Overview of the Northeast Habitat Climate Vulnerability Assessment Methods

The goal of this project is to provide regional fisheries, habitat, and protected species managers and scientists with a practical tool to efficiently assess the relative vulnerability of habitats to climate change. The results of the assessment may be used to improve essential fish habitat (EFH) designations and aid in EFH consultations, set habitat conservation priorities, understand cumulative impacts of fishery management actions, and provide long-term context for the management of protected and fishery species.

Project Geographic Scope: The northern and southern boundaries of the study area are the U.S./Canadian border and Cape Hatteras, NC, respectively. The assessment focuses on marine, estuarine, and riverine habitats out to the U.S. EEZ and up-river to capture the full habitat range of diadromous species.

Key Elements of the Assessment

- This assessment considers the overall vulnerability of habitat to climate change to be a function of two main components: exposure and sensitivity.
- The exposure component considers the magnitude and overlap of the projected changes in climate with the distribution of each habitat.
- The sensitivity component includes habitat characteristics, or traits, that are believed to be indicative of the response of a habitat to potential changes in climate.
- Exposure and sensitivity scoring relies on expert elicitation which is based on defined criteria, but allows experts to use their expert opinion to account for the complexities of these habitats.

Vulnerability Assessment Methodology Selection

- We reviewed eleven existing climate vulnerability assessment methodologies, and selected four for further consideration at an in-person workshop in summer 2018. The steering committee decided to develop a hybrid assessment based on the NOAA Fisheries Climate Vulnerability Assessment methodology[1] and the Northeastern Association of Fish and Wildlife Agencies' Vulnerabilities of Northeastern Fish and Wildlife Habitats to Climate Change[2].

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[1] Morrison et al. (2015). Methodology for Assessing the Vulnerability of Marine Fish and Shellfish Species to a Changing Climate. NOAA Technical Memorandum NMFS-OSF-3. https://www.st.nmfs.noaa.gov/Assets/ecosystems/climate/documents/TM%20OSF3.pdf

[2] Galbraith, Hector. 2013. The Vulnerabilities of Fish and Wildlife Habitats in the Northeast to Climate Change. A report to the Northeastern Association of Fish and Wildlife Agencies and the North Atlantic Landscape Conservation Cooperative. Manomet, MA. https://lccnetwork.org/resource/vulnerabilities-fish-and-wildlife-habitats-northeast-climate-change

- We surveyed potential users of the assessment results (e.g., NOAA Fisheries' regional programs including Habitat Conservation Division, fishery management council staff, etc.) to inform the assessment design and scope.

Development of Assessment Framework

- We selected fifty-two habitat sub-classes to be assessed. Habitats are organized based on a modified Cowardin classification, and include the riverine, estuarine, and marine systems to capture the range of habitats used by NOAA trust species (Appendix 1).
- We developed descriptions for nine sensitivity attributes that are indicative of a habitat's response to changes in climate. These are:
    - Habitat condition
    - Habitat fragmentation
    - Ability to spread or disperse
    - Resilience, resistance
    - Changes in abiotic factors
    - Sensitivity and intensity of non-climate stressors
    - Dependence on critical ecological linkages
- The sensitivity attributes descriptions contain information about the relationship of that attribute to climate change, guidance on how to use expert opinion, and definitions for scoring bins indicative of low, moderate, high, and very high sensitivity (Appendix 2).
- Please note: This assessment does not utilize a separate adaptive capacity component; rather, we include these traits within our sensitivity attributes. Sensitivity and adaptive capacity are difficult concepts to characterize, as they are often the inverse of each other. Traits that confer low sensitivity can also be thought to confer high adaptive capacity (e.g., ability to spread or disperse). By defining all traits as sensitivity, we have eliminated the need to create an arbitrary distinction. Furthermore, work done on the Fish Climate Vulnerability Assessment has shown that arbitrary changes in how traits are classified, sensitivity or adaptive capacity, can have unintended consequences of the outcome of the assessments.
- We developed habitat profiles that contain information about each habitat relevant for each sensitivity attribute primarily from published literature, as well as professional judgement.
- We selected ten exposure factors, which are climate variables that could impact the habitat. These are:
    - Sea surface temperature
    - Bottom temperature
    - Air temperature
    - Stream temperature

    - Sea surface salinity
    - Bottom salinity
    - pH
    - Sea level rise
    - Precipitation
    - Streamflow
- Not all exposure factors are relevant to all habitats -- the exposure of each habitat is assessed for between two and six exposure factors.
- The HCVA is assessing climate exposure under end-of-century projections based on the Intergovernmental Panel on Climate Change RCP 8.5 emissions scenario using two climate models:
    - The Regional Ocean Modeling System: Northwest Atlantic Dynamical Downscaling (ROMS-NWA) was used for exposure factors, when available. The end-of-century time frame is 2070-2099. The historic reference period is 1976-2005.
    - The Coupled Model Intercomparison Project 5 (CMIP5) was used for exposure factors where ROMS-NWA does not have projections. The end-of-century time frame for this model is 2050-2099. The historic reference period is 1956-2005.
- For exposure factors not represented directly in the ROMS-NWA or CMIP5 climate models, we developed a scoring system based on published literature of projections driven by climate models (stream temperature[3], streamflow[4], sea level rise[5]).
- We compiled existing spatial data of the distribution of each habitat in the assessment across the study region for use in the exposure scoring, when available. Text descriptions of habitat distribution were developed for habitats with limited spatial data.

Pilot Assessment

- The project team conducted a pilot assessment to evaluate the assessment methodology and make necessary modifications. Participants scored the sensitivity of three trial habitats.

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[3] Letcher, Benjamin H., Daniel J. Hocking, Kyle O'Neil, Andrew R. Whiteley, Keith H. Nislow, and Matthew J. O'Donnell. 2016. "A Hierarchical Model of Daily Stream Temperature Using Air-Water Temperature Synchronization, Autocorrelation, and Time Lags." *PeerJ* 4: e1727. doi:10.7717/peerj.1727.
[4] Demaria, E.M.C., Palmer, R.N., and Round, J.K. 2015. Regional climate change projections of streamflow characteristics in the Northeast and Midwest U.S. Journal of Hydrology: Regional Studies 5: 309-323.
[5] Sweet, WV, Kopp, RE, Weaver, CP, Obeysekera, J, Horton, RM, Thieler, ER, Zervas C. 2017. Global and regional sea level rise scenarios for the United States. National Oceanic and Atmospheric Administration, National Ocean Service. NOAA Technical Report NOS CO-OPS 083. p. 1-56.

- Feedback from the pilot test scorers was used to improve the sensitivity attribute descriptions, tighten up the scoring bins, and identify additional information that needed to be added to the habitat profiles.

Sensitivity Scoring

- Fifteen habitat experts were selected to conduct the sensitivity scoring--five each for the marine, estuarine, and riverine systems. The experts were from several federal agencies and academic institutions.
- Training: Each expert attended a web-based training in which they were introduced to all materials, scoring protocols, and the online scoring database.
- Preliminary scoring: Each expert independently scored each attribute for every habitat in their system by using a 5 tally scoring system. This system allows each scorer to indicate the uncertainty or geographic variability in their score by distributing the five tallies between the four scoring bins (low, moderate, high, very high). Scorers also provided a data quality score (between one and three) to reflect the availability and caliber of information for each attribute.
- Final scoring: Scorers gathered at an in-person workshop to compare and discuss the preliminary scores. This process helps identify errors and allows for sharing of information among the experts with the purpose of leveraging the collective knowledge of the group. The experts were encouraged to make adjustments to the distribution of their tallies (score) based on these discussions; however, we were not searching for consensus and no expert was compelled to change their scores.

Exposure Scoring

- Five experts relied on climate projections and spatial habitat data (distribution) to score the exposure of each habitat to each of the exposure factors.
- As with sensitivity scoring, scorers distributed five tallies between the four scoring bins (low, moderate, high, very high), and provided a data quality score to reflect the availability or confidence in the information for each exposure factor and habitat distribution. Scoring bins were based on the standardized historic anomaly (z-score, difference between the projected end-of-century mean for each exposure factor and the variability of the historic mean).

Vulnerability Analysis

- For every habitat we calculate a weighted mean for each sensitivity attribute and exposure factor. This is done by summing all the tallies in each scoring bin across experts (5 experts per habitat) and calculating a weighted mean (1=low; 2=Moderate, 3=High; 4=Very High).

- Sensitivity attribute means were used to determine the overall sensitivity component score using a logic rule described in Table 1 below. The same was done for the exposure factors.
- Overall vulnerability rank is determined in the same way as described in Morrison et al. (2015). Low, moderate, high and very high component scores are assigned 1, 2, 3, and 4, respectively. The product of the exposure and sensitivity component scores is then classified where 1-3 results in a low vulnerability rank, 4-6 a moderate vulnerability rank, 8-9 a high vulnerability rank, and 12-16 a very high vulnerability rank. Results can be displayed visually using a vulnerability matrix, to show final ranks as well as component scores (Figure 1).

Bootstrap Analysis

- A bootstrap analysis was conducted to determine the habitat vulnerability rank probability considering the distribution of the tallies in each attribute. This is useful in determining threshold effects, when the distribution of tallies is very close to a threshold used in scoring. The bootstrap consists of: for each attribute or factor, resample the tallies summed across scorers (with replacement) then recalculate the attribute or factor mean using the resampled tallies. Use the same scoring rubric to find the sensitivity and exposure component scores, and vulnerability rank. Repeat the process 1,000 times and record the occurrence of each outcome.

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

Table 1. Logic rule for calculating overall habitat's climate exposure and 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 sensitivity. Adapted from Hare et al. 2016[6].

[6] Hare JA, Morrison WE, Nelson MW, Stachura MM, Teeters EJ, Griffis RB, et al. (2016) A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. PLoS ONE 11(2): e0146756. doi:10.1371/journal.pone.0146756

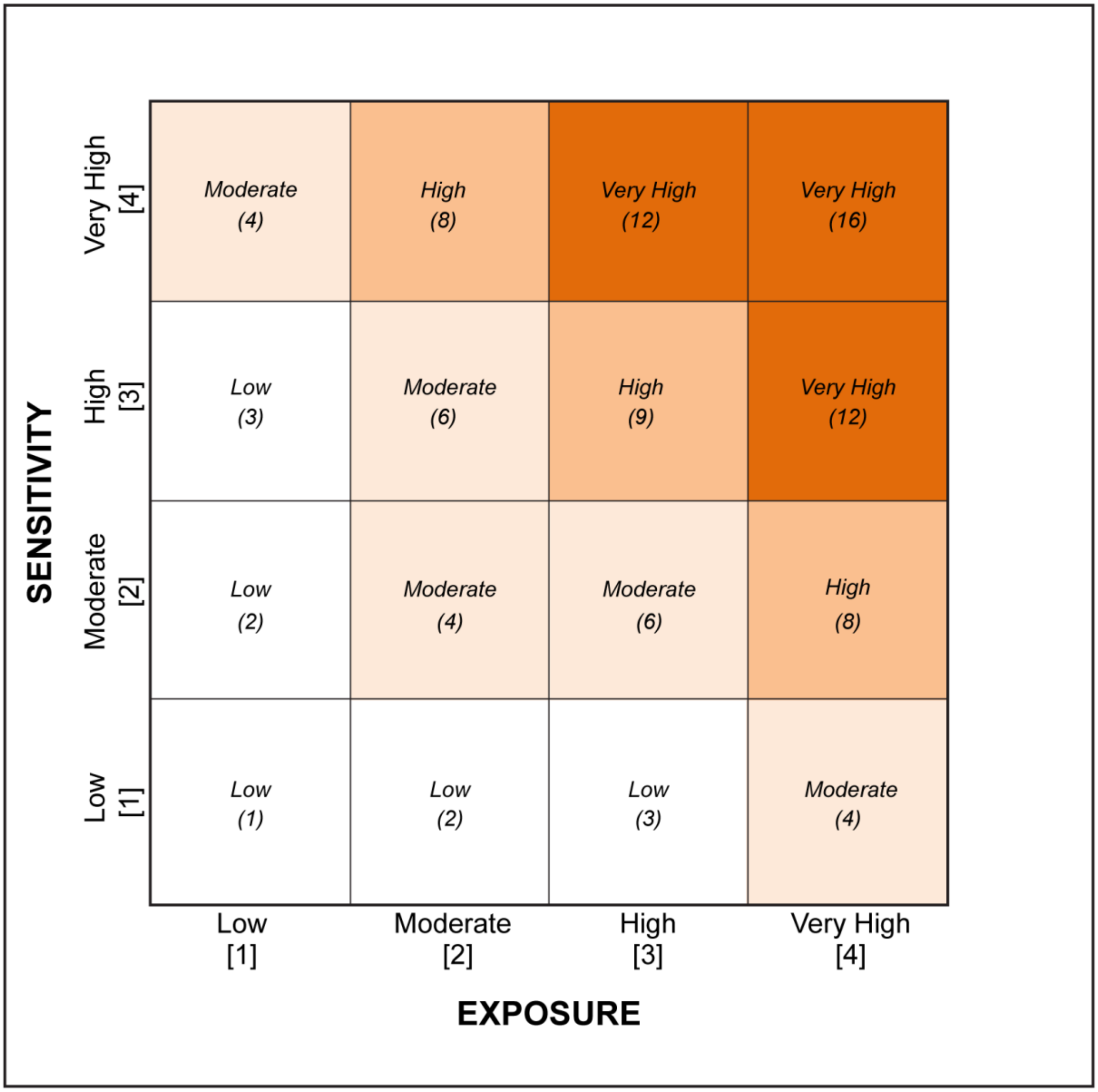


Figure 1. Matrix for determining habitat vulnerability rank based on component scores for exposure and sensitivity. Component scores are given a value of 1-4 (in brackets). Vulnerability rank is determined by multiplying the two component scores (in parentheses). Adapted from Morrison et al. 2015.

Appendix 1: Habitat Classification and Definitions

Habitat Class	**Sub-Class Habitats Included in Class**	**Definition**
Marine System: Open ocean overlying continental shelf and its associated high energy coastline with salinities > 30 ppt. The nearshore marine subtidal subsystem includes areas from the shoreline to locations where the depth reaches 200 meters, while the offshore marine subtidal system includes locations where the water is deeper than 200 meters. Intertidal sub-classes encompasses mean high to mean low water line, and include both the benthic habitat and the water from diurnal tidal inundation.		
Marine Rocky Bottom	• Marine subtidal rocky bottom bedrock, rubble, cobble/gravel (offshore; >200m) • Marine subtidal rocky bottom bedrock, rubble, cobble/gravel (nearshore; <200m) • Marine intertidal rocky bottom bedrock, rubble, cobble/gravel • Artificial fishing reefs and wrecks; groins/jetties	Rocky bottom habitat established on surfaces and crevices of relatively immobile rocky surfaces, including loose rocks of various sizes (rubble, cobble/gravel) and exposed bedrock. In addition, this habitat profile includes the epibenthic flora and fauna associated with hard bottoms, including calcareous algae (but not non-calcareous algae, which are included in marine aquatic bed habitat profile). Includes shallow corals growing on rocky bottom in <150m water depths. Artificial sub-class includes artificial fishing reefs and wrecks, groins/jetties.
Marine Unconsolidated Sand Bottom	• Marine subtidal unconsolidated sand bottom (offshore; >200m) • Marine subtidal unconsolidated sand bottom (nearshore; <200m) • Marine intertidal unconsolidated sand bottom	Subtidal offshore, inshore, and intertidal zone sand habitats. The nearshore marine subtidal sub-class includes areas from the mean low water to locations where the depth reaches 200 meters, while the offshore marine subtidal sub-class includes locations where the water is deeper than 200 meters. Intertidal sub-subclass includes the mean high to mean low water lines. This habitat subclass includes the epifauna and infauna associated with unconsolidated sand bottom, such as non-reef-forming mollusks (e.g., soft-shell clams, hard clams, sea scallops, surf clams, ocean quahogs), marine worms, small crustaceans, gastropods, and polychaetes. This subclass excludes specific habitats identified elsewhere (i.e., non-calcareous algal bed, rooted vascular beds, and reef-forming

		mollusks, i.e., blue mussels, eastern oysters).
Marine Unconsolidated Mud Bottom	• Marine subtidal unconsolidated mud bottom (offshore; >200m) • Marine subtidal unconsolidated mud bottom (nearshore; <200m) • Marine intertidal unconsolidated mud bottom	Subtidal offshore and nearshore zone mud habitats. The nearshore marine subtidal sub-class includes areas from the mean low water to locations where the depth reaches 200 meters, while the offshore marine subtidal sub-class includes locations where the water is deeper than 200 meters. This habitat subclass includes the epifauna and infauna associated with unconsolidated mud bottom, such as non-reef-forming mollusks (e.g., soft-shell clams, hard clams, sea scallops, surf clams, ocean quahogs), marine worms, small crustaceans, gastropods, and polychaetes. This subclass excludes specific habitats identified elsewhere (i.e., non-calcareous algal bed, rooted vascular beds, and reef-forming mollusks, i.e., blue mussels, eastern oysters).
Marine Reef (Offshore)	• Marine subtidal reef, coral-dominated hardbottom, Gulf of Maine (offshore) • Marine subtidal reef, coral-dominated hardbottom, canyons and seamounts (offshore)	Hard-bottom coral and sponge habitats in offshore zone (>150 m), including coral gardens, sponge gardens, coral thickets, etc. dominated by hard corals, soft corals, black corals, glass sponges, and demosponges. Shallow water corals (<200 m) are included in marine rocky bottom profile. *Note that the canyons and seamounts sub-class is characterized as "Mid-Atlantic" in the scoring database.*
Marine Reef (Mollusk)	• Marine subtidal reef, mollusk (oyster/mussel) (nearshore; <200m) • Marine intertidal reef, mollusk (oyster/mussel) • Cultured mollusks (aquaculture) in subtidal and intertidal zone	Bivalve reefs in the subtidal and intertidal zones in the marine system. May be on hard or soft substrates. Specifically focused on reef-building shellfish (e.g. mussels, oyster) that create a biotic hard substrate at the sediments. Note: non-reef-building shellfish (e.g., scallop, soft-shell clam, surf clam) are included in unconsolidated sand and mud bottom subclasses. The intertidal subclass includes both the reef and the water from diurnal tidal inundation. Differences between natural reefs and cultured shellfish are considered.

Marine Aquatic Bed	● Marine nearshore subtidal and intertidal kelp algal habitats ● Marine nearshore subtidal and intertidal non-kelp algal habitats ● Marine nearshore subtidal and intertidal rooted vascular bed	Algal and rooted vascular (seagrass) species occurring throughout the study area. Both groups photosynthesize, so are limited to the photo zone of the water column. This class also includes aquaculture for macroalgae (e.g., kelp farms in New England). Seagrasses occurring in the Marine system of the study area include species occurring only in full salinity waters (> 30 ppt). Algal species include, non-rooted, benthic macrophytes separated by kelp species and non-kelp species occurring in the Marine system. Both groups generally occur in both the subtidal and intertidal zones, although are mostly limited to the lower and middle elevations of the intertidal zone due to sensitivity to dessication.
Marine Water Column	● Marine subtidal water column, shallow / well-mixed ● Marine subtidal water column, shelf / stratified-surface ● Marine subtidal water column, shelf / stratified-bottom ● Marine subtidal water column, epipelagic ● Marine subtidal water column, mesopelagic/bathypelagic	The water column is a concept used in oceanography to describe the physical (temperature, salinity, light penetration) and chemical (pH, dissolved oxygen, nutrient salts) characteristics of seawater at different depths. Water column habitats create the foundation for marine food webs, home to primary producers such as phytoplankton and microbes. These habitats are highly dynamic and exhibit swift responses to environmental variables. The marine water column encompasses open ocean overlying continental shelf and its associated high energy coastline with salinities > 30 ppt. The shallow/well-mixed sub-class refers to the shallow inner shelf (<20m water depth), and is vertically mixed year round. The shelf/stratified surface are surface waters above the seasonal thermocline for areas <200m in depth, while the shelf/stratified bottom are bottom waters below the seasonal thermocline for areas <200m in depth. The epipelagic sub-class is the surface (0 to 200m) of slope waters (areas>200m in depth), while the mesopelagic and bathypelagic are the intermediate and bottom waters (200-1000m) of those slope waters.

Estuarine System: Semi-enclosed bodies with salinities ≤ 30.0 to > 0.5 ppt, brackish water. Includes subtidal and intertidal zones, where the intertidal sub-classes include both the benthic habitat and the water from diurnal tidal inundation.		
Estuarine Rocky Bottom	● Natural estuarine subtidal rocky bottom bedrock, rubble, cobble/gravel ● Natural estuarine intertidal rocky bottom bedrock, rubble, cobble/gravel ● Non-natural estuarine subtidal rocky bottom bedrock, rubble, cobble/gravel ● Non-natural estuarine intertidal rocky bottom bedrock, rubble, cobble/gravel	Bedrock, Rubble, Cobble/Gravel. Profile includes artificial reefs and wrecks in the subtidal, estuarine zone. Includes separate sub-classes for natural and non-natural bedrock rubble, cobble/gravel for both subtidal and intertidal zones in the estuarine system. This habitat subclass includes the epibenthic flora and fauna associated with these hard bottoms, but exclude the specific habitats identified elsewhere (i.e., non-calcareous algal and rooted vascular beds, coral-dominated hard bottom, mollusk reef). Calcareous algae is included in this class. Non-natural subclass includes riprap, artificial reefs and wrecks, and groin/jetties in the subtidal and intertidal, estuarine zones.
Estuarine Unconsolidated Bottom	● Estuarine subtidal unconsolidated sand bottom ● Estuarine intertidal unconsolidated sand bottom/shore ● Estuarine subtidal unconsolidated mud bottom ● Estuarine intertidal unconsolidated mud bottom/shore	Includes intertidal and subtidal sub-classes for both mud and sand habitats, as well as the overtopping water column for intertidal sub-classes. This habitat type includes the epifauna and infauna associated with unconsolidated bottom, such as non-reef-forming mollusks (e.g., soft-shell clams, hard clams, sea scallops, surf clams, ocean quahogs), marine worms, small crustaceans, gastropods, and polychaetes. This subclass excludes specific habitats identified elsewhere (i.e., non-calcareous algal bed, rooted vascular beds, and reef-forming mollusks, i.e., blue mussels, eastern oysters).
Estuarine Aquatic Bed	● Estuarine subtidal and intertidal kelp algal habitats ● Estuarine subtidal and intertidal non-kelp algal habitats ● Estuarine subtidal and intertidal rooted vascular bed	Algal and rooted vascular (seagrass) species occurring throughout the study area. Both groups photosynthesize, so are limited to the photo zone of the water column. This class also includes aquaculture for macroalgae (e.g., kelp farms in New England). Seagrasses occurring in the Estuarine system of the study area include species occurring in brackish (≤ 30 ppt to > 0.5 ppt). Algal species include non-rooted, benthic macrophytes separated by

		kelp and non-kelp species occurring in the salinity range of the Estuarine system. Both groups generally occur in both the subtidal and intertidal zones, although are mostly limited to the lower and middle elevations of the intertidal zone due to sensitivity to dessication.
Estuarine Reef	• Estuarine subtidal mollusk reef (oyster/mussel) • Estuarine intertidal mollusk reef (oyster/mussel) • Cultured mollusk reefs (aquaculture) in subtidal and intertidal zone	Bivalve reefs in the subtidal and intertidal zones in the estuarine system. May be on hard or soft substrates. Specifically focused on reef-building shellfish (e.g. mussels, oyster) that create a biotic hard substrate at the sediments. Note: non-reef-building shellfish (e.g., scallop, soft-shell clam, surf clam) are included in unconsolidated sand and mud bottom subclasses. The intertidal subclass includes both the reef and the water from diurnal tidal inundation. Differences between natural reefs and cultured shellfish are considered.
Estuarine Emergent Wetland	• Mid-Atlantic Estuarine intertidal emergent wetland, native persistent & non-persistent • Mid-Atlantic Estuarine intertidal emergent wetland, invasive spp. • New England Estuarine intertidal emergent wetland, native persistent & non-persistent • New England Estuarine intertidal emergent wetland, invasive spp.	Wetlands dominated by perennial plants (characterized by erect, rooted, herbaceous hydrophytes), in a estuarine system where salinity is greater than 0.5 ppt. Includes brackish to full salinity emergent wetlands, persistent and non-persistent.
Estuarine Water Column	• Estuarine subtidal water column (well-mixed)	The estuarine water column encompasses the stratum from the surface (mean low water) to a maximum depth of 200 m (although few if any estuaries approach this depth). This includes all estuaries types based on circulation (salt-wedge, well-mixed, partially-mixed, and fjord).

Riverine System: Terminates at the downstream end where the concentration of ocean-derived salts in the water ≥ 0.5 ppt. during the period of annual average low flow, or where the channel enters a lake.		
Riverine Rocky Streambed and Bank	• Riverine rocky streambed bedrock, rubble, cobble/gravel, tidal and non-tidal	Bedrock, rubble, cobble/gravel streambed and banks for tidal and non-tidal rivers. This includes the epibenthic flora and fauna associated with these hard bottoms but exclude specific habitats (algal beds, rooted vascular, emergent wetlands) that are included in other subclasses. Riverine rocky shores support sparse plant and animal communities, including lichens and blue-green algae. Also includes large woody debris, boulders, tree roots, and other structural elements that characterize rocky streambed/bank.
Riverine Unconsolidated Streambed and Bank	• Riverine sand streambed and bank, tidal and non-tidal • Riverine mud streambed and bank, tidal and non-tidal	Sand and mud streambeds and banks of tidal and non-tidal rivers, including large woody debris, tree roots, and other structural elements that occur in unconsolidated streambed/bank. Characterized by substrates lacking vegetation except for pioneering plants during brief favorable periods. This includes the epifauna/infauna and epiflora associated with these hard bottoms (e.g., freshwater mussels) but exclude specific habitats (algal beds, rooted vascular, emergent wetlands) that are included in other subclasses.
Riverine Aquatic Bed	• Riverine algal bed, tidal and non-tidal • Riverine rooted vascular bed, tidal and non-tidal	Riverine aquatic beds where the salinity is <0.5 ppt. during the period of annual average low flow. Terminates where the river or stream channel enters a lake. Algal beds occur in both tidal and non-tidal portions of a river. Algal bed species include filamentous green algae occurring in tidal portions of rivers (e.g., *Spirogyra* sp. and *Cladophora* sp.). Non-tidal, freshwater green algae species include muskgrass (*Chara* sp.) and brittle grass (*Nitella* sp.). Rooted vascular beds occur in the lower river within the influence of tidal action and include widgeon grass (*Ruppia maritima*)- a freshwater plant that is tolerant of both fresh

		and saltwater and wild celery (*Vallisneria americana*). In addition, the pondweed community, including sago pondweed (*Stuckenia pectinata*) and redhead grass (*Potamogeton perfoliatus*) are freshwater submerged plants that have some tolerance to salinities up to about 10 ppt. Hydrilla (*Hydrilla verticillata*) is an invasive freshwater plant that tolerates some salinity (up to 7 ppt). In freshwater, non-tidal portions of rivers, rooted vascular beds in the study area include water stargrass (*Heteranthera dubia*), widgeon grass, wild celery, Eurasian watermilfoil (*Myriophyllum spicatum*), and hydrilla.
Riverine Emergent Wetland	• Riverine tidal emergent wetland, native persistent and non-persistent • Riverine non-tidal emergent wetland, native persistent and non-persistent • Riverine tidal emergent wetland, invasive spp. • Riverine non-tidal emergent wetland, invasive spp.	Wetlands dominated by perennial plants (characterized by erect, rooted, herbaceous hydrophytes), in a riverine system where salinity is less than or equal to 0.5 ppt. Includes both tidal and non-tidal wetlands, and both native (persistent and non-persistent) and invasive species. Native tidal species include Spartina spp. and native non-tidal species include *Typha* spp. Invasive tidal species include common reed (*Phragmites australis*) and invasive non-tidal species include common reed and purple loosestrife (*Lythrum salicaria*)
Riverine Water Column	• Riverine water column, tidal and non-tidal	The 3-dimensional space of water for both tidal and non-tidal zones in the river. The class includes the physical, chemical, and biological components of the water, but not the river bottom/banks, submerged vegetation, or emergent and riparian vegetation. Terminates at the downstream end where the concentration of ocean-derived salts in the water ≥ 0.5 ppt. during the period of annual average low flow, or where the channel enters a lake.

Appendix 2: Sensitivity Attributes

Background

The goal of this project is to provide regional fisheries, habitat, and protected species managers and scientists with a practical tool to efficiently assess the vulnerability of habitats to climate change. Vulnerability is defined here as the extent to which a habitat could be impacted by climate change. The potential for a change in distribution and positive or negative effects of a changing climate are also assessed. This project considers the overall vulnerability of habitat to climate change to be a function of two main components: exposure and sensitivity/adaptive capacity.

Exposure is a measure of the predicted environmental change that a habitat may experience within the study area. It is the overlap between the current distribution of habitat and the magnitude and spatial distribution of the expected environmental change. The factors accounted for in exposure may include increases in temperature, changes to freshwater input, rise in sea level, ocean acidification and changes to ocean circulation. The exposure factors may vary from one assessment to another to capture the relevant environmental factors specific to the specific study area (e.g., sea ice coverage in the Arctic, coral bleaching in the tropics).

The sensitivity/adaptive capacity component is composed of habitat attributes that are believed to be indicative of the response of a habitat to potential changes in climate. Here attributes that describe the sensitivity and adaptive capacity of a habitat are combined, because of the difficulty in clearly separating these two components of vulnerability. This document provides definitions, justifications, and relationships with climate change, as well as scoring bins for each of the sensitivity/adaptive capacity attributes.

This vulnerability assessment can be completed at a variety of levels of detail with regards to habitats. The hierarchical Cowardin habitat scheme (Cowardin et al. 1979) is used as a structure and specific users can assess habitats of interest at different levels of specificity. The Cowardin scheme covers freshwater, estuarine, and marine habitats which matches well with the habitats used by managed fish and shellfish species and protected species.

This is the first version of this methodology. It is viewed that this assessment would be repeated at some frequency (5-10 years) and new information would be incorporated in each iteration.

This methodology leans heavily on expert opinions. Experts should use their knowledge to interpret these attributes and attribute bins. For example, experts may encounter a situation where the scoring bins suggest a specific attribute score, but their expert knowledge of the habitat leads them to think the score should be higher, lower, or more uncertain. We are counting on the experts to make these decisions.

Definition of Habitat

Habitat is defined as coastal rivers and watersheds, estuaries, and marine waters, from the bottom through the water column. This definition includes an area's physical, geological, chemical, and biological components that support the survival, growth, and reproduction of plants and animals (NAO 216-17: NOAA National Habitat Policy).

HCVA Sensitivity/Adaptive Capacity Attributes

Habitat Condition

Goal: To determine if a habitat's current status or condition is limiting the ability of that habitat to respond to climate induced changes.

Definition: The ability of the habitat to support a natural, fully-functional ecological community of organisms and the associated/expected ecosystem services.

Background and relationship to climate change: Healthy, intact habitats are expected to be less vulnerable to climate change than degraded habitats. Habitats that have been impacted by either natural or anthropogenic stressors and are in poor condition and have impaired functions, are generally not able to support productive and resilient organisms and communities. Habitat condition and quality can be reduced by a variety of anthropogenic factors, including sedimentation, nutrients, toxic chemicals, physical disturbance, and colonization by exotic and invasive species of plants and animals. In addition, climate change can affect the condition of habitats through various means including warming water, ocean acidification, and sea level rise. The degradation of habitat condition and quality affects a range of ecological processes, including primary and secondary production, trophic dynamics, succession, and species diversity (Deegan and Buchsbaum 2005; Robinson and Pederson 2005). Habitats in poor condition are vulnerable to novel or increased existing natural and anthropogenic stressors, resulting in synergistic and cumulative effects that reduces a habitat's resiliency and adaptation to climate change (Brander 2008; Jackson 2010; Staudt et al. 2012; Staudt et al. 2013; Crozier et al. 2019).

There are several large-scale habitat condition summaries that have been produced. These may be used to develop habitat profiles, along with more regionally specific studies into habitat condition.
EPA Coastal Condition Report
NMFS-FWS Status and Trends
Habitat Condition Assessments for Watershed Health

How to use expert opinion: Based on the background material provided with the assessment and the expert's knowledge, a determination needs to be made as to the condition of the habitat within the study area. It is likely that there is variability in habitat condition across most study areas and these variability should be considered by experts in their scoring.

Bins:

- **Low Sensitivity**: High quality habitat (near pristine over much of the region), and stable to positive trends in habitat condition across most of the range.
- **Moderate Sensitivity**: Moderate quality (generally intact but somewhat degraded), or stable trends in habitat condition over much of the range.
- **High Sensitivity**: Moderate quality over much of the range or poor quality over some of the range (generally intact but somewhat degraded), and decreasing trends in habitat condition over much of the range.
- **Very High Sensitivity**: Poor condition of habitat across much of the range (significantly degraded), and decreasing trends in habitat condition over the range.

Habitat Fragmentation

Goal: To determine the change in fragmentation of the habitat within the study area. Habitats can be fragmented by natural causes as well as by a variety of human activities. For our purposes, we are primarily interested in anthropogenic changes that generally occur over shorter time frames compared to natural fragmentation, and cause the habitat to reside outside its expected range of natural variability.

Definition: "A landscape-level process in which a specific habitat is progressively sub-divided into smaller, geometrically altered, and more isolated fragments as a result of both natural and human activities, and this process involves changes in landscape composition, structure, and function at many scales and occurs on a backdrop of a natural patch mosaic created by changing landforms and natural disturbances" (McGarigal and McComb 1999) (see http://www.umass.edu/landeco/pubs/mcgarigal.mccomb.1995.pdf and http://www.umass.edu/landeco/teaching/landscape_ecology/labs/fragprotocol.pdf). An alternative definition of fragmentation is “a process whereby a contiguous patch of habitat is transformed into a number of smaller, convoluted and/or disjunct patches, isolated from each other by a matrix of habitat unlike the original” (Wang et al. 2014).

Background and relationship to climate change: Continuous, well connected habitats are expected to be less vulnerable to climate change than fragmented, poorly connected habitats. Fragmentation of habitats can lead to loss of biodiversity and limit the ecological services that the habitat provides. Fragmented habitats also have increased edge effects, which can result in loss of smaller habitat patches through disturbance and change.

Background:
Wang et al. (2014): https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/2041-210X.12198
McGarigal et al. (2005):
http://www.umass.edu/landeco/teaching/landscape_ecology/labs/fragprotocol.pdf
Crozier et al. (2019):
https://www.researchgate.net/publication/334657545_Climate_vulnerability_assessment_for_Pacific_salmon_and_steelhead_in_the_California_Current_Large_Marine_Ecosystem

How to use expert opinion: Experts are asked to estimate the degree of anthropogenic fragmentation within the natural/historic ecological niche/range of the habitat (e.g., occurrence w/i MLW - 30 feet as the niche for eelgrass beds). Experts should consider whether fragmentation is detrimental to the habitat’s function. If this information is not available at the necessary scale, experts are asked to provide an opinion based on their experience and the background material provided.

Bins:
- **Low Sensitivity**: Habitat is not fragmented and is mostly in its natural, expected state, continuous with large to moderately-sized patches. Habitat function and/or connectivity is not currently limited, and habitat fragmentation is stable to decreasing.
- **Moderate Sensitivity**: Habitat is mostly continuous with limited fragmentation beyond its natural, expected state. Habitat function and/or connectivity is partially limited, and habitat fragmentation is generally stable.
- **High Sensitivity**: Habitat is fragmented beyond its natural, expected state. Habitat is partially continuous with numerous small to moderately-sized patches. Habitat function and/or connectivity is currently moderately limited, and habitat fragmentation is increasing.

Very High Sensitivity: Habitat is highly fragmented beyond its natural, expected state. Habitat is limited to numerous small patches. Habitat function and/or connectivity is severely limited, and habitat fragmentation is increasing.

Distribution/Range

Goal: To determine the extent of the geographic range of a habitat within the assessment area.

Definition: The historic geographic extent of a habitat, including the leading (i.e., the expanding or colonizing) edge and trailing (i.e., contracting or declining) edge, if applicable, and the water depths for which the habitat naturally occurs.

Background and relationship to climate change: Habitats that occur over a wide latitudinal and depth range within the assessment area are thought to be less vulnerable to climate change. Widely distributed habitats are more likely to be able to persist through a localized destructive event. On the other hand, habitats which exist only on small scales have an increased likelihood of being impacted by a single localized destructive event (i.e., storm, major pollution event, scouring). Habitats which can occur across a wide range of depths are also thought to have reduced sensitivity to change because certain depths may offer refugia to mitigate some changes. Finally, as habitats shift poleward with increasing water temperatures, it is important to keep in mind which habitats are expanding into the study area and which habitats are being pushed out of our study area.

How to use expert opinion: Large-scale maps of habitat distributions are generally available and experts should consider the range of the habitat within the assessment area. When accounting for range across the study area, experts should consider only the area where the habitat could naturally occur. For instance, SAV would only be expected to be at certain depths within the photic zone. Experts should also consider if the study area includes the trailing edge of the habitat distribution.

Bins:

Low Sensitivity: Habitat naturally is found across the latitudinal and depth range of the study area; habitat trailing edge is not found within the study area; or the leading edge of the habitat is expanding into the study area.

Moderate Sensitivity: Habitat is found across the latitudinal range of the study area where it occurs naturally but has a limited depth distribution; habitat trailing edge is not found within the study area.

High Sensitivity: Habitat is somewhat limited in latitude and depth, where it is expected to occur naturally, but the habitat trailing edge is not found within the study area.

Very High Sensitivity: Habitat has limited latitude and depth range within the study area and the trailing edge of the species' distribution is found within the study area.

Mobility/Ability to spread or disperse

Goal: To estimate the ability or capability of the habitat to spread to new areas if their current area becomes less suitable.

Definition: The ability or capability of a habitat to disperse, move, or spread to areas beyond its existing location. Biotic (plant) habitats may disperse vegetatively or reproductively (e.g., seeds, propagules). Some habitats may have the intrinsic capacity to disperse (e.g., salt marsh), but their capability may be limited if extrinsic barriers exist (e.g., seawalls).

Background and relationship to climate change: The mobility of a habitat is a function of (1) the availability of suitable areas to inhabit (e.g., corridors for marsh migration) and (2) intrinsic capacity to disperse (e.g., seeds, propagules, sponge or bivalve larvae). The ability or capability to move, spread, or disperse decreases the vulnerability of a habitat to climate change. As conditions change, if a habitat can expand into new suitable areas the habitat will be more likely to persist over the long term. However, natural or man made barriers can impact a habitat's ability to move or spread into otherwise suitable areas. This attribute is primarily focused on biotic habitats, or the biotic component of abiotic habitats (e.g., epifauna or epiflora). The inability of some abiotic habitats such as large boulders to disperse does not necessarily make those habitats more sensitive to climate change, while the high mobility of others (e.g., marine water column) does not make them less sensitive. For biotic habitats, mobility influences the habitat's ability to adapt to gradual change (e.g., to fill a shifting thermal niche). This attribute is related to, but distinct from, habitat fragmentation, as habitats with low mobility may also be more susceptible to fragmentation.

How to use expert opinion: Scorers should consider both the ability of a habitat to move or spread, as well as natural or anthropogenic barriers to that expansion. When scoring an abiotic habitat, consider only the biotic component of that habitat. If there is no biotic component, give it a low sensitivity score. In cases where scorers judge that the abiotic habitat itself is sensitive due to its lack of mobility, scorers should use their expert opinion to score accordingly. For example, hard bottom reef habitat generally includes epifauna and epiflora communities. While the abiotic (rock) component of the habitat may have low mobility, the associated epifauna and epiflora may have a high ability/capability to spread or move. In this example, we may consider this habitat to have a low sensitivity for this attribute.

Bins:

- **Low Sensitivity**: High ability / capability to spread or move (e.g., water column habitats)
- **Moderate Sensitivity**: Habitats which, given time, can move or spread into new areas as they become available, assuming the new areas are not blocked by some sort of barrier.
- **High Sensitivity**: Habitats in which the ability to spread is limited by the availability of suitable areas with proper conditions, or because of the presence of barriers.
- **Very High Sensitivity**: Habitats with little or no ability to disperse or move; or habitats in which their ability to spread is blocked by anthropogenic barriers.

Resistance

Goal: To determine, on a relative scale, how durable a habitat (including its function and ecosystem services) is to changing conditions or exposure to disturbance.

Definition: The ability of a habitat to tolerate a stressor and persist while retaining its functionality when subjected to a disturbance.

Background and relationship to climate change: In the literature, resilience and resistance are related concepts. Here we define resistance as the magnitude of disturbance that can be withstood without changing the functional processes and services normally provided by that habitat. Certain marine habitats are inherently more durable than others. Habitats that are solid and durable will be less likely to be impacted by increased physical disturbances that may arise with projected changes in climate (e.g., increased wave energy, storm frequency or intensity).

References:

https://academic.oup.com/bioscience/article/67/3/208/2900174

How to use expert opinion: There is no one measure of resistance and thus experts must use their opinion as guided by the scoring bins. Looking at past disturbances, how durable is the habitat and is the function of the habitat maintained when disturbances occur? Consider disturbances such as hydrodynamic energy (e.g., wave, current, eddy), sea level rise, and coastal storms. Do not consider other abiotic disturbance factors (e.g., temperature, pH, salinity) as those will be scored under “sensitivity to changes in abiotic factors.”

Bins:

Low Sensitivity: Very resistant to natural disturbance. Functionality of habitat retained even in high disturbance; epiflora and epifauna also adapted to high disturbance.

Moderate Sensitivity: Moderately resistant to natural disturbance. Functionality and services of habitat can be compromised by disturbance; epiflora, epifauna and infauna somewhat adapted to disturbance.

High Sensitivity: Generally not adapted for resistance to significant natural disturbance. Functionality of habitats impacted by disturbance; epiflora, epifauna and infauna not well adapted to disturbance.

Very High Sensitivity: Minimally resistant to natural disturbance. Habitat function easily disturbed in a way that directly impacts services to related epiflora, epifauna and infauna.

Resilience

Goal: To determine, on a relative scale, the rate of recovery for a habitat to likely climate-related disturbances.

Definition: Resilience measures the ability of, and the time period for, a habitat to recover from a disturbance. Recover in this sense means the return to approximately the functional equivalency prior to the disturbance (i.e., the time frame to return to the previous state after a disturbance).

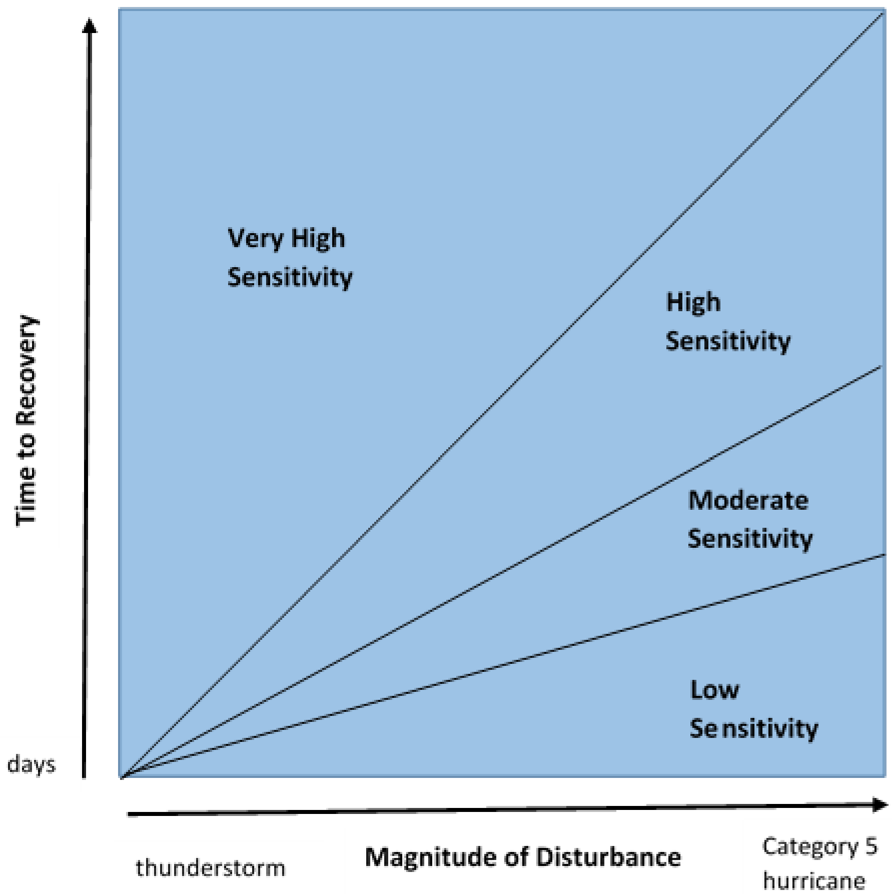
Background and relationship to climate change: In the literature, resilience and resistance are related concepts. Resilience measures the ability of a habitat to recover from a disturbance. Recover in this sense means return close to functional equivalency. In some cases, these disruptive events can increase adaptation capacity by the proliferation of remaining resistant individuals. A habitat that has a high rate of recovery after a disturbance is thought to be better able to adapt to changes in climate. This can be accomplished by the habitat bouncing back, or re-establishing itself, after a disruptive event.

References:

http://www.pnas.org/content/114/31/8301

https://www.nefsc.noaa.gov/publications/tm/tm181/

How to use expert opinion: Looking at past disturbances, how long has it taken for the habitat to return to original structure and function. Past disturbances can include extreme natural events or seasonal changes in conditions, including hydrodynamic energy (e.g., wave, current, eddy), sea level rise, and coastal storms. If a habitat is re-established in a new location, consider whether the change in location alters its function within the geographic context of the study area. Scorers should consider both the magnitude of the possible disturbances and the rate of recovery of the habitat to those various disturbances. Refer to the following conceptual diagram as guidance:



Bins:

Low Sensitivity: Very resilient to high natural disturbance. Habitat function, structure, and services of the habitat is able to return to the previous state in a relatively short period even after high disturbance; epiflora, epifauna, and infauna also able to recover in a short period after high disturbance.

Moderate Sensitivity: Moderately resilient to moderate natural disturbance. Habitat function, structure, and services of the habitat is able to return to the previous state in a relatively short period after moderate disturbance; epiflora, epifauna, and infauna somewhat able to recover in a short period after moderate disturbance.

High Sensitivity: Generally not resilient to moderate to high natural disturbance. Habitat function, structure, and services of the habitat is unable to return to the previous state in a relatively short period after moderate disturbance; epiflora, epifauna, and infauna also unable to recover in a short period after moderate disturbance.

Very High Sensitivity: Minimally resilient to natural disturbance. Habitat function, structure, and services unable to return to the previous state even after minimal disturbance; epiflora, epifauna and infauna also unable to recover after minimal disturbance.

Sensitivity to changes in abiotic factors

Goal: To determine, on a relative scale, how susceptible a habitat is to an acute or persistent change in physical and chemical conditions which are anticipated under climate change (e.g., temperature, pH, salinity).

Definition: Sensitivity to changes in abiotic factors is a measure of a habitat's ability to tolerate changes in chemical and physical characteristics of the environment. For this study, abiotic factors include temperature, salinity, dissolved oxygen, and carbonate chemistry/CO2 concentration, but may include other factors (e.g., nitrogen) and synergistic effects.

Background and relationship to climate change: This attribute seeks to evaluate how sensitive a habitat is to changes in multiple abiotic factors. Slightly sensitive represents a chronic impact with effects being demonstrated on the scale of 1 year or more. Moderately sensitive represents a chronic impact with effects being demonstrated on the scale of less than a year. Highly sensitive represents an acute impact. Habitats that are sensitive to changes in abiotic factors will be more vulnerable to climate change than habitats that are not sensitive to changes in abiotic factors because of the compounding effects of multiple stressors.

How to use expert opinion: Experts should take into account both the number of abiotic factors as well as magnitude (see Table below). Abiotic factors stressors include: temperature, salinity, dissolved oxygen, sea level rise, and carbonate chemistry/CO2 concentration, but may include other factors (e.g., nitrogen) and synergistic effects. Take synergistic impacts into account and treat the synergistic effect as another factor. The expert should then sum across columns to estimate the sensitivity. Avoid double counting the same factors between this attribute and sensitivity and intensity of non-climate stressors.

Sensitivity	Temperature	Dissolved O_2	Carbonate Chemistry/ CO2 concentration	Salinity	Other Abiotic Factors	Synergistic Factors
Not	0	0	0	0	0	0

sensitive						
Slightly sensitive	1	1	1	1	1	1
Moderately sensitive	2	2	2	2	2	2
Highly sensitive	3	3	3	3	3	3

Bins:
- **Low Sensitivity**: Score < 5
- **Moderate Sensitivity**: Score 5-7
- **High Sensitivity**: Score 8-10
- **Very High Sensitivity**: Score > 10

Sensitivity and intensity of non-climate stressors

Goal: To determine the relative impact of non-climate impacts currently affecting the habitats.

Definition: The sensitivity of a habitat to existing non-climate stressors, as well as a measure of the intensity of each non-climate stressor, can increase its vulnerability to climate change. For this study, non-climate stressors may include dredging/filling, pollution/eutrophication, invasive species, harmful algal blooms, and shoreline hardening, but can also include other stressors (e.g., fishing gear) and synergistic effects.

Background and relationship to climate change: Habitats that are already stressed by human influences are likely to be more vulnerable to change. Impacted habitats are less able to resist climate change impacts and are less resilient to disturbance. Habitats that are sensitive to non-climate stressors may be vulnerable to novel or increased existing natural and anthropogenic stressors, resulting in synergistic and cumulative effects that reduces a habitat's resiliency and adaptation to climate change (Brander 2008; Jackson 2010; Staudt et al. 2012; Staudt et al. 2013). Consider only negative impacts to non-climate stressors when scoring the sensitivity (e.g., if a habitat will be positively impacted by eutrophication, it should not be scored highly sensitive).

This report contains detailed information on a wide-range of anthropogenic impacts to habitats in the Northeast Region: [NOAA Tech Memo on Non-fishing habitat impact report]

How to use expert opinion: Estimate the sensitivity and intensity of the habitat for all applicable non-climate stressors, from highly sensitive (3), moderately sensitive (2), slightly sensitive (1), or not sensitive (0). The sum of sensitivity scores determines the sensitivity of the habitat. Additional and relevant non-climate stressors not listed in the table should be described and scored in "Other/Synergistic Effects". Experts should take into account both the number of non-climate stressors as well as intensity (adjust score higher for stressors with high intensity, but do not adjust score lower for stressors with low intensity). For example, submerged aquatic vegetation (SAV) is very sensitive to mechanical impacts from dredging, but if the probability or intensity of dredging in a geographic area is low the habitat is not vulnerable to the stressor in that location. However, the score should not be lowered for SAV in that location because the intensity is low. On the other hand, SAV may not be sensitive to harmful algal blooms (HAB) and generally able to tolerate those conditions, but if the intensity of HAB is very high and the blooms substantially impair light transmittance over weeks or months it may increase the vulnerability of SAV in an estuary. In this case, the sensitivity score should be adjusted higher.

Scorers should also consider projected future changes in the magnitude of each stressor in addition to its current magnitude. An example may be that an increasing trend in shoreline hardening may warrant higher scores if a habitat type may be sensitive to wide-spread shoreline hardening. Take synergistic impacts into account and treat the synergistic effect as another stressor. Avoid double counting the same factors between this attribute and sensitivity to changes in abiotic factors.

	Dredging/ filling	Pollution/ Eutrophication	Harmful Algal Bloom	Invasive Species	Shoreline Hardening/ Built Environment	Other / Synergistic Effect
Not sensitive	0	0	0	0	0	0
Slightly sensitive	1	1	1	1	1	1
Moderately sensitive	2	2	2	2	2	2

Highly sensitive	3	3	3	3	3	3

Bins:

Low Sensitivity: Score < 5
Moderate Sensitivity: Score 5-7
High Sensitivity: Score 8-10
Very High Sensitivity: Score > 10

Dependency on critical ecological linkages

Goal: To determine the relative importance of other species in maintaining the ecological function and health of a habitat. This trait is included because some habitats are not only vulnerable to direct impacts of climate change but also to the climate impacts on key species that are associated with the habitats.

Definition: Some habitats may depend upon associated species to maintain the health or function of a habitat. In some extreme cases, certain habitats cannot exist without the active maintenance or engineering of associated species. Examples of high-dependency habitats include coral reef symbionts (i.e., zooxanthellae), grazers on eelgrass, riparian vegetation or beavers in riverine habitats, urchin grazers on macroalgae, rocky intertidal invertebrates and vegetated communities.

Background and relationship to climate change: Habitats requiring the active participation or presence of associated species to maintain the health or function of a habitat. The more dependencies on ecological linkages, the higher likelihood that one or more of these linkages will be affected by climate change.

How to use expert opinion: Ecosystems, of which habitats are part of, are inherently complicated. All habitats depend on associated species to some extent. Experts should use their judgment to determine the relative importance linkages between keystone species and the likelihood that these linkages could be disrupted by changes in climate.

Bins:

Low Sensitivity: Habitats which can persist without intervention from ecological engineers or keystone species.

Moderate Sensitivity: Habitats which have limited dependence on outside species in order to maintain their function.

High Sensitivity: Habitats which depend on key linkages with other species to maintain their condition or function.

Very High Sensitivity: Habitats which are actively maintained by a key species, or suite of species, which may be vulnerable to changes in climate conditions. Without intervention from these species, the habitats will become degraded.