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GULF OF MEXICO REGIONAL ACTION PLAN TO IMPLEMENT THE NOAA FISHERIES CLIMATE SCIENCE STRATEGY

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Cover Photo Credit: Red grouper on Pulley Ridge, April 2008. Andrew David, NOAA Fisheries, SEFSC; taken by a Phantom ROV owned/operated by the Undersea Vehicles Program at the University of North Carolina Wilmington from the NOAA Ship *Gordon Gunter*.

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ACRONYM

ACL	Annual Catch Limit
AMO	Atlantic Multidecadal Oscillation
AMOC	Atlantic Meridional Overturning Circulation
AOML	Atlantic Oceanographic and Meteorological Laboratory, a NOAA OAR facility
BOEM	Bureau of Ocean Energy Management, U.S. Department of the Interior
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CIMAS	Cooperative Institute for Marine and Atmospheric Studies
CMIP5	Coupled Model Intercomparison Project Phase 5, internationally coordinated climate model experiments of the World Climate Research Programme
CPRA	Coastal Protection and Restoration Act
CSCOR	Center for Sponsored Coastal Ocean Research, part of the NOAA National Centers for Coastal Ocean Science
CTD	Conductivity, Temperature, and Depth, a package of electronic oceanographic instruments that measure seawater conductivity, temperature, and depth
EBFM	Ecosystem-Based Fisheries Management
EcoFOCI	Ecosystems and Fisheries-Oceanography Coordinated Investigations, a joint NOAA Fisheries & OAR program
ENSO	El Niño Southern Oscillation
EIS	Environmental Impact Statement
ESA	Endangered Species Act
FAO	Food and Agriculture Organization of the United Nations
FIO	Florida Institute of Oceanography
FSSI	Fish Stock Sustainability Index
FTE	Full time equivalent employee
FWRI	Fish and Wildlife Research Institute
GFDL	Geophysical Fluids Dynamics Laboratory, a NOAA facility
GLOBEC	Global Ocean Ecosystem Dynamics, an international program
GMFMC	Gulf of Mexico Fishery Management Council (or Gulf Council)
GMRAP	Gulf of Mexico Regional Action Plan
GOM	Gulf of Mexico
GoMexSI	Gulf of Mexico Species Interactions Database, a program managed by Texas A&M University--Corpus Christi
GSMFC	Gulf States Marine Fisheries Commission
HC	Office of Habitat Conservation, NOAA Fisheries
HMS	Highly Migratory Species, a division of the Office of Sustainable Fisheries, NOAA 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)

LUMCON	Louisiana Universities Marine Consortium
MSE	Management Strategy Evaluation
NAS	National Academy of Sciences
NASA	National Atmospheric and Space Administration
NMFSPI	National Marine Fisheries Service Instruction
NOAA	National Oceanic and Atmospheric Administration
NCSS	NOAA Fisheries Climate Science Strategy
NCCOS	National Centers for Coastal Ocean Science
NCEI	National Centers for Environmental Information, NOAA National Environmental Satellite, Data, and Information Service
NFWF	National Fish and Wildlife Foundation
NGO	Non-Governmental Organization
NMFS	National Marine Fisheries Service, line office in NOAA, aka NOAA Fisheries
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 in NOAA
OCA	Ocean and coastal acidification
OCM	Office of Coastal Management, office in NOS
PBR	Potential Biological Removal
PR	Office of Protected Resources, NOAA Fisheries
RCT	Regional Collaboration Team, a NOAA cross-line office
RESTORE Act	Resources and Ecosystems Sustainability Act, Tourist Opportunities, and Revived Economies of the Gulf States Act of 2012
RFMO	Regional Fishery Management Organization
SECOORA	Southeast Coastal Ocean Observing Regional Association
SEDAR	SouthEast Data, Assessment, and Review
SEAMAP	Southeast Area Monitoring and Assessment Program
SERO	Southeast Regional Office, NOAA Fisheries
SEFSC	Southeast Fisheries Science Center, NOAA Fisheries
SF	Office of Sustainable Fisheries, NOAA Fisheries
ST	Office of Science & Technology, NOAA Fisheries
UNOLS	University-National Oceanographic Laboratory System
USACE	U.S. Army Corp of Engineers
USFWS	U.S. Fish and Wildlife Service, within U.S. Department of the Interior
USGS	United States Geologic Survey

EXECUTIVE SUMMARY

Warming ocean temperatures, sea level rise, and ocean and coastal acidification are thought to be key climate change drivers that result in biological impacts in the Gulf of Mexico. Understanding how major climate drivers such as these affect marine and coastal habitat distribution and quality, ecosystems and estuarine productivity, and living marine resources and their prey is critical for wise management. These changes could lead to direct and indirect effects on marine resource-dependent businesses and communities, such as a loss of fishing opportunities or deterioration of coastal infrastructure due to inundation or immersion as the level of oceans rises with the melting of polar ice caps. Anticipated result: some resources may become more or less productive and will likely result in a shift in the availability of living marine resources that support human communities.

The Gulf of Mexico Regional Action Plan (GMRAP) follows the approach presented in the NOAA Fisheries Climate Science Strategy (Strategy) (Link et al. 2015). Using a deliberative process that included input from stakeholders and the public, we assessed our related scientific work and identified 62 actions to help meet climate science needs for the Gulf of Mexico. Of these 62 actions, the highest priorities for climate science information and services include:

- Conducting climate vulnerability assessments for marine species in the Gulf of Mexico, their habitats, and associated human communities. These analyses will help identify species especially vulnerable to climate change to help fill research gaps and set priorities for the region (Actions 31, 32).
- Identifying and prioritizing multidisciplinary data needs for a comprehensive monitoring program for climate science in the Gulf of Mexico. A data needs assessment 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 NGO partners (Actions 47, 49). The analysis would include a data gap analysis to assess the adequacy of existing data and surveys to provide climate science information.
- Creating and regularly updating a plan for expanding the Ecosystem Status Report for the Gulf of Mexico to include human dimensions. The plan would include information that can be used to track trends in indicators of ecosystem health (Action 36).
- Establishing a formal Gulf of Mexico climate science team composed of experts within the Southeast Fisheries Science Center (SEFSC), Atlantic Oceanographic and Meteorological Laboratory (AOML), Highly Migratory Species (HMS), and Southeast Regional Office (SERO). The team would meet regularly to share ideas, build capacity and partnerships, identify training needs, and spearhead implementation of actions within the Gulf of Mexico Regional Action Plan (Actions 53, 54).
- Identifying new and maintaining critical baseline data in the Gulf of Mexico. For example, we will continue planning a comprehensive Gulf-wide survey for marine mammals with our partners. The frequency of current assessment surveys is very

low for marine mammals, and it has not been possible to assess trends in population size for any marine mammal stocks in the Gulf of Mexico (Actions 37, 38).

- Continuing building capacity to include climate and environmental covariates in stock assessments, hiring a management strategy evaluation specialist to identify harvest control rules that remain effective during anticipated climate changes, and identifying areas of overlap between Regional Action Plan efforts and those of Ecosystems Based Fisheries Management (Actions 15, 54, 49).
- Collaborating with colleagues across NOAA and external partners to share ideas for developing climate-informed reference points (Actions 2, 3).

All actions are important steps to meet climate science needs in the Gulf of Mexico, but we do not have the capacity to accomplish all possible actions in the near term. Our 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 re-directing staff. Our approach also includes 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 we receive increased funding for this work, we will prioritize and strategically stage actions that require additional funding.

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 developed a 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 our 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 will help reduce negative impacts and increase the resilience of 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 (Fig. 1).

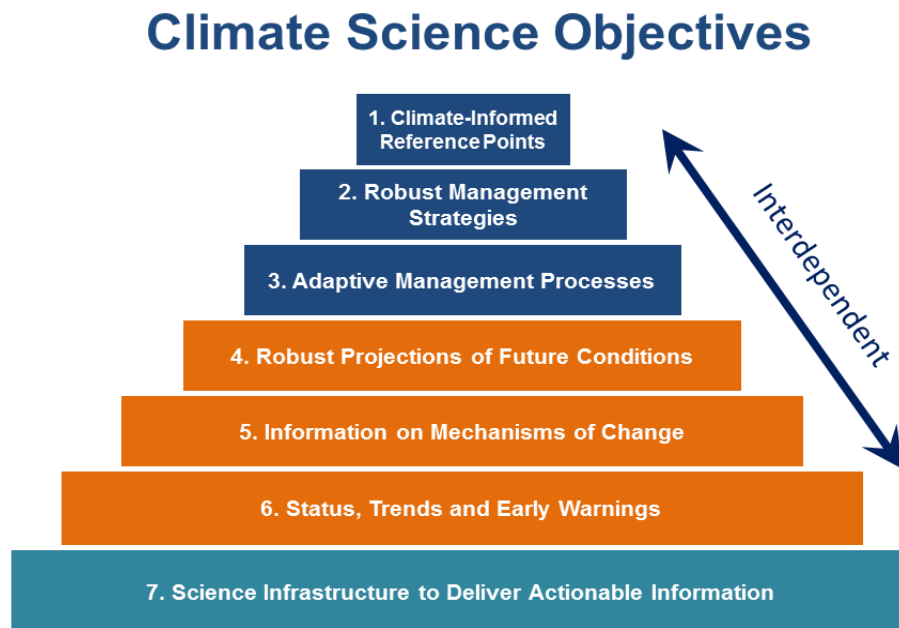


Figure 1. Seven objectives, discussed in the NOAA Fisheries Climate Science Strategy, provide decision-makers with the information they need to reduce negative impacts and increase resilience in a changing climate. Although all 7 objectives are interdependent,

they are somewhat sequential in that upper objectives build upon the lower ones. From the bottom to the top of pyramid, 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 1, 2 and 3) 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 NOAA Fisheries Climate Science Strategy: Gulf of Mexico Regional Action Plan (GMRAP), focuses on identifying priority actions that should be considered for the next three to five years to address climate change throughout the Gulf of Mexico. The GMRAP identifies current activities that contribute to our understanding of climate change impacts on Living Marine Resources (LMRs) and management in the Gulf of Mexico. 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 GULF OF MEXICO REGIONAL ACTION PLAN

NOAA Fisheries Southeast Fisheries Science Center (SEFSC) and Southeast Regional Office (SERO) identified a core working group to develop the GMRAP. Participants were drawn from the different components of the SEFSC and SERO divisions and laboratories located in offices and laboratories across the southeast region, as well as NMFS Headquarters Offices and colleagues from the NOAA Atlantic Oceanographic and Meteorological Laboratory. During development, drafts were shared across all southeast organizational divisions, other NOAA offices, Gulf of Mexico Fishery Management Council, Gulf States Marine Fisheries Commission, and the general public for input, comment, and revision.

As part of the development of the GMRAP, 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 GMRAP core working group during the development of the GMRAP plan.

REGIONAL ASSESSMENT

The Gulf of Mexico is a semi-enclosed, oceanic basin connected to the Atlantic Ocean by the Straits of Florida and to the Caribbean Sea by the Yucatan Channel. Although it covers approximately 218,000 square miles, it is a small basin by oceanic standards. One quarter of the Gulf of Mexico is a very deep basin (over 3,000 meters deep), while 35% is continental shelf (GMFMC 2004). Most of the oceanic water entering the Gulf of Mexico flows through the Yucatan Channel, a narrow and deep channel (1,650-1,900 m), and exits through the Straits of Florida. In the Gulf of Mexico, this flow produces the most pronounced circulation feature, known as the Loop Current. Eddies created on the boundary of the Loop Current periodically separate from the main current and progress northward and northwestward, influencing an upwelling of cold, nutrient-rich water along the continental shelf that, in turn, support physical and biogeochemical processes.

Large scale circulation systems with downstream effects that appear linked to the Yucatan Current and Loop Current includes 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 Gulf of Mexico, such as precipitation in the Midwest (Enfield et al. 2001), Atlantic hurricane activity (Vimont and Kossin 2007), depth of the mixed layer, and the size of the Atlantic Warm pool (Zhang et al. 2012).

In modeling studies, the AMO appears synchronized with the Yucatan Current and Loop Current through the influence of the AMOC (Knight et al. 2005; Liu et al. 2012; Zhang & Wang 2013). When the AMOC is strong, the Yucatan Current and Loop Current strengthen, bringing warm Caribbean water into the Gulf of Mexico. An AMO warm phase includes warmer surface temperatures in the Gulf of Mexico. Likewise, a weakening of the Loop Current is expected with a slowdown of the AMOC (Rahmstorf et al. 2015; Srokosz & Bryden 2015), which is predicted

to occur during this century. This is expected to reduce regional warming in the deep Gulf of Mexico (Liu et al. 2012; 2015). At the same time, however, a weakening of the Loop Current is predicted to exacerbate summertime surface warming in the northeastern shelf region of the Gulf of Mexico, due to a lack of dissipation of heat via vertical mixing with the deeper ocean (Liu et al. 2015).

Together, these oceanic features are responsible for driving many of the physical, biological, and chemical properties of the region on the scales relevant to marine populations (Lindo-Atichati et al. 2012, Karnauskas et al. 2015). Karnauskas et al. (2015) examined over 100 ecosystem indicators for the Gulf of Mexico and found that a major ecosystem-wide reorganization was associated with changes in the AMO from the cool phase to the warm phase in the mid-1990s. Since this is the only AMO regime shift that coincides with modern fisheries data collection in the Gulf of Mexico, the ability to detect the effects of this climate mode on specific ecosystem components is limited.

Warming ocean temperatures may have the most wide-ranging effects on fishery resources in the Gulf of Mexico, through both indirect and direct effects. Temperature can affect preference-driven shifts in population distributions (Pinsky et al. 2013; Sydeman et al. 2015). Recent surveys of seagrass bed assemblages in the northern Gulf of Mexico that were replicated and compared with those from the 1970s revealed numerous tropical or subtropical species that were absent from surveys in the 1970s (Fodrie et al. 2010). Snappers, groupers, butterflyfish, wrasses, and parrotfish appear to have shifted their ranges and are contributing to the tropicalization of northern Gulf of Mexico seagrass fish assemblages (Fodrie et al. 2010). Stocks in the Gulf of Mexico are limited in their ability to migrate northward due to the coastal Gulf States' borders. Studies are showing that assemblages that historically were in the northern Gulf of Mexico appear to have shifted southwestward toward deeper water over the past few decades (Pinsky et al. 2013). In addition, changes in water temperature and circulation can result in the loss of suitable pelagic habitat, as exemplified in modeling research for spawning bluefin tuna and larval bluefin tuna (Muhling et al. 2011; Muhling et al. 2015). However, future responses of marine organisms are challenging to predict because of gaps in knowledge on the physiology and plasticity of many organisms.

Gulf of Mexico corals are susceptible to higher temperatures and have experienced significant bleaching, disease outbreaks, and mortality in recent years (Coles and Riegl 2012, Harvell et al. 1999, Maynard et al. 2015). The Gulf of Mexico contains unique and varied coral reefs. Coral systems are found atop salt domes that rise out of the deep basin in the west (Flower Garden Banks); high relief carbonate banks in the northeast and central east region (drowned reefs and pinnacles); plate forming scleractinian corals along shallower portions (60 m) of Pulley Ridge in the southeast, and shallow coastal ecosystems that support a variety of diverse hard bottom communities. Mortality of corals in these ecologically diverse systems will directly affect habitat quality of reef-dependent fish species.

Many habitats and species in Gulf of Mexico estuaries and marine systems are dependent on the quantity, quality, and timing of freshwater inflows--in particular, the Mississippi River runoff. These inflows have historically deposited sediments that have built the extensive wetlands along the northern Gulf of Mexico border and support estuarine productivity throughout the region.

However, with the expansion of industrialized agricultural activities across the greater Mississippi watershed over the past century, this runoff is also laden with excessive nutrients, primarily nitrogen. The result is that the northwestern Gulf of Mexico currently experiences the largest area of seasonal hypoxia (dissolved oxygen $\leq 2.0 \text{ mg}\cdot\text{L}^{-1}$) in the western hemisphere (Rabalais et al. 2007, Bianchi et al. 2010). These low dissolved oxygen events occur each summer and have a variety of physiological and ecological effects on aquatic organisms, including direct mortality (McInnes and Quigg 2010), habitat loss and reduced growth (Craig and Crowder 2005, Craig 2012), impaired reproduction (Thomas and Rahman 2011), and indirectly affect species and food web interactions (Rose et al. 2009, de Mutsert et al. 2015). Model predictions that used a doubled CO_2 climate scenario suggest that climate-driven changes in river discharge would increase the severity of hypoxia in the Gulf by 30-60% relative to recent years (Justic et al. 2007). Increased water temperatures will exacerbate the negative effects of hypoxia on living organisms, because warmer water holds less dissolved oxygen than cooler water (Portner and Knust 2007).

Ocean and coastal acidification (OCA) is a stressor which has the potential to affect organisms directly or indirectly. Ocean and coastal acidification can affect habitat, prey species, and have cascading effects throughout ecosystems. For instance, OCA 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), including commercially and recreationally valuable reef fish. In the laboratory, OCA 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), and altered settlement/habitat preference cues (Munday et al. 2009). It has also been shown to increase mortality and reduce growth of eastern oysters (Dickinson et al. 2012) and delay juvenile development in boreal shrimp (Bechmann et al. 2011). In coastal regions, acidification can also be caused by increased nutrient loading and eutrophication, as the microbial degradation of organic matter increases CO_2 production and lowering seawater pH (Wallace et al. 2014). Model results from the Gulf of Mexico suggest that eutrophication from the Mississippi River will not only affect hypoxia, but eutrophication will also increase the likelihood of ocean acidification (Cai et al. 2011).

The recent, relatively rapid increase in sea level rise is predicted to result in seawater inundation of estuaries, coastal flooding, 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 Gulf of Mexico has been experiencing accelerated losses of saltwater wetlands (95,000 acres from 2004-2009, more than double the loss between 1998-2004; Dahl and Stedman 2013) due primarily to storms, but land subsidence, changes in freshwater inflows (due to diversions or changes in storm patterns), and sea level rise also have been playing a role. Salt marshes in estuaries of the Gulf of Mexico are important habitats that support many fishery species including penaeid shrimps, blue crabs, red drum, and spotted seatrout (Zimmerman et al. 2000), and flooding of the vegetated edge of the marsh appears to be important in determining the value of 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 these species are estuarine dependent, as are more commercially important Gulf of Mexico species such as shrimp and menhaden (Karnauskas et al. 2013).

Marine mammals and sea turtles are subject to a range of anthropogenic and natural stressors that could be exacerbated with the addition of climate impacts and stressors. In a review of potential impacts of climate change on marine mammals, Simmonds and Isaac (2007) noted that impacts would most likely be severe for small populations with limited habitat ranges, and that impacts may be mediated by changes in prey availability or distribution. For marine mammal species in the Gulf of Mexico, changes in circulation patterns associated with climate change would be expected to have an impact on the processes that concentrate the prey resources required to support marine mammal populations. In addition, there is limited ability of oceanic marine mammals to shift distributions further north to adapt to ocean temperature changes due to a surrounding orientation of the coastline. For coastal and estuarine dolphins, the frequency and intensity of harmful algal blooms and disease events may vary with changes in climate. Since these factors are currently the most common causes of Unusual Mortality Events, they may have significant effects on the viability of marine mammal populations. Finally, animals occupying estuarine habitats are likely to be impacted by habitat loss through sea level change, wetland loss, or erosion of coastlines. The possible impacts of climate change on marine mammal populations in the Gulf are unknown; however, given their dependency on specific habitat types and slow population growth, it is probable that ecosystem changes will have significant effects on marine mammal population dynamics. It is unclear whether or not dolphins that have established residency in a particular estuary would be able to adapt to a significant loss of estuarine habitat.

Climate changes would have profound effects on the long-term survival prospects of sea turtles given their dependence on both beaches and ocean habitats throughout the Gulf of Mexico, Southeast U.S. Atlantic Ocean, and Caribbean Sea. Sea turtles are globally distributed in the tropical and temperate regions and are particularly susceptible to climate change as their life cycle requires beaches as well as neritic and open ocean habitats. Sea level rise has the potential to negatively affect sea turtle nesting habitat throughout the Southeastern United States (see Hawkes et al. 2009 for a discussion of sea level rise effects on sea turtles globally). Changes in temperature have been demonstrated to have several effects on sea turtles as sex determination is temperature dependent and increased temperatures have been shown to cause an earlier start to nesting in Florida (Pike et al. 2006; Weishampel et al. 2010). Hawkes et al. (2007) modeled sex ratios on a North Carolina beach under a warming temperature scenario and showed that sex ratios would become overwhelmingly female biased. Warming temperatures also result in reduced or zero hatch success for many nests. In addition, an earlier start to the nesting season has been shown to decrease the length of the nesting season for loggerhead turtles and to increase the nesting season length for green turtles (Pike et al. 2006; Weishampel et al. 2010). Changes in the length of a nesting season can alter the overall reproductive productivity of a species and consequently the long-term population trends. Along with impacts to nesting beaches, climate change would alter the distribution and habitat use of sea turtles through such effects as altered currents, food availability, and predator distribution (Hawkes et al. 2009). Additionally, increased water temperature is likely to result in increased sea turtle strandings as turtles may remain in areas longer before migrating in winter which would result in an increase in cold stunning if temperature drops rapidly with a passing front.

The impact of climate change upon Gulf Coast fishing communities will occur as both primary and secondary effects of many of the above mentioned drivers. For example, the State of

Louisiana has already acknowledged land loss over the next fifty years as a result of sea level rise, subsidence, and other factors to be possibly as much as 1,750 square miles (CPRA 2012). This means that current infrastructure (docks, fish houses, marinas, etc.) will need to be modified or relocated to accommodate rising water levels and in some extreme cases entire communities may need to relocate. This can lead to longer commutes for fishermen and others who work at these locations and add to the transportation costs of goods and services related to seafood commerce. Saltwater intrusion into freshwater marsh and other habitats as a result of rising sea levels has and will continue to have an impact upon nurseries for many fish and shellfish species. Loss or changes in habitat may cause negative impacts, such as a decline in stocks reliant on that habitat or force some species to move. Alternatively, there could be positive impacts: changes may be beneficial and provide opportunity or new locations for different species to colonize. In any of these cases, fishermen may need to adapt by switching species, changing gear, moving to new locations, or, in extreme cases, reduce their reliance on fishing as their main source of income.

Finally, Gulf of Mexico resources were threatened and many were injured as a result of the Deepwater Horizon incident. The reports, [*A Comprehensive Restoration Plan for the Gulf of Mexico: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement \(2016\)*](#) and [*RESTORE Council Comprehensive Plan*](#), describe the range of these impacts and will guide restoration activities in the Gulf of Mexico. Many of the restoration goals (e.g., replenish and protect living coastal and marine resources) and restoration types (e.g., fish and water column invertebrates, marine mammals, sea turtles) outlined in the plans may also align with climate science needs and priorities and are necessary context for understanding the current ecosystem and potential climate impacts in the Gulf of Mexico ecosystem.

STRENGTHS, WEAKNESSES, AND OPPORTUNITIES

The Southeast Fisheries Science Center and its partners are prepared 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 instead it seeks to identify some examples of regional strengths, weaknesses, and opportunities. The latter are described in more detail in the description of actions that follow.

Strengths

Expert staff conducting rigorous scientific studies in the Gulf of Mexico, strong regional partnerships, and a history of resource surveys in the Gulf of Mexico are three examples of our strengths.

The Southeast Fisheries Science Center has talented staff conducting climate relevant research across the southeast region. SEFSC scientists have conducted research on the effects of hypoxia on commercially important finfish species (Craig and Crowder 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). Also, SEFSC scientists have 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 have a thorough understanding of oceanographic circulation in 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 (Liu et al. 2012; Objective 4). 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.

We also maintain strong partnerships with a wide variety of federal, state, university, non-governmental, and international partners. 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 Gulf of Mexico. For example, the SEFSC maintains close collaborations with SERO, AOML, GFDL, the Gulf Council, Gulf States Marine Fisheries Commission, Gulf of Mexico Large Marine Ecosystem program, international partners (Mexico and Cuba), 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 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 Gulf of Mexico. SEFSC coordinates 15 resource surveys in the Gulf of Mexico 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 Area Monitoring and Assessment Program (SEAMAP). SEAMAP is a fisheries-independent collaborative sampling program conducted from 1972 to the present that assesses the abundance and distribution of fish and demersal invertebrate fauna in Gulf of Mexico shelf waters. Data from this survey provide a long time series that has been used in various stock assessments, integrated ecosystem assessments, and developed into 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-related change in the Gulf of Mexico (Objectives 6 & 7).

Weaknesses

With the strengths described above, we also face 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 Gulf of Mexico 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 our scientists have been able to conduct some climate-related research in the Gulf of Mexico, 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 they 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 Gulf of Mexico 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, we would be faced with 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 Gulf of Mexico. Dialogue between scientists, managers, and stakeholders including fishermen can always be strengthened. For example, boosting our 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 GMRAP provides a plan for acting on opportunities highlighted by assessing our climate science strengths and weaknesses in the Gulf of Mexico.

Strengthening climate science coordination within NOAA and with other partners throughout the Gulf of Mexico 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. We hope 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 (all objectives). We will continue to work closely with SERO, AOML, other NOAA programs and laboratories, Federal partners, States, the GMFMC and GSMFC, academia, private research facilities, the fishing industry, environmental NGOs and other partners around the Gulf of Mexico. We also plan to establish a regional NOAA climate team including staff from SEFSC, SERO, HMS, AOML, and other regional partners. This climate team will meet regularly to enhance our ability to identify research gaps and overlapping needs for climate science, generate multidisciplinary strategies, leverage existing data, and set joint priorities (Objective 7).

In the Gulf of Mexico, we also envision a unique opportunity to improve science coordination in the wake of the Deepwater Horizon oil spill. Out of that event has come a new and energized focus on understanding the Gulf of Mexico as a large marine ecosystem to make best use of the funding that is now dedicated to restoring it as well as to make it and the human communities dependent upon it more resilient in the future. Many SEFSC scientists and NOAA Fisheries managers are engaged in the ongoing RESTORE efforts, thus we anticipate opportunities for meeting climate science needs and priorities that overlap with the RESTORE Act Science Program and other Deepwater Horizon-related monitoring, restoration, and science programs (Objective 7).

We also have an opportunity to conduct strategic planning for climate science in the Gulf of Mexico (Objective 7). We can evaluate our current suite of surveys and data for gaps, coordinate and standardize data collection efforts across the Gulf, identify climate ready cruises in coordination with partners, and work with partners to develop a comprehensive and coordinated plan for meeting climate science needs. We can incorporate into our 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 integrate with ecosystem-based fisheries management efforts that dovetail with climate science priorities. Conducting climate vulnerability assessments for species in the Gulf of Mexico 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 Gulf of Mexico also presents an opportunity for us 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 our capacity to interact with managers and stakeholders and maintaining liaison activities between science and management are critical (Objectives 1, 2, 3, 7). Initial planning and coordination to capitalize on these opportunities will stretch our current capacity, but it 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 NOAA partners across the region, including expertise and resources being applied through various DWH programs, are critical to managing living marine resources in the Gulf of Mexico. NOAA Fisheries Southeast Fisheries Science Center and Southeast Regional Office consist of a strong scientific and management team with expertise that crosses many disciplines. The goal of most of our 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 our 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 our partners, and enhance our science infrastructure.

The GMRAP team assessed our ongoing work and identified 62 draft actions to help meet climate science needs for the Gulf of Mexico. In this section and in Table 1, we discuss our approach for making progress on these activities over the next three to five years with level funding by strategically aligning existing programs to include climate science, re-directing staff, and collaborating with partners. We also include actions that could be accomplished over the next three to five years with increased funding. As funding becomes available, we will prioritize and scale these actions as needed to meet our needs within the constraints of any new resources. Some actions in our plan are necessary prerequisites for others, and we will also consider the need to sequence activities appropriately in the event that funding becomes available. Actions are presented in relation to the seven Strategy objectives identified in Figure 1.

Table 1. GULF OF MEXICO REGIONAL ACTION PLAN TABLE

Shaded actions indicate action items that require increased funding. If additional funding is received, these actions would be prioritize and strategically staged. Acronyms are defined in the first section.

No.	Action Name	Funding Scenario	Time Frame (years)	Action Description	Partners
Objective 1 – Climate Informed Reference Points					
1	Climate-informed reference points	Increase	2017-2021	Evaluate the capacity of the current stock assessment methodology to account for environmental and climatic impacts when estimating management points to produce climate-appropriate biological reference points and buffers.	SERO, GMFMC, HMS
2	Climate-informed reference points	Level	2017-2021	Increase collaborations with colleagues across the agency and with external partners on approaches for developing climate-informed reference points.	SERO, SF, ST, HMS, AOML, NOAA’s Regional Climate Centers (Southern), Southeast Regional Climate Center, NOAA’s National Climatic Data Center, Gulf Regional Collaboration Team (RCT), NOAA Restoration Center
3	Workshop for climate-informed reference points	Level	2017-2021	Collaborate with colleagues across NOAA and external partners to share ideas and explore development of climate-informed reference points.	SERO, ST, SF, HMS, AOML, Academia, SEDAR, ICCAT, IEA partners, Gulf RCT
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, DWH restoration planning, and other management actions and products.	SERO, HC, PR, HMS, ST, GMFMC, NOAA Restoration Center

5	Climate-informed reference points	Increase	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	Stakeholder priorities	Increase	2017-2021	Assess stakeholder priorities to establish societal objectives for income distribution and productivity in fisheries, and to develop reference points to assess the impact of climate change scenarios relative to the societal objectives.	SERO, SF, HMS, ST, GMFMC, Sea Grant
Objective 2 – Robust Management Strategies					
7	Management strategy evaluation	Level	2017-2021	Use Management Strategy Evaluations to identify harvest control rules that remain effective during anticipated climate changes.	SERO, HMS, SF, GMFMC
8	Management objectives	Level	2017-2021	Continue collaborative efforts with international neighbors and partners to share management objectives in light of anticipated climate impacts.	SERO, GMFMC, GSMFC, Department of State, ICCAT, FAO, CITES, Harte Research Institute, Academia, Gulf of Mexico Alliance, Mexico, Cuba, and others
9	Ecosystem considerations	Increase	2017-2021	Adapt the Alaska Fishery Science Center’s ecosystem considerations summary (e.g., Alaska Marine Ecosystem Considerations 2014 Report) for the Gulf of Mexico to accompany management documents.	SERO, ST, SF, HMS, PR, GMFMC
10	Ecosystem considerations	Increase	2017-2021	Incorporate ecosystem information needs identified by DWH restoration and science programs when developing or planning research activities.	NOAA Damage Assessment Remediation and Restoration Program, RESTORE Act Council, RESTORE Act Science Program,

					NOAA Restoration Center, National Fish and Wildlife Gulf Environmental Benefit Fund, National Academy of Sciences Gulf Research Program, and others
11	Community resilience	Increase	2017-2021	Begin process to identify management strategies and define objectives to mitigate vulnerability and/or promote resilience of coastal communities.	SERO, GMFMC, HMS, Sea Grant Climate Community of Practice, Emergency Managers, States and coastal communities
Objective 3 – Adaptive Management Processes					
12	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
13	Event 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
14	Fishermen observations (Citizen science)	Increase	2017-2021	Establish more formal methods for scientists and managers to learn about ecosystem changes observed by long time fishermen and other stakeholders who are on the water frequently.	Fishing industry, GMFMC Advisory Panels, SERO, HMS, SF, ST, SEDAR, Sea Grant
15	Environmental covariates in stock assessments	Level and Increase	Ongoing	Continue to include environmental covariates in stock assessments.	SERO, AOML, GMFMC, HMS, SEDAR
16	Increase dialogue between scientists and	Level and Increase	2017-2021	Increase dialogue between scientists and managers to enhance collaborative adaptive management process.	SERO, HMS, SF, ST, PR, HC, NOAA Restoration Center, AOML, RESTORE

	managers				Act Council, GOMA, GMFMC
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, Gulf RCT
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	Down-scaled climate model validation	Increase	2017-2021	Collaborate with NOAA partners to consider a retrospective evaluation of the utility of the climate models for long term forecasting to establish process for validating downscaled climate models and use validations to improve forecasts.	AOML, Academia, GFDL, NOS-NCCOS-CSCOR, Northern Gulf Institute, 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 along the northern Gulf of Mexico.	AOML, Academia
21	Decadal forecast system	Increase	2017-2021	Build and evaluate a decadal forecast system for physical and biogeochemical processes in the Gulf of Mexico by downscaling existing CMIP5 decadal forecast simulations to a regional scale.	AOML, Academia, GCOOS, SECOORA
22	Apply models	Increase	2017-2021	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, Gulf of Mexico IEA team
23	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, USACE NOS-NCCOS-CSCOR- Ecological Effects of Sea Level Rise
24	Apply models	Level	Ongoing	Continue to examine and develop an Atlantic bluefin tuna	HMS, NASA, NOAA, AOML, RC

				physiological model to better understand climate impacts on the species and its spawning in the Gulf of Mexico.	
25	Apply models	Increase	2017-2021	Evaluate long term effects of climate change on the frequency of red tide events and dolphin unusual mortality events in the Gulf of Mexico.	SERO, AOML, NOS, States
26	Apply models	Increase	2017-2021	Integrate outputs from climate models into existing spatial density models for marine mammals.	AOML, USGS
27	Apply models	Increase	2017-2021	Examine the impact of land loss due to sea level rise on estuarine bottlenose dolphin stocks and habitat.	SERO, AOML, Academia USGS, NOS/ Office for Coastal Management
28	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, NCEI, NOAA Climate Program, Academia, GMFMC
29	Predicting income distribution and productivity	Increase	2017-2021	Assess the potential economic impact of climate change on the commercial and recreational fishing industries.	SERO, ST, NOS, HMS, Sea Grant
30	Predicting 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 Gulf of Mexico.	SERO, ST, NOS, AOML, HMS, Academia, Sea Grant, Climate Community of Practice
Objective 5 – Understand the Mechanisms of Change					
31	Vulnerability assessments	Level	2016-2017	Conduct the scoping necessary for implementing species vulnerability assessments.	SERO, NOAA Fisheries HQ, HMS, AOML, NOS, NOAA Climate Program
32	Vulnerability assessments	Level and increase	2017	Conduct climate vulnerability assessments.	SERO, ST, PR, SF, HC, HMS, AOML, Academia, GMFMC, Gulf Coast Prairie Landscape Conservation Cooperative (for

					habitat)
33	Vulnerability assessments	Increase	Ongoing	Adapt community social vulnerability indices for coastal and fishing communities in the Gulf of Mexico based on the outcome of the species vulnerability analyses.	SERO, ST, HMS, NOS, Sea Grant, Climate Community of Practice, Gulf of Mexico Research Initiative - Consortium for Resilient Gulf Communities
34	Research	Increase	2017-2021	Expand collaborative research efforts focused on understanding the drivers and mechanisms of climate change in the Gulf of Mexico.	AOML, NOAA Climate Program, USGS, USFWS, Academia
35	Research	Increase	Ongoing	Continue research on the climate-driven displacement of ecologically important habitats.	SERO, HC, PR, HMS, NOAA Restoration Center, Academia, State agencies, RESTORE Act Science Program, USFWS, USACE
Objective 6 – Track Change and Provide Early warnings					
36	Ecosystem status report	Level	2017, Periodic	Regularly update the Ecosystem Status Report for the Gulf of Mexico (2013) and strategy for accomplishing the update.	SERO, GMFMC, AOML, HMS, and others
37	Baseline data	Increase	2017-2021	Create a strategy to identify new and maintain current critical baseline data identified in the Gulf of Mexico comprehensive monitoring program (see Objective 7).	SERO, NCEI, RESTORE, States, Academia
38	Baseline data	Level	2016-2017	Explore the feasibility (technical and budget) of conducting a comprehensive, Gulf-wide survey for marine mammals.	PR, BOEM, Academia
39	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
40	Baseline data	Level	2017-2021	Continue to build partnerships for coordinating an in-water monitoring long-term network for sea turtles.	SERO, FWS, state agencies

41	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 (e.g. FWRI)
42	Tracking change	Increase	2017-2021	Conduct a needs assessment for the components of an early warning toolbox for the Gulf of Mexico.	AOML, NOAA Climate Program, Academia
43	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
44	International coordination	Level	Ongoing	Continue to collaborate with the Gulf of Mexico Large Marine Ecosystem Program.	NOS-OCM-Gulf Region, Gulf of Mexico IEA Team, International partners
Objective 7 – Science Infrastructure to Deliver Actionable Information					
45	Strategic planning	Level	2016-2018	Include climate science in the SEFSC's upcoming strategic plan.	SERO, AOML, GMFMC, HMS
46	Strategic planning	Level	2016-2018	Review and assess the recommendations from the March 2016 Ecosystems Science Program Review and develop a strategy to address and incorporate them into planning activities for climate science needs.	SERO
47	Strategic planning	Increase funding or dedicate staff time	2016-2018	Conduct a detailed science and data gap analysis for the Gulf of Mexico.	AOML, SERO, HMS, HC, NOAA Restoration Center, GMFMC, RESTORE Act Science Program, Academia, Northern Gulf of Mexico Sentinel Site Cooperative
48	Strategic planning	Increase funding or dedicate staff time	2016-2018	Identify climate ready and/or multi-mission cruises in the Gulf of Mexico.	AOML, OMAO, NOS, Academia (e.g., LUMCOM, FIO), UNOLS, NSF, States
49	Strategic planning	Increase	2017-2019	Develop a comprehensive and collaborative monitoring program for climate and other ecosystem and ecological information	SERO, ST, SF, HMS, PR, HC, NOAA Restoration Center, AOML, NOAA IEA

				necessary to meet NOAA Fisheries mission for Gulf of Mexico species and habitats, including ecosystem approaches to fisheries management (e.g., Ecosystem Based Fisheries Management) and Deepwater Horizon related monitoring, restoration, and science programs.	and Climate Programs, States, GMFMC, RESTORE Act Council, International partners, FWS, others
50	Strategic planning	Level	2016-2017	Coordinate science needs and priorities with DWH related monitoring, restoration, and research.	HC, SERO, NOAA Restoration Center, RESTORE Act Council, NRDA trustees, NOAA RESTORE Act Science Program, NAS Gulf Research Program
51	Strategic planning	Increase	2017-2021	Establish a joint team with FWS and Gulf MEX-US to identify priority studies and data for Gulf of Mexico sea turtle populations.	SERO, AOML, Academia, FWS, Gulf MEX-US
52	Strategic planning	Level	2016-2017	Review and discuss the report resulting from the NOAA Fisheries Economics & Human Dimensions Program Climate Science Workshop with respect to planning and collaborative research efforts in the southeast.	SERO, ST
53	Build capacity	Level + staff time	2016 - 2017	Establish a formal SEFSC, OAR/AOML, SERO Gulf of Mexico climate science team with regular meetings and hold a kick-off meeting.	SERO, OAR/AOML, NCEI, HMS, Gulf Regional Collaboration Team, NOAA Climate Program, Sea Grant Climate Community of Practice
54	Build capacity	Level	2016	Hire a Management Strategy Evaluation FTE position at the SEFSC.	
55	Build capacity	Increase funding or dedicate staff time	2016, 2017-2021	Identify and secure the people resources needed to conduct the work of this Action Plan (i.e. climate science researcher and coordinator, survey statistician, other skill sets) through hiring new FTEs, contractor services, or	SERO, AOML, HQ, Academia

				cooperative research programs.	
56	Build capacity	Increase	2017-2021	Invest in existing staff professional development to build or strengthen expertise to meet climate science needs.	AOML, SERO, HQ, NOAA Climate Program, Academia
57	Build capacity	Increase	2017-2021	Develop short term rotational assignments and/or exchanges between NOAA programs to build capacity and share ideas.	AOML, SERO, HQ, HMS, NOAA Climate Program, NCEI, Climate Cooperative Institutes, Academia
58	Build capacity	Level	2016-2018	Strengthen relationship with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL).	GFDL, AOML
59	Build capacity	Level	2016-2018	Evaluate existing external and internal funding opportunities for climate science priorities and coordinate proposals.	SERO, HQ, HMS, AOML, NOAA Climate Program, RESTORE Act Science Program
60	Build capacity	Level	2017-2021	Initiate a partnership with NOAA's National Centers for Environmental Information (NCEI).	NCEI, AOML, SERO, HQ
61	Build capacity	Increase	2017-2021	Initiate a Citizen Science program for the Gulf of Mexico to help address climate science needs.	SERO, ST, HMS, AOML, NOS, Gulf NEPs, NERRs, Sanctuaries, Sea Grant
62	Strategic planning	Level	2015	Convene a workshop to collect external data and information for developing the GMRAP.	SERO, HQ SF, HMS, GMFMC, Academic

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 to incorporate changing climate conditions into these reference points is critical for supporting climate-ready living marine resource management. It is also a genuine challenge and will require in many cases additional data, analyses, and modeling that goes beyond current practices. With level funding, our actions under Objective 1 include collaborating and sharing ideas with other scientists and managers for developing appropriate climate-informed biological reference points for species management in the Gulf of Mexico. With increased funding, and dependent on progress under other plan Objectives, we would prioritize and stage the remaining actions under Objective 1.

Level funding

- Increase collaborations with colleagues across the agency and with external partners on approaches for developing climate informed reference points (Action #2). This is a challenging area for exploration, and working with partners and other NOAA offices will strengthen our approach. Climate-informed reference points also have potential to be incorporated into DWH restoration planning and adaptive management processes and could influence restoration reference points.
- Collaborate with colleagues across NOAA and external partners to share ideas and explore how to develop climate informed reference points. This should involve partners working on similar efforts such as the Integrated Ecosystem Assessment (IEA), but effort would need to identify other potential partners and address clear goals, timing, decision support tools, and other inputs. (Action #3).

Increased funding

- Evaluate the capacity of the current assessment methodology to account for environmental and climatic impacts when estimating reference points to produce climate-appropriate biological reference points and buffers (Action #1).
- Continue to incorporate climate and ecosystem considerations into Essential Fish Habitat and Habitat Areas of Particular Concern designations, National Environmental Policy Act reviews, DWH restoration planning, and other management actions and products (Action #4).
- Examine the ability of protected species reference points to explicitly incorporate changes in climate (Action #5), and consider related uncertainty for ESA actions, including section 7 biological opinions, section 4 listing and recovery decision, cumulative effects analyses for critical habitat designations, incidental take recommendations, etc. 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 at that level. 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. We are interested in exploring 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 us to predict how PBR or other metrics would change under different climate scenarios.

- Assess stakeholder priorities to establish societal objectives for income 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 Management Strategy Evaluation (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 we would prioritize and stage the remaining actions under Objective 2.

Level 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). Work being carried out includes the use of MSE, in both single-species and multi-species frameworks, to understand whether current control rules are robust to future predicted changes in climate. To date, this work has focused largely on the effects of episodic natural mortality events, such as red tide, on the reef fish complex on the West Florida Shelf. Current research is creating an operational red tide index to understand predictability of red tide events with future climate change, and this has been incorporated into MSEs to re-evaluate policies under changing climate. The work has resulted in presentations to the GMFMC Science and Statistical Committee on single-species management strategy evaluation and an initial scoping exercise to understand the Council's desired management performance metrics. Further exchange is needed to advance the process of defining the Council's management goals in light of climate effects and ecosystem processes. The existing work on single-species and multi-species MSE involves a significant investment of leveraged funds from various internal grants and not Center funding. 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 SEFSC with a goal of it being filled in 2016.

- Continue collaborative efforts with the GMFMC, Gulf States Marine Fisheries Commission (GSMFC), international partners (Mexico and Cuba), Regional Fishery Management Organizations (RFMOs, 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)) to share management objectives in light of anticipated climate impacts on population, community, and ecosystem processes (Action #8).

Increased funding

- Consider adapting the Alaska Fishery Science Center’s ecosystem considerations summary (e.g., Alaska Marine Ecosystem Considerations 2014 Report) for the Gulf of Mexico to accompany management documents, including stock assessments, fishery management plans, Biological Opinions, consultations, environmental assessments, and environmental impact statements (Action #9). Inclusion of climate information into the management process should depend on the current condition and suspected susceptibility to climate-driven forcing. For example, for a fish stock that is thought to be currently held at a biomass roughly around the theoretical maximum sustainable yield, the management goal would be to optimize year-to-year yields through the inclusion of environmental information. Preliminary management strategy evaluation work in this realm suggests that the mechanisms of environmental change have to be very well understood in order for a fishery to actually achieve increased yields through the incorporation of environmental drivers (Punt et al. 2014) and thus the expected gain needs to be evaluated in light of the cost of the necessary research to achieve such gains. Inclusion of climate information may play a more important role in preventing collapses of stocks that have been overfished to the point where low recruitment years become more probable or in cases where a recruitment regime shifts is suspected. Thus, priorities for inclusion of climate information in fisheries management should be created via a dialogue between scientists who can evaluate the risk of population collapse in the absence of information and managers who make decisions about the acceptable levels of risk and the value in optimization of resources.
- Incorporate ecosystem information needs identified by DWH restoration and science programs when developing or planning research activities. Coordinate with internal and external partners and potential end-users of the research and modeling activities with high potential to impact restoration planning and implementation activities (Action #10).
- Begin process to identify management strategies and define objectives to mitigate vulnerability and/or promote resilience of coastal communities, based on data, assessments, and dialogue with managers, decision-makers, and fishing communities (Action #11).

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,

we will focus our efforts on continuing to include environmental covariates in stock assessments and create decision tables that provide quantitative advice to managers. With increased funding we would prioritize and stage the remaining actions under Objective 3 that expand our ability to respond to climate related events when they happen and our knowledge of community resilience.

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 #12). Initiatives such as the Gulf of Mexico Ecosystem Status Report (Karnauskas et al. 2013) 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. 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.
- Continue to include environmental covariates in stock assessments and harvest control rules (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 Gulf of Mexico, operational models are currently being developed to predict climate effects on the dynamics of select species in the reef fish complex. Such initiatives include an index of natural mortality for grouper species based on red tide events (Walters et al. 2013) and predictions of recruitment strength for red snapper (Karnauskas et al. 2013). These predictions can be incorporated into stock assessments for these species to modify and shape key parameters (natural mortality and recruitment). 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 (e.g., Harford et al. 2014). Some of this ongoing work can be accomplished with level funding, but to expand this work would require increased funding.

Increased funding

- Improve our capacity to respond in real time to climate related events, e.g., fish kills, red tide, and harmful algal blooms, by collecting additional samples, analyzing new data, and improving forecasts and models (Action #13). This capacity would allow us to provide 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 National Centers for Coastal Ocean Science (NCCOS) Center for Sponsored Coastal Ocean Research, Center for Coastal Fisheries and Habitat Research, Office of Response and Restoration, and the Damage Assessment, Remediation, and Restoration Program.
- Establish more formal methods for scientists and managers to learn about ecosystem changes observed by long time fishermen or those who fish frequently (Action #14). 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.

- 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 #16). For example, in the Gulf of Mexico, 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 us detect and respond to climate influences on populations; in other cases, detecting such effects may be cost-prohibitive and we may need to focus on risk-adverse management policies. These collaborative planning efforts should be a guiding force for future climate-related fisheries research priorities in the region.
- 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 our capacity to adaptively manage fish stocks in a changing climate, we also 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 Region 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 us 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 Gulf of Mexico. With level funding, we will focus on current research. With increased funding we would prioritize and stage the remaining actions under Objective 4 in Table 1. We also note that investments in many of these research and modeling efforts would benefit from integration into the Gulf of Mexico comprehensive

monitoring program and other strategic planning efforts described in Objective 7 and this assessment could affect how we prioritize these actions.

Level funding

- Use a high-resolution regional ocean-biogeochemistry model to downscale the model projection of the carbon and biogeochemical parameters from the Coupled Model Intercomparison Project Phase 5 (CMIP5) along the northern Gulf of Mexico for the 21st century (Action #20). This ongoing research will provide a range of realistic scenarios of future environmental changes in terms of physical and biogeochemical processes in the northern Gulf of Mexico for the research community and fisheries resource managers. The first step in identifying the future states of marine and coastal ecosystems, including their dependent human communities, is predicting the future physics of the atmosphere and ocean under agreed upon climate change scenarios. This is accomplished by downscaling global climate models to be of use in the region of interest. Fortunately, this has already been done to varying degrees throughout much of the Gulf of Mexico. AOML has developed various downscaled models of climate predictions for the Gulf of Mexico which provide the basis for an understanding of future physical states in this region (Liu et al. 2012).
- Continue research on sea level rise and use existing down-scaled climate models to map predicted coastal flooding (Action #23). Flooding of salt marshes controls access to the marsh surface for aquatic organisms and likely regulates the value and use of this habitat for shrimp and juvenile fish. Even small sea level changes in the marshes and bays of Texas and Louisiana can have a strong impact on nursery grounds of penaeid shrimp (Zimmerman et al. 2000, Rozas 1995). In collaboration with SERO, this research has potential to assist in creating adaptive management plans for other species, including the anticipated loss of mangroves from sea level rise and for recommendations regarding seasonality of Gulf sturgeon spawning.
- Continue to examine and develop an Atlantic bluefin tuna physiological model to better understand climate impacts on the species and its spawning in the Gulf of Mexico (Action #24). Predictions of future physical states of the Gulf of Mexico can be used in conjunction with the vulnerability assessments of species to help characterize the future states of marine and coastal ecosystems and the communities that depend on them. These predictions can be combined with physiological models to understand the potential impacts of climate on specific organisms. Work funded by the National Atmospheric and Space Administration (NASA) and NOAA in conjunction with AOML suggest a decreased spawning habitat for bluefin tuna in the Gulf of Mexico based upon downscaled climate models. NOAA Fisheries will continue to develop a bluefin tuna physiological model to better understand climate impacts.

Increased funding

- Collaborate with partners to consider a retrospective evaluation of the utility of the climate models for long term forecasting to establish process for validating downscaled climate models and use validations to improve forecasts (Action #19).
- Build and evaluate a decadal forecast system for physical and biogeochemical processes in the Gulf of Mexico by downscaling existing CMIP5 decadal forecast simulations to a regional scale (Actions #21). Results from the regional forecast system will provide

insight into habitat conditions, including estimates of uncertainty for the next decade (2015 - 2023) and provide a potential method for adaptive management at shorter time scales. This work adds a biogeochemical component to this modeling framework to understand past and future predicted changes in the productivity and other biogeochemical properties of the ecosystem. Other work has been carried out nationally to understand the extent of species distributions due to climate change (e.g., the OceanAdapt project at Rutgers University). Once we have established an understanding of predicted physical changes, we can use ecosystem and human dimensions models and our scientific knowledge to predict how this physical environment will produce the future state of the marine and coastal ecosystem, including dependent human communities.

- 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 #22). Through leveraged funding with partners, a suite of ecosystem models has been developed for the Southeast region with the goal of using these models to predict future states of ecosystems in the Gulf of Mexico. Models that have been parameterized for the Gulf of Mexico and in use to date include Ecosim/Ecopath, OSMOSE (Grüss et al. 2015), and Atlantis. In the process of developing these models, significant data gaps have been highlighted and additional funds have been allocated from outside sources to address these gaps. Examples include the compilation of a diet data base (GoMexSI) and workshops to address the use of existing data sets in ecosystem model parameterization (e.g., Florida RESTORE Act Centers of Excellence Program). 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 could also be valuable for understanding the broader ecosystem benefits of restoration investments in the Gulf of Mexico, 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 long term effects of climate change on the frequency of red tide events and dolphin unusual mortality events in the Gulf of Mexico (Action #25) in collaboration with partners.
- Integrate outputs from climate models into existing spatial density models for marine mammals (Action #26). Survey data and habitat information are current inputs into spatial distribution maps for marine mammals in the Gulf of Mexico. We plan to use existing climate model outputs to predict potential changes to those distributions. This action requires close collaboration with AOML and other partners.
- Examine the impact of land loss due to sea level rise on estuary bottlenose dolphin stocks and habitat (Action #27). To accomplish this action we must partner with AOML or other organizations to develop models that project land loss and terrestrial water flow changes over time.

- Develop a standard modeling toolbox and best practices for modeling under uncertainty to link future ocean and freshwater states with LMRs and with the ability to couple models across types (Action #28).
- Assess the potential economic impact of climate change on the commercial and recreational fishing industries, particularly in terms of changes in income distribution and productivity at the vessel level (Action #29). The projected impacts of climate change on human communities will be multifaceted and generate behavioral changes among resource users, relocation of infrastructure, and migration of human communities. Currently, fishermen are modifying fishing behavior based upon species shifts that have been reported in the Gulf, as species move to deeper waters. Traveling longer distances and gear modifications may be required if those species continue to be targeted. Land losses due to sea level rise and subsidence are currently forcing modifications of shorelines and infrastructure and may force relocation of businesses or entire human communities.
- Begin to assess possible impact of climate change scenarios on the well-being and vulnerability of fishing communities in the Gulf of Mexico (Action #30) 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 the Gulf of Mexico IEA Program. 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 Strategy calls for vulnerability assessments to be conducted for LMRs in all regions to help guide more specific research and possible management actions. With level funding we will create a plan for conducting vulnerability analyses and initiate our first assessment. If additional funding becomes available we will prioritize and stage the remaining research oriented actions under Objective 6

in Table 1, to support conducting additional vulnerability analyses and applying those analyses to fishing and coastal communities.

Level funding

- Conduct the scoping necessary for implementing species vulnerability assessments with all interested parties (Action #31). This planning process will include considering and defining which species and/or species groups will be targeted or prioritized and funding mechanisms. Vulnerability assessments will target species important to commercial and recreational fisheries, including Gulf Council-managed, Atlantic HMS, and transboundary species. Scoping will consider and integrate with the stock assessment prioritization in the region. Proper scoping is key to identifying the candidate species for assessment.
- Conduct climate vulnerability assessments for Gulf of Mexico species identified through scoping. (Action #32). Increased funding will be necessary to extend the vulnerability assessments for habitats and associated human communities. 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 Gulf of Mexico. This framework has been internally vetted and peer-reviewed (Hare et al. 2016). Staff will also investigate methodologies used for conducting habitat vulnerability assessments, such as those used by the Landscape Conservation Cooperatives. Vulnerability analyses may help identify process-based research gaps and priorities for related field and laboratory research for the SEFSC. Increased funding and redirection of staff time will be required to pursue vulnerability assessments for multiple species.

Increased funding

- Adapt community social vulnerability indices for coastal and fishing communities in the Gulf of Mexico based on the outcome of species vulnerability analyses (Action #33).
- Consider more collaborative research efforts focused on understanding the drivers and mechanisms of climate change in the Gulf of Mexico, including process studies that examine primary productivity, plankton, and other trophic levels. Identify existing cruises or surveys that could collect this information (Action #34). 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. Our 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 and expand research on climate-driven habitat displacement (Action #35). For example, climate-driven habitat displacement of marsh grass by mangrove habitat and of mangrove habitat (e.g., that recede against vertical seawalls), and habitat management (e.g., tidal wetland mitigation banks). SEFSC research on the effects of sea level rise and marsh habitat on the productivity of various estuarine-dependent species (Minello et al. 2015, Rozas et al. 2015) has improved assessments of shrimp populations.

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

Actions under Objective 6 focus primarily on strengthening baseline data in the Gulf of Mexico. With level funding, we will focus our efforts on developing plans for updating the Ecosystem Status Report, an important tool for tracking trends in the Gulf of Mexico, and a Gulf-wide marine mammal survey. With increased funding we would prioritize and stage the remaining actions under Objective 6 in Table 1 that would expand our ability to track trends for particular species or habitats, and predicts impacts to fishing communities in the Gulf of Mexico. We also note that investments in baseline data and tracking trends would benefit from integration into the Gulf of Mexico comprehensive monitoring program and other strategic planning efforts described in Objective 7.

Level funding

- Create a plan for regularly updating the Ecosystem Status Report for the Gulf of Mexico, including expanding the human dimensions component (Action #36). The plan will include information regarding who will be involved, costs, funding sources, timeline, etc. Tracking trends in ecosystems can be carried out through the development of indicators intended to represent various parts of the system. In the Gulf of Mexico, ecosystem indicators have been developed and published through the first Ecosystem Status Report for the Gulf of Mexico which was released in 2013. Several presentations have been given to the GMFMC and its Science and Statistical Committee, and the management body has expressed interest in receiving regular updates of ecosystem indicators thought to affect commercially and recreationally important LMRs. A synthesis of the initial reported suite of indicators was carried out, and the analysis resulted in a publication describing an apparent ecosystem-wide reorganization in the Gulf in the mid-1990s (Karnauskas et al. 2015). While biannual updates to the Status Report would be ideal, updates have not yet been feasible with existing staffing levels. It has been recognized that the initial suite of indicators used in these reports were lacking in the representation of socioeconomic components, and development of indicators to represent this component of the ecosystem are ongoing. As subsequent updates of the Ecosystem Status Report are planned, efforts will be made to increase the inclusion of indicators representing human communities.
- Continue to explore the feasibility (technical and budget) of conducting a comprehensive, Gulf-wide survey for marine mammals (Action #38). 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 Gulf of Mexico (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. Planning is underway now, and our sister agencies, Bureau of Ocean Energy Management (BOEM, Department of the Interior) and international partners are critical to the success of this survey.

- Continue to collaborate with Gulf of Mexico Large Marine Ecosystem Program (Action #44). Obtaining critical baseline data and tracking changes in the Gulf of Mexico will depend in part on maintaining strong international relationships.

Increased funding

- Create a strategy for obtaining and maintaining additional critical baseline data identified by the Gulf of Mexico comprehensive monitoring program and other strategic planning efforts described in Objective 7 (Action #37). Consider including a needs assessment for creating an early warning toolbox for the Gulf of Mexico (Action #42).
- Continue to build partnerships in support of coordinating an in-water monitoring long-term network for sea turtles. For protected species science and management, one significant requirement is to improve the capability to monitor trends over the long-term. 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 baseline data need in the Gulf of Mexico could be met by the establishment of in-water index sites for monitoring trends in life history stages aside from nesting females (Action #40).
- Assess socio-economic data needs for examining impacts of climate change on fishing and coastal communities, such as fishing crew employment data (Action #39). 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 Region 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 within the Gulf of Mexico region.
- Identify social and economic indicators to identify thresholds that will provide the basis for early warnings about impacts on the fishing industry and fishing communities (Action #43). For example, an early analysis conducted at the SEFSC found a relationship between the El Nino Southern Oscillation (ENSO) and headboat effort in the Gulf of Mexico (Carter and Letson 2009). The work included a model that could be used to forecast changes in head boat effort anticipated with different ENSO patterns that might occur with climate change. By identifying thresholds that could be used to generate early warning signals, we may be able to alleviate some of the anticipated adverse effects of climate change on the fishing industry and communities.
- Build or expand partnerships to determine changes to marsh, mangrove, and other shoreline habitats from climate change (remote sensing data collected by States, U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers (USACE), and

others)) (Action #41). Incorporate these data into appropriate assessments and consultations (i.e., NOAA Fisheries ESA section 7 and essential fish habitat assessments, stock assessments, other models).

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 that provides the climate science needs of NOAA Fisheries. This includes the information needed to implement ecosystem-based fisheries management in a changing climate. With level funding, we will focus efforts to include Gulf of Mexico climate science requirements in all SEFSC’s strategic planning processes and on expanding climate science coordination across NOAA programs and with other partners across the region. Increased funding will allow the SEFSC to stage the remaining actions under Objective 7 in Table 1 to further develop our capacity to address climate science requirements in the Gulf of Mexico.

Level funding

- Include climate science coordination and prioritization in the SEFSC’s upcoming strategic planning effort (Action #45). Working closely with SERO, AOML, other NOAA offices, the GMFMC and other partners in the Gulf will be a critical component of the strategic planning process. We also plan to incorporate recommendations from a number of recent reports and reviews such as the March 2016 Ecosystem Science Program Review (Action #46) and the NOAA Fisheries Economics & Human Dimensions Program Climate Science Workshop (Action #52). We will also consider how our climate science needs and priorities overlap with RESTORE Act Science Program and other Deepwater Horizon related monitoring, restoration, and science programs (Action #50). All of this work in concert contributes toward the scientific information needed for effective ecosystem-based fisheries management in a changing climate.
- 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 #59).
- Continue and strengthen collaborations with 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. We plan to establish a formal SEFSC / AOML / SERO / HMS Gulf of Mexico climate science team with regular meetings (in person or virtual) (Actions #53). Having regular meetings of a formal team will enhance our ability to identify overlapping requirements and opportunities for climate science, generate multidisciplinary mechanisms of change, leverage existing data, identify research gaps, and set joint priorities. This group would be responsible for implementing, managing, and updating the GMRAP, and would coordinate with other partners such as the Sea Grant Climate Community of Practice for the Gulf of Mexico and NOAA’s Geophysical Fluid Dynamics Laboratory (Action #58).
- Build capacity by hiring a Management Strategy Evaluation full time equivalent (FTE) employee at the SEFSC (Action #54). While this position will not be dedicated to climate

science, the expertise of this individual will contribute to assessing our climate science needs and priorities in the Gulf of Mexico.

- Initiate a partnership with NOAA’s National Centers for Environmental Information (NCEI) to determine how we could utilize their data portal for climate science and related data products related to NOAA Fisheries mission and needs (Action #60).
- Convene a workshop to discuss and collect external data and information needed for the GMRAP. 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 #62). This action item has already been accomplished. As part of the development of the GMRAP, 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, Florida. 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 the GMRAP.

Increased funding

- Conduct a data gap analysis (Action #47), in coordination with ongoing Deepwater Horizon related activities, to assess the adequacy of existing surveys and/or data streams for meeting climate science needs. For this analysis we would assess existing data and identify and prioritize multidisciplinary data needs, including biological, ecosystem, climate, physical, chemical, socio-economic, and other necessary data in coordination with SERO, AOML, and other appropriate partners and consider relevant timeframes for planning. Management strategy evaluation is a potential tool for this assessment. A data gap analysis would support baseline data collection needs under Objective 6 of this plan.
- Identify climate ready and/or multi-mission cruises in the Gulf of Mexico (Action #48). 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.
- Using the priorities of the updated strategic plan, the results of the data gap analysis, and the goal of multi-mission cruises in the Gulf of Mexico, develop a comprehensive and collaborative monitoring program for the Gulf of Mexico with our partners (Action #49). This program 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 supports the NOAA Fisheries mission. It may also include identification of likely changes and drivers of change in the Gulf of Mexico and opportunities for Citizen Science program development (Action #61). This would give us a much more complete vision for coupled biological and oceanographic data needs, strengthen partnerships, and allow us to be as efficient as

possible within budgets. The plan would also consider (1) overlap with RESTORE Act Science Program and other Deepwater Horizon related monitoring, restoration, and science programs, and (2) the information needed to implement ecosystem-based fisheries management (EBFM) in a changing climate. The initial planning and coordination for this effort would be substantial, but we believe a comprehensive monitoring plan to address shared data needs is our best chance to ensure that we can provide the information needed to make climate-informed decisions that reduce anticipated climate impacts and increase resilience for our coastal communities.

- 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 #55), or secure these skills through contractor services or cooperative research institutes. An FTE position could possibly be shared with AOML, to increase collaboration between line offices. We would also consider building capacity for climate science by providing professional development opportunities for existing staff, such as on statistical techniques for multivariate time series analysis, or contracting experts to help us develop new capabilities (Action #58). 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 #57).
- Initiate a Citizen Science program to address Gulf of Mexico climate science needs as determined in the comprehensive monitoring program and other strategic planning efforts. It may be possible for the SEFSC citizen science program to build on existing programs managed under GCOOS, Councils, or other entities. Other data gaps may also be filled by the strategic development of citizen science programs, as fishery participants and other stakeholders often have a detailed understanding of how the physical environment affects fish populations at very fine scales (Action #61).

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	Obj.
Support and participate in regional climate variability workshop in October 2015, hosted by SECOORA, to engage stakeholders and develop input for the GMRAP.	Oct 2015	7
Number of new collaborative climate science 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 Gulf of Mexico climate science team meetings.		7
Hiring completed for Management Strategy Evaluation FTE position		7

at the SEFSC.		
Number of marine mammal species surveyed Gulf-wide.		6
Complete update to the 2013 Ecosystem Status Report for the Gulf of Mexico, and determination of how frequently it should be updated.		6
Plan in place for conducting vulnerability assessments.		5
Number of species for which climate vulnerability assessment is completed.		5
Completion new Atlantic bluefin tuna physiological model to better understand climate impacts on the species and its spawning in the Gulf of Mexico.		4
Complete new high-resolution regional ocean-biogeochemistry model to downscale the CMIP5 model projection of carbon and biogeochemical parameters along the northern Gulf of Mexico.		4
Number of stock assessments that have incorporated environmental covariates.		3
Number of new or stronger internal or external partnerships instituted to achieve climate science and management objectives.		1,2,6,7
Participation in a regional or national workshop or meeting to explore the development of climate informed reference points.		1

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