South Atlantic Regional Action Plan to Implement the NOAA Fisheries Climate Science Strategy

Draft for Public Review
February 2017

Southeast Fisheries Science Center
http://www.sefsc.noaa.gov/

TABLE OF CONTENTS

TABLE OF CONTENTS ii

ACRONYMS iii

EXECUTIVE SUMMARY v

INTRODUCTION 1

DEVELOPMENT OF THE SOUTH ATLANTIC REGIONAL ACTION PLAN 2

REGIONAL ASSESSMENT 3

STRENGTHS, WEAKNESSES, AND OPPORTUNITIES 7

- Strengths 7
- Weaknesses 9
- Opportunities 10

ACTION PLAN 11

- Action Table 11
- Objective 1: Identify appropriate, climate-informed reference points for managing living marine resources (LMRs) 18
- Objective 2: Identify robust strategies for managing LMRs under changing climate conditions 19
- Objective 3: Design adaptive decision processes that can incorporate and respond to changing climate conditions 20
- Objective 4: Identify future states of marine and coastal ecosystems, LMRs, and LMR dependent human communities in a changing climate 22
- Objective 5: Identify the mechanisms of climate impacts on LMRs, ecosystems, and LMR dependent human communities 25
- Objective 6: Track trends in ecosystems, LMRs and LMR-dependent human communities and provide early warning of change 26
- Objective 7: Build and maintain the science infrastructure needed to fulfill NOAA Fisheries mandates with changing climate conditions 28

METRICS 31

ACKNOWLEDGEMENTS 32

REFERENCES 32

ACRONYMS

ACL	Annual catch limit
AMO	Atlantic Multidecadal Oscillation
AMOC	Atlantic Meridional Overturning Circulation
AOML	NOAA Oceanic and Atmospheric Research's Atlantic Oceanographic and Meteorological Laboratory
ASMFC	Atlantic States Marine Fisheries Commission
BOEM	Bureau of Ocean Energy Management, under the Department of the Interior
CariCOOS	Caribbean Coastal Ocean Observing System
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMIP5	Coupled Model Intercomparison Project Phase 5, internationally coordinated climate model experiments of the World Climate Research Programme
CSCOR	Center for Sponsored Coastal Ocean Research (part of NOAA's National Centers for Coastal Ocean Science
CTD	Package of electronic instruments that measure conductivity, temperature, and depth.
EcoFOCI	Ecosystems and Fisheries-Oceanography Coordinated Investigations (a joint NOAA Fisheries & OAR program)
ENSO	El Niño Southern Oscillation
ESA	Endangered Species Act
FAO	Food and Agriculture Organization of the United Nations
FEP	Fishery Ecosystem Plan
FSSI	Fish Stock Sustainability Index
FTE	Full time equivalent employee
GFDL	Geophysical Fluids Dynamics Laboratory (NOAA)
GLOBEC	Global Ocean Ecosystem Dynamics, an international program
HC	Office of Habitat Conservation (NOAA Fisheries)
HMS	Highly Migratory Species, a division of the Office of Sustainable Fisheries
HQ	Headquarters offices of NOAA Fisheries
ICCAT	International Commission for the Conservation of Atlantic Tunas
IEA	Integrated Ecosystem Assessment
LMR	Living marine resource(s)
MAFMC	Mid Atlantic Fishery Management Council
MSE	Management Strategy Evaluation
NASA	National Aeronautics and Space Administration
NCCOS	National Centers for Coastal Ocean Science
NCEI	National Centers for Environmental Information (program within NOAA's National Environmental Satellite, Data, and Information Service)
NERR	National Estuarine Research Reserve
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service (Line Office in NOAA)
NRDA	Natural Resources Damage Assessment

NSF	National Science Foundation
OAR	Office of Oceanic & Atmospheric Research (Line Office of NOAA)
OCM	Office of Coastal Management (Office in NOS in NOAA)
PR	Office of Protected Resources (NOAA Fisheries)
RFMO	Regional Fishery Management Organization
SAFMC	South Atlantic Fishery Management Council
SEAMAP	Southeast Area Monitoring and Assessment Program
SECART	Southeast and Caribbean Regional Collaboration Team (NOAA cross-line office)
SECOORA	Southeast Coastal Ocean Observing Regional Association
SEDAR	SouthEast Data, Assessment, and Review, cooperative process for conducting stock assessment projects in NOAA Fisheries' Southeast Region.
SERO	Southeast Regional Office (NOAA Fisheries)
SEFSC	Southeast Fisheries Science Center (NOAA Fisheries)
SF	Office of Sustainable Fisheries (NOAA Fisheries)
SOCAN	Southeast Ocean and Coastal Acidification Network
ST	Office of Science & Technology (NOAA Fisheries)
UGA	University of Georgia
USACE	U.S. Army Corp of Engineers
USFWS	U.S. Fish and Wildlife Service, under the Department of the Interior
USGS	United States Geological Survey

EXECUTIVE SUMMARY

Key climate change drivers that are thought to result in biological impacts in the South Atlantic include warming ocean temperatures, sea level rise, and ocean and coastal acidification. Understanding how major climate drivers such as these will affect marine habitat distribution and quality, ecosystem and estuarine productivity, living marine resources, and their prey in the future is critical for management. These changes could lead to direct and indirect effects on marine resource dependent businesses and communities, such as loss of fishing opportunities or coastal infrastructure due to severe inundation or immersion as sea-level rises. Some resources may become more or less productive and could result in a shift in the availability of living marine resources that support human communities.

The South Atlantic Regional Action Plan follows the approach presented in the NOAA Fisheries National Climate Science Strategy (Strategy, Link et al. 2014). Our ongoing work was assessed and 68 draft actions were identified to help meet climate science needs for the South Atlantic. Of these 68 actions, our highest priorities for climate science information and services include:

- Conduct climate vulnerability assessments for species in the South Atlantic, their habitats, and associated human communities. These analyses will help identify species especially vulnerable to climate change to help identify research gaps and set priorities for the region (Actions #30, 31, 32).
- This vulnerability assessment will help identify and prioritize multidisciplinary data needs for climate science in the South Atlantic. A data needs assessed would include biological, ecosystem, climate, physical, chemical, socio-economic, and other necessary data and would be conducted in coordination with a broad range of federal, state, academic, and non-governmental organizations (NGO) partners in coordination with the Southeast Regional Office (SERO) and Atlantic Oceanographic and Meteorological Laboratory (AMOL). The analysis would include a data gap analysis to assess the adequacy of existing data and surveys to provide climate science information (Actions #55, 57).
- Develop an Ecosystem Status Report for the South Atlantic. This report will include information that can be used to track trends and would include a human dimensions component (Action #39).
- Establish a formal, regional climate team including Southeast Fisheries Science Center (SEFSC), AOML, and SERO participants and others with regular meetings and communications. This team will share ideas, build capacity and strengthen collaboration with regional partners, and spearhead implementation of actions within the Regional Action Plans of the South Atlantic, Gulf of Mexico, and the Caribbean (Action #60).
- Plan and execute a monitoring plan for obtaining and maintaining critical baseline data in the South Atlantic (Actions #41, 57).
- Continue to build the capacity to consider climate science in the stock assessment process, including using environmental covariates in stock assessments (Action #15).
- Hire a management strategy evaluation (MSE) specialist who will use MSE to identify harvest control rules that remain effective during anticipated climate changes (Action #62).

- Collaborate with colleagues across NOAA and external partners to share ideas for developing climate-informed reference points through a workshop or meeting. (Action #1).

All actions are important to meet climate science needs in the South Atlantic, but there is no capacity to accomplish all actions in the near term. The approach for making progress on these activities over the next three to five years with level funding includes strategically aligning existing programs to include climate science, supporting ongoing efforts, and realigning staff if appropriate. The RAP also identifies actions that could be accomplished over the next three to five years with increased funding. Staging the actions appropriately will be important in cases where actions are dependent on others. If funding for this work is received, actions would be prioritized and strategically staged. Without additional funding, the completion of these actions may not be possible within five years. Many of these actions are supported by the NOAA Policy on Ecosystem Based Fisheries Management. There is also considerable overlap between the actions of the South Atlantic, Gulf of Mexico, and Caribbean Regional Action Plans. A Regional Climate Team will help identify these areas of overlap and work to identify partners and areas of collaboration.

INTRODUCTION

Climate change affects every aspect of the NOAA Fisheries mission from fisheries management to protected species and habitat conservation. With this in mind, NOAA Fisheries has developed a NOAA Fisheries Climate Science Strategy (Strategy) (Link et al. 2015) to meet the growing demand for scientific information to better prepare for and respond to climate-related impacts on the nation's living marine resources and resource-dependent communities. The overarching goal is to address and improve the resilience of sustainable fisheries, valuable living marine resources, fishing communities, and businesses in the face of climate change. NOAA defines resilience as the ability to prepare and plan for, absorb, recover from, and adapt to adverse events.

The Climate Science Strategy identifies seven common objectives designed to meet related science information requirements. It is part of NOAA Fisheries' proactive approach to increase the production, delivery, and use of climate-related information to fulfill NOAA Fisheries mandates in a changing climate. Implementing this Strategy is expected to help reduce impacts and increase the resilience of our valuable living marine resources (LMR), and the people, businesses, and communities that depend on them. The seven objectives of the Strategy are considered interdependent and build from basic information needs and science capacity to science-informed decision-making and management (Figure 1).

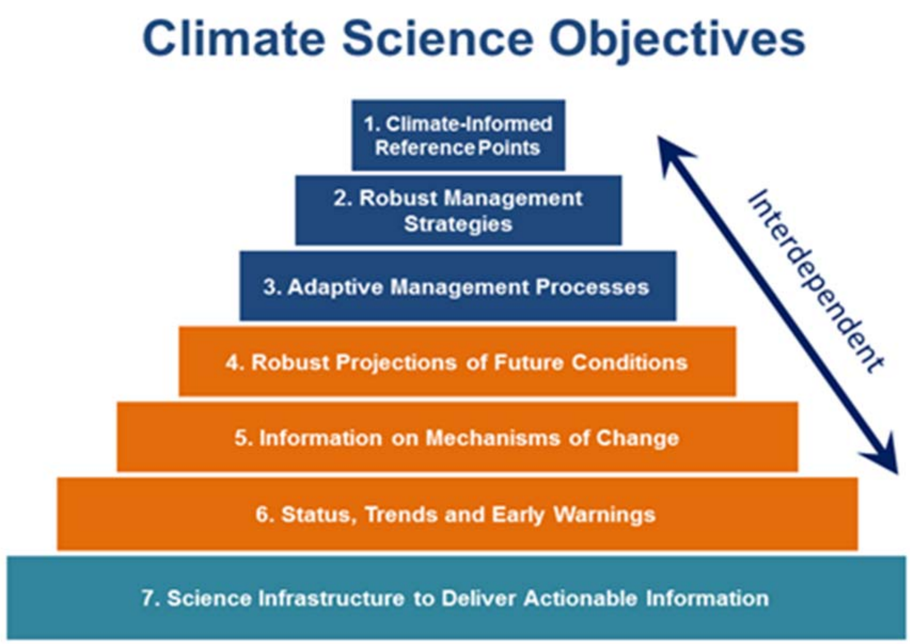

Figure 1. Seven objectives, discussed in the NOAA Fisheries Climate Science Strategy, provide decision-makers with the information they need to reduce negative impacts and increase resilience in a changing climate. Although all 7 objectives are interdependent, they are somewhat sequential -- the upper objectives

build upon the lower ones. The bottom layer (Objective 7) is the infrastructure needed to support production and delivery of information required in Objectives 1-6. Middle layers (Objectives 6, 5, and 4) focus on the collection and production of climate ready information and the monitoring, research, and modeling of the information required to provide climate-ready management advice in Objectives 3, 2 and 1. Top Layers (Objectives 3, 2 and 1) describe the assessment, delivery, and use of climate ready information in management and decision making.

The Climate Science Strategy provides a nationally consistent blueprint to guide efforts by NOAA Fisheries and partners in each region. One of these efforts is the development of Regional Action Plans that are customized and implemented in each NOAA Fisheries region. Regional Action Plans are customized to identify and assess the strengths, weaknesses, and priority actions over the next three to five years. Scientists and managers can use regional action plans to prioritize and identify research gaps, identify potential impacts for marine species and their habitats, and determine best management approaches to reduce impacts and increase resilience of fish stocks, protected resources, fisheries, and fishing-dependent communities. The Strategy and Regional Action Plans are also key parts of NOAA Fisheries efforts to implement ecosystem-based fisheries management (EBFM). EBFM requires consideration of climate and other impacts on marine ecosystems, fish stocks, and fisheries.

This document, the *South Atlantic Regional Action Plan to Implement the NOAA Fisheries Climate Science Strategy* (SARAP), focuses on identifying priority actions that should be considered for the next three to five years to address climate change in the South Atlantic. The SARAP identifies current activities that contribute to the understanding of climate change impacts on living marine resources (LMRs) and management in the South Atlantic. The document also recommends new activities that could be undertaken in the next three to five years to improve our understanding and management. Successful implementation of these actions will require building new and strengthening existing collaborations with partners and stakeholders.

DEVELOPMENT OF THE SOUTH ATLANTIC REGIONAL ACTION PLAN

NOAA Fisheries SEFSC and SERO identified a core working group to develop the SARAP. Participants in the working group were drawn from the different components of the SEFSC and SERO divisions and laboratories across the southeast region, as well as Headquarters Offices and colleagues from the AOML. During development, drafts were shared across all southeast divisions, other NOAA offices, the South Atlantic Fishery Management Council (SAFMC), and Atlantic States Marine Fisheries Commission (ASMFC). This draft will be shared with the general public for input, comment, and revision.

As part of the development of the SARAP, staff considered the outputs of the “Climate Variability and Fisheries Workshop: Setting Research Priorities for the Gulf of Mexico, South Atlantic, and Caribbean Regions,” which was held in October 2015 at St. Petersburg Beach, Florida. The workshop was hosted by the Southeast Coastal Ocean Observing Regional

Association (SECOORA). Workshop participants represented a diverse array of scientific expertise, as well as resource and environmental managers and representatives of the fishing industry.

In a series of facilitated plenary and breakout sessions, participants discussed regional and cross-regional impacts of environmental change on fisheries and other living marine resources and discussed where important research and monitoring needs existed. The workshop executive summary highlighted the participants' top research and monitoring priorities for understanding climate impacts on living marine resources and addressing management needs over the next one to three years. These priority actions were considered by the SARAP core working group during the development of the SARAP plan.

REGIONAL ASSESSMENT

The southeast Atlantic Ocean and coastal region of United States encompasses a large area from Cape Hatteras, North Carolina to Key West, along the Straits Florida. The width of the continental shelf (< 100 m deep) varies across the region, ranging from about 10 km in southern Florida to 50 km off Cape Canaveral to over 120 km off Georgia. This large portion of the region is identified as a Large Marine Ecosystem (LME) and has a surface area of about 300,000 km^2. The Gulf Stream, a powerful ocean current, is the dominant oceanographic feature that strongly influences the oceanographic and temperature dynamics of the outer (40 m – shelf break) continental shelf waters. It originates off south Florida, bringing warm water northward along the southeast coast of the U.S., and its meanders and warm and cold core rings significantly affect the physical oceanography of the continental shelf and slope. These features also tend to aggregate prey and predators, and are frequently targeted by commercial and recreational fishing activities. The inner (0-20 m) and middle (20-40 m) shelves are dominated by 18 estuaries, including the Albemarle-Pamlico Sound (the second largest estuary in the nation) and Indian River Lagoon, river systems, and their runoff; local winds; and Gulf Stream eddies (Atkinson et al. 1985; Lee et al. 1991). Even so, the southeast U.S. Atlantic continental shelf is characterized by relatively low freshwater input as compared to other regions of the U.S. and lacks a nutrient rich water mass, such that inorganic nitrogen rarely accumulates in resident shelf waters (Yoder 1991). The mid-shelf current flow is strongly influenced by local wind events with frequencies of two days to two weeks. Vertically well-mixed conditions are present in fall and winter, in contrast with vertically stratified conditions in the spring and summer.

The primary source for delivery of nutrients to the southeast U.S. continental shelf waters is Gulf Stream induced upwelling events of North Atlantic Central Water (NACW) that occur approximately every ten days, related to the strength and position of the Gulf Stream and upwelling-favorable winds (Atkinson 1977, Lee & Atkinson 1983, Hyun & He 2010). Winter and spring conditions affecting wind and the density of shelf water usually inhibit the NACW from penetrating beyond the outer shelf. In contrast, summer wind conditions and warmer, less dense shelf waters are more favorable to allow penetration of NACW shoreward as a bottom intrusion of the outer and middle shelf, and the narrow inner shelf off Florida (Yoder et al. 1985; Yoder 1991). Upwelling typically occurs when the Gulf Stream is more intensive, located closer to shore, and southwest winds are consistently strong, causing deep, cold, nutrient-rich waters to replace surface waters that have been pushed northward and eastward (Aretxabaleta et al. 2006; Hyun & He 2010). The nutrient rich, cold NACW bottom intrusions give rise to plankton blooms and are the most important processes affecting summer plankton productivity where they occur (Yoder 1991). Plankton blooms, in turn, can affect life history processes at higher trophic levels such as fish larval development (Yoder 1983) and spawning (Checkley et al. 1988).

As a whole, the Southeast U.S. Continental Shelf LME is considered a moderately productive Class II ecosystem (150-300 gCm-2yr-1; Aquarone 2009), largely due to the interactions between the Gulf Stream and continental shelf waters, as well as substrate types. Substrates on the continental shelf and shelf-break consist primarily of sand and mud substrates, with patches of hard, rocky temperate reefs scattered throughout the region (Miller & Richards 1980; Schobernd & Sedberry 2009). Pelagic fish species that occur over hard and soft bottom substrates include mackerels, tunas, and bonitos (scombrids); jacks, pompanos, jack mackerels, and scads (carangids); herrings, shads, and menhandens (clupeids); and anchovies (engraulids). In the benthic fish community, various drum and croakers (sciaenids), porgies and sea bream (sparids), flounders (paralichythids), sea robins (triglids), tilefishes (malacanthids), and others occur over soft substrates (Walsh et al. 2006), while snappers (lutjanids), groupers and sea basses (serranids), trigger fish (balistids), grunts (haemulids), and others mainly occur over hard substrates (Bacheler et al. 2013). Tropical coral reefs also occur off southeastern Florida and the Florida Keys, with associated diverse fish communities, and deep-water coral pinnacles range from Florida to North Carolina (Lumsden et al. 2007). The warming influence of the Gulf Stream allows tropical and subtropical species to inhabit areas as far north as North Carolina (Miller & Richards 1980), especially in deeper water (Whitfield et al. 2014).

Large scale circulation systems that influence the oceanography of the southeastern U.S. Atlantic and Gulf Stream include the Atlantic Meridional Overturning Circulation (AMOC) and the Atlantic Multidecadal Oscillation (AMO). The AMOC is a current in the Atlantic Ocean that carries warm upper waters into far-northern latitudes and returns cold deep waters southward into the South Atlantic. It is a major transporter of heat from the tropics into the North Atlantic and changes in the AMOC are predicted to have profound implications for climate change (Bryden et al. 2005; Smeed et al. 2014). The AMO is a measure of basinwide sea surface temperature variation in the North Atlantic that switches between cool and warm phases; these oscillations occur on scales of 55-70 years (Knudsen et al. 2011). The AMO has been linked to a number of drivers and pressures influencing the region, such as Atlantic hurricane activity (Vimont and Kossin 2007), depth of the mixed layer, and the size of the Atlantic Warm pool (Zhang et al. 2012).

There is limited information on large-scale patterns of environmental change that can be attributed to climate change in the southeastern U.S. Atlantic region, due in part to incomplete region-wide ocean observing systems and limited knowledge on the influence of natural long-term variability (Hoegh-Guldberg et al. 2014). The Gulf Stream appears to be weakening along with the broader, related AMOC (Ezer et al. 2013; Rahmstorf et al. 2015), which may have implications for regional primary and secondary productivity patterns if it results in declines in the magnitude, duration or frequency of Gulf Stream-related upwelling events.

Changes in Gulf Stream strength have also been found to be highly correlated with changes in coastal sea level north of Cape Hatteras, North Carolina; accelerated sea level rise is possibly linked to weakening in the Gulf Stream (Ezer et al. 2013). Models of projected sea level rise are showing that most areas in the southeast US region can expect approximately 0.75-1m rise in sea level by 2100 (Kopp et al. 2014, Parris et al. 2012). Even under median warming scenarios, flooding hazards due to sea level rise in the southeast will significantly increase (Little et al. 2015). In addition to coastal flooding, sea level rise will result in seawater inundation and erosion causing loss of estuaries and freshwater wetlands, with potential negative effects to estuarine species less tolerant of salinity changes and changes in estuarine productivity (Zhang et al. 2004; Ogden et al. 2005; Arroyo et al. 2011; Ezer and Atkinson 2014).

The Atlantic coastline in the southeast U.S. is dominated by flat coastal marshes in the Carolinas and the limestone landscapes of south Florida. Salt marshes in US South Atlantic estuaries are important habitats that support many fishery species including penaeid shrimps, blue crabs, groupers, snappers, and numerous finfish, and flooding of the vegetated edge of the marsh appears to be important in determining the value of this habitat for these species (Rozas 1995). Changes in spatial extent and water quality of estuarine habitats will likely be ecologically as well as economically significant because of commercially important estuarine dependent species.

Barrier islands such as North Carolina's Outer Banks provide physical barriers between waves and tidal energy of the ocean and mainland features. However, increased severe storms numbers and intensity are predicted for this region (Ingram et al. 2013). In addition to important coastal infrastructure supporting fisheries, it also presents risk for marine aquaculture. Significant impacts to the aquaculture industry from hurricanes has already been realized in the southeast U.S region including damage to hatcheries, loss of aquaculture gear, mortality of shellstock owing to sand movement due to high wave energy, and loss of broodstock (J. Morris, pers. obs).

Increased ocean temperature is expected to have a range of impacts to ocean ecosystems affecting biodiversity redistribution, water quality, physiology, and eutrophication (García Molinos et al. 2015; Holmyard 2014; Intergovernmental Panel on Climate Change (IPCC) 2014). In the southeast U.S. region, sea surface temperature is predicted to increase by as much as 3^{0}C by 2100 (Ingram et al. 2013). However, analysis of bottom-water (seafloor) temperature data collected from April – October during southeast fishery-independent surveys (the cooperative Southeast Reef Fish Survey (see Bacheler et al. 2014) and the <u>SEAMAP-South Atlantic Coastal Trawl survey</u>) indicate that mean seafloor water temperatures have not changed considerably over the past several decades. Data suggest an annual increase of 0.01°C in seafloor water temperature over the time series, and due to high inter-annual variability, it results in an insignificant ($P = 0.63$) annual increase.

Because climate change is projected to include a suite of environmental shifts (Hollowed et al. 2013), it is difficult to predict with certainty how marine ecosystems in the U.S. southeast Atlantic region will be affected. While there have been many studies on climate change and fisheries impacts in other areas of the Atlantic (Fogarty et al. 2008; Gaichas et al. 2014; Nye et al. 2009; 2013), there are few examples of clear or likely climate effects on southeastern fish and fisheries. It is expected that species distributions will shift poleward with climate change, and there is evidence of warming of Mid-Atlantic shelf-edge waters (Forsyth et al., 2015) that would support this hypothesis. Hare et al. (2010; 2012) predicted a northward range expansion of Atlantic croaker (*Micropogonias undulatus*) and gray snapper (*Lutjanus griseus*), due to warming temperatures and related decreases in young-of-the-year winter mortality in the northern portion of the range of those species. Fishery landings of blueline (gray) tilefish (*Caulolatilus microps*), which are found at depths of about 30 - 300 m throughout the southeast region, have increased considerably in recent years in the Mid-Atlantic region. Commercial landings of blueline tilefish from Virginia-north averaged 11,000 lb per year for 2005-2013. However, commercial landings in 2014 increased to over 217,000 lb (MAFMC 2015). Anecdotal reports also suggest landings of snowy grouper (*Epinephelus niveatus*), which occur in similar depths as blueline tilefish, may be increasing in Mid-Atlantic waters. Such observations are consistent with earlier studies, such as one by Parker & Dixon (1998) which found increases in abundance and species richness of tropical reef fish species on a North Carolina hardbottom site in the period 1990 -1993, as compared to studies done earlier in the period 1975-1980.

In an ongoing effort, J. Morley and M. Pinsky (Rutgers University) are examining SEAMAP-South Atlantic Coastal Trawl survey data (1990-2014) to assess whether species-specific shifts in distribution have occurred over time. Preliminary results indicate no major directional trends in distribution shifts, with similar numbers of species shifting northward and southward, respectively, during the study period.

Future climate-related warming of coastal and ocean waters could favor further expansion of invasive species, such as lionfish. Range expansion north of Cape Hatteras and into the nearshore waters of the North Carolina shelf, could result in predation- and potentially competition-driven impacts in those areas (Whitfield et al. 2014). The broader impact of lionfish on temperate reef fish communities and related fisheries has yet to be assessed.

In terms of habitat, warming air temperatures have likely been the driving factor that has led to the documented northward expansion of mangrove habitats along the Atlantic coast of Florida (Saintilan et al. 2014). This could result in increased production of fish species that utilize mangrove habitats as juveniles (Serafy et al. 2015 and references therein). Warming temperatures are expected to also result in increased coral bleaching and susceptibility to disease, with cascading effects on the fish and invertebrates that utilize coral reefs as habitat (e.g., Graham et al. 2007). Patterns of decreasing coral cover over time have been documented in the Florida Keys (Palandro et al. 2008; Ruzicka et al. 2013; Toth et al. 2014).

Ocean and coastal acidification is a stressor which has the potential to affect organisms directly or indirectly. Ocean acidification can weaken the framework of coral reefs, making them more susceptible to storm damage and affecting reef dependent organisms (Alvarez-Filip et al. 2009, Fabricius et al. 2014) such as the snapper-grouper complex. While no data are available at the southeast regional scale, data have been collected at Gray's Reef National Marine Sanctuary beginning in 2006 and indicate increasing atmospheric and seawater CO2 concentrations (Scott Noakes, University of Georgia, unpub. data). Studies are needed to determine how ocean acidification will impact southeastern shallow- and deep-water coral reefs and their associated ecosystems (Kleypas et al. 2006).

In the laboratory, ocean and coastal acidification has resulted in numerous physiological and behavioral changes to finfish, including decreased larval survival and growth rates (Bromhead et al. 2015), decreased hunting efficiency (Pistevos et al. 2015), altered settlement/habitat preference cues (Munday et al. 2009), and changes in circadian clocks (Schunter et al. 2016). It has also been shown to impact shell formation and other physiological functions in mollusks (Allison et al. 2011; Hilmi et al. 2015), increase mortality and reduce growth of eastern oysters (Dickinson et al. 2012), and delay juvenile development in boreal shrimp (Bechmann et al. 2011). Yet Ekstrom et al. (2015) predict that at large regional scales, ocean acidification effects and impacts on regional shellfish growers will remain low in the southeast U.S. region until after 2099. Acidification impacts may arise in some coastal regions where river discharge and eutrophication locally accentuate it through microbial degradation of organic matter, which increases carbon dioxide production and lowers seawater pH (Wallace et al. 2014).

STRENGTHS, WEAKNESSES, AND OPPORTUNITIES

The SEFSC and its partners are in a good position to increase the production, delivery, and use of climate-related information required to fulfill NOAA Fisheries mandates. Weaknesses and a number of opportunities were identified through the assessment and development of this Regional Action Plan. This review is not meant to be comprehensive, but seeks to identify some examples of regional strengths, weaknesses, and opportunities, and the latter are described in more detail in the description of actions that follow.

Strengths

Expert staff conducting rigorous scientific studies in the Southeast U.S. Atlantic, strong partnerships across the region, and a history of resource surveys in the Southeast U.S. Atlantic are three examples of our strengths.

The SEFSC has experts conducting climate relevant research across the southeast region. SEFSC scientists have conducted research on the effects of hypoxia on commercially important finfish species (Craig et al. 2005, Craig 2012, Craig and Bosman 2013), the effects of red tide on mortality of grouper species (Walter et al. 2013), and has ongoing research into the drivers of recruitment strength in snapper and grouper species (Karnauskas et al. 2013). SEFSC research on coral reef ecology includes responses of corals to various physical drivers (Miller et al. 2009; Albright et al 2010) as well as monitoring to track population status (Williams et al 2006). SEFSC scientists that are using biophysical modeling to assess red snapper population connectivity within and between the Gulf of Mexico and Southeast U.S. Atlantic have also partnered with physical oceanographers in AOML to carry out research related to larval ecology and predicted climate impacts on large pelagic species such as bluefin tuna (Muhling et al. 2011, Muhling et al. 2015). Scientists in the southeast also have a thorough understanding of the oceanographic circulation of the Gulf of Mexico, and AOML scientists have developed various downscaled models of climate predictions for the Gulf of Mexico that provide the basis for an understanding of future physical states in this region, including studies of the North Atlantic Meridional Overturning Circulation and its links to Gulf Stream dynamics (McCarthy et al 2014; Perez et al 2015; Liu et al. 2012; Objective 4). SEFSC scientists and partners are also studying effects of sea level rise to coastal habitats such as salt marshes and mangroves, which are important nursery habitats for LMRs (Zimmerman et al 2000; Ellin et al 2013; Ensign et al 2016). Southeast Economics & Human Dimensions scientists have been building the tools to assess the impacts of fishery management actions for some time. Many of these tools help form the basis for building both economic and social assessment of climate change.

Strong partnerships with a wide variety of federal, state, university, non-governmental, and international partners have been maintained. These partnerships are a strong foundation for leveraging science and research in support of management objectives in light of anticipated climate impacts on ecosystems and human communities in the Southeast U.S. Atlantic. For example, the SEFSC maintains close collaborations with SERO, AOML, GFDL, the SAFMC, ASMFC, South Atlantic Large Marine Ecosystem program, international partners and Regional Fishery Management Organizations (e.g., the International Convention for the Conservation of Atlantic Tunas (ICCAT)), and other organizations (e.g., Food and Agricultural Organization (FAO), and Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES), Intergovernmental Oceanographic Commission Sub-Commission for the Caribbean and Adjacent Regions). Cooperative institutes in the region such as the Cooperative Institute for Marine and Atmospheric Studies (CIMAS) at the University of Miami and the Cooperative Institute for Ocean Exploration, Research and Technology (CIOERT) Northern Gulf Institute will continue to be important in facilitating collaboration (Objective 7).

Research in the region is also supported by a history of data collection efforts in the Southeast U.S. Atlantic. SEFSC coordinates over a dozen resource surveys in the region on an annual or biennial basis. These surveys are designed to sample a variety of LMRs across life stages, including shrimp, groundfish, small pelagics, reef fish, ichthyoplankton, juvenile and adult sharks, coral and benthic communities, and protected resources. Five of these surveys are conducted on NOAA ships, whereas the remaining are conducted on smaller federal, state, university, or contract research vessels.

While some surveys are conducted exclusively by NOAA Fisheries, others are conducted in conjunction with various state and university partners, best exemplified by the Southeast Reef Fish Survey (SERFS). SERFS is a cooperative (SEFSC and South Carolina Department of Natural Resources Marine Resources Monitoring, Assessment, and Prediction, [MARMAP]) fishery-independent monitoring and research program initiated in 2010 that merged with the long-term MARMAP program. MARMAP began in 1972 with trawl and larval fish surveys, while the current primary gear of SERFS consists of chevron traps with attached video cameras that are deployed at 1500 stations from St. Lucie Inlet, FL to Cape Hatteras, NC. SERFS is a region-wide survey that targets limestone or hard bottom reef-associated species on the continental shelf and continental shelf-break of the Southeast U.S. Atlantic.

The Southeast Area Monitoring and Assessment Program (SEAMAP) SEAMAP is a fisheries-independent collaborative sampling program conducted from 1983 to the present that assesses the abundance and distribution of fish and demersal invertebrate fauna in South Atlantic shelf waters. The SERFS (with MARMAP and SEAMAP) are the only existing long term fishery-independent survey off the Southeast U.S. Atlantic that monitors reef fish length frequency, abundance, and life history. These data provide critical input for the assessments of stock status conducted by NMFS, and greatly assist stock assessment scientists and decision makers in the management of the snapper/grouper complex in the southeastern U.S. Atlantic. Data from these surveys provide a long time series that has been used in various stock assessments, integrated ecosystem assessments, and to develop annual hypoxia maps. Data collected by these ongoing programs are important for detecting trends and changes in abundance and distributions of LMRs as they relate to environmental and climate changes in the Southeast U.S. Atlantic (Objective 6 & 7).

Weaknesses

With the strengths described above, there are also numerous challenges to achieving the goals and implementation of the NOAA Fisheries Climate Science Strategy, including infrastructure and region-wide coordination needs.

Meeting climate science needs in the Southeast U.S. Atlantic while also addressing the full scope of SEFSC responsibilities will strain existing staff time and resources. Conducting needed climate science research, from project design to working with managers to implement research findings, requires substantial staff time, effort, and expertise. While SEFSC scientists have been able to conduct some climate-related research in the Southeast U.S. Atlantic, much of this work has depended on proactive interest of the individual and personally forged collaborations with academic and federal partners, and has been funded opportunistically, often using a combination of programmatic funds and competitive funding opportunities. These scientific pursuits are the cornerstone of any research enterprise, but do not offer a systematic way to meet climate science needs in the region. Resources directed at climate-related science and research in the Southeast must be distributed and balanced across the needs of the SEFSC's three major sub-regions of jurisdiction, the Southeast U.S. Atlantic region, U.S. Virgin Islands and Puerto Rico in the Caribbean, and the Gulf of Mexico. Fully addressing the emerging needs of managers seeking scientific advice related to climate impacts and other changes in these regions would benefit from strategic planning for resources and workforce (Objectives 2 & 7).

The importance of strong baseline monitoring in strengthening our understanding of relationships between LMRs and their dynamic environments cannot be overemphasized. Few fisheries and protected resource surveys in the Southeast U.S. Atlantic occur on spatial and temporal time scales that allow scientists to resolve links between climate drivers and species, populations, or ecosystem responses. Most data collection efforts were initiated and grew in response to management questions or problems, and therefore coordination and standardization among these surveys could be improved. Current surveys would also benefit from the coupling of biological observations with physical environmental parameters, and from making data collection efforts more fully compatible to increase the power to detect change, ascribe mechanistic causes, and predict future states (Objectives 3, 4, 6 & 7). With new data streams, however, there would be a capacity challenge for processing samples and conducting data analysis and modeling. For example, determining climate-informed reference points for management will be a genuine challenge and will require in many cases additional data, analyses, and modeling that exceeds current practices, staffing, and funding levels (Objectives 1, 2, 3, 4, 5, 6, & 7).

Greater region-wide coordination and targeted partnerships for climate science research could strengthen our ability to prioritize information needs, leverage existing resources, and enhance our ability to deliver critical climate science in the Southeast U.S. Atlantic. Dialogue between scientists, managers, and stakeholders including fishermen can always be strengthened. For example, boosting partnerships with stakeholders in the region could lead to hypotheses by hearing from fishermen who have observed changes over their careers or new data by implementing a Citizen Science program.

Opportunities

The SARAP provides a plan for acting on opportunities highlighted by assessing our climate science strengths and weaknesses in the Southeast U.S. Atlantic.

Strengthening climate science coordination within NOAA and with other partners throughout the Southeast U.S. Atlantic will be critical to leveraging resources (expertise and funding) and identifying efficiencies where possible to meet escalating demands for science, particularly in a budget-constrained environment. There is a need to build new and strengthen existing partnerships in the region by identifying potential partners to engage or coordinate with for implementing each action item within the plan. The plan identifies the need to continue to work closely with SERO, AOML, other NOAA programs and laboratories, Federal partners, States, the SAFMC and ASMFC, academia, private research facilities, the fishing industry, environmental NGOs and other partners around the Southeast U.S. Atlantic. Through the establishment of a regional NOAA climate team including staff from SEFSC, SERO, HMS, AOML, and other regional partners, our ability to identify research gaps, identify overlapping needs for climate science, generate multidisciplinary strategies, leverage existing data, and set joint priorities will be enhanced(Objective 7).

There is also an opportunity to conduct strategic planning for climate science in the Southeast U.S. Atlantic (Objective 7). Evaluations of our current suite of surveys and data for gaps, coordinate and standardize data collection efforts across the region, identify climate ready cruises in coordination with partners, and work with partners to develop a comprehensive and coordinated plan for meeting climate science needs is essential. The RAP identifies the need to incorporate planning recommendations that have come from recent reviews, such as the March 2016 Ecosystem Science Program Review and the NOAA Fisheries Economics & Human Dimensions Program Climate Science Workshop, and to integrate with EBFM efforts that dovetail with climate science priorities. Conducting climate vulnerability assessments for species in the Southeast U.S. Atlantic and their habitats, and linking those analyses to the fisherman and communities that depend on these species is also top priority for the Southeast region. Vulnerability analyses will help identify process-based research gaps and priorities for related field and laboratory research for the SEFSC and can be integrated into planning for climate science needs in the region (all Objectives).

Even with partnerships, the SEFSC will need to expand its climate expertise. Strategic planning for climate science provides an opportunity to assess our climate science capacity and the workforce investments that may be necessary to secure scientific and coordination expertise. There may also be an opportunity to expand appropriate professional development and training for existing staff to enhance our current capabilities and foster the sharing of skills and techniques, as well as creativity and innovation (Objective 7).

Planning for meeting the scientific needs of managers in the Southeast U.S. Atlantic also presents an opportunity to work with the broad range of managers and stakeholders across the region to ensure that our products and tools are aligned with the most critical needs of the end-users of our information. Strengthening capacity to interact with managers and stakeholders and to maintain liaison activities between science and management is critical (Objectives 1, 2, 3, 7). Initial planning and coordination to capitalize on these opportunities will stretch current capacity, but has the potential to provide enhanced research efficiencies, expanded partnerships, and enhanced capabilities. These are all important means to support climate-informed decision-making that can mitigate or reduce anticipated climate impacts or provide adaptive responses to increase resilience for fisheries, protected species, and coastal communities.

ACTION PLAN

Scientific data, information, and advice produced by NOAA Fisheries and partners across the region are critical to managing living marine resources in the US South Atlantic. NOAA Fisheries SEFSC and the SERO consist of a strong scientific and management team with expertise that crosses many disciplines. The goal of most ongoing science and research supports living marine resource management in today's world and often must address immediate, short term needs and questions. To monitor and understand the impacts of the changing climate on living marine resources and the habitats and ecosystems upon which they depend, will require the SEFSC to rebalance existing resources and expertise, expand our strategic vision with partners, and enhance science infrastructure.

The South Atlantic Regional Action Plan team assessed ongoing work and identified 68 actions to help meet climate science needs for the South Atlantic. In this section and in Table 1, our approach for making progress on these activities over the next three to five years is described with level funding by strategically aligning existing programs to include climate science, re-directing staff as needed and appropriate, and collaborating with partners. Actions that could be accomplished over the next three to five years with increased funding are also included. As funding becomes available, prioritization and scaling of these actions will be done as needed to meet our needs within the constraints of any new resources. Some actions in the plan are necessary prerequisites for others, and there is a need to consider sequencing activities appropriately in the event that funding becomes available. Actions are presented in relation to the seven Strategy objectives identified in Figure 1.

Action Table

Table 1. DRAFT SOUTH ATLANTIC REGIONAL ACTION PLAN TABLE
Shaded actions indicate action items that require increased funding. If additional funding is received, the SEFSC would prioritize and strategically stage these actions. Acronyms are found on p.iii.

No.	Action Name	Funding Scenario	Time Frame (years)	Action Description	Partners

Objective 1 – Climate Informed Reference Points					
1	Workshop for Climate Informed Reference Points	Level	2017-2021	Collaborate with colleagues across NMFS, NOAA and external partners on approaches for developing climate-informed reference points.	SERO, ST, SF, HMS, AOML, Regional Climate Centers (Southern), NOAA's National Climate Data Center, Southeast and Caribbean Regional Collaboration Team (SECART), Academia, SEDAR, ICCAT, IEA partners
2	Climate Informed Reference Points	Level and increase	2017	Evaluate the capacity of the current stock assessment methodology to account for environmental and climatic impacts when estimating management points to produce climate-appropriate reference points and buffers.	SERO, SAFMC, HMS
3	Climate Informed Reference Points	Increase	2017-2021	Incorporate environmental and climatic impacts in the establishment of reference points and use in stock assessments.	SERO, HMS, SAFMC
4	Climate Informed Reference Points	Increase	2017-2021	Continue to incorporate climate and ecosystem considerations into Essential Fish Habitat and Habitat Areas of Particular Concern designations, National Environmental Policy Act Reviews, restoration planning, and other management actions and products.	SERO, HC, PR, HMS, ST, SAFMC, NOAA Restoration Center
5	Climate Informed Reference Points	Level	2017-2021	Continue and expand incorporation of climate-related information and uncertainty into protected species reference points and related ESA actions (i.e. incidental take recommendations, biological opinions, listing, recovery, critical habitat designation) in a consistent manner across the region.	SERO, PR, ST, Academia
6	Climate Informed Reference Points	Increase	2017-2021	Assess stakeholder priorities to establish societal objectives for resource distribution and productivity in fisheries, and develop reference points to assess the impact of climate change scenarios relative to the societal objectives.	SERO, SF, HMS, ST, SAFMC, Sea Grant
Objective 2 – Robust Management Strategies					
7	Management strategy evaluation	Increase	2017-2021	Use Management Strategy Evaluations to identify harvest control rules, mitigate vulnerability, and/or promote resilience of coastal communities that remain effective during anticipated climate changes.	SERO, HMS, SF, SAFMC, States, Sea Grant Climate Community of Practice
8	Management Strategies	Level and	2017-2021	Continue and expand collaborative work with international neighbors, RFMOs and	SERO, SAFMC, ASMFC, HMS,

		increase		partners to incorporate climate impacts and ecosystem processes into management objectives and actions.	Department of State, ICCAT, FAO, CITES, Academia, Gulf of Mexico Alliance, Mexico, Cuba, and others
9	Ecosystems Considerations	Increase	2017-2021	Develop an ecosystem considerations summary (similar to Alaska Marine Ecosystem Considerations 2014 Report or SAFE report) for the South Atlantic to accompany management documents.	SERO, ST, SF, HMS, PR, SAFMC
10	Management Strategies	Increase (or reallocation)	2017-2021	Develop management strategy (in concert with research & development under Obj 5) to guide implementation of assistive strategies to enhance climate resilience of reef corals.	FKNMS, SERO, NPS, Florida FWC
Objective 3 –Adaptive Management Processes					
11	Decision tables	Level and increase	2017-2021	Develop capacity to present quantitative advice using decision-theoretic approaches.	Academia, NOAA Climate Services Program, and Regional Integrated Sciences and Assessments Teams
12	Events analysis	Increase	2017-2021	Improve the ability to respond in real time to future climate related events.	SERO, NOS/NCCOS, NOAA Office of Response and Restoration, Damage Assessment, Remediation and Restoration Program
13	Fishermen observations (citizen science)	Increase	2017-2021	Establish more formal methods for scientists and managers to learn about ecosystem and potential climate-related changes observed by senior fishermen and other stakeholders who are on the water frequently.	Fishing industry, SERO, SAFMC Citizen Science program and Advisory Panels, HMS, Sea Grant
14	Increase dialogue	Level and increase	2017-2021	Increase dialogue between scientists and managers to enhance the collaborative adaptive management process.	SERO, HMS, SF, ST, PR, HC, NOAA Restoration Center, AOML, SAFMC,
15	Environmental covariates in stock assessments	Level and Increase	Ongoing	Continue to include environmental covariates in stock assessments.	SERO, AOML, SAMFC, HMS, SEDAR
16	Ecosystem Status	Ongoing / level	2017-2018	Contribute to the revision of the SAFMC Fishery Ecosystem Plan and identify the synergies between the FEP and the RAP.	SAFMC, SERO
17	Community resilience	Increase	2017-2021	Identify and discuss major factors (human and natural) that would increase the resilience of fishing communities highly vulnerable to climate change impacts.	SERO, NOS/NCCOS, HMS, Sea Grant, Climate Community of Practice, SECART

18	Protected resources management	Increase	2017-2021	Incorporate climate science adaptive management plans into Endangered Species Act analyses and reports.	SERO, PR, HC
Objective 4 – Project Future Conditions					
19	Downscale climate model validation	Increase	2017-2021	Evaluate, validate, and improve regional downscaled ocean-biogeochemistry models that are currently known to resolve key regional ocean processes reasonably well. Identify how to improve the models in the future.	AOML, Academia, GFDL, NOS-NCCOS-CSCOR, NOAA Climate Services
20	Physical and biological predictions	Level	Ongoing	Use a high-resolution regional ocean biogeochemistry model to downscale the CMIP5 model projection of carbon and biogeochemical parameters for the South Atlantic.	AOML, Academia
21	Physical and biological predictions	Increase	2018-2021	Expand research to assess the downstream effects of Gulf Stream oceanographic changes on populations of managed species (see Action #35).	SERO, ST, PR, SF, HMS, HC, OAR, AOML, GFDL, Academia
22	Apply models	Level	Ongoing	Continue research on sea level rise and use existing down-scaled climate models to map predicted coastal flooding.	AOML, NOS, USGS, HCD, SERO, PR, HC, Academia (UNC IMS), USACE NOS-NCCOS-CSCOR-Ecological Effects of Sea Level Rise, States
23	Apply models	Increase	2018-2021	Apply existing down scaled climate models to evaluate climate impacts on species identified via vulnerability analyses and their critical ecosystem habitats (coral reef, estuarine spawning habitat).	AOML, Academia, NSF, South Atlantic IEA team
24	Apply models	Increase	2017-2021	Collaborate with partners who have climate data and evaluate effects of climate change on the frequency of unusual mortality events for protected species in the South Atlantic.	SERO, AOML, NOS, States
25	Apply models	Increase	2017-2021	Integrate outputs from climate models into existing spatial density models for marine mammals to predict potential changes to their distributions.	AOML, GFDL, USGS
26	Apply models	level/ increase	2017-2021	Continue research applying biophysical modeling and other approaches to assess red snapper population connectivity within and between Gulf of Mexico and South Atlantic regions.	University of Miami, NC State University, FL Fish and Wildlife research Institute
27	Standard modeling toolbox	Increase	2017-2021	Develop a standard modeling toolbox and best practices for modeling under uncertainty to link future ocean and freshwater states and LMRs, with ability to couple models across types.	SERO, AOML,HMS, SAFMC, Academia
28	Predict income	Increase	2017-	Assess the potential economic impact of	SERO, ST, HQ, HMS,

	distribution and productivity		2021	climate change on the commercial and recreational fishing industries for the South Atlantic region.	NOS, Academia, Sea Grant
29	Predict impacts on community well-being	Increase	2017-2021	Assess impacts of different climate change scenarios on the well-being and vulnerability of fishing communities in the South Atlantic.	SERO, ST, NOS, AOML, HMS, Academia, Sea Grant, Climate Community of Practice
Objective 5 – Understand the Mechanisms of Change					
30	Vulnerability assessments	Level	2017	Conduct the scoping necessary for implementing vulnerability assessments for South Atlantic species (fish, marine mammals, sea turtles, other protected species).	SERO, NOAA Fisheries HQ, AOML, HMS, NOS, NOAA Climate Program
31	Vulnerability assessments	Level and increase	2017-2018	Conduct species climate vulnerability assessments.	SERO, ST, PR, SF, HMS, HC, SAFMC, AOML, Academia, South Atlantic LCC (for habitat)
32	Vulnerability assessments	Increase	Ongoing	Adapt community social vulnerability indices for coastal and fishing communities in the South Atlantic based on the outcome of species vulnerability analyses.	SERO, HMS, ST, NOS, Sea Grant, Climate Community of Practice, SAFMC
33	Research	Increase	2017-2021	Expand collaborative research efforts focused on understanding the drivers and mechanisms of changing climate conditions in the South Atlantic.	AOML, NOAA Climate Program, USGS, USFWS, Academia
34	Research	Increase	Ongoing	Continue research on the climate driven displacement of ecologically important habitats.	SERO, HC, PR, Academia, State agencies, USFWS, USACE
35	Research	Increase	2017-2021	Conduct research on influence of Gulf Stream oceanographic characteristics (including Gulf Stream positional variability, AMOC, and eddies) on populations of managed, ecologically, and economically important species, their habitats, and the potential effects of climate change on those influences. Also see Action #21.	SERO, ST, PR, SF, HMS, HC, OAR, AOML, GFDL, Academia
36	Research to develop assistive coral enhancement strategies	Increase	2017-2021	Identify, develop, and assess the risks of tools to improve and propagate climate-resilience traits within reef coral populations.	AOML, Academia, NCCOS,
37	Research on coral stress and disease	Increase	2017-2021	Conduct research to better understand and develop means to mitigate the linkage of warm-stress-induced coral bleaching with subsequent coral disease outbreaks and mortality.	AOML, Academia, NCCOS
38	Research	Level	Ongoing	Coordinate with SOCAN and UGA to identify and address issues related to ocean acidification in the region.	SOCAN, UGA , SERO

Objective 6 – Track Change and Provide Early warnings					
39	Ecosystem Status Report	Partial with level, increase	Ongoing	Develop an Ecosystem Status Report for the South Atlantic Region.	SERO, SAMFC,HMS, AOML, and others
40	Baseline data; tracking change	Level	Initiated	Discuss options for coordinating fishery-independent survey approaches to improve the utility of survey-generated information pertaining to species whose ranges overlap the South Atlantic-Mid-Atlantic boundary.	NEFSC, GARFO, ASFMC, MAFMC, SAFMC
41	Baseline data	Increase	2017-2018	Create a strategy to identify new and maintain critical baseline data identified in the South Atlantic comprehensive monitoring program (see Objective 7).	SERO, NCEI, States, Academia
42	Baseline data	Level	2017-2018	Explore the feasibility (technical and budget) of conducting a comprehensive, South Atlantic-wide survey for marine mammals.	PR, BOEM, Academia
43	Baseline data	Increase	2017-2021	Collaboratively assess socio-economic data needs for examining impacts of climate change on fishing and coastal communities.	SERO, ST, HQ, SF, HMS, Economic Development Administration
44	Baseline data	Increase	2017-2021	Establish a network for long-term monitoring of protected resources, such as nesting populations of sea turtles in the South Atlantic.	SERO, FWS, state agencies, and others
45	Baseline data	Increase	2017-2021	Build or expand partnerships for coordinating an in-water monitoring long-term network for sea turtles.	SERO, FWS, state agencies
46	Baseline data	Increase	2017-2021	Build or expand partnerships to determine changes to marsh, mangrove, and other shoreline habitats from climate change.	SERO, PR, HC, Academia, USFWS, USGS,USACE, State labs (FWRI)
47	Tracking change	Increase	2017-2021	Conduct a needs assessment for the components of an early warning toolbox for the South Atlantic Region.	AOML, NOAA Climate Program, Academia
48	Tracking change	Increase	2017-2021	Explore social and economic indicators that could provide early warnings about impacts on the fishing industry and fishing communities.	SERO, ST, HQ SF, HMS, NOS, NOAA Climate Program, Sea Grant
49	Tracking change; coral	Partial with level, increase	Ongoing	Continue coral monitoring efforts to track population status over changing environmental conditions.	AOML, Academia, NCCOS, NPS
50	Build capacity	Level	2017-2019	Continue to collaborate with South Atlantic Large Marine Ecosystem Program to obtain critical baseline data and track changes in the South Atlantic	South Atlantic Large Marine Ecosystem Program
51	Baseline data; tracking	Increase	2018-2021	Implement survey calibration studies or expand current surveys across the South	NEFSC, GARFO, ASFMC, MAFMC,

	change			Atlantic-Mid-Atlantic boundary to address data needs for species whose distribution overlaps that boundary (see Action # 48).	SAFMC
Objective 7 – Science Infrastructure to Deliver Actionable Information					
52	Strategic planning	Level	2017-2018	Include climate science in the SEFSC's upcoming strategic plan.	SERO, AOML, SAFMC, HMS, others
53	Strategic planning	Level	2017-2018	Review/assess the recommendations from the March 2016 Ecosystems Science Program Review and develop a strategy to address and incorporate them into planning for climate science needs.	SERO
54	Strategic planning	Increase funding or dedicate staff time	2017-2018	Conduct a detailed science and data gap analysis for the South Atlantic.	AOML, SERO, HMS, HC, NOAA Restoration Center, SAFMC, Academia,
55	Strategic planning	Increase funding or dedicate staff time	2017-2018	Identify climate ready and/or multi-mission cruises in the South Atlantic.	AOML, OMAO, NOS, Academia, NSF, States, University-National Laboratory System
56	Strategic planning	Increase	2017-2019	Develop a comprehensive and collaborative monitoring program for climate and other ecosystem and ecological information necessary to meet NOAA Fisheries mission for the South Atlantic species and habitats, including ecosystem approaches to fisheries management (e.g, Ecosystem Based Fisheries Management), restoration, and science programs.	SERO,ST, SF, HMS,PR,HC, AOML, States, SAFMC, FWS, HMS, others
57	Infra-structure	Increase	2017-2021	Develop partnerships with the SAFMC Citizen Science program for the South Atlantic to help address climate science needs.	SERO, ST, AOML, NOS, SAFMC, Sea Grant, NERRs, Sanctuaries
58	Strategic planning	Increase	2017-2021	Establish a joint team with FWS to identify priority studies and data for South Atlantic sea turtle populations.	SERO, AOML, Academia, FWS, states, others
59	Strategic Planning	Level	2017-2018	Strategize on collaborative research efforts in the Southeast that address recommendations from the NOAA Fisheries Economics & Human Dimensions Program Climate Science Workshop on "Increasing Resilience in Fishing Communities to a changing climate Workshop."	SERO, ST
60	Build capacity	Level and Increase	2017-2021	Establish a formal SEFSC, OAR/AOML, SERO South Atlantic climate science team with regular meetings and hold a kick off meeting.	SERO, OAR, AOML, Climate Communities of Practice, SOCAN, IOOS partners, HMS
61	Build capacity	Level	2017	Hire a Management Strategy Evaluation FTE position at the SEFSC.	

62	Build capacity	Increase	2017	Identify and secure the staffing resources needed to conduct the work of this Action Plan (i.e., climate science researcher/coordinator, survey statistician, other and additional skill sets) through hiring new FTEs, contractor services, or cooperative research programs.	SERO, AOML, HQ, Academia
63	Build capacity	Increase	2017-2021	Invest in existing staff professional development to build or strengthen expertise to meet climate science needs and develop short term rotational assignments and/or exchanges between NOAA programs to build capacity and share ideas.	AOML, SERO, HMS, HQ Offices, NOAA Climate Program, NCEI, Climate Cooperative Institutes, Academia
64	Build capacity	Level	2017-2018	Strengthen relationship with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL).	GFDL, AOML
65	Build capacity	Level	2017-2018	Evaluate existing external and internal funding opportunities for climate science priorities and coordinate proposals.	SERO, HQ , HMS, AOML, NOAA Climate Program
66	Infra-structure	Increase	2017-2021	Initiate a partnership with NOAA's National Centers for Environmental Information (NCEI)	NCEI, AOML, SERO, HQ SF
67	Strategic planning	Completed		Convene a workshop to collect external data and information for developing the SARAP.	SERO, HQ SF, HMS, SAFMC, Academia

Objective 1: Identify appropriate, climate-informed reference points for managing living marine resources (LMRs)

Reference points are the thresholds upon which living marine resource management decisions are made. Determining how climate-related effects should be incorporated into these reference points to reflect changing conditions is critical for supporting climate-ready living marine resource management. It is also a challenge and will require additional data, analyses, and modeling that could easily extend beyond current state of the art practices. With level funding, actions under Objective 1 include collaborating with other scientists to share ideas for developing appropriate biological reference points for management in the U.S. South Atlantic. With increased funding, and dependent on progress under other plan Objectives, the remaining actions under Objective 1 would be prioritized and staged.

Level funding

- Increase collaboration with colleagues across the agency and with external partners on approaches for developing climate informed reference points in the U.S. South Atlantic Region. Collaborations will likely include a workshop and other methods. This is a challenging area for exploration, and working with partners and other NOAA offices will strengthen outcomes. This could be coordinated across the southeast (Gulf of Mexico, South Atlantic, and Caribbean) or nationally (Action #1).
- Assess if current stock assessment methodology in the South Atlantic account for environmental and climatic impacts, as well as the acceptable level of risk defined by the SAFMC when developing or estimating reference points (Action #2). This work can be

incorporated into workshops on climate informed reference points (Action #1) or other approaches to be used by the SERO, SEFSC, and partners.

- Examine the ability of protected species reference points to explicitly incorporate changes in climate (Action #5). The national *Guidance for Treatment of Climate Change in NMFS ESA Decisions* (NMFSPI 02-110-18) will be used to help maintain standards for identifying best available science, developing future projections, and applying the principle of institutionalized caution. For example, under the Marine Mammal Protection Act potential biological removal (PBR) is the annual level of human caused mortality that still allows a depleted stock of marine mammals to increase to its optimum sustainable population size or allows a stock that is at its optimum sustainable population to remain there. The PBR formula includes parameters, such as population size, that may sometimes reflect changes in climate. If, for example, a change in climate were to cause a decrease in population size, PBR for that population could also decrease, prompting management action. However, impacts of climate change may be more subtle or more complicated than the relationship described in this simplified example. The goal is to explore ways to more explicitly include changes in climate in PBR model parameters or to include the results of vulnerability assessments in PBR or other protected species benchmarks. The results of these studies could potentially reduce uncertainty in our estimates, or allow predictions of how PBR or other metrics would change under different climate scenarios.

Increased funding

- Incorporate environmental and climatic impacts in the establishment of reference points and use in stock assessments (Action #3) using information gathered during the collaborative efforts described in Action #1.
- Continue to incorporate explicit climate and ecosystem considerations into Essential Fish Habitat Designations, Habitat Area of Particular Concern, restoration planning, and NEPA reviews (Action #4), as well as into protected species reference points and related ESA actions, such as incidental take recommendations, biological opinions and listing decisions (Action #5).
- Assess stakeholder priorities to establish societal objectives for resource distribution and productivity in fisheries, and develop reference points to assess the impact of climate change scenarios relative to the societal objectives. Hold workshops and/or use other methods to begin to assess stakeholder priorities (Action #6).

Objective 2: Identify robust strategies for managing LMRs under changing climate conditions

With level funding, Objective 2 actions focus on continuing to use MSE to identify harvest control rules that remain effective under different climate scenarios and strengthening our ability to collaboratively identify robust management strategies. With increased funding, the remaining actions under Objective 2 would be prioritized and staged.

Level funding

- Continue and expand collaborative work with the Fishery Management Councils, HMS advisory panel, international neighbors, and other organizations to incorporate climate impacts and ecosystem processes into management (Action #8). Recognizing that addressing climate change impacts on fisheries requires explicit action to advance both science and management considerations, this RAP recommends actions to advance the science capability but also recognizes that many agencies and non-profits are doing useful work on climate change impacts and provide great opportunities to partner and develop relationships. In the South Atlantic, partners include the SAFMC, State government agencies, ASMFC, NOAA National Marine Sanctuary Program (NMS), (Florida Keys NMS and the Grays Reef NMS), NOAA Office of Ocean and Coastal Acidification, the Southeast and Caribbean Regional Action Team (SECART), NOAA Office of Highly Migratory Species, AOML, and others.

Increased funding

- Use MSE to identify harvest control rules that remain effective during anticipated climate changes (Action #7). The Southeast Region is currently investigating the efficiency of current harvest control rules used by the Gulf of Mexico Fisheries Management Council (GMFMC) and the intent is for this work to expand to include the SAFMC harvest control rules. Existing work on single-species and multi-species MSE involves a significant investment of leveraged funds from various internal grants. As yet, MSEs do not explicitly include climate information; it requires precursor work to be completed (inputs from Objectives 4, 5, and 6). To conduct more routine and regular LMR management strategy evaluations, additional core programmatic funding or research time will need to be dedicated. A new full-time MSE position has been created for the Science Center with a goal of it being filled early in 2017.
- Develop an ecosystem considerations summary (similar to the Alaska Marine Ecosystem Considerations 2014 Report) for the South Atlantic to accompany management documents, including stock assessments, fishery management plans, Biological Opinions, environmental assessments and environmental impact statements (Action #9). This relates to the development of an Ecosystem Status Report for the South Atlantic region (Action #40).
- Develop a management strategy (in concert with research & development under Objective 5) to guide implementation of strategies to enhance climate resilience of reef corals. Specifically, evaluation of risk to benefits and trigger points (e.g., climate, population, or community status thresholds) for implementation of specific strategies should be developed. (Action #10).

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

Objective 3 targets tools and dialogue between scientists and managers focused on when and where climate information has the greatest capacity to improve management. With level funding, our efforts will be focused on continuing to include environmental covariates in stock assessments and create decision tables that provide quantitative advice to managers. With increased funding the remaining actions under Objective 3 would be prioritized and staged.

Level funding

- Develop capacity to present quantitative advice using decision-theoretic approaches, for example constructing decision tables that quantify management tradeoffs under various scenarios of climate change (Action #11). Southeastern initiatives such as the Gulf of Mexico Ecosystem Status Report (Karnauskas et al. 2013), and the development of the South Atlantic Ecosystem Status Report (Action # 39) can serve to motivate this dialogue and highlight to science and management communities the range of drivers that may be important to consider. This information can then be better tailored to the management process; for example, in other regions various management documents are accompanied by "ecosystem considerations" summaries that then help form the basis of decision-making (a future action for the South Atlantic, Action #9). To implement this action with level funding would require redirection of current staff time; otherwise increased funding is required to incorporate this adaptive management tool.
- Strengthen dialogue and planning between scientists and managers to (1) support the adaptive decision processes that respond to climate changes and (2) promote studies focused on when and where climate information has the greatest capacity to improve management (Action # 14). For example, in the South Atlantic, a prioritization exercise could be carried out by scientists and managers together to understand where the inclusion of climate information could improve the management process. In some cases, focused research programs may help detect and respond to climate influences on populations; in others, detecting such effects may be cost-prohibitive and the focus may be on risk-adverse management policies. These collaborative planning efforts should be a guiding force for future climate-related fisheries research priorities in the region.
- Continue to include environmental covariates in stock assessments (Action # 15). Informing short-term tactical management essentially requires obtaining and delivering a mechanistic understanding of climate effects on various processes at the scales at which management acts. In the South Atlantic, temperature is being used to standardize catch per unit effort and this information is being used in stock assessments. Increased funding would allow the study of additional environmental covariates such as pH, salinity, and dissolved oxygen and potential effects on key biological parameters such as early life stages, recruitment dynamics, and feeding and growth rate of managed species. When understanding the specific mechanisms driving population dynamics is not possible, other statistical methods can be used to make one-year-ahead predictions of population parameters. Some of this ongoing work can be accomplished with level funding, but to expand this work would require increased funding.
- Continue to contribute to the revision of the SAFMC Fishery Ecosystem Plan (FEP) and identify the synergies between the FEP and the RAP (Action #16).

Increased funding

- Improve capacity to respond to climate related events in real time, e.g., coral bleaching or disease, red tide, or fish kills, by collecting additional samples, analyzing new data, and improving forecasts and models (Action #12). This events analysis capacity would allow a rapid response in the form of scientific advice to managers, and capture important episodic data. This capacity could be in the form of an events analysis team and could include development of a rapid evaluation tool to recognize events. Partners include the marine mammal stranding networks, State partners, as well as the SAFMC and their Citizen Science initiative.

- Establish more formal methods for scientists and managers to learn about ecosystem changes observed by long time fishermen or those who fish frequently. This action could be accomplished by scientists attending Council Advisory Panels, creating a poll, or by creating some other process to hear about observations. It could eventually become a component of a Citizen Science effort (Action #13 and Action #58).
- Begin to identify major factors (human and natural) that would increase the resilience of fishing communities highly vulnerable to climate change impacts (Action #17). Providing a clear understanding of the possible impacts of climate change on fisheries, resource users, and consumers is fundamental to offering management the tools to accommodate climate change in decision-making. In addition to improving capacity to adaptively manage fish stocks in a changing climate, there is a need to improve the resilience of fishing communities that are vulnerable to climate impacts. Jacob and Jepson (2009) proposed a composite indicator based on the existing Fish Stock Sustainability Index (FSSI), which represented the sustainability of the suite of fish species a community relies upon for its income. A similar index was adapted for climate change data in the Northeast and combined with a diversity index to determine which communities were dependent upon species that were susceptible to climate change impacts (Colburn et al. In Press). Measures like these can provide information to managers and constituents to assist in decision-making and contribute to the dialogue on the anticipated impacts of climate change. Such measures may also help progress toward the identification of factors that will affect the resilience of fishing communities.
- Consider how to incorporate climate science and adaptive management into ESA-listed species recovery plans and ESA section 7 jeopardy, adverse modification, and cumulative effects analyses for biological opinions (Action #18). For example, counties in coastal Florida are developing adaptive management plans that may require modifications to existing shoreline armoring (e.g., taller vertical seawalls) and the use of living shorelines in areas where appropriate to mitigate sea level rise. These regional plans could be incorporated into ESA section 7 analyses and reports.

Objective 4: Identify future states of marine and coastal ecosystems, LMRs, and LMR dependent human communities in a changing climate

Actions under Objective 4 focus primarily on modeling efforts to identify future states for species, habitats, and human communities in the South Atlantic. With level funding, efforts will focus on ongoing research efforts. With increased funding, the remaining actions under Objective 4 would be prioritized and staged. It is noted that investments in many of these research and modeling efforts need to be integrated into the South Atlantic comprehensive monitoring program and other strategic planning efforts described in Objective 7, which could affect how these actions are prioritized.

Level funding

- Use a high-resolution regional ocean biogeochemistry model to downscale the Coupled Model Intercomparison Project Phase 5 (CMIP5 model) projection of carbon and biogeochemical parameters for the South Atlantic. This model can provide a range of realistic scenarios of future environmental and ecosystem changes in terms of physical and biogeochemical processes (ocean and coastal circulation, acidification, temperature, nutrients, etc.) in the South Atlantic for the research community and fisheries resource managers (Action #20).

- Continue research on sea level rise (e.g., Kopp et al. 2015; Krasting et al. 2016), use existing down-scaled climate models to map predicted coastal flooding, and assess ecosystem services and impacts on marsh and estuarine dependent species (e.g. forage species, black sea bass, gray snapper, shrimp, Atlantic and shortnose sturgeon, bottlenose dolphin). Integrate into the South Atlantic comprehensive monitoring program and other strategic planning efforts described in Objective 7 (Action #22).
- Continue research applying biophysical modeling and other approaches to assess red snapper population connectivity within and between Gulf of Mexico and South Atlantic regions (Action #26).

Increased funding

- Collaborate with NOAA partners to evaluate, validate, and improve regional ocean-biogeochemistry models that are currently known to resolve key regional ocean processes reasonably well and identify what is needed to improve the models in the future. This would be a retrospective evaluation of the utility of climate models. The goal is to be able test various hypotheses on the mechanisms of climate impacts and ultimately to predict the future states of LMRs in the region (Action #19).
- Expand research to assess the potential effects of climate change on Gulf Stream oceanographic characteristics (including Gulf Stream positional variability, AMOC, and eddies; Ezer et al. 2013; Rahmstorf et al. 2015), with downstream effects to populations of managed species (Action #21 and see Action #35).
- Apply existing down scaled climate models to evaluate climate impacts on species identified via vulnerability analyses and their critical ecosystem habitats, e.g., coral reef, estuarine, spawning habitats (Action #23). Through leveraged funding with partners, a suite of ecosystem models has been developed for the Southeast region and could be used to predict future states of ecosystems in the South Atlantic. Similarly, models have been parameterized for the Gulf of Mexico, including Ecosim/Ecopath, OSMOSE (Grüss et al. 2015), and Atlantis, and could have application in the U.S. South Atlantic. The development of ecosystem models will continue to require significant investments that cannot be absorbed within near-term programmatic funds, and these costs should be evaluated against the relative value of predictions from these models. The region should continue to work in collaboration with external partners to: continue to evaluate the feasibility of parameterizing and updating large-scale, end-to-end ecosystem models; understand the uncertainty around various predictions from ecosystem models; and explore how suites of ecosystem model predictions can be incorporated into management advice. Further development of ecosystem models will be valuable for understanding the broader ecosystem benefits of restoration investments along the U.S. South Atlantic, including linkages between coastal and nearshore habitat restoration and offshore LMRs. These evaluations should then drive funding and research priorities for ecosystem modeling efforts in the longer term.

- Evaluate effects of climate change on the frequency of unusual mortality events for protected species (cold stuns for turtles, strandings of marine mammals, health related effects [viruses, bacteria, cancers]) in the South Atlantic by collaborating with partners who have climate data, such as AOML and NOS (Action #24). Integrate into the South Atlantic comprehensive monitoring program and other strategic planning efforts described in Objective 7. Examine this risk using down-scaled model projections developed as part of the Actions in this Objective.
- Integrate outputs from climate models into existing spatial density models for marine mammals. Survey data and habitat information are current inputs into spatial distribution maps for marine mammals in the South Atlantic. Use existing climate model outputs to predict potential changes to those distributions. This action requires close collaboration with AOML, Geophysical Fluid Dynamics Laboratory (GFDL), and other partners. Integrate into the South Atlantic comprehensive monitoring program and other strategic planning efforts described in Objective 7. (Action #25).
- Develop a standard modeling toolbox and best practices for modeling under uncertainty to link future ocean and freshwater states and LMRs, with ability to couple models across types. Develop techniques that enable indicators to be included in stock assessment models and projections of stock status (Action #27). Integrate into the South Atlantic comprehensive monitoring program and other strategic planning efforts described in Objective 7.
- Assess the potential economic impact of climate change on commercial and recreational fishing industries, particularly in terms of changes in income distribution and productivity at the vessel level. Integrate into the South Atlantic Comprehensive monitoring program and other strategic planning efforts described in Objective 7 (Action #28).
- Begin to assess possible impacts of climate change scenarios on the well-being and vulnerability of fishing communities in the Gulf of Mexico (Action #29) using conceptual and dynamic models to explore the relationship between climate-related changes in ecosystem services and changes in vulnerability and wellbeing of specific human communities. Few ecosystem models are able to couple human behavioral responses or social impacts to offer comprehensive predictive outcomes. Factors modeled in ecosystem models are often not the same indicators used in models of human behavioral responses and social impacts. This complicates any attempt to incorporate social and economic activity in ecosystem models. Furthermore, ecosystem models are already highly complex; adding social and economic indicators will add another layer of complexity that will challenge any comprehensive attempt to couple dynamic representations of biological and socioeconomic processes. Trying to fully account for all the tradeoffs and distributional effects between the different components will also pose some difficulty. Finally, because of the complexity of the human response behavior, the addition of such information will add increasing uncertainty to any predictive model. Yet, there remains an urgent need to bring together a comprehensive ecosystem approach and integrated assessment tool to support fisheries management in the face of a changing climate. The incorporation of human dimensions in management considerations is currently a major focus of IEA Programs. Given current funding levels, a good approach would be to leverage information, statistical techniques, and research findings from the IEA program for application to specific fisheries management issues.

Objective 5: Identify the mechanisms of climate impacts on LMRs, ecosystems, and LMR dependent human communities

Conducting vulnerability analyses is the most critical action under Objective 5. The Climate Science Strategy calls for vulnerability assessments to be conducted for LMRs in all regions to guide specific research and management actions. With level funding, we propose scoping and conducting vulnerability assessments for key species or fishery management plans. With increased funding, the remaining research oriented actions under Objective 5 in Table 1, including conducting additional vulnerability analyses for protected species and communities would be prioritized and staged. There would also be an increase in research and applying those analyses to fishing and coast communities.

Level funding

- Scope priority species vulnerability assessments with all interested parties and identify funding mechanisms. Consider interplay with stock assessment prioritization and management needs in the region. The vulnerability assessment tool can assess many species at once. However, the first step will be to determine which specific species it will be most useful and critical to focus on. Many species are managed across eight fishery management plans in the South Atlantic, and it is not feasible to conduct assessments on every one (Action #30). Additionally, vulnerability assessments will be needed for protected species, marine mammals, and sea turtles as well.
- Conduct climate vulnerability assessments for identified/priority species in the South Atlantic (Action #31). These analyses, similar to those conducted in other regions using a framework developed by NOAA Fisheries (Morrison et al. 2015) provide a relative ranking of which species are at low risk, moderate risk, or high risk of being impacted due to specific climate changes anticipated in the U.S. South Atlantic. This framework has been internally vetted and peer-reviewed (Hare et al. 2016).Vulnerability analyses may help identify process-based research gaps and priorities for -related field and laboratory research for the SEFSC. This is typically a regionally-led process, with NOAA headquarters offering support for implementation of the framework (M. Nelson, pers. comm.). Increased funding and redirection of staff time will be required to pursue vulnerability assessments for all species in the region.
- Continue to work with NOAA Southeast Ocean and Coastal Acidification Network and the University of Georgia to identify and address issues related to ocean acidification in the region (Action #39).

Increased funding

- Adapt community social vulnerability indices for coastal and fishing communities in the South Atlantic based on the outcome of species vulnerability analyses (Action #32).
- Expand collaborative field and laboratory research focused on understanding the drivers and mechanisms of climate change in the South Atlantic, including process studies that examine primary productivity, plankton, and other trophic levels and priority species (Action #33). Existing cruises or surveys that could collect this information will be identified (Action #56). Work currently conducted by the SEFSC to identify mechanisms of climate impacts is carried out through a combination of programmatic funds and competitive funding opportunities. Scientists have conducted research on the effects of

hypoxia on commercially important finfish species (Craig et al. 2005, Craig 2012, Craig and Bosman 2013), the effects of red tide on mortality of grouper species (Walters et al. 2013), and we have ongoing research into the drivers of recruitment strength in snapper and grouper species (Karnauskas et al. 2013). SEFSC research on coral reef ecology includes responses of corals to various physical drivers (Miller et al. 2009). SEFSC scientists have also partnered with physical oceanographers in AOML to carry out research related to larval ecology and predicted climate impacts on large pelagic species (Muhling et al. 2011, Muhling et al. 2015). Many of these research projects have been supported by internal competitive funding programs such as Fisheries and the Ecosystem and Habitat Assessment Improvement Program and often involve collaborations with academic partners.

- Continue research on the climate driven displacement of ecologically important habitats, such as displacement of marsh grass by mangrove habitat, and the impact on shrimp and juvenile fish nursery habitat (Action #34).
- Research the influence of Gulf Stream oceanographic characteristics (including Gulf Stream positional variability, AMOC, and eddies) on populations of managed, ecologically, and economically important species, and the potential effects of climate change on those influences (e.g., Ezer et al. 2013; Rahmstorf et al. 2015) (Action #35 and Action #21).
- Identify, develop, and assess risks for using tools to propagate climate-resilience traits within reef coral populations. Strategies might include (but are not limited to) improved population enhancement techniques, selective breeding, manipulating symbiotic partners, strategic translocation, or stress conditioning (Action #36).
- Research is needed to better understand and develop means to mitigate the linkage of warm-stress-induced coral bleaching with subsequent coral disease outbreaks and mortality (Action #37).

Objective 6: Track trends in ecosystems, LMRs and LMR-dependent human communities and provide early warning of change

Information on the status and trends of ecosystems, LMRs, and LMR-dependent human communities is essential to tracking and proving early warning of the impacts of changes in climate. Sound scientific advice for the sustainable management of marine resources is founded on this information. Historically numerous data-based assessments of LMRs are produced to support management advice, such as for stock assessments, but have not always explicitly incorporated climate change data. Objective 6 actions focus primarily on strengthening this aspect in baseline data in the U.S. South Atlantic region. With level funding, the development of an Ecosystem Status Report for the region will be initiated, an important tool for tracking ecosystem and LMR trends in the South Atlantic; options for coordinating fishery-independent surveys for fish species whose ranges overlap the South Atlantic-Mid-Atlantic management boundary will be considered, as well as for region-wide marine mammal surveys; and the continuation of coral monitoring. Increased funding would allow expansion of capabilities to address the actions to improve tools, track trends of species and habitats, and predict impacts to fishing communities along the U.S. South Atlantic coast. These investments in baseline data to track changing trends would be integrated into the overall science infrastructure that is described in Objective 7 and will support the understanding of the mechanisms of change (Objective 5) and our ability to predict future conditions of ecosystems, LMRs, and the coastal communities dependent on them.

Level funding

- Complete an assessment for the development of an Ecosystem Status Report for the South Atlantic, including a human dimensions component (Action #39). Tracking trends in ecosystems can be accomplished through the identification of indicators intended to represent various parts of the system, including commercially and recreationally important LMRs. While an Ecosystem Status Report was developed and released in 2013 for the Gulf of Mexico, one has not been developed for the U.S. South Atlantic region. The first step for the new product entails a detailed scoping of the effort including who will be involved, costs, funding sources, timeline, etc., modeled after the Gulf of Mexico report. To implement this action with level funding will require redirection of current staff time. Full development of a report for the South Atlantic, including biannual updates, would require *increased* funding. The completed report would be used to guide the development of an ecosystem considerations summary (Action #9). Note: This effort differs from the SAFMC's FEP.
- Discuss coordination of fishery-independent survey approaches to improve the utility of survey-generated information pertaining to species (e.g., blueline tilefish, snowy grouper, black sea bass) whose ranges overlap the South Atlantic-Mid-Atlantic boundary (Action #40). Current surveys target a different suite of fish species in the Mid-Atlantic (groundfish) and South Atlantic (reef fish) regions. Thus, inferences currently cannot be made about potential changes in species-specific ranges across the South Atlantic-Mid-Atlantic boundary due to, for example, climate change.
- Explore the feasibility (technical and budget) of conducting a comprehensive, South Atlantic-wide survey for marine mammals (Action #42). For marine mammals, the frequency of current assessment surveys is very low and it has not been possible to assess trend in population size for any of the stocks in the South Atlantic (Waring et al. 2014). Establishing regular, standardized assessment surveys and associated analytical tools for monitoring trend will be critical for understanding potential responses to climate change. Sister agency BOEM and international partners are critical to the success of this plan.
- Continue coral monitoring efforts (National Coral Reef Monitoring Program and partner efforts and SEFSC elkhorn-focal monitoring) to track population status over changing environmental conditions. With increased funding, enhance and expand effort to target other listed species and effects of specific bleaching and disease events (Action #49).
- Continue to collaborate with and maintain strong relationship the South Atlantic Large Marine Ecosystem Program and other external partners to obtaining critical baseline data and track changes in the South Atlantic (Action #50).

Increased funding

- Create a strategy to identify new and maintain critical baseline data identified in the South Atlantic comprehensive monitoring program and other strategic planning efforts described in Objective 7 (e.g, ichthyoplankton survey, broad scale temperature variations, protected species surveys) (Action #41).

- Assess socio-economic data needs for examining impacts of climate change on fishing and coastal communities, e.g., fishing crew employment data (Action #43). NOAA Fisheries' Human Dimensions Team has developed a set of community social vulnerability indices for coastal and fishing communities in all regions to provide a foundation for community level measures of well-being and fishing dependence (Jepson and Colburn 2013, Colburn and Jepson 2012, Himes-Cornell and Kasperski 2015, and Pollnac et al. 2015). Recently, a sea level rise indicator was added to that suite of indicators as a first step to include measures of climate change impacts. In addition, recent work in the Northeast has produced a model for using species vulnerability to climate change with fishing dependence to capture a community's dependence upon stocks that are vulnerable to climate change. This type of research should be explored for application to the South Atlantic and can be integrated into the South Atlantic comprehensive monitoring program and other strategic planning efforts described in Objective 7.
- Improve the capability to monitor trends for protected species over the long term and integrate into the South Atlantic comprehensive monitoring program and other strategic planning efforts described in Objective 7 (Action #44). For example, for sea turtles, standardized nest counts exist that provide long-term monitoring of a small portion of the population. However, the methodologies are not always consistent across nesting survey locations, limiting the ability to integrate across multiple data collection programs. A network for long-term monitoring of nesting populations of sea turtles in the South Atlantic should be established to continue collecting baseline data on, and evaluate/monitor trends in, hatchling sex ratios, pivotal temperatures and upper thermal thresholds, nesting habitat use (loss and gains), nesting phenology, etc.
- Build partnerships in support of coordinating an in-water monitoring long-term network for sea turtles. A baseline data need in the South Atlantic could be met by the establishment of in-water index sites for monitoring trends in life history stages aside from nesting females (Action #45).
- Build or expand partnerships to determine changes to marsh, mangrove, and other shoreline habitats from climate change (remote sensing data, USFWS, and USACE survey data). These data would be incorporated into appropriate assessments and consultations (i.e., NMFS Section 7 and EFH assessments, stock assessments, other models) (Action #46).
- Conduct a needs assessment for an early warning toolbox to identify which physical, biological, social, and economic indicators will track climate trends and identify thresholds that will provide early warnings of impacts to LMRs and the fishing industry and fishing communities (Actions #47 and 48).
- Implement survey calibration studies or expand current surveys across the South Atlantic-Mid-Atlantic boundary to address data needs for species whose distribution overlaps that boundary (Action #51).

Objective 7: Build and maintain the science infrastructure needed to fulfill NOAA Fisheries mandates with changing climate conditions

Actions under Objective 7 fall into two categories, strategic planning and building capacity to conduct work in support of climate science. With level funding, efforts will focus on how to include climate science needs for the South Atlantic in the SEFSC's strategic planning process and on strengthening climate science coordination within NOAA and with other partners in the South Atlantic. With increased funding the remaining actions under Objective 7 (Table 1) to further develop our capacity to address climate science requirements in the U.S. South Atlantic would be prioritized and staged.

Level funding

- Include climate science coordination and prioritization in the development of the SEFSC's upcoming strategic plan (Action #52). Working closely with SERO, AOML, other NOAA offices, the SAFMC, and other partners in the South Atlantic will be a critical component of the strategic planning process. Incorporate recommendations from a number of recent reports and reviews such as the March 2016 Ecosystem Science Program Review (Action #53) and the NOAA Fisheries Economics & Human Dimensions Program Climate Science Workshop "Increasing Resilience in Fishing Communities to a changing climate Workshop" (Action #59) into the development of the SARAP. Climate science is an integral part of our ecosystem science program, and the review recommendations may influence some of the implementation of elements of the SARAP. All of this work in concert contributes toward the scientific information needed for effective ecosystem-based fisheries management in a changing climate.
- Continue and strengthen relationships with NOAA's AOML and other programs in OAR, similar to the many informal SEFSC-AOML workshops and joint funding proposals that have been coordinated in the past. Establish a formal SEFSC/SERO/AOML/HMS climate science team with regular meetings (Action #60)to enhance the ability to identify overlapping requirements and opportunities for climate science, generate multi-disciplinary mechanisms of change, leverage existing data, identify research gaps, and set joint priorities.
- The Regional Climate Team will also strengthen coordination with GFDL, Climate Communities of Practice, SOCAN, IOOS partners, NOAA regional partnerships, as well as other partners identified in the RAP for the Gulf of Mexico, South Atlantic, and Caribbean. (Action #64).
- Build capacity by hiring a Management Strategy Evaluation full time equivalent employee (FTE) at the SEFSC (Action #61). While this position will not be dedicated to climate science, the expertise of this individual will contribute to assessing the climate science needs and priorities in the region.
- Evaluate existing external and internal funding opportunities for climate science priorities and objectives in concert with strategic planning processes. Strategic planning and increased coordination across the SEFSC will potentially strengthen climate science related proposals (Action #65).
- COMPLETED: Convene a workshop to discuss and collect external data and information needed for the SARAP. Attendees will be a blend of academic, state, Council, NOAA and other federal partners with expertise in climate science, physical oceanography and living marine resource disciplines (Action #67). This action item has already been accomplished. As part of the development of the SARAP, staff considered the outputs of the "Climate Variability and Fisheries Workshop: Setting Research Priorities for the Gulf

of Mexico, South Atlantic, and Caribbean Regions," held in October 2015 in St. Petersburg Beach, FL. Hosted by the Southeast Coastal Ocean Observing Regional Association (SECOORA), the workshop participants represented a diverse array of scientific expertise, as well as resource and environmental managers and fishing industry. Through a series of facilitated plenary and breakout discussions, participants discussed regional and cross-regional impacts of environmental change on fisheries and other living marine resources and where research and monitoring needs existed. The workshop executive summary highlighted the participants' top research and monitoring priorities for understanding climate impacts on living marine resources and addressing management needs over the next one to three years. These priority actions were considered during the development of this SARAP.

Increased funding

- Conduct a detailed gap analysis to assess the adequacy of existing surveys and data streams for meeting climate science needs (Action #54). This analysis would entail assessing existing data and identifying and prioritizing multidisciplinary data needs, including biological, ecosystem, climate, physical, chemical, socio-economic, and other data in coordination with SERO, HMS, AOML, USGS, and other partners. Management strategy evaluation is a potential tool for this assessment. This data gap analysis would support baseline data collection needs under Objective 6 of this plan.
- Identify climate ready and multi-mission cruises in the U.S. South Atlantic (Action #55). To fill some of the identified data gaps, opportunities should be explored for leveraging additional data collection on existing surveys, making use of advanced sampling technologies, and assessing days at sea on NOAA, academic, and industry vessels.
- Develop and execute a comprehensive and collaborative monitoring program for the South Atlantic with partners, based on the priorities of the updated strategic plan, results of the data gap analysis, and goal of multi-mission cruises in the South Atlantic, (Action #56). This also relates to Action #41. The plan would include multidisciplinary monitoring and research for climate and other ecosystem information together with fisheries, protected species, corals, primary productivity, plankton, and higher trophic levels that support the NOAA Fisheries mission. It may include identification of likely changes and drivers of change in the South Atlantic and opportunities for Citizen Science development (Action #57). This goal is to provide a more complete vision for coupled biological and oceanographic data needs, strengthen partnerships, and encourage efficiency within budgets. The initial planning and coordination for this effort would be substantial, but we believe this comprehensive monitoring plan will address shared data needs and provide the information needed to make climate-informed decisions that reduce anticipated climate impacts and increase resilience for coastal communities.
- Coordinate with the SAFMC and other partners to initiate Citizen Science programs for the U.S. South Atlantic to help address climate science needs, as determined by the comprehensive monitoring program and other strategic planning efforts. Knowledge or data gaps may also be filled by the strategic development of citizen science programs, as fishermen and other stakeholders often have a detailed understanding of how they physical environment affects fish populations at very fine scales (Actions #13 and 57)
- Establish a joint team with the U.S. Fish and Wildlife Service (USFWS) to identify priority studies and data for U.S. South Atlantic sea turtle populations. This would be

integrated into the comprehensive monitoring program and other strategic planning efforts described in Objective 7 (Action #58).

- Expand climate expertise across NOAA in the Southeast. Build capacity by investing in additional FTEs such as dedicated climate science researchers, climate science coordinators, and survey statisticians (Action #62), or secure these skills through contractor services or cooperative research institutes. New positions could potentially be shared with AOML, which would increase collaboration between line offices. Another avenue to build capacity for climate science is by providing professional development opportunities for existing staff, such as on statistical techniques for multivariate time series analysis, or contracting experts to help develop new capabilities. Additionally, short-term rotational assignments or exchanges between various NOAA programs could be developed, with the goal of building capacity and sharing ideas between offices (Action #63).
- Initiate a partnership with NOAA's National Centers for Environmental Information (NCEI) to determine how to utilize their data portal for climate science and related data products related to NOAA Fisheries mission and needs (Action #66).

METRICS

The following metrics will be used, and continuously evaluated for their value, to assess the quality of the output and outcomes of this Action Plan. The metrics are organized by objective; these are in reverse order, and begin with Objective 7 as each objective builds upon each other in this progression.

Accomplishment	Date completed	Objective
Support and participate in regional climate variability workshop in October 2015, hosted by SECOORA to engage stakeholders and develop input for the SARAP.	Oct 2015	7
Number of new collaborative climate research projects.		7
Number of collaborative proposals for climate science submitted to external and internal funding opportunities.		7
Number of formal and/or informal SEFSC, AOML, SERO South Atlantic climate science meetings.		7
Hiring completed for Management Strategy Evaluation FTE position in the SEFSC.		7
Develop an Ecosystems Status Report for the South Atlantic.		6
Number of marine mammal species surveyed in the South Atlantic.		6
Establish plan for conducting vulnerability assessments.		5
Number of species for which climate vulnerability assessments is completed.		5
Complete new Use a high-resolution regional ocean-biogeochemistry model to downscale the CMIP5 model projection of carbon and biogeochemical parameters for the South Atlantic.		4

Number of meetings between fisheries managers, scientists and fishery participants to Increase dialog between all partners and fishermen to learn about ecosystem and/or potential climate-related changes observed.		3
Number of stock assessments that have incorporated environmental covariates.	Ongoing	3
Number of new or stronger internal or external partnerships instituted to achieve climate science and management objectives.		1/2/6/7
Participation in regional or national workshop/meeting to explore the development of climate informed reference points.		1

ACKNOWLEDGEMENTS

We would like to thank all who contributed to earlier versions of this draft. We also thank the staff at the SEFSC, SERO and NOAA Fisheries ST and HC and SF, and the South Atlantic Fishery Management Council for their review and input in development this draft.

Special thanks to the South Atlantic Regional Action Plan team for their contributions to this plan: Karla Gore, Roldan Muñoz, Heidi Lovett, Sunny Snider, Mike Jepson, Jennifer Cudney, Akbar Marvasti, Mandy Karnauskas, Eric Hoffmayer, John Lamkin, John Walter, Shannon Calay, Matt McPherson, John Quinlan, David Carter, Lance Garrison, Chris Sasso, Margaret Miller, Allison Moulding, Chris Kelble, and Sang-ki Lee.

REFERENCES

Allison EH, Badjek MC, and Meinhold K. 2011. The implications of global climate change for molluscan aquaculture. In: SHUMWAY SE (ed.). Shellfish Aquaculture and the Environment. John Wiley & Sons, Inc.

Alvarez-Filip L, Dulvy NK, Gill JA, Cote IM, and Watkinson. 2009. Flattening of Caribbean coral reefs: region-wide declines in architectural complexity. P Roy Soc B-Biol Sci 276:3019-3025.

Aretxabaleta A, Nelson JR, Blanton JO, Seim HE, Werner FE, Bane JM, and Weisberg R. 2006. Cold event in the South Atlantic Bight during summer of 2003: Anomalous hydrographic and atmospheric conditions, J. Geophys. Res., 111, C06007, doi:10.1029/2005JC003105.

Arroyo AM, Naim SM, and Hidalgo JZ. 2011. Vulnerability to climate change of marine and coastal fisheries in Mexico. Atmosfera 24:103-123.

Aquarone MC. 2009. XV-51 Southeast U.S. Continental Shelf: LME#6. In LME Briefs, Large Marine Ecosystems of the World (LME Portal). www.lme.noaa.gov.

Atkinson LP. 1977. Modes of Gulf Stream intrusion into the South Atlantic Bight shelf waters. Geophys Res Lett 4:583-586.

Atkinson LP, Menzel DW, and Bush KA. 1985. Oceanography of the southeastern U.S. continental shelf. American Geophysical Union, Washington, D.C.

Bacheler NM, Schobernd CM, Schobernd ZH, Mitchell WA, Berrane DJ, Kellison GT, and Reichert MJM. 2013. Comparison of trap and underwater video gears for indexing reef fish presence and abundance in the southeast United States. Fisheries Research **143**:81-88.

Bacheler NM, Berrane DJ, Mitchell WA, Schobernd CM, Schobernd ZH, Teer BZ, and Ballenger JC. 2014. Environmental conditions and habitat characteristics influence trap and video detection probabilities for reef fish species. Marine Ecology Progress Series, **517**, 1-14.

Bechmann RK, Taban IC, Westerlund S, Godal BF, Arnberg M, Vingen S, Ingvarsdottir A, Baussant T. 2011. Effects of Ocean Acidification on Early Life Stages of Shrimp (*Pandalus borealis*) and Mussel (*Mytilus edulis*). J Toxicol Env Heal A 74:424-438.

Bromhead D, Scholey V, Nicol S, Margulies D, Wexler J, Stein M, Hoyle S, Lennert-Cody C, Williamson J, Havenhand J, Ilyina T, and Lehodey P. 2015. The potential impact of ocean acidification upon eggs and larvae of yellowfin tuna (*Thunnus albacares*). Deep-Sea Res Pt Ii 113:268-279.

Bryden HL, Longworth HR, Cunningham SA. 2005. Slowing of the Atlantic meridional overturning circulation at 25 degrees N. Nature 438:655-657.

Checkley DM, Raman S, Maillet GL, Mason KM. 1988. Winter storm effects on the spawning and larval drift of a pelagic fish. Nature 335:346-348.

Colburn LL and Jepson M. 2012. Social Indicators of Gentrification Pressure in Fishing Communities: A Context for Social Impact Assessment. Coastal Management 40(3): 289-300.

Dickinson GH, Ivanina AV, Matoo OB, Portner HO, Lannig G, Bock C, Beniash E, and Sokolova IM. 2012. Interactive effects of salinity and elevated CO2 levels on juvenile eastern oysters, *Crassostrea virginica*. J Exp Biol 215:29-43.

Ekstrom JA, Suatoni L, Cooley SR, Pendleton LH, Waldbusser GG, Cinner JE, Ritter J, Langdon C, van Hooidonk R, Gledhill D, Wellman K, Beck MW, Brander LM, Rittschof D, Doherty C, Edwards PET, and Portela R. 2015. Vulnerability and adaptation of US shellfisheries to ocean acidification. Nature Climate Change, **5(3)**, 207-214, doi: 10.1038/nclimate2508.

Ezer T, Atkinson LP, Corlett WB, and Blanco JL. 2013. Gulf Stream's induced sea level rise and variability along the U.S. mid-Atlantic coast. J Geophys Res-Oceans **118**:685-697.

Ezer T and Atkinson LP. 2014. Accelerated flooding along the US East Coast: On the impact of sea-level rise, tides, storms, the Gulf Stream, and the North Atlantic Oscillations. Earth's Future 2:362-382.

Fabricius KE, De'ath G, Noonan S, and Uthicke S. 2014. Ecological effects of ocean acidification and habitat complexity on reef-associated macroinvertebrate communities. P Roy Soc B-Biol Sci 281.

Fogarty M, Incze L, Hayhoe K, Mountain D, and Manning J. 2008. Potential climate change impacts on Atlantic cod (Gadus morhua) off the northeastern USA. Mitigation and Adaptation Strategies for Global Change, **13(5-6),** 453-466.

Forsyth JST, Andres M and Gawarkiewicz GG. 2015. Recent accelerated warming of the continental shelf off New Jersey: Observations from the CMV Oleander expendable bathythermograph line. Journal of Geophysical Research **120**:2370-2384.

Gaichas SK, Link JS, and Hare JA. 2014. A risk-based approach to evaluating Northeast U.S. fish community vulnerability to climate change. ICES Journal of Marine Science: Journal du Consell fsu048.

García Molinos J, Halpern BS, Schoeman DS, Brown CJ, Kiessling W, Moore PJ, Pandolf JM, Poloczanska ES, Richardson AJ, and Burrows MT. 2015. Climate velocity and the future global redistribution of marine biodiversity. Nature Climate Change, doi: 10.1038/nclimate2769.

Graham NAJ, Wilson SK, Jennings S, Polunin NVC, Robinson J, Bijoix JP, and Daw TM. 2007. Lag effects in the impacts of mass coral bleaching on coral reef fish, fisheries, and ecosystems. Conservation Biology 21:1291-1300.

Hare JA, Alexander MA, Fogarty MJ, Williams EH, Scott JD. 2010. Forecasting the dynamics of a coastal fishery species using a coupled climate–population model. Ecological Applications 20:452-464.

Hare JA, Wuenschel MJ, and Kimball ME. 2012. Projecting range limits with coupled thermal tolerance-climate change models: an example based on gray snapper (*Lutjanus griseus*) along the US east coast.

Hilmi N, Allemand D, Kavanagh C, Laffoley D, Metian M, Osborn D, and Reynaud S. (eds.) 2015. Bridging the gap between ocean acidification impacts and economic valuation: regional impacts of ocean acidification on fisheries and aquaculture, IUCN, Gland, Switzerland: International Union for Conservation of Nature and Natural Resources.

Himes-Cornell A, and Kasperski S. 2015. Assessing climate change vulnerability in Alaska's fishing communities. Fish. Res. 162:1-11.

Hoegh-Guldberg O, Cai R, Poloczanska ES, Brewer PG, Sundby S, Hilmi K, Fabry VJ, and Jung S. 2014. The Ocean. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, and, and White LL (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1655-1731.

Hollowed AB, Barange M, Beamish RJ, Brander K, Cochrane K, Drinkwater K, Foreman MGG, Hare JA, Holt J, Ito SI, Kim S, King JR, Loeng H, Mackenzie BR, Mueter FJ, Okey TA, Peck MA, Radchenko VI, Rice JC, Schirripa MJ, Yatsu A, and Yamanaka Y. 2013. Projected impacts of climate change on marine fish and fisheries. ICES Journal of Marine Science, **70**, 1023-1037.

Holmyard N. 2014. Climate change: Implications for fisheries & aquaculture, Key Findings from the Intergovernmental Panel on Climate Change Fifth Assessment Report. University of Cambridge, Cambridge, UK.

Hyun KH and He RY. 2010. Coastal upwelling in the South Atlantic Bight: A revisit of the 2003 cold event using long term observations and model hindcast solutions. J Marine Syst 83:1-13.

Ingram KT, Dow K, Carter L, and Anderson J. 2013. Climate of the Southeast United States: Variability, change, impacts, and vulnerability. Washington, D.C. Island Press.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change Synthesis Report 2014.

Jepson M and Colburn LL. 2013. Development of Social Indicators of Fishing Community Vulnerability and Resilience in the U.S. Southeast and Northeast Regions. U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-F/SPO-129, 64 p.

Kleypas JA, Feely RA, Fabry VJ, Langdon C, Sabine CL, and Robbins LL. 2006. Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research, report of a workshop held 18–20 April 2005, St. Petersburg, FL, sponsored by NSF, NOAA, and the U.S. Geological Survey, 88 pp.

Knudsen MF, Seidenkrantz MS, Jacobsen BH and Kuijpers A. 2011. Tracking the Atlantic Multidecadal Oscillation through the last 8,000 years. *Nature Communications*, 2, 178.
Kopp RE, Horton RM, Little, C. M., Mitrovica, J. X., Oppenheimer, M., Rasmussen, D. J., Strauss, B. H. & Tebaldi, C. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future, 2, 383-406.
Krasting JP, Dunne JP, Stouffer RJ, and Hallberg R. 2016. Enhanced Atlantic sea-level rise relative to the Pacific under high carbon emission rates. Nature Geoscience 9(3). doi:10.1038/ngeo2641.
Lee TN and Atkinson LP. 1983. Low-frequency current and temperature variability from Gulf Stream frontal eddies and atmospheric forcing along the southeast U.S. outer continental shelf. J Geophys Res 88:4541-4567.
Lee TN, Yoder JA, and Atkinson LP. 1991. Gulf Stream frontal eddy influence on productivity of the southeast U.S. continental shelf. Journal of Geophysical Research 96:22,191-22,205.
Link JS, Griffis R, and Busch S. 2015. NOAA Fisheries Climate Science Strategy, NOAA Technical Memorandum NMFS-F/SPO-155. U.S. Dept. of Commerce.
Little CM, Horton RM, Kopp RE, Oppenheimer M, Vecchi GA, and Villarini G. 2015. Joint projections of US East Coast sea level and storm surge. Nature Climate Change.
Lumsden SE, Hourigan TF, Bruckner AW, and Dorr G (eds.) 2007. The State of Deep Coral Ecosystems of the United States. NOAA Technical Memorandum CRCP–3. Silver Spring MD.
MAFMC (Mid-Atlantic Fishery Management Council). 2015. 2015, 2016, and 2017 Tilefish Specifications, Environmental Assessment, Regulatory Impact Review, and Initial Regulatory Flexibility Analysis. Mid-Atlantic Fishery Management Council. Dover, DE. 122 pp.
Miller GC and Richards WJ. 1980. Reef fish habitat, faunal assemblages, and factors determining distributions in the South Atlantic Bight. Proc. Gulf Carib. Fish. Inst. 32:114-130.
Munday PL, Dixson DL, Donelson JM, Jones GP, Pratchett MS, Devitsina GV, and Doving KB. 2009. Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. PNAS 106:1848-1852.
Nye JA, Link JS, Hare JA, and Overholtz WJ. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. Marine Ecology Progress Series 393:111-129.
Nye JA, Gamble RJ, and Link JS. 2013. The relative impact of warming and removing top predators on the Northeast US large marine biotic community. Ecological Modelling, 264, 157-168.
Ogden JC, Davis SM, Barnes TK, Jacobs KJ, and Gentile JH. 2005. Total System Conceptual Ecological Model. Wetlands 25:955-979.
Palandro DA, Andrefouet S, Hu C, Hallock P, Muller-Karger FE, Dustan P, Callahan MK, Kranenburg C, and Beaver CR. 2008. Quantification of two decades of shallow-water coral reef habitat decline in the Florida Keys National Marine Sanctuary using Landsat data (1984–2002). Remote Sensing of Environment 112: 3388-3399.
Parker RO and Dixon RL. 1998. Changes in a North Carolina reef fish community after 15 years of intense fishing - global warming implications. Transactions of the American Fisheries Society 127:908-920

Parris A, Bromirski P, Burkett V, Cayan D, Culver M, Hall J, Horton R, Knuuti K, Moss R, Obeysekera J, Sallenger A, and Weiss J. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1.

Pollnac R, Seara T, Colburn L, Jepson M. 2015. Taxonomy of USA East Coast Fishing Communities in Terms of Social Vulnerability and Resilience. Environmental Impact Assessment Review 55: 136-143.

Pistevos JCA, Nagelkerken I, Rossi T, Olmos M, and Connell SD. 2015. Ocean acidification and global warming impair shark hunting behaviour and growth. Sci Rep-Uk 5.Pollnac, R.B., T.

Rahmstorf S, Box JE, Feulner G, Mann ME, Robinson A, Rutherford S, and Schaffernicht EJ. 2015. Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. Nat Clim Change 5:475-480.

Rozas L. 1995. Hydroperiod and its influence on nekton use of the salt marsh: a pulsing Ecosystem, *Estuaries*. pp. 18:579-590.

Ruzicka R, Colella M, Porter J, Morrison J, Kidney J, Brinkhuis V, Lunz K, Macaulay K, Bartlett L, Meyers M, and Colee J. 2013. Temporal changes in benthic assemblages on Florida Keys reefs 11 years after the 1997/1998 El Nino. Mar Ecol Prog Ser 489:125-141.

Saintilan, N, NC Wilson, K Rogers, A Rajkaran and KW Krauss. 2014. Mangrove expansion and salt marsh decline at mangrove poleward limits. Global Change Biology 20: 147-157, doi: 10.1111/gcb.12341.

Schobernd CM and Sedberry GR. 2009. Shelf-edge and upper-slope reef fish assemblages in the South Atlantic Bight: habitat characteristics, spatial variation, and reproductive behavior. Bulletin of Marine Science 84:67-92.

Schunter C, Welch MJ, Ryu T, Zhand H, Berumen ML, Nilsson GE, Munday PL, Ravasi T. 2016. Molecular signatures of transgenerational response to ocean acidification in species of reef fish. Nature Climate Change. Publ.Online 1Aug2016. DOI: 10.1038/NClimate3087.

Serafy JE, Shideler GS, Araujo RJ, and Nagelkerken I. 2015. Mangroves Enhance Reef Fish Abundance at the Caribbean Regional Scale. PLOS ONE DOI:10.1371/journal.pone.0142022.

Smeed DA, McCarthy GD, Cunningham SA, Frajka-Williams E, Rayner D, Johns WE, Meinen CS, Baringer MO, Moat BI, Duchez A, and Bryden HL. 2014. Observed decline of the Atlantic meridional overturning circulation 2004-2012. Ocean Sci 10:29-38.

Toth L, van Woesik R, Murdoch T, Smith S, Ogden J, Precht W, and Aronson R. 2014. Do no-take reserves benefit Florida's corals? 14 years of change and stasis in the Florida Keys National Marine Sanctuary. Coral Reefs 33:565-577.

Vimon DJ and Kossin JP. 2007. The Atlantic Meridional Mode and hurricane activity. *Geophysical Research Letters,* pp. 34, L07709, doi:10.1029/2007GL029683.

Wallace RB, Baumann H, Grear JS, Aller RC, and Gobler CJ. 2014. Coastal ocean acidification: The other eutrophication problem. Estuarine, Coastal and Shelf Science 148:1–13.

Walsh HJ, Marancik KE, and Hare JA. 2006. Juvenile fish assemblages collected on unconsolidated sediments off the southeast United States continental shelf. Fishery Bulletin 104:256-277.

Waring GT, Josepheson E, Maze-Foley K, and Rosel PE. 2014. U.S. Atlantic and Gulf of Mexcio Marine Mammal Stock Assessments – 2013. NOAA Technical Memorandum NMFS-NE-228.

Whitfield PE, Muñoz RC, Buckel CA, Degan BP, Freshwater DW, and Hare JA. 2014. Native fish community structure and Indo-Pacific lionfish *Pterois volitans* densities along a depth-temperature gradient in Onslow Bay, North Carolina, USA. Marine Ecology Progress Series 509:241-254.

Yoder JA. 1983. Statistical analysis of the distribution of fish eggs and larvae on the southeastern U.S. continental shelf with comments on oceanographic processes that may affect larval survival. Estuarine Coastal and Shelf Science 17(6):637-650.

Yoder JA (1991) Warm-temperate food chains of the Southeast Shelf ecosystem. In: Sherman K, Alexander LM, Gold BD (eds) Food chains, yields, models, and management of large marine ecosystems AAAS Symposium. Westview Press, Inc., Boulder, Colorado USA

Yoder JA, Atkinson LP, Bishop SS, Blanton JO, Lee TN, and Pietrafesa LJ. 1985. Phytoplankton dynamics within Gulf Stream intrusions on the southeastern United States continental shelf during summer 1981. Cont Shelf Res 4:611– 635.

Zhang KQ, Douglas BC, and Leatherman SP. 2004. Global warming and coastal erosion. Clim Change 64:41-58.

Zhang L, Wang C, and Wu L. 2012. Low-frequency modulation of the Atlantic warm pool by the Atlantic multidecadal oscillation. Climate Dynamics, 39, 1661–1671.