NOAA Fisheries Climate Science Strategy

Gulf of Mexico Regional Action Plan

Draft August 11, 2016

1. EXECUTIVE SUMMARY

Key climate change drivers that are thought to result in biological impacts in the Gulf of Mexico include warming ocean temperatures, sea level rise, and ocean and coastal acidification. Understanding how major climate drivers such as these will affect marine habitat distribution and quality, ecosystems and estuarine productivity, living marine resources, and their prey is critical for management. These changes could lead to direct and indirect effects on marine resource dependent businesses and communities, such as loss of fishing opportunities or coastal infrastructure due to inundation or immersion as sea-level rises. 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 (NCSS, Link et al. 2015). We assessed our ongoing work and identified 65 draft actions to help meet climate science needs for the Gulf of Mexico. Of those 65 actions, our highest priorities for climate science information and services include:

- Conducting climate vulnerability assessments for species in the Gulf of Mexico, their habitats, and associated human communities. These analyses would help identify species especially vulnerable to climate change to help set research gaps and priorities for the region (Actions 32, 33).
- Identifying and prioritizing multidisciplinary data needs for a comprehensive monitoring program for climate science in the Gulf of Mexico. Data needs assessed would include biological, ecosystem, climate, physical, chemical, socio-economic, and other necessary data and would be in coordination with a broad range of federal, state, academic and NGO partners (Actions 48, 50). This analysis includes a data gap analysis to assess the adequacy of existing data and surveys to provide climate science information.
- Creating a plan for expanding the Ecosystem Status Report for the Gulf of Mexico to include human dimensions and for regularly updating the report. This report includes information that can be used to track trends in indicators of ecosystem health (Action 37).
- Establishing a formal Gulf of Mexico climate team including at least Southeast Fisheries Science Center (SEFSC), AOML, Highly Migratory Species (HMS) experts, and SERO participants with regular meetings and communications. This team would serve to share ideas, build capacity and partnerships, identify training needs, and spearhead implementation of actions within the Gulf of Mexico Regional Action Plan (Actions 54, 56).
- Creating a plan for obtaining and maintaining critical baseline data in the Gulf of Mexico. For example, we want to continue planning a comprehensive, Gulf-wide survey for marine mammals with our partners. For marine mammals, the frequency of current

assessment surveys is very low and it has not been possible to assess trends in population size for any of the stocks in the Gulf of Mexico (Actions 38, 39).

- Continuing to build our capacity to consider climate science in our stock assessment process. We want to continue to build our ability to include environmental covariates in stock assessments, hire a management strategy evaluation specialist who will use management strategy evaluation to identify harvest control rules that remain effective during anticipated climate changes, and identify areas of overlap between Regional Action Plan efforts and those of Ecosystems Based Fisheries Management (Actions 16, 56, 64).
- Collaborating with our colleagues at NOAA and external partners to share ideas for developing climate-informed reference points. We would like to plan a workshop or meeting to work together on this exciting challenge (Actions 2, 3).

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. We also include actions that could be accomplished over the next three to five years with increased funding. All draft 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. Staging the actions appropriately will also be important in some cases, as some actions are dependent on others. If we receive increased funding for this work, we would prioritize and strategically stage actions that require additional funding.

2. 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 increase resilience and support sustainable fisheries, valuable living marine resources, fishing communities, and businesses in the face of climate change.

The Strategy identifies seven common objectives designed to meet these 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 impacts and increase the resilience of our valuable living marine resources (LMR), and the people, businesses, and communities that depend on them. The seven objectives of the Strategy are considered interdependent and build from basic information needs and science capacity through to science-informed decision-making and management (Fig. 1).

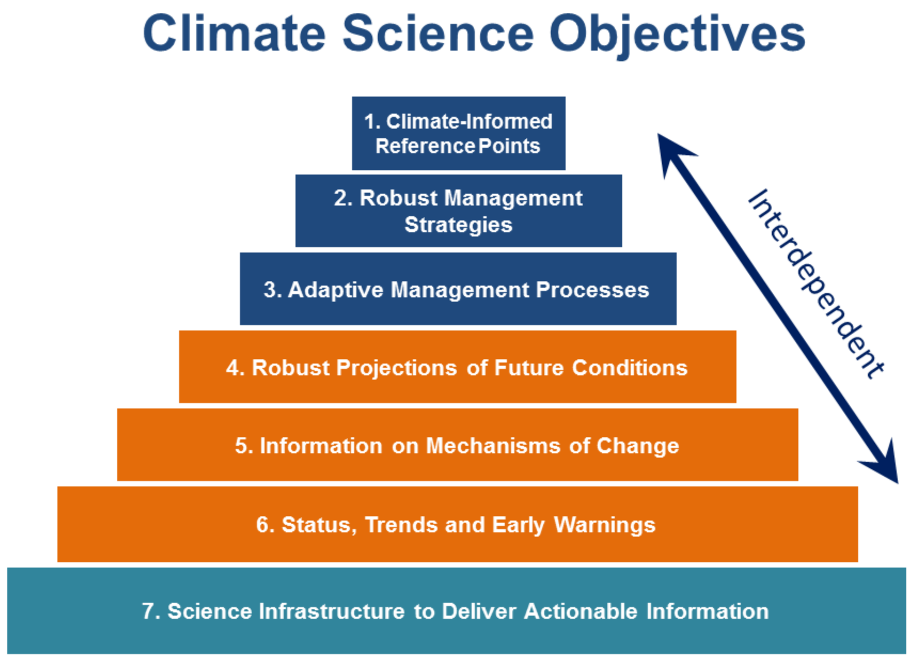

Figure 1. Seven objectives, discussed in the NOAA Fisheries Climate Science Strategy, will provide decision-makers with the information they need to reduce impacts and increase resilience in a changing climate.

The Strategy provides a nationally consistent blue-print 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 priority species, and determine best management approaches to reduce impacts and increase resilience of fish stocks, fisheries, and fishing-dependent communities.

This document, the 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 in the Gulf of Mexico. The GMRAP identifies current activities that contribute to our understanding of climate change impacts on 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.

3. 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 about 218,000 square miles, it is a small basin by oceanic standards. One quarter is characterized by a very deep basin (over 3,000 meters deep) and 35% is continental shelf (GMFMC 2004). Most of the oceanic water entering the Gulf flows through the Yucatan Channel, a narrow and deep (1,650-1,900 m) channel. Water leaves the Gulf through the Straits of Florida, and this pattern of water movement produces the most pronounced circulation feature in the Gulf of Mexico basin, known as the Loop Current. Eddies shed by the Loop Current periodically penetrate northward and northwestward into the Gulf of Mexico and can influence upwelling of cold, nutrient-rich water along the continental shelf and other physical and biogeochemical processes across the entire basin.

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. 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 the 21st 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 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 seagrass fish assemblages (Fodrie et al. 2010). Stocks in the Gulf of Mexico are limited in their ability to migrate north due to the coastal border. Studies are showing that assemblages that historically were in the northern Gulf appear to have shifted southwest towards 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. 2013). 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 highly susceptible to higher temperatures and have experienced significant bleaching, disease outbreaks, and mortality in recent years (Coles and Riegl 2013, 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 varied 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 fresh water inflows and in particular, Mississippi river runoff. These inflows have historically deposited sediments that have built the extensive wetlands along the northern 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 ≤ 2.0 mg·L-1) in the western hemisphere (Rabalais et al. 2007, Bianchi et al. 2010). These low dissolved oxygen events occurs 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 effect species and food web interactions (Rose et al. 2009, de Mutsert et al. 2015). Model predictions using a doubled CO2 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, since 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 acidification can weaken the framework of coral reefs, making them more susceptible to storm damage and affecting reef dependent organisms (Alvarez-Filip et al. 2009, Fabricius et al. 2014) such as the snapper grouper complex. 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 carbon dioxide 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 also increases 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, were more than double that loss between1998-2004, Dahl and Stedman 2013) due primarily to storms, but land subsidence and sea level rise 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 this habitat for these species (Rozas 1995). Changes in spatial extent and water quality of estuarine habitats will likely be ecologically as well as economically significant because of these estuarine dependent species as well as commercially important species in the Gulf of Mexico 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 the orientation of the coastline. For coastal and estuarine dolphins, the frequency and intensity of harmful algal blooms and disease events may change 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. 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. 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.

Sea turtles are globally distributed in the tropical and temperate regions and particularly susceptible to climate change as their life cycle involves beaches along with neritic and open ocean habitats. Sea level rise has the potential to negatively affect sea turtle nesting habitat throughout the Southeast U.S. (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 increase the nesting season length for green turtles (Pike et al. 2006; Weishampel et al. 2010). Changes in the length of nesting season can alter the overall reproductive productivity of a species and the long-term population trends. Along with impacts to nesting beaches, climate change would alter the distribution and habitat use of sea turtles in-water 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. 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.

The impact of climate change upon Gulf Coast fishing communities and their inhabitants 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 of 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 a decline in stocks reliant on that habitat, force some species to move, or provide opportunity for new species to take hold. 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.

4. ACTION PLAN

Scientific data, information, and advice produced by NOAA Fisheries and NOAA partners across the region are critical to managing living marine resources in the Gulf of Mexico. NOAA Fisheries Southeast Fisheries Science Center (SEFSC) and Regional Office (SERO) 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 Gulf of Mexico Regional Action Plan team assessed our ongoing work and identified 65 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).

Table 1. DRAFT GULF OF MEXICO REGIONAL ACTION PLAN TABLE

Shaded actions indicate action items that require increased funding. If we receive additional funding we would prioritize and strategically stage these actions. Acronyms are defined in section 7 (starting on page 35).

No.	Action Name (short title; add rows as needed for Actions)	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 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 our efforts to collaborate 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
3	Workshop for Climate Informed Reference Points	Level	2017-2021	Plan a workshop/meeting to explore how to develop climate informed reference points.	SERO, ST, SF, HMS, AOML, Academia, SEDAR, ICCAT, IEA partners
4	Climate Informed Reference Points	Increase	2017-2021	Continue to incorporate climate and ecosystem considerations into incidental take recommendations, Essential Fish Habitat Designations, National Environmental Policy Act reviews, Habitat Areas of Particular	SERO, HC, PR, HMS, ST, GMFMC

				Concern, and other management actions and products.	
5	Climate Informed Reference Points	Increase	2017-2021	Examine the ability of protected species reference points to explicitly incorporate changes in climate.	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 develop reference points to assess the impact of climate change scenarios relative to the societal objectives.	SERO, SF, HMS, ST, GMFMC, Sea Grant
7	Climate Informed Reference Points	Increase	2017-2021	Incorporate climate informed reference points into ESA Section 7 biological opinions as appropriate.	SERO, PR
Objective 2 – Robust Management Strategies					
8	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
9	Management objectives	Level	2017-2021	Continue collaborative efforts with the GMFMC, international partners (Mexico and Cuba), RFMOs, and other organizations to share management objectives in light of anticipated climate impacts.	SERO, ST, SF, HMS, GMFMC, GSMFC, Department of State, ICCAT, FAO, CITES, Harte Research Institute, Academia, Gulf of Mexico Alliance, and others
10	Ecosystems Considerations	Increase	2017-2021	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.	SERO, ST, SF, HMS, PR, GMFMC

11	Ecosystems Considerations	Increase	2017-2021	Coordinate with NOAA's Damage Assessment Remediation and Restoration Program, NOAA Restoration Center, RESTORE Act Council, and the RESTORE Act Science Program on ecosystem considerations for research and ongoing activities.	NRDA trustees, RESTORE Act Council, RESTORE Act Science Program, NOAA Restoration Center
12	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, Coastal communities
Objective 3 – Adaptive Management Processes					
13	Decision tables	Level and Increase	2017-2021	Develop capacity to present quantitative advice using decision-theoretic approaches.	Academia
14	Events analysis	Increase	2017-2021	Improve the ability response to possible climate related events in real time.	SERO, NOS/NCCOS
15	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 or those who fish frequently.	Fishing industry, GMFMC Advisory Panels, SERO, HMS, SF, ST, SEDAR
16	Environmental covariates in stock assessments	Level and Increase	Ongoing	Continue to include environmental covariates in stock assessments.	SERO, AOML, GMFMC, HMS
17	Increase dialogue between scientists and managers	Level and Increase	2017-2021	Increase dialogue between scientists and managers to enhance to collaborative adaptive management process.	SERO, HMS, SF, ST, PR, HC, NOAA Restoration Center, AOML, RESTORE Act Council, GOMA

18	Community resilience	Increase	2017-2021	Begin to 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
19	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					
20	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
21	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
22	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
23	Apply existing models to priority species	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	AOML, Academia, NSF

				spawning habitat).	
24	Apply existing models to priority species	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
25	Apply existing models to priority species	Level	Ongoing	Continue to examine /develop an Atlantic bluefin tuna physiological model to better understand climate impacts on the species and its spawning in the Gulf of Mexico.	HMS, NASA, NOAA, AOML, RC
26	Apply existing models to priority species	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
27	Apply existing models to priority species	Increase	2017-2021	Integrate outputs from climate models into existing spatial density models for marine mammals.	AOML, USGS
28	Apply existing models to priority species	Increase	2017-2021	Examine the impact of land loss due to sea level rise on estuary bottlenose dolphin stocks/habitat.	SERO, AOML, Academia USGS, NOS/ Office for Coastal Management
29	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, Academia, GMFMC
30	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
31	Predicting	Increase	2017-2021	Begin to assess possible impact of climate	SERO, ST, NOS, AOML, HMS,

	impacts on community well-being			change scenarios on the wellbeing and vulnerability of fishing communities in the Gulf of Mexico.	Academia
Objective 5 – Understand the Mechanisms of Change					
32	Vulnerability assessments	Level	2016-2017	Create a plan for conducting vulnerability assessments.	SERO, NOAA Fisheries HQ, HMS, AOML, NOS
33	Vulnerability assessments	Level and increase	2017	Conduct climate vulnerability assessments.	SERO, ST, PR, SF, HC, HMS, AOML, Academia, GMFMC, Gulf Coast Prairie LCC (for habitat)
34	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 Outreach Community of Practice, Gulf of Mexico Research Initiative - Consortium for Resilient Gulf Communities
35	Research	Increase	2017-2021	Expand collaborative research efforts focused on understanding the drivers and mechanisms of climate change in the Gulf of Mexico.	AOML, Academia
36	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					
37	Ecosystem Status Report	Level	2017, Periodic	Create a plan for regularly updating the 2013 Ecosystem Status Report for the Gulf of Mexico.	SERO, GMFMC, AOML, HMS, and others
38	Baseline data	Increase	2017-2021	Create a plan to identify and maintain critical baseline data identified in the Gulf of Mexico	SERO, States, Academia

				comprehensive monitoring program (see Objective 7).	
39	Baseline data	Level	2016-2017	Continue to explore the feasibility (technical and budget) of conducting a comprehensive, Gulf-wide survey for marine mammals.	PR, BOEM, Academia
40	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,, many others
41	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, and many others
42	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, USACE, State labs (FWRI)
43	Tracking change	Increase	2017-2021	Consider the possibility of developing an early warning toolbox.	AOML, Academia, other NOAA Science Centers
44	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, other NOAA Science Centers, etc.
45	International coordination	Level	Ongoing	Continue to collaborate with the Gulf of Mexico Large Marine Ecosystem Program.	NOS-OCM-Gulf Region, International partners
Objective 7 – Science Infrastructure to Deliver Actionable Information					
46	Strategic planning	Level	2016-2018	Include climate science in the SEFSC's upcoming strategic plan.	SERO, AOML, GMFMC, HMS
47	Strategic planning	Level	2016-2018	Create a plan to incorporate recommendations from the March 2016 Ecosystems Science Program Review into planning for climate science needs.	SERO

48	Strategic planning	Increase funding or dedicate staff time	2016-2018	Conduct a *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 (for coastal/ estuarine/marsh-based data).
49	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
50	Strategic planning	Increase	2017-2019	Develop a *comprehensive and collaborative monitoring program* for climate and other ecosystem and ecological information for the Gulf of Mexico.	SERO, ST, SF, HMS, PR, HC, NOAA Restoration Center, AOML, NOAA IEA and Climate Programs, States, GMFMC, RESTORE Act Council, International partners, FWS, others
51	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
52	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
53	Strategic Planning	Level	2016-2017	Review and discuss the report resulting from the NOAA Fisheries Economics & Human	SERO, ST

				Dimensions Program Climate Science Workshop with respect to planning and collaborative research efforts in the southeast.	
54	Build capacity	Level + staff time	2016	Establish a formal SEFSC, AOML, SERO Gulf of Mexico climate science team with regular meetings.	SERO, AOML, HMS, Gulf Regional Collaboration Team, Sea Grant Climate Community of Practice
55	Build capacity	Level	2016-2017	Plan a climate science kick-off meeting for the above team to initiate the effort and assess needs.	SERO, AOML, HMS, Sea Grant
56	Build capacity	Level	2016	Hire a Management Strategy Evaluation FTE position at the SEFSC.	
57	Build capacity	Increase funding or dedicate staff time	2016, 2017-2021	Consider investment in FTE climate science researcher/coordinator, survey statistician, and additional FTE/contractor time.	SERO, AOML, HQ, Academia
58	Build capacity	Increase	2017-2021	Invest in existing staff professional development to build or strengthen expertise to meet climate science needs.	AOML, SERO, HQ, HMS, other NOAA Science Centers, Academia
59	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, Academia
60	Build capacity	Level	2016-2018	Strengthen relationship with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL).	GFDL, AOML
61	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
62	Build Capacity	Level	2017-2021	Initiate a partnership with NOAA's National	NCEI, AOML, SERO, HQ

				Centers for Environmental Information (NCEI).	
63	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
64	Strategic Planning	Level	2017	Consider areas of overlap between this Climate Regional Action Plan and Ecosystems Based Fisheries Management.	SERO, HQ SF, HMS
65	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 climate-related effects should be incorporated into these reference points to reflect changing conditions is critical for supporting climate-ready living marine resource management. It is also a genuine challenge and will require in many cases, additional data, analyses, and modeling that goes beyond current practices. With level funding, our action under Objective 1 includes collaborating with other scientists and managers to share ideas for developing appropriate climate-informed biological reference points for 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 2.

Level funding

- Increase our efforts to collaborate 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 we believe it working with our partners and other NOAA offices will strengthen our approach.
- Plan a workshop or meeting to explore how to develop climate informed reference points —include timing, identifying partners (e.g., partners working on similar efforts such as the Integrated Ecosystem Assessment) (IEA), to be involved, goals, and objectives. Consider collaborating across Regions (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 incidental take recommendations, Essential Fish Habitat Designations, National Environmental Policy Act reviews, Habitat Areas of Particular Concern, and other management actions and products (Action #4).
- Examine the ability of protected species reference points to explicitly incorporate changes in climate (Action #5). For example, under the Marine Mammal Protection Act potential biological removal (PBR) is the annual level of human caused mortality that still allows a depleted stock of marine mammals to increase to its optimum sustainable population size or allows a stock that is at its optimum sustainable population to remain there. The PBR formula includes parameters, such as population size, that may sometimes reflect changes in climate. If, for example, a change in climate were to cause a decrease in population size, PBR for that population could also decrease, prompting management action. However, impacts of climate change may be more subtle or more complicated than the relationship described in this simplified example. 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).
- Incorporate climate informed reference points into ESA section 7 biological opinions, in particular for cumulative effects analyses on critical habitat essential features (Action #7).

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 #8). 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 grouper 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 #9).

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 #10). 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.
- Coordinate with NOAA's Damage Assessment Remediation and Restoration Program, NOAA's Restoration Center, the RESTORE ACT Council (the Gulf Coast Ecosystem Restoration Council established by the Resources and Ecosystems Sustainability Act, Tourist Opportunities, and Revived Economies of the Gulf States Act of 2012), and the RESTORE Act Science Program on ecosystem considerations for research and ongoing activities (Action #11).
- 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 #12).

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 #13). 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 (Action # 16). 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 snapper-grouper complex. Such initiatives include an index of natural mortality for grouper species based on red tide events (Walter 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 inform 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 to climate related events in real time, e.g., fish kills, red tide, by collecting additional samples, analyzing new data, and improving forecasts and models (Action # 14). 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 could include the National Centers for Coastal Ocean Science (NCCOS) Center for Sponsored Coastal Ocean Research and Center for Coastal Fisheries and Habitat Research.

- Establish more formal methods for scientists and managers to learn about ecosystem changes observed by long time fishermen or those who fish frequently. This action could be accomplished by scientists attending Council Advisory Panels, creating a poll, or by creating some other process to hear about observations. It could eventually become a component of a Citizen Science effort.
- 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 # 17). 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 others, 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 # 18). 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 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 # 19). 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 #21). 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 (Liu et al. *in review*)). 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 #24). 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. 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 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 #25). 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 #20).
- 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 #22). 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 #23). 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. 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 #26) in collaboration with partners
- Integrate outputs from climate models into existing spatial density models for marine mammals (Action #27). 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 #28). 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, with the ability to couple models across types (Action #29).
- 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 #30). 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 behaviors 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 wellbeing and vulnerability of fishing communities in the Gulf of Mexico (Action #31), 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, 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

- Create a plan for species vulnerability assessments with all interested parties and identify funding mechanisms (Action # 32). Vulnerability assessments will target species important to commercial and recreational fisheries, including both Gulf Council-managed species and Atlantic HMS species. We also want to consider the interplay with stock assessment prioritization in the region. ,. This would allow Councils and NOAA Fisheries to identify species that may be at greater risk of overexploitation due to climate factors, thus making them priority candidates for assessment.
- Conduct climate vulnerability assessments for priority species in the Gulf of Mexico, their habitats, and associated human communities (Action #33). 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).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 #34).
- 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 tropic levels. Identify existing cruises or surveys that could collect this information (Action #35). 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 (Walter 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 #36), 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., Florida mangrove 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 informed assessments of shrimp populations.

The report, A Comprehensive Restoration Plan for the Gulf of Mexico: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement (2016), has been developed to guide restoration activities in the Gulf of Mexico and is available at this website: http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan. 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 plan suggest that a variety of Gulf of Mexico restoration activities may also be useful for addressing the goals of Objective 5.

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 #37). 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 #39). 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. 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 plan 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.
- 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 that for monitoring trends in life history stages aside from nesting females (Action #41).
- Assess socio-economic data needs for examining impacts of climate change on fishing and coastal communities, such as fishing crew employment data (Action #40). NOAA Fisheries' Human Dimensions Team has developed a set of community social vulnerability indices for coastal and fishing communities in all regions to provide a foundation for community level measures of well-being and fishing dependence (Jepson and Colburn 2013, Colburn and Jepson 2012, Himes-Cornell and Kasperski 2015, and Pollnac et al. 2015). Recently, a sea level rise indicator was added to that suite of indicators as a first step to include measures of climate change impacts. In addition, recent work in the Northeast has produced a model for using species vulnerability to climate change with fishing dependence to capture a community's dependence upon stocks that are vulnerable to climate change. This type of research should be explored for application 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 #44). For example, an early analysis conducted at the SEFSC found a relationship between the El Nino Southern Oscillation (ENSO) and head boat 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, U.S. Army Corp of Engineers (USACE) survey data). 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 in support of climate science. With level funding, we will focus our efforts on how we include climate science needs for the Gulf of Mexico in the SEFSC's strategic planning process and on strengthening climate science coordination within NOAA and with other partners in the Gulf of Mexico. With increased funding we would prioritize and stage the remaining actions under Objective 7 in Table 1 that could further develop our capacity and strategy for climate science in the Gulf of Mexico.

Level funding

- Include climate science coordination and prioritization in the SEFSC's upcoming strategic planning effort (Action #46). 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 #47) and the NOAA Fisheries Economics & Human Dimensions Program Climate Science Workshop (Action #53). We will also consider how our climate science needs and priorities overlap with RESTORE Act Science Program and other Deep Water Horizon related monitoring, restoration, and science programs (Action #51).
- 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 #61).
- Continue and strengthen collaborations with AOML. Such efforts have been made through informal SEFSC-AOML workshops, and a number of joint funding proposals have been submitted. We would like to consider establishing a formal SEFSC / AOML / SERO / HMS Gulf of Mexico climate team, with regular meetings or communications (Actions #54 and #55). Having regular meetings and a formal team would enhance our ability to identify overlapping needs 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 #60).
- Build capacity by hiring a Management Strategy Evaluation full time equivalent (FTE) employee at the SEFSC (Action #56). 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 discussion 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 #62).
- Consider areas of overlap between this Climate Regional Action Plan and Ecosystems Based Fisheries Management (Action #64).
- 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 #65). 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, FL. Hosted by the Southeast Coastal Ocean Observing Regional Association (SECOORA), the workshop participants represented a diverse array of scientific expertise, as well as resource and environmental managers and fishing industry. Through a series of facilitated plenary and breakout discussions, participants discussed regional and cross-regional impacts of environmental change on fisheries and other living marine resources and where research and monitoring needs existed. The workshop executive summary highlighted the participants' top research and monitoring priorities for understanding climate impacts on living marine resources and addressing management needs over the next one to three years. These priority actions were considered during the development of the GMRAP.

Increased funding

- Conduct a data gap analysis (Action #48), in coordination with ongoing Deep Water 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. 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 #49). 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.
- Initiate a Citizen Science program for the Gulf of Mexico to address climate science needs as determined in Gulf of Mexico comprehensive monitoring program and other strategic planning efforts. Knowledge or data gaps may also be filled by the strategic development of citizen science programs, as fishery participants and other stakeholders

often have a detailed understanding of how they physical environment affects fish populations at very fine scales (Action #63).

- 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 #50). 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 tropic 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. 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 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 #57). Such a 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 #59).

5. METRICS

Accomplishment	Date completed	Obj.
Convened regional climate variability workshop in October 2015, hosted by the SECOORA to engage stakeholders and develop input for the GMRAP.	Oct 2015	7
Areas of overlap identified between this Climate Regional Action Plan and Ecosystems Based Fisheries Management.		7
Identified areas for collaboration with NOAA's GFDL.		7
Information available on possible partnership with NOAA's NCEI.		7
Collaborative proposals submitted to external and internal funding		7

opportunities for climate science.		
Formal or informal SEFSC, AOML, SERO Gulf of Mexico climate science team with regular meetings.		7
Convened a climate science kick-off meeting for the Gulf of Mexico climate science team to initiate the effort.		7
Management Strategy Evaluation FTE position in place at the SEFSC.		7
Climate science included in the SEFSC's upcoming strategic plan.		7
Strategy for how to incorporate recommendations from the March 2016 Ecosystems Science Program Review into planning for climate science needs.		7
Continued to pursue a comprehensive, Gulf-wide survey for marine mammals.		6
Established plan for regularly updating the 2013 Ecosystem Status Report for the Gulf of Mexico.		6
Plan in place for conducting vulnerability assessments.		5
Climate vulnerability assessments completed for first species.		5
New research results regarding an Atlantic bluefin tuna physiological model to better understand climate impacts on the species and its spawning in the Gulf of Mexico.		4
New research result of using a high-resolution regional ocean-biogeochemistry model to downscale the CMIP5 model projection of carbon and biogeochemical parameters along the northern Gulf of Mexico.		4
Environmental covariates used in stock assessments.		3
Presentation of quantitative advice using decision-theoretic approaches as part of fisheries management process.		3
Management Strategy Evaluation used to identify harvest control rules that remain effective during anticipated climate changes.		2
New or stronger partnerships for climate science and management objectives.		1/2/6/7
Planned workshop/meeting to explore how to develop climate informed reference points.		1

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7. ACRONYMS

ACL	Annual catch limit
AMO	Atlantic Multidecadal Oscillation
AMOC	Atlantic Meridional Overturning Circulation
AOML	NOAA Oceanic and Atmospheric Research's Atlantic Oceanographic and Meteorological Laboratory
BOEM	Bureau of Ocean Energy Management, under the Department of the Interior
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora)
CMIP5	Coupled Model Intercomparison Project Phase 5, internationally coordinated climate model experiments of the World Climate Research Programme
CSCOR	Center for Sponsored Coastal Ocean Research (part of NOAA's National Centers for Coastal Ocean Science
CTD	Package of electronic instruments that measure conductivity, temperature, and depth.
EcoFOCI	Ecosystems and Fisheries-Oceanography Coordinated Investigations (a joint NOAA Fisheries & OAR program)
ENSO	El Niño Southern Oscillation
ESA	Endangered Species Act
FAO	Food and Agriculture Organization of the United Nations
FIO	Florida Institute of Oceanography
FTE	Full time equivalent employee
FWS	U.S. Fish and Wildlife Service, under the Department of the Interior
GFDL	Geophysical Fluids Dynamics Laboratory (NOAA)
GLOBEC	Global Ocean Ecosystem Dynamics, an international program
GMFMC	Gulf of Mexico Fishery Management Council or Gulf Council
GoMexSI	Gulf of Mexico Species Interactions Database, managed by Texas A&M Chorpus 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
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
NASA	National Atmospheric and Space Administration
NCCOS	National Centers for Coastal Ocean Science
NCEI	National Centers for Environmental Information (program within NOAA's National Environmental Satellite, Data, and Information Service)
NOAA	National Oceanographic and Atmospheric Administration
NOS	National Ocean Service (Line Office in NOAA)
NRDA	Natural Resources Damage Assessment
NSF	National Science Foundation
OAR	Office of Oceanic & Atmospheric Research (Line Office of NOAA)
OCM	Office of Coastal Management (Office in NOS in NOAA)
PR	Office of Protected Resources (NOAA Fisheries)
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
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
USGS	United States Geologic Survey

8. REFERENCES

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

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

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

Bianchi TS, DiMarco SF, Cowan Jr. JH, Hetland RD, Chapman P, Day JW, and Allison MA. 2010. The science of hypoxia in the northern Gulf of Mexico: A review. Science of the Total Environment 408:1471-1484.

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

113:268-279.

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

Cai WJ, Hu X, Huang WJ, Murrell MC, Lehrter JC, Lohrenz SE, Chou WC, Zhai W, Hollibaugh JT, Wang Y, Zhao P, Guo X, Gundersen K, Dai M, Gong GC. 2011. Acidification of subsurface coastal waters enhanced by eutrophication. *Nature Geoscience*, 4(11), 766-770.

Carter D and Letson D. 2009. Structural vector error correction modeling of integrated sportfishery data. *Marine Resource Economics.* pp. 24: 19-41.

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

Colburn, LL, Jepson M, Weng C, Seara T, Weiss JL, and Hare JA. In Press. Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the U.S.: An emerging methodology. Marine Policy.

Coles SL and Riegl B. 2012. Thermal tolerances of reef corals in the Gulf: a review of the potential for increasing coral survival and adaptation to climate change through assisted translocation. *Marine Pollution Bulletin*, 72(2), 323-332.CPRA (Coastal Protection and Restoration Authority), 2012. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Baton Rouge, Louisiana: CPRA, 188p.

Craig JK. 2012. Aggregation on the edge: Effects of hypoxia avoidance on the spatial distribution of shrimp and demersal fishes in the northern Gulf of Mexico. Marine Ecology Progress Series 445:75-95.

Craig J and Bosman S. 2013. Small spatial scale variation in fish assemblage structure in the vicinity of the northwestern Gulf of Mexico hypoxic zone. Estuaries and Coasts, 36, 268–285.

Craig JK, and Crowder LB. 2005. Hypoxia-induced habitat shifts and energetic consequences in Atlantic croaker and brown shrimp on the Gulf of Mexico shelf. Marine Ecology Progress Series 294:79-94.

Dahl TE and Stedman SM. 2013. Status and trends of wetlands in the coastal watersheds of the Conterminous United States 2004 to 2009. U.S. Department of the Interior, Fish and Wildlife Service and National Oceanic and Atmospheric Administration, National Marine Fisheries Service. 46 p.

de Mutsert K, Steenbeek J, Lewis K, Buszowski J, Cowan HR. JH, and Christensen V. 2015. doi: 10.1016/j.ecolmodel.2015.10.013

Deepwater Horizon Natural Resource Damage Assessment Trustees. 2016. Deepwater Horizon oil spill: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. Retrieved from http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan.

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

Enfield D, Mestas-Nuñez A, and Trimble P. 2001. The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental U.S. vol. 28, no. 10.

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

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

Fodrie FJ, Heck KL, Powers SP, Graham WM, and Robinson KL. 2010. Climate-related, decadal-scale assemblage changes of seagrass-associated fishes in the northern Gulf of Mexico. Global Change Biol 16:48-59.

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

Grüss A, Schirripa MJ, Chagaris D, Drexler M, Simons J, Verley P, Shin Y-J, Oliveros-Ramos R, Karnauskas M, Ainsworth CH. 2015. Trophic structure of the West Florida Shelf ecosystem in the 2000s: Evaluation of diet patterns and natural mortality rates of gag grouper (*Mycteroperca microlepis*) using the individual-based, multi-species model OSMOSE. *Journal of Marine Systems* 144:30-47

Gulf of Mexico Fishery Management Council (GMFMC). 2004. FINAL EIS for the Generic Essential Fish Habitat Amendment to all the fishery management plans of the Gulf of Mexico (GOM).

Hare J.A., Morrison W.E., Nelson M.W., Stachura M.M., Teeters E.J., Griffis R.B., et al. 2016. A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. PLoS ONE 11(2): e0146756.

Harford W, Karnauskas M, Walter JF, Liu H (in review). Nonparametric modeling reveals environmental effects on Bluefin tuna recruitment in Atlantic, Pacific, and Southern Oceans. *Fisheries Oceanography*

Harvell CD, Kim K, Burkholder JM, Colwell RR, Epstein PR, Grimes DJ, Hofmann EE, Lipp EK, Osterhaus ADME, Overstreet RM, Porter JW, Smith GW and Vasta GR. 1999. Emerging marine diseases - climate links and anthropogenic factors. *Science*, 285(5433), 1505-1510Hawkes L A, Broderick A C, Godfrey M H and Godley, BJ (2009). Climate change and marine turtles. Endang. Spec. Res. 7, 137-154.

Hawkes LA, Broderick AC, Godfrey MH, Godley BJ (2007) Investigating the potential impacts of climate change on a marine turtle population. GlobalChanBiol 13:1-10.

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

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

Jacob, S. and M. Jepson. 2009 Creating a Community Context for the Fishery Stock Sustainability Index. Fisheries 43(5): 228-231.

Justic D., Bierman V., Scavia D., and Hetland R. 2007. Forescasting Gulf's hypoxia: the next 50 years. Estuaries 30:791-801.

Karnauskas M, Schirripa MJ, Craig JK, Cook GS, Kelble CR, Agar JJ, Black BA, Enfield DB, Lindo-Atichati D, Muhling BA, Purcell KM, Richards PM, and Wang CZ. 2015. Evidence of climate-driven ecosystem reorganization in the Gulf of Mexico. Global Change Biol 21:2554-2568

Karnauskas M, Schirripa MJ, Kelble CR, Cook GS, Craig JK (2013) Ecosystem status report for the Gulf of Mexico. NOAA Technical Memorandum NMFS-SEFSC-653. Department of Commerce, 52 p.

Knight JR, Allan RJ, Folland CK, Vellinga M, and Mann ME 2005. A signature of persistent natural thermohaline circulation cycles in observed climate. *Geophysical Research Letters*, 32, L20708.

Knudsen MF, Seidenkrantz MS, Jacobsen BH and Kuijpers A. 2011. Tracking the Atlantic Multidecadal Oscillation through the last 8,000 years. *Nature Communications*, 2, 178.

Lindo-Atichati D, Bringas F, Goni G, Muhling B, Muller-Karger F,and Habtes S. 2012. Varying mesoscale structures influence larval fish distribution in the northern Gulf of Mexico. *Marine Ecology Progress Series*, pp. 463:245-257.

Link, JS, Griffis R, and Busch S (Editors). 2015. NOAA Fisheries Climate Science Strategy. U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-F/SPO-155, 70p.

Liu YY, Lee SK, Enfield DB, Muhling BA, Lamkin JT, Muller-Karger FE, and Roffer MA. 2015. Potential impact of climate change on the Intra-Americas Sea: Part-1. A dynamic downscaling of the CMIP5 model projections. J Marine Syst 148:56-69.

Liu Y, Lee S-K, Muhling BA, Lamkin JT, Enfield DB. 2012. Significant reduction of the Loop Current in the 21st century and its impact on the Gulf of Mexico. Journal of Geophysical Research, 117, C05039.

Liu Y, Lee S-K, Enfield DB, Muhling BA, Lamkin JT, Muller-Karger FE, Roffer MA. 2015. Potential impact of climate change on the Intra-Americas Sea: Part-1. A dynamic downscaling of the CMIP5 model projections. Journal of Marine Systems 148:59-69.

Liu Y, Lee S-K, Muhling BA, Lamkin JT, and Enfield DB. 2012. Significant reduction of the Loop Current in the 21st century and its impact on the Gulf of Mexico. J Geophys Res. 117: C5039. doi:10.1029/2011JC007555.

Maynard J, van Hooidonk R, Eakin CM, Puotinen M, Garren M, Williams G, Heron SF, Lamb J, Weil E, Willis B, and Harvell CD. 2015. Projections of climate conditions that increase coral disease susceptibility and pathogen abundance and virulence. Nat Clim Change 5:688-695

McInnes A and Quigg A. 2010. Near-annual fish kills in small embayments: Casual versus causal factors. Journal of Coastal Research. 26: 957-966.

Miller J, Muller E, Rogers C, Waara R, Atkinson A, Whelan KRT, Patterson M, and Witcher B. 2009. Coral disease following massive bleaching in 2005 causes 60% decline in coral cover on reefs in the US Virgin Islands. Coral Reefs 28:925-937.

Minello TJ, Rozas LP, Hillen SP, and Salas SP. 2015. Variability in salt marsh flooding patterns in Galveston Bay, Texas. NOAA Technical Memorandum NMFS-SEFSC-678, 12 p.

Morrison WE, Nelson MW, Howard JF, Teeters EJ, Hare JA, Griffis RB, Scott JD, and Alexander MA. 2015. Methodology for Assessing the Vulnerability of Marine Fish and Shellfish Species to a Changing Climate. NOAA Technical Memorandum NMFS-OSF-3. Department of

Commerce, 48 p.
Muhling BA, Lee S-K, Lamkin JT, and Liu Y. 2011. Predicting the effects of climate change on bluefin tuna (Thunnus thynnus) spawning habitat in the Gulf of Mexico. ICES J Mar Sci. 68(6): 1051-1062.
Muhling, BA, Liu Y, Lee SK, Lamkin JT, Roffer MA, Muller-Karger F, and Walter III JF. 2015. Potential impact of climate change on the Intra-Americas Sea: Part 2. Implications for Atlantic bluefin tuna and skipjack tuna adult and larval habitats. J Mar Sys 148(2015): 1-13.
Munday PL, Dixson DL, Donelson JM, Jones GP, Pratchett MS, Devitsina GV, and Doving KB. 2009. Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. PNAS 106:1848-1852.
Ogden JC, Davis SM, Barnes TK, Jacobs KJ, and Gentile JH 2005. Total System Conceptual Ecological Model. Wetlands 25:955-979.
Pike DA, Antworth RL, and Stiner JC. 2006. Earlier nesting contributes to shorter nesting seasons for the Loggerhead Seaturtle, *Caretta caretta* . JHerpetol 40:91-94.
Pinsky ML, Worm B, Fogarty MJ, Sarmiento JL, and Levin SA. 2013. Marine Taxa Track Local Climate Velocities. Science 341:1239-1242.
Pistevos JCA, Nagelkerken I, Rossi T, Olmos M, and Connell SD. 2015. Ocean acidification and global warming impair shark hunting behaviour and growth. Sci Rep-Uk 5.Pollnac, R.B., T. Seara, L.L. Colburn and M. Jepson. 2015. Taxonomy of USA East Coast Fishing Communities in Terms of Social Vulnerability and Resilience. Environmental Impact Assessment Review 55:136-142.
Pollnac R, Seara T, Colburn L, Jepson M. 2015. Taxonomy of USA East Coast Fishing Communities in Terms of Social Vulnerability and Resilience. Environmental Impact Assessment Review 55: 136-143.
Portner H and Knust R. 2007. Climate change affects marine fishes through the oxygen limitation of thermal tolerance. *Science*, 315, 95-97.Punt AE, A'mar T, Bond NA, Butterworth DS, de Moor CL, De Oliveira JAA, Haltuch MA, Hollowed AB, and Szuwalski. C. 2014. Fisheries management under climate and environmental uncertainty: control rules and performance simulation. ICES Journal of Marine Science 71(8): 2208-2220.
Rabalais NN, Turner RE, Sen Gupta BK, Boesch DF, Chapman P, and Murrell MC. 2007. Characterization and Long-Term Trends of Hypoxia in the Northern Gulf of Mexico: Does the Science Support the Action Plan? Estuaries and Coasts 30(5): 753-772.
Rahmstorf S, Box JE, Feulner G, Mann ME, Robinson A, Rutherford S, and Schaffernicht EJ. 2015. Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. Nat Clim Change 5:475-480.
Rose KA, Sable SE, Adamack AT, Murphy CA, Kolesar SE, Craig JK, Breitburg DL, Thomas P, Brouwer MH, and Cerco CF. 2009. Does hypoxia have population-level effects on coastal fish? Musings from the virtual world. Journal of Experimental Marine Biology and Ecology 381:S188-S203.
Rozas L. 1995. Hydroperiod and its influence on nekton use of the salt marsh: a pulsing Ecosystem, *Estuaries.* pp. 18:579-590.
Simmonds, MP and Issac SJ. 2007. The impacts of climate change on marine mammals: early

signs of significant problems. Oryx Vol 41(1): 19-26.

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

Srokosz MA and Bryden HL. 2015. Observing the Atlantic Meridional Overturning Circulation yields a decade of inevitable surprises. Science 348:1330-+.

Sydeman WJ, Poloczanska E, Reed TE, and Thompson SA. 2015. Climate change and marine vertebrates. Science 350:772-777.

Thomas P and Rahman MS. 2011. Extensive reproductive disruption, ovarian masculinization and aromatase suppression in Atlantic croaker in the northern Gulf of Mexico hypoxic zone. Proceedings of the Royal Society, B. doi:10.1098/rspb.2011.0529.

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

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

Walters AW, Bartz KK, and McClure MM. 2013. Interactive effects of water diversion and climate change for juvenile Chinook salmon in the Lemhi River basin (U.S.A.). Conservation Biology 27: 1179-1189.

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

Weishampel JF, Bagley DA, Ehrhart LM, and Weishampel AC. 2010. Nesting phenologies of two sympatric sea turtle species related to sea surface temperature.*Endangered Species Research.* 12: 41-47.

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

Zhang L and Wang C. 2013. Multidecadal North Atlantic sea surface temperature and Atlantic meridional overturning circulation variability in CMIP5 historical simulations. *Journal of Geophysical Research*, 118, 5772–5791.

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

Zimmerman R, Minello T and Rozas L. 2000. Salt marsh linkages to productivity of penaeid shrimps and blue crabs in the northen Gulf of Mexico. *Concepts and controversies in tidal marsh ecology.* Dordrecht, Kluwer Academic. Pp 293-314.