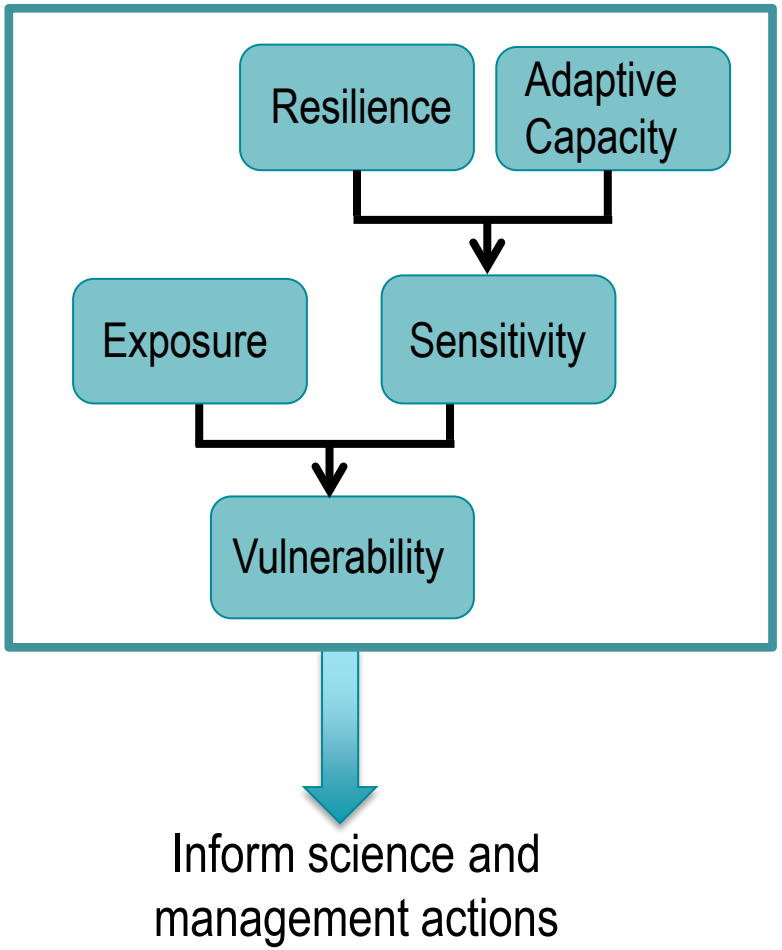
Produce a practical and efficient tool for assessing the vulnerability of a wide range of fish stocks to a changing climate

Objectives:

1. Develop relative vulnerability rankings across species
2. Determine attributes/factors driving vulnerability
3. Identify data quality and data gaps

Vulnerability Assessment Framework

- Used widely in terrestrial systems, with only a few examples from marine systems
- Uses currently existing knowledge and expert opinion
- Uses quantitative data when available, and qualitative information when data is lacking



What do we mean by vulnerability?

- Vulnerability = risk of *changes in stock abundance or productivity in a changing climate*
- Stocks with ability to shift distributions in a changing climate may receive a "low vulnerability" ranking
- Subset of the attributes may be useful in identifying stocks that possess the *ability to shift distributions*

Methodology

Exposure

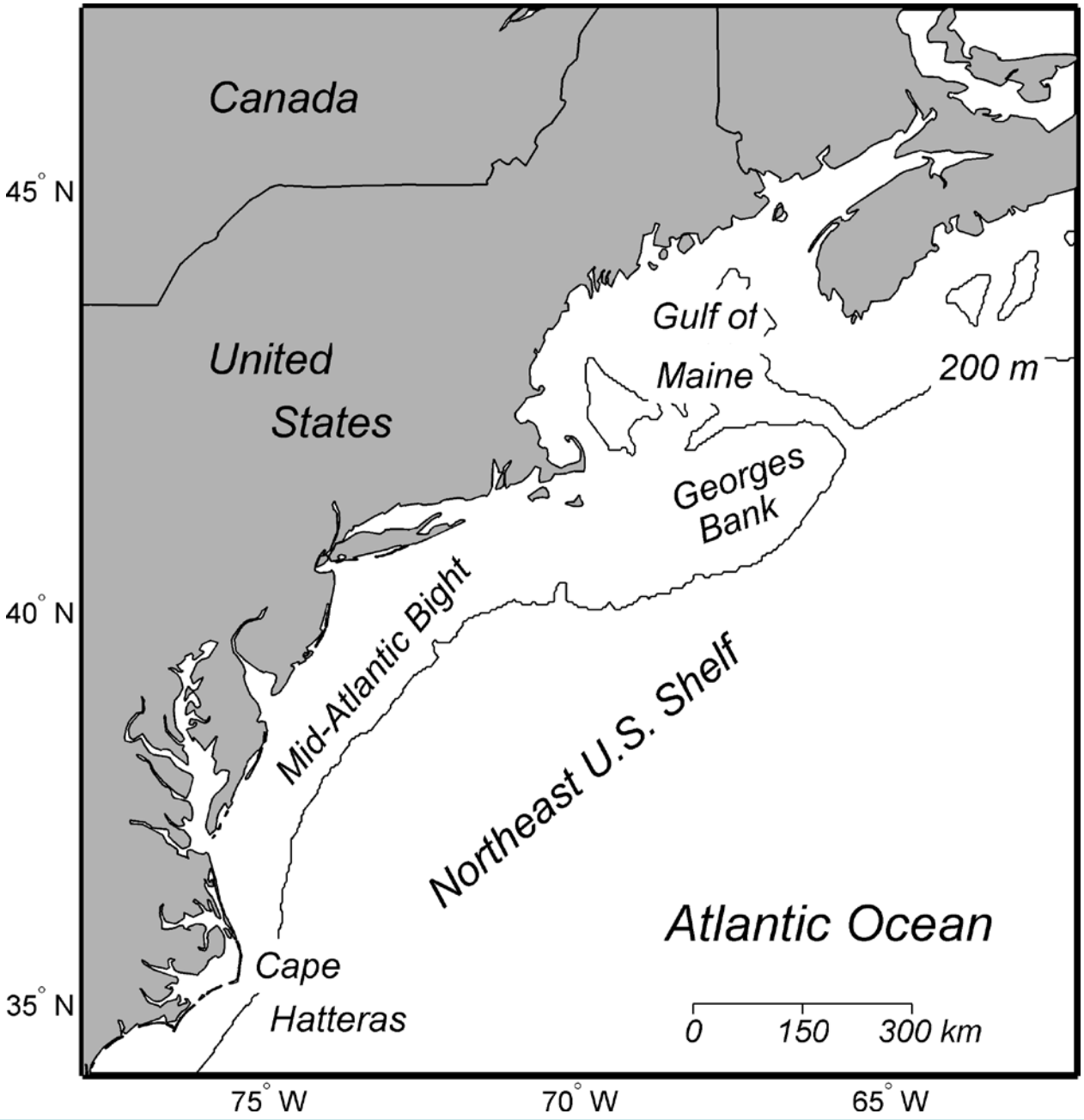
- Sea surface temperature
- Air temperature
- Salinity
- Ocean acidification (pH)
- Precipitation
- Currents
- Sea level rise

*** Exposure factors will vary depending on the region*

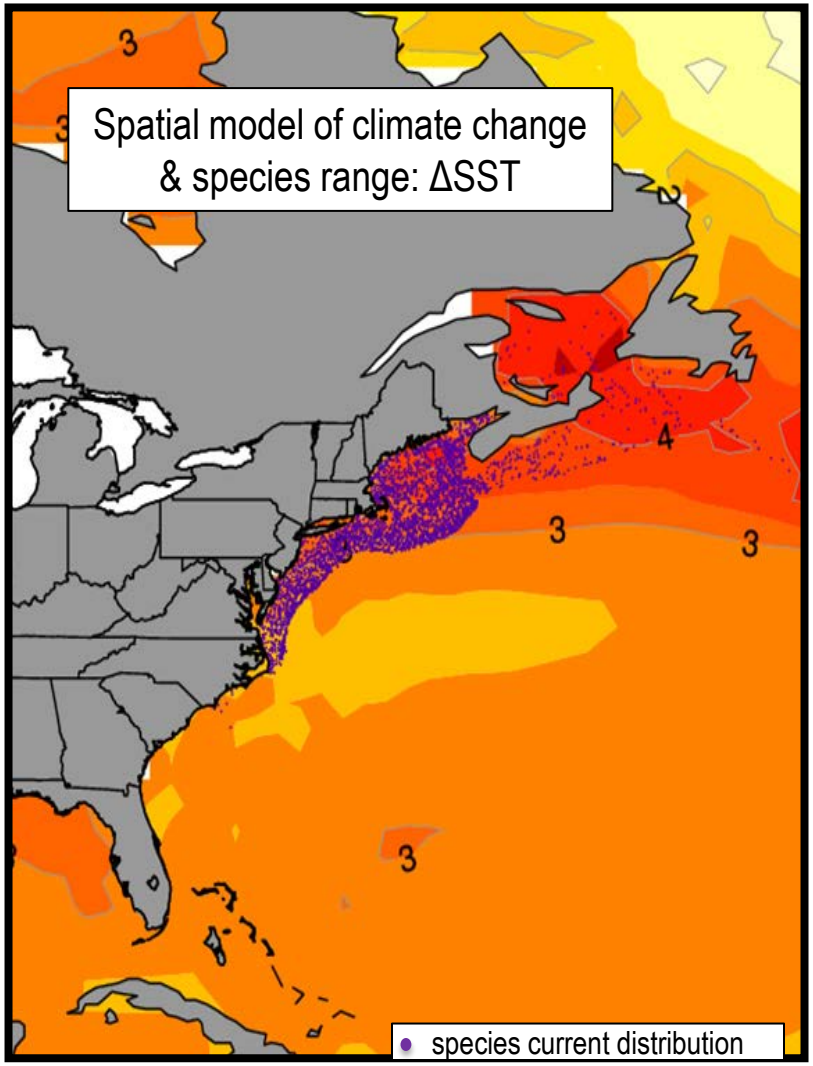
Sensitivity

- 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 Requirements
- Population Growth Rate
- Dispersal of Early Life Stages

Domain


Canada
United States
Gulf of Maine
200 m
Georges Bank
Mid-Atlantic Bight
Northeast U.S. Shelf
Atlantic Ocean
Cape Hatteras
45° N
40° N
35° N
75° W
70° W
65° W
0
150
300 km

Exposure



- Defined as how much climate-related change a species is likely to experience
- Quantified as the spatial overlap between a species' current distribution and the expected climate change
- Mean change is related to current variability (Z-score, weighted by the standard deviation in the historical period)
- Changes in variability are measured with an F-test
  (future variability/current variability)
- Info available at:
  "Climate Change Web Portal"
  http://www.esrl.noaa.gov/psd/ipcc/ocn/ccwp.html

5 Point Tally Scoring System

- The scoring for each attribute is done by the experts assigning 5 tallies within the 4 scoring bins
- This gives experts the ability to express uncertainty in their score

Example:

Expert Scores - Low uncertainty scenario			
Low	Moderate	High	Very High
	5		

Expert Scores - Moderate uncertainty			
Low	Moderate	High	Very High
		3	2

Expert Scores - Higher uncertainty scenario			
Low	Moderate	High	Very High
1	1	2	1

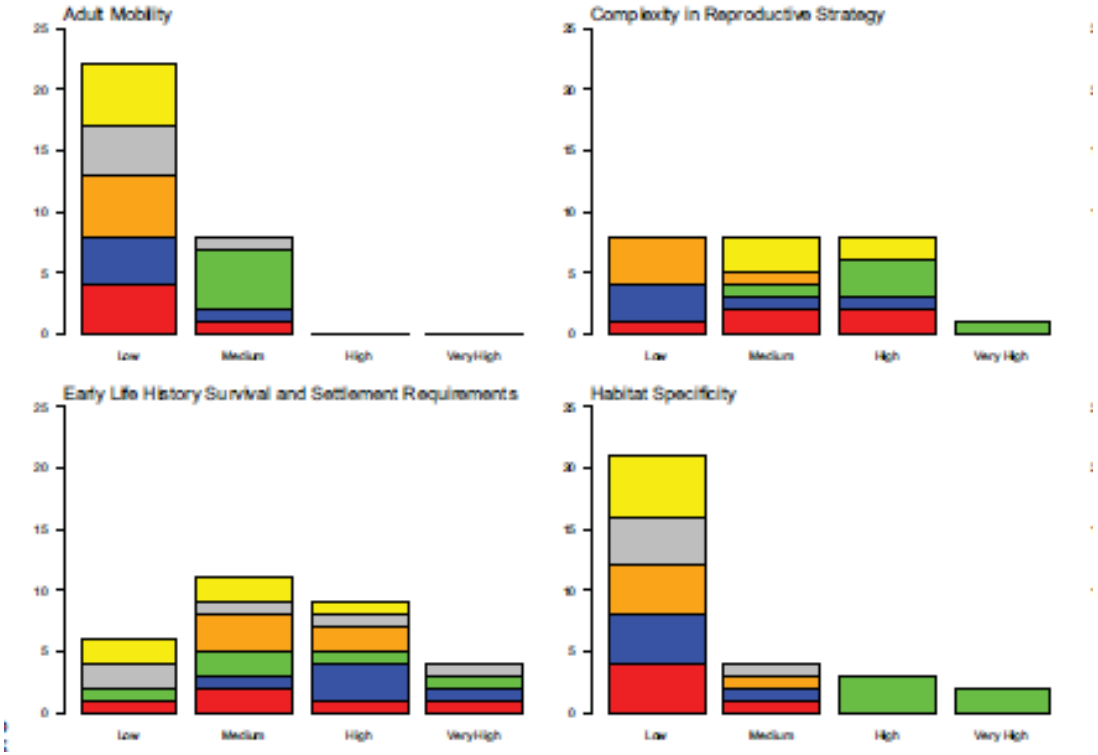
Data Quality Score

- Data quality is different than uncertainty; however, they can be related
- This score will be used to identify data gaps

Data Quality Score	Description
3	**Adequate Data.** The score is based on data (observed, modeled or empirically measured) for the species in question and comes a from reputable source.
2	**Limited Data.** The score is based on data which has a higher degree of uncertainty. The data may be based on related or similar species, come from outside the study area, or the reliability of the source may be limited.
1	**Expert Judgment.** The attribute score reflects the expert judgment of the reviewer based on their general knowledge of the species or ecosystem.
0	**No Data.** No information to base an attribute score on. Very little is known about the species or related species and there is no basis for forming an expert opinion (use judiciously).

Expert Scoring Process

- Experts score individually prior to workshop
- Experts compare and discuss scores at workshop
- Experts can adjust their scores if needed



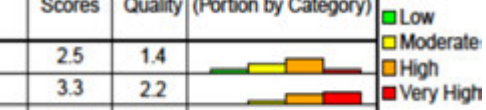
Each color represents the 5 tallies for one expert

Alewife Assessment

Biological Sensitivity = High
Climate Exposure = Very High
Data Quality = 79% of scores ≥ 2

Overall vulnerability
Very high

Alosa pseudoharengus	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Stock Status	2.5	1.4	
Other Stressors	3.3	2.2	
Population Growth Rate	2.2	1.4	
Spawning Cycle	3.2	2.9	
Complexity in Reproduction	3.2	3.0	
Early Life History Requirements	3.3	2.4	
Sensitivity to Ocean Acidification	1.5	1.8	
Prey Specialization	1.5	3.0	
Habitat Specialization	2.6	3.0	
Sensitivity to Temperature	2.0	3.0	
Adult Mobility	1.6	2.8	
Dispersal & Early Life History	2.8	2.6	
Sensitivity Score	High		
Sea Surface Temperature	4.0	3.0	
Variability in Sea Surface Temperature	1.0	3.0	
Salinity	1.7	3.0	
Variability Salinity	1.2	3.0	
Air Temperature	4.0	3.0	
Variability Air Temperature	1.0	3.0	
Precipitation	1.3	3.0	
Variability in Precipitation	1.4	3.0	
Ocean Acidification	4.0	2.0	
Variability in Ocean Acidification	1.0	2.2	
Currents	2.0	1.0	
Sea Level Rise	2.8	1.5	
Exposure Score	Very High		
Overall Vulnerability Rank	Very High		



- Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Air Temperature (4.0).
- Biological Sensitivity: High. Four sensitivity attributes scored above 3.0: Other Stressors (3.3), Early Life History Requirements (3.3), Spawning Cycle (3.2), Complexity in Reproduction (3.2). Alewife are exposed to a number of other stressors including habitat destruction.
- Distributional Vulnerability Rank: Low. Alewife have a relatively high degree of spawning site fidelity, limiting the ability of the species to shift distribution.
- Directional Effect in the Northeast U.S. Shelf: The effect of climate change on Alewife is likely to be negative (90-95% certainty in expert scores). Climate change will probably cause marine distributions to continue to shift, thereby causing longer migrations to natal rivers. Changes in rivers from increased precipitation and warming may cause decreases in productivity particularly in the southern portion of the Northeast U.S. shelf.
- Data Quality: 79% of the data quality scores were 2 or greater indicate that data quality is moderate.

Blueback Assessment

Biological Sensitivity = High
Climate Exposure = Very High
Data Quality = 88% of scores ≥ 2

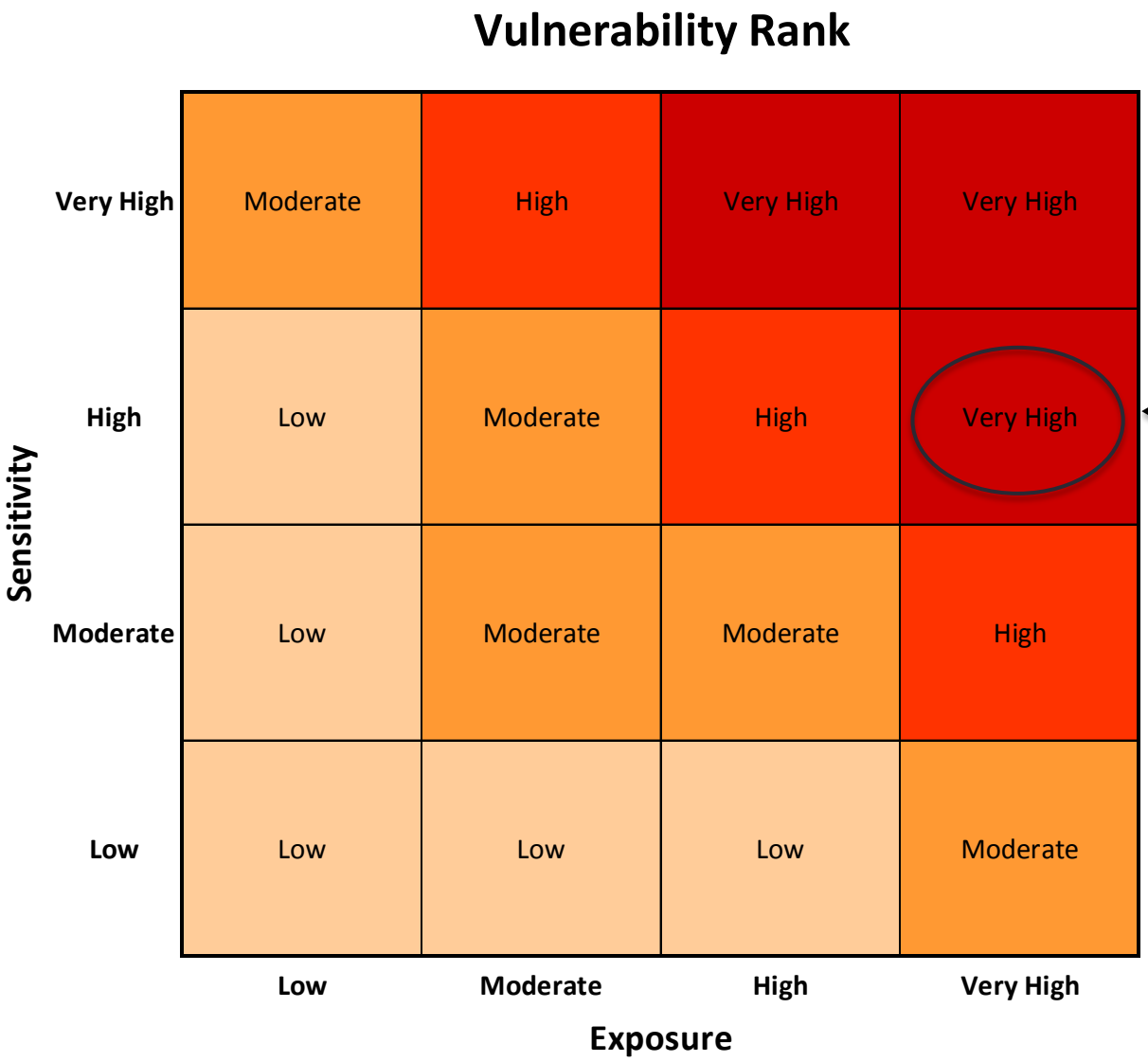
Overall vulnerability
Very high

Alosa aestivalis	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Stock Status	2.7	1.2	
Other Stressors	2.7	2.0	
Population Growth Rate	2.3	2.0	
Spawning Cycle	3.5	2.8	
Complexity in Reproduction	3.2	3.0	
Early Life History Requirements	3.3	2.5	
Sensitivity to Ocean Acidification	1.5	2.2	
Prey Specialization	1.8	3.0	
Habitat Specialization	2.3	3.0	
Sensitivity to Temperature	1.8	3.0	
Adult Mobility	1.3	2.8	
Dispersal & Early Life History	3.2	2.6	
Sensitivity Score	High		
Sea Surface Temperature	4.0	3.0	
Variability in Sea Surface Temperature	1.0	3.0	
Salinity	1.8	3.0	
Variability Salinity	1.2	3.0	
Air Temperature	4.0	3.0	
Variability Air Temperature	1.0	3.0	
Precipitation	1.3	3.0	
Variability in Precipitation	1.4	3.0	
Ocean Acidification	4.0	2.0	
Variability in Ocean Acidification	1.0	2.2	
Currents	2.0	1.0	
Sea Level Rise	2.6	1.5	
Exposure Score	Very High		
Overall Vulnerability Rank	Very High		

Low
Moderate
High
Very High

- Climate Exposure: Very High. Three exposure factors contributed to this score: Ocean Surface Temperature (4.0), Ocean Acidification (4.0) and Air Temperature (4.0).
- Biological Sensitivity: High. Four sensitivity attributes scored above 3.0: Spawning Cycle (3.5), Early Life History Requirements (3.3), Complexity in Reproduction (3.2), and Dispersal and Early Life History. Dispersal of eggs and larvae is limited.
- Distributional Vulnerability Rank: Medium (73%). Blueback Herring have a relatively high degree of spawning site fidelity, limiting the ability of the species to shift distribution. However, migrations occur over a wide range (from Northeast U.S. Shelf to Florida) providing more opportunity for straying from natal spawning sites.
- Directional Effect in the Northeast U.S. Shelf: The effect of climate change on Blueback Herring is estimated to be neutral, but this estimate has a high degree of uncertainty (<66% certainty in expert scores). Blueback Herring is distributed to Florida, so northward range shifts will likely move Blueback Herring into the Northeast U.S. Shelf. However, changes in rivers from increased precipitation and warming may cause decreases in productivity particularly in the southern portion of the Northeast U.S. shelf. The magnitude of these contrasting effects is unknown.

Vulnerability Scoring Rubric



Alewifes

Bluebacks

For River Herring –

- May just be a starting point or
- Data may already exist to assess the expert opinion

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Outline

Vulnerability assessment methodology

1. Need
2. Goals and objectives
3. Vulnerability assessment framework
4. Potential uses
5. Methodology
6. Output/Results
7. Assessments completed or on-going

Potential Uses

Science:

- Identify stocks that can benefit from incorporating environmental variability into stock assessments
- Identify gaps in information for use in shaping research priorities
- Identify stocks that could benefit from increased monitoring to better quantify when expected climate impacts occur

Management:

- Inform management decisions about catch amounts, and rebuilding plans
- Provide information for use in EIS's, BiOps and other decision making documents
- Identify potential management actions that might reduce vulnerability and increase stock resilience in a changing climate

Need

Climate Change is a long-term change in part of the land-atmosphere-ocean system

Already observing impacts of climate change on variety fish stocks.

Expected Changes:

- Changes in stock *productivity*
- Changes in *distribution*
- Changes in species *interactions*

Need– What About a Quantitative Approach?

In NE, quantitative models have been completed for 5 species (Atlantic cod, Atlantic croaker, Cusk, Atlantic salmon, River herring)

Math:

- 1-2 years per species
- 50+ species (NE only)
- = 50-100 years

http://3.bp.blogspot.com/_TNHOnYQjgYY/Sj5OKl52BkI/AAAAAAAAAEI/YUnjWm1hgAk/s1600-h/fish2.jpg

Sensitivity

Definition: Biological attributes believed to be indicative of the stock's response to climate change. They include the stock's resilience and its adaptive capacity[1]

12 attributes relate to current life history characteristics:

- 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 Requirements
- Population Growth Rate
- Dispersal of Early Life Stages

[1] Williams et al. 2008

Assessments Completed or On-going

- Northeast Vulnerability Assessment (NEVA) results are available from PLOS ONE and included all NEFMC, MAFMC, and ASMFC managed species (82 species)
- Vulnerability assessments currently being implemented for Bering Sea and California Current ecosystems

Vulnerability Narratives

Anguilla rostrata	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Stock Status (Status)	2.7	1.0	
Other Stressors (Other)	2.8	1.7	
Population Growth Rate (Pop Growth)	2.8	1.8	
Spawning Cycle (Spawning)	2.5	2.2	
Complexity in Reproduction (Repr Complx)	2.7	1.9	
Early Life History Requirements (ELH)	2.6	1.2	
Sensitivity to Ocean Acidification (OA)	1.1	2.0	
Prey Specialization (Prey)	1.1	3.0	
Habitat Specialization (Hab)	2.6	3.0	
Sensitivity to Temperature (Sens Temp)	1.3	3.0	
Adult Mobility (Adult Mobil)	1.2	3.0	
Dispersal & Early Life History (Dispersal)	1.1	2.6	
Sensitivity Score	Moderate		
Sea Surface Temperature (SST)	4.0	3.0	
Var. in Sea Surface Temperature (Var SST)	1.0	3.0	
Salinity (Salinity)	1.6	3.0	
Var. Salinity (Var Sal)	1.2	3.0	
Air Temperature (Air Temp)	4.0	3.0	
Var. Air Temperature (Var Air Temp)	1.0	3.0	
Precipitation (Precip)	1.3	3.0	
Var. in Precipitation (Var Precip)	1.4	3.0	
Ocean Acidification (OA)	4.0	2.0	
Var. in OA (Var OA)	1.0	2.2	
Currents (Currents)	2.4	1.0	
Sea Level Rise (Sea Level)	0.0	0.0	
Exposure Score	Very High		
Overall Vulnerability Rank	High		

Low
Moderate
High
Very High

American eels
Overall Vulnerability = High
Exposure = Very High
Sensitivity = Moderate

Eels are catadromous: spawning in the ocean, developing in marine and freshwater water habitats, then growing, and maturing in freshwater.

Seven sensitivity attributes scored above 2.5, but none above a 3.0. In Northeast U.S., the species is at or near historically low levels due to a combination of historical overfishing, habitat loss, food web alterations, predation, turbine mortality, environmental changes, contaminants, and disease…