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Northeast Regional Action Plan – NOAA Fisheries Climate Science Strategy

US DEPARTMENT OF COMMERCE
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Northeast Regional Action Plan – NOAA Fisheries Climate Science Strategy

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Editorial Notes

Information Quality Act Compliance: In accordance with section 515 of Public Law 106-554, the Northeast Fisheries Science Center completed both technical and policy reviews for this report. These predissemination reviews are on file at the NEFSC Editorial Office.

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1. EXECUTIVE SUMMARY

The Northeast U.S. Shelf Ecosystem supports a wide array of living marine resources from Atlantic sea scallops, one of the most valuable, to the North Atlantic Right whale, one of the most endangered. All of these resources - fish, invertebrates, marine mammals, sea turtles, plants, habitats, and other ecosystem components - are being impacted by climate change and multidecadal climate variability. In fact, the pace of observed climate change in the Northeast U.S. is faster than in many other U.S. Large Marine Ecosystems, and future change in the Northeast U.S. Shelf ecosystem is projected to be greater than many other portions of the world's oceans. These changes in climate are already creating significant challenges for the region. Species distributions are becoming out of sync with the spatial allocations of management. The productivity of some iconic species is decreasing, making rebuilding and recovery difficult. Some ports rely on one or two fisheries; changes in these fisheries could have dramatic consequences for the human communities connected to these ports. Changes in science and management can be slow, while changes in the physics, chemistry, and biology of the ecosystem are occurring rapidly. Despite these challenges, there are opportunities. Some species in the region are responding positively to the changes in climate: moving into the region and increasing in productivity. For many managed species, management actions can occur relatively rapidly: the New England Fisheries Management Council (NEFMC) and Mid-Atlantic Fisheries Management Council (MAFMC) have developed specification procedures and framework adjustments that can be implemented within a year of receiving new, peer-reviewed advice. The region has an excellent marine science infrastructure and advanced technologies offer new tools for observing, understanding, and adapting to change. Recognizing the opportunities and challenges resulting from climate change, NOAA Fisheries released the Climate Science Strategy in August 2015. This Strategy develops a national framework to meet the growing demand for information to better prepare for and respond to climate-related impacts on the nation's living marine resources and resource-dependent communities.

The Strategy calls on each region to develop a Regional Action Plan to customize and execute the Strategy over the next 3-5 years. The Plan and Strategy cover all NOAA Fisheries mission elements: sustainable fisheries, protected resources, aquaculture, habitat, and ecosystems; work is needed across all of these mission elements. Here, the Northeast Regional Action Plan (NERAP) applies to the Northeast U.S. Shelf Ecosystem, which extends from North Carolina to Maine, and includes watersheds, estuaries, the continental shelf and the open ocean. The Northeast Regional Action Plan identifies 15 NERAP Actions of highest priority. These actions are ordered by the objectives of the NOAA Fisheries Climate Science Strategy (e.g., NERAP Action 1 is associated with Objective 1 of the Strategy). Actions are prioritized for *No New Resources* and *New Resources* scenarios (Table 1). Under *No New Resources*, the Plan describes actions that can be taken to advance the NOAA Fisheries Climate Science Strategy at current funding and staffing levels. These actions are broadly consistent with activities currently underway at Northeast Fisheries Science Center (NEFSC) and the Greater Atlantic Regional Fishery Office (GARFO) and within the region but will require greater integration across the NEFSC and GARFO and greater collaboration with partners throughout the region. Under *New Resources*, the Plan prioritizes actions that can be taken with $2 million in additional funding. The description of actions under *New Resources* is limited and does not encompass everything that is needed to accomplish the action.

The recommended Northeast Regional Action Plan (NERAP) actions are:

NERAP Action 1 - Give greater emphasis to climate-related Terms of Reference and analyses in stock assessments.

NERAP Action 2 - Continue development of stock assessment models that include environmental terms (e.g., temperature, ocean acidification).

NERAP Action 3 - Develop climate- related products and decision support tools to support protected species assessments and other management actions.

NERAP Action 4 - Increase social and economic scientist involvement in climate change research through multidisciplinary work on climate that includes both social and natural sciences.

NERAP Action 5 - Develop Management Strategy Evaluation capability to examine the effect of different management strategies under climate change.

NERAP Action 6 - Improve spatial management of living marine resources through an increased understanding of spatial and temporal distributions, migration, and phenology.

NERAP Action 7 - Continue to build industry-based fisheries and ocean observing capabilities and use information to develop more adaptive management.

NERAP Action 8 - Work with NOAA Oceanic and Atmospheric Research and academic scientists to develop short-term (day to year) and medium-term (year to decade) living marine resource forecasting products.

NERAP Action 9 - Work with NOAA Oceanic and Atmospheric Research and academic scientists to develop and improve regional hindcasts and climatologies.

NERAP Action 10 - Conduct research on the mechanistic effects of multiple climate factors on living marine resources with a goal of improving assessments and scientific advice provided to managers.

NERAP Action 11 - Develop and implement vulnerability assessments in the Northeast U.S. Shelf Region.

NERAP Action 12 - Continue production of the NEFSC Ecosystem Status Report, and other related products, and improve the distribution of information from the reports through the formation of an NEFSC Environmental Data Center.

NERAP Action 13 – Maintain ecosystem survey effort in the Northeast U.S. Shelf ecosystem including the Bottom Trawl Survey, Ecosystem Monitoring Program, Sea Scallop Survey, Northern Shrimp Survey, Clam Survey, and Protected Species Surveys and expand where possible (e.g., data poor species).

NERAP Action 14 – Initiate a Northeast Climate Science Strategy Steering Group (NECSSSG) to coordinate, communicate, facilitate, and report on issues related to climate change and living marine resource management.

NERAP Action 15 – Coordinate with other NOAA Programs to link living marine resource science and management to climate science and research activities

A critical element of this Action Plan is partnerships. The challenges are great, the issues are complex, and resources are limited. By working together, we can reduce the impacts of climate change on living marine resources and increase the resilience of the ecosystem to this change, including living marine resources and the people, businesses, and communities that depend on them.

2. INTRODUCTION

The NOAA Fisheries Climate Science Strategy seeks to increase the production, delivery, and use of the climate-related information required to fulfill the National Marine Fisheries Service (NOAA Fisheries) mandates (Link et al. 2015). These mandates are derived from numerous statutes, primarily the Magnuson-Stevens Fishery Conservation and Management Act (MSA); Fish and Wildlife Coordination Act (FWCA); Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA); Endangered Species Act (ESA); Marine Mammal Protection Act (MMPA); National Aquaculture Act (NAA); Coral Reef Conservation Act (CRCA); and the National Environmental Policy Act (NEPA). There are also a number of other statutes and Executive Orders that have bearing on the mission of NOAA Fisheries including the Federal Ocean Acidification and Monitoring Act (FOARAM); Federal Power Act; Clean Water Act; Coastal Zone Management Act; Comprehensive Environmental Response, Compensation, and Liability Act; Oil Pollution Act; Fish and Wildlife Coordination Act; Coastal Wetlands Planning, Protection, and Restoration Act; American Recovery and Reinvestment Act; Executive Order 13547 Stewardship of the Ocean, Our Coasts, and the Great Lakes; Executive Order 13653 Preparing the United States for the Impacts of Climate Change; Executive Order 13642 Making Open and Machine Readable the New Default for Government Information; Executive Order 12898 Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations; and Executive Order 12866 Regulatory Planning and Review.

In general, these mandates are intended to instruct and support NOAA Fisheries to work in 5 thematic areas: fisheries, protected species[1], aquaculture, habitats, and ecosystems. NOAA Fisheries primarily focuses on fisheries in federal waters, that being generally 3 miles from the coast to the 200 mile extent of the Exclusive Economic Zone (EEZ). However, many marine species also use coastal, estuarine, and fresh waters during some portion of their life cycle, which can broaden the spatial scope of NOAA Fisheries activities in the region. Further complicating the mission, many species migrate outside the U.S. EEZ into other national jurisdictions or international waters. Multiple fisheries also interact with marine mammals and other protected

[1] For the purposes of this document only, "protected species" refers to ESA listed species, MMPA protected marine mammals, ESA Candidate Species and Species of Concern.

species. Moreover, the MSA requires consideration of human communities and fishing industries (Clay and Olson 2008), food production (Olson et al. 2014), and the sustainability of marine species and their habitats (Fluharty 2000). Further, before designation of critical habitat under the ESA, careful consideration must be given to economic impacts (NOAA Fisheries Critical Habitat website). Clearly, the NOAA Fisheries mission of science and management activities extends from the headwaters of watersheds to the deep ocean and includes interactions among physical, chemical, biological, and human components of ecosystems.

One requirement of the NOAA Fisheries Climate Science Strategy is for each region to develop a Regional Action Plan. The NOAA Fisheries Climate Science Strategy defines 7 interdependent objectives with the goal to inform and fulfill NOAA Fisheries mandates in a changing climate (Figure 1). The Strategy also identifies 4 near-term actions, 1 of which is the development of Regional Action Plans, to customize and execute the Strategy over the next 3-5 years in a given region. The Northeast Regional Action Plan, addresses this near-term action. The Northeast U.S. Shelf Ecosystem extends from Cape Hatteras, North Carolina to the western end of the Scotian Shelf and includes the Mid-Atlantic Bight, Southern New England, Georges Bank, and the Gulf of Maine. Regional Action Plans are intended to: (1) identify strengths, weaknesses, and priority needs and actions to implement the 7 National Climate Science Strategy Objectives in each region over the next 5 years; and (2) increase awareness, partnerships and support for these efforts internally and externally at regional to national scales. This document provides information related to both of these goals.

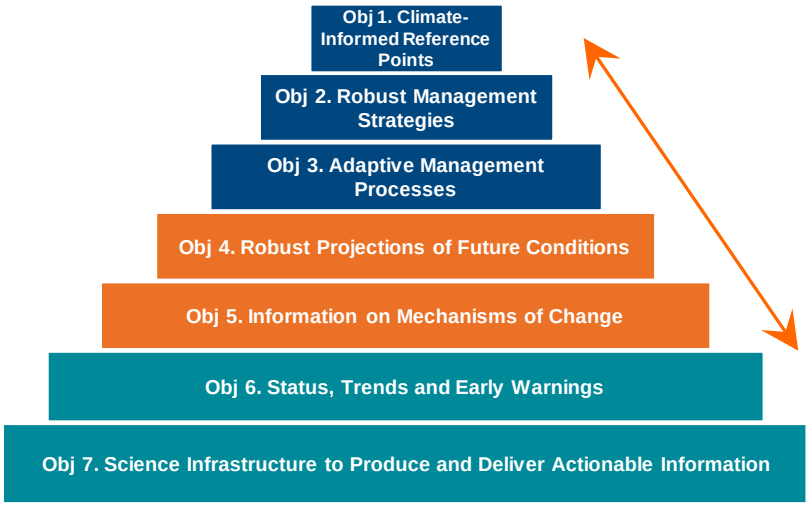

Figure 1. The NOAA Fisheries Climate Science Strategy is organized around the seven priority science objectives

This Northeast Regional Action Plan has 3 sections. The first section – Development of the Northeast Regional Action Plan - describes the process used to develop the Regional Action Plan. This section starts with a summary of the effects of climate change on living marine resources in the Northeast U.S. The strengths, weaknesses, opportunities, and challenges to implementing the Strategy in the Northeast U.S. are then identified. A range of needs is described and prioritized for the region based on the assessment of strengths and weaknesses and relative to the 7 objectives of the NOAA Fisheries Climate Science Strategy. The second section - Action Plan - provides more detailed information for the NERAP Actions defined in the Plan. Specific actions under budget neutral (*No New Resources*) and budget increase (*New Resources)* scenarios are described. The third section - Timeline and Metrics - presents a plan for managing actions under the Regional Action Plan and for evaluating success.

The NOAA Fisheries Climate Science Strategy and Regional Action Plans are closely related to the NOAA Fisheries Ecosystem-Based Fisheries Management (EBFM) Policy. One purpose of the EBFM policy is to, "*Build on the agency's (and its partners') past progress and clarify the agency's commitment to integrating its management programs for living marine resources and their habitats under changing climate, ecological, and ocean conditions.*" Further, the draft EBFM Road Map states, "*NOAA Fisheries, in collaboration with its partners and stakeholders, has already begun the process of implementing EBFM, through the recognition of the need for ecosystem considerations in a number of actions including: . . . The need to better understand, prepare for, and respond to effects of climate variability and change on marine ecosystems and fisheries.*" Thus, implementation of the Northeast Regional Action Plan will be in close coordination with the broader implementation of the EBFM Policy and Road Map regionally and nationally.

3. DEVELOPMENT OF THE NORTHEAST REGIONAL ACTION PLAN

The Northeast Fisheries Science Center (NEFSC) and Greater Atlantic Regional Fisheries Office (GARFO) established a Working Group to develop the Northeast Regional Action Plan. The Working Group is representative of the different components of NEFSC and GARFO, as well as other NOAA Fisheries offices in the Northeast Region (see Appendix A). Two NEFSC and two GARFO staff members formed a smaller Leadership Group from the Working Group (see Appendix A). The Action Plan covers the Northeast U.S. Shelf, which extends from Cape Hatteras, North Carolina, to the western end of the Scotian Shelf and includes the Mid-Atlantic Bight, Southern New England, Georges Bank, and the Gulf of Maine.

Each member of the Working Group was asked, individually, to identify regional strengths, weaknesses, opportunities, challenges, and needs related to each objective of the NOAA Fisheries Climate Science Strategy. The idea was to capture a broad perspective across the related, but varied, GARFO and NEFSC organization. Staff from the New England Fishery Management Council (NEFMC), Mid-Atlantic Fishery Management Council (MAFMC), and Atlantic States Marine Fisheries Commission (ASMFC) were also asked to provide input on regional strengths, weaknesses, opportunities, challenges, and needs related to each objective based on their involvement in fisheries management (see Appendix B). Representatives of different line offices of NOAA (National Ocean Service, Office of Oceanic and Atmospheric Research, National Centers for Environmental Information, other NOAA Fisheries offices) that work in the Northeast U.S. (see Appendix B) were also asked to provide similar input. This input was solicited at the individual level and not meant to represent the official comments of NOAA Line Offices. A list of relevant documents was compiled and reviewed to ensure that existing information was used in the development of the Regional Action Plan (see Appendix C). Finally, the NOAA Fisheries Climate Science Strategy was reviewed to ensure that the priorities identified in the Northeast Regional Action Plan were consistent with priorities identified in the NOAA Fisheries Climate Science Strategy.

The input and review of existing documents was used to complete the assessment of regional strengths, weaknesses , challenges, and opportunities (Regional Assessment Section) and to draft a list of actions to implement the NOAA Fisheries Climate Science Strategy in the Northeast region. These draft lists of strength, weaknesses, and actions were reviewed by the

working group to ensure completeness and to formulate the draft actions at approximately the same level of detail. The working wroup then prioritized a list of 63 actions. Working group members were asked to rank actions as high, medium, or low priority. There were no restrictions on the number of actions in each category, but working group members were asked to strive for an even distribution to provide a range in individual rankings. Working group members were given the following guidance/questions to help frame their rankings.

- Respondents should consider NOAA Fisheries mission as a whole
  - "Fisheries" refers to harvested species: managed, unmanaged, highly migratory, etc.
  - "Protected species" refers to ESA listed species, MMPA protected marine mammals, ESA Candidate Species, and Species of Concern unless otherwise specified.
  - "Habitat" components include pelagic, benthic, marine, estuarine, and freshwater areas of the Northeast U.S. Shelf ecosystem.
  - "Ecosystem" components range from physical oceanography to the economic and social aspects of human communities.
  - "Aquaculture" refers to the development and sustainability of cultured plants, invertebrates, and vertebrates.
  - "National Environmental Policy Act (NEPA) issues" references the environmental review of potential impacts of planned projects or permits.

- Does the action address a high priority need in the Northeast U.S. Region?

- Does the action advance climate science related to NOAA Fisheries Mission in the Northeast U.S. Region (NOAA Fisheries Mission and NEFSC and GARFO Strategic Plans)?

- Will the action reduce uncertainty of management advice related to NOAA Fisheries Mission in the Northeast U.S. Region (NOAA Fisheries Mission and NEFSC and GARFO Strategic Plans)?

- Does the action lead to tangible improvements or increased knowledge within the 5 year time frame?

Working group members were asked to identify their top 10 actions if no new resources are available and their top 10 actions if new resources are available. In preranking discussions, Working Group members noted that their prioritization may differ depending on the resources available, so top 10 actions were identified separately for the no new resources and the new resources scenarios. For each of the top 10 actions, working group members were asked to identify, to the best of their ability, the specific steps that should be taken in the next 5 years. working group members were also asked to identify important partners. Members could state why the action is important and provide additional comments if desired, but these latter 2 responses were optional.

Following Working Group ranking, the leadership group then compiled the ranks and the action statements. The numbers of high, medium, and low ranks were then tabulated for each draft action. The numbers of top 10 ranks were also tabulated for each action. The leadership group then used these rankings, while considering the NOAA Fisheries Climate Science Strategy

and input from external and NOAA Partners (Appendix B), to combine some actions and to identify NERAP actions of highest priority for the region; these NERAP actions are itemized in Section 4 below. The full list of the 63 actions developed and considered by the working group is presented in Appendix D.

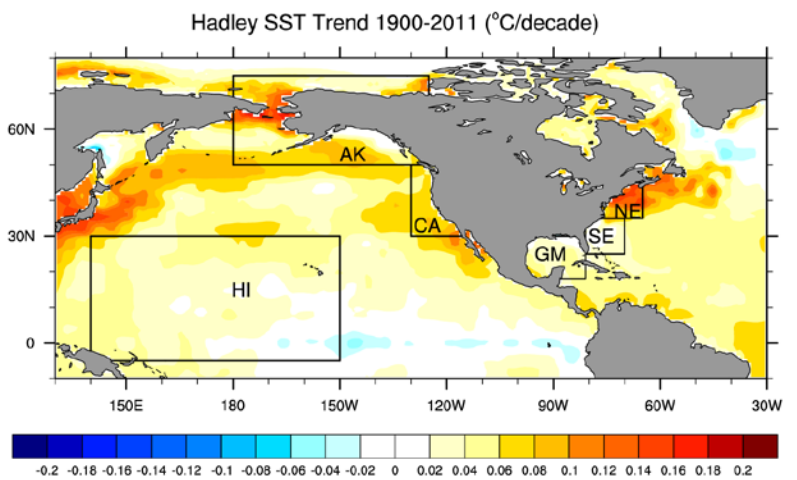

Figure 2 Hadley SST trend from 1900 to 2011. *HadISST dataset*.

NERAP Actions were aligned with the most applicable objective from the NOAA Fisheries Climate Science Strategy, as well as NOAA Fisheries mission elements. This latter step will help users of the Regional Action Plan to view the actions identified for a particular mission area, as well as the actions identified as overall priorities.

The draft NERAP was then opened for public comment from May 9 – July 29, 2016. Comments were received from 24 individuals / organizations and these comments were considered when finalizing the NERAP.

Assessment of Regional Strengths and Weaknesses

Climate Change and Variability in the Northeast U.S. Shelf Ecosystem

The Northeast U.S. Continental Shelf extends from Cape Hatteras, North Carolina to the western end of the Scotian Shelf and includes the Mid-Atlantic Bight, Southern New England, Georges Bank, and the Gulf of Maine. The climate of this ecosystem is changing, both as a result of anthropogenic climate change and natural climate variability. Anthropogenic climate change is a long-term change in the climate system that is primarily attributed to greenhouse gas emissions (IPCC 2014). These changes include warming, ocean acidification, sea-level rise, and changes in ocean currents. The evidence for anthropogenic climate change is widely accepted (IPCC 2014; NCA 2014). The Northeast U.S. Shelf has experienced some of the greatest warming over the past century (Figure 2) and some of the greatest rates of sea-level rise of any area around the world. The anthropogenic climate change signal is occurring simultaneously with natural climate variability, and these 2 signals can interact at the decadal and subdecadal scale.

Within the North Atlantic Ocean, there are several large-scale components of natural climate variability that impact climate in the Northeast U.S., including the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO). The NAO is measured as the difference in atmospheric pressure between the Icelandic Low and the Azores High and is linked to the strength and direction of the westerlies across the North Atlantic (Hurrell et al. 2003). A negative NAO is associated with cold, dry air over the Northeast U.S. Shelf, and a positive NAO is associated with warm, wet air over the region. The NAO went through a predominantly negative phase in the 1960s and early 1970s and then a predominantly positive

phase from the mid-1970s to early-1990s. In recent years, the NAO has been more variable, fluctuating between negative and positive phases on a 1-3 year scale (EcoAp 2015). The AMO represents a pattern of sea surface temperatures across the North Atlantic Ocean (Schlesinger and Ramankutty 1994). A negative AMO is related to cooler temperatures across the North Atlantic (early 1960s to late-1990s). A positive AMO is related to warmer temperatures across the North Atlantic Ocean (late-1990s to the present) (EcoAp 2015). The AMO has a period of approximately 70 years in the observational record, but the regularity of the oscillation is uncertain (Chylek et al. 2012). The recent positive phase of the AMO co-occurs with the anthropogenic climate signal (i.e., warming over the past 30 years) making it difficult to separate climate change and decadal-scale climate variability on the Northeast U.S. Shelf on the decadal scale (Figure 3).

More recently, climate variability in the Pacific Ocean has been linked to changes in both ocean temperature (Pershing et al. 2015) and air temperature (Chen et al. 2014, 2015) in the Northeast U.S Shelf ecosystem. The Pacific Decadal Oscillation (PDO) is inversely related to spring and summer sea surface temperature in the Gulf of Maine (Pershing et al. 2015). This long-distance connection between the Atlantic and Pacific Oceans suggests that atmospheric forcing is an important mechanism driving the climate variability of the Northeast U.S. Shelf. For example, the extreme warming observed in 2012 on the Northeast U.S. Shelf (warmest on record) was primarily driven by air-sea heat flux (Chen et al. 2014, 2015). The anomalous position of the atmospheric jet stream in the fall-winter of 2011-2012 reduced the heat loss from the Northeast U.S. Shelf waters and resulted in less cooling in the fall and winter of 2011-2012 (Chen et al. 2014).

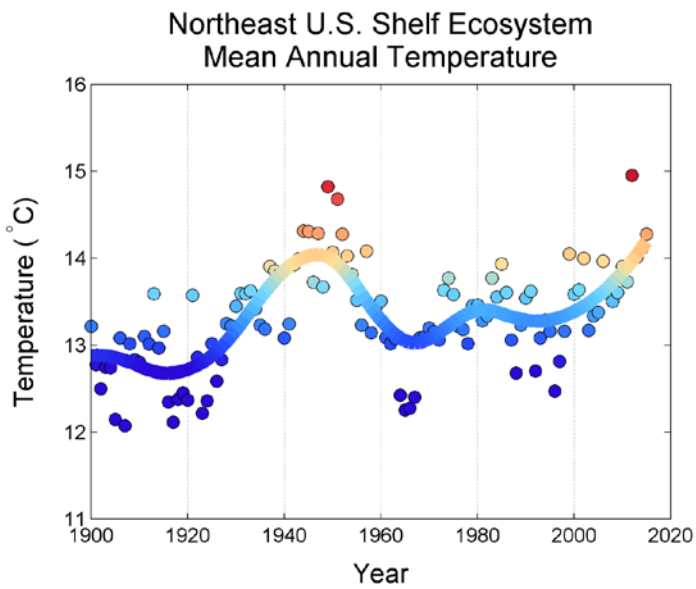

Figure 3. Annual sea-surface temperature on the Northeast U.S. Shelf from the ERSSTv3b dataset. Colors represent annual temperatures. The line is a LOWESS smoother of annual temperature. The multi-decadal variability (peaks in the 1850s, 1950s, and 2010s) is closely related to the Atlantic Multidecadal Oscillation.

While it appears that the 2012 warming event was primarily driven by the atmosphere, ocean advection also plays an important role in the ocean temperature on the Northeast U.S. Shelf (Rossby and Benway 2000; Mountain and Kane 2010; Shearman and Lentz 2010; Gawarkiewicz et al. 2012). Although the Gulf Stream does not flow directly over the Northeast U.S. Shelf, a more northern position of the warmer Gulf Stream is associated with reduced transport of colder Labrador water that enters the shelf from the north (Pershing et al. 2001; Rossby and Benway 2000) and warmer temperatures over the outer Northeast U.S. Shelf (Nye et al. 2011). New research has pointed to a robust relationship between the Atlantic Meridional Overturning Circulation (AMOC) and ocean conditions on the Northeast U.S. Shelf (Goddard et

al. 2015; Saba et al. 2016). Observations of the interannual variability of AMOC at 26.5^{o}N and slope water intrusions into the Gulf of Maine's Northeast Channel (42.25^{o}N) are significantly correlated when the AMOC is lagged 1–2 years (Saba et al. 2016). A similar correlation is reported between observations of sea surface height (lagged 2 years) and ocean temperature in the Mid- Atlantic Bight (Forsyth et al. 2015) with a potential link to AMOC such that increased sea-level height on the shelf may be related to a reduction of AMOC (Goddard et al. 2015). However, this link has been questioned in other studies indicating no reduction in Gulf Stream transport, which is a surface component of AMOC (Rossby et al. 2014).

As a result of climate change and natural variability, there have been changes in a number of physical parameters in the Northeast U.S. Shelf over the past 30-40 years (EcoAp 2015) and climate models project that these changes will continue. Air and ocean temperatures are increasing in the Northeast U.S., which can impact organisms, their habitats, and ultimately the human communities that depend on these organisms and habitats. Air temperature is an important indicator of trends in freshwater and coastal water temperature owing to efficient heat exchange occurring in the shallow waters (Hare and Able 2007). The Northeast U.S. Shelf is one of the fastest warming regions of the world's oceans (Figure 1) (Pershing et al. 2015), but the relative effect of the climate change signal and the AMO signal is unclear (Solomon et al. 2011). The warming signal has a seasonal component, with summers warming faster than winters (Friedland and Hare 2007). The Northeast U.S. is also a "hotspot" for sea-level rise, with rates in the past five decades approximately 3–4 times higher than the global average (Sallenger et al. 2012). Land subsidence along portions of the Mid-Atlantic coast contributes to apparent sea-level rise (Eggleston and Pope 2013). Annual precipitation and river flows have increased and the timing of snowmelt is earlier, while the magnitude of extreme precipitation events has also increased (Karl and Knight 1998, McCabe and Wolock 2002, Walsh et al. 2014). As examples, the timing of high river flows in New England has shifted 1-2 weeks earlier over the past 30 years (Hodgkins et al. 2003) and the magnitude and frequency of floods in the Northeast U.S. have increased over the past 75 years (Collins 2009; Armstrong et al. 2014). Dissolved CO_2 is increasing, which is resulting in the "acidification" of shelf waters at rates comparable to global averages. Salinities were decreasing from the 1970s into the 1990s likely due to the transport of low salinity ice melt from the Arctic (Greene and Pershing 2007, Bisagni 2016), but are now increasing, potentially due to an increased influence of Atlantic Warm Temperate water (EcoAp 2015, Gawarkiewicz et al. 2012). Climate projections from global climate models suggest that both temperature and precipitation will increase over time in the Northeast US. However, there is higher confidence in the temperature projections (IPCC 2013, NCA 2014). Increases in dissolved CO_2 will continue, but there is a substantial amount of seasonal and regional scale variability. Projected trends in salinity are more complex, with increased freshwater input from the Labrador Coastal Current and increased addition of saltier water as the Gulf Stream is expected to shift northwards; it is not clear how the salinity regime will change in response. For example, a high-resolution global climate model, which resolves regional oceanography, projects an increase in Atlantic Warm Temperate water entering the Gulf of Maine leading to both an enhanced warming and increases in salinity (Saba et al. 2016).

These changes in climate are causing numerous changes in fish, invertebrate, marine mammal, sea turtle, and marine plant populations, as well as in the habitats that these species use. In turn, the changes with individual species are impacting predator-prey relationships and competition in the ecosystem, as well as impacting the human communities that interact with the species and habitats. When the Northeast U.S. Shelf is analyzed as a single region, the

distribution of a large number of species is dominated by a shift of populations to the northeast and into deeper water (Nye et al. 2009; Pinsky et al. 2013); however, at the species-specific level there is variability (e.g., spiny dogfish is shifting southward). When the Northeast U.S. Shelf is analyzed as 2 distinct regions, in the Mid-Atlantic Bight, the northeastern distribution shift is primarily evident, whereas in the Gulf of Maine a southwestern shift into deeper water is more evident (Kleisner et al. 2016). This difference is explained by regional-scale oceanography and bathymetry. The phenology of spawning time of a large number of species has also changed (Walsh et al. 2015), with some species spawning earlier in the year and some later. In addition to changes in distribution and phenology, there is evidence of a change in productivity for some species. For example, winter flounder, Atlantic cod, and southern New England yellowtail flounder productivity has decreased in recent decades, whereas Atlantic croaker productivity has increased (Fogarty et al. 2008; Hare et al. 2010; Bell et al. 2014; Pershing et al. 2015; Miller et al. 2016). These changes are not restricted to fish species. Sea turtle nesting habitats also are being affected by changing climate conditions (Saba et al. 2012). Coastal shellfish productivity will likely be impacted by ocean acidification (Talmage and Gobler 2010), affecting coastal fisheries and aquaculture. Sea-level rise is expected to impact coastal habitats used by freshwater, estuarine, and marine species (Morris et al. 2002; Craft et al. 2008; Kirwan et al. 2010, 2016; Carey et al. 2015) and have dramatic effects on coastal communities, as well as fishing and aquaculture (Ford and Smit 2004; Howard et al. 2013). Fishing remains an important factor in the management of marine species, but recognition of the relative importance of climate, ecosystem, and habitat interactions has increased. In addition, other human pressures including shipping, dams, and energy development are impacting NOAA Fisheries trust resources. Coupled with the rapid rate of climate change in the Northeast U.S. Shelf, multiple stressors are creating numerous and serious challenges to the management of living marine resources in the Northeast U.S. However, there are some opportunities created by climate change in the region. Adaptive strategies need to be developed to meet both short-term and long-term management objectives.

Regional Strengths

The Northeast U.S. region is in a good position to implement the NOAA Fisheries Climate Science Strategy and to increase the production, delivery, and use of the climate-related information required to fulfill NOAA Fisheries mandates. Below follow examples of various efforts underway related to the intersection of climate science and living marine resource management. This review is not meant to be comprehensive but seeks to identify regional strengths and provide some examples.

There is a long history of ecosystem and climate research in the Northeast U.S. region. In 1871, Spencer Baird was appointed the first Commissioner of Fish and Fisheries for the United States Fish Commission and advocated that fisheries needed to be studied, understood, and managed in the context of the ecosystem, including humans. This concept was expanded upon by preeminent scientists working for the precursors of the NEFSC (e.g., Henry Bigelow, Victor Loosanoff, Oscar Sette, Lionel Walford, George Clarke, and Charles and Marie Fish). Studies through the first half of the 20th century emphasized the importance of the ecosystem in affecting fishery yields (Sette 1943), and changes in species distribution were linked to changes in climatic conditions during this period (Taylor et al. 1957). Through the latter half of the 20th century, attention turned more toward single-species approaches, but the importance of the environment in affecting fishery productivity was still recognized (Sissenwine 1974). In 1999,

the NOAA Fisheries Ecosystem Advisory Panel reaffirmed the importance of considering ecosystem interactions in fishery management, specifically including human dimensions (NOAA Fisheries 1999). This long history of an ecosystem and climate focus sets the stage for the development of Ecosystem-based Management that includes the effect of climate change on living marine resources and on the human communities that utilize them (Link 2016).

A number of preeminent research institutions and research universities are located in the Northeast U.S. region. There are formal relationships that exist between NOAA and many of these organizations including the Cooperative Institute for the North Atlantic Region (CINAR), Cooperative Institute for Climate Science (CICS), and the Cooperative Institute for Climate and Satellites (CICS-NC). There are also collaborative relationships between regional universities and other federal agencies: North Atlantic Coast Cooperative Ecosystem Studies Unit (NACCESU) and USGS Cooperative Research Units. There are NOAA Sea Grant programs throughout the Northeast U.S. and there have been a number of large-scale projects between academics and research institutions and NOAA investigators, including Global Ocean Ecosystem Dynamics (1989-2002) and Comparative Analysis of Marine Ecosystem Organization (2009-2012). Research done with and by these institutions will continue to contribute to our understanding of the effect of climate change on marine species and ecosystems.

With this science capacity in the region, there has been a number of recent significant studies that advance the objectives of the NOAA Fisheries Climate Science Strategy and lay the foundation for moving forward. Many of these studies are cited throughout this document and listed in Appendix C. There is also a number of new programs and opportunities in the region, including a collaboration between NOAA Fisheries and NOAA Research, Sustainable management and resilience of U.S. fisheries in a changing climate, and a NOAA Sea Grant effort, Northeast Sea Grant Consortium Regional Ocean Acidification Request for Proposals. The NOAA Ocean Acidification Program provides sustained funding to the NEFSC for monitoring and experimental work and funds a number of science projects in the region. There are National Science Foundation opportunities including the Coastal SEES program and the Long-Term Ecological Research (LTER) New Site Competition. There are NOAA Fisheries internal funding programs that have supported research applicable to the NOAA Fisheries Climate Science Strategy including the Fisheries and the Environment, Improve Stock Assessment, Habitat Information for Stock Assessment, Stock Assessment Analytical Methods, Sea Turtle Assessment, and Advanced Sampling Technology Working Group. As interest in understanding the effect of climate change on fisheries, protected species, habitat, ecosystems, and aquaculture grows, the opportunities to conduct science in these areas will grow as well.

The NOAA Chesapeake Bay Office (NCBO) has been engaged in a number of climate related activities – Chesapeake Bay is the largest estuary in the Northeast U.S. Shelf ecosystem. NCBO has been developing a climate resiliency work plan in support of the 2014 Chesapeake Bay Program Agreement outcomes. This work plan consists of 2 components. The Monitoring and Assessment component calls for continually monitoring and assessing the trends and likely impacts of changing climatic and sea level conditions on the Chesapeake Bay ecosystem. The effectiveness of restoration and protection policies, programs and projects will also be evaluated. The Adaptation component calls for restoration and protection projects to enhance the resiliency of the Chesapeake Bay ecosystem from the impacts of coastal erosion, coastal flooding, more intense and more frequent storms, and sea-level rise.

In addition to having a strong research base and funding, the region has exceptional experimental and observational capabilities. NOAA Fisheries supports experimental facilities at the Sandy Hook Laboratory and the Milford Laboratory. A number of other institutions and universities in the region have experimental facilities (e.g., Environmental Systems Laboratory, Darling Marine Center, Smith Laboratory, Marine Ecosystems Research Laboratory, University of Connecticut, Rutgers University). An experimental approach is also used in the field such as studying the effect of trawling on benthic habitat (Sullivan et al. 2003) and caging studies to examine fish ecology (Meng et al. 2008). Fisheries science in the region developed with the understanding of the importance of the ecosystem, and fisheries observations and marine ecosystem observations have been combined since the early 20th century. Portions of the legacy continue today with the NEFSC Ecosystem Monitoring Surveys, Bottom Trawl Survey, and protected species surveys (e.g., Atlantic Marine Assessment Program for Protected Species); many of the NEFSC surveys started in the 1960s and 70s and represent time series in excess of 40 years. These surveys collect a range of information on targeted species information, as well as a broader suite of ecosystem and climate components, providing the ability to analyze the interactions between targeted species and their environment. These programs include traditional and new technologies such as acoustic (e.g., Northeast Acoustic Network), optical (e.g., HabCam), and genomics (e.g., Environmental Sample Processor). There are also 2 Integrated Ocean Observing System Regional Associations: Northeastern Regional Association of Coastal and Ocean Observing Systems and Mid-Atlantic Coastal Ocean Observing System. Other observing systems operate in the region including the Chesapeake Bay Interpretive Buoy System and the Pioneer Array on the outer Southern New England Shelf, which is supported by the Ocean Observatories Initiative Program (National Science Foundation funded). Collaboration between NOAA Fisheries and these other large-scale experimental and observational activities continues to grow and can be leveraged to meet the goals of the Climate Science Strategy.

Modeling capabilities in the region are also quite advanced. Single-species fisheries assessments use a range of models from simple data-limited and index models to age-structured models (NEFSC 2014). Multispecies models are used in some fish assessments, (NEFSC 2006) and environmental variables are beginning to be included in some single species models (NEFSC 2014; Miller et al. 2016). Similarly, protected species assessments utilize a range of models formulations (Moore and Merrick 2011), and explicitly climate-driven models (Meyer-Gutbrod et al. 2015) are under development. Ecosystem modeling capability in the region is well developed with network-type models for Northeast U.S. Shelf ecoregions (Link et al. 2008) and complete system models like Atlantis (Link et al. 2014; Townsend 2014; Ihde 2015); these models are being developed to provide strategic advice. There is an evaluation of a range of population and ecosystem models underway at the NEFSC to provide tactical fisheries advice (NEFSC Ecosystem Considerations: Modeling Approaches). The region also has a diversity of ocean models. Data assimilative hindcast models are available providing dynamical reanalysis of past conditions (Chen and He 2010; Chen et al. 2011; Kang and Curchitser 2013). In addition, oceanographic forecast models have been developed (Beardsley and Chen 2014; Wilkin et al. 2014) and are starting to be used in living marine resource management applications (NEFSC 2014; Turner et al. 2015). Century-scale projections from global climate models are available for the region (NOAA Climate Change Web Portal) and have been used in the recent Fisheries Climate Vulnerability Assessment (Hare et al. 2016). Evaluations of high-resolution global models (Saba et al. 2016) and decadal prediction skill are underway (Keenlyside et al. 2015; Xie

et al. 2015). The region is poised to begin integrating across biological, oceanographic, and climate models in support of assessment and the provision of management advice.

The region has strong social science capacity. The NEFSC has a Social Sciences Branch, with fisheries anthropologists, resource economists, and other social scientists who work on a range of issues including the impact of climate change on communities (Colburn et al. 2016) and fishing businesses (Gaichas et al. 2016). Both GARFO and NEFSC recognize the importance of linking natural science, social science, and management. GARFO has identified community resiliency as 1 of its 7 strategic goals (GARFO Strategic Plan FY2015-2019), with the purpose of developing an integrated approach among programs to enhance fishery community resiliency. NEFSC has identified social sciences in 1 of its 7 strategic foci (NEFSC Strategic Science Plan 2016-2021): to improve understanding of economic and socio-cultural factors in marine resource management. Many universities in the region also have social scientists who are working with NOAA Fisheries. There are even examples of linking climate change to economic effects through marine populations such as sea scallop (Cooley et al. 2015). The NEFMC and MAFMC are integrating social sciences into their development of Ecosystem-based Fisheries Management approaches (e.g., East Coast Climate Change and Fisheries Governance Workshop) to develop more meaningful links between natural sciences, social sciences, and management objectives in the future.

Importantly, there are strong research interactions forming with the fishing industry. The Research-Set-Aside program funds research through the sale of set-aside allocations for quota or days-at-sea (DAS) managed fisheries. These projects focus on research to improve assessments but could be used for research related to the NOAA Fisheries Climate Science Strategy. Cooperative environmental monitoring with lobstermen has been ongoing at the NEFSC since 2001 (Environmental Monitors on Lobster Traps [eMOLT]), and similar programs have started recently (e.g., Lobster Research Fleet). Work with butterfish and Atlantic mackerel fishermen also aims to support stock assessment (NEFSC 2014), as well as examine the importance of the environment in the distribution and productivity of the stocks. The Northeast Cooperative Research Program has existed since the late 1990s; within it, the Study Fleet is deploying environmental sensors on fishing vessels, and work is underway to transmit the data in near-real time and make it available to ocean forecasting models. The Social Sciences Branch has conducted over 100 oral histories with fishermen and fishing community members, and the NMFS Voices from the Fisheries program has hundreds more. These can be mined for Local and Traditional Ecological Knowledge, including signals of climate change. Further collaboration and cooperation with industry will be critical for the success of the NOAA Fisheries Climate Science Strategy.

Strong interactions have also formed between the NEFSC Milford Laboratory and marine aquaculture industry and state managers. Members of the East Coast Shellfish Growers Association and other organizations work closely with staff to identify research priorities, enable access to commercial aquaculture sites, and provide consultation on experimental design. Milford staff conducts research to support the industry on shellfish rearing, disease resistance, and interactions with the environment. The staff provides advice to regulators including the Connecticut Bureau of Aquaculture and have conducted investigations to support management in multiple sites with shellfish habitats including Narragansett Bay, East River, and Greenwich Harbor. Cooperation with the pharmaceutical industry on the development of immune-enhancing probiotics is also a major research focus. An important focus of this research is the longer term effects of climate change on aquaculture species selection, siting, and infrastructure needs.

There is an improved understanding of the habitat requirements of fisheries and some protected species in the region. Essential Fish Habitat (EFH) for all managed fish and invertebrate species has been defined, and habitat needs for some ESA listed species have been identified (see critical habitat designations for North Atlantic Right Whales, the Gulf of Maine distinct population segment (DPS) of Atlantic Salmon, and the Northwest Atlantic DPS of loggerhead sea turtle at Greater Atlantic Regional Office Protected Resources). This information is used in a variety of management decisions and recommendations made by NOAA Fisheries. The GARFO Habitat Conservation Division and Protected Resources Division routinely work together to identify and conserve both EFH and ESA listed species either through the fishery management process or through consultations with Federal agencies on actions that may adversely affect those resources. The EFH and ESA consultation processes are required under federal regulations and are designed so that federal agencies and their partners account for and attempt to minimize adverse effects of their activities on NOAA trust resources. The NOAA Chesapeake Bay Office works to protect and restore a variety of habitats in the Chesapeake Bay watershed. The Chesapeake Bay Interpretive Buoy System (CBIBS) is one of the most comprehensive coastal monitoring systems in the United States. This network, combined with other Chesapeake Bay field programs, makes NCBO a key component of efforts to couple physical impacts of a changing climate to living marine resources and human communities in Chesapeake Bay. There are also numerous place-based management structures that are designed in part to protect habitat. For example, Stellwagen Bank National Marine Sanctuary (SBNMS) is a region containing a shallow, primarily sandy bank surrounded by deeper water in the western Gulf of Maine. SBNMS is heavily utilized by humans and by marine species, including the North Atlantic Right Whale and Atlantic Cod. The National Estuarine Research Reserve System (NERRS) has nine sites throughout the Northeast U.S. Shelf ecosystem stretching from Chesapeake Bay-Virginia NERR to Wells NERR (in Maine). NERRs sites are designated to protect and study estuarine systems. In addition, the 2 Northeast U.S. regional fishery management councils have designated a number of protected areas specifically for the purpose of habitat protection including seasonal closures, gear restricted areas, and Habitat Areas of Particular Concern (HAPC). Of particular note is the MAFMC Deep Sea Corals Amendment to the Mackerel, Squid, and Butterfish Fishery Management Plan (FMP), which protects areas that are known or highly likely to contain deep sea corals; and, the NEFMC Habitat Omnibus Amendment 2, which designated EFH and HAPC in New England waters.

There are numerous habitat restoration projects underway in the Northeast U.S. region designed to reduce the stress of human development on marine resources in the region (NOAA Restoration Center Northeast Region). Most rivers and streams in the Northeast U.S. contain fish passage barriers, which contribute to decreased productivity of many of the region's diadromous species. Coastal hardening with concrete seawalls and bulkheads has increased coastal erosion and negatively impacted coastal habitats. In addition, dredging, filling, and development have reduced natural coastal habitats. Restoration efforts are underway throughout the region: removing passage barriers, replacing seawalls with "living shorelines," repairing salt marsh beds, and widening bridges and culverts to improve tidal flow in coastal wetlands. Increased gentrification of coastlines also contributes to destruction of coastal habitat and increased point source pollution. The Social Sciences Branch has developed community gentrification pressure vulnerability indicators (Colburn and Jepson 2012) to track this process.

Management and science structures and procedures are well developed and coordinated. The New England Fishery Management Council, Mid-Atlantic Fishery Management Council and

Atlantic State Marine Fisheries Commission manage fishery resources and have formal cooperative arrangements. Management of Atlantic Highly Migratory Species (HMS) is under authority of the Secretary of Commerce, who has delegated that authority to NMFS. NOAA works with federally-Recognized Tribes in the region (see NOAA Tribal Relations). A U.S. Tribal Climate Resilience Toolkit has been developed and NOAA is committed to developing policies and procedures that improve relations and cooperative activities with Federally-Recognized Tribes on a government-to-government basis. The Atlantic Scientific Review Group advises NOAA Fisheries on the status of marine mammal stocks. There is a regionwide stranding and disentanglement program for marine mammals and sea turtles. Permitting processes exist for aquaculture in state waters, and there are venues for communicating across the region (see Aquaculture in the Greater Atlantic Region). The Northeast Regional Ocean Council and the Mid-Atlantic Regional Council on the Ocean are active and developing the concept of ecosystem-based management in the region as part of the National Ocean Policy. There are numerous federal (e.g., Environmental Protection Agency, U.S. Fish and Wildlife Service, United States Geological Survey); state (North Carolina Division of Marine Fisheries, Virginia Marine Resources Commission, Maryland Department of Natural Resources, Delaware Department of Natural Resources and Environmental Control, Pennsylvania Fish and Boat Commission, State of New Jersey Department of Environmental Protection, New York State Department of Environmental Conservation, Vermont Fish and Wildlife, Connecticut Department of Energy and Environmental Protection, Rhode Island Department of Environmental Management, Massachusetts Division of Ecological Restoration, Massachusetts Division of Marine Fisheries, New Hampshire Fish and Game Department, Maine Department of Marine Resources); and local agencies and organizations with living marine resource responsibilities and interests. This list is not complete but serves to illustrate the management and organizational infrastructure that is in place in the region.

Protected species management has incorporated climate and environmental variables in standard abundance, distribution, and bycatch analyses. The Atlantic Marine Assessment Program for Protected Species (AMAPPS) has been collecting oceanographic and climate data associated with marine mammal, sea turtle, and sea bird visual and acoustic observations. These data have been used to model distribution and abundance included in stock assessments, and as such could be used to predict distribution changes caused by climate change. Mid-Atlantic sea turtle temperature preferences have also been demonstrated via analysis of both fishery-dependent and fishery-independent data (Murray and Orphanides 2013) and studies have been completed on the projected response of sea turtle populations to climate change (Saba et al. 2012). Similarly, sea surface temperature has been used as an indicator of potential sea turtle-fishery interactions in the southern Mid-Atlantic Bight (Braun-McNeill et al. 2008). Climate change information is used in ESA decisions in the region. A Climate Change Workshop was held as part of the ESA listing determination process for River Herring and a Climate Change Subgroup has been established as part of the Technical Expert Working Group for River Herring. Several studies have been published on river herring and climate change during this period (e.g., Lynch et al. 2014; Tommasi et al. 2015). Analyses were completed on climate change effects on habitat and distribution of cusk (Hare et al. 2012), which is an ESA Candidate Species, and there has been substantial work completed on the effects of climate change and decadal-scale variability on Atlantic Salmon populations and habitats (e.g., Walsh and Kilsby 2007; Todd et al. 2012; Mills et al. 2013; Friedland et al. 2014; Perry et al. 2015).

There is increased recognition of the interactions among climate change, marine resources, and human communities, which has influenced the conceptual development about assessment and management in an ecosystem impacted by climate change. The Fishery Management Councils are developing Ecosystem-Based Fisheries Management in the region that includes consideration of climate, species interactions, and habitat. The NEFSC Climate, Ecosystem, Habitat, and Assessment Steering Group has developed a process for including climate, ecosystem, and habitat factors into benchmark and update assessments, and there are discussions underway with the Fishery Management Councils to include climate, ecosystem, and habitat Terms of Reference in update and benchmark assessments. NOAA Fisheries has developed Guidance for Treatment of Climate Change in NOAA Fisheries ESA Decisions. Other institutions are also focusing on climate change and contributing to the advancement of ideas and potential approaches (e.g., Island Institute, Rhode Island Saltwater Anglers Association, Cooperative Institute of the North Atlantic Region). There are also numerous environmental nongovernmental organizations (NGO) active in the region. These range from organizations working around the world (e.g., The Nature Conservancy, the Environmental Defense Fund) to local organizations (e.g., Save the Bay, Barnegat Bay Partnership). Many of these organizations are actively involved in living marine resource science and management and contributing to climate change adaptation activities. There are numerous interactions with GARFO and NEFSC on research projects, Fishery Management Council committees, and protected species committees and panels.

Aquaculture organizations in the region are considering the effects of climate change, primarily ocean acidification, on their businesses (NROC Aquaculture White Paper). Studying the effects of climate change on aquaculture organisms and industry is a component of the NEFSC Strategic Plan. There are regional climate and health related initiatives working with the aquaculture industry (e.g., Interstate Shellfish Sanitation Conference, NCCOS Cooperative Oxford Laboratory, NEFSC Milford Laboratory). Numerous research activities and educational programs are also underway at regional universities and research institutions (e.g., Marine Biological Laboratory, University of North Carolina Wilmington, University of Rhode Island, Roger Williams University, University of Maine, Rutgers University). Aquaculture is related to other NOAA Fisheries mission areas as well. For example, increasing physical habitat complexity in the nearshore environment through aquaculture operations can have beneficial impacts affecting the provision of ecosystem services including abundance, growth, and diversity of juvenile marine finfish (Clynick et al. 2008). Shellfish aquaculture has been shown to improve water quality by reducing nutrient loads and may also provide important long-term data sets to inform our understanding of ocean acidification (e.g., Tracking Ocean Alkalinity using New Carbon Measurement Technologies) and how this may affect primary production within the nearshore coastal and freshwater ecosystems (Gledhill et al. 2015).

Finally, the region has made substantial progress on immediate-term actions defined in the NOAA Fisheries Climate Science Strategy (see Appendix E):

1. Conduct climate vulnerability analyses in each region for all living marine resources to better understand what is at risk and why.

The NOAA Fisheries Climate Science Strategy calls for climate vulnerability analyses in each region for all living Marine Resources as an immediate action. In response, the Northeast Fisheries Climate Vulnerability Assessment has been completed. The assessment evaluated the

vulnerability to a change in productivity, the potential for a shift in distribution, and the directional effect of climate change on 82 fish and invertebrate species in the region (Morrison et al. 2015; Hare et al. 2016). This fisheries vulnerability assessment has been linked to an indicator of community dependence on climate vulnerable species (Colburn et al. 2016). Additional indicators of climate impact to communities are available and in development as part of a nationwide NOAA Fisheries Community Social Vulnerability Indicators project (Jepson and Colburn 2013). Further, NOAA Fisheries staff from the Northeast U.S. region are involved in the development of marine mammal and sea turtle vulnerability assessments.

2. Establish and strengthen ecosystem indicators and status reports in all regions to better track, prepare for, and respond to climate-driven changes.

The Ecosystem Assessment Program (now reorganized to the Ecosystem Dynamics and Assessment Branch) at the NEFSC produces an Ecosystem Status Report that tracks a number of indicators related to fisheries, protected species, habitat, aquaculture, and the broader ecosystem, including both social and natural science indicators. The first NEFSC Ecosystem Status Report was produced in 2009 (EcoAp 2009), and 2 have been completed subsequently (EcoAp 2012, 2015). The Ecosystem Assessment Program, working with other groups in the NEFSC, is also developing Annual Ecosystem Reports for the Fishery Management Councils and has developed a Climate Change webpage to provide regionally specific information on the changes observed in the Northeast U.S. Shelf ecosystem and the impacts on living marine resources and human communities.

3. Develop capacity to conduct management strategy evaluations regarding climate change impacts on management targets, priorities, and goals.

The region is starting to develop Management Strategy Evaluation (MSE) capabilities. The MAFMC has used an MSE approach to evaluate control rules for the Atlantic mackerel fishery (Wiedenmann 2015). The issue of setting harvest control rules for data poor species using an MSE framework has also been dealt with more generally (Wiedenmann et al. 2013). An MSE framework is being developed to evaluate harvest control rules in Atlantic herring (Deroba 2015). Further, the NEFMC is looking to incorporate MSE-like frameworks into their Risk Policy. The NEFSC has established an MSE Working Group to continue to develop this approach within NOAA Fisheries. It includes both social and natural scientists. Although this work is in its infancy and not yet connected to issues related to climate, the value of MSE is recognized in the region, and the application of the approach will increase.

Regional Weaknesses

Despite the number and magnitude of strengths related to incorporating climate change into the NOAA Fisheries mission in Northeast U.S., there remain substantial weaknesses that will inhibit the region's ability to fully implement the NOAA Fisheries Climate Science Strategy.

Science and management processes have developed around the concept of equilibrium and the general goal to return a resource or a system to a past equilibrium state. Accepting that climate change is occurring calls into question one of the basic assumptions of these models and presents a new challenge to the institutions, infrastructure, and processes that support living marine resource management. The magnitude of these challenges and acknowledgement of the

additional uncertainties results in well-placed caution in management advice. Partnerships are critical to obtaining the needed information to inform management in a changing climate. The NEFSC Strategic Plan recognizes "*the importance of building trust through full engagement of stakeholders and partners and improved external communications*." Similarly, the GARFO Strategic Plan states "*goals and strategic objectives rely on close coordination with, and participation of, our partners and stakeholders*." There are numerous partners and stakeholders, and some are identified in Appendix F as examples.

Although the region has funding to achieve many of its mandates, living marine resource assessment and management are still resource-limited. There is a number of data poor species; assessments where species are of an unknown status; and a number of questions regarding the effect of climate change, ecosystem interactions, and habitat effects on living marine resources. Social and economic data to understand the impacts of climate change on people, businesses, and communities that interact with living marine resources are also limited. Although progress has been made on integrating climate change into regional living marine resources management, these efforts are just the beginning. Addressing these issues more completely will require creative efforts from all stakeholders including NOAA Fisheries such as building collaborations; leveraging resources; identifying common goals; and other forms of partnering, coordinating, and aligning activities (Nichols et al. 2011).

Changing species distributions create a number of challenges and opportunities to resource management. There are 2 Fishery Management Councils in the Northeast U.S. region with living marine resources moving across the management boundaries, thus creating added complication for science and management. There are 12 coastal states in the region and watersheds extend into 2 other East Coast states. Many of the managed species move through the Northeast U.S. Shelf Ecosystem during seasonal migrations, occupying other parts of the Atlantic during other times of the year and coming under an array of different management authorities (South Atlantic Fisheries Management Council, North Atlantic Fisheries Organization), states (e.g., South Carolina, Georgia, Florida), and countries (e.g., Canada). As a result, governance is complex. Predominant federal laws include the Magnuson-Stevens Fishery Management and Conservation Act, Atlantic Coastal Fisheries Cooperative Management Act, the Endangered Species Act, and the Marine Mammal Protection Act. Numerous other federal laws and agencies interact with the NOAA Fisheries mission including the National Environmental Policy Act, Deepwater Port Act, and Clean Water Act. Regulations include quotas, time and space closures/restrictions, incidental catch limits, targeted catch limits, limited-access fisheries, and gear restrictions. There also are numerous laws and regulations from each of the 14 states and a wide array of stakeholders that have differing perspectives on and goals for living marine resource management. Further, the science and management processes can be relatively slow; the time between data collection and management decisions can be relatively long (1-3 years). An important component of climate resilience is developing adaptive management that can respond to changing conditions. This complexity argues for Ecosystem-Based Management (EBM) (see Dolan et al. 2016), but getting to a holistic perspective that encompasses management and impacts on both natural and human systems is a massive undertaking. There are institutions and directives that move toward EBM, and NOAA Fisheries has released an EBFM Policy. EBFM is in the continuum between single-species management and EBM (see Dolan et al. 2016) and encompasses integrating climate change into living marine resource management. As EBFM moves forward, there is the need to keep the goals and approaches of EBM in mind so that in the future, the concepts remain compatible.

Although the development of EBFM in the Northeast U.S. region is a priority (e.g., NEFSC Strategic Plan, NEFMC EBFM Committee, MAFMC EAFM Guidance Document), there remain major obstacles. NOAA Fisheries and the NEFSC focus most of the resources on the continental shelf. The Northeast U.S. Shelf ecosystem is highly connected to coastal and freshwater systems and to offshore systems. Recognition of the importance of these connections is growing, but there remains work to be done. Similarly, recognition of the importance of the connections with the Southeast U.S. Shelf and Canadian waters is growing, but again, there remains work to be done.

There is a large focus on fisheries issues in the Northeast U.S. region, more specifically finfish. Yet, shellfish, namely Atlantic sea scallop, American lobster, Atlantic surf clam, and ocean quahog are the most valuable fisheries in the region. Northern inshore squid is also an important resource. Diadromous species, some of which are listed as endangered or threatened, play an important ecosystem function. Many species in the ecosystem utilize a wide range of habitats including freshwater, estuaries, shelf, and in some cases open ocean systems. Marine mammals, sea turtles, protected fish, aquaculture, habitats, and ecosystems are included the NOAA Mission, but financial support and agency focus for these mission elements is less than that for fisheries management. With less support, the opportunities to integrate climate change into these areas of the NOAA Fisheries mission are fewer. The focus on commercial and recreational fisheries issues contributes in part to the focus on fishing as the major factor affecting living marine resources in the region. During the 1970s when foreign fleets were operating in U.S. waters, fishing effort was very high. As fishing effort has reduced, the relative importance of other processes, including climate change, in regulating fishery dynamics has increased. Thus factors in addition to fishing need to be integrated into the assessment and management of living marine resources in the region. Yet even as fishing has been a strong focus, the social, cultural, and economic factors that contribute to how, when, where, and why people fish have received much less overall attention. Both EBFM and EBM require ecological and human dimensions for effective implementation. These factors includes many additional ocean uses besides fishing that impact living marine resources, such as shipping, aquaculture, and energy development.

Although substantial progress has been made on understanding the potential effects of climate change on protected species in the region, there remain many more questions. Many of the protected fish species in the region are relatively data poor, making basic assessment of status difficult. There are more than 10 fish species that are Candidate Species under the ESA and/or Species of Concern and 3 endangered/threatened fish species in the region. A recent emphasis on river herring (the Technical Expert Working Group) has generated new information, and there has been research for endangered/threatened fish species, but important gaps still remain in the data for these species and others. Many of these species are diadromous, yet most of the science effort focuses on Atlantic salmon (Northeast Fisheries Science Center Salmon Team). There is also no coordinated, multidisciplinary effort comparable to the Northwest Fisheries Science Center Watershed Program for developing basic and applied science in support of the management of diadromous species in freshwater and estuarine environments. Many of the protected marine mammal and sea turtle species in the region are also data poor; approximately half of the marine mammals and all the sea turtles are classified with low-quality data in the region (Merrick et al. 2004). Many of the protected species only use the region for part of the year, and climate-related changes in their use of the Northeast U.S. Shelf ecosystem are largely unexplored.

The focus on wild-captured fisheries has deemphasized aquaculture, but natural linkages between wild-capture and cultured fisheries are being recognized. In addition, there is growing interest in seaweed aquaculture in the Northeast U.S. The new NEFSC Strategic Plan includes aquaculture under a sustainable fisheries theme, so integration is underway. The demand for domestic marine aquaculture is increasing rapidly (Fisheries of the United States 2013), as is the demand for science to support sustainable aquaculture. The Northeast U.S. region makes up approximately 30% of the national aquaculture production. Efforts are also expanding to include offshore areas as well as traditional nearshore areas. There are a number of intersections between climate change and aquaculture in the Northeast U.S. region, including the impact of sea-level rise on aquaculture operations and the effect of ocean acidification and warming on cultured species. Sustainable aquaculture practices can provide important ecosystem functions such as habitat enhancement through a combination of seaweed, finfish, clam, oyster and mussel culture; considering the effect of climate change on the interactions between these components is an important need. Aquaculture can also play a role in habitat restoration (e.g., improving water quality) and climate mitigation (e.g., taking up carbon dioxide) (see Kim et al. 2014). There is a lot of science needed to support this growing industry and its resilience and adaptation to climate change.

Much of the fishing infrastructure in the Northeast U.S. is vulnerable to sea-level rise as are many local communities (see indicators of sea-level rise impacts on fishing infrastructure in Colburn et al. 2016). The science infrastructure is also vulnerable to sea-level rise. Many living marine resources will be impacted by sea-level rise, primarily through loss of coastal and estuarine habitats. There will be additional indirect effects of sea-level rise, including the release of land-based contaminants into marine systems and changes in trophic interactions. Many of these impacts and interactions are poorly understood in the context of living marine resource management.

In addition to the numerous issues listed above, there are a number of scientific issues in the region that limit furtherance of the NOAA Fisheries Climate Science Strategy. One main issue, and perhaps the critical issue, is the general lack of mechanistic understanding; most of the work completed in the region to date is correlative and/or descriptive. For example, species distribution modeling estimates a statistical function between components of the environment and species occurrence or abundance (see Hare et al. 2012). These past studies have made critical findings, but it is now necessary to increase our understanding of the mechanisms and the incorporation of these mechanisms into modeling. This is true for both social and natural science issues and assessments. Similarly, our understanding of the links between habitat, productivity, and distribution is limited, as is our knowledge of the spatial extent of habitats (e.g., mapping of pelagic and benthic habitats).

The Northeast U.S. shelf ecosystem is highly seasonal and has one of the greatest seasonal ranges in temperatures in the world (Liu et al. 2005). In response, many living marine resources move into and out of the Northeast U.S. shelf ecosystem or move among different regions of the ecosystem. These movements coupled with the governance complexity, expose resources to a range of different regulations, stressors, and authorities throughout the year. The strong seasonality can also create a bias in surveys and other data collection in the system. Approaches have been developed for correcting the NEFSC Bottom Trawl survey for bias introduced by survey sampling through dynamic habitat. In essence this approach addresses the assumption that the survey is synoptic and calculates the availability of a species to the survey through time and space (NEFSC 2014).

Although the region has substantial observing capabilities, decreases in funding and limited coordination present challenges. Further, limited coordination between adjoining regions presents problems for understanding climate impacts on living marine resources that move between and are distributed over different regions (e.g., the Southeast U.S. Shelf Ecosystem, the Scotian Shelf Ecosystem). Support for long-term ecosystem and climate observations has decreased with termination of the 50 year Continuous Plankton Recorder (CPR) survey and decreasing the Ecosystem Monitoring program (EcoMon) from 6 to 4 shelf-wide surveys per year. Data collected during the EcoMon surveys are particularly relevant to the NOAA Fisheries Climate Science Strategy, with approximately 95% of the hydrographic data for the Northeast U.S. Shelf in the World Ocean Database coming from the NEFSC. Efforts are underway to restore this program, and the Ecosystem Monitoring Survey increased to 5 surveys per year in FY2016, but some of the surveys have been limited by ship time allocations and ship maintenance issues, resulting in incomplete surveys of the Northeast U.S. Shelf. Additionally, the CPR program has ended and operations have been transferred to the Sir Alister Hardy Foundation of Ocean Science (SAHFOS). There are a number of other long-term observing programs in the Northeast U.S., but coordination across the ecosystem is limited. MARACOOS and NERACOOS have some interaction, but the platforms used are very different, resulting in differing coverage across the ecosystem. Similarly, the Pioneer Array is coming online, but this is a 5 year deployment and not well integrated with other large observing programs in the region. While new technologies are being developed, operational use remains limited, as does the collaborative use of data across disciplines and institutions. Social science observing systems, such as regular social and economic surveys, are also limited and not well integrated with the physical and biological observing systems. Further, there has been little work on including social and economic variables in climate models, and it is difficult to attach social and economic variables to preexisting marine-species based and ecosystem models largely because of fit-of-scale issues. In addition, ethnographic research that provides context is similarly limited in funding, and integration with quantitative models is much less well understood. Qualitative data can, however, be more easily integrated into conceptual models; that starting point is currently being explored and linked to MSEs.

Another weakness in the region is relative lack of familiarity with climate data, ability to work with large, complex datasets, and ability to integrate data across datasets and disciplines. The lack of familiarity extends across most institutions and stakeholders in the region. The increased use of new technologies (e.g., acoustics, genomics, and optics) exacerbates this problem. The distributed nature of data also presents a problem. Clearly, there are individuals and work groups that have the capacity and knowledge to integrate climate and living marine resource data, but these skills are not widespread. In addition, the availability of consolidated data and indicators is not widespread.

There are major scientific questions that need to be investigated to advance the NOAA Fisheries Climate Science Strategy. For one, there is the specific need for information on ocean acidification effects on living marine resources in the region. Molluscs and crustaceans represent the majority of commercial landings from a value perspective, but there is relatively little specific information on the effects of ocean acidification on federally-managed molluscs and crustacean species. In fact, although there has been important research on many species in the Northeast U.S., many others remain data poor. Understanding of species interactions is also limited. Without this basic knowledge, developing information on how species interactions will change as a result of climate change is extremely difficult. Questions related to prey switching,

functional forms, trophic transfer, and forage are all important and relevant to climate change. On the social science side, questions related to fishers' and aquaculturists' decision-making in response to climate change (e.g., switch species, take longer trips to follow species no longer common where previously fished, move entire households to new communities nearer previously fished species) are poorly understood and funds for research are limited.

There are also major needs from the climate modeling perspective. Most climate models are relatively coarse resolution (approximately 100 km). Higher-resolution climate models have demonstrated that changes in regional circulation patterns are an important component of climate change. Thus higher resolution global models and downscaled, higher resolution regional models are needed. Another modeling issue is the development, evaluation, and use of models that have skill on the 1-20 year time frame. Most work to date has focused on the 50+ year time frame, highlighting the impact of climate change on long-term dynamics. However, most living marine resource decisions are made on shorter time scales. The Northeast U.S. Shelf appears to be a very difficult region to predict at seasonal to interannual time scales, so assessment of forecasting skill are also very important. Finally, the issue of model and data continuity is critical. Most, if not all of the physical and climate modeling will be developed outside of NOAA Fisheries. If products are integrated into management processes, these products need to be operationalized and their ongoing production assured. As an example, a hindcast climatology product developed by academic partners in 2013 was used to support the most recent butterfish assessment (Manderson et al. in review). However, the hindcast is only now being updated as part of Climate Program Office funding (see Appendix H). This uncertainty about continuation of data production makes its use in a next assessment less valuable and makes the assessment working groups circumspect about the inclusion of new data, information, and analyses.

Prioritization

The definition of strengths and weaknesses in the region by the Northeast Regional Action Plan Working Group led to the identification of 63 draft actions across the 7 NOAA Fisheries Climate Science Strategy Objectives (Appendix D). There was overlap in some of the draft actions, but all identify important steps in meeting the objectives of the NOAA Fisheries Climate Science Strategy. The relevant mission area is also identified for each of the 63 draft actions (Appendix D).

Fifteen NERAP Actions of highest priority were defined from the list of 63 draft actions (discussed below and listed in Appendix G). These NERAP Actions represent groups of similar draft actions. For each NERAP Action, specific activities are described under a *No New Resources* and a *New Resources* scenario. The activities under the *No New Resources* represent potential activities that are in line with current efforts and current staffing levels. The implementation of these activities is dependent on broader, NEFSC and GARFO-wide prioritization of activities for FY17 and beyond, as well as the annual appropriation of funds to NEFSC and GARFO, and the other science and management demands placed on NEFSC and GARFO. The activities under the *New Resources* scenario are less dependent on annual appropriations and external demands, and more dependent on the level of *New Resources* available.

The prioritization under *No New Resources* and *New Resources* can be considered sequentially. The priorities under *No New Resources* would be followed first. If additional funding is made available, the priorities under *New Resources* would be addressed as prioritized

unless restricted by the funding provided (e.g., funding to directly support a NERAP Action or an initial draft action [Appendix D]).

4. ACTION PLAN

Northeast Regional Actions and Priorities

Northeast Regional Action Plan (NERAP) Actions are listed and described by NOAA Fisheries Climate Science Strategy objective. Many NERAP Actions are relevant to multiple objectives, but are aligned with the most relevant objective. A list of the NERAP Actions is provided first, followed by descriptions of activities planned for each NERAP Action under the *No New Resources* and *New Resources* scenarios. Actions are also prioritized under a *No New Resources* and *New Resources* scenario (Table 1). The concept is that activities under *No New Resources* would occur as prioritized under the Ranking *No New Resources* and these activities would be augmented by additional activities as listed under Ranking *New Resources*. These NERAP Actions are also mapped to the immediate, short-term, and intermediate term actions described in the NOAA Fisheries Climate Science Strategy (see Appendix E).

In total, 15 NERAP Actions were identified (in order by objective not priority). Many of these priorities address multiple NOAA Fisheries mission elements (sustainable fisheries, protected resources, aquaculture, habitat, and ecosystem) and this Plan would work across all of these mission elements.

NERAP Action 1 - Give greater emphasis to climate-related Terms of Reference and analyses in stock assessments.

NERAP Action 2 - Continue development of stock assessment models that include environmental terms (e.g., temperature, ocean acidification).

NERAP Action 3 - Develop climate- related products and decision support tools to support protected species assessments and other management actions.

NERAP Action 4 - Increase social and economic scientist involvement in climate change research through multidisciplinary work on climate that includes both social and natural sciences.

NERAP Action 5 - Develop Management Strategy Evaluation capability to examine the effect of different management strategies under climate change.

NERAP Action 6 - Improve spatial management of living marine resources through an increased understanding of spatial and temporal distributions, migration, and phenology.

NERAP Action 7 - Continue to build industry-based fisheries and ocean observing capabilities and use information to develop more adaptive management.

NERAP Action 8 - Work with NOAA Oceanic and Atmospheric Research and academic scientists to develop short-term (day to year) and medium-term (year to decade) living marine resource forecasting products.

NERAP Action 9 - Work with NOAA Oceanic and Atmospheric Research and academic scientists to develop and improve regional hindcasts and climatologies.

NERAP Action 10 - Conduct research on the mechanistic effects of multiple climate factors on living marine resources with a goal of improving assessments and scientific advice provided to managers.

NERAP Action 11 - Develop and implement vulnerability assessments in the Northeast U.S. Shelf Region.

NERAP Action 12 - Continue production of the NEFSC Ecosystem Status Report and other related products and improve the distribution of information from the reports through the formation of a NEFSC Environmental Data Center.

NERAP Action 13 - Maintain ecosystem survey effort in the Northeast U.S. Shelf ecosystem including the Bottom Trawl Survey, Ecosystem Monitoring Program, Sea Scallop Survey, Northern Shrimp Survey, Clam Survey, and Protected Species Surveys and expand where possible (e.g., data poor species).

NERAP Action 14 - Initiate a Northeast Climate Science Strategy Steering Group (NECSSSG) to coordinate, communicate, facilitate, and report on issues related to climate change and living marine resource management.

NERAP Action 15 - Coordinate with other NOAA Programs and partners to link living marine resource science and management to climate science and research activities

Table 1. Summary of NERAP Actions and Ranking under *No New Resources* and *New Resources* scenarios. The prioritization under the two scenarios can be considered sequentially. The priorities under *No New Resources* would be followed first. If new resources are made available, the priorities under *New Resources* would be addressed depending on prioritization and on the level and type of resources available.

Prioritization with No New Resources

NOAA Fisheries Climate Science Strategy Objective	NERAP Action Number	Action Statement	Ranking No New Resources	Ranking New Resources	Draft Actions (see Appendix D)	Requested Resources ($1,000s)	Cumulative Requested Resources ($1,000s)	Details of Requests
1	2	Continue development of stock assessment models that include environmental terms (e.g., temperature, ocean acidification).	1		32			
7	13	Maintain ecosystem survey effort in the Northeast U.S. shelf ecosystem including the Bottom Trawl Survey, Ecosystem Monitoring Program, Sea Scallop Survey, Northern Shrimp Survey, Clam Survey, and Protected Species Surveys.	2		22			
1	1	Give greater emphasis to climate-related Terms of Reference and analyses in stock assessments.	3		30			
5	10	Conduct research on the mechanistic effects of multiple climate factors on living marine resources with a goal of improving assessments and scientific advice provided to managers	4		1, 2, 3, 10			
3	6	Improve spatial management of living marine resources through an increased understanding of spatial and temporal distributions, migration, and phenology.	5		13, 14, 19, 34			
6	12	Continue production NEFSC Ecosystem Status Report and other related products and improve the distribution of information from the reports through the formation of an Environmental Data Center	6		26, 51			
7	14	Initiate a Northeast Climate Science Strategy Steering Group (NECSSSG) to coordinate, communicate, facilitate, and report on issues related to climate change and living marine resource management	7		23, 25, 33, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62			
4	8 & 9	Work with NOAA Oceanic and Atmospheric Research and academic scientists to develop short-term (day to year) and medium-term (year to decade) living marine resource forecasting products. Work NOAA Oceanic and Atmospheric Research and academic scientists to develop and improve regional hindcasts and climatologies.	8		36, 37, 38			
2	5	Develop Management Strategy Evaluation capability to examine the effect of different management strategies under climate change.	9		28			
6	11	Develop and implement vulnerability assessments in the Northeast U.S. Shelf Region	10		43, 44, 45, 46, 47, 48			
2	4	Increase social and economic scientist involvement in climate change research through multidisciplinary work on climate that includes both social and natural sciences	11		8			
1	3	Develop climate related products and decision support tools to support protected species assessments and other management actions.	12		31, 35, 40			
3	7	Continue to build industry-based fisheries and ocean observing capabilities and use information to develop more adaptive management.	13		20, 27			
1	15	Links to Stock Assessment Improvement Program	14		32			
7	15	Links to NOAA Fisheries Habitat Programs	15		17, 49			
3	15	Links to NOAA Integrated Ecosystem Assessment Program and Ecosystem-based Fisheries Management	16		29, 52			
5	15	Links to NOAA Ocean Acidification Program	17		9, 11			
7	15	Watershed Program for the East Coast	18		5, 6, 12, 24, 39, 50, 63			
5	15	Other Actions Identified	19		4, 7, 15, 16, 21, others			
7	15	Links to NOAA Fisheries Office of Aquaculture	20		18, 41, 42			

Table 1, continued. Summary of NERAP Actions and Ranking under *No New Resources* and *New Resources* scenarios. The prioritization under the two scenarios can be considered sequentially. The priorities under *No New Resources* would be followed first. If new resources are made available, the priorities under *New Resources* would be addressed depending on prioritization and on the level and type of resources available.

NOAA Fisheries Climate Science Strategy Objective	NERAP Action Number	Action Statement	Ranking No New Resources	Ranking New Resources	Draft Actions (see Appendix D)	Requested Resources ($1,000's)	Cumulative Requested Resources ($1,000's)	Details of Requests
1	2	Continue development of stock assessment models that include environmental terms (e.g., temperature, ocean acidification).		1	32	150	150	1 FTE
3	6	Improve spatial management of living marine resources through an increased understanding of spatial and temporal distributions, migration, and phenology.		2	13, 14, 19, 34	150	300	1 FTE
1	3	Develop climate related products and decision support tools to support protected species assessments and other management actions.		3	31, 35, 40	90	390	1 post-doc
5	10	Conduct research on the mechanistic effects of multiple climate factors on living marine resources with a goal of improving assessments and scientific advice provided to managers		4	1, 2, 3, 10	100	490	1 post-doc + 10K supplies
2	5	Develop Management Strategy Evaluation capability to examine the effect of different management strategies under climate change.		5	28	90	580	1 FTE
4	8 & 9	Work with NOAA Oceanic and Atmospheric Research and academic scientists to develop short-term (day to year) and medium-term (year to decade) living marine resource forecasting products. Work NOAA Oceanic and Atmospheric Research and academic scientists to develop and improve regional hindcasts and climatologies.		6	36, 37, 38	180	760	2 post-docs
6	12	Continue production NEFSC Ecosystem Status Report, and other related products, and improve the distribution of information from the reports through the formation of an Environmental Data Center		7	26, 51	175	935	1 IT contractor + 25K
7	14	Initiate a Northeast Climate Science Strategy Steering Group (NECSSSG) to coordinate, communicate, facilitate, and report on issues related to climate change and living marine resource management		8	23, 25, 33, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62	190	1,125	1 post-doc + 100K workshops
6	11	Develop and implement vulnerability assessments in the Northeast U.S. Shelf Region		9	43, 44, 45, 46, 47, 48	150	1,275	1 FTE
3	7	Continue to build industry-based fisheries and ocean observing capabilities and use information to develop more adaptive management.		10	20, 27	175	1,450	1 IT contractor + 25K
2	4	Increase social and economic scientist involvement in climate change research through multidisciplinary work on climate that includes both social and natural sciences		11	8	90	1,540	1 post-doc
1	1	Give greater emphasis to climate-related Terms of Reference and analyses in stock assessments.		12	30	0	1,540	No new resources
7	13	Maintain ecosystem survey effort in the Northeast U.S. shelf ecosystem including the Bottom Trawl Survey, Ecosystem Monitoring Program, Sea Scallop Survey, Northern Shrimp Survey, Clam Survey, and Protected Species Surveys.		13	22	180	1,720	1 FTE +30K
3	6	Improve spatial management of living marine resources through an increased understanding of spatial and temporal distributions, migration, and phenology.		14	13, 14, 19, 34	90	1,810	1 post-doc
5	10	Conduct research on the mechanistic effects of multiple climate factors on living marine resources with a goal of improving assessments and scientific advice provided to managers		15	1, 2, 3, 10	100	1,910	1 post-doc + 10K supplies
2	5	Develop Management Strategy Evaluation capability to examine the effect of different management strategies under climate change.		16	28	90	2,000	1 post-doc
7	15	Watershed Program for the East Coast		17	5, 6, 12, 24, 39, 50, 63	0	2,000	
5	15	Other Actions Identified		18	4, 7, 15, 16, 21, others	0	2,000	
7	15	Links to NOAA Fisheries Habitat Programs		19	17, 49	0	2,000	
3	15	Links to NOAA Integrated Ecosystem Assessment Program and Ecosystem-Based Fisheries Management		20	29, 52	0	2,000	
5	15	Links to NOAA Ocean Acidification Program		21	9, 11	0	2,000	
1	15	Links to Stock Assessment Improvement Program		22	32	0	2,000	
7	15	Links to NOAA Fisheries Office of Aquaculture		23	18, 41, 42	0	2,000	

Descriptions of NERAP Actions

Objective 1 - Identify appropriate, climate-informed reference points for managing living marine resources.

NERAP Action 1 - Give greater emphasis to climate-related Terms of Reference and analyses in stock assessments. [Return to NERAP Action List] [Return to Executive Summary]

In general, 2 categories of stock assessments are conducted by the NEFSC: benchmark assessments and update assessments. Benchmark assessments evaluate new models, new data, and new approaches to conducting the assessment. Update assessments use a defined methodology from a previous benchmark assessment and update the data and rerun the models. The endpoint of many assessments is to provide information on reference points to be used in management (see Box 1). Since most NEFSC assessments currently do not include climate factors, the introduction of these factors would need to take place in benchmark assessments. The terms of reference (TORs) for conducting an assessment establish the information required by managers and outline the types of models and analyses that should be included in the assessment. Prior to each assessment, the TORs are agreed to by the NEFSC, GARFO, and the appropriate management body (i.e., NEFMC, MAFMC, ASMFC). The fishery assessment schedule is developed by the Northeast Region Coordinating Council (NRCC), which includes high-level representatives from the NEFSC, GARFO, MAFMC, NEFMC, and ASMFC. Assessment scheduling is an NRCC consensus decision, but the NEFSC Science and Research Director has the ultimate responsibility for staff tasking and prioritization (see Description of the process in Stock Assessment Peer-Review Process for more details).

Box 1 – Definition of Reference Points

Reference points are the thresholds upon which living marine resource management decisions are made. Development of reference points is a primary objective for NOAA Fisheries and can include single-species measures of maximum sustainable yield, thresholds for habitat designations, potential biological removal of marine mammals, multispecies fishing rates, and thresholds for ecosystem-level indicators. Reference points are typically developed via modeling exercises that synthesize a broad suite of observational and experimental information. Strengthening the ability of NOAA Fisheries to incorporate consideration of climate change into all the steps that lead to providing reference points is critical and is an important goal of the NOAA Fisheries Climate Science Strategy (modified from NOAA Fisheries Climate Science Strategy, Link et al. 2015).

In 2009, an Office of Inspector General recommended that NOAA should more aggressively pursue ecosystem approaches to fisheries management, which requires additional data and new models. As a result, the NEFSC started including ecosystem TORs in benchmark stock assessments. However, many of these ecosystem analyses were conducted in parallel with assessment modeling and not incorporated into the assessment. In 2014, the NEFSC formed the Climate, Ecosystem, Habitat, and Assessment Steering Group to provide structure and direction to NEFSC efforts pertaining to climate, ecosystem, and habitat research, and the integration and inclusion of this research into the assessments of living marine resources. More broadly, the group aims to provide guidance on the development and application of EBFM in the Northeast Region. This group has developed guidance on the incorporation of climate, ecosystem, and habitat factors into the TORs for assessments, but the NRCC has not reviewed the guidance, nor is it being used by the NEFSC in the development of TORs for benchmark assessments.

No New Resources – The NEFSC would continue to work to include climate-related TORs in stock assessments. However, this work should be done in partnership with the other Northeast Regional Coordinating Council members. Further, this action is strongly related to Stock Assessment Program Review, Ecosystem Program Review, and the NEFSC Strategic Plan and the actions defined therein. Because of the linkages between climate, ecosystem, and habitat issues, new developments in ecosystem understanding (e.g., ecosystem targets, thresholds) and habitat understanding (e.g., availability, population productivity) should also be included in TORs. In FY17, the NEFSC plans to hold a workshop to review previous efforts to incorporate climate, ecosystem, and habitat factors in assessments. The workshop would include participants from NEFSC, GARFO, NEFMC, MAFMC, and ASMFC, as well as scientists and managers from other institutions. This workshop should focus on assessments completed in the Northeast region but should also examine examples from other regions. Barriers to including climate, ecosystem, and habitat factors in assessments should be identified and draft guidelines should be prepared for the inclusion of these factors in all assessments. Based on this workshop, a plan for climate, ecosystem, and habitat-related TORs should be presented at the NRCC for discussion and eventual consensus approval. These guidelines should then be used in subsequent assessments. Further, the guidelines should be reviewed in a workshop in FY20. The format should be similar to the FY17 workshop, with an added topic of progress made over the 3 years. The guidelines should then be revised and presented to the NRCC again for discussion, changes, and eventually consensus approval in FY21.

New Resources – No resources are needed for this action; this action is a top priority of the Northeast Regional Action Plan and should be implemented with *No New Resources*. Many of the other NERAP Actions directly relate to improving assessments and these improvements should be incorporated into assessment TORs. Thus, the review of climate, ecosystem, and habitat factors in assessment TORs in FY20 should be an important measure of the success of the Regional Action Plan.

NERAP Action 2 - Continue development of stock assessment models that include environmental terms (e.g., temperature, ocean acidification). [Return to NERAP Action List] [Return to Executive Summary]

Over the past several years, a number of stock assessment models have been modified to be able to include environmental effects. Previous assessment models in the Northeast U.S. could not include environmental terms even if an environmental effect was known. Four recent efforts highlight the progress that has been made and provide examples for future work from which to build.

1. A state-space assessment model has been developed that simultaneously treats environmental covariates as stochastic processes and estimates their effects on recruitment (Miller et al. 2015). The model was applied to southern New England yellowtail flounder using data from the most recent benchmark assessment. Both spawning stock biomass and the environment (i.e., Mid-Atlantic Bight cold pool) were important predictors of recruitment and led to annual variation in estimated biomass reference points and associated yield. This study also emphasized the importance to the stock assessment forecast of being able to forecast the environmental effect; this need is addressed in NERAP Actions 8 and 9.

2. The ability to incorporate an environmental covariate was built into the Age-Structured Assessment Program (Miller and Legault 2015). This new formulation is being used to investigate the effect of warming on the rebuilding of southern New England winter flounder (Bell et al. in prep). Stock Synthesis is another model that has been applied globally, but rarely used in the Northeast U.S. Most of the parameters in Stock Synthesis can change over time in response to environmental or ecosystem factors (Methot and Wetzel 2013). This functionality can be used in the future to advance the incorporation of climate change in stock assessments.

3. The assessment model used for Atlantic sea scallops was recently coupled to a biogeochemical model to investigate the effects of ocean acidification and warming on scallop dynamics. Three effects were included: ocean acidification effects on larval survival, ocean acidification effects on adult growth, and warming effects on adult growth (Cooley et al. 2015).

4. Species distribution modeling was used to define the thermal habitat of butterfish (NEFSC 2014). The time and space sampling of this dynamic habitat by the NEFSC Bottom Trawl was then used to estimate the amount of habitat sampled versus the total amount of habitat. These values were used to bound the availability estimates in the stock assessment model. A similar procedure was also used in the scup and bluefish assessment.

There are other approaches that are under development in the Northeast region and elsewhere, and these approaches form the foundation for continued progress incorporating climate factors in assessment models. These approaches include understanding how climate change is affecting data collection programs that support stock assessment. For many fisheries, fishery-independent surveys are the scientific backbone of the assessment and management process. However, an important source of uncertainty is the spatial extent and timing of surveys relative to spatial distributions and timing of migrations of the species being surveyed. With a stable climate, interannual changes in distributions and timing of migrations add variance to abundance estimates, but survey indices are unbiased through time. However, with climate change and decadal-scale variability, indices for some stocks may no longer track changes in abundance accurately. Similar problems likely exist for fishery-dependent indices of abundance (catch-per-unit-effort [CPUE]) that are used in the assessment of management of some species.

Moving forward, multiple alternative models and approaches need to be developed and evaluated. To be incorporated into assessments, these models and approaches need to undergo a formal scientific peer-review process. Assessments are prepared during a Northeast Regional Stock Assessment Workshop (SAW) and then reviewed by an independent panel of stock assessment experts called the Stock Assessment Review Committee (SARC). Only the fourth example listed above has been approved through the SAW/SARC process. Further, both the ability to forecast environmental factors and better estimate historical environmental factors are necessary to include environmental terms in stock assessments models (see NERAP Actions 8 and 9).

No New Resources – With no new resources, current efforts would continue. Many of these efforts have been supported by internal NOAA Fisheries fund competitions (e.g., NOAA Fisheries Improve a Stock Assessment, NOAA Fisheries Stock Assessment Analytical Methods,

NOAA Fisheries and the Environment, NOAA Fisheries Habitat Information Use in Stock Assessments). Competitive funding from sources external to NOAA Fisheries, including the NOAA Ocean Acidification Program and the NOAA Climate Program Office, has also been important. Priorities should be discussed by the Climate, Ecosystem, Habitat and Assessment Steering Group, and collaborative efforts across the NEFSC and with other researchers in the region should be encouraged.

New Resources - Hire a federal employee (or postdoctoral associate) to complement expertise already at the NEFSC and develop applications of models within the current stock assessment process. The position would work closely with other NEFSC staff involved in linking stock assessment models with climate factors. Priorities would be discussed by the Climate, Ecosystem, Habitat, and Assessment Steering Group (under *No New Resources*). In addition, in FY18 the NEFSC would host a workshop on including environmental variables in stock assessment models. The workshop would build off a similar effort hosted by the Massachusetts Marine Fisheries Institute, Incorporating Change in Assessments and Management, held in 2013. The purpose of the workshop would be to review efforts throughout the Northeast U.S. region and identify common themes and important limitations of the methods. The results of this workshop would then be used to direct the work of the federal employee (or postdoctoral associate) in FY19-FY21.

NERAP Action 3 - Develop climate- related products and decision support tools to support protected species assessments and other management actions. [Return to NERAP Action List] [Return to Executive Summary]

Climate change is an important consideration for meeting management objectives under the ESA and MMPA. The impact of climate change on the current and future status of a species is a factor considered when determining whether the species warrant listing under the ESA. NMFS also considers the impacts of climate change to ESA listed species' habitats and ecosystems. In addition, when considering effects of actions on ESA listed species in ESA section 7 consultations, consideration is given to how the effects of activities may change because of climate change, as well as the impact of climate change on the future survival and recovery of listed species and designated critical habitat. Previous work completed in the Northeast U.S. focused on changes in habitat and used species distribution models coupled with climate models to project changes in habitat volume and distribution (Hare et al. 2012; Lynch et al. 2014). These studies were part of a larger effort to understand the interaction between climate change and the Endangered Species Act for NOAA Fisheries (Seney et al. 2013).

NOAA Fisheries developed Guidance for the Treatment of Climate Change in NMFS ESA Decisions subsequent to the above-mentioned studies (see also McClure et al. 2013). The guidance recognizes that climate change makes the evaluation of protected species more difficult by changing the future extinction risk to a species. The guidance provides specific instructions for incorporating climate change in ESA considerations:

- Consideration of future climate condition uncertainty
- Selecting a climate change projection timeframe
- Evaluating the adequacy of existing regulatory mechanism to reduce greenhouse gas emissions
- Critical habitat designation in a changing climate
- Consideration of future beneficial effects

- Responsiveness and effectiveness of management actions in a changing climate
- Incorporating climate change into project designs

Based on this guidance, NOAA Fisheries would need additional scientific support for ESA-related decisions and actions. Information is also important to inform proactive conservation efforts for Species of Concern.

There is similar uncertainty in the assessment of status and threats of climate change for marine mammals under the MMPA[2]. Marine mammal assessments follow National Guidelines for Assessing Marine Mammal Stocks (GAMMS). Distribution of marine mammals is likely to be impacted by climate change through oceanographic changes and changes in prey distributions (Macleod 2009). These changes in distribution may impact Take Reduction Plans designed to limit the take of marine mammals through commercial fishing activities. Climate change may also impact the productivity of some marine mammals. For example, decreases in zooplankton prey abundance may reduce productivity of North Atlantic right whale (Meyer-Gutbrod et al. 2015). Although assessment guidelines are national, there is a clear need to incorporate climate change consideration in marine mammal assessments and management in the Northeast U.S. region, including changes in the physical environment, changes in habitat conditions, and changes in species interactions.

No New Resources – Climate-related efforts supporting ESA and MMPA actions would continue at a low level. Current efforts include work on North Atlantic right whale, Atlantic salmon, sea turtles, and river herring; these efforts should continue. Most of these efforts are supported by temporary funds for specific projects; to continue these efforts, additional temporary funding would be needed. To the extent that additional support can be provided (e.g., Fisheries and the Environment, Office of Protected Resources) these approaches should be applied to other species. Support for the Marine Mammal and Sea Turtle Climate Vulnerability Assessment should also continue (see NERAP Action 11). Finally, NEFSC and GARFO staff should initiate a strategic discussion regarding the support for climate information in ESA and MMPA activities, and the NEFSC Climate, Ecosystem, Habitat and Assessment Steering Group should lead this discussion. The NOAA Fisheries Guidance for the Treatment of Climate Change in NMFS ESA Decisions should be reviewed in FY16 and ESA-related decisions should be supported in the FY16-FY21 period. In addition, a workshop should be convened in FY17 to review the Guidelines for Assessing Marine Mammal Stocks (GAMMS) related to climate change and a regional strategy should be developed. The focus should be on defining the approaches for including climate change in MMPA assessments and decisions and the type of climate information required. This strategy should then be followed to the extent possible during the FY17-FY21 period.

New Resources – Support a postdoctoral associate to work on incorporating climate change factors in ESA and MMPA assessments and decisions. The postdoctoral associate would work with NEFSC and GARFO staff on a jointly agreed upon topic and provide scientific products in support of decisions. Topics may include climate related changes in the physical environment, habitat conditions, and species interactions. The postdoctoral associate would also provide climate expertise to other projects by providing and reviewing information used in a

[2] Some marine mammals are listed under the ESA.

variety of decisions. The position would focus on population projections with the inclusion of climate factors using species distribution models, population models, or ecosystem models.

Objective 2 - Identify robust strategies for managing living marine resources under changing climate conditions.

NERAP Action 4 - Increase social and economic scientist involvement in climate change research through multidisciplinary work on climate that includes both social and natural sciences. [Return to NERAP Action List] [Return to Executive Summary]

Ecosystems include humans, and climate change acts on human communities both directly (e.g., sea-level rise) and indirectly (e.g., species range shifts). There is an ongoing effort in the NEFSC to conduct multidisciplinary work in the Northeast U.S. region that better integrates social and natural sciences. Recent work in this collaboration includes portfolio analyses in the MAFMC Ecosystem Guidance documents (Jin et al. 2016; Gaichas et al. 2016; EAFM Guidance). The NOAA Fisheries Community Social Vulnerability Indicators (CSVIs) have been expanded to include new measures of climate change vulnerability, including an indicator of community dependence on climate vulnerable species (Colburn et al. 2016) linked to Northeast Fisheries Climate Vulnerability Assessment (Morrison et al. 2015; Hare et al. 2016). An indicator of Community Sea-level Rise Risk Vulnerability has also been calculated, along with an indicator of the impact of sea-level rise on seafood commerce businesses (Colburn et al. 2016). These indicators are currently or will shortly be available nationwide, with the exception of some indicators for certain states or territories (see Colburn et al. 2016 for details). Additional community climate indicators are under development. Work on how seafood enters and flows through the regional food system (Stoll et al. 2015; Pinto da Silva et al. in review) will help to further elucidate the climate impacts of species range changes on seafood available to consumers and community resilience. Local ecological knowledge has been used to better understand Atlantic cod populations in the Gulf of Maine (Ames 2004) and is being used to examine Atlantic cod spawning areas on Georges Bank. Traditional ecological knowledge also offers mechanisms to understand and interpret changes in ecosystems (Berkes et al. 2000). The ICES WGNARS is also incorporating human dimensions into a regional Integrated Ecosystem Assessment, which includes a conceptual model linked to an MSE approach. Climate is a focal component of the conceptual models developed in support of the Integrated Ecosystem Assessment, and its impacts are core to preliminary MSE results. These activities are part of broader agency efforts to develop and support EBFM regionally and nationally (Link 2016).

No New Resources – Continue time series analysis on changes in Community Social Vulnerability Indicators including those for climate change, and engage with Coastal and Ocean Climate Applications projects (see Appendix H). Begin to describe a baseline of how the current climate and market system provides seafood for the region. NEFSC and GARFO are working to discern possible strategies for boosting community resilience within NMFS legal authorities based on results of the GARFO/West Coast Region Community Resilience Working Group. The Working Group provided its recommendations to NEFSC and GARFO Leadership, as well as the Marine Fisheries Advisory Committee (MAFAC). GARFO is considering convening a working group of interested parties and community leaders in 2017 to further investigate GARFO's role and responsibilities related to community resilience. In addition, in cases when species are likely to move to areas under the jurisdiction of a different council or councils, encourage the relevant

councils to determine the most effective structure for the management of those species using the best scientific and climatic data. Make use of existing community social and climate vulnerability indicators and of the new such indicators that can be constructed with additional temporary funds. NEFSC and GARFO are also working to communicate results of community vulnerability assessments to states and communities. Social and natural scientists could present talks on research that may be incorporated into the management process. Continue to provide social scientist support for development of EBFM in Northeast U.S. region. Conduct literature review of regional local ecological knowledge, traditional ecological knowledge, and climate, as well as perform conceptual modeling of the relationships involved. Include community social vulnerability indicators (including to climate change) in annual Ecosystem Reports for the Fishery Management Councils and Atlantic States Marine Fisheries Commission, fisheries engagement indicators can be calculated annually, as can community level sea-level rise data. Census-based indicators are available every 5 years. Finally, an Economics and Social Science Program Review is planned for FY17 (http://www.st.nmfs.noaa.gov/science-program-review/). Climate-related responses related to this program review will be addressed in coordination with activities underway as part of the NERAP.

New Resources – Hire postdoctoral associate or contractor to expand social vulnerability work and community social vulnerability indicators (e.g., social capital), to contribute to the development of integrated models (e.g., Atlantis), and to further flesh out a baseline of how the current climate and market system provides seafood for the region. Efforts would also increase to conduct and analyze new sets of oral histories that record the heritage and local knowledge of fishermen, aquaculturists, and communities particularly in relation to climate change and resilience strategies (eFolke et al. 2005; Azzurro et al. 2011). Expand cooperative research opportunities and include fishermen in all stages of the research, not just data collection but also planning and evaluation. Fund informational outreach presentations by scientists to be held throughout the region, in order to facilitate access to as many fishermen and fishing community members as possible. As new climate indicators are added to the CSVIs, add these to annual Ecosystem Reports for Fishery Management Councils and Atlantic States Marine Fisheries Commission. Evaluate the Mid-Atlantic Fisheries Management Council Fishery Performance Reports and the Fishers' North Sea Stock Survey to inform climate and fishery assessments in the region.

NERAP Action 5 - Develop management strategy evaluation capability to examine the effect of different management strategies under climate change. [Return to NERAP Action List] [Return to Executive Summary]

Management strategy evaluation (MSE) is a simulation technique that allows the evaluation of a range of management options and identifies tradeoffs in performance across the range of options (A'mar et al. 2008). An operating model is developed to represent the "true" dynamics of the system based on current understanding. An estimation model is used to assess the state of the system based on various observing or sampling processes. Finally, the effect of different management strategies can be examined in the context of the operating and estimation model. Conceptually, MSE is similar to ocean observing system simulation experiment (OSSE) framework (Arnold and Dey 1986). Several MSEs have been developed in the Northeast U.S. region to: (1) examine harvest controls rules for the MAFMC (Wilberg et al. 2015), (2) evaluate harvest control rules for Atlantic mackerel (Wiedenmann 2015), and (3) evaluate management

and regulatory options for summer flounder (Wiedenmann and Wilberg 2014). There are also several MSEs underway in the NEFSC; an example is an evaluation of harvest control rules in Atlantic herring and multispecies management procedure testing (Deroba 2015). Although MSEs have been developed in the region, they have not been used to evaluate the effect of climate change on living marine resource management. More broadly, MSEs are relatively new the Northeast region, and further development is needed before MSEs can be applied to policy decisions.

No New Resources -There is very little climate-related MSE work that can be conducted without new resources. The NEFSC should continue to develop MSEs and seek external funding to apply the approach to climate-related issues. The NEFSC should also continue to and expand work with academic scientists involved in MSE work in the region. Finally, the NEFSC and GARFO should continue to work together and with the NEFMC, MAFMC, and ASMFC to incorporate climate factors into management frameworks.

New Resources - Hire a federal employee and a postdoctoral associate to work on climate-related MSEs at the regional level and contribute to the national level effort. These new staff would work closely with NEFSC staff and academic scientists already working on MSEs. These new staff would also work closely with others outside of the NEFSC (e.g., Fishery Management Councils, GARFO Protected Resources Division) to identify the goals of the evaluation and to develop a collective understanding of the constraints and uncertainties inherent in applying climate data in the management context. MSEs should be developed related to management under changing distributions and productivity through direct (e.g., thermal tolerance, ocean acidification effects) and indirect (e.g., species interactions, habitat) effects. They would also evaluate the impacts of climate-related regime shifts and climate-driven changes in habitat. They would work both on fishery and protected species issues including: climate-informed reference points, spatial allocations, ESA Section 7 and MSA EFH consultations (time of year windows and spatial overlaps), FMP and TRP regulations (dates of requirements, spatial closures), ESA listing decisions (extinction risk considerations), ESA recovery plans and candidate species (future changing recovery needs). A workshop would be held in FY18 to examine adaptive management responses to climate change across the NOAA Fisheries mission. This workshop would include NOAA Fisheries, NEFMC, MAFMC and ASMFC committee members and staff, and academic scientists and would seek to review the current state of use of MSE in the region, define various adaptive management responses, and discuss how these responses can be evaluated with MSE. This workshop would then guide NEFSC work related to this action from FY18-FY21. Additionally, an MSE workshop focused on protected resources would be held in FY19. This workshop would include NOAA Fisheries, US Fish and Wildlife, academic scientists, and other stakeholders.

Objective 3 - Design adaptive decision processes that can incorporate and respond to changing climate conditions.

NERAP Action 6 - Improve spatial management of living marine resources through an increased understanding of spatial and temporal distributions, migration, and phenology. [Return to NERAP Action List] [Return to Executive Summary]

There is ample evidence that species distributions on the Northeast U.S. Shelf are changing (Nye et al. 2009; Pinsky et al. 2013; Kleisner et al. 2016; Walsh et al. 2015). Studies

include adult fish and invertebrates, fish early life history stages, fishery landings, and North Atlantic right whale distributions. A recent Fisheries Climate Vulnerability Assessment found that most managed fish and invertebrate species in the region have a high or very high potential for a change in distribution (Hare et al. 2016). Species distribution models coupled with climate models have indicated that changes in distribution will continue for the foreseeable future. These changes are not unidirectional. Many species are shifting northward and into deeper waters, but a recent study finds that in the Gulf of Maine species are shifting to deeper waters and to the southwest, where waters are cooler (Kleisner et al. 2016). However, not all changes in distribution are associated with climate factors; the northward expansion of summer flounder on the Northeast U.S. Shelf was attributed to a growing population and larger fish moving further north in warmer months (Bell et al. 2015). The mechanisms responsible for regional and species-specific variability in changes in distribution are important to understand, and these changes potentially impact management in many ways. Species cross from one management jurisdiction to another. Although presenting new challenges, these shifting distributions do not mean that part of the stock becomes unmanaged or inaccessible to fishermen, who are often mobile and fish a wide variety of areas. Even management of transboundary species with Canada can be adjusted to accommodate shifting distributions. However, spatial management structures may become out-of-sync with the distribution of the resource. The economics of a fishery change as the distance to fish from ports change. Stock structure may change, which has implications for reference points and stock status determinations (Link et al. 2010). What may be more problematic could be the effect that shifting distributions have on suitable habitat and productivity of a stock. Changes in timing of migrations and spawning could also make existing spatial management regulations (e.g., closed areas) more or less effective than intended. They could also decouple larval distribution from favorable conditions for survival and growth, having a significant effect on stock productivity, sustainable yield, and (when applicable) rebuilding potential.

No New Resources - Continue current efforts analyzing distribution data and applying information in living marine resource management. Most work to date has been based on the NEFSC trawl survey, but numerous other datasets exist in the region including distribution data for other species. Work should be conducted using other datasets including other NEFSC surveys, state surveys, Northeast Area Monitoring and Assessment Program (NEAMAP) surveys, Canadian surveys, and Southeast Fisheries Science Center (SEFSC) surveys. In addition, cooperative work with industry is underway and will be continued (NEFSC Observer Program, Study Fleet, Cooperative Catchability studies). Tagging data should also be incorporated into this effort where appropriate. Changes in the distribution of commercial and recreational catches and discards should also be examined as spatial changes in fishing may have important implications for assessments and management. Further, most work has focused on adult stages; work should be conducted on understanding distribution changes of early life stages: eggs to juveniles. In particular, the connections between life stages through the availability of appropriate habitat should be examined (see Walsh et al. 2015). Finally, most work has been completed on commercially exploited fish and invertebrates; emphasis should also be given to other species including recreationally important fish, protected species, and forage species.

In addition to analytical work, efforts to identify and share data among organizations and institutions should continue. The Essential Fish Habitat Database under development at the NEFSC could be used as the focal point for these efforts; this site is currently set up to serve

state trawl survey data, and new datasets would be added as they are identified and approval is granted for their addition to the database. Interactions with other data portals should also increase (e.g., OceanAdapt, Marine Ecosystems Outlook Dashboard). Additionally, methods of accounting for survey bias should continue to be developed (see NERAP Action 2). The development of species distribution models should continue in the NEFSC; an informal Working Group has already formed.

Species Distribution Models are one way to account for survey bias and to integrate understanding of species distributions (e.g., butterfish). These models also have a direct link to physical models (NERAP Action 10 and 11) and can be used in short (days to years) and medium-term (years to decades) scientific advice. However, most species distribution models completed in the region to date focus on elements of pelagic habitat (e.g., temperature and salinity). Further, most of these models focus on spatial distribution rather than distribution in time, for example timing of events or seasonal processes. Efforts should be made to broaden the scope of these models to include components of benthic habitat or prey habitat (e.g., terrain ruggedness as a component in a species distribution model for cusk, Hare et al. 2012) and to examine changes in timing of distribution (e.g., how changes in streamflow patterns may change the migration cues for diadromous species, Tommasi et al. 2015). Efforts should continue on a broad range of species including protected species, fishery species, and forage species.

Finally, stock structure, which is largely defined spatially, needs to be reevaluated in light of documented distribution changes. Link et al. (2010) presented a decision-tree approach, and one recent assessment revisited stock structure prior to initiating the benchmark assessment process (i.e., black sea bass). These efforts should continue on a stock-by-stock basis. A workshop was held to evaluate species distribution modeling of marine mammals in a climate change context (Silber et al. 2016). A North Atlantic Regional Team sponsored workshop was held in FY16 related to species distributions. In addition, regulatory and management barriers exist to changing stock boundaries. A workshop would be held in FY18 with NEFSC, GARFO, Council / Commission staff, and other experts to review these regulatory and management barriers and to develop potential processes and strategies for overcoming these barriers.

New Resources - Hire 2 new staff (federal employee and a postdoctoral associate) to contribute to the management implications of climate-driven changes in distribution. One position would focus on forage fish issues, in support of the MAFMC Forage Fish Amendment and other forage-related management questions in the region. This position would augment, not replace current resources devoted to forage fish (e.g., Atlantic mackerel, Atlantic herring, and river herring). The purpose is to develop an understanding of the effect of climate change on forage in the Northeast U.S. region and then to better understand the effect of changes in forage on higher-trophic levels, including marine mammals. It would also investigate the potential effects on all life stages of managed species (e.g., Atlantic salmon, Atlantic cod).

The second position would support the ongoing re-evaluations of stock structure in the Northeast U.S. region. This position would conduct interdisciplinary stock structure studies and again would augment not replace current resources devoted to stock identification and stock assessment. This position would also develop and work with Management Strategy Evaluations (MSE) to better understand the effect of changing stock structure on assessments and management of living marine resources. Both positions would be expected to consider distributions from a species perspective, not a regional management perspective, so if the species extended into Canadian or Southeast U.S. Shelf waters, partnerships and collaborations would be developed with scientists in these regions.

Finally, in FY18 the NEFSC would convene a workshop to address larger issue of climate change effects on stock distribution and identification. The purpose of this workshop would be to develop a regional framework for addressing climate change effects on stock identification and distribution. This framework would then be used in subsequent assessments and management. Further, new approaches for measuring distribution would be presented including observing programs (e.g., http://www.redmap.org.au/) and statistical approaches (Thorson et al. 2016).

NERAP Action 7 - Continue to build industry-based fisheries and ocean observing capabilities and use information to develop more adaptive management. [Return to NERAP Action List] [Return to Executive Summary]

The Northeast Cooperative Research Program is responsible for the coordination and implementation of federally-supported collaborative fisheries research in the Northeast which includes NEFSC-directed projects, research funded through Research Set-aside Programs, a Study Fleet, Cooperative Research and Survey Programs, an Enhanced Biological Sampling Program, and Environmental Monitors on Lobster Traps. The Research Set-aside programs directly support science and assessment related to specific fisheries (e.g., Atlantic sea scallop and monkfish). Cooperative Research and Survey Programs include the Maine-New Hampshire Trawl Survey, Northeast Area Monitoring and Assessment Program, and a NEFSC Longline Survey Study for the Gulf of Maine. These surveys involve industry, collect data used in assessments, and in many cases provide information about relatively data poor species (e.g., cusk and thorny skate). The Enhanced Biological Sampling Programs provides industry-collected fish and invertebrates for age, growth, and maturity studies to fill data gaps identified by NEFSC and GARFO scientists. The Study Fleet are a subset of fishing vessels from which high quality, self-reported data on fishing effort, area fished, gear characteristics, catch, and environmental observations are collected. The eMOLT program started in 2001 and developed low-cost strategies to measure bottom temperature, salinity, and current velocity with the help of nearly 100 lobstermen dispersed along the entire New England coast. In recent years, efforts between the eMOLT program and the Study Fleet have been combined with the deployment of temperature sensors on Study Fleet boats and the development of satellite-based near-real time reporting of these observations. During FY15, several weather stations were purchased and deployed in a pilot program with the National Weather Service to use fishing boats to collect meteorological observations for use in weather modeling. There are also other cooperative research efforts in the region that can be leveraged for expanding the integration of climate-related information into living marine resource management (e.g., Mid-Atlantic Fisheries Management Council Managing Cooperative Fisheries Research Program, Commercial Fisheries Research Foundation). The potential for industry vessels to collect oceanographic data could increase observing capacity in the region by at least an order of magnitude and provide critical observations of the water column and near surface atmosphere. These observations can contribute to modeling but can also help fishermen make decisions with regard to limiting their incidental catch and their ability to adapt to changing conditions. Facilitating these interactions in short term (days to years) applications would help develop the relationships necessary to make adaptive decisions in the medium term (years to decades).

No New Resources - Work should continue with Study Fleet and eMOLT to improve environmental data collection and the efficiency of data provisioning. This would improve the

ability of using biological and environmental data from these programs in the assessment and management of living marine resources. Specific activities include work with the pelagic fisheries in the Mid-Atlantic including the evaluation and improvement of species distribution models for use in real-time decision making in the Atlantic mackerel, Atlantic herring, Butterfish and Longfin Squid fisheries. Development of tools to help industry avoid incidental catch of river herring should also continue. These projects would include engagement with industry to work toward an improved understanding of the system. In addition, the NEFSC Gulf of Maine longline survey should continue, and data could be used in protected species assessments including Cusk and Thorny Skate. The Cusk model developed by Hare et al. (2012) could be updated using longline data and a similar Thorny Skate model could be developed. Finally, emphasis should be given to the collection, transmission, and archiving of environmental data from Study Fleet and eMOLT. The data handling processes should continue to be improved with wireless technologies and satellite-transmission of data. Additionally, the archive of data should be made available to the oceanographic modeling community. The collaboration with NOAA National Weather Service should also continue in an effort to improve the data used in weather models. Increased fishing industry investment in such processes would be improved by moving toward research that is completely collaborative and participatory, i.e., where fishermen are involved in planning and write-up as well as data collection. There are also opportunities to work more closely with the recreational fishing community. There are several recreational-based surveys that could contribute to the understanding of the effect of climate change on fisheries including the survey activities of Marine Recreational Information Program (MRIP). These opportunities could be tied to the social and economic components of recreational fishing through NERAP Action 4. Finally, there are many other cooperative research activities in the region: industry working with universities, states, and nongovernmental organizations. Better coordination and communication between these programs and NOAA programs is needed.

New Resources - Fund a new staff member (federal employee or contractor) to increase ability to collect and distribute climate related data from Cooperative Research Program activities including Study Fleet, eMOLT, and the NEFSC Longline Survey Study for the Gulf of Maine. The new staff member would support the development of automated data transfers to allow rapid collection and availability of environmental data to a broad community of scientists, modelers, managers, and fishermen. This rapid collection of data would support other actions described in the Regional Action Plan. In addition, the effort would support adaptive decision-making by industry and managers based on near-real time conditions. These feedback loops based on short-term products (days to months) would then be used to communicate medium-term products as well (years to decades).

Objective 4 - Identify future states of marine, coastal, and freshwater ecosystems; living marine resources; and living marine resource-dependent human communities in a changing climate.

NERAP Action 8 - Work with NOAA Oceanic and Atmospheric Research and academic scientists to develop short-term (day to year) and medium-term (year to decade) living marine resource forecasting products. [Return to NERAP Action List] [Return to Executive Summary]

Actions are described below in combination with NERAP Action 9.

NERAP Action 9 - Work with NOAA Oceanic and Atmospheric Research and academic scientists to develop and improve regional hindcasts and climatologies. [Return to NERAP Action List] [Return to Executive Summary]

Numerous advances have been made in the Northeast U.S. region linking living marine resource models to oceanographic and climate models. These efforts have included fishery and protected species applications at the day to year (Manderson et al. in prep; Turner et al. 2015), year to decade (Bell et al. in prep; Pershing et al. 2015), and decade to century scales (Hare et al. 2010, 2012; Lynch et al. 2014; Cooley et al. 2015). In addition, oceanographic and climate modeling in the region is advancing rapidly with data assimilative hindcasts and nowcasts (ROMS, FVCOM), work on decadal forecasting (Stock et al. 2011), the development of regional downscaled climate and earth system models (see Appendix D), the development of regional climatologies (NODC, NCBO), and the examination and use of high-resolution global models (Saba et al. 2016). These efforts take interdisciplinary groups to develop and improve applications and, as a result of work done to date, strong ties have formed in the region between NOAA Fisheries, NOAA Research (NOAA Oceanic and Atmospheric Research; OAR), and academic scientists. Additional ties with the NOAA National Ocean Service, U.S. Geological Service, U.S. Fish and Wildlife Service, and the Environmental Protection Agency are needed to better incorporate information about climate changes in freshwater and estuarine systems with benefits to fishery and protected species. Further, to transition these efforts to living marine resource assessments and management takes collaboration with assessment scientists and managers and takes a commitment to support operational use of models and products once developed and used. Specifically for fisheries management, information is needed from the seasonal to 3 year time scale for specifying catch limits and in the 3-10 year time scale to inform rebuilding plans, framework adjustments, and fishery management plan amendments. Despite scientific advancements in forecasting and opportunities for collaboration, it is important to note that the Northeast U.S. Shelf is a difficult region to forecast future environmental conditions from seasonal to decadal-scales (Stock et al. 2015; Chen et al. 2015) because of the atmospheric variability and complexity of ocean circulation. Thus, although the development of forecasting is an important element of the Northeast Regional Action Plan, there are major challenges that need to be addressed.

Box 2. Definitions of Prediction, Forecast, and Projection (modified from IPCC 2007 Glossary).

A prediction is an estimate of the actual evolution of the climate or ecosystem (e.g., at seasonal, interannual or long-term time scales). Predictions are usually probabilistic in nature.

A forecast is a prediction made into the future and is typically highly sensitive to initial conditions.

A projection is distinguished from a forecast to emphasize that projections depend on a set of assumptions (e.g., a climate scenario, a fishing rate). These assumptions may or may not be realized and are therefore subject to substantial uncertainty.

No New Resources - Continue collaborations with NOAA Research (OAR), the Integrated Ocean Observing System, and academic scientists on issues related to short-term (days to years) and medium-term (years to decades) prediction and forecasting in the context of living marine resource management. The oceanographic and climate modeling to support this forecasting includes hindcasts, nowcasts, forecasts, and projections (see Box 2). In FY17 and FY18, these collaborations would be opportunistic but would include work with Geophysical Fluid Dynamics Laboratory, Earth System Research Laboratory, and Coastal and Ocean Climate

Application Program (COCA) funded projects (Appendix H). In addition, efforts to develop species distribution modeling in the NEFSC should continue; for example, there are ongoing projects related to marine mammals, river herring, and Mid-Atlantic fisheries. Where possible these activities should be linked to assessment and management needs. An excellent example is species distribution modeling using a Regional Ocean Models hindcast and nowcast to evaluate availability to the trawl surveys in the butterfish, bluefish, and scup assessments and to fishery operations for Atlantic mackerel, Atlantic herring, and longfin inshore squid. Links to industry should be strengthened both in terms of prediction and evaluation. Emphasis should be given to the development of an ensemble modeling approach, which is widely used in long-term (decades to centuries) projections. Other elements of this Northeast Regional Action Plan that need modeling output should also be supported by providing model output or links to model output and instruction on its use (e.g., NOAA Climate Change Portal). Post FY18, efforts would be more strategic. Efforts at the medium-term time scale (years to decades) should work on issues related to fishery stock rebuilding and sustainability, protected species assessment and recovery, and evaluation of the sustainability of aquaculture operations. Efforts at the short-term (days to years) scale should focus on days-to-weeks forecasts in support of fishery operations and incidental-catch reduction and months-to-years forecasts in support of fishery stock assessments (e.g., Hobday et al. 2016). A Climate, Ecosystem, Habitat, and Assessment Steering Group sponsored workshop should be held late in FY17 to develop the FY18-FY21 priorities, thereby allowing staff in the NEFSC and GARFO to develop proposals for internal and external funds to support these priorities.

New Resources - Hire 2 temporary personnel (i.e., postdoctoral associates) to couple climate and living marine resource models and to complete research-to-operations transition for models that have demonstrated value in an assessment or management context. These temporary personnel should have strong ties to the Geophysical Fluid Dynamics Laboratory, Earth System Research Laboratory, and Coastal and Ocean Climate Application Program (COCA) funded projects (Appendix H), as well as to computer scientists that are developing web-delivery of climate-related products. The living marine resource models could be single species, multispecies, and full ecosystem models. Initially, temporary personnel would be used to support projects already underway but would then be transitioned to priority areas identified in the FY17 workshop. An emphasis would be on making products transparent and available to the broader community by providing not only the product, but also metadata and provenance related to the product; this emphasis is similar to the efforts underway in support of the National Climate Assessment (NCA 2014). An important element is to ensure that models developed in the region can be continued to support the operational needs of assessments and management. NOAA Fisheries, NOAA Research, the Integrated Ocean Observing System, or other partners may support this need, and as operational products are identified, plans for continuing their production should be developed.

Objective 5 - Identify the mechanisms of climate impacts on ecosystems, living marine resources, and living marine resource-dependent human communities.

NERAP Action 10 - Conduct research on the mechanistic effects of multiple climate factors on living marine resources with a goal of improving assessments and scientific advice provided to managers. [Return to NERAP Action List] [Return to Executive Summary]

A mechanistic understanding of the effect of climate change on behavioral, physiological, ecological, and biophysical processes is critical to improving scientific advice to managers. There is a long history of research in the region on environmental effects on individuals and populations (Laurence 1975). The NEFSC currently has seawater laboratory facilities in Sandy Hook, New Jersey and Milford, Connecticut. Both facilities have the ability to manipulate temperature, carbonate chemistry, and other factors and the ability to examine interactive effects of multiple-stressors. Scientists at these facilities have experience working with phytoplankton, molluscs, crustaceans, and fish. Joint investments by NOAA OAR Ocean Acidification Program and the NEFSC are supporting climate-related work at these facilities focused on the effect of ocean acidification on the early life stages of fish and molluscs, including biochemical, physiological, behavioral, and ecological responses (Chambers et al. 2014; Stehlik et al. 2015; Meseck et al. 2016). In addition, research is underway collaboratively at other laboratory facilities in the region (e.g., Woods Hole Oceanographic Institution). The effect of temperature on evacuation rates is also being studied (Stehlik et al. 2015); evacuation is a key parameter in calculating consumption, which is critical to multispecies and ecosystem models. The NEFSC has a long history of field-based process studies including the Global Ocean Ecosystem Northwest Atlantic/Georges Bank Program (GLOBEC, Wiebe et al. 2002). These studies differ from monitoring and observing in that they seek to test hypotheses or better understand mechanisms affecting living marine resources. Support for field-based process studies has declined since GLOBEC, and most natural science field work conducted by NOAA Fisheries in the region is dedicated to long-term monitoring. Finally, the NEFSC has a long history of retrospective research: analyzing previously collected data to improve the understanding of the coupled climate-living marine resource-human systems. Retrospective research allows the study of long time scales and large space scales that characterize climate variability and change. Recent studies examining the change in distribution of living marine resources in the Northeast U.S. region represent examples of retrospective research (e.g., Nye et al. 2009; Pinsky et al. 2013; Walsh et al. 2015; Kleisner et al. 2016). Social science retrospective studies related to climate change include Jin et al. (2016) and planned creations of time series based on Colburn et al. (2016), as well as the possibility of exploring fishermen's observations over time. It is important to note that restrospective studies are dependent on other programs to collect data, and thus the Northeast Regional Action Plan also prioritizes the continuation of NOAA Fisheries observing activities in the region (NERAP Action 13) and laboratory studies to better understand the mechanistic effects of climate change on living marine resources (NERAP Action 10).

No New Resources - Continue laboratory experiments at the Sandy Hook and Milford laboratories. These experiments should involve the effects of increasing water temperature, ocean acidification, and decreasing O_2 on key fishery, protected, and aquaculture species that are most susceptible to climate change. The Northeast Fisheries Climate Vulnerability Assessment should be used as one source to prioritize species to study. Other factors include management and assessment priorities and preservation, recreational, and commercial value to the region. Much of this work should focus on ocean acidification owing to funding from the NOAA Ocean Acidification program and on temperature owing to funding from Coastal and Ocean Climate Application Program. Further, the temperature work should address thermal habitat as well as temperature effects on vital rates. However, opportunities to study other climate factors and the synergistic effect among factors should be pursued as well as opportunities to examine interactions between and among species. To continue this research, appropriate staffing should be maintained and planned improvements in the facilities need to be completed. These

improvements include increase in the ocean acidification capacity at Milford, improving seawater quality at Sandy Hook, and creating a closed-system at Sandy Hook to facilitate work at salinities typical in continental shelf waters. Collaborative research with other institutions should also continue and be encouraged (e.g., work at Woods Hole Oceanographic Institution). Collaborative research should also include external researchers working at NEFSC facilities to make additional use of the experimental facilities and to investigate a broader range of species, life stages, and populations (e.g., joint experimental work with Rutgers University at the Sandy Hook Laboratory). Finally, to the extent possible, links need to be made between the experimental work and climate modeling efforts in the region (NERAP Actions 8, 9, and 10). To this end, a workshop would be held in FY17 to bring the experimental groups in the region together, to compare and contrast capabilities and research, and to try to link these groups with retrospective analyses and living marine resource modeling efforts in the region. Research recommendations from stock assessments, as well as from the NEFMC, MAFMC, and ASMFC and other sources will be compiled prior to this workshop to provide a starting point for the workshop discussions.

New Resources - Fund one postdoctoral associate at the Sandy Hook Laboratory and one postdoctoral associate at the Milford Laboratory with a small allowance for supplies and travel to conduct research related to the effect of climate factors on the key fishery, protected, and aquaculture species in the region. Research should be integrated with ongoing activities but represent new approaches, ideas, or biological impacts. This new work should be directly tied to modeling and assessment activities, for example the effect of climate factors in isolation or in combination on a vital rate of fishery, protected, or aquaculture species. Additionally, collaborative work with regional partners would be strongly encouraged.

Objective 6 - Track trends in ecosystems, living marine resources, and living marine resource-dependent human communities and provide early warning of change.

NERAP Action 11 - Develop and implement vulnerability assessments in the Northeast U.S. Shelf Region. [Return to NERAP Action List] [Return to Executive Summary]

Climate change is already affecting fishery resources and the communities that depend on them, and these impacts are expected to increase in the future. To help fishery managers and scientists identify ways to reduce these risks and impacts, NOAA Fisheries, in collaboration with NOAA Oceanic and Atmospheric Research, Earth Systems Research Laboratory, developed a methodology to rapidly assess the vulnerability of U.S. marine stocks to climate change (Morrison et al. 2015). This methodology uses existing information on climate and ocean conditions, species distributions, and life history characteristics to estimate the relative vulnerability of fish stocks and species to potential changes in climate (see NOAA Climate Change Portal). The methodology is based on the general trait-based vulnerability assessment framework (Foden et al. 2013). The methodology was recently implemented in the Northeast U.S. region for 82 species of fish and invertebrates including all federally managed fishery species, many state managed fishery species, and most protected diadromous and marine fish species in the region (Hare et al. 2016). The methodology is being implemented in other regions of the United States as part of the NOAA Fisheries Climate Science Strategy. This Fisheries Climate Vulnerability Assessment has been linked to human communities in the Northeast through the new climate indicators developed for Community Social Vulnerability Indicators

(Colburn et al. 2016). As the Species Vulnerability Assessment is completed in other regions, the Community Social Vulnerability Indicators could be completed in turn.

No New Resources - NOAA Fisheries Office of Science and Technology is leading an effort to adapt the Climate Vulnerability Assessment framework for use with marine mammals and sea turtles. NEFSC and GARFO would continue to contribute to this effort. A social vulnerability assessment has been linked to the fisheries climate vulnerability assessment (Colburn et al. 2016). These interactions should continue, as should the collection of time series data on changes in community resilience and vulnerability, including those for climate change. Finally, the Northeast Fisheries Climate Vulnerability Assessment should be repeated with the next International Panel of Climate Change Assessment Report. Hare et al. (2016) identified several improvements, and progress should be made on these issues. Some of these improvements would be facilitated by other actions identified in this Regional Action Plan (e.g., regional downscaling).

ew Resources - Additional capacity for vulnerability assessments would be added to the NEFSC through the funding of a new federal employee or contractor and support for organizing workshops. This position would be responsible for the adapting the Climate Vulnerability Assessment Methodology for habitats and aquaculture operations and in the Northeast and highly migratory species in the Western Atlantic. The development of these assessments would be coordinated with appropriate national (e.g., Habitat Conservation Office) and regional (e.g., Southeast Fisheries Science Center, Southeast Regional Office) offices, as well as external partners (e.g., members of the aquaculture industry). This additional capacity would also contribute to the support of the specific actions identified above.

NERAP Action 12 - Continue production of the NEFSC Ecosystem Status Report, and other related products, and improve the distribution of information from the reports through the formation of a NEFSC Environmental Data Center. [Return to NERAP Action List] [Return to Executive Summary]

The NEFSC Ecosystem Status Report, Ecosystem Advisories, and State of the Ecosystem reports meet one of the immediate-term actions defined in the NOAA Fisheries Climate Science Strategy. These products provide information on the current and past states of the Northeast U.S. Shelf Ecosystem and are presented via the web: Ecosystem Status Report and Ecosystem Considerations Update. The information in these products is also provided to the NEFMC and MAFMC in State of the Ecosystem reports designed specifically for the Councils. The current NEFSC Ecosystem Status Report consists of 12 sections: (1) Introduction, (2) Climate Forcing, (3) Physical Pressures, (4) Production, (5) Benthic Invertebrates, (6) Fish Communities, (7) Protected Species, (8) Human Dimensions, (9) Ecosystem Services, (10) Stressors and Impacts, (11) Status Determinations, and (12) Synthesis. The report draws on information collected across the NEFSC from oceanographic to social indicators. The information is presented in several management contexts including driver-pressure-state-impact-response model, ecosystem services, and overfishing/overfished. The report also incorporates relevant information from partners including the Environmental Protection Agency Coastal Condition Reports and Audubon Society Project Puffin. Efforts were underway to improve the electronic distribution of data from these reports, but the project ended before full implementation could be achieved (ECO-OP). This effort is similar to efforts underway to increase availability of information and data from the National Climate Assessment.

No New Resources - Continue production of the NEFSC Ecosystem Status Report for a broad range of partners and Annual Ecosystem Reports for the Fishery Management Councils and Atlantic States Marine Fisheries Commission. Improve reports based on input from partners and stakeholders. Work toward steadily increasing the scope of the reports to encompass the entire Northeast U.S. Shelf Ecosystem (watersheds to open ocean) including social and economic indicators and other social science data. Also work to include industry-based data (e.g., eMOLT, observer program, etc.), harvesting related data, and data from coastal and estuarine regions (e.g., Chesapeake Bay Interpretive Buoy System). Continue engagement with the Fisheries Management Councils and reach out to other stakeholders for comment and input. Continue to expand the scope of the NEFSC Ecosystem Status Report including additional Community Social Vulnerability Indicators building off recent community vulnerability assessment. Improve communication on release of reports. Existing and new community social vulnerability indicators (including climate-related) are or would be available at http://www.st.nmfs.noaa.gov/humandimensions/social-indicators/map for easy exploration by the public. Establish an NEFSC Environmental Data Center in the Northeast to inform broad range of climate-related activities (e.g., single species, protected species, habitat, and ecosystems). Efforts to develop an NEFSC Environmental Data Center are underway, but the initial plans are relatively small scale owing to limited resources.

New Resources - Fund a new staff member (federal employee or contractor) to support development of the NEFSC Environmental Data Center, as well as the production of the NEFSC Ecosystem Status report and other related products. The emphasis would be on programming and web development in support of the NEFSC Ecosystem Status Report and climate factors used in assessments. Priority datasets would include those in the NEFSC Ecosystem Status Report and those environmental datasets being used in stock assessments (e.g., Cold Pool Index in the Southern New England Yellowtail Flounder assessment, Miller et al. 2016). The NEFSC Environmental Data Center would focus on derived data products, automating their production, and describing their source and steps in production. The concept is fully transparent development of indicators (Signell et al 2016) and incorporation into assessment and management products. These activities would be completed in cooperation with the Essential Fish Habitat Database also under development by the NEFSC. In addition to the NEFSC Environmental Data Center, efforts would be made to improve the NEFSC Ecosystem Status Report through more stakeholder and partner involvement. The goal is to make the report more useful to living marine resource managers and decision-makers throughout the region and to better integrate with other products and groups with similar goals (e.g., Gulf of Maine Quarterly Outlook, Community Social Vulnerability Indicators). The current report would be made available for public comment, with emphasis on how managers use the information and what improvements could be made. Following the public comment period, several workshops would be held throughout the region in FY18 to overview the report and receive additional input from managers and decision-makers about the content. A work plan for improving the report would then be developed and shared with partners and stakeholders. The new staff member involved with the NEFSC Environmental Data Center would also work with other NEFSC and GARFO staff to implement these changes to the NEFSC Ecosystem Status Report and related products. This work-plan would then be followed for FY19-FY21.

Objective 7 - Build and maintain the science infrastructure needed to fulfill NOAA Fisheries mandates under changing climate conditions.

NERAP Action 13 - Maintain ecosystem survey effort in the Northeast U.S. Shelf ecosystem including the Bottom Trawl Survey, Ecosystem Monitoring Program, Sea Scallop Survey, Northern Shrimp Survey, Clam Survey, and Protected Species Surveys and expand where possible (e.g., data poor species). [Return to NERAP Action List] [Return to Executive Summary]

The NEFSC has a long history of conducting surveys of the Northeast U.S. Shelf ecosystem ranging from chemistry through to marine mammals and seabirds. This effort should be maintained and is fundamental to success of the NOAA Fisheries Climate Science Strategy in the region. The Ship of Opportunity Continuous Plankton Recorder survey was ended in 2013;this was the longest running oceanographic survey in the Northwest Atlantic Ocean, and operations were successfully transferred to the Sir Alister Hardy Foundation for Ocean Science (SAHFOS).

One issue facing the survey programs in the Northeast U.S. region is the strong seasonal nature of the Northeast U.S. Shelf ecosystem. The ability to sample the same parts of the seasonal cycle is critical, as is sampling over the seasonal cycle to capture the seasonal dynamics of the ecosystem.

Another issue facing survey programs in the Northeast is NOAA Fisheries announced a commitment to improve transparency and address stakeholder concerns related to NEFSC surveys by considering and, to the extent possible, transitioning to the use of industry vessels in NEFSC bottom trawl survey work. The intention is to maintain survey protocols, thereby maintaining the ecosystem, climate, habitat, and fishery survey data and time series.

No New Resources - The following surveys should be conducted at pre-2012 levels and supported during the seasonally correct times of year:

- Bottom Trawl Survey – 2 times per year (including Ecosystem Monitoring Program operations)
- Ecosystem Monitoring Program – 4 times per year
- Sea Scallop Survey – 1 time per year
- Northern Shrimp Survey – 1 time per year
- Clam and Ocean Quahog Survey – 1 time per year.

In addition various protected species surveys should be supported (e.g., North Atlantic right whale, sea turtles, Atlantic Marine Assessment Program for Protected Species). To the extent possible, climate, ecosystem, and habitat information should be collected on all surveys, thereby allowing simultaneous environmental and biological data to be collected and used in a number of analyses related to other actions described here in the Regional Action Plan. Continued collection of fishery-dependent data is also critical to living marine resource management, and these data can be used to improve the scientific understanding of the effect of climate change on fisheries in the Northeast U.S. region.

New Resources - Hire a federal employee to facilitate the collection of environmental data on all NEFSC surveys. Environmental data include conductivity-temperature-depth (CDT) operations, Thermo-salinograph measurements, nutrients samples, and carbonate chemistry samples and measurements. Data would be integrated into NEFSC databases and made publically available, including the development of interpreted products, for example

climatologies and anomalies. The new staff member would also contribute expertise to the analyses of environmental data in the context of living marine resource assessments and management. Work with other programs to expand surveys and expand variables collected on surveys. Priority would be given to the NEFSC Longline Survey in the Gulf of Maine and other cooperative research efforts. Priority would also be given to variables and approaches defined during the evaluation of observing activities conducted as part of NERAP Action 14.

NERAP Action 14 – Initiate a Northeast Climate Science Strategy Steering Group (NECSSSG) to coordinate, communicate, facilitate, and report on issues related to climate change and living marine resource management. [Return to NERAP Action List] [Return to Executive Summary]

The NOAA Fisheries Climate Science Strategy presents an ambitious vision for collecting and incorporating climate information into the management of living marine resources. The Regional Action Plan presented here puts forth a plan for the next 5 years for NOAA Fisheries in Northeast Region. The Climate Science Strategy and the Regional Action Plan are integrated and rely on partnerships and collaborations with many other ongoing programs and activities. Given the distributed nature of the effort, there is a need for a Steering Group to track work initiated as part of this Regional Action Plan.

No New Resources - Northeast Climate Science Strategy Steering Group (NECSSSG) should be established to coordinate implementation of the NOAA Fisheries Climate Science Strategy in the Northeast U.S. region. This Northeast Regional Action Plan is the organizing document for the implementation and the NECSSSG would track the implementation. It is important to note that this Regional Action Plan represents the Northeast, inclusive of the region North Carolina to Maine and including the Mid-Atlantic, southern New England, Georges Bank, and the Gulf of Maine. The NECSSSG would be a small group of NOAA Fisheries staff (e.g., GARFO, NEFSC, NCBO, HQ offices). This Steering Group would then work through the existing committees, teams, organizations, partnerships, and activities in the region. Additional internal NMFS coordination would occur through the NEFSC Climate, Ecosystem, Habitat, and Assessment Steering Group, GARFO climate points of contacts, and NOAA Fisheries workshops and committees. Additional NOAA coordination would occur through the North Atlantic Regional Team and direct interactions with the other line offices. Coordination with groups external to NOAA would occur through existing structures (e.g., Northeast Regional Coordinating Committee, direct contact with NEFMC, MAFMC, and ASMFC, Cooperative Institute of the North Atlantic Region, Atlantic Scientific Review Group, Integrated Ocean Observing Systems, the Regional Tribal Operations Committee, and other regional organizations and meetings). If over time, greater coordination and oversight is needed to further climate issues with partners, the NEFSC and GARFO will work to develop Terms of Reference and participant selection criteria to identify participants for an expanded and external NECSSSG.

Communication and partnerships are critical to the success of the Northeast Regional Action Plan. The activities and results of the plan need to be communicated through a variety of mechanisms to a wide range of audiences including scientists, stakeholders, and the wider-public. Additionally, partnerships are necessary to achieve the scientific and management objectives of the plan. Given the already established groups involving numerous stakeholders that are actively discussing and/or involved in climate issues in the region (e.g., NEFMC, MAFMC, ASMFC, Atlantic Scientific Review Group, CINAR and others included in Appendix

F), NMFS will continue to work through these avenues to avoid duplication of effort. A number of workshops are also planned and/or proposed in this plan to increase coordination, communications, and partnerships.

In addition to tracking the implementation of the actions described in the Regional Action Plan and generally working to improve communication and strengthen partnerships, NEFSC and GARFO would undertake the following activities:

- Coordinate with Councils (including their Scientific and Statistical Committees), ASMFC, Take Reduction Teams, Atlantic Scientific Review Group, NMFS HMS and other groups as applicable on the development and evaluation of climate information for living marine resource management. Initial steps involve an evaluation of staffing on Plan Development Teams, Fishery Management Action Teams, and other committee memberships. Additional steps include continue support for EBFM activities for MAFMC, NEFMC, ASMFC, and continue engagement with these partners on climate change issues including presentations and participation in meetings and workshops. Subsequent steps include linking climate-related MSE efforts with management agencies in the region.
- Coordinate with other NOAA-line offices in the region through participating in the North Atlantic Regional Team, NOAA in New England, NOAA Eastern Region Climate Services, and other similar efforts.
- Coordinate with the Northeast Regional Ocean Council and the Mid-Atlantic Regional Council of the Ocean. Both Councils have developed draft ocean plans that are currently being finalized (Northeast Regional Planning Body, Mid-Atlantic Regional Ocean Action Plan).
- Review funding opportunities in the region and work to align opportunities and actions under this plan (e.g., Saltonstall-Kennedy Grant Program, Coastal Ecosystem Resilience Grants Program, NOAA Sea Grant programs).
- Initiate discussion with NEFSC, GARFO, SEFSC, SERO and HQ to identify overlaps and joint issues of interest. This discussion should include current issues and potential future issues related to climate change and cover all NMFS mission activities. Hold a workshop and develop a document that identifies joint issues of interest. Workshop should include representatives from NEFSC, GARFO, SEFSC, SERO, and HQ as well as the East Coast Fishery Management Councils and East Coast Marine Fisheries Commissions.
- Increase interactions with Canadian scientists and managers. Identify and use existing opportunities and develop new avenues for addressing issues of joint concern, including physical, biological, chemical, social and economic impacts of climate change. Initially, the following venues would be targeted for increasing interactions: ICES Working Group on the Northwest Atlantic Regional Sea (WGNARS), other ICES Workings Groups and Steering Groups, and the Canada/USA Transboundary Steering Committee. Other avenues for increasing interaction would be identified during the FY17-FY21 period.
- Develop an outreach strategy for communicating results of NOAA Fisheries Climate Science Strategy implementation in Northeast Region (including New England and the Mid-Atlantic). This strategy would be coordinated with GARFO and NEFSC communications teams. The purpose of the strategy is to improve stakeholder and

public awareness and engagement with NOAA Fisheries activities on climate change in the Northeast U.S. region. Develop and implement a plan for this improvement by using existing personnel and resources to work with stakeholders and the public. Develop stakeholder engagement and communications teams for each region. Improve scientific communication among NOAA Fisheries components in the Northeast.

- Incorporate CEQ's Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions in NEPA documents.
- Support the development of regional meetings (such as Regional Association for Research on the Gulf of Maine and the Maine and the Northeast Coastal Acidification Network) that encourage interactions among scientists and managers in the region. Encourage broad regional NOAA Fisheries participation. Address cutting-edge issues including adaptation strategies, links to management and regulation, and population responses.
- Continue to develop partnerships with tribal governments and meet to discuss climate change issues. Broaden support of GARFO and NEFSC staff for tribal issues.
- Improve partnerships with NOAA Educational Resources Office and other organizations to contribute to national and regional education efforts as they relate to climate change and the NOAA Fisheries mission. Develop internship and education plan for NEFSC and GARFO in combination with the NEFSC Academic Programs Office.
- Support the development of regional town halls and other meetings with fishermen and fishing communities to improve outreach to fishermen and fishing communities regarding impacts of climate change.
- Increase climate literacy among GARFO, NEFSC, and regional NMFS HQ staff to assist in identifying the climate vulnerabilities and needs in all regional programs and mandates. Make staff aware of seminars, lectures, short-courses, and other related opportunities.
- Track and report progress on Action Plan through quarterly teleconferences. Participants include NEFSC Climate, Ecosystem, Habitat, and Assessment Steering Group and GARFO climate points of contact. Develop list of climate and living marine resource related activities in the region. List would include federal and state-level activities. Make GARFO and NEFSC staff aware of climate related funding opportunities. Serve as a clearinghouse to connect scientists and managers interested in climate change in the Northeast U.S. region.
- Continue to improve the accessibility of data and information that is developed by activities under this plan and by activities that contribute to this plan. This is consistent with Executive Order 13642 and NOAA's Plan for Increasing Public Access to Research Results.
- Coordinate activities with other NOAA Fisheries programs and initiatives (see NERAP Action 15)

New Resources – Hire a project manager with scientific experience to staff the NECSSSG. The staff member would assist the NECSSSG to make progress on the activities listed above. In addition, the following list of activities would also be pursued.

- Conduct gap analysis comparing NOAA Trust Resources to regional natural and social science observing capabilities. Identify critical gaps and initiate data collection programs if possible. Focus on NEFSC surveys but also include surveys and observing capabilities of other government entities (e.g., other federal agencies, state agencies), institutions (e.g., universities), and organizations (Regional Integrated Ocean Observing System Associations, nongovernmental organizations).
- Develop regional Ecosystem Observing Plan in collaboration with regional associations (Integrated Ocean Observing Systems) and other long-term observing efforts in the region. Plan should include variety of platforms including ships, moorings, gliders, and autonomous vehicles. Plan should also include the variety of facets of climate change in the region: mean state, variability, extreme events, phenology, etc. Plan should also include the broad array of observing assets in the region: federal, state, local, non-governmental, etc.
- Hold workshops with federally recognized tribes to identify, discuss, and coordinate living marine resource science and management related to climate change.
- Develop framework for dealing with emergent, climate-related NOAA Trust Resource issues including social and economic aspects. Encourage councils to adjust management programs in cases where species are changing their distribution.
- Support NEFMC, MAFMC, and ASMFC inclusion of best available climate information in fishery management decisions.
- Support redesign and expansion of NEFSC Climate Change webpage. Make page more dynamic. Improve links to other components of the science enterprise in the Northeast U.S.region including cooperative research and citizen science opportunities.
- Lead an annual Northeast Climate Change and Living Marine Resource Science and Management Workshop. The workshop will be coordinated with science and management partners in the Northeast. The workshop will cover a range of issues including science, assessment, management, and governance. This could be coupled with ongoing activities such as regional American Fisheries Society meetings, annual Regional IOOS Association meetings, or Fishery Management Council and Fisheries Commission related meetings. The purpose would be to institute a broader conversation regarding the science, assessment, and management of living marine resources in a changing climate.
- Provide partial support for an East Coast Climate Change and Fisheries Governance Workshop every 2-3 years to ensure information is being exchanged among regions on the East Coast. Canada Department of Fisheries and Oceans Canada managers and scientists should be included.
- Develop monthly seminar series with live-broadcasting capabilities.
- Expand regional town hall and other meetings with stakeholders to improve outreach regarding climate change impacts.
- Expand collaborative science to increase fishing industry investment in research and support for its results.
- Expand outreach and collaboration with state agencies. Work with the Atlantic States Marine Fisheries Commission and link NOAA Fisheries efforts with state-based efforts (e.g., Climate Change and Massachusetts).

NERAP Action 15 – Coordinate with other NOAA Programs and partners to link living marine resource science and management to climate science and research activities. [Return to NERAP Action List] [Return to Executive Summary]

Watershed Program for the East Coast - There were a number of draft actions identified related to diadromous species in the Northeast U.S. Shelf (Appendix D). Diadromous species are important in the region for a variety of reasons (e.g., protected species, commercial and recreational harvest, ecosystem interactions): Atlantic salmon, Atlantic sturgeon, shortnose sturgeon, rainbow smelt, alewife, blueback herring, American eel, hickory shad, American shad, striped bass, sea-run brook trout, sea lamprey, white perch, and tom cod. These species are included in the larger group of species considered in many of the actions prioritized here, but there are also a number of specific needs that exceed the scope of the NOAA Fisheries Climate Science Strategy and this Northeast Regional Action Plan. On the West Coast, the Northwest Fisheries Science Center hosts the Watershed Program, which investigates the ecology of freshwater and estuarine ecosystems to assist with the management and recovery of Pacific salmon (*Oncorhynchus* spp.) and other NOAA trust resources. The Program provides technical support to NOAA Fisheries policy makers and regulatory staff, and collaborates with other agencies (e.g., USGS, FWS), tribes, and educational institutions on research and outreach related to the management of Pacific salmon and other diadromous fishes. NOAA Fisheries should consider developing such a program on the East Coast in coordination with Department of the Interior and the Environmental Protection Agency.

Links to NOAA Integrated Ecosystem Assessment Program and Ecosystem-Based Fisheries Management - There is a continued need to develop and implement single-species models, multi-species, and ecosystem models that include species interactions in fisheries and protected species management and fully and appropriately include social and economic data. The EBFM Policy and EBFM Road Map are national level efforts. There also are efforts underway in the NEFSC (Richards and Jacobson 2016; Curti et al. 2013; Link et al. 2010) and throughout the region (Townsend 2014; Fay et al. 2013; Stock et al. 2014, http://www.noaa.gov/iea/). Further, both the MAFMC and NEFMC are working toward Ecosystem-Based Fisheries Management; the NEFSC and GARFO need to continue to support these efforts. These activities are not directly related to the NOAA Fisheries Climate Science Strategy, but the activities conducted under the Regional Action Plan would support and contribute to these efforts. EBFM, as implemented by the FMCs, could alter the management processes in the region, either incrementally or fundamentally, and impacts to the stakeholders and the management and regulatory programs would need careful consideration.

An Ecosystem-based approach allows stressors other than climate change and fishing to be considered in the assessment and management of marine resources. There are a number of other stressors affecting marine resources: eutrophication, hypoxia, chemical contamination, habitat alterations, disease, ocean noise, energy development, dams, etc. Understanding the cumulative effects of these stressors is crucial to EBFM and EBM. Consideration of multiple stressors and cumulative impacts is particularly relevant to meet National Environmental Policy Act mandates (see CEQ Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews).

Links to NOAA Fisheries Habitat Programs - Coordination with Habitat Conservation Division and Restoration Center is required to meet the needs for the Northeast region.

Integration between this Northeast Regional Action Plan and the Habitat Assessment Improvement Plan is also needed. One element is to better understand the response of habitats to climate change including pelagic habitats, benthic habitats, estuarine habitats, and freshwater habitats. A second element is to identify habitats vulnerable to climate change with a particular emphasis on spawning and nursery habitats since early life stages tend to be more vulnerable to climate change than adult stages. Based on the recent climate vulnerability assessment, temperature increases, ocean acidification, sea-level rise, and changes to stream discharge magnitudes and timing should be emphasized. These actions are embedded in NERAP Actions above but also need to be connected to other habitat-related programs in the Northeast U.S. region.

Additionally, coordination among the NEFSC, GARFO, and NOAA Chesapeake Bay Office (NCBO) is needed. NCBO is the lead agency coordinating implementation of efforts in the Chesapeake Bay to meet the recently established Climate Resiliency Goal of the 2014 Chesapeake Bay Agreement. Linkages between the NCBO effort and actions identified in this Northeast Regional Action Plan, include (1) development of a climate resiliency analysis matrix and set of Climate Smart Conservation Framework facilitated workshops to explore adaptive management of tidal and nontidal wetlands; (2) facilitation of a small workshop series to develop an analytical framework for aligning monitoring efforts to support climate change impact and trend analyses and adaptive management for submerged aquatic vegetation, oysters and blue crab; (3) facilitation of a workshop to review global circulation models and other climate scenarios, downscaling techniques, and historical observation data to establish a framework for climate analysis in the watershed modeling and ecological assessments. Work in Chesapeake Bay can also serve as a model for other estuaries in the region.

Links to NOAA Fisheries Office of Aquaculture - Aquaculture is a growing commercial sector in the Northeast U.S. region, and important impacts from climate change have been identified. Aquaculture can also be used in restoration of some endangered species, in enhancement of wild populations, as a mitigation measure to impacts expected from climate change, and to enhance and restore coastal habitats. One example of mitigation is the potential use of culturing and harvesting seaweeds as a carbon dioxide capture mechanism (Trevathan-Tackett et al. 2015). As efforts to promote and support sustainable aquaculture in the Northeast U.S. grow, the need for information on the effects of climate change on aquaculture would also grow. Aquaculture components are integrated with many of the actions identified above, but a number of other aquaculture related needs were identified during the development of the Northeast Regional Action Plan. Research and observations to better understand the effect of climate change on aquaculture operations would require strong partnerships and participation with the aquaculture industry. Some efforts are underway (e.g., Tracking Ocean Alkalinity using New Carbon Measurement Technologies), but further developing these partnerships and collaborations is outside the scope of the Northeast Regional Action and should be an emphasis of the Office of Aquaculture, as well as NEFSC and GARFO. Multiple stressor laboratory and mesocosm experiments to understand the effect of climate change on aquaculture species are partly built into the NERAP Action 10, but the development of a mesocosm capacity with the NEFSC is beyond the scope of the Northeast Regional Action Plan. There are several facilities with the capability to host mesocosms (e.g., University of Rhode Island, Woods Hole Oceanographic Institution, University of Connecticut), and discussions could be initiated to use these facilities in support of NOAA Fisheries Office of Aquaculture and the NMFS Climate Science Strategy. Finally, consideration was given to regionwide benthic surveys in estuaries

stratified by the presence/absence of aquaculture operations to evaluate the impact of aquaculture on habitats and other living marine resources. This action is outside the scope of the NOAA Fisheries Climate Science Strategy, but there is a clear need to understand the interaction between aquaculture and ecosystems in the region.

Links to NOAA Ocean Acidification Program - A number of the actions identified overlap with activities funded by the NOAA Ocean Acidification Program. Specifically, the prioritization of maintaining monitoring capabilities and expanding experimental programs are directly in line with NOAA Ocean Acidification activities at the NEFSC. The development of a large-scale mesocosm capacity was identified as an action during the development of the Northeast Regional Action Plan. As described above in the links to aquaculture section, the development of a mesocosm capacity with the NEFSC is beyond the scope of the Regional Action Plan. However, the NEFSC would reach out to potential partners and assist in identifying potential funding sources. Also, an evaluation of regional progress on NOAA Ocean and Great Lakes Acidification Research Plan was identified as a potential action.

Links to Stock Assessment Improvement Plan - The Marine Fisheries Stock Assessment Improvement Plan (SAIP) presents a plan for enhancing and modernizing NOAA Fisheries programs for data collection, information technology, data management, stock assessments, scientific research, and fisheries management. The SAIP includes specific recommendations for improving the quality of NOAA Fisheries' stock assessment programs and emphasizes the need for the agency to foster partnerships and cooperative research programs with other federal agencies, state agencies, private foundations, universities, commercial and recreational fishing organizations and individuals, environmental groups, and others with a vested interest in collecting similar types of data. The SAIP defines 3 tiers of stock assessments:

Tier 1 - Improve stock assessments by using existing data
Tier 2 - Elevate stock assessments to new national standards of excellence
Tier 3 - Next generation assessments

Tier 3 assessments include those that explicitly incorporate ecosystem considerations such as multispecies interactions and environmental effects, fisheries oceanography, and spatial and seasonal analyses. Thus, the NOAA Fisheries Climate Science Strategy and Northeast Regional Action Plan contribute to the SAIP goals of improving assessments.

Other Actions Identified - Numerous other actions were identified during the development of the Regional Action Plan that were not selected as NERAP Actions for implementation within the next 5 years (e.g., Draft Actions 4, 7, 15, 16, 21, Appendix D). This does not mean that these actions are not important or will not yield important information related to living marine resource management. In many cases, the actions' links to climate change were not as strong as the priority actions chosen. In other cases, actions were more closely affiliated with the mission of another federal agency or predominantly within another region. Finally, some actions, while being important, would require substantial resources to bring the necessary expertise to GARFO and NEFSC. University partners would better serve these actions. We encourage other groups and funding agencies to support these actions, and the NEFSC and GARFO would be willing partners for such activities.

Partnerships

Partnering is critical to the success of the Northeast Regional Action Plan. Effective management of living marine resources in the face of climate change needs to be collaborative and iterative. Partnerships within NOAA, with other federal agencies, federally recognized tribes, states, industry, research institutions, NGOs, funding agencies, and citizen groups are all necessary for this action plan to be successful. Both the NEFSC and GARFO Strategic Plan recognize the importance of collaborative research and management, and these core values apply to this Regional Action Plan as well. NEFSC and GARFO will continue to strengthen existing partnerships and identify potential new partnerships to contribute to the objectives of the NOAA Fisheries Climate Science Strategy. A partial list of partners can be found in Appendix F.

5. PRIORITIES, TIMELINE, AND METRICS

Prioritized list of specific activities identified for 15 NERAP Actions under *No New Resources* and *New Resources*. Priorities under *No New Resources* are listed first, followed by priorities under *New Resources*.

Specific Actions Under the *No New Resources* (NNR) Scenario

Priority	NERAP Action #	Specific Action	FY17				FY18				FY19				FY20				FY21				Metrics
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
1	2	Continue development of models that include enviromental factors																					New models developed to include climate in stock assessments
1	2	Continue development of trawl survey availability metrics																					Survey availaibility approach operationalized
1	2	Discuss climate-stock assessment priorities at CEHASG		M	R						M	R							M	R			Reports completed and distributed
2	13	Maintain Trawl Survey time series																					Trawl surveys completed (2x per year)
2	13	Maintain EcoMon time series																					EcoMon surveys completed (4x per year)
2	13	Maintain Scallop Survey time series																					Scallop survey completed (1x per year)
2	13	Maintain Shrimp Survey time series																					Shrimp survey completed (1x per year)
2	13	Conduct Marine Mammals surveys																					Marine mammal surveys completed
2	13	Conduct Clam surveys																					Clam survey completed
2	13	Maintain fishery dependent data collection programs																					Fishery-dependent data collected
3	1	Climate-related TORs in assessments approved by NRCC					R	Re			F								Rw	Re			TOR reviews and approved by NRCC; used in stock assessments
3	1	Hold workshops re: climate-related TORs in assessments				W	R										W	R					Workshop held and report completed
4	10	Continue lab work at Milford Laboratory (inc OA capabilities)																					Experiments conducted and results published in peer-reviewed literature; OA systems developed and used
4	10	continue lab work at Sandy Hook Laboratory (improve SW, closed system)																					Experiments conducted and results published in peer-reviewed literature; sea water improved; close system developed and used
4	10	Participate in CPO-NMFS funded COCA projects (current projects end FY19)																					NEFSC staff contribute to projects
4	10	Conduct collaborative experiments with others (e.g., WHOI) and use of NEFSC facilities by other researchers (e.g., Rutgers)																					Collaborative projects are completed; external researchers use NEFSC facilities

Key to Acronyms in Timeline	
W	Workshop
R	Report
F	Finalize
Re	Revise
Rw	Review
M	Meeting
NH	New Hire

Specific Actions Under the *No New Resources* (NNR) Scenario

NNR	NERAP Action #	Specific Action	FY17				FY18				FY19				FY20				FY21				Metrics
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
4	10	Workshops to examine links between experiments and assessment models		W	R																		Reports completed and distributed
4	10	Develop database of research recommendations																					Database developed and maintained
5	6	Conduct distribution analyses from other datasets (e.g., tagging, ELS, fishery independent, fishery dependent)																					Distribution analyses completed and published in peer-reviewed literature
5	6	Evaluate changes in distribution for broader set of species (protected species, recreational fisheries, forage fish)																					Distribution analyses completed and published in peer-reviewed literature
5	6	Improve data sharing (EFH Database, EDC, OceanAdpat)																					Data sharing is increased
5	6	Develop species distribution models that include benthic habitat																					Distribution analyses completed and published in peer-reviewed literature
5	6	Develop species distribution models that include predator / prey interactions																					Distribution analyses completed and published in peer-reviewed literature
5	6	Develop species distribution models that include timing of life history events																					Distribution analyses completed and published in peer-reviewed literature
5	6	NART Distribution Workshop FY16	R																				Workshop held and report completed
5	6	Species Moving and Management Workshop						W	R														Workshop held and report completed
5	6	Continue efforts to re-evaluate stock structure on stock-by-stock basis																					Stock structure evaluated prior to assessments
6	12	Continue production of NEFSC Ecosystem Status Report																					ESR produced at ~2 year interval
6	12	Continue production of State of the Ecosystem for NEFMC, MAFMC, and ASMFC																					FMC reports completed annually
6	12	establish Environmental Data Center																					EDC establsihed, used, and expanded
6	12	Develop mechanism for stakeholder contribution to NEFSC Ecosystem Status Report																					Change ESR based on stakeholder input
7	14	Establish Northeast Climate Science Strategy Steering Group			M				M				M				M				M		WG established and meets annually

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Specific Actions Under the *No New Resources* (NNR) Scenario

NNR	NERAP Action #	Specific Action	FY17				FY18				FY19				FY20				FY21				Metrics
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
7	14	Evaluate PDT, FMAT, other committee membership																					Committee membership evaluated and distributed
7	14	Contribute to EBFM activities in the region																					EBFM developments in region continue
7	14	Contribute to MSE to management in region																					MSE developments in region continue
7	14	Coordinate with NART and NOAA ERCS																					Interactions with NART and NOAA ERCS continue
7	14	Coordinate with NRCO and MARCO																					NEFSC and GARFO staff contribute to NROC and MARCO activities
7	14	Identify overlap issues among SEFSC, SERO, NEFSC, GARFO					W	R															Workshop held and report completed; communications increase among entities
7	14	Increase interactions with DFO (e.g., WGNARS, TMGC)																					Communications increase among entities
7	14	Develop outreach strategy for NERAP				F																	Outreach strategy developed and distributed
7	14	Support RARGOM and Mid-Atlantic analog; support NECAN, MACAN																					Meetings supported by NEFSC and GARFO involvement
7	14	Continue tribal engagment																					Interactions with tribes continue
7	14	Strengthen relationships with NOAA Office of Education																					Interactions with Education Office continue
7	14	Develop regional town hall meetings																					Town hall meetings are held and improved via post-meeting surveys
7	14	Increase climate literacy among GARFO, NEFSC																					GARFO and NEFSC increase climate literacy
7	14	Track progress on NERAP																					Progress on NERAP tracked and reported
7	14	Expand collaboration with industry																					Collaborations with industry increased
7	14	Work to make NOAA Fisheries data available																					Data sharing is increased
		Northeast Climate Science Strategy Steering Group continues to make progress on various activities listed under NERAP Action 14																					

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Specific Actions Under the *No New Resources* (NNR) Scenario

NNR	NERAP Action #	Specific Action	FY17				FY18				FY19				FY20				FY21				Metrics
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
8	8	Continue to develop short-term forecasts																					Development of short-term forecasts continues
8	8	Continue links to CPO-NMFS COCA projects																					NEFSC staff contribute to projects
8	8	Continue to develop medium-term forecasts																					Development of medium-term forecasts continues
8	8	Hold workshop to discuss forecasting modeling priorities			W	R																	Workshop held and report completed
9	5	Continue MSE work and integration with NEFSC MSE WG																					MSE developments in region continue
10	11	Repeat NEVA (w/ improvements)																					NEVA is re-done based on next IPCC Assessment Report
11	4	Continue social indicators work (COCA interaction) COCA ends FY19																					NEFSC staff contribute to projects
11	4	Continue economic portfolio work (DePiper)																					NEFSC staff contribute to projects
11	4	Continue discussions on NEPA and climate decisions																					Consider climate change in managements actions per CEQ/NEPA 2016 guidance
11	4	Conduct coastal resilency engagement (GARFO)																					GARFO further considers climate change in coastal resilency
11	4	Provide social scientist support for development of EBFM in Northeast U.S. region																					EBFM developments in region continue
11	4	Conduct literature review of Local Ecological Knowledge																					SSB completes literature review of LEK in Northeast Region
11	4	Conduct Economic and Social Sciences Program Review							W	R													Review completed
12	3	Continue Protected Resources and climate efforts (e.g., North Atlantic right whale, sea turtle, Atlantic salmon, river herring, thorny skate)																					Efforts with climate change and protected species c ontinues
12	3	Participate in Marine Mammal and Sea Turtle Vulnerability Assessment																					Support NMFS S&T lead efforts
12	3	Hold CEHASG Meeting ESA Guidelines and other protected species considerations	W	R																			Workshop held and report completed
12	3	Hold CEHASG Meeting GAMMS & Climate Change					W	R															Workshop held and report completed

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Specific Actions Under the *No New Resources* (NNR) Scenario

NNR	NERAP Action #	Specific Action	FY17				FY18				FY19				FY20				FY21				Metrics
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
13	7	Continue to use Study Fleet and eMOLT data to improve oceanographic and meterological models																					Efforts continue with data collection, archiving, distribution, and use
13	7	Continue Gulf of Maine Longline Survey																					Longline survey completed (1x per year)
13	7	Continue Species Distribution Modeling (Atlantic mackerel, Atlantic herring, river herring)																					SDM efforts continue
13	7	Hold CEHASG Marine Recreational Information Program Meeting			M	R																	Workshop held and report completed
17	15	Hold discussions re: Watershed Program for East Coast																					Discussion with NMFS HQ held
15	15	Strengthen links to NOAA Fisheries IEA program																					Intergration with IEA program continues
14	15	Strengthen links to NOAA Fisheries Habitat programs																					Intergration with Habitat programs continues
19	15	Strengthen links to NOAA Fisheries Aquaculture																					Discussion with NMFS HQ held
16	15	Strengthen links to OA Program																					Intergration with OA Program continues
18	15	Improve coordination between NEFSC and NCBO and GARFO and NCBO																					Intergration with with NCBO continues
18	15	Strengthen links to university partners																					Intergration with university partners continues

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W	Workshop
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Re	Revise
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Specific Actions Under the *New Resources* Scenario

NR	NERAP Action #	Specific Action	FY17				FY18				FY19				FY20				FY21				Metrics
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
1	2	Hold environmental variables in assessment models workshop						W	R														Workshop held and report completed
1	2	Hire FTE to link environment to stock assessment models	NH																				Hiring action completed
2	6	Hire FTE to examine forage fish distributions	NH																				Hiring action completed
2	6	Hire post-doc to support stock ID studies	NH																				Hiring action completed
2	6	Hold stock identification and climate change workshop							W	R													Workshop held and report completed
3	3	Hire post-doc to incorporate climate change factors in ESA and MMPA assessments and decisions	NH																				Hiring action completed
4	10	Hire 2 post-docs to support experimental work at the Milford and Sandy Hook laboratories	NH																				Hiring action completed
5	5	Hire FTE / post-doc to expand MSE work to include climate factors	NH																				Hiring action completed
5	5	Hold adaptive management workshop							W	R													Workshop held and report completed
5	5	Hold adaptive management workshop focused on protected resources											W	R									Workshop held and report completed
6	8	Hire post-docs to contribute to forecasting work	NH																				Hiring action completed
6	8	Improve model provenance																					Model provenance improved
7	12	Hire FTE to support Environmental Data Center	NH																				Hiring action completed
7	12	Hold workshops to discuss regional Ecosystem Reporting FY18					W	W	W	W	R	R											Workshop held and report completed
8	14	Hire FTE to support NECSSSG	NH																				Hiring action completed
8	14	Conduct gap analaysis of NEFSC and GARFO science enterprise and LMRs				R																	Gap analysis completed; report produced
8	14	Develop regional Ecosystem Observing Plan								R													Observing plan developed and completed
8	14	Hold workshop with federally recognized tribes				W	R																Workshop held and report completed
8	14	Develop framework for dealing with emergent climate LMR issues in the region												R									Report completed
8	14	Support NEFMC, MAFMC, and ASMFC inclusion of best available climate information in fishery management decisions																					FMPs revised as needed
8	14	Improve NEFSC climate change page								F													NEFSC climate change webpage updated

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Specific Actions Under the *New Resources* (NNR) Scenario

NR	NERAP Action #	Specific Action	FY17				FY18				FY19				FY20				FY21				Metrics
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
8	14	Hold LMR Management and Climate Change Workshop								W	R			W	R			W	R			W	Workshop held and report completed
8	14	Support East Coast Climate Change and Fisheries Governance workshop						W								W							Workshop supported
8	14	Develop monthly seminar series with webcasting																					Monthly seminars held
8	14	Expand regional town hall meetings																					Regional town hall meetings held
8	14	Expand collaboration with industry																					Collaborations with industry increased
8	14	Expand collaboration and outreach to state agencies																					Collaborations with state agencies increased
8	14	Northeast Climate Science Strategy Steering Group continues to make progress on various activities listed under NERAP Action 14																					Meetings are held and documented and progress is made on NERAP Actions
9	11	Hire FTE to support Vulnerability Assessments	NH																				Hiring action completed
9	11	Conduct or participate in Habitat VA																					Habitat VA completed
9	11	Conduct or participate in HMS VA																					HMS VA completed
9	11	Conduct or participate in VA																					Aquaculture VA completed
10	7	Hire FTE to support Bottom Temperature work as part of cooperative research	NH																				Hiring action completed
11	4	Hire post-doc to support social and economic activities	NH																				Hiring action completed
11	4	Communicate with states and communities related to social and economic activities																					Communications with staes and communities increased
13	13	Hire FTE to support enviornmental observations	NH																				Hiring action completed
13	13	Expand environmental obsevations on surveys																					Climate observations expanded on surveys
18	15	Hold mesocosm capability workshop				W	R																Workshop held and report completed

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6. ACKNOWLEDGEMENTS

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APPENDIX A. NORTHEAST REGIONAL ACTION PLAN WORKING GROUP MEMBERS

NERAP Leadership Group
Jon Hare - NEFSC - Director
Jen Anderson - GARFO - National Environmental Policy Act Program
Diane Borggaard - GARFO - Protected Resources Division
Kevin Friedland - NEFSC - Ecosystem Assessment Program

NERAP Working Group
Peter Burns - GARFO - Sustainable Fisheries Division
Kevin Chu - GARFO - Stakeholder Engagement (Aquaculture)
Trish Clay - NEFSC - Social Sciences Branch
Matt Collins - HQ (at GARFO) - Habitat Restoration Office
Peter Cooper - HQ (at GARFO) - Highly Migratory Species
Paula Fratantoni - NEFSC - Oceanography Branch
Mike Johnson - GARFO - Habitat Conservation Division
John Manderson - NEFSC - Northeast Cooperative Research Program
Lisa Milke - NEFSC - Aquaculture and Enhancement Division
Tim Miller - NEFSC - Population Dynamics Branch
Chris Orphanides - NEFSC - Protected Species Branch
Vince Saba - NEFSC - Ecosystem Assessment Program

APPENDIX B. EXTERNAL AND NOAA PARTNERS CONSULTED IN DRAFT DEVELOPMENT

External Partners
Mid-Atlantic Fishery Management Council Staff
New England Fishery Management Council Staff
Atlantic States Marine Fisheries Commission Staff
Federally Recognized Tribes

NOAA Partners
Dwight Gledhill - NOAA OAR Ocean Acidification Program
Elizabeth Turner - NOAA NOS Center for Sponsored Coastal Ocean Research
Charlie Stock - NOAA OAR Geophysical Fluid Dynamics Laboratory
Michael Alexander - NOAA OAR Earth Systems Research Laboratory
Ben Haskell - NOAA NOS National Marine Sanctuaries
Ellen Mecray - NOAA NCEI Regional Climate Services
Nicole Bartlett - NOAA North Atlantic Regional Team
Bruce Vogt – NOAA Chesapeake Bay Office

APPENDIX C. BACKGROUND DOCUMENTS AND WEBSITES

These documents were identified by the Northeast Regional Action Plan Working Group and used to support the development of the Northeast Regional Action Plan.

Websites and Workshop Reports

- NOAA Climate Change Web Portal
- CINAR Climate Change Workshop
- DOI Tribal Cooperative Landscape Conservation Program
- East Coast Climate Change and Fisheries Governance Workshop
- Fishing Community Resiliency Presentation - Peter Burns at GARFO
- Flood Frequency Estimates for New England River Restoration Projects: Considering Climate Change in Project Design
- GARFO 2013 Climate Change and Management Needs (internal GARFO Coordination Team document developed to support GARFO supervisor and NEFSC meeting)
- Greater Atlantic Regional Fisheries Office Strategic Plan FY 2015-2019 (associated climate change priorities such as community resilience)
- Island Institute Climate Change Workshop Report
- Island Institute Ocean Acidification Panel Report
- Island Institute Preparing for an Uncertain Fishing Future: Bringing communities together with climate and marine scientists to understand predictive capabilities and information needs
- MAFMC Climate Change White Paper
- National Climate Assessment; Northeast Chapter
- NEFSC Climate Science Plan - 2009
- NEFSC Ecosystem Considerations Webpage
- Northeast Fisheries Climate Vulnerability Assessment (will be available soon)
- Northeast Fisheries Science Center Strategic Plan FY 2016-2012
- Proposal for GARFO-WCR Study Group on Fishing Community Resilience (associated with above presentation)
- Protected Resources and Climate Change Workshop Report
- River Herring Climate Workshop and Climate Subgroup Research Needs/Data Gaps
- Understanding Climate Change on Fish Stocks of the Northeast Shelf - JOSS & NMFS
- Union of Concerned Scientists - Confronting Climate Change in the U.S. Northeast
- Gulf of Maine Council State of the Gulf of Maine Report
- Climate Change and Sea Level Rise Projections for Boston: the Boston Research Advisory Group Report.

APPENDIX D. LIST OF NORTHEAST REGIONAL ACTION PLAN DRAFT ACTIONS

Draft actions were initially identified by the Northeast Regional Action Plan Working Group after reviewing the regional strengths, weaknesses, and needs. These draft actions were subsequently reviewed, prioritized, and consolidated into the NERAP Actions identified in the main text of this document. Draft Actions were also mapped to NOAA Mission Areas and NOAA Fisheries Climate Science Strategy Objectives. The average Working Group ranks (3=High, 2=Moderate, 1=Low) and the number of top 10 rankings are also presented.

MSFMCA	Aquaculture	MMPA	ESA	Habitat	Ecosystem	Objective	**Action #**	**DRAFT Action Statement**	**Average Rank**	**Number of Top 10 Identifiers - No New Resources**	**Number of Top 10 Identifiers - New Resources**
x	x	x	x			5	1	Conduct laboratory research to improve biological parameterization in coupled species-climate models. Research should evaluate the effect of climate variables on biological parameters in isolation and in combination (e.g., the effect of temperature on consumption, and the effect of temperature and pH on larval survival).	1.923077	2	3
x	x	x	x			5	2	Conduct laboratory and field-based process research on species to assess behavioral, physiological, ecological and biophysical impacts from climate change (e.g., temperature, ocean acidification and sea level rise) with an emphasis on cumulative impacts, multiple stressors and synergistic interactions.	2.153846	3	4
x	x	x	x			5	3	Conduct research to establish abundance estimates and vital rates (e.g., mortality, population growth) and evaluate climate related changes for data poor species.	1.923077	1	1
				x		5	4	Conduct research on how climate change (e.g., warming, ocean acidification, changes in streamflow) can affect exposure to contaminants in freshwater and estuarine systems.	1.230769	0	0
x	x		x			5	5	Conduct research into climate impacts on watersheds (i.e. rivers, estuaries) that includes field-based studies and regional models. Research includes understanding the interaction of human structures and changes to watersheds to habitat function and connectivity.	1.615385	2	3
x	x		x	x		5	6	Conduct research on the impacts of climate change within the critical transition zone between freshwater and marine environments and assess the affects on NOAA Trust Resources	1.615385	1	2
x	x	x	x			5	7	Conduct research on species' ability to adapt and acclimate to climate change (e.g., evolution, phenotypic plasticity, assisted migration). Reseach should include the ability of habitat to change in response to climate change (e.g., ability of salt marsh to migrate landward with sea-level rise)?	2.230769	3	4
x	x	x	x	x	x	7	8	Increase social and economic scientist involvement in IEAs and climate change research. Most critically through creation of integrated models (e.g., A-CLIM). Efforts should focus on involving social scientists and economists from the beginning rather than as an add-on to a ongoing project.	2.538462	2	1

MSFMCA	Aquaculture	MMPA	ESA	Habitat	Ecosystem	Objective	**Action #**	**DRAFT Action Statement**	**Average Rank**	**Number of Top 10 Identifiers - No New Resources**	**Number of Top 10 Identifiers - New Resources**
x	x			x	x	5	9	Develop large-scale mesocosm capacity to evaluate effects of multiple stressors (e.g., warming, OA) on trust resource species and habitats (e.g., similar to efforts that have been advanced by the european ocean acidification research community). Conduct multistressor studies considering increased pCO2 (decreased Ωarag) combined with one or more other stressors such as temperature, hypoxia, and salinity.	2	0	1
x	x	x	x			5	10	Conduct research on the mechanistic effects of climate on resource species as a means to incorporate climate drivers in historical and projected population models.	2.615385	4	5
x	x			x	x	7	11	Evaluate regional progress on NOAA Ocean and Great Lakes Acidification Research Plan (http://www.pmel.noaa.gov/co2/files/feel3500_without_budget_rfs.pdf). Review ocean acidification monitoring network and work with partners to fill high priority gaps.	1.923077	2	1
x			x		x	5	12	Conduct research on the effects of climate change on food webs of diadromous species. Efforts are needed across life stages.	2	2	4
x		x	x	x	x	5	13	Conduct research on the spatial and temporal distribution and migration of species (including phenology). Coordinate distribution research with Canada as distributions shifts outside of US boundaries and with SEFSC as distributions shift into the Northeast U.S. Shelf ecosystem.	2.538462	4	7
x		x	x	x	x	5	14	Conduct research on climate effects on the distribution of key forage species (e.g., capelin, Atlantic herring, Atlantic menhaden) and the potential effects on all life stages of managed species (e.g., Atlantic salmon, Atlantic cod, striped bass, Atlantic bluefin tuna)	2.461538	5	5
x	x	x	x			5	15	Conduct research on how climate change can change impacts of disease and parasites on resource species on the Northeast U.S. shelf ecosystem	1.615385	1	1
x	x	x	x	x	x	5	16	Conduct research on regime shift effects on NOAA Trust Resources related to thresholds in climate-related variables.	1.846154	0	0

MSFMCA	Aquaculture	MMPA	ESA	Habitat	Ecosystem	Objective	**Action #**	**DRAFT Action Statement**	**Average Rank**	**Number of Top 10 Identifiers - No New Resources**	**Number of Top 10 Identifiers - New Resources**
				x		5	17	Conduct research and observations to better understand the response of habitat to climate change. Evaluate habitat prioirites identified in other documents (e.g., Habitat Assessment Improvement Plan, Fishery Management Plans) relative to climate change.	2.307692	4	3
	x					5	18	Conduct research and observations to better understand the effect of climate change on aquaculture operations. Evaluate aquaculture prioirites identified in other documents (e.g., state plans, NOAA Aquaculture plans) relative to climate change.	1.769231	1	0
x	x	x	x	x	x	5	19	Conduct research on species and ecosystem phenology (e.g., mismatches of altered spawning and migration cues and prey availability, physiological adaptations to altered temperature regimes).	2.461538	3	4
x			x	x		6	20	Conduct long-term surveys focused on habitats not well sampled by standard trawl surveys (e.g., complex rocky reef habitats). Surveys should also address concerns about the catchability of specific species collected during bottom trawl surveys for important groundfish stocks, and enhance data collection for data poor species and species of concern that are specifically associated with these habitats.	2.230769	1	3
			x			6	21	Quantify and monitor sea turtle nesting habitat availability and monitor sea turtle nesting and habitat availability to determine how climate change may affect the size and distribution of nesting beaches. Coordinate with US Fish and Wildlife Service, other federal agencies, and the appropriate state partners to continue to monitor sea turtle nesting numbers.	2	2	1
x		x	x	x	x	7	22	Maintain existing surveys and expand where possible (e.g., data poor species) to provide foundation for temporal and spatial comparisons in climate assessments. Recognize seasonal and interannual variability in the Northeast U.S. Shelf Ecosystem in the design of surveys.	2.769231	5	6
x	x	x	x	x	x	7	23	Conduct gap analysis comparing NOAA Trust Resources to regional observing capabilities. Identify critical gaps and initiate data collection programs if possible.	2.076923	2	1
x	x		x	x	x	7	24	Coordinate research and observing on freshwater and estaurine systems with other federal agencies; continue interagency communication on climate change to understand science, needs, and application of science to needs	1.692308	1	0

MSFMCA	Aquaculture	MMPA	ESA	Habitat	Ecosystem	Objective	**Action #**	**DRAFT Action Statement**	**Average Rank**	**Number of Top 10 Identifiers - No New Resources**	**Number of Top 10 Identifiers - New Resources**
x	x	x	x	x	x	7	25	Develop regional Ecosystem Observing Plan in collaboration with Regional Associations (Integrated Ocean Observing Systems) and other long-term observing efforts in the region. Plan should include variety of platforms including ships, moorings, gliders, and autonomous vehicles.	2.615385	3	3
x	x	x	x	x	x	6	26	Establish an Environmental Data Center in the Northeast to inform broad range of climate-related activities (e.g., single species, protected species, habitat, and ecosystems).	2.076923	1	2
x	x	x	x	x	x	3	27	Continue to build Industry-based ocean observing network including fixed and mobile gear. Support integration of data into ocean forecast models and make data available for ocean hindcast models. Develop real time engagement with the industry via Northeast Cooperative Research Program and other cooperative efforts to collect biological and ocean data to describe the ecosystem.	2.230769	2	3
x	x	x	x	x	x	2	28	Develop Management Strategy Evaluation capability to examine the effect of different management strategies under climate change. Specific issues to be addressed are management strategies for changing productivity and distribution, simulating regime shifts and effects on NOAA trust resources and management strategies, and evaluating climate-informed reference points.	2.230769	4	4
x		x	x		x	1	29	Continue development of multispecies models and use of predator indices in single-species models. Build off of efforts underway in NEFSC and others.	2	3	2
x		x	x			1	30	Give greater emphasis to climate-related Terms of Reference and analyses in stock assessments. Current Terms of Reference language may touch on climate/environmental analyses but there needs to be more comprehensive analysis, and attempts to tie in such analyses within assessment models, instead of current practice of a complementary analysis. Need broad NEFSC participation in stock assessment process to contribute climate, ecosystem (including human communities), and habitat expertise.	2.615385	5	4
x		x	x			1	31	Increase understanding of climate impacts on protected species populations to evaluate and set “allowable” removal levels in a changing climate.	1.846154	0	1
x			x			1	32	Continue development of stock assessment models (e.g., Age Structured Assessment Program, new state-space model) that include environmental terms (e.g., temperature, ocean acidification).	2.769231	6	5

MSFMCA	Aquaculture	MMPA	ESA	Habitat	Ecosystem	Objective	**Action #**	**DRAFT Action Statement**	**Average Rank**	**Number of Top 10 Identifiers - No New Resources**	**Number of Top 10 Identifiers - New Resources**
x	x	x	x			2	33	Develop framework for dealing with emergent climate related NOAA Trust Resource issues including social and economic aspects.	2	2	1
x		x	x			2	34	Review stock structure questions in the Northeast U.S. Shelf Ecosystem related to climate-driven changes in distribution. All managed species should be included. Framework for review should be consistent among stocks.	2.076923	0	0
		x	x			1	35	Incorporate climate factors in marine mammal assessments. Review structure of marine mammal assessments, review potentially relevant climate information, and identify methods to includle climate information in assessments. Work with NMFS HQ and other regions on developing national guidelines.	2.153846	2	1
x	x	x	x	x	x	4	36	Work with NOAA OAR and academic scientists to develop regionally downscaled climate projections that are based on both statistical and dynamical downscaling methods. Develop mechanisms to continue improvement and production of select products.	2.307692	3	4
x	x	x	x	x	x	4	37	Work with NOAA and academic scientists to develop and improve robust regional hindcasts and climatologies. Develop mechanisms to continue improvement and production of select products.	2.307692	2	2
x	x	x	x	x	x	4	38	Work with NOAA and academic scientists to develop short-term (days to months) and medium-term (months to years) forecasting products. Incorporate forecasts into NOAA Fisheries products (e.g., assessments, bycatch avoidance, short-term outlooks).	2.153846	4	3
x	x		x	x	x	4	39	Work with USGS, EPA, and NOAA to develop coupled watershed - ocean climate projections for the region for simulating and projecting aspects of freswater habitats.	1.615385	1	1
				x		2	40	Incorporate coupled climate-species models in habitat considerations for assessments and other products related to MSA, MMPA, and ESA. These efforts should incorporate Local Ecological Knowledge if possible.	2.384615	2	2

MSFMCA	Aquaculture	MMPA	ESA	Habitat	Ecosystem	Objective	**Action #**	**DRAFT Action Statement**	**Average Rank**	**Number of Top 10 Identifiers - No New Resources**	**Number of Top 10 Identifiers - New Resources**
	x					5	41	Conduct multiple stressor laboratory and mesocosm experiments to understand the effect of climate change on aquaculture species.	1.692308	1	1
	x			x		6	42	Conduct regionwide benthic surveys in estuaries where aquaculture is taking place and where it is not to assess how susceptible these habitats are to climate change.	1.461538	0	0
x	x	x	x	x	x	2	43	Continue to expand and develop community social and climate vulnerability indicators to more fully assess marine and coastal climate change impacts on fishing communities.	2.461538	1	3
		x	x			6	44	Develop and implement a climate vulnerability assessment for marine mammals and sea turtles. A national effort is already underway, and NEFSC and GARFO should continue their support.	2.230769	1	1
x			x			6	45	Develop and implement a climate vulnerability assessment for highly migratory species. Work with NMFS HQ and SEFSC to ensure coastwide and national coordination.	2.076923	1	1
x	x		x			6	46	Update fish and shellfish vulnerability assessment. Plan an update with the next International Panel on Climate Change (e.g., Assement Report 6). Make improvements in vulnerability assessment framework in the Northeast including use of downscaled climate models, updated species profiles, updated exposure factors and sensitivity attributes, including climate model uncertainty, including different RCPs, and including a broader set of stakeholders in the assessment.	2.076923	3	2
				x		6	47	Develop and implement a climate vulnerability assessment for habitat in the Northeast U.S. Shelf Ecosystem. Work with NMFS HQ to ensure coastwide and national coordination.	1.923077	1	2
	x					6	48	Develop and implement a climate vulnerability assessment for aquaculture in the Northeast U.S. Shelf Ecosystem. Work with NMFS HQ to ensure coastwide and national coordination.	1.769231	1	0

MSFMCA	Aquaculture	MMPA	ESA	Habitat	Ecosystem	Objective	**Action #**	**DRAFT Action Statement**	**Average Rank**	**Number of Top 10 Identifiers - No New Resources**	**Number of Top 10 Identifiers - New Resources**
				x		6	49	Identify climate vulnerable and climate resiliant spawning and nursery habitats for fish and invertebrates in the ecosystem based on mutlitdecadal climate projections.	2.076923	1	2
x			x	x		2	50	Continue restoration efforts for diadromous species. Examples of activities include involve GARFO and NEFSC in prioritization of restoration activities. Establish an entity like the Watershed Program at the Northwest Fisheries Science Center. Form Technical Working Groups for diadromous species similar to the River Herring Technical Expert Working Group.	1.923077	1	1
x	x	x	x	x	x	6	51	Continue production of Ecosystem Status Report for a broad range of partners and Annual Ecosystem Reports for the Fishery Management Councils and Atlantic States Marine Fisheries Commission. Improve reports based on input from partners and stakeholders. Improve communication on release of reports. Work toward steadily increasing the scope of the reports to encompass the entire Northeast U.S. Shelf Ecosystem (watersheds to open ocean) including social and economic indicators.	2.384615	3	3
x	x	x	x	x	x	3	52	Coordinate with NEFMC, MAFMC, and ASMFC Ecosystem-Based Fisheries Management activities particularly related to species interactions. Ensure Councils consider broad approach to species interactions including protected species, nontarget species, and highly migratory species.	2.230769	2	1
x	x	x	x	x	x	3	53	Increase interactions with Canadian scientists and managers. Identify and use existing opportunities and develop new venues for addressing issues of joint concern, including physical, biological, social, and economic impacts of climate change. (This is already in process with the MSEs being created for WGNARS.)	2	0	0
x	x	x	x	x	x	3	54	Coordinate with Councils, ASMFC, Scientific and Statistical Committees, Take-reduction Teams, Atlantic Scientific Review Group, NMFS HMS, and other groups as applicable on the development and evaluation of adaptive management in response to climate change (e.g., warming, sea-level rise, ocean acidification). This includes stakeholder involvement to help define the most important steps and potential solutions. As an example, work with fisheries managers to evaluate a suite of spatial allocation schemes .	2.615385	5	3

MSFMCA	Aquaculture	MMPA	ESA	Habitat	Ecosystem	Objective	**Action #**	**DRAFT Action Statement**	**Average Rank**	**Number of Top 10 Identifiers - No New Resources**	**Number of Top 10 Identifiers - New Resources**
x	x	x	x	x	x	7	55	Develop outreach strategy for communicating results of NOAA Fisheries Climate Science Strategy implementation in Northeast Region (including New England and the Mid-Atlantic Region).	1.846154	1	0
x	x	x	x	x	x	7	56	Improve stakeholder and public awareness and engagement with NMFS activities on climate change including physical, biological, social and economic information	2.307692	4	3
x	x	x	x	x	x	7	57	Support the development of regional meetings (such as Regional Association for Research on the Gulf of Maine) that encourage interactions among scientists and managers in the region. Encourage broad regional NMFS participation.	2.153846	2	2
x	x	x	x	x	x	3	58	Continue to develop partnerships with tribal governments and meet to discuss climate change issues. Broaden involvement of GARFO and NEFSC staff.	1.461538	1	0
x	x	x	x	x	x	3	59	Initiate discussion with NEFSC, GARFO, SEFSC, SER and HQ to identify overlaps and joint issues of interest. This discussion should include current issues and potential future issues related to climate change and cover all NMFS mission activities.	2	2	1
x	x	x	x	x	x	7	60	Improve partnerships with NOAA Educational Resources Office and other organizations to contribute to national and regional eduaction efforts as they relate to climate change and the NOAA Fisheries Mission.	1.692308	0	0
x	x	x	x	x	x	7	61	Provide training to increase climate literacy among GARFO, NEFSC and regional NMFS HQ staff to assist in identifying the climate vulnerabilities and needs in all regional programs and mandates.	1.769231	2	0
x	x	x	x	x	x	7	62	Develop NE Climate Science Strategy Working Group that include NEFSC, GARFO, NOAA OAR, regional NMFS HQ, and other federal and non-federal partners to review and communicate on climate-related actvities in the region. Compile a list of climate-related groups/committees, as well as activities (e.g., workshops), in the Northeast (i.e., region-specific social network analysis). Purpose is to keep track of different activities and assist in making connections among different activities.	2.153846	3	3
x	x	x	x	x	x	2	63	Conduct research and share information on climate change mitigation (e.g., helping species adapt through fish-friendly culvert crossings) and climate change adaptation (e.g., working with fishing communities). Work with other governmnet agencies, research instiututions, and community groups where appropriate.	1.769231	2	2

APPENDIX E. NOAA FISHERIES CLIMATE SCIENCE STRATEGY ACTIONS

The NERAP Actions for preserving Living Marine Resources (LMR) defined in the Northeast Regional Action Plan are cross-referenced to the immediate, near term (6-24 months), and medium term (2-5 years) categories defined in the NOAA Fisheries Climate Science Strategy.

	Climate Science Strategy Actions	NERAP Action
Immediate actions	1. Conduct climate vulnerability analyses in each region for all LMRs to better understand what is at risk and why.	11
	2. Establish and strengthen ecosystem indicators and status reports in all regions to better track, prepare for, and respond to climate-driven changes.	12
		7
		13
	3. Develop capacity to conduct management strategy evaluations regarding climate change impacts on management targets, priorities, and goals.	5
Near-term actions	1. Strengthen climate-related science capacity regionally and nationally to fulfill NOAA Fisheries information requirements in a changing climate.	2
		6
		7
		4
		3
	2. Develop RAPs to customize and execute this Strategy in each region over the next 3 to 5 years, through NOAA Fisheries regional Science Centers, Regional Offices and many partners.	This document
		14
	3. Ensure that adequate resources are dedicated to climate-related, process-oriented research to better understand how climate impacts LMRs, how to reduce impacts and how to increase resilience of LMRs, and LMR-dependent communities.	10
	4. Establish standard, climate-smart terms of reference to apply to all of NOAA Fisheries LMR management, environmental compliance requirements, and other processes that cross multiple mandates and core policy areas.	1

	Climate Science Strategy Actions	NERAP Action
Medium-term Actions	1. Establish regular, NOAA-wide, national, climate-science workshops with LMR emphasis, with a focus on climate-ready BRPs and science for setting Harvest Control Rules, ESA evaluations (section 7 and section 10), essential fish habitat consultations, aquaculture, and NEPA analyses in a changing climate.	National
	2. Increase awareness of and training for NOAA Fisheries science and management staff on the impacts of climate change on LMRs and climate-informed LMR management practices.	14
	3. Organize and conduct regime-shift detection workshops for each region.	Underway
	4. Organize and conduct distribution shift workshops, with implications for stock and population identification and unit area across all LMRs in each region.	6
	5. Organize and conduct vital rate workshops, with implications for LMR life-history parameters across all LMRs in each region.	10 13
	6. Organize and conduct workshops aimed at identifying regional data gaps (biological, physical, and socio-economic) related to climate variability and change and devising data collection programs aimed at filling those gaps, especially socio-economic gaps.	4 13
	7. Develop and execute national and regional science communication plans for increasing dissemination of climate-related LMR science and information to technical users and other interested stakeholder audiences.	13; National
	8. Expand and support engagement with international partners to advance the production, delivery, and use of climate-related information (e.g., Climate-LMR related workshops, symposia, meetings, etc.) with specific focus on climate-informed biological reference points, climate-smart Harvest Control Rules, management strategy evaluations for climate-ready LMR management (including species and habitat recovery) and, climate-smart protected species and habitat consultations.	13; National
	9. Continue and expand NOAA Fisheries participation in cross-governmental, national efforts to advance climate-related science.	National
	10. Work with partners to re-evaluate risk policies under changing climate and ocean conditions.	5
	11. Establish science-based approaches for shifting biological reference points to account for changing productivities, distributions, and diversities.	2
	12. Conduct management strategy evaluations on climate scenarios in extant ecosystem and population models in conjunction with the NOAA IEA program, NOAA Fisheries Stock Assessment Improvement Plan Update/Next Generation Stock Assessment, NOAA Fisheries Protected Resources Stock Assessment Improvement Plan, and development of ESA Five-Year Status Reviews.	5

	Climate Science Strategy Actions	NERAP Action
Medium-term Actions	13. Establish science-based thresholds for exiting and entering fisheries.	5
	14. Establish and implement clear policies and practices for incorporating climate change into all NEPA and ESA (i.e., listing, recovery planning, interagency consultations, and permitting) activities.	3
	15. Establish and implement standards and guidelines for incorporating climate change information into Fisheries Management Plans and Fisheries Ecosystem Plans.	1
	16. Develop and implement standards and practices to promote climate resilience and climate mitigation in NOAA Fisheries habitat conservation activities.	11
	17. Develop climate-driven regional ocean models for use in projecting climate impacts on LMRs.	8
	18. Develop a national inventory of key science and information gaps related to NOAA Fisheries LMR and socio-economic responsibilities, building on regional data/information gap assessments.	4
	19. Increase support for existing programs addressing priority needs and objectives identified in this Strategy (e.g., Fisheries Oceanography, FATE, and IEAs).	National
	20. Establish common climate-smart input data vectors/matrices for inclusion in LMR assessments in conjunction with NOAA Fisheries Stock Assessment Improvement Plan Update/Next Generation Stock Assessment and Protected Resources Stock Assessment Improvement Plan, and development of ESA Five-Year Status Reviews.	National
	21. Identify and support process research linking changing climate and ocean conditions to LMR dynamics.	10
	22. Identify and maintain capability to execute oceanographic cruises for climate-smart observations and process research.	13
	23. Increase capability to undertake climate-smart, socio-economic research projects and analyses of human uses of LMRs and their ecosystems.	4
	24. Develop climate-resilient and climate-mitigating aquaculture strategies	11

APPENDIX F. PARTIAL LIST OF REGIONAL PARTNERS

The below includes examples of regional partners including federal, state, academic, industry, and nongovernment organizations.

NOAA Fisheries Northeast Fisheries Science Center
NOAA Fisheries Greater Atlantic Regional Fishery Office
NOAA Chesapeake Bay Office
NOAA North Atlantic Regional Team
NOAA Fisheries Headquarters (e.g., Office of Protected Resources, Office of Sustainable Fisheries, Atlantic Highly Migratory Species, Office of Science and Technology)
NOAA Fisheries Southeast Fisheries Science Center
NOAA Fisheries Southeast Regional Office
NOAA Research Geophysical Fluid Dynamics Laboratory
NOAA Research Earth Systems Research Laboratory
NOAA Research Climate Program Office
NOAA Ocean Explorer
NOAA Sea Grant (state specific programs listed below)
NOAA Fisheries Sea Grant Fellowship
NOAA National Estuarine Research Reserve System
NOAA National Marine Sanctuaries
NOAA Satellite and Information Service
NOAA National Oceanographic Data Center
NOAA National Weather Service
NOAA Weather Northeast River Forecast Center
NOAA Weather Mid-Atlantic River Forecast Center
NOAA Office of Aquaculture
NOAA Integrated Ecosystem Assessment Program
NOAA Ocean Acidification Program
NOAA Northeast Regional Climate Center
NOAA Regional Climate Services, Eastern Region
DOI Northeast Climate Science Center (University of Massachusetts)
DOI Southeast Climate Science Centers (North Carolina State University)
Environmental Protection Agency (EPA)
EPA Region 1
EPA Region 2
EPA Region 3
EPA Atlantic Ecology Division Laboratory
U.S. Army Corp of Engineers North Atlantic Division
U.S. Fish and Wildlife Service
United States Geological Survey (USGS)

USGS New England Water Science Center
USGS Water Science Center for Maryland, Delaware, and District of Columbia
Marine Mammal Commission
Regional Tribal Operations Committee
Ocean Observatories Initiative
NSF Ocean Sciences
Northeast Regional Ocean Council
Mid-Atlantic Regional Council on the Ocean
Northeast Regional Association Coastal Ocean Observing System
Mid-Atlantic Regional Association Coastal Ocean Observing System
Gulf of Maine Council on the Marine Environment
North Carolina Division of Marine Fisheries
North Carolina Sea Grant
Virginia Marine Resources Commission
Virginia Sea Grant
Maryland Department of Natural Resources
Maryland Sea Grant
Delaware Department of Natural Resources and Environmental Control
Delaware Sea Grant
Pennsylvania Fish and Boat Commission
Pennsylvania Sea Grant
State of New Jersey Department of Environmental Protection
New Jersey Sea Grant Consortium
New York State Department of Environmental Conservation
New York Sea Grant
Vermont Fish and Wildlife
Lake Champlain Sea Grant
Connecticut Department of Energy and Environmental Protection
Connecticut Sea Grant
Rhode Island Department of Environmental Management
Rhode Island Sea Grant
Massachusetts Division of Ecological Restoration
Massachusetts Division of Marine Fisheries
Woods Hole Sea Grant
MIT Sea Grant
New Hampshire Fish and Game Department
New Hampshire Sea Grant
Maine Department of Marine Resources
Maine Sea Grant
Mid-Atlantic Fishery Management Council

New England Fishery Management Council
Atlantic States Marine Fisheries Commission
Atlantic Scientific Review Group
NOAA Cooperative Institute of the North Atlantic Region
NOAA Cooperative Institute for Climate Science
NOAA Cooperative Institute for Climate and Satellites
NOAA Living Marine Resources Cooperative Science Center
Fisheries and Oceans, Canada
Transboundary Resource Assessment Committee
Transboundary Management Guidance Committee
International Council for the Exploration of the Sea
North Pacific Marine Science Organization

Industry* (e.g., captains, boat owners, dealers, processors, sectors, associations, recreational, commercial)
Northeast Seafood Coalition
Seafreeze, Ltd
The Town Dock

NGOs*
The Nature Conservancy
Environmental Defense Fund
Natural Resource Defense Council
Pew Charitable Trusts

* - examples based on groups that commented on the Draft Northeast Regional Action Plan

APPENDIX G. NORTHEAST REGIONAL ACTION PLAN ACTION ITEM TABLE

Action Name	Funding Scenario (Level or Increase)	Time Frame	Action Description	Tentative point of contact	Partners	Other Objectives Addressed (1 – 7)
Objective 1 – Climate Informed Reference Points						
Climate Terms of Reference	Level / Increase	2017-2021	NERAP Action 1 - Give greater emphasis to climate-related Terms of Reference and analyses in stock assessments.	Jim Weinberg	MAFMC, NEFMC, ASMFC	
Climate-explicit stock assessment models	Level / Increase	2017-2021	NERAP Action 2 - Continue development of stock assessment models that include environmental terms (e.g., temperature, ocean acidification).	Tim Miller	CINAR, academic institutions, NOAA Fisheries SF and S&T	
Climate informed protected species management	Level / Increase	2017-2021	NERAP Action 3 - Develop climate- related products and decision support tools to support protected species assessments and other management actions.	Sean Hayes / Diane Borggaard	NOAA Fisheries PR, Atlantic Scientific Review Group, CINAR, academic institutions, SEFSC, SERO	
Objective 2 – Robust Management Strategies						
Social and Economic Research	Level / Increase	2017-2021	NERAP Action 4 - Increase social and economic scientist involvement in climate change research through multidisciplinary work on climate that includes both social and natural sciences.	Trish Clay	CINAR, academic institutions, NOAA Fisheries SF	
Management Strategy Evaluations	Level / Increase	2017-2021	NERAP Action 5 - Develop Management Strategy Evaluation capability to examine the effect of different management strategies under climate change.	Sarah Gaichas	NOAA Fisheries ST, CINAR, academic institutions	

Objective 3 – Adaptive Management Processes						
Distributions and Spatial Management	Level / Increase	2017-2021	NERAP Action 6 - Improve spatial management of living marine resources through an increased understanding of spatial and temporal distributions, migration, and phenology.	Jon Hare	SEFSC, DFO, ASMFC, MAFMC, NEFMC, CINAR, academic institutions	
Cooperative Research	Level / Increase	2017-2021	NERAP Action 7 - Continue to build industry-based fisheries and ocean observing capabilities and use information to develop more adaptive management.	John Hoey	Industry, IOOS, NEFMC, MAFMC, ASMFC	
Objective 4 – Project Future Conditions						
Apply climate forecasts and projections	Level / Increase	2017-2021	NERAP Action 8 - Work with NOAA Oceanic and Atmospheric Research and academic scientists to develop short-term (day to year) and medium-term (year to decade) living marine resource forecasting products.	Vince Saba	GFDL, ESRL, CINAR, academic institutions	
Improve hindcasts and climatologies	Level / Increase	2017-2021	NERAP Action 9 - Work with NOAA Oceanic and Atmospheric Research and academic scientists to develop and improve robust regional hindcasts and climatologies.	Jon Hare	GFDL, ESRL, CINAR, academic institutions	
Objective 5 – Understand the Mechanisms of Change						
CINAR, academic institutions	Level / Increase	2017-2021	NERAP Action 10 - Conduct research on the mechanistic effects of multiple climate factors on living marine resources with a goal of improving assessments and scientific advice provided to managers.	Tom Noji	NOAA OA Program, CINAR, academic institutions	
CINAR, academic institutions						
Vulnerability Assessments	Level / Increase	2017-2021	NERAP Action 11 - Develop and implement vulnerability assessments in the Northeast U.S. Shelf Region.	Jon Hare	CINAR, academic institutions,	

					NOAA Fisheries HMS, NOAA Fisheries ST	
Track Ecosystem Conditions	Level / Increase	2017-2021	NERAP Action 12 - Continue production of the NEFSC Ecosystem Status Report and other related products and improve the distribution of information from the reports through the formation of an NEFSC Environmental Data Center.	Kevin Friedland	CINAR, academic institutions	
Objective 7 – Science Infrastructure to Deliver Actionable Information						
Maintain NEFSC Surveys	Level / Increase	2017-2021	NERAP Action 13 – Maintain ecosystem survey effort in the Northeast U.S. Shelf ecosystem including the Bottom Trawl Survey, Ecosystem Monitoring Program, Sea Scallop Survey, Northern Shrimp Survey, Clam Survey, and Protected Species Surveys and expand where possible (e.g., data poor species).	Jon Hare	IOOS, OOI,	
Northeast Climate Science Strategy Working Group	Level / Increase	2017-2021	NERAP Action 14 – Initiate a Northeast Climate Science Strategy Steering Group (NECSSSG) to coordinate, communicate, facilitate, and report on issues related to climate change and living marine resource management.	Jon Hare	Internal	
Coordinate with Other Programs	Level / Increase	2017-2012	NERAP Action 15 – Coordinate with other NOAA Programs and partners to link living marine resource science and management to climate science and research activities	Jon Hare	HAIP, Aquaculture, Watershed Program, IEA Program, NOAA OA Program	

APPENDIX H. COASTAL AND OCEAN CLIMATE APPLICATIONS PROJECTS

In partnership with the National Marine Fisheries Service (NMFS) Office of Science and Technology, NOAA Research Climate Program Office's Coastal and Ocean Climate Applications (COCA) program initiated a new program: Sustainable management and resilience of U.S. fisheries in a changing climate: a collaboration between NOAA Research and NOAA Fisheries. The following text is largely taken from a NOAA Climate Program Press Release. Seven projects were competitive awarded in FY 2015 and focused on increasing the understanding of climate-related impacts on fish stocks and fisheries. The roughly $5 million in grants cover a 2-3-year time period.

Resilient and sustainable fisheries provide an important source of jobs, food, recreation, and economic activity for the nation. In 2013, U.S. marine commercial and recreational fisheries contributed $195 billion in sales impacts and provided 1.7 million jobs.

Warming oceans, rising seas, ocean acidification, and hypoxia are impacting America's marine life and the many people, businesses, communities, and economies that depend on them. Climate-related impacts can affect the abundance, distribution, and productivity of fish stocks. Fishermen, seafood processors, fishery managers, and other decision makers need more information on current and future changes to better prepare and respond to changing climate.

To address these issues, a collaboration between NOAA Research (Office of Oceanic and Atmospheric Research) and NOAA Fisheries (National Marine Fisheries Service) has been developed to advance understanding of current and future climate-related impacts on living marine resources and the communities that depend on them. The goal is to inform sustainable management and resilience of the nation's fisheries in a changing climate.

Six projects support research to understand and respond to climate impacts on fish and fisheries in the Northeast U.S. Shelf Ecosystem.

1. Gulf of Maine Research Institute (GMRI): Evaluating Social-Ecological Vulnerability and Climate Adaptation Strategies for Northeast U.S. Fishing Communities

   Lead Principal Investigator (PI): Katherine Mills (Gulf of Maine Research Institute),

   Co-PIs: Jenny Sun (GMRI), Steve Eayrs (GMRI), Jonathan Labaree (GMRI), Troy Hartley (Virginia Institute of Marine Science), Jon Hare (Northeast Fisheries Science Center, Director), Lisa Colburn (Northeast Fisheries Science Center, Narragansett Laboratory), Eric Thunberg (NOAA Fisheries)

2. University of Rhode Island: Robust harvest strategies for responding to climate induced changes in fish productivity

   Lead Principal Investigator (PI): Jeremy Collie (University of Rhode Island)

Co-PIs: Jon Hare (Northeast Fisheries Science Center, Director), Richard Bell (Northeast Fisheries Science Center, Narragansett Laboratory), David Richardson (Northeast Fisheries Science Center, Narragansett Laboratory)

3. Mid-Atlantic Fishery Management Council: Climate velocity over the 21st century and its implications for fisheries management in the Northeast U.S. region

   Lead Principal Investigator (PI): Malin Pinsky (Rutgers University)
   Co-PI: Richard Seagraves (Mid-Atlantic Fishery Management Council)

4. Rutgers University and NOAA Earth Systems Research Laboratory: A high-resolution physical-biological study of the Northeast U.S. shelf: Past variability and future change

   Lead Principal Investigators (PI): Enrique Curchitser (Rutgers University), Michael Alexander (Earth Systems Research Laboratory)
   Co-PI: Charles Stock (Geophysical Fluid Dynamics Laboratory)

5. Rutgers University, NOAA Northeast Fisheries Science Center, University of Delaware - MARACOOS, and University of Rhode Island: Indicators of habitat change affecting three key commercial species of the U.S. Northeast Shelf: A design to facilitate proactive management in the face of climate change

Lead Principal Investigators (PI): Brad Seibel (University of Rhode Island), Vincent Saba (NOAA Northeast Fisheries Science Center), Peter Moore (University of Delaware - MARACOOS), Grace Saba (Rutgers University)

6. Northeastern University: Predicting social impacts of climate change in fisheries

   Lead Principal Investigator (PI): Steven Scyphers (Northeastern University)
   CO-PIs: Jonathan Grabowski (Northeastern University), Steven Gray (Michigan State University), Loren McClenachan (Colby College), J. Lad Akins (Reef Environmental Education Foundation), Pamela Schofield (United States Geological Survey)

7. NOAA Southwest Fisheries Science Center (SWFSC): Ecosystem Tipping Points in The North Pacific: Identifying Thresholds in Response to Climate Change and Potential Management Strategies.

   Lead Principal Investigators (PI): Francisco Werner (NOAA SWFSC) and Robert Webb

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