Northeast Regional Action Plan - NOAA Fisheries Climate Science Strategy

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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, habitats, and other ecosystem components - are being impacted by climate change and multi-decadal climate variability. In fact, the pace of observed climate change in the Northeast U.S. is faster than in many of the other U.S. Large Marine Ecosystems, and future change in the Northeast U.S. Shelf ecosystem is projected to be greater than 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 management and regulation are 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: moving into the region and increasing in productivity. Technology offers new tools for observing, understanding, and adapting to change. The region has an excellent marine science infrastructure. On the national scale, 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. This document represents the Northeast U.S. Regional Action Plan for implementing the NOAA Fisheries Climate Science Strategy. The Northeast U.S. Shelf Ecosystem extends from North Carolina to Maine, and includes watersheds, estuaries, the continental shelf and the open ocean. Fourteen actions are identified, and the activities to be undertaken over the next three-to-five years are described.

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 change on living marine resources, and increase the resilience of the ecosystem to change, including people, businesses and communities.

2. INTRODUCTION

The NOAA Fisheries Climate Science Strategy seeks to increase the production, delivery, and use of the climate-related information required to fulfill 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 (ACFCM); 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: 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; and Executive Order 13653 Preparing the United States for the Impacts of Climate Change.

In general, these mandates are intended to instruct and support the National Marine Fisheries Service (NOAA Fisheries) to work in five thematic areas: fisheries, protected species[1], aquaculture, habitats, and ecosystems. NOAA Fisheries primarily focuses on fisheries in federal waters, that being generally three miles from the coast to the 200 mile extent of the Economic Exclusive Zone. 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. Exclusive Economic Exclusion Zone (EEZ) into other national jurisdictions or international waters. Moreover, the MSA requires taking into account 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). 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 and NOAA is in the position to integrate science and management across this Large Marine Ecosystem.

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 seven interdependent objectives with the goal to inform and fulfill NOAA Fisheries mandates in a changing climate (Figure 1). The Strategy also identifies four near-term actions, one 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. This document, the Northeast Regional Action Plan, addresses this near-term action. The Region covered is the Northeast U.S. Shelf Ecosystem, which extends from Cape Hatteras, North Carolina to the western end of the Scotian Shelf and includes the

[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.

Mid-Atlantic Bight, Southern New England, Georges Bank, and the Gulf of Maine. Regional Action Plans are intended to: 1) identify strengths, weaknesses, priority needs and actions to implement the seven NCSS Objectives in each region over the next five 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.

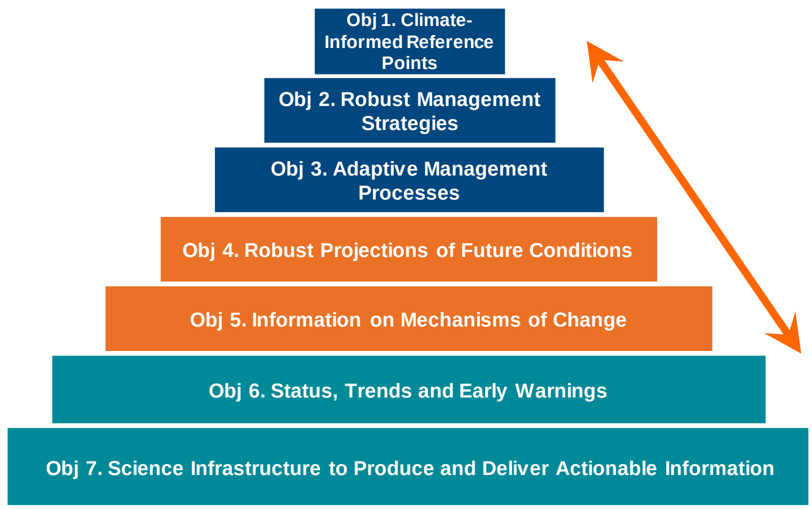

Figure 1. The NOAA Fisheries Climate Science Strategy is organized around the seven priority science objectives

The Northeast Regional Action Plan has three sections. The first section - Regional Assessment - describes the process used to develop the Regional Action Plan. This section starts with a summary of the effect 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 are described and prioritized for the region based on the assessment of strengths and weaknesses and relative to the seven objectives of the NOAA Fisheries Climate Science Strategy. The second section - Action Plan - provides more detailed information for the High Priority needs. Specific actions under a budget neutral (*No New Resources*) and budget increase (*New Resources)* scenario are described. The third section - Timeline and Metrics - presents a plan for managing actions under the Regional Action Plan and for evaluating success.

3. REGIONAL ASSESSMENT

DEVELOPOMENT 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 (NERAPWG). NERAPWG is representative of the different components of NEFSC and GARFO, as well as other NOAA Fisheries Offices in the Northeast Region (see Appendix 1). Two NEFSC and two GARFO staff members formed a smaller leadership group from the NERAPWG (see

Appendix 1). 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 to identify regional strengths and weaknesses, opportunities and challenges, and needs related to each objective of the NOAA Fisheries Climate Science Strategy. This was done by each individual NERAPWG member; the idea was to capture a broad perspective across the related, but varied, GARFO and NEFSC perspectives. Because on their involvement in fisheries management – a priority for NOAA Fisheries – 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 and weaknesses, opportunities and challenges, and needs related to each objective based on their involvement in fisheries management (see Appendix 2). The Priority (over a < 6 month planning horizon), Near-Term (6-24 months) and Mid-Term (2-5 years) actions identified in the NOAA Fisheries Climate Science Strategy were also considered. Finally, representatives of different line offices of NOAA (NOS, OAR, NCEI, other NMFS offices) that work in the Northeast U.S. (see Appendix 2) were asked to provide input on regional strengths and weakness, opportunities and challenges, and needs related to each objective. This input was solicited at the individual level and not meant to represent the official comments of NOAA Line Offices. Finally, 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 5).

This input was used to complete the assessment of regional strengths and weaknesses and 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 group then prioritized the final 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 NERAPWG members were asked to strive for an even distribution to provide a range in individual ranking. NERAPWG 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 invertebrates and vertebrates
    - “National Environmental Policy Act (NEPA) issues” related 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 five year time frame?

NERAPWG 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 pre-ranking discussions, NERAPWG members expressed 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, NERAPWG members were asked to identify, to the best of their ability, the specific steps that should be taken in the next five years. NERAPWG members were also asked to identify important partners. Members could state why the action is important and provide additional comments if desired, but these later two responses were optional.

Following NERAPWG ranking, the Leadership Group 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 and considered the NOAA Fisheries Climate Science Strategy to combine some actions and to identify Priority Actions for the region; these Priority Actions are itemized in Section 4 below. The full list of the 63 actions developed and considered by the NERAPWG is presented in Appendix 3.

Priority Actions were aligned with the most applicable objective from the NOAA Fisheries Climate Science Strategy and to 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.

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 attributed to greenhouse gas emissions. The evidence for anthropogenic climate change is widely accepted (IPCC 2014, NCA 2015). The Northeast U.S. Shelf has experienced some of the greatest warming over the past decade (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 - the two signals can amplify or cancel each other out.

Within the North Atlantic Ocean, there are two basin-scale indices of natural climate variability that impact climate in the Northeast U.S.: 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

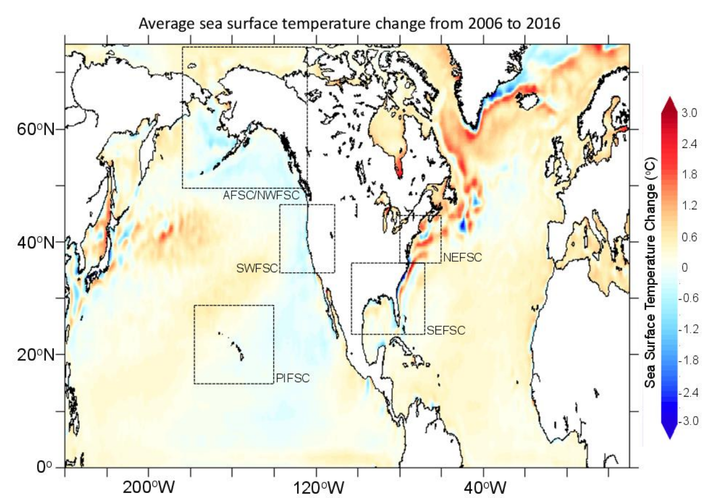

Figure 2 Change in SST from 2006-2016 compared to 1981-2016 climatology from the OISST v2 dataset.

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 one to three year scale (EcoAP 2015). The AMO represents a pattern of sea surface temperatures across the North Atlantic (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 (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 (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 Ocean 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

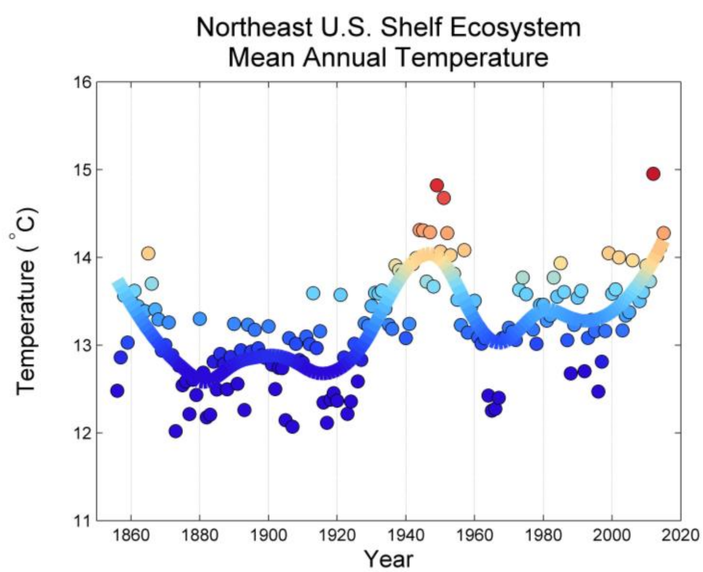

Figure 3. Annual sea-surface temperature on the Northeast U.S. Shelf from the ERSSTv3b dataset. Colors represent annual temperatures. The line is a lowess smoother of annual temperature. The multi-decadal variability (peaks in the 1850's, 1950's, and 2010') is closely related to the Atlantic Multidecadal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

fall-winter of 2011-2012 reduced the heat-loss from the Northeast U.S. Shelf waters and resulted in a less cooling in the fall and winter of 2011-2012 (Chen et al. 2014).

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, 2010; 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, 2010). 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°N and Slope Water intrusions into the Gulf of Maine's Northeast Channel (42.25°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 Middle- 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 marine 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), 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), but are now increasing , potentially due to 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. Changes in the Labrador Coastal Current and the Gulf Stream will impact temperature and salinity conditions. For example, a high-resolution global climate model, which resolves regional oceanography, projects an increased 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, shellfish, marine mammal, and sea turtle 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 habitat. 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 two 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 and Atlantic Cod productivity has decreased in recent decades, whereas Atlantic Croaker productivity has been increasing (Fogarty et al. 2008, Hare et al. 2010, Bell et al. 2014, Pershing et al. 2015). 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 both coastal fisheries on wild resources and aquaculture sites. 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; Carey et al., 2015; Kirwan et al., 2016) and have dramatic effects on coastal communities (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 develop 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 supported 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 (e.g., 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 (e.g., 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 in marine resources and on the human communities that utilize them.

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 have 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 above and in Appendix 5. There are 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 RFP. 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 two 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) and this experimental approach is used in the field (e.g., effect of trawling on benthic habitat, Sullivan et al. 2003; caging studies to examine fish ecology, Meng et al. 2008). Since fisheries science in the region developed with the understanding of the importance of the ecosystem, 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 1960's and 70's and represent time series in excess of forty years. These surveys collect a range of information on targeted species information, as well as a broader suite of ecosystem and climate information, providing the ability to analyses the interactions between targeted species and their environment. These programs include traditional and new technologies such as acoustic (e.g., Northeast Acoustic Network) and optical (e.g., HabCam). There are also two Integrated Ocean Observing System Regional Associations: Northeastern Regional Association of Coastal and Ocean Observing Systems and Mid-Atlantic Coastal Ocean Observing System; and the Chesapeake Bay Interpretive Buoy System operates in the region. The Pioneer Array on the outer Southern New England Shelf is now operational with support from 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 used 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 there are models under development that are explicitly climate-driven (Meyer-Gutbrod et al. 2015). 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 also an evaluation of a range of models underway at the NEFSC to provide tactical fisheries advice (NEFSC Ecosystem Considerations: Modeling Approaches). The region 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 have been used in the region and evaluations of high-resolution global models (Saba et al. 2016) and decadal prediction skill are underway (Stock 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. in review) and fishing businesses (Gaichas et al., in review). Both GARFO and NEFSC recognize the importance of linking natural science, social science, regulation, and management. GARFO has identified Community Resiliency as one of its seven 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 one of its seven 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 climate effects on marine populations (e.g., 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 linkages between natural sciences, social sciences, management objectives, and regulation 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 (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 examines the importance of the environment in the distribution and productivity of the stocks. The Northeast Cooperative Research Program has existed since the late 1990’s; 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 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.

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 through either 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, combined with other Chesapeake Bay field programs, makes NCBO a key component of efforts to couple physical impacts of a changing climate. 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 has nine sites throughout the Northeast U.S. Shelf ecosystem stretching from Chesapeake Bay-Virginia NERRs to Wells NERRs (in Maine). NERRs sites are designated to protect and study estuarine systems. In addition, the two 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., which 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 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 supports Federally-Recognized Tribes in the region (see NOAA Tribal Relations). A U.S. Tribal Climate Resislence 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 region-wide 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, 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 interest. 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 due to climate change. Mid-Atlantic sea turtle temperature preferences have also been demonstrated via analysis of both fishery-dependent and -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, which is an ESA Candidate Species (Hare et al. 2012) 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, Friedland et al. 2014, Perry et al. 2015).

There is increased recognition of the interaction among climate change, marine resources, and human communities, which has influenced the thinking 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 non-governmental organizations (ENGO) 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, Barneget 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 thinking about 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 Division). 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). Aquaculture is related to other NOAA Fisheries mission areas. For example increasing physical habitat complexity in the nearshore environment through aquaculture operations can have beneficial impacts affecting the abundance, growth and diversity of juvenile marine finfish (Clynick et al. 2008). Shellfish aquaculture 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 6):

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. The Northeast Fisheries Climate Vulnerability Assessment has been completed and 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. 2016, Hare et al. 2016). This fisheries vulnerability assessment has been linked to a social vulnerability assessment providing information on the vulnerability of communities along the east coast to climate change (Colburn et al., in press). Additional indicators of climate impact to communities are available and in development as part of a nationwide NOAA Fisheries social indicators project (Jessop and Colburn 2013). Further, NOAA Fisheries staff from the Northeast U.S. 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 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 Ecosystem Status Report was produced in 2009 (EcoAp 2009), and two have been completed subsequently (EcoAp 2012, EcoAp 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.

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, 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 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 obtain the needed information to inform management. 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*".

Although the region has sufficient funding to achieve many of its mandates, living marine resource assessment and management is still resource limited. There are 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 impcats of climate change on people, businesses, and communities that interact with living marine resources is also limiting. 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: 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 two Fishery Management Councils in the Northeast U.S. region with 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).

The legal and regulatory framework 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 to name a few. Regulations include quotas, time and space closures/restrictions, incidental catch limits, targeted catch limits, limited access-fisheries, gear restrictions and more. 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 are relatively slow; the time between data collection and management decisions is relatively long. 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. 2015), but getting to a holistic perspective that encompasses management and regulation and impacts on both marine and human systems is a massive undertaking. There are institutions and directives that move toward EBM, but integration with the NOAA Fisheries mission has been slow. However, there is commitment and energy to support the development of Ecosystem-Based Fisheries Management in the region (see Dolan et al. 2015), which 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 (NEFSC Strategic Plan), 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., and 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 part of 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 is less. 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 1970's 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 (as a factor removing fish from the ocean) has been a strong focus of concentration, 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 ecosystem and human dimensions for effective implementation. This includes many additional ocean uses besides fishing that impact living marine resources, such as shipping 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 a Candidate

Species under the ESA and/or Species of Concern, and three 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 remain 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) and there is no coordinated, multidisciplinary effort comparable to the Northwest Fisheries Science Center Watershed Program for developing basic and applied science in support of diadromous species in freshwater 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 de-emphasized aquaculture, but natural linkages between wild-capture and cultured fisheries are being recognized. The new NEFSC Strategic Plan includes aquaculture under a Sustainable Fisheries Theme, so integration is beginning. 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 such as Integrated Multi-Trophic Aquaculture 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. 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 (Colburn et al. in press). 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 correlative 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, exposes 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 poises 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 decr1970'seased 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 is 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. 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 on line, but this is a 5 year deployment and not well integrated with other large observing programs in the region. While new technologies are being develop, 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 pre-existing marine-species based and ecosystem models due largely to fit-of-scale issues. In addition, ethnographic research that provides context 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 is a starting point currently being explored and linked to MSEs

Another weakness in the region is relative general 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 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 wide-spread.

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 fishermen 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. 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 was used to support the most recent butterfish assessment. However, the hindcast has not been updated due to lack of funding. This uncertainty about continuation of data production, makes its use in the 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 lead to the identification of 63 draft actions across the 7 NOAA Climate Science Strategy Objectives (Appendix 3). 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 3).

Fifteen Priority Actions were defined from the list of 63 draft actions (discussed below and listed in Appendix 7). These Priority Actions group similar actions into larger coherent units. For each Priority Action identified below, specific activities are described under a *No New Resources* and a *New Resources* scenario. The activities under the *No New Resources* represent potential activities. 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 other science demands placed on NEFSC and GARFO. The activities under the *New Resources* scenario are less dependent on annual appropriations and other science, regulatory, and management demands, and more dependent on the level of new resources available.

4. ACTION PLAN

PRIORITY ACTIONS

Priority Actions are described by NOAA Fisheries Climate Science Strategy objective. Many Priority Actions are relevant to multiple objectives, but are aligned with the most relevant objective. A list of the Priority Actions is provided first, followed by descriptions of activities planned for each Priority Action under the *No New Resources* and *New Resources* scenarios (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 Priority Actions are also are mapped the immediate, short-term, and intermediate term actions described in the NOAA Fisheries Climate Science Strategy.

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

Priority Action 2 - Continue development of stock assessment models (e.g., Age Structured Assessment Program, new state-space model, multi-species models) that include environmental terms (e.g., temperature, ocean acidification).

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

Priority Action 4 - Increase social and economic scientist involvement in climate change research.

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

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

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

Priority 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.

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

Priority 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.

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

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

Priority 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, and Protected Species Surveys and expand where possible (e.g., data poor species).

Priority 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.

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

Table 1. Summary of Priority Actions and Ranking Under No New and New Resources Scenarios.

NOAA Fisheries Climate Science Strategy Objective	Priority Action Number	Action Statement	Ranking No New Resources	Ranking New Resources	Draft Actions (see Appendix 3)	Requested Resources ($1,000's)	Cumulative Requested Resources ($1,000's)	Details of Requests
1	2	Continue development of stock assessment models (e.g., Age Structured Assessment Program, new state-space model, multi-species models) that include environmental terms (e.g., temperature, ocean acidification).	1	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.	5	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.	12	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	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.	9	5	28	90	580	1 post-doc
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	6	36, 37, 38	180	760	2 post-docs
6	12	Continue production 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	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	7	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	10	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.	13	10	20, 27	175	1,450	1 IT contractor + 25K
2	4	Increase social and economic scientist involvement in climate change research.	11	11	8	90	1,540	1 post-doc
1	1	Give greater emphasis to climate-related Terms of Reference and analyses in stock assessments.	3	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, and Protected Species Surveys.	2	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.	5	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	4	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.	9	16	28	90	2,000	1 post-doc
7	15	Watershed Program for the East Coast	17	17	5, 6, 12, 24, 39, 50, 63	0	2,000	
7	15	Links to NOAA Fisheries Habitat Programs	14	19	17, 49	0	2,000	
3	15	Links to NOAA Integrated Ecosystem Assessment Program and Ecosystem-Based Fisheries Management	15	20	29, 52	0	2,000	
5	15	Links to NOAA Ocean Acidification Program	16	21	9, 11	0	2,000	
7	15	Links to NOAA Fisheries Office of Aquaculture	19	22	18, 41, 42	0	2,000	
5	15	Other Actions Identified	18	18	4, 7, 15, 16, 21	0	2,000	

DESCRIPTIONS OF PRIORITY ACTIONS

Objective 1 - Identify appropriate, climate-informed reference points for managing LMRs.

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

In general, two 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 previously defined methodology from the previous benchmark assessments and update the data and re-run the models. 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 a benchmark assessment establish the information requirements of managers and outline the types of models and analyses that would 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 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).

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 Ecosystem-Based Fishery Management (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 NRCC partners have not reviewed this guidance, nor has it been fully implemented 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 should be done in partnership with the other NRCC members. In addition, 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 prepared for the inclusion of these factors in 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 three years. The guidelines should then be revised and presented to the NRCC again for discussion, changes, and eventually consensus approval.

New Resources – No resources are needed for this action. But many of the other 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.

<u>Priority Action 2 - Continue development of stock assessment models (e.g., Age Structured Assessment Program, new state-space model, multi-species models) that include environmental terms (e.g., temperature, ocean acidification).</u>

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 Priority Actions 8 & 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.

No New Resources – With no new resources, current efforts would continue. Many of these efforts have been supported by internal fund competitions (e.g., NOAA Ocean Acidification Program, 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). 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 Center and develop applications of models within the current stock assessment process. The position would work closely with the Fisheries and the Environment staff and other NEFSC staff involved in linking stock assessment models with climate factors. The position would also work with other stock assessments staff in ways to incorporate environmental terms in stock assessments. Priorities would be discussed by the Climate, Ecosystem, Habitat, and Assessment Steering Group. In addition, in FY18 the NEFSC would host a workshop on including environmental variables in stock assessment. 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.

<u>Priority Action 3 - Develop climate- related products and decision support tools to support protected species assessments and other management actions.</u>

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 due to 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. 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.

The regulatory framework for marine mammals is different than for endangered species (MMPA vs ESA)[2], but climate change creates similar uncertainty in the assessment of status and threats. 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 design to limit the take of marine mammals through other human activities. Climate change may also impact the productivity of some marine mammals. For example, decreases in 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. To the extent that additional support can be provided (e.g., Fisheries And The Environment, Office of Protected Resources, staff re-alignments) these approaches should be applied to other species (e.g., thorny skate). Support for the Marine Mammal and Sea Turtle Climate

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

Vulnerability Assessment should also continue (see Priority Action 11). Finally, NEFSC and GARFO staff should initiate a strategic discussion regarding the support for climate information in ESA and MMPA actions 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 early 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 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 LMRs under changing climate conditions.

Priority Action 4 - Increase social and economic scientist involvement in climate change research.

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 integrate social science into ecosystem science in the Northeast U.S. region. Recent work in this collaboration includes portfolio analyses in the MAFMC Ecosystem Guidance documents (Jin et al. 2016, Gaichas et al. 2016). The Northeast Fisheries Climate Vulnerability Assessment has been linked to a set of social indicators to evaluate the vulnerability of human communities to climate change (Colburn et al. in review; Hare et al. 2016; Morrison et al. 2015). The ICES WGNARS is also incorporating human dimensions into a regional Integrated Ecosystem Assessment, which includes a conceptual model linked to an MSE approach.

No New Resources – Continue time series analysis on changes in community resilience and vulnerability including those for climate change, and engage with Coastal and Ocean Climate Applications projects (see Appendix 4). 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. In addition, review Council oversight for cases where species are likely to move to areas under the jurisdiction of a different council or councils and advise the Councils of the need to revise FMPs to include analyses of the impacts of climate change on any proposed regulatory measures. Make use of existing community social and climate vulnerability indicators and of the new such indicators that can be constructed with additional 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 used in Environmental Impact Statement NEPA documents. Continue to provide social scientist support for development of EBFM in Northeast U.S. region. Conduct literature review of local ecological knowledge and climate, as well as 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 five years.

New Resources – Hire postdoctoral associate or contractor to expand social vulnerability work and Community Social Vulnerability Indicators (e.g., social capital) and to contribute to the development of integrated models (e.g., Atlantis). Efforts would also increase to conduct and analyze new sets of oral histories that record the heritage and local knowledge of fishermen and fishing communities particularly in relation to climate change and resilience strategies (e.g., Folke 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. Add the community-level indices based on Hare et al. (2016) and Morrison et al. (2015) species vulnerability indicators and community-level indices of marine infrastructure vulnerability to various levels of sea-level rise to Ecosystem Status Reports.

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

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 simulating 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: 1) to examine harvest controls rules for the MAFMC (Wilberg et al., 2015), 2) to 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 including an evaluation of harvest control rules in Atlantic herring and multi-species management procedure testing (e.g., 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.

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 work with academic scientists involved in MSE work in the region. Finally, the NEFSC and GARFO should continue to work the NEFMC, MAFMC, and ASMFC to incorporate climate factors into management and regulatory 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 already working on MSEs. These scientists would evaluate different management strategies related to changing distributions and productivity through direct (e.g., thermal tolerance, ocean acidification effects) or 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). Finally, a workshop would be held in FY17 and FY19 to examine adaptive management responses to climate change. 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.

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

<u>Priority Action 6 - Improve spatial management of living marine resources through an increased understanding of spatial and temporal distributions, migration, and phenology.</u>

There is ample evidence that species distributions on the Northeast U.S. Shelf are changing (Nye et al. 2009, Pinsky et al. 2014, Kleisner et al 2016, Walsh et al. 2016). 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. 2014). The mechanisms responsible for regional and species-specific variability in changes in distribution are important to understand. These changes potentially impact management in many ways. Species cross from one management jurisdiction to another. Spatial management structures 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).

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 state surveys, Northeast Area Monitoring and Assessment Program (NEAMAP), Canadian surveys, Southeast Fisheries Science Center surveys (SEFSC), and fishery-dependent data (e.g., NEFSC Observer Program, Study Fleet). Tagging data should also be incorporated into this effort where appropriate. Further, most work has focused on adult stages; work should be conducted on understanding distribution changes of early life stages: eggs to juveniles. Finally, most work has been completed on commercially exploited fish and invertebrates; emphasis should now 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. Additionally, methods of accounting for survey bias should continue to be developed. 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 (Priority 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. 2014).

Finally, stock structure, which is largely defined spatially, needs to be re-evaluated 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 North Atlantic Regional Team sponsored workshop is being 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 two 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 developing MAFMC Forage Fish plan 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. 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. 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 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 FY17 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.

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

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 Long-Line 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, 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. 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 Study Fleet have been combined with the deployment of temperature sensors on Study Fleet boats and the development to 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. The potential for industry vessels to collect oceanographic data could increase observing capacity in the region by an order of magnitude at least 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 efficient 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 should 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. Information from this later model could be considered in NOAA Fisheries' decision on whether to list Thorny Skate under the Endangered Species Act. 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.

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, LMRs, and LMR-dependent human communities in a changing climate.

Priority 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.

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

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 scale (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., 2012), the development of regional downscaled climate and earth system models (see Appendix 4), 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 Oceanic and Atmospheric Research (OAR), and academic scientists. Additional ties with USGS, FWS, and EPA are needed to better incorporate climate changes in freshwater and estuarine systems. 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.

No New Resources - Continue collaborations with NOAA Oceanic and Atmospheric Research (OAR), IOOS, and academic scientists on issues related to short-term (days to years) and medium-term (years to decades) forecasting in the context of living marine resource management. The oceanographic and climate modeling to support this forecasting includes hindcasts, nowcasts, forecasts, and projections. 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 4). 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 ROMs 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. 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 workshop should be held early in FY17 to develop the FY18-FY21 priorities, thereby allowing researchers in the NEFSC and GARFO to develop proposals for internal and external funds to support these priorities.

New Resources - Hire two 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 4), as well as to computer scientists that are developing web-delivery of climate-related products. 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 metadata and provenance related to the product; this emphasis is similar to the efforts underway in support of the National Climate Assessment (NCA 2015). 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 these needed and as operational products are identified, plans for continuing their production should be developed.

<u>Objective 5 - Identify the mechanisms of climate impacts on ecosystems, LMRs, and LMR-dependent human communities.</u>

<u>Priority 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.</u>

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. Current climate-related work at these facilities has 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. These studies are largely funded by the NOAA Ocean Acidification Program and by NEFSC base funds. 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 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. 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. (In review), as well as the possibility of exploring fishermen observations over time.

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. However, opportunities to study other climate factors and the synergistic effect among factors should be pursued. 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 be encouraged; for example there is work ongoing with Woods Hole Oceanographic Institution and these efforts should continue. Finally, to the extent possible, links need to be made between the experimental work and climate modeling efforts in the region (Priority Actions 8, 9, and 10). To this end, a workshop would be held in FY17 to bring the experimental groups in the region together, 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.

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, LMRs, and LMR-dependent human communities and provide early warning of change.

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

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. 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. for 82 species of fish and invertebrates including all federally managed fishery species and protected marine fish species in the region (Hare et al. 2016). The methodology is being implemented in other regions of the U.S. 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. in press). As the Species Vulnerability Assessment is completed in other regions, the Community Social Vulnerability climate indicators would be completed in turn.

No New Resources - NOAA Fisheries 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 (see Priority Action 11). A social vulnerability assessment has been linked to the fisheries climate vulnerability assessment (Colburn et al. in review). 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).

New 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.

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

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 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 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 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 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 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 Environmental Data Center, as well as the production of the Ecosystem Status report and other related products. The emphasis would be on programming and web development in support of the Ecosystem Status Report and climate factors used in assessments. Priority datasets would include those in the 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 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 indicator development 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 Environmental Data Center, efforts would be made to improve the 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 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 Environmental Data Center would also work with other NEFSC and GARFO staff to implement these changes to the 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.

Priority 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, and Protected Species Surveys and expand where possible (e.g., data poor species).

The NEFSC has a long history of supporting surveys of the Northeast U.S. Shelf ecosystem 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, and while this was the longest running oceanographic survey in the Northwest Atlantic Ocean, 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.

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

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 includes Conductivity-Temperature-Depth operations, Thermo-salinograph measurements, nutrients samples, and carbonate chemistry samples and measurements. Data would be integrated into NEFSC databases and made publically available. 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 Long Line Survey and other cooperative research efforts.

Priority 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.

The NOAA Fisheries Climate Science Strategy presents an ambitious vision for incorporating climate information into the management of living marine resources. The Regional Action Plan presented here puts forth a plan for the next five 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 oversee 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. It is important to note that this steering group 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. This Regional Action Plan is the organizing document for the implementation and the NECSSSG would oversee the implementation. The NECSSSG would be composed of GARFO, NEFSC, NCBO, Science and Technology, as well as representatives of different NOAA and non-NOAA partners. In addition to overseeing the implementation of the Actions described in the Regional Action Plan, the NECSSSG would work on the following topics.

- 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 Plan Development Teams, Fishery Management Action Teams, and other committee memberships, 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.
- 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.
- 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 principles from each institution as well as the FMCs and MFCs.

- Increase interactions with Canadian scientists and managers. Identify and use existing, and develop new venues 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 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.
- 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 NOAA Fisheries participation.
- 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. Develop list of climate-related activities in the region. 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.

New Resources – Hire administrative staff member 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.
- 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.
- Hold Workshop 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. Review Council oversight for cases where species are likely to move to areas under the jurisdiction of a different council or councils.
- Work with Councils and Commission to revise FMPs to include analyses of the impacts of climate change on any proposed regulatory measures.
- 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. including cooperative research and citizen science opportunities.
- 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 fishermen and fishing communities to improve outreach regarding climate change impacts.
- Expand collaborative science to increase fishing industry investment in research and support for its results.

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

Watershed Program for the East Coast - There were a number of actions identified related to diadromous species in the Northeast U.S. Shelf. 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. 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 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 (*Oncorhynchus* spp.) and other diadromous fishes. NOAA Fisheries should consider developing such a program on the East coast in coordination with USGS and FWS.

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. There are efforts underway in the NEFSC (Richards and Jacobson 2016, Curti et al. 2013, Link et al. 2010) and throughout the region (Townsend et al. 2013, 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.

Links to NOAA Fisheries Habitat Programs - Coordination with Habitat Conservation Division, and Restoration Center is required to meet the needs for the region identified here. Integration between this Northeast Regional Action Plan 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. These actions are embedded I Priority Actions above but also need to be connected to other habitat-related programs in the Northeast U.S.

Additionally, coordination with the 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 Priority 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 non-tidal 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. 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. Multiple stressor laboratory and mesocosm experiments to understand the effect of climate change on aquaculture species is partly built into the Priority 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, the action was identified to conduct region wide 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 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. This was deemed to be more appropriate for the Principal Investigators funded by the NOAA Ocean Acidification program at the NEFSC.

Other Actions Identified - Numerous other actions were identified during the development of the Regional Action Plan that were not selected as priority actions for implementation within the next five year. This does not mean that these actions are not important or may 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. Whereas some 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, NGO's, 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. The Northeast Regional Action Plan Working Group would be charged with strengthening partnerships and identifying potential new partnerships. Specific partners are noted in Appendix 7.

5. TIMELINE AND METRICS

Timeline						
	FY16	FY17	FY18	FY19	FY20	FY21
Priority Setting for Modeling		X		X		
Experimental Workshop		X		X		
OA Plan Review	X					X
Stock Identification Workshop		X			X	
SEFSC Workshop		X		X		X
Canada Workshop		X			X	
ESA Workshop	X			X		
MMPA Workshop		X			X	
Assessment Workshop			X			
TOR Review Workshop		X			X	
ESR Stakeholder Comment			X		X	
Annual Status of the Ecosystem Report	X	X	X	X	X	X
Adaptive Management Workshop		X		X		
Federally Recognized Tribes Workshop			X		X	
Mesocosm Discussion		X				
Aquaculture Discussion		X		X		
Habitat Discussion		X			X	
Hire New Staff		X	X			
NERAPSG Meeting		X	X	X	X	X
Milestones						
CEH ToRs in benchmark assessments FY17-F21		X	X	X	X	X
Stock Assessments - CEHASG Meetings	X	X	X	X	X	X
Workshop Reports	X	X	X	X	X	X
NERAPSG Meeting Reports		X	X	X	X	X

6. ACKNOWLEDGEMENTS

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Appendix 1 - Northeast Regional Action Plan Working Group Members

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

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

Appendix 2 - 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 3 – 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 Priority 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 (1=High, 2=Moderate, 3=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 inclulde 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 experients to understand the effect of climate change on aquaculture species.	1.692308	1	1
	x			x		6	42	Conduct region wide 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 to 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 RCP's, 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 CenterForm 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 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, non-target species, highly migratory species and others.	2.230769	2	1
x	x	x	x	x	x	3	53	Increase interactions with Canadian scientists and managers. Identify and use existing 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 spatial allocation schemes and evaluate more a suite of 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 instiutions, and community groups where appropriate.	1.769231	2	2

Appendix 4. Coastal and Ocean Climate Applications Projects

In partnership with the National Marine Fisheries Service (NMFS) Office of Science and Technology, CPO'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 OAR and NMFS. 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 two- to three-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 address these issues, a collaboration between the Office of Oceanic and Atmospheric Research and the 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, Narragansett Laboratory), 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, Narragansett Laboratory), 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.

   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)

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 (NOAA Earth Systems Research Laboratory)

Appendix 5 - 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

- 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
- 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

Various publications and associated/relevant research needs:

- A'mar, ZT, Punt, AE, and Dorn, MW. 2009. The evaluation of two management strategies for the Gulf of Alaska walleye pollock fishery under climate change. ICES Journal of Marine Science 66: 1624-1632.
- Beechie et al 2013 related to salmon habitat
- Bell et al 2014a related to climate effects on MAB species

- Bell et al 2014b related to climate effects on MAB species
- Brander, K., Neuheimer, A., Andersen, K.H., and Hartvig, M. 2013. Overconfidence in model projections. ICES J. Mar. Sci. 70: 1065–1068. doi:10.1093/icesjms/fst055.
- De Oliveira, JAA and Butterworth, DS. 2005. Limits to the use of environmental indices to reduce risk and/or increase yield in the South African anchovy fishery. South African Journal of Marine Science 27(1):191-203.
- Evans et al. 2015. When 1+1 can be >2: Uncertainties compound when simulating climate, fisheries and marine ecosystems. Deep-Sea Research II 113 (2015) 312–322. http://dx.doi.org/10.1016/j.dsr2.2014.04.006
- Fogarty et al. 2009 related to climate effects on groundfish
- Friedland et al. 2013 related to climate effects on groundfish
- Friedland et al. 2015 related to climate effects on groundfish
- Gregr, E.J. and K.M.A. Chan. 2015. Leaps of faith: how implicit assumptions compromise the utility of ecosystem models for decision-making. BioScience. doi:10.1093/biosci/biu185
- Grimm, N.B., Chapin III, F.S., Bierwagen, B., Gonzalez, P., Groffman, P.M., Luo, Y., Melton, F., Nadelhoffer, K., Pairis, A., Raymond, P.A. and Schimel, J., 2013. The impacts of climate change on ecosystem structure and function. Frontiers in Ecology and the Environment, 11(9), pp.474-482.
- Haltuch, MA, and Punt, AE. 2011. The promises and pitfalls of including decadal- scale climate forcing of recruitment in groundfish stock assessment. CJFAS 68: 912-926.
- Hare et al 2010 related to climate effects on MAB species
- Hare et al., 2012 related to assessing climate impacts on data poor species
- Ianelli, JN et al. 2011. Evaluating management strategies for eastern Bering Sea walleye pollock (Theragra chalcogramma) in a changing environment. ICES Journal of Marine Science 68(6): 1297-1304.
- Lead Authors: Amber Himes-Cornell and Mike Orbach; Authors: Stewart Allen, Guillermo Auad, Mary Boatman, Patricia M. Clay, Mike Dalton, Di Jin, Sam Herrick, Dawn Kotowicz, Cary Lopez, Phil Loring, Paul Niemeier, Karma Norman, Lisa Pfeiffer, Mark Plummer, Michael Rust, Merrill Singer, and Cameron Speirs. 2012. Section 4 Impacts of Climate Change on Human Uses of the Ocean. In: Griffis, Roger and Howard, Jennifer, eds., *Oceans and Marine Resources in a Changing Climate: Technical Input to the 2013 National Climate Assessment.* Draft Report. United States Global Change Research Project, Washington, DC. http://downloads.globalchange.gov/nca/Griffis_Howard_Ocean_Marine_Resources_Final_1-14-13.pdf Discusses social science knowledge to date on impacts of climate change on oceans and coasts.
- Lynch et al., 2014 related to assessing climate impacts on data poor species,
- Mills et al 2013 related to salmon
- Nye et al. 2009 related to distribution shifts
- Perry et al., 2015 related to incorporating climate change projections into riparian restoration planning and design
- Pinsky and Fogarty 2012 related to distribution shifts

- Pinsky et al. 2014 related to distribution shifts
- Planque, B., Bellier, E., and Loots, C. 2011. Uncertainties in projecting spatial distributions of marine populations. ICES Journal of Marine Science, 68: 1045–1050
- Punt, AE et al. 2014. Fisheries management under climate and environmental uncertainty: control rules and performance simulation. ICES Journal of Marine Science 71(8): 2208-2220.
- Staudinger, M.D., Carter, S.L., Cross, M.S., Dubois, N.S., Duffy, J.E., Enquist, C., Griffis, R., Hellmann, J.J., Lawler, J.J., O'Leary, J. and Morrison, S.A., 2013. Biodiversity in a changing climate: a synthesis of current and projected trends in the US. Frontiers in Ecology and the Environment, 11(9), pp.465-473.
- Tommasi et al., 2015 related to assessing climate impacts on data poor species
- Walsh et al. 2015 related to distribution shifts

Appendix 6 - NOAA Fisheries Climate Science Strategy Actions

The Priority Actions defined in the Northeast Regional Action Plan are cross-referenced to the Immediate, Near-Term (6-24 months) and Medium-Terms (2-5 years) Actions defined in the NOAA Fisheries Climate Science Strategy.

<table>
<tr><th></th><th>Climate Science Strategy Actions</th><th>Northeast Regional Action Plan Priority</th></tr>
<tr><td rowspan="5">Immediate actions</td><td>1. Conduct climate vulnerability analyses in each region for all LMRs to better understand what is at risk and why.</td><td>11</td></tr>
<tr><td rowspan="3">2. Establish and strengthen ecosystem indicators and status reports in all regions to better track, prepare for and respond to climate-driven changes.</td><td>12</td></tr>
<tr><td>7</td></tr>
<tr><td>13</td></tr>
<tr><td>3. Develop capacity to conduct management strategy evaluations regarding climate change impacts on management targets, priorities, and goals.</td><td>5</td></tr>
<tr><td rowspan="9">Near-term actions</td><td rowspan="5">1. Strengthen climate-related science capacity regionally and nationally to fulfill NOAA Fisheries information requirements in a changing climate.</td><td>2</td></tr>
<tr><td>6</td></tr>
<tr><td>7</td></tr>
<tr><td>4</td></tr>
<tr><td>3</td></tr>
<tr><td rowspan="2">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</td><td>This document</td></tr>
<tr><td>14</td></tr>
<tr><td>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.</td><td>10</td></tr>
<tr><td>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.</td><td>1</td></tr>
</table>

	Climate Science Strategy Actions	Northeast Regional Action Plan Actions
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	Northeast Regional Action Plan Actions
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 7 - Northeast Regional Action Plan Action Item Table

Action Name (short title; add rows as needed for Actions)	Funding Scenario (Level or Increase)	Time Frame (years)	Action Description (short description of who, what, key products and expected outcomes)	POC (name)	Partners	Other Objectives Addressed (1 – 7)
Objective 1 – Climate Informed Reference Points						
Climate Terms of Reference	Level / Increase	2017-2021	Priority 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	Priority Action 2 - Continue development of stock assessment models (e.g., Age Structured Assessment Program, new state-space model, multi-species 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	Priority Action 3 - Develop climate- related products and decision support tools to support protected species assessments and other management actions.	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	Priority Action 4 - Increase social and economic scientist involvement in climate change research.	Trisch Clay	CINAR, academic institutions, NOAA Fisheries SF	
Management Strategy Evaluations	Level / Increase	2017-2021	Priority Action 5 - Develop Management Strategy Evaluation capability to examine the effect of different management	Sarah Gaichas	NOAA Fisheries ST, CINAR,	

			strategies under climate change.		academic institutions	
Objective 3 – Adaptive Management Processes						
Distributions and Spatial Management	Level / Increase	2017-2021	Priority 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	Priority 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	Priority 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	Priority 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	Priority 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	Level /	2017-	Priority Action 11 - Develop and implement vulnerability	Jon Hare	CINAR,	

Assessments	Increase	2021	assessments in the Northeast U.S. Shelf Region.		academic institutions, NOAA Fisheries HMS, NOAA Fisheries ST	
Track Ecosystem Conditions	Level / Increase	2017-2021	Priority Action 12 - Continue production of the Ecosystem Status Report, and other related products, and improve the distribution of information from the reports through the formation of an Environmental Data Center.	Kevin Friedland	CINAR, academic institutions	
Objective 7 – Science Infrastructure to Deliver Actionable Information						
Maintain NEFSC Surveys	Level / Increase	2017-2021	Priority 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, 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	Priority 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	Priority Action 15 – Coordinate with other NOAA Programs 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	

Title: Climate velocity over the 21st century and its implications for fisheries management in the Northeast U.S.

Funding Opportunity Title: NOAA Climate Program Office Understanding Climate Impacts on Fish Stocks and Fisheries to Inform Sustainable Management (Option 2)

Funding Opportunity Number: NOAA-OAR-CPO-2014-2004106

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Abstract

A series of climate workshops recently held by the Mid-Atlantic Fishery Management Council (Council) identified the need to generate projections of future climate velocities (i.e., the rate and direction that isotherms shift across the seascape) in the region as explanatory mechanisms for the response of fish distributions to climate change. The purpose of the proposed research is to inform the Council about the rate, magnitude, and uncertainty surrounding future distributional changes for managed and other important species likely to occur as a result of climate change over the next several decades and for the remainder of this century.

In this proposal, we are proposing to project climate velocities and species distributions for a suite of species important to the Council in the Northeast U.S. Continental Shelf Large Marine Ecosystem (NE LME). We will downscale and bias-correct IPCC-class global climate model projections for 2020-2100, build species niche models from temperature and other environmental data, and develop an ensemble of species distribution projections. These ensembles will account for uncertainty more completely than has been done in the past, including uncertainty in greenhouse gas emissions, climate model formulation, climate variability, statistical niche model formulation, and niche model parameters. We will rank species by the rate and magnitude of range shift as well as the uncertainty in those values while also diagnosing the dominant source of uncertainty. In collaboration with the Council, we will identify potential priority species for adaptation of fisheries management to climate. Finally, we will expand an existing website to share these projections with the public, fishing communities, and other stakeholders.

The results of the proposed research will help the Council in the development of an adaptive fishery management framework that can deal effectively with shifting distributions of both managed and unmanaged fish stocks as part of its Ecosystem Approach to Fisheries Management (EAFM) Guidance Document. The Council proposes a novel, adaptive approach to conducting this work by utilizing its EAFM Working Group to help refine the analyses as the modeling work unfolds. EAFM WG oversight is expected to insure that the results of the proposed work will directly address the information and analytical needs required for inclusion in the Council's EAFM Guidance Document.

The research we propose directly addresses the primary focus of the COCA competition by seeking to understand and predict the future scope of distributional changes of fish stocks in the Mid-Atlantic as a result of climate change induced warming of the Atlantic Ocean. These analyses are critical to understanding future changes in the region and are a fundamental prerequisite to integrating these effects into fishery stock assessment and management efforts. The proposed research also supports the attainment of NOAA's long-term NGSP goal of climate adaptation and mitigation by improving our scientific understanding of the changing climate and its impacts on fisheries. Ultimately, the work will help the Council and Nation to prepare for and mitigate against the impacts of climate change with the goal of maintaining sustainable fisheries which support vibrant coastal fishing communities.

Scientific Objectives

This project will focus on four objectives related to living marine resources in the northeast U.S.:

- Develop climate-velocity-driven species distribution projections for 2020 through 2100
- Characterize the dominant sources and magnitude of uncertainty in these projections
- Identify potential priority species for adaptation of fisheries management to climate
- Develop a website to share these projections with the public and other stakeholders

Proposed Methodology

Overview and focal species

Temperature has strong and well-understood impacts on fish and marine invertebrate physiology, abundance, and distribution (Pinsky et al. 2013b; Pörtner & Knust 2007). These impacts are often expressed in terms of a thermal niche, or the range of temperatures within which an organism can survive and reproduce. As temperatures warm or cool, thermal niches move across the seascape and are therefore expected to affect the distribution and abundance of species (Burrows et al. 2011; Cheung et al. 2009; Hare et al. 2012a). The rate and direction that thermal niches move is termed "climate velocity," and climate velocities vary substantially from one location to another in the ocean (Burrows et al. 2011). Analyses of historical scientific surveys have shown that changes in marine animal distributions are explained well by climate velocity, thereby providing confidence in the thermal niche approach (Pinsky et al. 2013b).

Any projections, however, can be highly misleading if not accompanied by an understanding of uncertainty in those projections (Planque et al. 2011). Uncertainty in future species distributions derives not only from a range of possible future temperatures, but also from uncertainty in species responses to temperature and uncertainty in model form or parameters (Planque et al. 2011). Past research in the NE LME has shown that species distributions are shifting (Murawski 1993; Nye et al. 2011; Nye et al. 2009; Overholtz et al. 2011; Pinsky et al. 2013b) and has projected future distributions with uncertainty for a small number of individual species (Hare et al. 2010; Hare et al. 2012a; Hare et al. 2012b). Other work has projected future distributions for a range of species, including some in the NE LME, but has not characterized the magnitude or sources of climate uncertainty (Cheung et al. 2009; Shackell et al. 2014).

Species of particular interest to the Council include those that are the focus of Fishery Management Plans (FMPs), commercially and recreationally important species that may become substantially more abundant north of Cape Hatteras in the coming century (most were historically found in low numbers in the NE LME), and forage species that are important prey for any of the above (Table 1). We propose to produce the species distribution projections needed by the Council, characterize uncertainty in these projections, help to identify priorities for climate adaptation, and share the results with a wide range of stakeholders through a website.

Table 1. Focal species for species distribution projections

Common name	Scientific name	Relevance
Summer flounder	*Paralichthys dentatus*	Summer Flounder, Scup, and Black Sea Bass FMP
Scup	*Stenotomus chrysops*	Summer Flounder, Scup, and Black Sea Bass FMP
Black sea bass	*Centropristis striata*	Summer Flounder, Scup, and Black Sea Bass FMP
Monkfish/goosefish	*Lophius americanus*	Mackerel, squid, butterfish FMP
Atlantic mackerel	*Scomber scombrus*	Mackerel, squid, butterfish FMP
Illex squid	*Illex illecebrosus*	Mackerel, squid, butterfish FMP
Longfin squid	*Doryteuthis pealeii*	Mackerel, squid, butterfish FMP
Butterfish	*Peprilus triacanthus*	Mackerel, squid, butterfish FMP
Spiny dogfish	*Squalus acanthias*	Spiny Dogfish FMP

Golden tilefish	*Lopholatilus chamaeleonticeps*	Tilefish FMP
Bluefish	*Pomatomus saltatrix*	Bluefish FMP
King mackerel	*Scomberomorus cavalla*	Potential future Mid-Atlantic U.S. species
Spanish mackerel	*Scomberomorus maculatus*	Potential future Mid-Atlantic U.S. species
Snowy grouper	*Epinephelus niveatus*	Potential future Mid-Atlantic U.S. species
Spanish sardine	*Sardinella aurita*	Potential future Mid-Atlantic U.S. species
Atlantic thread herring	*Opisthonema oglinum*	Potential future Mid-Atlantic U.S. species
Sand lance	*Ammodytes* spp.	Forage
Atlantic menhaden	*Brevoortia tyrannus*	Forage
Atlantic herring	*Clupea harengus*	Forage
Round herring	*Etrumeus teres*	Forage
Striped anchovy	*Anchoa hepsetus*	Forage
Bay anchovy	*Anchoa mitchilli*	Forage

Data on historical distributions

Building models for climate-velocity-driven species distributions starts with data on the historical distribution and abundance of each species. We propose to use a set of five scientific surveys relevant to the northeast U.S. (Table 2), including surveys that sample species at lower latitudes but that may move into the northeast U.S. over the coming century. Surveys were chosen based on consistent methods and the availability of *in situ* temperature data. All surveys are fishery-independent, and the NEFSC and DFO surveys have been operating for more than 40 years. The datasets are currently available in the Pinsky lab or through the MAFMC.

Table 2. Proposed scientific surveys for data on historical species distributions

Organization	Survey	Region	Reference
Northeast Fisheries Science Center (NEFSC)	Bottom Trawl Survey	Cape Hatteras, NC to the Gulf of Maine	Azarovitz (1981)
Department of Fisheries and Oceans (Canada)	Multi-Species Bottom Trawl Survey	Bay of Fundy and Scotian Shelf, NS	Shackell and Frank (2003)
Northeast Area Monitoring and Assessment Program (NEAMAP)	Multispecies research trawl surveys	Cape Hatteras, NC to Cape Cod, MA	Bonzek et al. (2013)
Southeast Area Monitoring & Assessment Program South Atlantic (SEAMAP-SA)	Coastal Survey (bottom trawl)	Cape Canaveral, FL to Cape Hatteras, NC	SEAMAP-SA (2000)
Southeast Area Monitoring & Assessment Program South Atlantic (SEAMAP-SA)	Reef Fish Survey (traps and longlines)	St. Lucie, FL to Cape Hatteras, NC	Bacheler et al. (2013)

Data on environmental conditions

Explanatory variables for species distribution projections are primarily of two types: environmental factors that can be projected forward over the coming century, and environmental conditions that are approximately constant over the coming century. From the set of possible explanatory variables, we will focus on temperature, benthic habitat, and solar elevation given the clear evidence linking them to species abundance and distribution in the scientific surveys. Temperature has a well-understood physiological impact on marine ectotherms (Pörtner & Knust 2007) and historical tests with marine fish and invertebrates suggest that temperature in particular has a strong ability to explain changes in species distributions (Pinsky et al. 2013b). However, benthic habitat may be an important constraint for species closely tied to certain habitat types (Hare et al. 2012a), and solar elevation can affect the catchability of some species in the survey gear (Casey & Myers 1998). The relative importance of these variables will be testing in the model-building process. We do not include depth because models with depth terms poorly explain changes in species depth through time, while models without a depth term perform substantially better (Pinsky et al. 2013b). Many species in the northeast have been moving towards deeper waters (Nye et al. 2009; Pinsky et al. 2013b), and we expect that this pattern will continue.

We will use *in situ* bottom and surface temperature measurements from the scientific surveys (Table 2). For benthic habitat, we will use a Terrain Ruggedness Index (Hare et al. 2012a) calculated from the 3-arc second NGDC Coastal Relief Model (http://www.ngdc.noaa.gov/mgg/coastal/coastal.html) (Manderson et al. 2011). Terrain ruggedness is the square root of the sum of the difference of squared elevations between a focal grid cell and the eight surrounding grid cells. In addition, we will use sediment grain size maps derived from the usSEABED database (Goff et al. 2008; Reid et al. 2005). Both terrain ruggedness and grain size will be matched to the locations of each species observation.

Building species niche models

The core of a climate-velocity-driven species distribution projection is a model that estimates a species' thermal niche. However, to fit this model statistically, we also need to account for other factors that affect the observed abundance and distribution of a species. As in Pinsky et al. (2013b), we will fit two-part statistical models to account for the large number of zeros in the scientific survey biomass data. The first part of the model will be fit to presence/absence data, while the second will be fit to log-abundance data where the species is present (Fletcher et al. 2005). We will use an ensemble of statistical techniques to explore uncertainty in numerical model formulation (Planque et al. 2011), including Generalized Additive Models (GAMs) (Wood 2011), Generalized Linear Models (GLMs) (Guisan et al. 2002), and Boosted Regression Trees (BRTs) (Elith et al. 2008). All three methods have been useful for species distribution modeling (Elith et al. 2006).

Explanatory factors will include bottom temperature, surface temperature, Terrain Ruggedness Index, sediment grain size, solar elevation, survey, season, survey gear type, and region-wide average biomass for the year. Penalized regression splines (GAMs) and quadratic terms (GLMs) will be used for each temperature, benthic habitat, and solar-elevation terms to allow non-linear responses. BRTs automatically fit non-linear responses for continuous terms. The categorical survey, season and gear type terms will help account for differences in catchability between and within surveys. Similarly, the average biomass terms corrects for region-wide changes in abundance (such as from overfishing or recovery) that are not relevant to our focus on spatial shifts (Pinsky et al. 2013b).

In each of the models, we will eliminate terms using smoothing penalties (GAMs), Akaike's Information Criterion (GLMs), or cross-validation (BRTs). We will also investigate survey-dependent and season-dependent responses to temperature and benthic habitat, but expect that such interaction terms will be eliminated during model selection based on previous analyses (Hare et al. 2012a). We will evaluate model performance with sensitivity (presence/absence), specificity (presence/absence), Area Under the Curve (presence/absence), point biserial correlation (presence/absence), % deviance explained (log-abundance), serial correlation (log-abundance), and cross-validation performance (both). We will also test for spatial autocorrelation in the residuals and add spatial error terms if necessary (Dormann et al. 2007).

Climate projections

Our approach for climate projections will use the delta method for regional bias corrections and climate downscaling. This method has the advantage of allowing us to consider an ensemble of Global Climate Models (GCMs) for our projections, thereby including a major source of uncertainty in future climate change and contributing towards our goal of accounting for the dominant sources of uncertainty throughout our projection process. The delta method has been widely applied in species distribution modeling, including for species in the NE LME (Hare et al. 2012a; Hare et al. 2012b; Shackell et al. 2014). However, previous applications have not examined multiple species and multiple climate models. In this proposal, we will apply the delta method in the northeast U.S. for the years 2020-2100 across an ensemble of climate models, across multiple climate change scenarios, and across more than twenty species.

The delta method calculates projected temperature from GCM *m* in year *t* for a particular location ($\hat{T}_{t,m}$) as the sum of the observed climatological temperature ($\bar{T}^o$) and the expected change in temperature from model *m* ($\Delta_{t,m}$), after correcting for drift in the model ($D_{t,m}$).

$$\hat{T}_{t,m} = \bar{T}^o + \Delta_{t,m} - D_{t,m}$$

The drift term helps account for the fact that climate models can spuriously warm or cool through time, even without forcing from greenhouse gases. If not accounted for, this "model drift" can lead to over- or under-estimation of future warming (Sen Gupta et al. 2013).

We will calculate the first term ($\bar{T}^o$) by developing historical climatologies from the more than 30,000 surface and bottom temperature measurements available from public regional databases from 1977-2013 in the NE LME and adjacent Scotian Shelf (Fratantoni et al. 2011; Gregory 2004). We will trim bottom temperature measurements to those within 10m of the bottom by using a 1' gridded dataset of the seafloor terrain (Amante & Eakins 2009). We will bin and average the measurements by 0.25° latitude and longitude and by two month periods, a spatial and temporal resolution that balances high data density with low intra-bin variance (Hare et al. 2012a). We will also evenly weight each decade so that heavily sampled later decades do not dominate the averages.

The expected temperature change ($\Delta_{t,m}$) will be calculated from each of thirteen GCMs that are part of the latest phase of the Coupled Model Intercomparison Project (CMIP5) (Knutti & Sedláček 2013). These models (Table 3) have met rigorous quality standards in order to be included in the Intergovernmental Panel on Climate Change (IPCC) reports. Together, they help to characterize uncertainty in future climate change. Temperature change is calculated relative to a reference time period that matches the climatologies (1977-2013):

$$\Delta_{t,m} = T^p_{t,m} - \bar{T}^p_{1977-2013,m}$$

for projected temperature $T^p_{t,m}$ in year *t* (2020 to 2100) from model *m*, and average modeled temperature $\bar{T}^p_{1977-2013,m}$ over the reference period. As for the climatologies, this calculation will be applied separately to each two-month period throughout the year and for each of surface and bottom temperatures. Given the resolution of the GCMs, these calculations will be applied to 1° grid cells, and climate model output will be re-gridded to 1° where necessary.

We will also linearly interpolate $\Delta_{t,m}$s among adjacent depths when the observed depth from the climatology does not match the depth bins in a climate model. We will use the lowest depth bin if a model does not extend as deep as actual ocean depth. We note that these re-gridded data are already available within the Pinsky lab from a previous project (Pinsky et al. 2013b).

Across all climate models, we will examine two future climate scenarios, which are expressed in terms of Representative Concentration Pathways (RCPs). RCPs provide standardized scenarios of future greenhouse gas emissions, land use change, and other processes that affect global warming (van Vuuren et al. 2011). We will examine a "business-as-usual"

(RCP8.5) and a "mitigation" (RCP4.5) climate change scenario. Scenario names indicate their radiative forcing values (e.g., 4.5 or 8.5 watts/m^2) in the year 2100.

Table 3. General circulation models (GCMs) from the Coupled Model Intercomparison Project 5 (CMIP5) to be included in the climate model ensemble

Modeling center	Country	Model name
Centre National de Recherche Meteorologiques	France	CM5
Institut Pierre Simon Laplace	France	CM5A-MR
Institut Pierre Simon Laplace	France	CM5B-LR
Met Office Hadley Centre	U.K.	HadGem2-CC
Max Planck Institut fur Meteorologie	Germany	ESM-LR
Max Planck Institut fur Meteorologie	Germany	ESM-MR
Meteorological Research Institute	Japan	CGCM3
National Center for Atmospheric Research	USA	CCSM4
Norwegian Climate Centre	Norway	NorESM1-M
Norwegian Climate Centre	Norway	NorESM1-ME
Geophysical Fluid Dynamics Laboratory	USA	CM3
Geophysical Fluid Dynamics Laboratory	USA	ESM2G
Geophysical Fluid Dynamics Laboratory	USA	ESM2M

The term for model drift ($D_{t,m}$) will be calculated for each climate model from its respective control simulation (i.e., without external forcing from greenhouse gases). The drift term is calculated as the difference between future temperature in the control run ($T_{t,m}^{c}$) and average temperature during a reference period in the control run ($\bar{T}_{1977-2013}^{c}$):

$$D_{t,m} = T_{t,m}^{c} - \bar{T}_{1977-2013}^{c}$$

To reduce the influence of internal variability, we will then smooth the $D_{t,m}$s over time with a linear regression, as is common practice (Sen Gupta et al. 2013). We will calculate drift separately for each GCM, RCP, grid cell, season, and surface and bottom temperature.

While straightforward to apply, we recognize that this projection, downscaling, and bias correction method has a number of assumptions. For example, the delta method assumes that differences between $\bar{T}_{1977-2013}^{o}$ and $\bar{T}_{1977-2013,m}^{p}$ result primarily from biases in the mean climate state, rather than from differences in the phase of climate variability. We average this reference period over 37 years to minimize the influence of climate variability and to help meet this assumption. In addition, the method assumes that changes in ocean temperature result predominately from large-scale changes in radiative forcing and hydrodynamic changes resolved by the models, rather than unresolved local-scale shelf processes (Hare et al. 2012a; Stock et al. 2011). Finally, the method assumes that the mean climate state and amount of warming are not strongly correlated. These assumptions are likely valid to first order (Stock et al. 2011) and so can serve as initial guidance to the Council. However, additional research on dynamic and statistical downscaling will be helpful in refining climate projections for the region. When such projections become available, it will be straightforward to re-run our models with new climate data.

Projections and analysis

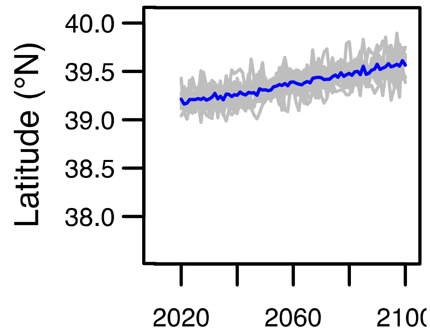

Figure 1. Preliminary projections of longfin squid distribution. The y-axis shows the latitude of the distribution centroid. Each grey line indicates a climate model from Table 3 and the blue line is the ensemble mean.

Future projections of species shifts under future climate will be calculated by applying the species niche models to the projected, annual temperature fields while holding other terms constant (e.g., benthic habitat). We will then calculate the rate of shift of the distribution centroid and high and/or low latitude range edges in terms of latitude (°N/decade), depth (m/decade), and absolute horizontal speed (km/decade) (see example in Fig. 1). For definition of range edges, we will use an optimal probability threshold for each presence/absence model as defined by the minimum difference threshold (Jiménez-Valverde et al. 2008; Lobo et al. 2008).

Uncertainty

An accounting of uncertainty is critical for incorporating projections into management decisions. Highly uncertain projections carry less weight, while more certain projections can play a stronger role (Planque et al. 2011). For projection of distributions, uncertainties derive from the observation process, conceptual and numerical model formulations, parameter estimates, model evaluation, spatial and temporal scales, and adaptation of species (Planque et al. 2011). In addition, uncertainty about future climate derives from numerical model formulation, internal climate variability, and emissions scenarios. We have previously addressed conceptual model uncertainty by demonstrating the utility of climate velocities for explaining shifts in marine distributions (Pinsky et al. 2013b). We will discuss adaptation but do not plan to address it quantitatively given data limitations. Other sources of uncertainty are addressed above (e.g., model evaluation) or will be addressed with an ensemble approach.

We will calculate ensemble projections across each year in two time periods (2020-2060 and 2060-2100) and across each two-month seasonal period (n = 6), statistical niche model type (n=3), GCM (n = 13), and emissions scenario (n = 2). To account for uncertainty in niche model parameterization and the observation process, we will repeat this process 1000 times while sampling each parameter from its uncertainty distribution and adding an error value sampled from model residuals. A scientific workstation with 256GB of RAM and a 10TB harddrive is available in the Pinsky lab for these calculations.

We will recalculate the speed of shift for each iteration of the projection process, and determine the amount of uncertainty for each species. We hypothesize that we will find higher uncertainty for species with fewer historical observations. We will also decompose variation in these projections to identify the dominant sources of variation and uncertainty. This decomposition is a key aspect of our research, addresses Objective 2, and will shed new light on areas in need of scientific research to improve projections going forward. We will fit a general linear model to the rates of shift with species, GCM, emissions scenario, statistical niche model type, time period, seasonal period, and year within time period as categorical variables, plus error terms as continuous variables. The year term accounts for internal climate variability. We will use the sums of squares to determine the proportion of variance explained by each factor.

Identifying potential management priorities

To aid the Council in choosing priority fisheries for which to address climate adaptation, we will rank species by the speed of shift (centroid and range edges) and the magnitude of uncertainty. Species with high speeds and low uncertainty will be suggested as highest priorities, while those with low speeds and high uncertainty will be the lowest. This approach fits well with the NMFS Methodology for Assessing the Vulnerability of Marine Fish Stocks to a Changing Climate (Hare et al. 2014). We will also examine the magnitude of shift relative to historical distributions (proportion of habitat lost and gained) and relative to U.S. vs. Canadian waters. We will also highlight species fished with less mobile gear (e.g., traps) and those managed with static temporal or spatial allocations (scup, black sea bass, summer flounder, bluefish, longfin squid, and spiny dogfish). These latter management systems are less responsive to shifts in distribution.

Communicating results

The primary purpose of this project is to provide tools and information to improve the adaptation of fisheries and fisheries management to climate change. In addition to the partnership between research and management (Pinsky and Seagraves) that underlies this project and the integration of project results into the Council process (see below under Collaborative Partnerships), we will also expand our audience through a website designed for a broad range of decisionmakers, members of the fishing community, and the public.

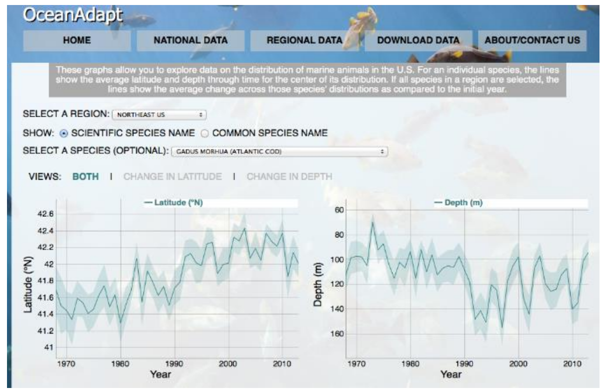

Figure 2. Image from the OceanAdapt website, showing historical changes in the distribution of Atlantic cod (*Gadus morhua*). In the proposed project, the website will be expanded to include future projections.

The website will leverage the current OceanAdapt portal (http://oceanadapt.rutgers.edu), which was developed by Pinsky and NMFS colleagues to provide information on historical shifts in marine species distributions (Fig. 2). The website curates and serves up data from NMFS and other bottom trawl surveys around North America in a fully traceable manner. Through the proposed project, we will expand the database underlying the website to host our ensemble of projections of species distributions through 2100, then expand the visualization tools to allow visitors to explore these data. We will use graphs to show shifts in the centers and edges of species distributions, as well as maps to display these changes in geographic context. In addition, we will partner with the Duke Marine Geospatial Ecology Lab (Halpin and Boustany) and will provide data to their climate change decision support tool if both of our projects are funded.

Relevance to the Competition and to NOAA's NGSP

As noted in the Federal Funding Opportunity description, this competition is focused on understanding and responding to the impacts of climate variability and change on NOAA's marine resource management responsibilities, including implications for marine ecosystems, fish stocks, fishery management, and the communities and economies that depend on them. The research we propose directly addresses the primary focus of the competition by seeking to understand and predict the likely future scope of distributional changes of fish stocks in the Mid-Atlantic as a result of climate-change-induced warming of the Atlantic Ocean.

The proposed research will inform the development of future Council management policies that seek to incorporate ecosystem considerations into existing management programs. By directly addressing the information needs identified by the Council in its Strategic Plan, the proposed research is also directly relevant to NOAA's National Climate Goal and Strategic Plan. This stems from the fact that the Council's vision for Mid-Atlantic fisheries - *Healthy and* *productive marine ecosystems supporting thriving, sustainable marine fisheries that provide the greatest overall benefit to stakeholders* is closely aligned with NOAA's Vision of the Future- *Healthy ecosystems, communities, and economies that are resilient in the face of change*.

Having a reasonable understanding of the future state of the ecosystems in the Mid-Atlantic as they respond to climate change is a fundamental prerequisite to the development of management policies that allow for the achievement of both the Council and NOAA's vision for the future of those ecosystems. The proposed research will provide the tools for the prediction of the future distributions of fish stocks in response to climate change. The research also directly supports NOAA's Mission statement – to understand and predict changes in climate, weather, oceans and coasts; to share knowledge and information with others; and to conserve and manage ecosystems and resources.

The proposed research is directly relevant to NOAA's long-term objective relative to climate adaptation and mitigation. The results will contribute to informing society about the anticipated impacts of climate change and help to respond to its impacts by improving our understanding of the changing climate system and its impacts on fishery resources. The results of our research will inform the Council about the future states of Mid-Atlantic ecosystems, which in turn will help identify mitigation and adaptation choices to be considered when making future fishery management decisions.

The research will contribute to the public's understanding of the vulnerability of fisheries to climate change and to help the Council make informed decisions. Most importantly, the research will contribute to the Council's EAFM effort, which involves weighing the trade-offs that are inescapable when deciding between alternative courses of action when responding to climate change impacts.

Annual and Final Progress Report Template

Information in this first section is standard and can be copied from previous reports:

NOAA Award Number - NOAA-OAR-CPO-2014-2004106

Time Period Addressed by this report - *(e.g., August 2015 - March 2016 or final report)*
August 2015 - March 2016

Project Title - Climate velocity over the 21st century and its implications for fisheries management in the Northeast U.S.

Principal Investigator(s) - *Include institution, email address, and phone number*
Malin Pinsky – Assistant Professor, Rutgers University
Institute of Marine and Coastal Sciences and Department of Ecology, Evolution, & Natural Resources; (848) 932-8242; malin.pinsky@rutgers.edu

Richard Seagraves – Senior Scientist, Mid-Atlantic Fishery Management Council
(302) 526-5259; rseagraves@mafmc.org

Project Team Members - *Any additional team members who are not the lead PIs working on this project- please note graduate students and postdocs.*
James Morley – Postdoc, Rutgers University; (717) 858-2584; jw.morley@rutgers.edu

Project Goal- *Describe your project's goal social media style using 140 characters or less*

Our research will inform the marine resource management community about the rate, magnitude, and uncertainty surrounding future changes in fish distribution.

Geographical Location of Study – The continental shelf of the northeast U.S., from Cape Hatteras, NC to the Gulf of Maine and Georges Bank

Partners - *List any partners collaborating on the project including NOAA, other federal agencies, academia, non-governmental organizations, private sector, etc.*

NOAA
NEAMAP (VIMS)
MAFMC

End User(s) – *If applicable, list the end users you are working with on this project who will directly benefit from the project results and deliverables.*

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Rich Seagraves (PI on the project) is Chief Scientist on the Mid-Atlantic Fishery Management Council, so we anticipate our work will be useful to the MAFMC. Further, we are presenting results to council members of the MAFMC in June of 2016 and will fine tune output from our analysis based on their feedback. We are also working in association with the National Marine Fisheries Service, specifically individuals that are involved with NOAA's climate change and ecosystem based fisheries management initiatives.

Matching Funds/Leveraging - *List any matching funds and/or activities/research being leveraged for this project.*

A related project has been funded by The Pew Charitable Trusts to expand the methods to other regions in the US (outside the northeast US).

Research Objectives - *Provide one paragraph on the objective of the project*

The purpose of our research is to inform the marine resource management community about the rate, magnitude, and uncertainty surrounding future distribution changes that are likely to occur as a result of climate change in the 21st century. We will also project changes in suitable habitat area for important resource species within the northeast region as a result of climate change. Ultimately, species with robust projections that are predicted to be sensitive to climate change will be identified for proactive management.

Research Approach and Methodology - P*rovide information on the methodological framework, models used, theory developed and tested, project monitoring and evaluation criteria, etc. (Limit 2 pages)*

We are calibrating statistical models of species distribution using data from the Northeast Fisheries Science Center's annual bottom trawl survey, as well as other surveys in the region. The models use a two-part generalized additive model (GAM) framework and include habitat variables such as bottom temperature and seafloor rugosity. Species distributions are being projected forward using output from a set of 13 IPCC-class global climate models. Temperature projections from climate models are being downscaled to ¼ degree latitude × longitude resolution based on a regional climatology derived from temperatures recorded at sea during the survey. The delta method is being used to project temperatures forward, which is a standard way to incorporate finer-spatial scale climatology onto the relatively course scale of climate projection models.

We summarize results for distribution projections under two scenarios for future climate, which are expressed in terms of Representative Concentration Pathways (RCPs). RCPs provide standardized scenarios of future greenhouse gas emissions, land use change, and other processes that affect global warming. We examine projected responses to a "mitigation" (RCP4.5) and a "business-as-usual" (RCP8.5) climate change scenario, with the latter scenario representing more intense global warming. Projected distribution changes for a given species represent directional shifts in the predicted mean center of biomass. These changes occur when the areas of overlap between preferred temperatures and bathymetry shift across the seascape. Uncertainty in distribution projections arise from multiple factors including differences in carbon emissions scenarios and uncertainty among the 13 climate projection models.

The information below should be updated annually. If this is the final report, it should include information from the entire project, not just specific reporting periods.

Accomplishments - Research Results and Findings - *Include the most recent findings from this reporting period that resulted from your research. (Limit 2 pages)*

The general difference between the two climate change scenarios for all regions was an increase in the range of species responses under the business-as-usual scenario, and also more extreme values within regions. For example, Atlantic butterfish *Peprilus triacanthus* and weakfish *Cynoscion regalis* are both projected to shift northward on the east coast of the U.S. with increases in water temperature. However, the magnitude of that shift is dependent on the intensity of ocean warming, especially for weakfish which are predicted to be relatively robust to moderate increases in temperature. For both of these species, under a business-as-usual scenario, distributions are projected to shift northwards by about 2° latitude. Under this more intense warming scenario, major areas of thermal habitat are predicted to open up for weakfish on the northern Mid Atlantic Bight shelf and for butterfish in the Gulf of Maine.

An important result from preliminary modeling is that, within any given region, species that are projected to shift similar distances may vary greatly in the uncertainty among model predictions. For example, weakfish and butterfish in the northeast were projected to shift similar distances under the RCP8.5 scenario, but the prediction for weakfish was less precise among climate models. Species that are projected to shift a large distance and that have a low uncertainty, such as butterfish, may be the highest priority species, while those with more uncertainty may be somewhat lower priority.

Accomplishments - Deliverables produced – *Include deliverables produced during this reporting period (e.g., workshop, whitepapers, website, outreach activities, tools, etc.) and/or future work developed based on project results. (Limit 2 Pages)*

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Presented preliminary results at the Climate Impacts on Fish PI Meeting workshop in Princeton, May 16.

Highlights of Accomplishments – *Include a bulleted list of up to five accomplishments. Accomplishments should be written in a narrative form, 2-3 sentences each.*

- Survey data from the NEFSC, SEAMAP, and MARMAP have been obtained and standardized for use in projection modeling.
- We have assimilated the temperature projection data for the northeast region, from the 13 climate forecasting models.
- Thermal envelope models have been developed for each species of interest, which will be used for projecting species distribution changes.
- Preliminary distribution projections have been developed.

Significant Deviations from Proposed Workplan - *Provide information on changes to the project, if any (e.g., shift in priorities following consultation with program manager, delayed fieldwork due to late arrival of funds, obstacles encountered during the course of the project that have impacted outcome delivery) (one paragraph)*

We have no significant deviations to report at this time.

List of completed, peer and non-peer reviewed publications, white papers, or reports (with internet links if possible) - *For peer-review publications, list either published or in press, but not "in review".*

None to date

List website addresses relevant to the project for further information (if available)

http://oceanadapt.rutgers.edu

List of presentations/seminars, photos, or other visuals related to project - *If you wish to share these items, please upload them as an attachment with the annual progress report.*

1. Rogers L, Pinsky M, (2015) Quantifying Spatial Patterns of Risk to Species from Climate Change. 145^{th} Annual Meeting of the American Fisheries Society, Portland, OR.
2. Pinsky M, Rogers L, Frolicher T (2016) Can we "future-proof" marine spatial planning? Ocean Sciences Meeting, New Orleans, LA.

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For Final Report please include - *PowerPoint slide summarizing project and major accomplishments (should be in .ppt format)*

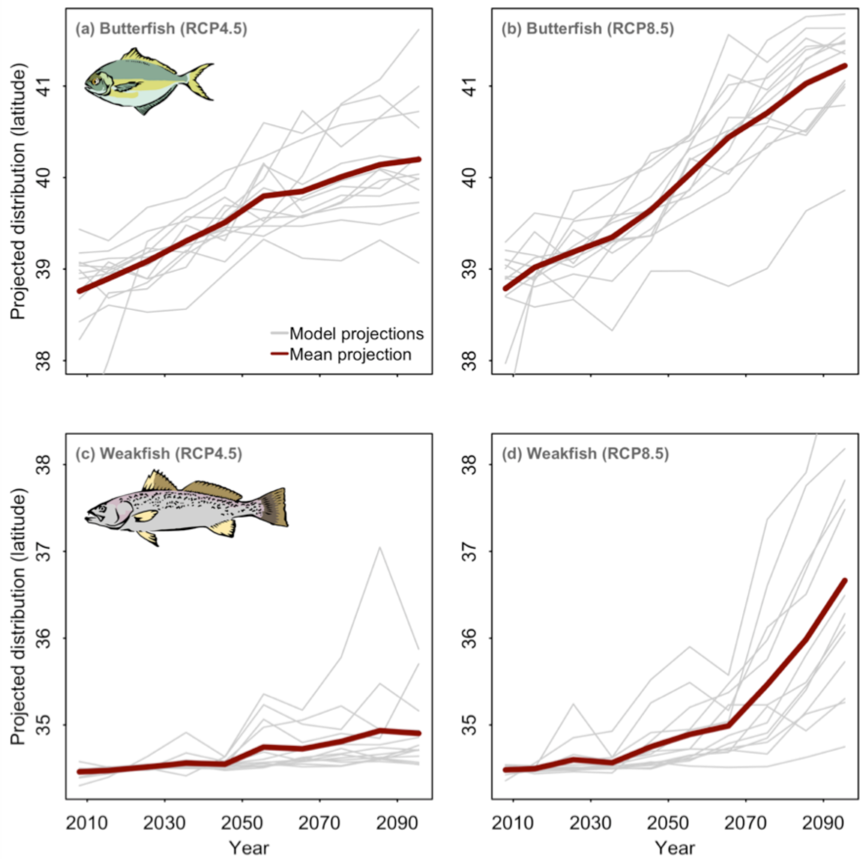
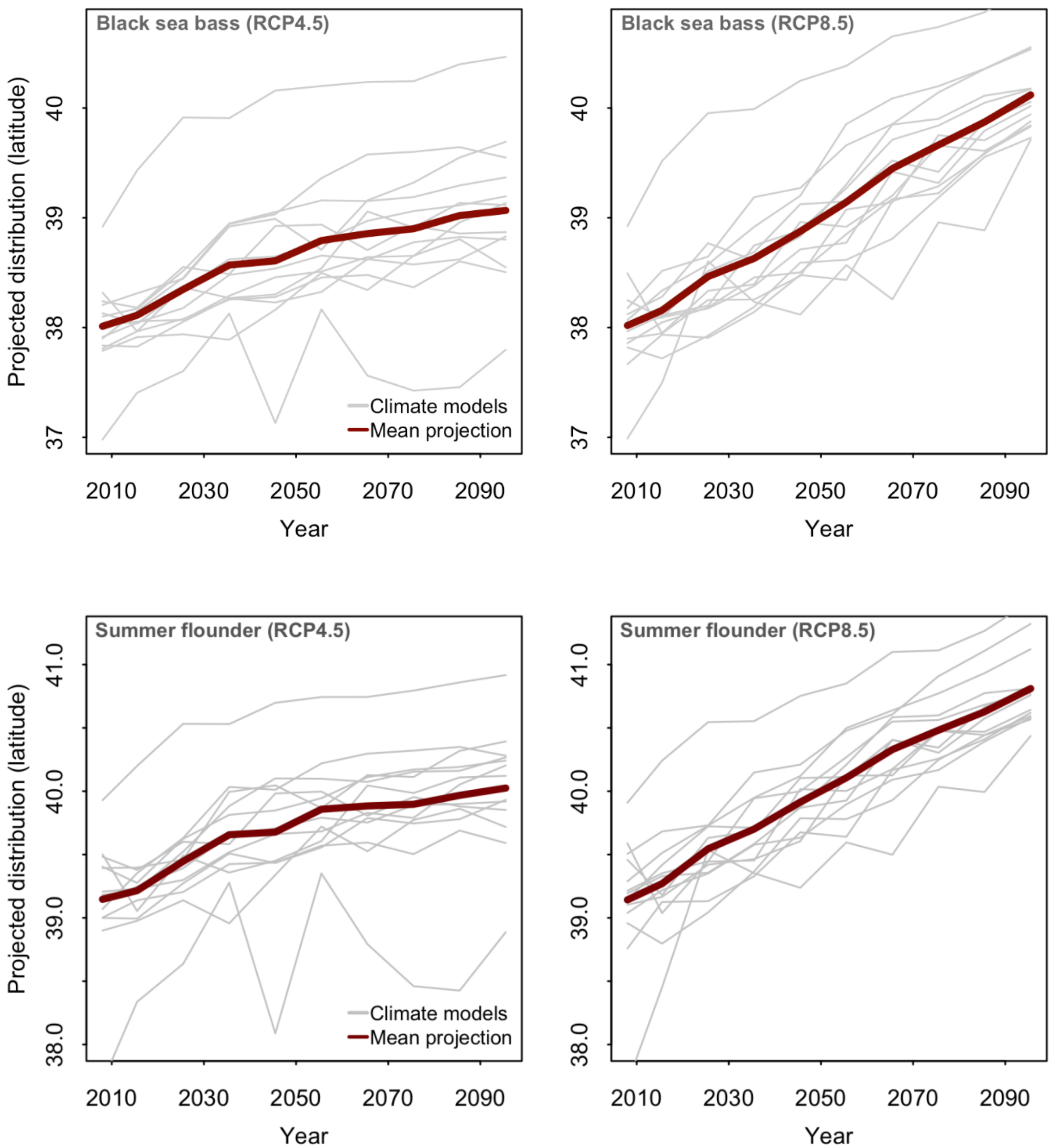


Fig. 1 *Projected changes in distribution for Atlantic butterfish (a, b) and weakfish (c, d) on the northeast U.S. continental shelf using a mitigation (a, c) and a business-as-usual climate scenario (b, d). Gray lines show distribution projections from individual climate models (n = 13) and the red line shows the model average. Values are averaged over 10 year periods.*


Black sea bass (RCP4.5)
Black sea bass (RCP8.5)
Summer flounder (RCP4.5)
Summer flounder (RCP8.5)
Projected distribution (latitude)
Year
Climate models
Mean projection
37
38
39
40
38.0
39.0
40.0
41.0
2010
2030
2050
2070
2090

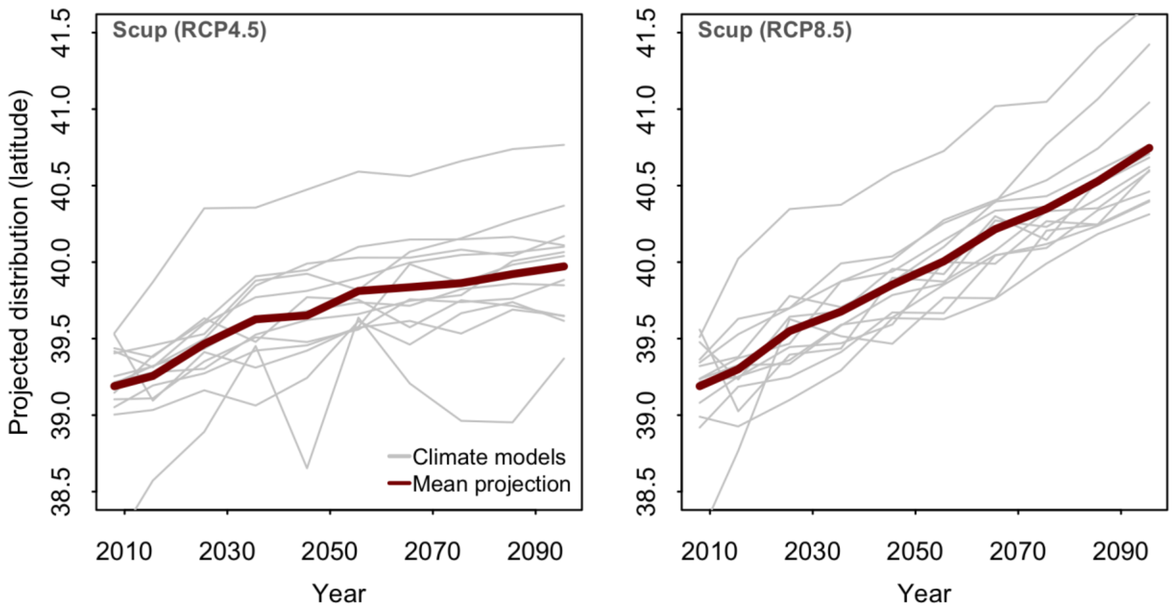


Fig. 2 *Projected changes in distribution for black sea bass, summer flounder and scup on the northeast U.S. continental shelf using a mitigation (RCP4.5) and a business-as-usual climate scenario (RCP8.5). Gray lines show distribution projections from individual climate models (n = 13) and the red line shows the model average. Values are averaged over 10 year periods*