Coastal Alabama Comprehensive Oyster Restoration Strategy

2021 REVISION

Alabama Department of Conservation and Natural Resources, Marine Resources Division and the National Oceanic and Atmospheric Administration

Coastal Alabama Comprehensive Oyster Restoration Plan

2021 Revision

by the

Alabama Department of Conservation and Natural Resources,
Marine Resources Division

and the

National Oceanic and Atmospheric Administration

published by the

Deepwater Horizon Alabama Trustee Implementation Group

EXECUTIVE SUMMARY

The eastern oyster (*Crassostrea virginica*) has played an important role in the cultures of coastal Alabama's inhabitants for over 12 centuries and was a driver of economic development in the region during the 19th and 20th centuries. Oysters also play a critical role in the function of Alabama's coastal and estuarine ecosystems by enhancing water quality, providing habitat for other ecologically and economically important species, and protecting shorelines against erosion. Despite their cultural, economic, and ecological importance, Alabama's oyster populations have been in decline since the 1950s due to harvest activities, dredging, pollution, and coastal development. Alabama's already declining oyster resources were further damaged by the 2010 *Deepwater Horizon* (DWH) oil spill.

The Alabama Department of Conservation and Natural Resources (ADCNR), Marine Resources Division (Alabama MRD) has been conducting oyster restoration, consisting mostly of cultch planting, since the 1970s. However, despite these efforts, Alabama's oyster populations have not returned to historic levels. Major storms, changing environmental conditions, and widespread predation have limited the success of past restoration efforts and present an ongoing challenge to fisheries managers and restoration planners. The continued decline of Alabama's oyster populations demonstrates the need for a comprehensive approach to oyster restoration across coastal Alabama, particularly in light of potentially rapidly changing future environmental conditions and ongoing stressors.

This document describes Alabama's existing oyster resources, discusses past and ongoing oyster restoration activities, and presents a comprehensive long-term plan to guide future oyster restoration efforts, in consideration of changing environmental conditions. The overarching goal of this comprehensive oyster restoration strategy document is to:

Create new reefs and restore, replenish, or enhance existing reefs to improve connectivity and establish a network of intertidal and subtidal oyster resources in Coastal Alabama that, collectively, are more resilient against variability in environmental conditions and other factors to support sustainable harvest and provide ecosystem services now and into the future.

In response to the environmental and economic damage caused by the DWH oil spill, the DWH Trustees developed a Programmatic Damage Assessment and Restoration Plan/Programmatic Environmental Impact Statement (PDARP/PEIS) (DWH NRDA Trustees 2016) and a Strategic Framework for Oyster Restoration Activities (DWH NRDA Trustees 2017). These documents were intended to guide the restoration of oysters and other environmental resources that were injured by the DWH oil spill under the Natural Resource Damage Assessment and Restoration Program. This comprehensive oyster restoration strategy for coastal Alabama aligns with the goals of the PDARP/PEIS and Strategic Framework to guide future oyster restoration efforts in Alabama using funding from the DWH oil spill settlement and other funding sources.

AUTHORS AND CONTRIBUTORS

Name	Title	Affiliation
Joe Dalrymple	Scientist	Volkert, Inc.
Bethany Kraft	Restoration Ecologist	Volkert, Inc.
Jason Herrmann	Biologist	ADCNR, Marine Resources Division
John Mareska	Biologist	ADCNR, Marine Resources Division
Kevin Anson	Chief of Fisheries	ADCNR, Marine Resources Division
Emily Seale	Natural Resources Planner	ADCNR
Kelly Swindle	Coastal Restoration Specialist	ADCNR
Dr. Amy Hunter	Deepwater Horizon Oil Spill Restoration Coordinator	ADCNR
Chris Blankenship	Commissioner	ADCNR
Eric Weissberger	Marine Habitat Resource Specialist	NOAA
Estelle Wilson	Marine Habitat Restoration Specialist	NOAA
Dan VanNostrand	Deepwater Horizon Implementation Team Lead	NOAA

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ACES	Alabama Cooperative Extension Service
ACF	Alabama Coastal Foundation
ADCNR	Alabama Department of Conservation and Natural Resources
ADPH	Alabama Department of Public Health
Alabama MRD	Alabama Department of Conservation and Natural Resources, Marine Resources Division
AL TIG	Alabama Trustee Implementation Group
CPMC	Claude Peteet Mariculture Center
DWH	*Deepwater Horizon*
EDRP	Emergency Disaster Recovery Program
EIS	Environmental Impact Statement
FDA	United States Food and Drug Administration
GEBF	Gulf Environmental Benefit Fund
GOMA	Gulf of Mexico Alliance
GOMESA	Gulf of Mexico Energy Security Act
GoMRI	Gulf of Mexico Research Initiative
GSMFC	Gulf States Marine Fisheries Commission
MAM	Monitoring and Adaptive Management
MSX	Multinucleate Sphere Unknown
NEPA	National Environmental Policy Act
NFWF	National Fish and Wildlife Foundation
NGO	Non-governmental organization
NRDA	Natural Resource Damage Assessment
NSSP	National Shellfish Sanitation Program
OCS	Outer Continental Shelf
PDARP/PEIS	Programmatic Damage Assessment and Restoration Plan/Programmatic Environmental Impact Statement
RPII/EA	*Deepwater Horizon* Oil Spill AL TIG Final Restoration Plan II and Environmental Assessment
SAV	Submerged aquatic vegetation
USACE	United States Army Corps of Engineers

1.0 INTRODUCTION

1.1 PURPOSE OF DOCUMENT

The primary purpose of this document is to develop a long-term plan to yield sustainable and resilient eastern oyster (*Crassostrea virginica*) populations in coastal Alabama and guide future oyster restoration efforts. Implementation of the strategies identified may be funded through a number of sources, including but not limited to the *Deepwater Horizon* (DWH) Alabama Trustee Implementation Group (AL TIG), the National Fish and Wildlife Foundation Gulf Environmental Benefit Fund (NFWF GEBF), and the funding streams associated with the RESTORE Act. These and other potential funding sources are further described in Appendix A – Potential Funding Sources for Future Oyster Restoration and Research.

The specific goals of this Oyster Strategy Document are to:

- Identify strategies to yield sustainable and resilient oyster populations in coastal Alabama;
- Prioritize potential restoration and enhancement strategies for implementation in the next 3-5 years;
- Identify science and/or data gaps that could help inform future restoration efforts; and
- Identify adaptive management strategies to address uncertainties associated with changing environmental conditions and/or project implementation.

This document focuses on a plan to help meet the DWH Trustees' oyster restoration goals described in the PDARP/PEIS (DWH NRDA Trustees 2016) and the Strategic Framework for Oyster Restoration Activities (DWH NRDA Trustees 2017):

- "Restore oyster abundance and spawning stock to support a regional oyster larvae pool sufficient for healthy recruitment levels to subtidal and nearshore oyster reefs."
- "Restore resilience to oyster populations that are supported by productive larval source reefs and sufficient substrate in larval sink areas to sustain reefs over time."
- "Restore diversity of oyster reef habitats that provide ecological functions for estuarine-dependent fish species, vegetated shoreline and marsh habitat, and nearshore benthic communities."

Achieving the goals outlined in the PDARP/PEIS will also support the goals and objectives identified for restoration of oyster resources using other DWH funding sources.

The AL TIG approved its Final Restoration Plan II and Environmental Assessment (RPII/EA) (AL TIG 2018) in 2018, which included a project to construct an oyster hatchery and remote set facility in Alabama. Additionally, the project included the development of this Coastal Alabama Comprehensive Oyster Restoration Strategy as a supplement and companion document to the 2016 Alabama Oyster Management Plan. While the 2016 Alabama Oyster Management Plan provides details of traditional oyster reef restoration techniques such as cultch planting, relaying (relocating wild oysters to restoration sites), seed deployment, and cultivating, as well as information on the use of hatchery-raised, remote set oysters with a focus on the oyster fishery, this comprehensive oyster restoration strategy focuses on Alabama's oyster resources for both the ecological services they provide and to facilitate sustainable oyster harvest into the future.

Following the recommended approaches, techniques, and monitoring considerations of this comprehensive oyster restoration strategy will help align the AL TIG's goals for the use of hatchery raised remote set oysters with the oyster restoration goals of the PDARP/PEIS (DWH NRDA Trustees 2016), as detailed above.

1.2 SIGNIFICANCE OF OYSTERS IN COASTAL ALABAMA

1.2.1 Cultural

Oysters have played an important role in human culture along the coast of Alabama for hundreds of years. Ancient shell middens, thought to date back to the Mississippian period (800 CE to 1600 CE), can be found in Bon Secour Bay and Grand Bay, on Dauphin Island and along Mobile Bay (Sledge 2015). According to the University of South Alabama's Center for Archaeological Studies, oysters were not only important to the native peoples' diets but were also used to build their communities up above sea level. Based on archaeological findings, it is believed that oyster harvesting was accomplished by the women and children in the native communities (Walthall 1980). Two sites can be visited at parks managed by the Alabama Department of Conservation and Natural Resources: The Dauphin Island Shell Mounds and the Blakeley Indian Mounds near Spanish Fort. Over time, the residents and occupiers of coastal Alabama changed. However, oysters remained important to these communities as a food source and building material, including in modern-day construction of roads in coastal Alabama such as the Old Shell Road in Mobile (Figure 1).

Figure 1. Old Shell Road in Mobile, Alabama

Source: University of South Alabama Archives

Fishing methods and gear used in the Gulf Coast oyster fishery have changed very little since the late 1800's when Alabama first began keeping state records. In one of the earliest recorded laws related to oyster management in the Gulf region (1852), Alabama banned the use "of all mechanical oyster harvesting in Alabama waters other than by rake or tongs" (GSMFC 2012). Tonging remains the primary means of harvesting oysters in Alabama. Although vessels used in harvesting have changed from wooden canoes to boats with outboard engines, the vessels have always been constructed with wide beams, flat bottoms, and a large deck area.

Formerly considered an expensive delicacy outside of the harvesting area due to the cost of preservation and transportation, oysters are now popular at restaurants across North America. They remain a staple on coastal Alabama restaurant menus and in holiday recipes. Oysters are even used in tourism marketing strategies for many of Alabama's coastal cities (Gulf Shore and Orange Beach Tourism 2021, Oystergardening.org 2021).

1.2.2 Economic

Alabama began keeping records on oyster harvesting in 1880. That year, about 327,000 pounds of oysters were tonged from Mobile Bay (GSMFC 2012). The National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) commercial fisheries query tool provides access to fisheries landing data back to 1950. In that timespan, the quantity of oysters brought to the dock and the revenue generated at the dock have varied widely. The range of annual landings ranges from 11,476 lbs. in 1989 to 2,191,400 lbs. in 1951. The range of dockside (wholesale) revenue ranges from $30,838 in 1989 to $3,640,170 in 2006. Average landings from 2015 through 2020 were 85,149 lbs. and average dockside revenues totaled $1,207,881 (NOAA 2021a).

Factors impacting harvest statistics are complex and involve the interaction of environmental factors, fisheries management and regulatory considerations, capabilities of the harvest community, and demand for the product. As an example, extreme drought conditions can lead to oyster drill proliferation and subsequent oyster predation, reducing oyster numbers (Dugas et al. 1997). Severe tropical storm events can cause physical destruction of reef structures, an increase in silt suspension in the water column, and a decrease in the salinity of the waters over the oyster reefs, all resulting in a reduction in spat production. Human impacts, such as dredging, oil and chemical spills, and nutrient run-off, also have detrimental impacts on oyster populations. In addition to lethal impacts, human impacts can cause sublethal responses ranging from a decrease in fertilization, abnormal embryo development, stunted larval growth/settlement, and spat disruption (Weng and Wang 2019, Boulais et al. 2018, Vignier et al. 2017, Ringwood et al. 2004).

Negative publicity related to the safety of eating raw oysters has periodically affected the demand, resulting in low dockside pricing. And when economic times are difficult for the oyster harvesting community, fishers often resort to more lucrative employment opportunities.

Muth et al. (2002) suggests the traditional harvest oyster industry has economic impacts on three different primary sectors: the harvesting sector, the wholesaling/processing sector, and the retail sector. This means that the amount of oysters harvested and the price at the dock not only affect the oyster fishers/harvesters, but also directly impact transporters/shippers, wholesalers, processors, restaurant owners and workers, and grocery store owners and employees.

Starting in 2012 with one farm, the relatively new Alabama oyster aquaculture industry grew to 21 farms by 2019, producing oysters through off-bottom farming using an adjustable long-line system or floating cages (ACES 2020). Reporting differs from NMFS requirement for traditional commercial harvesters, but the Alabama Cooperative Extension Service (ACES) provided the following highlights for 2019 (the most recent year available):

- Farm gate value for Alabama oyster commercial operations was at least $1,452,000.
- Total number of single market oysters sold was at least 2,425,000.
- Oyster market prices ranged from $0.50 to $0.70 per oyster with a weighted average price of $0.59.
- Operators reported 34 full-time employees and 30 part-time employees.
- At least 74 acres were permitted for oyster aquaculture with at least 40 acres used in production.

The ACES noted detrimental impacts similar to those faced by the traditional oyster industry in Alabama also impact the oyster aquaculture community.

1.2.3 Ecological

Oysters and oyster reefs are not only important to the economy of coastal Alabama but are also an essential component of the local ecosystem. Oysters filter pollutants and nutrients from the water column, contributing to cleaner water and potentially avoiding or mitigating harmful algal blooms while also supporting carbon sequestration (Grabowski et al. 2012). An individual adult oyster can filter plankton, removing nitrogen and pollutants from as much as 50 gallons of water per day, providing an enormous benefit to Alabama coastal waters that are increasingly impacted by runoff and pollution (Koenig 2018, Kellogg et al. 2014). This benefit is maximized in healthy reef systems where recruitment is high and juvenile oysters are abundant because oysters remove nitrogen at the highest rate as they develop from spat to adult stage (Dalrymple and Carmichael 2015).

Oysters also remove suspended solids from the water column and package them into bundles which they release as pseudofeces. This bundle is then utilized by other organisms on the oyster reef for food. Oyster feces and pseudofeces deposited on the benthos can also play an important role in benthic microbial processes (Mortazavi et al. 2015, Carmichael et al. 2012, Newell et al. 2005). The reef community assimilates carbon and nitrogen from phytoplankton and detritus, making it available to consumers higher in the food chain. The reef community also mineralizes organic carbon and releases nitrogen and phosphorus in forms usable by primary producers (Higgins et al. 2013).

Oyster reefs protect shorelines from erosion, stabilize sediments and provide habitat for commercially and ecologically important species of fish and invertebrates, including future generations of oysters. Mature reefs have stabilizing influences on erosional processes and act as stable islands of hard substrate in unstable soft bottom environments that are particularly beneficial to fixed, filter-feeding species (Grabowski et al. 2012). Crevices in the reef serve as spawning areas and shelter for invertebrates, juvenile and small fishes, as well as the organisms serving as a food source for those species (Peterson et al, 2003). Oyster reefs buffer coastal areas from wave energy, not only reducing erosion, but also guarding submerged aquatic vegetation (SAV) and coastal wetlands which in turn provide their own hazard mitigation benefits (Meyer et al. 1997).

2.0 EXISTING CONDITIONS: THE CURRENT STATE OF ALABAMA'S OYSTER RESOURCES AND VARIABLES AFFECTING SURVIVAL

2.1 OVERVIEW OF ALABAMA'S OYSTER RESOURCES – PAST AND PRESENT

Commercial oyster landings have been recorded in Alabama since 1880. Landings peaked at over 2,000,000 lbs. annually during the 1950's (Figure 2). While landings have fluctuated annually, they have shown a declining trend from the 1950's to the present (NOAA 2021a, VanderKooy 2012). Throughout the recorded history of Alabama's oyster fishery, shifts in environmental parameters and hydrology, major hurricanes, and anthropogenic impacts have affected landings. Physical damage and the effects of silting were caused by hurricanes Ivan (2004) and Katrina (2005) as well as persistent drought conditions since 2005. These extended drought conditions have created favorable conditions for the proliferation of the oyster drill snail, *Stramonita haemastoma*, a natural predator of oysters.

Anthropogenic impacts such as dredging, construction and maintenance of navigation channels, coastal development, and pollution have altered habitat conditions in historically productive coastal waters. In addition, the DWH oil spill in 2010 may have exacerbated oyster decline. This extended period of decline of Alabama's oyster resources has not been seen throughout the recorded history of the fishery. The Alabama Department of Conservation and Natural Resources (ADCNR), Marine Resources Division (Alabama MRD) has largely responded by utilizing restoration techniques, such as cultch planting and oyster relaying, which have been widely used and historically successful across the Gulf Coast. However, recent, and persistent adverse environmental conditions continue to cause widespread mortality of oysters and impede the success of recent large-scale cultch planting projects. Alabama MRD is investigating the use of other techniques to increase oyster populations including remote setting of hatchery-raised oysters to help mitigate mortality and allow oysters to proliferate.

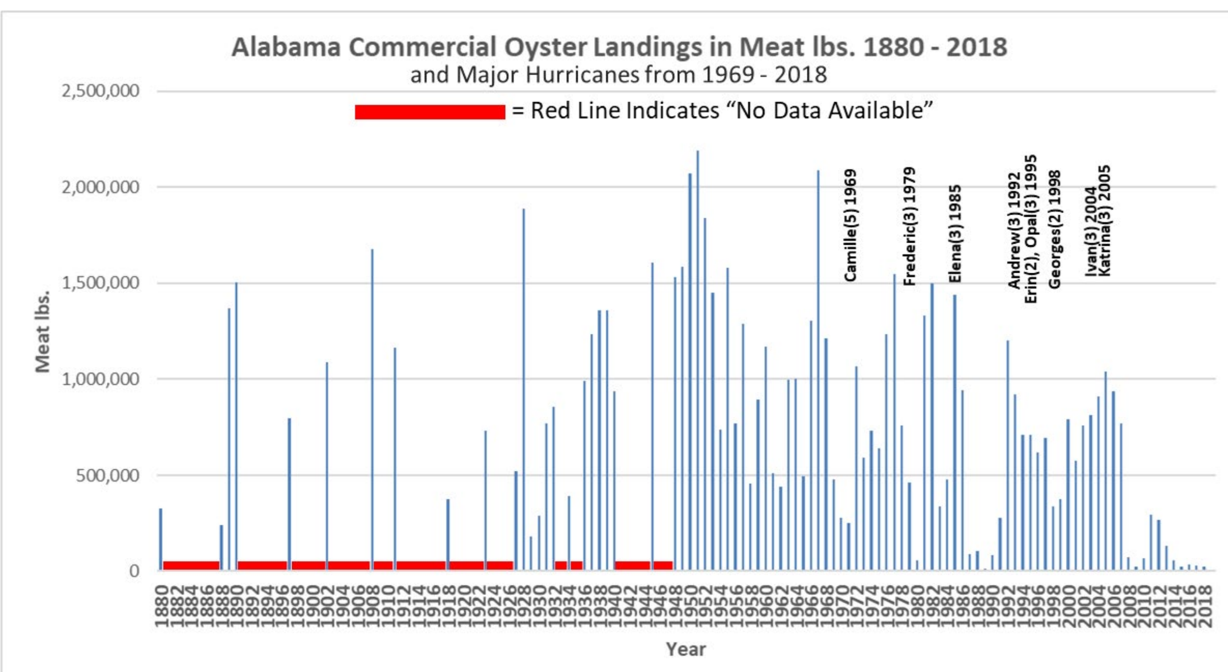

Figure 2. Commercial Oyster Landings in Alabama 1880 – 2018 and Major Hurricanes From 1969 – 2018

2.2 FACTORS AFFECTING SURVIVAL

Oyster survival is affected by many factors and influenced by complex interactions among those factors. The following sections provide an overview of major historical and current factors which have shaped existing conditions for oysters in Alabama.

2.2.1 Environmental Factors

Oysters can tolerate a wide range of salinities, temperatures, and oxygen levels. They can tolerate brief influxes of freshwater; however, their optimum salinity range is approximately 15 – 30 ppt, although this can vary by location (Shumway 1996). Oysters can also use oxygen over a wide range of changing salinities and temperatures (Shumway 1996). Oxygen consumption increases as water temperature increases or salinity decreases (Shumway and Koehn 1982). Oysters can even tolerate brief periods of anoxia (Shumway 1996).

Recent seasonal changes in salinity and dissolved oxygen have negatively impacted oyster survival directly, from the physiological effects of extended sub-optimal conditions, and indirectly, by causing conditions that enhance predation by oyster drill snails. Impacts of predation are discussed below in section 2.2.4*, Predation and Disease*. In 2017, extended freshets (periods of freshwater influx where salinity drops below 5 ppt), coupled with low dissolved oxygen (< 4 mg/L) and high summer water temperatures decimated oysters of all size classes on Alabama's largest harvestable public oyster reefs near Cedar Point.

Seasonal low dissolved oxygen levels were observed on Alabama's most productive reefs from 2017 - 2019. Several of Alabama's historically productive reefs including Whitehouse, Buoy, and King's Bayou reefs continually undergo hypoxic (<4 mg/L) and anoxic (<1 mg/L) conditions (Johnson et al. 2009) up to 1 meter above the bottom of the reef.

Hurricanes have historically impacted oyster reefs across the Northern Gulf of Mexico. Several major hurricanes including Camille (Category 5, 1969), Frederic (Category 3, 1979), Elena (Category 3, 1985), and Andrew (Category 3, 1992) were followed by sharp declines in oyster resources, based on commercial landings data (Figure 2). However, after these hurricanes, oyster landings eventually returned to approximately pre-hurricane levels within 3 years. Hurricanes Ivan (Category 3, 2004) and Katrina (Category 3, 2005) devastated Alabama's oyster reefs and were followed by a similar sharp decline in landings. Over a decade after Hurricanes Ivan and Katrina, the reefs have not returned to pre-hurricane productivity. In 2020, hurricanes Sally and Zeta (both Category 2) caused considerable damage in coastal Alabama. The effects of those storms on Alabama's oyster reefs are yet to be determined.

2.2.2 Anthropogenic Factors

Alabama's oyster reefs have been negatively impacted by several anthropogenic causes within the last century. Relic oyster reefs and submerged shell deposits in Mobile Bay were dredged extensively from the mid-1900's until 1982. Oyster shell was used as a raw material for various industrial purposes. The negative impacts of shell dredging were assessed and reported in a 1973 Environmental Impact Statement (EIS) prepared by the United States Army Corps of Engineers (USACE), Mobile District (USACE 1973). The EIS was prepared as required under the National Environmental Policy Act of 1970 (NEPA) to analyze the impacts of the USACE's decision to approve a permit renewal request for the Radcliff Materials company. The EIS included an assessment of mud plumes and sedimentation caused by the dredging process between 1947 and 1968 and concluded that oysters were destroyed by the practice. The EIS also acknowledged that continued dredging would result in lowered productivity on a continuing basis of about 2,000 acres of Mobile Bay, temporary minor damage to flora and fauna in up to 3,500 acres of the estuary, water quality degradation, and diminished aesthetic values. Despite these documented impacts, the USACE ultimately granted a permit to Radcliff Materials, authorizing the continued removal of up to 4 million cubic yards of shell material (USACE 1973).

Dredging and widening of the Mobile Ship Channel, the associated creation of Gaillard Island using the dredge spoils, and the construction of the Gulf Intracoastal Waterway have resulted in impacts to oyster resources in Mobile Bay, Oyster Bay, and other Alabama coastal waters. These activities have impacted oysters directly, through loss of habitat, and indirectly, through alteration of physical conditions and processes (Berger and Boland 1979, Carse and Lewis 2020, Coogan et al. 2021).

Other anthropogenic activities that have affected oyster populations include coastal development, commercial fishing, and pollution (Lenihan and Peterson 1998, Gregalis et al. 2008, Deason et al. 2014). Anthropogenic activities that affect water quality can indirectly affect oysters. For example, eutrophication in Mobile Bay resulting, in part, from sewage spills or from upland land uses (e.g., agriculture, commercial and residential development, etc.) may contribute to low dissolved oxygen in the estuary, which can negatively affect oyster survival. Similarly, as noted above, environmental contamination from anthropogenic sources such as chemical spills or discharge of contaminants into waterways can result in a range of sublethal impacts including reproductive failure (Weng and Wang 2019, Boulais et al. 2018, Vignier et al. 2017, Ringwood et al. 2004). In recent years, there has also been a growing body of evidence suggesting that ingestion of microplastics, such as clothing fibers and small plastic beads, from wastewater discharged into coastal waters may negatively affect oyster populations. Microplastic ingestion has been shown to negatively affect oyster reproductive ability, survival, and larval development (Sussarellu et al. 2015). Because oysters filter microplastics and store them in their tissues (Waite et al. 2018), this may also have implications for human health.

2.2.3 Deepwater Horizon Oil Spill

In 2010, the DWH oil spill caused unprecedented damage to oyster resources along the Gulf Coast. The DWH oil spill was an industrial disaster that began on April 20, 2010, in the Gulf of Mexico on the BP-operated Macondo Prospect. Several failed attempts were made to contain the oil, and the well was finally declared sealed on September 19, 2010. Approximately 3.19 million barrels (134 million gallons) of oil were released into the Gulf of Mexico (U.S. v. BP et al. 2015); by far the largest offshore oil spill in the history of the United States.

In response to the spill, federal and state agencies initiated a massive undertaking to protect beaches, estuaries, and wetlands. Due to the long duration of the spill as well as negative impacts from the response and cleanup operations, there was extensive injury to marine habitats and ecosystems. The injury to intertidal and subtidal oyster reefs was assessed across all Gulf States. The summary of injury to oysters described below is inclusive of the findings of the field studies conducted by the Natural Resource Damage Assessment (NRDA) Trustees in 2012 and 2013.

Injury to intertidal oysters occurred from shoreline oiling which killed oysters within 50 meters of marsh shorelines. Efforts to keep the oil offshore included large releases of freshwater which also resulted in loss or injury to oysters along some parts of the Gulf Coast. The cleanup response also contributed to reducing the cover of fringing oysters. These cleanup activities such as raking, washing, or laying oil boom adjacent to the marsh destroyed oyster cover through smothering and physical destruction (Powers et al. 2015, DWH NRDA Trustees 2016, Powers et al. 2017).

The shoreline oiling and cleanup activities caused a reduction of nearshore oysters over an estimated 155 miles (250 kilometers) of shoreline across the northern Gulf Coast (Roman 2015). The reduction of oyster cover was not only a direct result of the loss of oysters at the oiling and cleanup sites, but also an indirect loss because fewer adults were produced over time adjacent to oiled marsh habitats. The loss of oysters also translates into a loss of ecosystem services that oyster reefs provide such as filtering water, producing larvae to populate subtidal reefs utilized for public harvest, stabilizing shorelines, and providing nursery habitat for fish and invertebrates (Roman 2015, DWH NRDA Trustees 2016).

An estimated total of 8.3 million adult equivalent oysters were lost due to marsh oiling along Gulf Coast shorelines where oyster cover was removed or reduced by oiling or cleanup actions (Roman 2015). The loss of oyster shell cover also meant that an estimated 5.7 million oysters per year (adult equivalents) would be unable to settle and grow in nearshore areas across the northern Gulf of Mexico (DWH NRDA Trustees 2016).

Shoreline oiling which reduced wetland plant cover and decreased cover of intertidal oysters is associated with increased rates of shoreline erosion (Powers et al. 2015, Powers et al. 2017). Shoreline erosion attributed to the DWH oil spill was observed in Louisiana, Mississippi, and Alabama and doubled along 108 miles (174 kilometers) of coastal wetlands in the 3 years following the oil spill (Roman 2015, DWH NRDA Trustees 2016).

The DWH NRDA Trustees also concluded that oil spill-related mortality of subtidal and intertidal oysters in 2010 and 2011 also resulted in several years of recruitment loss or failure in the Northern Gulf of Mexico (DWH NRDA Trustees 2016).

2.2.4 Predation and Disease

Predation upon oysters, whether by finfish, crustaceans, or other invertebrates such as oyster drills, can be a source of significant mortality. Most specific predator-related mortality is difficult to quantify because remnants left behind after predators feed are often non-distinct. For example, debris left behind by foraging finfish including Sheepshead (*Archosargus probatocephalus*) and Red Drum (*Sciaenops ocellatus*) is identical to debris left behind by Blue Crabs (*Callinectes sapidus*) or Stone Crabs (*Menippe mercenaria*). Oyster shell is often found as a component of the gut contents of various finfish which demonstrates that they consume oysters in some capacity as they forage on oyster reefs. Feeding by oyster drills can, in most cases, be clearly identified by a distinct, cleanly cut hole located on the oyster valve which is made by the rasping of the snail's radula to gain access to the soft tissues within.

In Alabama, predation by oyster drills has been a major source of oyster mortality in recent years (Alabama MRD unpublished survey data and observations). Oyster drill populations are closely tied to salinity conditions. Changing precipitation patterns have resulted in frequent drought conditions in Alabama over the past 15 years, resulting in an increased prevalence of these naturally occurring snails. Oyster drills thrive in salinities greater than 10 ppt. They are not able to tolerate salinities lower than 10 ppt for extended periods and quickly succumb to salinities less than 5 ppt (Butler 1985). During typical non-drought years, regular precipitation patterns cause lower salinity (< 10 ppt) waters to periodically wash over these reefs several times a year, controlling the oyster drill population (Butler 1952, 1954, 1985; Cooley 1978; Schecter 1943; Wells 1961). However, intermittent drought conditions between 2005 and 2016 caused a decrease in the amount and duration of freshwater flowing from the Mobile and Tensaw rivers resulting in persistent high average salinities on Alabama's most productive oyster reefs in Lower Mobile Bay and Mississippi Sound. From 2005 to 2009, it was not uncommon to see up to 80% of cultch from sampled oyster reefs in Lower Mobile Bay to be covered in oyster drills and oyster drill eggs (Alabama MRD unpublished survey data and observations). In-water structures such as pilings and fishing gear such as crab pots were also frequently covered by oyster drills and carpeted by eggs.

Oysters can be affected by several diseases, most notably dermo, vibrio, and MSX. Dermo is a parasitic disease caused by the microbe *Perkinsus marinus*. Dermo is only known to affect the eastern oyster and has been linked to extensive mortality throughout its range. The disease was first documented in the Gulf of Mexico in the 1940s. Dermo is highly contagious and proliferates in waters where temperature remains above 68 degrees F (20 degrees C) and salinity remains greater than 12-15 ppt for extended periods. Vibrio is a bacterial pathogen caused by *Vibrio spp.* Vibrio infections can result in oyster mortality, particularly to larval stages, but can also cause serious illness in humans if consumed via raw oysters (Richards et al. 2015, FDA 2018). Vibrio is present in the Gulf of Mexico, including Alabama's coastal waters (DePaola et al. 2003, ADPH 2017). Multinucleate Sphere Unknown (MSX) is another parasitic microbial disease that can affect oysters. It is caused by the protozoan *Haplosporidium nelsoni*. So far, MSX has not been documented in the Gulf of Mexico (VIMS 2020).

2.2.5 Overall Habitat Suitability

As noted above, oyster survival and success are affected by many factors and their interactions. Habitat suitability at any given site can be thought of as the sum of all of the factors that affect oyster survival and success. For habitats to be suitable for oysters, a suite of appropriate conditions must exist (e.g., acceptable salinity and temperature range, adequate dissolved oxygen, suitable substrate, low predation rate, etc.). In many cases, if even one of the necessary conditions is not satisfied, otherwise suitable oyster habitat may not be suitable. For example, if a site has suitable substrate, temperature and salinity are within range, and predation is minimal, but the site undergoes frequent or extended periods of anoxia, oysters cannot survive. Similarly, if all other conditions are acceptable but a site lacks suitable substrate or is regularly exposed to extended freshets due to seasonal riverine inputs, the habitat may not be considered suitable.

Further complicating matters, many of the factors contributing to habitat suitability are interrelated or interdependent. Therefore, habitat suitability is also a product of the interactions among various factors influencing oyster survival and success. For example, dissolved oxygen concentration is affected by water temperature, predation rate is affected by salinity, oxygen consumption is affected by both temperature and salinity, and so on. As described above, many of these factors are also influenced by natural events and anthropogenic activities (e.g., loss of substrate after a hurricane, dredging to support navigation and commerce, oiling, or other environmental contamination from industrial accidents, etc.). Habitat suitability indices are numerical models that can be used to evaluate habitat suitability for a species of interest (e.g., oysters) based on selected inputs (Barnes 2007, Cake 1983, Sonia and Brody 1988). These models can be a useful tool for fishery management and restoration planning.

It is also important to recognize that habitat suitability is dynamic. Conditions change, sometimes quickly. There are many examples of historically suitable sites that no longer support living oysters. However, it is also possible that previously unsuitable sites could become suitable for oyster restoration if conditions improve. An overview of currently and historically suitable oyster habitats in Alabama is provided in the section that follows.

2.3 SITE-SPECIFIC OYSTER RESOURCES IN ALABAMA

Oysters can be found in Alabama waters from Upper Mobile Bay, including the Mobile-Tensaw River Delta to Lower Mobile Bay, Mississippi Sound, Bon Secour Bay, Wolf Bay, Perdido Bay and various tidal rivers and bayous. However, there are specific areas in which the natural hydrology and bottom substrate have provided ideal conditions for the establishment of thriving oyster reefs that have historically produced oysters in quantities sufficient to sustain commercial harvest. Oyster reefs in Alabama can be found at water depths ranging from 0 to 5 meters. The extent of Alabama's oyster reefs has been surveyed and mapped a number of times since the late 1800s. The first extensive effort to map Alabama's oyster reefs was made in 1896 (Ritter 1896). Alabama's oyster reefs were mapped subsequently in 1913 (Moore 1913), 1952 (Bell 1952), 1968 (May 1971), 1995 (Tatum et al. 1995), and 2001 by various agencies (DWH NRDA Trustees 2017). Figure 3 shows the current Alabama MRD Oyster Management Zones. For the purposes of the following discussion, the boundary between Upper and Lower Mobile Bay is considered to be the management zone boundary shown on Figure 3.

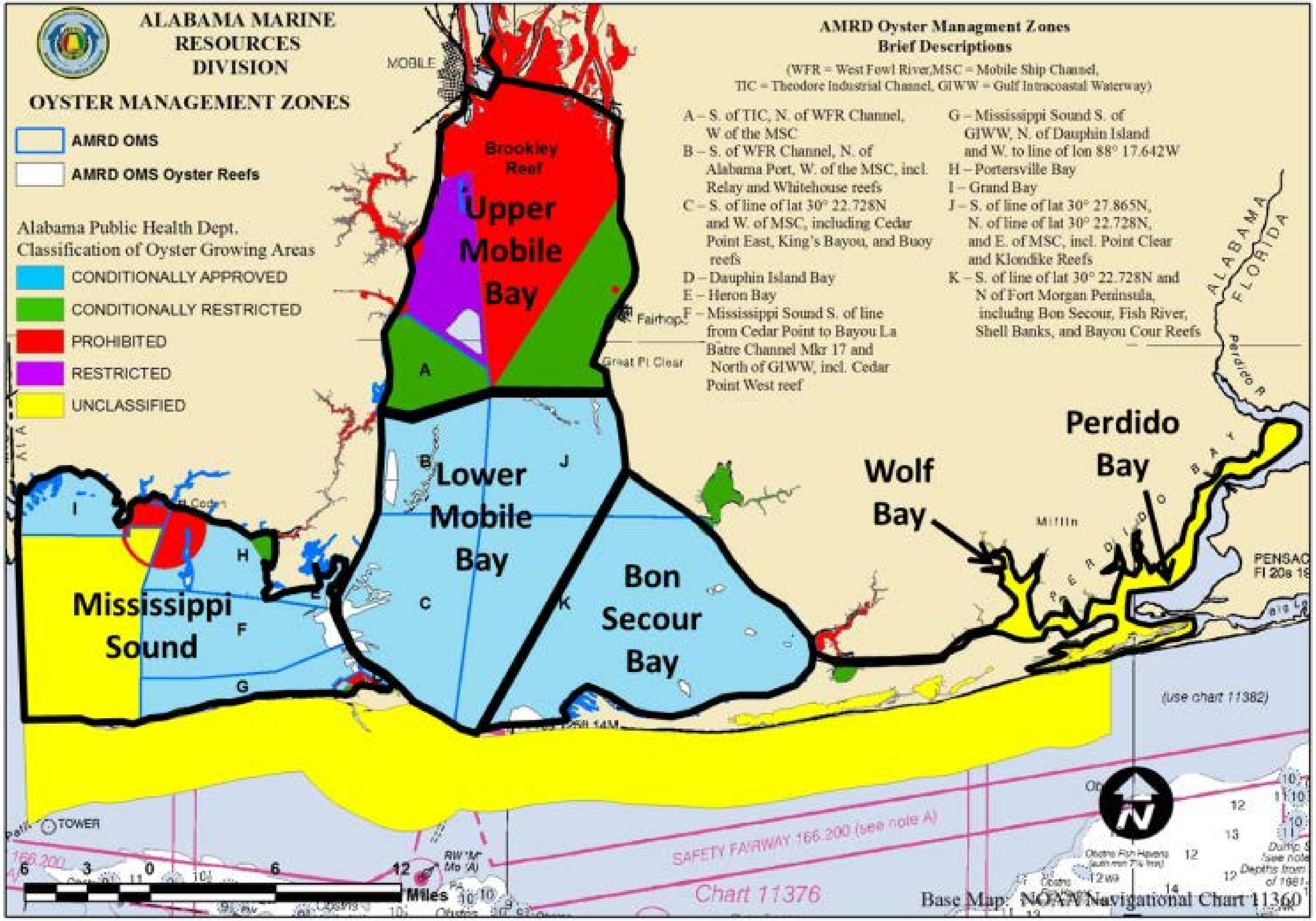

Figure 3. General Area Designations for Alabama's Inshore Waterbodies

Source: ADCNR 2020

Table 1 provides an overview of typical site conditions in each major segment of Alabama's coastal waters along with a typical range of suitable conditions for oyster growth and survival. The sections that follow provide a description of oyster resources in each segment.

Table 1. Typical Conditions in Alabama Waters

Parameters	Range of Suitable Conditions for Oysters	Upper Mobile Bay	Lower Mobile Bay	Mississippi Sound	Bon Secour Bay	Wolf Bay	Perdido Bay
Salinity – Summer (ppt)	[1,2,4,5,6]15-30	[*,7,8]1.0-18.3	[*,7,8,10]2.0-16.5	[*,10]2-28.4.0	[13]0 – 33	[12]15-19	[*,12]21-33
Salinity – Fall/Winter (ppt)	[1,2,4,5,6]15-30; >20 for spawning	[*,7,8]2.3-23.2	[*,7,8,10]3.5-18.5	[*,10]6.5-30.4	[13]0 – 33	[13]3.5 – 23.3	[*,12]22.8-33.4
pH	[1,6]7.9-8.2	*7.2-9.2	*7-8.8	*7.2-8.5	–	–	–
DO (mg/l)	[2]>3	[*,7,8]1.0-11.5	[*,7,8]0-11.7	*0-12.8	[13]3.5 – 18.2	[12]5.2-11.0	[*,12]5-6
Temperature (°C)	[1,2,3,4,5,6]20-32	[*,7,8]5.6-30.2	[*,7,10,11]8.0-30.7	[*,10]12-28	[13]3.6 – 29	[12]10-31	[13]6.8 – 29.7
Water Depth (m)	[6]<6	[*,7,9]2.0-3.6	[*,7,9]0-3.9	[*, 9]0-4.0	[13]0.3 – 2.4	*0-3	*0-3
Bottom Type	[1,2]Hard bottom	[7,9]Sand, clay, mud bottom	[7,9]Sand, clay, mud bottom	[7,9]Sand, clay mud bottom	[7]Sand, clay, mud bottom	Hard, sand, mud bottom	Sand, clay, mud bottom
Sources	[1]ALOMP 2016; [2]GSMFC 2012; [3]Kim et al. 2010; Kim et al. 2013; [4]Lowe et al. 2017; [5]Hofstetter 1990; [6]Shumway 1996; [7]Gregalis et al. 2008; [8]Gregalis et al. 2009; [9]Kim et al. 2012; [10]Casas et al. 2017; [11]Geraldi et al. 2009; [12]ADEM 2012; [13] Alabama MRD gillnet data 2001-2019; *Alabama MRD Sonde Data						

2.3.1 Upper Mobile Bay

Recent unpublished surveys in Upper Mobile Bay (2009 to the present), found oyster reefs of relatively high oyster density within 1 mile of the western shore of Mobile Bay. Small oyster reefs and shell deposits have also been found on the western edge of the Mobile Ship Channel. Brookley Reef, an oyster reef located near the western shore, consists of a hard oyster shell base that rises from 0.3 to 1 meter from the bottom. Currently Alabama MRD is using side-scan sonar and other survey methods to reevaluate the extent of the oyster reefs and shell deposits located in Upper Mobile Bay to better estimate the of the contribution of oyster larvae from Upper Mobile Bay to productive oyster reefs in Lower Mobile Bay and Mississippi Sound (Alabama MRD unpublished data). These efforts are described in greater detail in section 4.1.2*, Substrate Mapping and Characterization.*

2.3.2 Lower Mobile Bay

Productive reefs in Lower Mobile Bay predominantly occur along the western shore of Mobile Bay and near the Dauphin Island Bridge. Three subtidal reefs, Cedar Point East, Buoy Reef, and King's Bayou Reef are the predominant productive reefs currently and historically. Of these three reefs, Cedar Point East is currently the most productive, consisting of a hard shell base with some gradual variation in relief. Because of its location, which provides the necessary conditions for oyster growth and survival, Cedar Point East has been identified by Alabama MRD as a reef that is a high priority for cultch planting and other types of restoration. Buoy Reef and King's Bayou Reef are subject to periodic silting and currently have low productivity. Approximately 2 miles north of the Dauphin Island Bridge is the historically productive reef footprint of Whitehouse Reef. Studies have shown that this reef is subject to frequent hypoxic and anoxic conditions which have contributed to its decline since the late 1960s (Johnson et al. 2009). Point Clear and Klondike reefs near the eastern shore of Mobile Bay were surveyed in 1968 and determined to be live oyster reefs (May 1971). Recent surveys have shown that remnants of these natural reef footprints exist, but live oysters are absent. A 6-acre fishing reef called Grey Cane Reef was built on a northern portion of Klondike Reef. This reef consists of a ring of riprap surrounding a mound of limestone and oyster shell cultch. Recent surveys showed the presence of some harvestable oysters naturally growing on the cultch (DWH NRDA Trustees 2017).

2.3.3 Mississippi Sound

In the waters of Mississippi Sound, Cedar Point West and Heron Bay reefs have consistently had the highest oyster harvest since 2011. Cedar Point West, which is contiguous with Cedar Point East, is located on the west side of the Dauphin Island Bridge and, like Cedar Point East, is considered by Alabama MRD as a high-priority site for restoration due to its location and hard shell base. Heron Bay, which is a grouping of subtidal patch reefs ranging from hard sandy bottom to soft mud, has also been identified as a high-priority site for restoration due to its location which receives adequate nutrients through the Dauphin Island Bridge and the Cut-off Bridge spanning between Mon Louis Island and Cedar Point, and from numerous small bayous flowing into the small inlet. Portersville Bay is located to the west of Heron Bay. An area of hard bottom designated as Middle Ground was historically a productive area for oyster harvest. Recently, drought conditions and predation by oyster drills have hindered productivity in this area (May 1971, Tatum et al. 1995, DWH NRDA Trustees 2017).

2.3.4 Bon Secour Bay

Reefs in Bon Secour Bay include Fish River Reef, Bayou Cour Reef, Bon Secour Reef, and Shellbank Reef. These subtidal reefs have been marked, ringed with rip rap, and planted with limestone and oyster shell as a part of Alabama's artificial fishing reef program. Recent surveys of these reefs have shown that oysters are absent and that the shell material found within has deteriorated. Three Rivers and Navy Cove reefs are located at Little Point Clear on the Fort Morgan Peninsula. Intertidal and subtidal oysters are located within the small bayous extending to the northwest from Little Point Clear (May 1971, DWH NRDA Trustees 2017).

2.3.5 Wolf Bay and Perdido Bay

Wolf Bay and Perdido Bay are Unclassified waters, as termed by the United States Food and Drug Administration's (FDA) National Shellfish Sanitation Program (NSSP) and are therefore not approved for shellfish harvest (Figure 3). For this reason, these zones have not been surveyed extensively. No known continuous oyster reefs have been located. However, oyster growth does occur readily on piers, pilings, bulkheads, boulders, and riprap suggesting that oyster larvae enter the bays. Water bottoms in Wolf Bay and Perdido Bay range from hard and sandy to soft and muddy (DWH NRDA Trustees 2017).

2.4 SUMMARY OF KEY POINTS: EXISTING CONDITIONS

- Throughout the recorded history of Alabama's oyster fishery, shifts in environmental parameters, changes in hydrology, and major hurricanes have impacted landings.
- Persistent adverse environmental conditions continue to cause widespread mortality of oysters and impede the success of recent large-scale restoration planting projects.
- Seasonal low dissolved oxygen concentrations were recorded on Alabama's main productive reefs from 2017 - 2019. Several of Alabama's historically productive reefs continually undergo hypoxic and anoxic conditions up to 1 meter above the reef bottom.
- Recent seasonal changes in salinity and dissolved oxygen have negatively impacted oyster survival directly, from the physiological effects of extended sub-optimal conditions, and indirectly, by causing conditions that enhance predation by oyster drills.
- Alabama's oyster reefs have been negatively impacted by anthropogenic causes within the last century, including shell dredging, construction and maintenance of the Mobile Bay Ship Channel, coastal development, eutrophication of coastal waters from agricultural and residential fertilizer runoff, and pollution in coastal waterways.
- The 2010 DWH oil spill severely impacted oyster resources across the Gulf Coast.
- Habitat suitability for oysters is dynamic and is affected by many factors, both natural and anthropogenic, and by a complexity of interactions.

3.0 OVERVIEW OF POTENTIAL FUTURE ENVIRONMENTAL TRENDS

Suitability of oyster habitat is dependent upon a suite of biotic and abiotic factors, as described in section 2.2.1*, Environmental Factors*. It is important to recognize that changing environmental conditions have implications for oyster survival and success. To maximize restoration success, managers and planners must consider future environmental trends when selecting oyster restoration sites and techniques, and in identifying appropriate adaptive management strategies.

Precipitation is among the most immediately relevant environmental trends that drive oyster survival and success in Alabama. As noted above in in section 2.2.1*, Environmental Factors*, Alabama has experienced frequent drought conditions since 2005. This has resulted in higher salinities in Alabama's coastal waters because of reduced freshwater inputs in Upper Mobile Bay from riverine sources. Persistent salinities greater than 10 ppt have facilitated increased oyster drill predation compared to pre-2005 conditions.

The observed change in precipitation patterns in coastal Alabama over the past 15 years is consistent with most climate change projections. Climate models dating back as far as 2001, like the Hadley Centre Model [HadCM2] and the Canadian Climate Centre Model [CGCM1], have predicted an increase in drought frequency and longer dry periods between rain events for the Gulf Coast region (Twilley et al. 2001). Both models also predicted more intense rainfall events. As noted above, in section 2.2.1*, Environmental Factors*, extended freshets associated with heavy seasonal rainfall events have contributed to oyster mortality on Alabama's historically productive reefs in recent years. These predicted changes in precipitation patterns in coastal Alabama and the Gulf Coast region have been consistently echoed by more recent models and throughout the body of scientific literature (Christensen et al. 2007, Biasutti et al. 2012, IPCC 2018). The observed changes in precipitation in coastal Alabama over the last 15 years, which is consistent with climate change projections, might suggest that baseline precipitation patterns may be shifting toward drier conditions for most of the year, resulting in higher salinities and increased potential for drill predation in the future.

Low dissolved oxygen concentrations have also affected what have historically been Alabama's most productive oyster reefs in recent years as described in in section 2.2.1*, Environmental Factors*. Although the exact causes of these conditions have not been conclusively determined, dissolved oxygen concentration is negatively correlated with water temperature. Global surface temperatures are predicted to increase by 1.5 degrees Celsius above pre-industrial levels between 2030 and 2052 if global climate change continues at its current rate (IPCC 2018). Therefore, higher water temperatures and increased frequency and magnitude of hypoxic or anoxic events in coastal waters are factors that must be considered for restoration planning and adaptive management.

As previously noted, hurricanes have devastated Alabama's oyster reefs and have adversely affected productivity for over a decade. The frequency of storms has been relatively stable since 1878 when data were first collected (NOAA 2021b). However, based on current trends and climate change projections, it is likely that hurricanes will become more intense in the coming century with a greater proportion of hurricanes reaching categories 4 and 5 (NOAA 2021b; IPCC 2018). This suggests that although hurricanes will likely continue with the same frequency, the potential for destruction will be greater. Therefore, it will become increasingly important to consider storm resiliency when planning oyster restoration projects, particularly with regard to site selection and reef design.

Sea-level rise is a critical consideration for all coastal planning projects, including oyster restoration. The observed and predicted trend toward higher salinities in coastal Alabama waters may be exacerbated in the future by sea-level rise, which coupled with decreased precipitation, is predicted to increase salinities in many coastal estuaries including Mobile Bay (Twilley et al. 2001, Christensen et al. 2007, Biasutti et al. 2012, IPCC 2018). Global mean sea level has risen by 8–9 inches since 1880, with about a third of that coming in just the last two and a half decades. The rising water level is mostly due to a combination of meltwater from glaciers and ice sheets and thermal expansion of seawater as global ocean surface temperatures increase. Currently, the rate of sea-level rise for Dauphin Island is 4.13 ± 0.59 millimeters per year based on monthly mean sea level data from 1966 to 2020, which is equivalent to a change of 1.35 feet over 100 years (NOAA 2021b). Furthermore, the global rate of sea-level rise is accelerating; a trend which is predicted to continue (IPCC 2018, Lindsey 2020). In addition to inundation of coastal lands, sea-level rise is expected to contribute to increased destruction from future hurricanes (Lindsey 2020).

In summary, all of the environmental trends discussed above are either driven by or influenced by climate change. Although it is difficult to predict how oysters will respond to these changing conditions over the long term, potential responses include: changes in spawning timing and frequency (Hofmann et al. 1992, Wilson et al. 2005), changes in feeding and growth rate (Shumway 1996, La Peyre et al. 2009, Solomon et al. 2014), reduced larval survival and changes in spat settlement (La Peyre et al. 2009, Waldbusser et al. 2013, Ekstrom et al. 2015), increased mortality and reduced reproduction with exposure to pathogens (Soniat 1985, La Peyre et al. 2013), changes in sedimentation and burial (Weis et al. 1994, Johnson et al. 2009), and increased predation (Shumway 1996, La Peyre et al. 2013). Potential responses of oysters to direct and indirect stressors associated with climate changed are further described in the Strategic Framework for Oyster Restoration Activities (DWH NRDA Trustees 2017).

3.1 SUMMARY OF KEY POINTS: OVERVIEW OF POTENTIAL FUTURE ENVIRONMENTAL TRENDS

- Shifting precipitation patterns associated with climate change may result in increased frequency and duration of droughts and more intense rainfall events, potentially amplifying direct and indirect oyster stressors driven by salinity, including predation and disease.
- Rising global surface temperatures may result in increased frequency and magnitude of hypoxic or anoxic events in Alabama’s coastal waters.
- Increased intensity of hurricanes and tropical storms will result in greater potential for destruction over the next century, making reef resiliency a critical considering for long-term restoration planning.
- Sea-level rise may amplify the effects of changing precipitation patterns, resulting in higher average salinities in coastal Alabama waters, which may increase predation and other salinity-driven stressors.
- Climate change is a major driver of potential future environmental trends that must be considered for successful long-term restoration planning.

4.0 RESTORATION EFFORTS TO DATE

4.1 DATA GATHERING ACTIVITIES

Data gathering is critical to identifying restoration needs and addressing data gaps to inform restoration planning. Continuous gathering and review of data is also essential for evaluating restoration success and implementing adaptive management. An overview of data gathering activities to date is provided in the following sections. Additional information about data gathering activities and monitoring techniques used by Alabama MRD can be found in the 2016 Alabama Oyster Management Plan (Alabama MRD 2016).

4.1.1 Ongoing Oyster Monitoring

Alabama MRD conducts routine monitoring to establish baseline conditions, identify restoration needs, and evaluate restoration success. Alabama MRD has been collecting oyster monitoring data continuously since 1976. Data gathered during seasonal sampling events include oyster demography, reef dimensions, and environmental conditions and parameters. Oyster demography is monitored using quadrat, dredge, hand tong, and/or patent tong sampling. Reef dimensions are monitored as needed and depending on availability of funding using side-scan or multi-beam sonar and pole sounding. Environmental conditions and parameters are monitored by deploying remote data sondes or a vessel-deployed CTD rosette (conductivity, temperature, and depth sonde). These methods are described in detail in Alabama's 2016 Oyster Management Plan (Alabama MRD 2016).

4.1.2 Substrate Mapping and Characterization

Alabama's oyster reefs have been mapped multiple times by various agencies over more than a century, as described in section 2.3*, Site-specific Oyster Resources in Alabama*. In 2007 and 2008, Alabama MRD contracted with the Fisheries Ecology Laboratory at the Dauphin Island Sea Lab to conduct side-scan sonar and single-beam surveys on historically productive oyster reefs to monitor changes in the reef footprint in comparison to past surveys (ADCNR unpublished data). Visual interpretation of overlayed results suggest that reef footprints were similar to those mapped during Alabama MRD's 1968 survey (May 1971).

Larval transport modelling and recruitment studies have shown flow patterns and transport of oyster larvae from populations in northern Mobile Bay are directed southward down the bay's western shore to oyster reefs in Lower Mobile Bay and then west towards Mississippi Sound (Kim et al. 2013, Kim et al. 2010, Powers et al. 2009). They contribute a significant portion of recruitment on Alabama's public reefs in the Lower Mobile Bay and Mississippi Sound and help populate Cedar Point and Heron Bay reefs. Historically, Hollinger's Island and Whitehouse reefs, located in middle Mobile Bay, were productive oyster reefs that bridged the large gap between oyster populations in Upper Mobile Bay and the public reefs in Lower Mobile Bay. Currently, Hollinger's Island Reef is moderately productive, but Whitehouse Reef is non-productive, due to persistent hypoxic conditions on the water bottom.

The ongoing *Side-scan Mapping of Mobile Bay Relic Oyster Reefs* project uses sonar technology to (1) identify water bottoms in areas of mid-to-lower Mobile Bay suitable to support cultch material so that oyster populations can be re-established through efforts to seed reef areas with hatchery-raised oyster spat, and (2) survey the current extent and conditions of the relic oyster reefs identified in 1968 reef surveys conducted by Alabama MRD (May 1971) along with other water bottoms not yet surveyed. Engineering and design funding for this project was included in the AL TIG's RPII/EA (AL TIG 2018).

Mapping these areas with side-scan sonar will help identify the most suitable locations to establish a network of patch reefs, enhancing connectivity among the "islands of productivity" that currently exist. Modelling of larval transport in Mobile Bay has shown that high flushing rates and other physical factors prevent larval exchange among oyster populations in eastern and western Mobile Bay (as separated by the Mobile Ship Channel) resulting in negligible connectivity (Kim et al. 2013). Establishment of significant quantities of oysters on a network of patch reefs along a gradient of hydrological conditions in these areas could provide increased levels of natural recruitment to current commercial public reefs (Powers et al. 2009, Gregalis et al. 2008). It would also increase the resilience of the spawning stock and larval production within Alabama waters. Approximately 8,847 acres of non-contiguous, state-owned water bottoms have been targeted for side-scan mapping in mid-to-lower Mobile Bay, based on a survey of living and relic oyster reefs conducted in 1968 (Figure 4). An additional 5,153 acres of oyster bottoms have been identified for scanning in Upper Mobile Bay (Figure 4) to quantify the location and extent of existing oyster resources, which contribute to larval production and recruitment to Lower Mobile Bay oyster reefs.

By identifying and prioritizing locations in areas of low productivity for enhancement, Alabama MRD hopes to restore oyster abundance and spawning stock to support a regional oyster larvae pool sufficient for healthy recruitment levels to Alabama's subtidal and nearshore oyster reefs (Bannon and Herrmann 2020). This project is expected to be completed in Spring 2022.

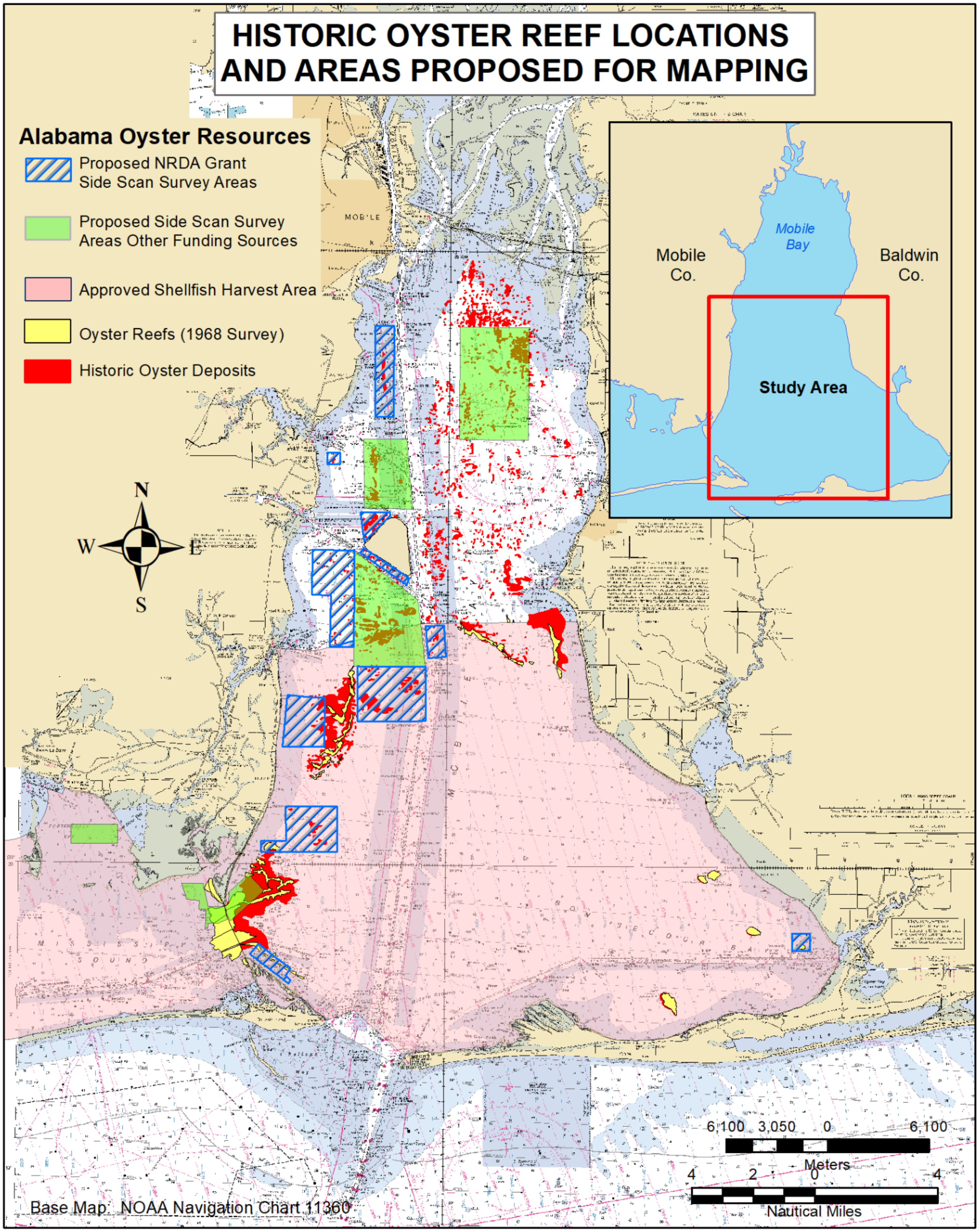

Figure 4. Historic Oyster Reef Locations and Areas Proposed for Mapping

4.1.3 Reef Configuration Studies

Some of Alabama's historically productive oyster reefs are no longer productive because of environmental conditions that have been permanently altered over time. To explore the potential for restoring such sites, Alabama MRD is investigating the advantages of arranging different types of cultch (various materials to which oyster larvae attach) in different configurations to promote settlement and growth of oysters on selected reef areas in Mobile Bay. The *Oyster Cultch Relief and Reef Configuration* project has three primary objectives: (1) determine if there are differences in oyster settlement, growth, and survival on reefs of differing levels of vertical relief and/or orientation to currents; (2) determine the best materials needed to restore oyster density in historical reef areas in which hydrology parameters like oxygen concentration, salinity, and oyster recruitment and survival are highly variable; and (3) estimate the cost/benefits of deploying cultch material in certain configurations other than traditional cultch broadcast methods. The project was included in the AL TIG's RPII/EA (AL TIG 2018).

The initial design of the project included arranging three different cultch types – cured oyster shell, limestone rock, and fossilized oyster shell – in two different experimental configurations: individual mounds and elongated mounds with furrows, with control plots built using typical cultch broadcasting methods. However, with fossilized oyster shell stocks depleted and unavailable, only cured shell and limestone were included as experimental cultch treatments.

Final project site selection and design were determined after pre-project surveys. Two sites were selected: (1) the 70-acre Denton Reef, an artificial fishing reef, located on the northern portion of Whitehouse Oyster Reef approximately 3 miles southeast of the mouth of East Fowl River and (2) the location of Alabama MRD's 2014 Reef Planting Project, a 36-acre reef approximately 1 mile north-northeast of the mouth of East Fowl River near the western shore of Mobile Bay. Physical conditions were used to determine which type of plot would be used at each site. For example, data indicate dissolved oxygen concentrations near the bottom at Whitehouse Reef, including Denton Reef, are consistently hypoxic or anoxic and not favorable for oyster growth (Patterson et al. 2014). Therefore, Denton Reef was picked to test elevated mounds that might offer growing oysters settlement substrates higher in the water column where oxygen concentrations are higher. At the other site, nearer to the mouth of Fowl River, where currents and sediments impact oysters, lower-relief, elongated mounds were used to determine the effects of relief, reef material, and orientation relative to currents and wave energy on oyster survival and growth.

At Denton Reef, six pyramidal cultch mounds were constructed using 45 cubic yards of material, with 15-foot-by-15-foot bases, rising approximately 4 feet off the 10-12-foot bottom. Three mounds were constructed from cured oyster shell and three from limestone. The mounds will be monitored over a 3-year period with quadrats to determine whether vertical position on the mound influences settlement, growth, and survival. Oyster settlement, growth, and survival on mounds will be monitored with quadrats and compared to two adjacent control plots, each constructed of 45 cubic yards of material spread over an approximately 50-foot-by-50-foot square area with 100 percent coverage of cultch at approximately 6 inches depth. One control plot was constructed of cured shell and the other of limestone.

At the second site, three elongated mounds, 2 feet wide, 1 foot high, and 120 feet long, were constructed using 30 cubic yards of material. The three mounds were oriented parallel to one another and separated by a maximum of 4 feet to create furrows between them. Each elongated mound was built with 60 feet of cured shell and 60 feet of limestone, with the three arranged in alternating orientation. As a control, 45 cubic yards of cultch material were broadcast over a 120-foot-by-120-foot area to attain 100 percent coverage to 1 inch depth. Like the experimental plots, the control plots were constructed with the first 60 feet of one type of cultch material and the second 60 feet with the other. Controls were oriented to alternate with experimental mounds and separated from them by a minimum of twenty feet. Oyster settlement, growth, and survival on the elongated mounds will be monitored with quadrats and compared to the control plot to determine the effects of shifting sand and silt related to currents and weather events.

Project construction was completed in 2020 and monitoring is ongoing.

4.1.4 National Fish and Wildlife Foundation Gulf Environmental Benefit Fund Oyster Restoration Studies

In fall of 2013, NFWF provided funding through the GEBF for several experimental oyster reef restoration studies in Alabama. This project included planting 60,501 cubic yards of cultch on oyster reefs in Mobile Bay and Mississippi Sound (Figures 5 and 6), experimental cultivation of six 6-acre plots of oyster reef (Figure 7), the planting of 41,069,890 seed oysters, and experimental remote setting of oysters (Figure 8). Fisheries-independent monitoring techniques included deploying larval settlement tiles near planted cultch, comparative gill net sets to monitor recruitment of finfish to newly planted areas, and SCUBA quadrat surveys to assess oyster density. Fisheries-dependent data was collected by monitoring commercial harvest through the Alabama Oyster Management Station. Through this fund the Auburn University Shellfish Laboratory was also contracted to perform a small-scale study to assess the effects of different planting densities and sizes on the survival of remote set oysters (Lappin 2018).

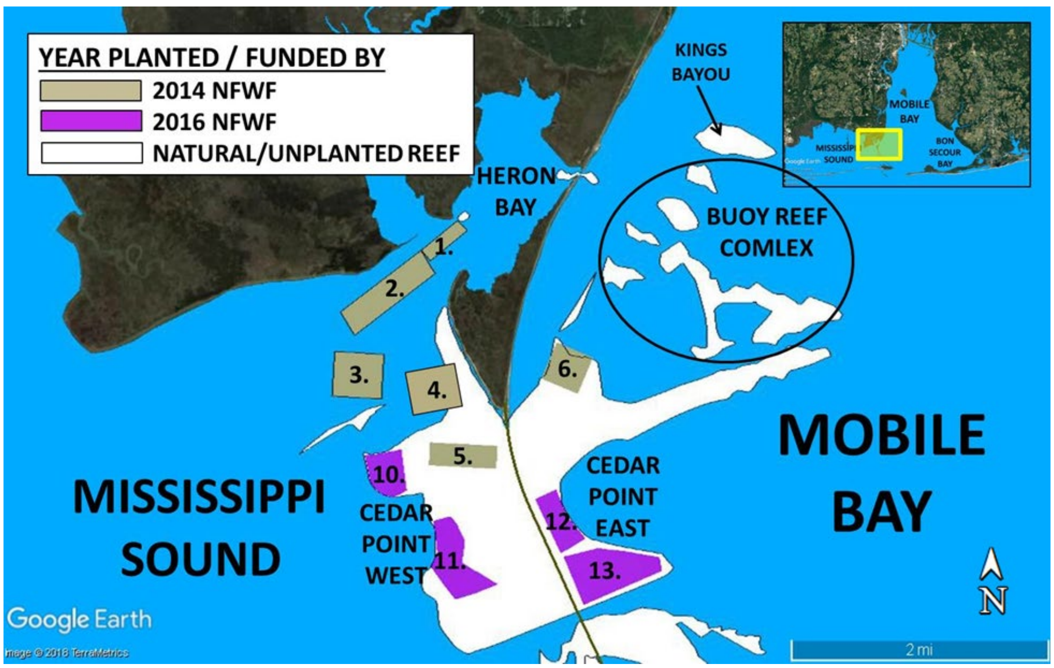

Figure 5. National Fish and Wildlife Foundation Cultch Plants in Lower Mobile Bay and Mississippi Sound, 2014 and 2016

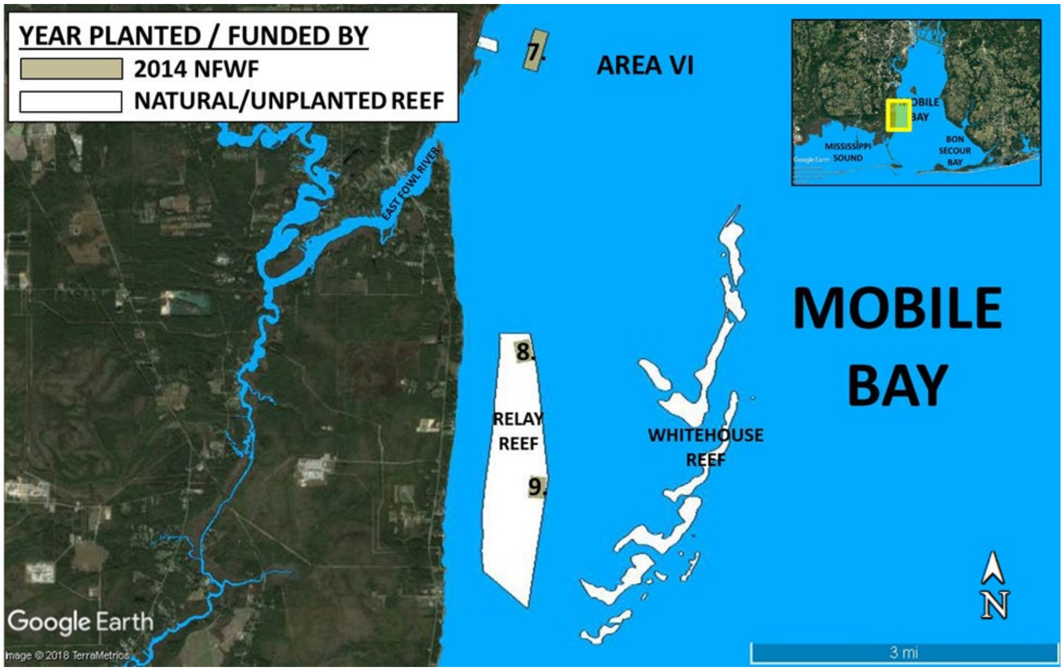

Figure 6. National Fish and Wildlife Foundation Cultch Plants in Mid Mobile Bay, 2014

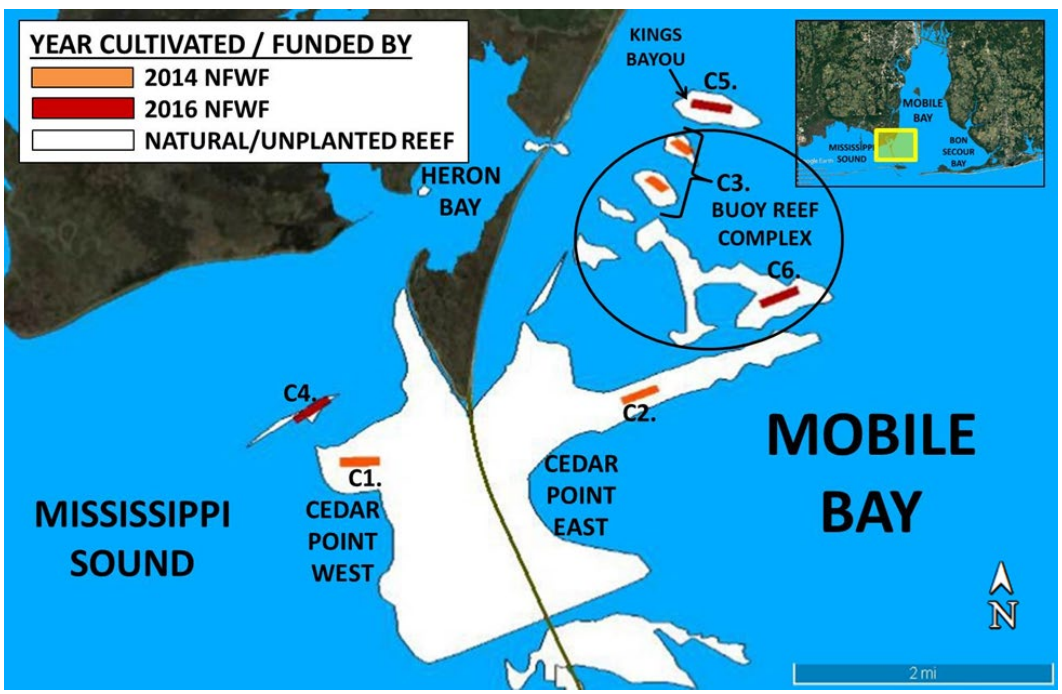

Figure 7. National Fish and Wildlife Foundation Oyster Reef Cultivation Study in Lower Mobile Bay and Mississippi Sound, 2014 and 2015

Figure 8. National Fish and Wildlife Foundation Remote Set Study in Lower Mobile Bay and Mississippi Sound, 2016 – 2017

4.1.5 Oyster Grow-Out and Restoration Reef Placement Study

The *Oyster Grow-Out and Restoration Reef Placement* study was funded in 2018 as part of the DWH NRDA Restoration Program and included in the AL TIG's RPII/EA (AL TIG 2018). The project will create up to three "off-bottom oyster grow-out areas" in Grand Bay, Portersville Bay, and Bon Secour Bay. The project will be conducted by ACES in coordination with its other oyster gardening activities (additional information about the Alabama Oyster Gardening Program can be found in section 4.2.5*, Other Restoration Efforts*). The project will also identify and establish priorities for locating future restoration reefs, including nearshore living shorelines and intertidal reefs. Project success will also be monitored in terms of oyster survival and reproduction at both the grow-out areas and restoration sites to determine effectiveness of these techniques in increasing the sustainability of oyster populations in Alabama. This project will build on other efforts such as Alabama Coastal Foundation's (ACF) Oyster Shell Recycling Program and the Mobile Bay Oyster Gardening effort, which recently received approval to expand into Little Lagoon. In addition, the project will extend investigations similar to the recently completed project funded by the NFWF GEBF, that demonstrated plantings of advanced stock-sized oysters in Mobile Bay and Mississippi Sound can potentially reduce aggressive predation by oyster drills. Monitoring will be conducted for the 5-year duration of the project to determine its effectiveness and support adaptive management activities. The implementation agreement was signed in November 2019 and full implementation is expected to take 5 years.

4.1.6 Review of Scientific Literature

In addition to direct monitoring and data collection, Alabama's managers gather insight by keeping abreast of relevant scientific publications. In this way, restoration planners and managers are able to utilize existing data from a variety of sources to inform restoration and management decisions. Frequent review of emerging science also helps managers stay aware of the latest techniques and innovations for oyster restoration and learn from the successes or shortcomings of other restoration efforts.

4.2 RESTORATION IMPLEMENTATION

Alabama MRD has engaged in oyster reef restoration, enhancement, and reef creation activities since the early 1970's. The majority of oyster restoration efforts in Alabama have consisted of cultch planting. Relaying oysters and distribution of seed oysters with cultch plantings have also been used in an effort to restore Alabama's oyster stocks. A summary of past and ongoing oyster restoration activities is provided in the following sections and additional information about restoration techniques implemented by Alabama MRD can be found in the Alabama Oyster Management Plan (Alabama MRD 2016).

4.2.1 Cultch Planting and Relayed Oysters

From 1972 to 2020, 766,034 cubic yards of cultch material have been planted on Alabama's public oyster reefs (Figure 9). Oysters settle on many types of materials including rubber, glass, shell, and plastic. Alabama MRD typically plants natural, non-toxic types of cultch for settlement substrate including oyster shell, clam shell, limestone, calica, and crushed concrete. Alabama MRD also uses oyster relays to transplant oysters from highly productive reefs to enhance reefs that have low productivity. Cultch planting and relays may also be used in reef creation projects. During relays conducted during 2010 and 2011, a total of 202,774 sacks of oysters and cultch were relayed from an established area in Upper Mobile Bay to create an oyster reef along the eastern shore of Mobile Bay.

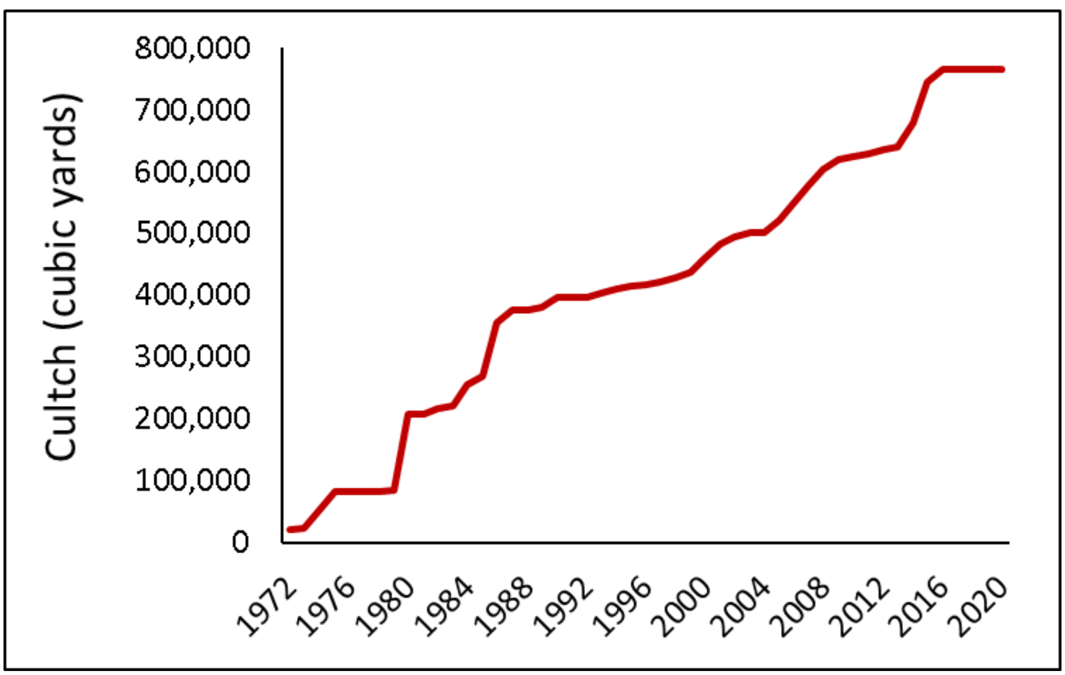

Figure 9. Cultch Deployed by Alabama MRD, 1972-2020 (Cumulative Total)

4.2.2 Emergency Disaster Recovery Programs I and II

In 2006, the Emergency Disaster Recovery Program I (EDRP I) was approved by Congress to provide assistance to Gulf state marine fisheries agencies to rehabilitate marine fisheries resources, including oysters, that were negatively impacted by hurricanes Katrina, Rita, and Wilma in 2005. In 2007, the Emergency Disaster Recovery Program II (EDRP II) was approved to help coastal communities who were directly or indirectly dependent on marine fisheries.

Approximately 77,337 cubic yards of oyster shell and limestone cultch were planted with the help of qualified commercial oyster harvesters in Lower Mobile Bay and Mississippi Sound between 2007 and 2012 with EDRP I and EDRP II funding. From 2008 through 2010, local harvesters participated in harvest data collection and reef sampling programs in which they were paid for turning in harvest data sheets and sampling Alabama's public oyster reefs. In 2010 and 2011 oyster relays were funded in which approximately 202,774 sacks (9,214 cubic yards) of cultch and oysters were transplanted from Upper Mobile Bay to Lower Mobile Bay with the help of qualified local oyster harvesters (Figure 10).

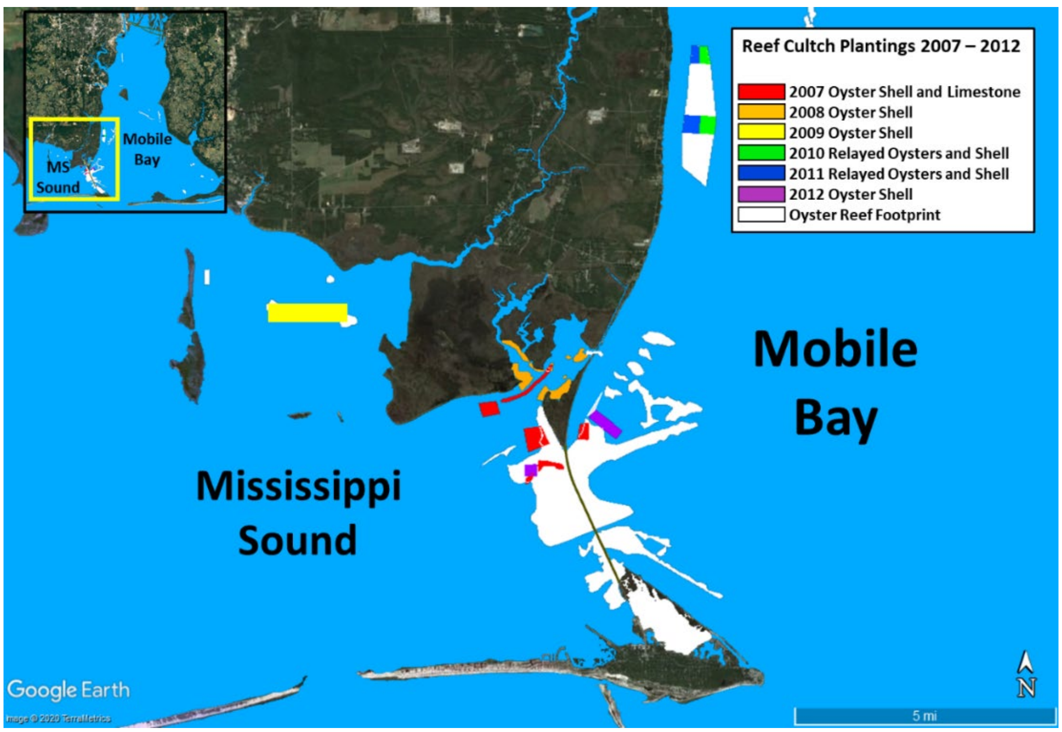

Figure 10. Emergency Disaster Recovery Program Cultch Plantings and Relays, 2007 – 2012

4.2.3 Deepwater Horizon NRDA Oyster Reef Restoration in Mobile County

In 2015, 65,540 cubic yards of material were planted to help restore 524 acres of historic oyster reefs in Mobile Bay and Mississippi Sound (Figure 11). This restoration project was developed during Phase III of Early Restoration as part of the DWH NRDA and was included in the *Programmatic and Phase III Early Restoration Plan and Early Restoration Programmatic Environmental Impact Statement* (DWH NRDA Trustees 2014). The purpose of the project was to enhance oyster biomass through the selective placement of oyster cultch in Alabama's estuarine waters.

Fisheries-independent monitoring techniques included SCUBA quadrat surveys to assess oyster density. Fisheries-dependent data were collected by monitoring commercial harvest through the Alabama Oyster Management Station, which was created in 2010 (Alabama MRD 2016). The first 3 years of monitoring did not detect a measurable increase in productivity, but productivity began to increase in 2019 and appears to be improving. Monitoring is expected to continue for approximately 10 years post-construction but could be slightly more or less depending on funding.

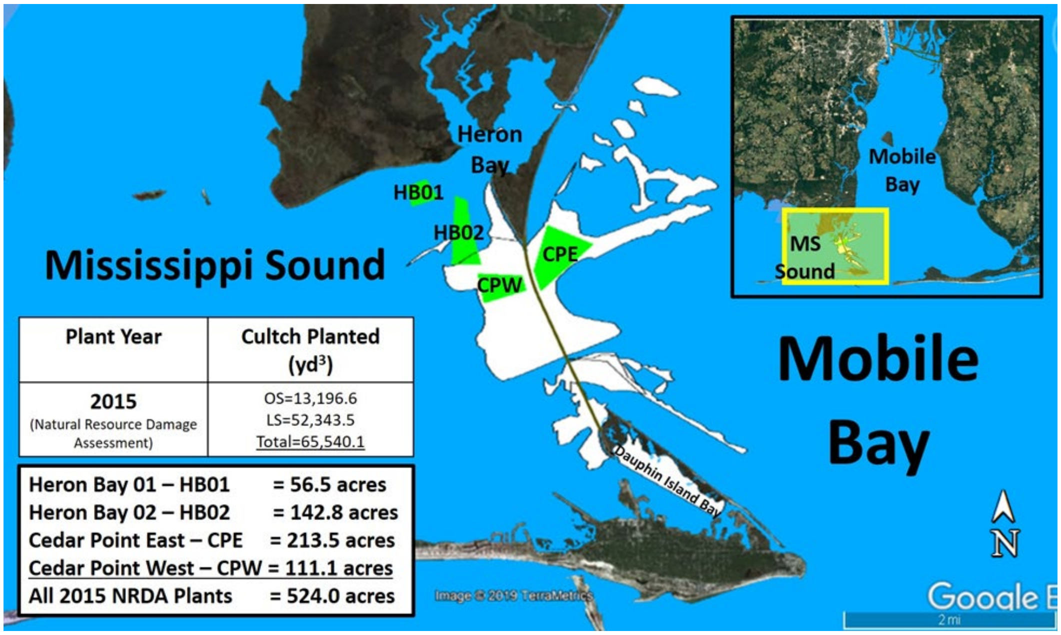

Figure 11. Deepwater Horizon Natural Resource Damage Assessment Cultch Plant in Lower Mobile Bay and Mississippi Sound, 2015

4.2.4 Oyster Hatchery at the Claude Peteet Mariculture Center

Remote set, spat-on-shell oysters can be deployed on existing reefs to help increase oyster density and enhance larval recruitment as reefs are being restored. To increase its capacity to produce spat-on-shell oysters for remote setting, the Alabama MRD will construct an oyster hatchery at the Claude Peteet Mariculture Center (CPMC) in Gulf Shores along with upgrading their remote set facility on Dauphin Island. The project was included in the AL TIG's RPII/EA (AL TIG 2018). The oyster spat produced as a result of this project will be used to supplement and encourage oyster recruitment in portions of Mobile Bay that have experienced reduced oyster production compared to the early 20th century.

The 45-acre complex at the CPMC provides an ideal location for broodstock maintenance and spawning, with ample space, water supply (via pumping stations at the Gulf of Mexico and Intracoastal Waterway), outdoor ponds, and waterfront access to make transport of cultured oysters easier. The project will entail acquisition of wild oyster broodstock from local waters and subsequent maintenance of the broodstock in existing ponds. When springtime water temperatures approach optimum spawning conditions, oyster broodstock will be gathered from the ponds and held in tanks systems where temperatures will be maintained at levels sufficient to prevent spawning while still maintaining adults in good condition. As needed, small batches of oysters will be retrieved from the holding tanks and induced to spawn in smaller, temperature-controlled systems. Released eggs and sperm will be combined to produce zygotes. The resulting larvae will be moved into culture systems and fed rations of paste algae. After 14 to 20 days in the CPMC culture system, the larvae develop into pediveligers, or footed larvae, ready to settle. At this point, the pediveligers will be transported to setting tanks at the remote set facility on Dauphin Island where they will be given approximately 3 days to set on cultch material, usually cured oyster shell, while being fed live, concentrated algae.

After the setting period, the tanks will be switched to flow through, and the spat will be fed by natural algae pumped into the system from the waters of Dauphin Island Bay and allowed to grow for approximately 2 weeks before placement. Cultch material and attached spat will be placed on a contracted barge and transported to suitable areas in Mobile Bay and Mississippi Sound to be identified by Alabama MRD.

This static water culture system is anticipated to produce up to approximately 65 million 10-day-old spat (24-day-old oysters) each year.

4.2.5 Other Restoration Efforts

Living Shorelines

A living shoreline is a shoreline protection technique that provides erosion control benefits; protects, restores, or enhances natural shoreline habitat; and maintains coastal processes through the strategic placement of plants, stone, sand fill, and other materials. Living shorelines are often constructed of materials specifically designed to support oyster recruitment, such as bagged shell, limestone, or engineered structures (e.g., reef blocks, reef balls, or Oyster Castles™). Living shorelines can also be planted or seeded with live oysters to jumpstart reef productivity.

Since 2005, The Nature Conservancy and partners, including Alabama MRD, have worked with stakeholders to install more than 9 miles of living shoreline reef at 17 locations across the Alabama Gulf Coast. This work, done in part with the support of 1,868 volunteers, represents more than $28 million invested to protect and restore Alabama's coastline (TNC 2020).

Oyster Gardening Program

The Alabama Oyster Gardening Program is a volunteer-based program that focuses on education, restoration/enhancement, and research. Volunteers with access to waterfront property in Mobile or Baldwin Counties grow oysters in "gardens" (cages containing live oysters) that hang from their piers from June to November. On average, each volunteer grows 1,000 or more oysters per season. At the end of the gardening season, the oysters are collected from the volunteers and planted on restoration reefs in Mobile Bay and Mississippi Sound (ACES 2019). Since the program's inception in 2001, oyster gardeners have produced over 940,000 oysters for restoration and enhancement of over 46.5 acres of oyster reef in Alabama (oystergardening.org 2020). The program is a collaboration among Auburn University's School of Fisheries, Aquaculture, and Aquatic Sciences; the Mississippi-Alabama Sea Grant Consortium; and the Alabama Cooperative Extension System.

Alabama Oyster Shell Recycling Program

The Alabama Oyster Shell Recycling Program was launched in 2016. Led by the Alabama Coastal Foundation, the program recycles oyster shells from local partnering restaurants and returns them to Alabama waters where they provide substrate for oyster spat. The project was funded through the NFWF Gulf Coast Conservation Grants Program. As of August 2021, the program has collected over 16 million shells; enough to cover approximately 40 acres of water bottom (ACF 2021). Alabama MRD serves as a member of the program's advisory committee.

4.3 RESTORATION SUCCESS AND LESSONS LEARNED

Historically, cultch planting was associated with restoration of oyster reefs after hurricane damage. After hurricane Frederic in 1979, approximately 186,010 cubic yards of cultch material were planted on Alabama's public oyster reefs between 1981 and 1985. Based on landings data, productivity on these reefs increased from 1981 to 1986, suggesting that cultch planting can be an effective technique for restoring reef productivity in the aftermath of major storm events (Figure 2). This was also the case after Hurricane Elena impacted Alabama in 1985. Approximately 146,000 cubic yards of cultch material were planted between 1989 and 2003, resulting in increased productivity from 1992 to 2004 (Figure 2).

Productivity has not significantly increased since Alabama's reefs were impacted by hurricanes Ivan (2004) and Katrina (2005), despite approximately 265,000 cubic yards of cultch material having been deployed between since 2005. Productivity continued to decline through 2018 (Figure 2). In 2019, quadrat surveys showed a marked increase of oyster density from the previous 5 years on some reef zones, resulting in Alabama MRD's decision to open public reefs for a limited harvest. However, oyster densities have not increased to historic levels.

The apparent differences in restoration outcomes between historical and more recent plantings is not due to lack of settlement substrate available to oyster larvae, but rather is an issue of survival once larvae have settled. The primary factors affecting survival of newly settled larvae appear to be related to changing environmental conditions such as temperature and salinity (Alabama MRD unpublished survey data and observations). High summer temperatures have led to prolonged hypoxic or anoxic conditions and changing precipitation patterns have led to extended freshets, resulting in mortality on some of Alabama's largest oyster reefs, as well as persistent high salinity conditions that have facilitated increased predation by oyster drills, as described in section 2.0, *Existing Conditions: The Current State of Alabama's Oyster Resources and Variables Affecting Survival*. Though there has been some increase of oyster density on planted cultch material, it has become clear that traditional cultch planting alone is no longer a viable solution for oyster restoration over the long term. Alabama MRD is exploring techniques to supplement cultch planting that will enhance reef productivity to restore stable and sustainable reef systems. These techniques include:

- strategically placing source reefs to feed public reefs based on best available substrate, water quality, and configuration data;
- restoring nearshore and intertidal reefs;
- using hatchery-raised remote set oysters to help mitigate oyster mortality by having some control over critical life stages of oysters from veliger larvae through metamorphosis, settlement, and growth; and
- developing and implementing a comprehensive monitoring program to better understand the success of oyster restoration efforts and inform measures to adaptively manage oyster restoration projects.

The lessons learned from these oyster reef restoration efforts provide guidance for future project planning to grapple with the challenges of dynamic environmental variability in the context of shifting baseline conditions. There are many variables that fisheries and other natural resource management agencies must take into consideration prior to developing a restoration strategy, many of which are beyond their control. The difficulty with formulating cultch planting strategies, especially the timing of project implementation, is that it is unknown how long favorable or unfavorable conditions will exist and when they will change again. While Alabama MRD will always face environmental unknowns, the agency has control over the types of materials, the locations targeted for reef enhancement or restoration, the configuration of how the material is planted, and restoration strategies utilized, including using hatchery-raised spat-on-shell oysters to enhance survivorship and population sustainability.

Regardless of how environmental factors enhance or impede restoration efforts, oyster larvae must have suitable substrate. Alabama MRD has found that under the current environmental conditions it is preferable to use a cultch material with increased longevity such as limestone for restoration activities. Planted oyster shell breaks down between 3 to 5 years while limestone has been shown to last a decade or more (Alabama MRD unpublished data and observations). A longer-lived material can be planted today and still be viable and available for settlement approximately ten years into the future, spanning the possible years in which environmental parameters are not conducive or optimal for oyster survival. Most oysters harvested in the fall of 2019 were culled from limestone rock planted by Alabama MRD in 2015 as part of the DWH NRDA cultch planting restoration project described above in section 4.2.3, *Deepwater Horizon NRDA Oyster Reef Restoration in Mobile County*.

Strategic restoration of oyster reefs along a gradient of environmental conditions could allow for a more resilient oyster population, capable of withstanding changing environmental conditions. This could allow Alabama's oyster population to remain viable as a whole even if some reefs are negatively impacted by changing conditions. Alabama MRD is currently utilizing side-scan sonar to assess known historically productive oyster reefs and potentially identify previously unknown areas with bottoms suitable for oyster restoration, as described above in section 4.1.2, *Substrate Mapping and Characterization*. One of the goals of this effort is to gain a better understanding of the sources of larvae produced in Upper Mobile Bay and to determine the feasibility of restoring a network of productive patch reefs under current conditions.

The way in which Alabama MRD continues to plant cultch material is being evaluated in light of changing environmental conditions and emerging science on oyster restoration. Some areas will still benefit from the traditional broadcast method. However, there are some historically productive reefs with environmental conditions that have been permanently altered over time. For example, the dissolved oxygen levels of Whitehouse Reef range from hypoxic to anoxic up to 1 meter from the bottom (Johnson et al. 2009). Restoration of this once thriving reef would fill a major geospatial gap in larval productivity between reefs in Upper Mobile Bay and those in Lower Mobile Bay and Mississippi Sound. To restore the productivity of this reef, the bottom would have to be elevated above the hypoxic/anoxic zone for any chance of oyster survival. Alabama MRD is currently performing small scale cultch mounding studies on a portion of Whitehouse Reef (Denton fishing reef) to determine how far above the bottom the cultch must be elevated for oyster survival and growth. Along with the mounding studies, Alabama MRD will conduct studies in which cultch is planted in slightly elevated elongate rows to determine if siltation can be reduced to allow oysters to survive and grow in these areas. These studies are described in detail above, in section 4.1.3, *Reef Configuration Studies.*

Utilizing hatchery-reared oyster spat-on-shell at selected restoration sites has been shown to be beneficial to jump start oyster productivity (Callam and Supan 2018). The purpose of remote setting is to increase the probability of survival of individual oysters past the earliest life stages, from free swimming larvae, to settling, and metamorphosis into spat. These spat covered shell can then be deployed strategically at restoration sites to enhance productivity. Availability of hatchery reared spat-on-shell oysters is often a limiting factor in Alabama MRD's ability to implement this technique. Construction of the oyster hatchery at the Claude Peteet Mariculture Center is expected to increase Alabama MRD's capacity to deploy remote set spat-on-shell oysters to enhance oyster restoration, as described above in section 4.2.4, *Oyster Hatchery at the Claude Peteet Mariculture Center*.

4.4 SUMMARY OF KEY POINTS: RESTORATION EFFORTS TO DATE

- Alabama MRD has conducted oyster monitoring seasonally since 1976, providing important baseline data to assess oyster productivity, determine restoration needs, and evaluate restoration success.
- Data gathering activities including substrate mapping, reef configuration studies, experimental deployment of remote set oysters, and ongoing review of scientific literature has informed restoration strategies and techniques.
- Alabama MRD has engaged in oyster reef restoration, enhancement, and reef creation activities since the early 1970s, with past efforts consisting mostly of cultch planting and relayed oysters.
- Alabama's oyster populations have not returned to historic levels despite continuous restoration efforts.
- The lack of oyster restoration success in Alabama appears to be a result of low survival among early life stages because of environmental factors such as temperature, salinity, DO, and predation by oyster drills.
- Alabama MRD is exploring techniques to supplement cultch planting, including strategic placement of source reefs, restoring nearshore and intertidal reefs, and deploying hatchery-raised remote set oysters, to enhance oyster productivity and restore sustainable reef systems.
- By constructing a new oyster hatchery in Gulf Shores and enhancing its existing facility at Dauphin Island, Alabama MRD will increase its capacity to produce spat-on-shell oysters, which will be used to supplement and encourage oyster recruitment in currently and historically productive portions of Mobile Bay.
- Strategic restoration of oyster reefs along a gradient of environmental conditions would allow for a more resilient oyster population, capable of withstanding changing environmental conditions.

5.0 OYSTER RESTORATION GOALS AND IMPLEMENTATION STRATEGY

5.1 RESTORATION GOAL

As noted at the beginning of this document, the purpose of this comprehensive oyster restoration strategy is to provide a road map for oyster restoration in Alabama in support of the restoration goals identified the PDARP/PEIS (DWH NRDA Trustees 2016) and the Strategic Framework for Oyster Restoration Activities (DWH NRDA Trustees 2017) and to support implementation of restoration projects via other funding sources, described in more detail in Appendix A – Potential Funding Sources for Future Oyster Restoration and Research. More specifically, the overarching goal of this comprehensive oyster restoration strategy document is to:

Create new reefs and restore, replenish, or enhance existing reefs to improve connectivity and establish a network of intertidal and subtidal oyster resources in Coastal Alabama that, collectively, are more resilient against variability in environmental conditions and other factors to support sustainable harvest and provide ecosystem services now and into the future.

5.2 APPROACH TO RESTORATION

Alabama's managers approach restoration by considering the major drivers and stressors affecting oysters, ecosystem response to those drivers and stressors, and the resulting effects on oysters. Managers then consider specific restoration actions to address adverse effects of drivers and stressors on oysters. The suite of potential restoration actions to be considered is described in the following sections and summarized in Table 2.

Restoration actions that would be considered to align, and in some cases, supplement the restoration techniques identified in the Strategic Framework for Oyster Restoration Activities (DWH NRDA Trustees 2017) to achieve the restoration goals identified in the PDARP/PEIS (DWH NRDA Trustees 2016). Many of these techniques have been or are currently being implemented in Alabama, as described in section 4.0, *Restoration Efforts to Date*. Restoration techniques identified in the Strategic Framework for Oyster Restoration Activities are as follows:

- **Technique 1:** Restore or create oyster reefs through placement of cultch in nearshore and subtidal areas.
- **Technique 2:** Construct living shorelines.
- **Technique 3:** Enhance oyster reef productivity through spawning stock enhancement projects such as planting hatchery-raised oysters, relocating wild oysters to restoration sites (relaying), oyster gardening programs, and other similar projects.
- **Technique 4:** Develop a network of oyster reef spawning reserves.

Managers will select the most appropriate techniques and specific restoration actions based on site conditions, current and anticipated future environmental conditions, resource availability and funding considerations, and desired outcomes to meet restoration goals. A conceptual model helps illustrate how restoration actions may alter drivers and/or existing conditions, and how the resulting changes may affect oysters (Figure 12).

The restoration actions proposed in this strategy document are at various stages of development and are intended to guide restoration efforts in a comprehensive manner to achieve the overarching restoration goal. Details such as specific project costs, design parameters, timelines, and durations are not estimated in this strategy document but would be determined as individual restoration actions reach further stages of development and move toward possible implementation. Costs of individual restoration actions will be dependent upon various factors, many of which are beyond the control of Alabama MRD. Factors may include project scope and scale, the types of materials selected, equipment required, availability of materials and labor, and project timing and duration. Similarly, project timing and duration may be affected by various factors including availability of funding and cost and availability of materials and labor.

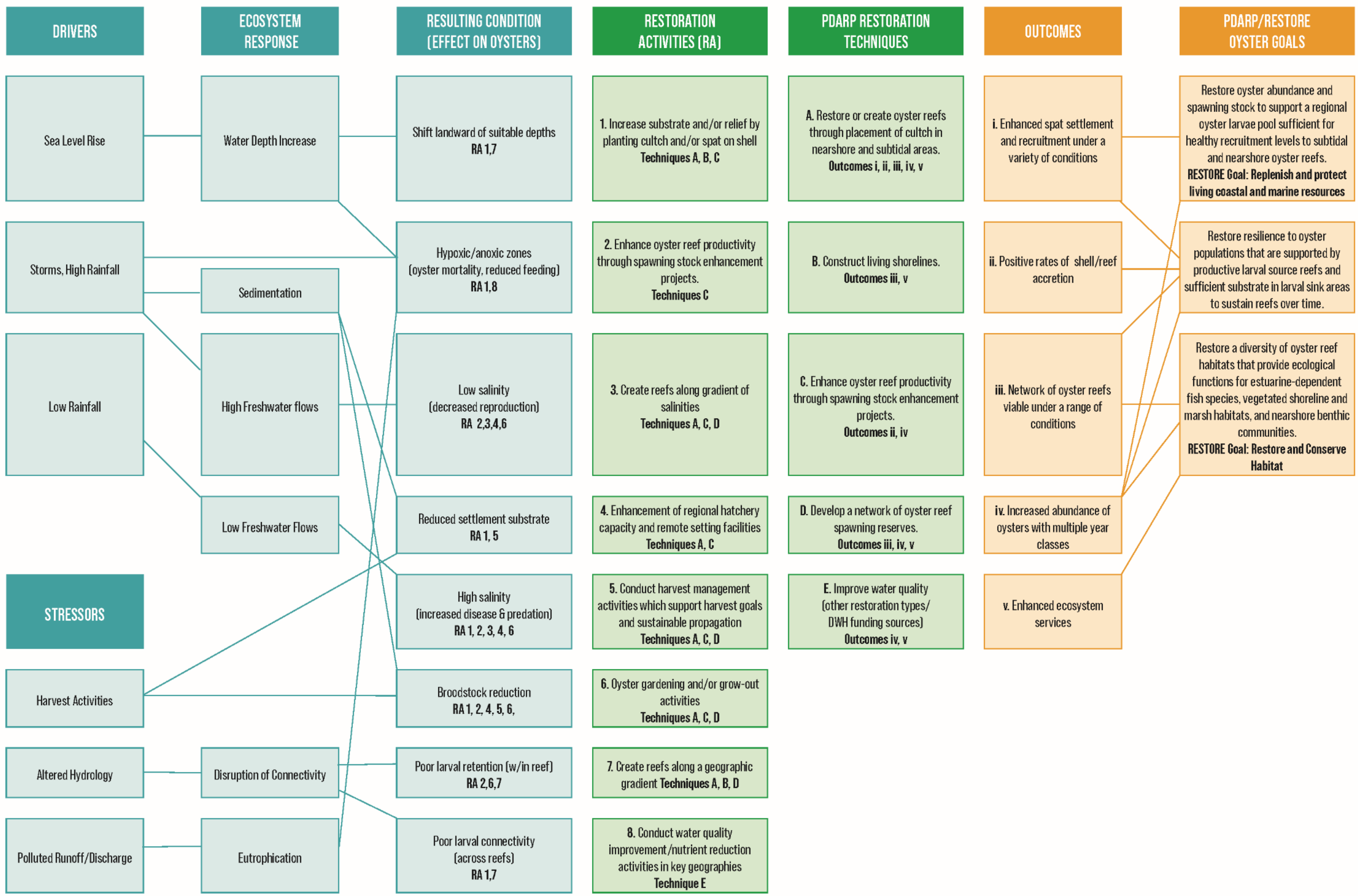

Figure 12. Conceptual Model for Comprehensive Oyster Restoration in Alabama

5.3 RESTORATION NEEDS AND IMPLEMENTATION STRATEGY

To achieve the overarching goal of this restoration strategy, managers and restoration planners must: (1) be able to identify optimal sites for placement of new reefs with consideration of changing environmental conditions; (2) continue to support existing reefs, enhancing connectivity within the larger network of reefs; and (3) understand how existing and potential future reefs would be connected by larval transport within the network. The following sections describe these needs and propose specific actions that can be implemented to achieve the overarching goal of this restoration strategy.

5.3.1 Identify Suitable Locations for New Reefs

Identification of potential sites for construction of new oyster reefs must be based a suite of suitable conditions including substrate type and quantity, proximity to existing oyster resources including intertidal reef areas, water quality, and larval supply (based on both proximity to existing oyster resources and flow regime). Regulatory considerations must also be taken into account when identifying suitable locations for new reefs. For instance, because construction of new reef in waters closed to shellfish harvest is not currently encouraged, potential restoration sites outside of areas conditionally approved for shellfish harvest by the Alabama Department of Public Health (ADPH) will need to take into account additional factors prior to reef construction. Restoration planners must also consider changing environmental conditions to facilitate long-term success and resiliency. Alabama MRD would consider the following actions to identify optimal locations for new oyster reefs.

5.3.1.1 Identify Areas with Potentially Suitable Substrates for Future Oyster Reefs

Side-scan sonar surveys in Mobile Bay, as described in in section 4.1.2, *Substrate Mapping and Characterization*, will help locate existing and relic subtidal oyster resources and identify areas with suitable substrate for potential oyster restoration, including construction of new reefs. These surveys are ongoing and are expected to continue through Spring 2022. Based on the findings of the side-scan surveys, additional areas may be surveyed in the future. Future areas that may be identified for side-scan surveys could include sites along the eastern shore, such as Perdido Bay, Wolf Bay, and Oyster Bay, or sites outside areas that are conditionally approved for shellfish harvest.

Upon completion of side-scan surveys, ground truthing is needed to confirm the findings and more precisely identify areas with suitable substrate for oysters. Ground truthing would be conducted using hand dredge surveys to determine if live oysters are present at relic reef sites or other locations where suitable substrates are identified. Ground truthing surveys can be conducted in a piecemeal fashion and can begin as soon as individual areas have been scanned. Ground truthing surveys have been completed at several locations along the western shore of Mobile Bay. The results of the ongoing substrate mapping surveys will be used to prioritize potential restoration sites based on substrate suitability. Alabama MRD has identified ongoing substrate mapping as a high priority restoration need.

5.3.1.2 Identify and Survey Existing Intertidal Reef Areas

While side-scan surveys will provide information about the locations of existing and relic subtidal oyster reefs, little is known about intertidal oyster resources in Mobile Bay. In addition to providing potentially suitable habitats for oyster restoration, existing intertidal reefs may contribute significantly to the larval supply in Mobile Bay. Therefore, surveying existing oyster resources in Alabama's intertidal waters would provide important data for management of existing oyster resources and long-term restoration planning. Because Alabama MRD does not routinely monitor intertidal oyster reefs, there is not an existing survey protocol. Therefore, a survey methodology would be developed prior to surveying intertidal oyster resources. This could consist of analysis of aerial imagery, LIDAR, or other techniques. Remote sampling techniques would likely require secondary ground-truthing surveys to validate findings.

Alabama MRD considers identification of existing intertidal oyster resources to be a high priority restoration need.

5.3.1.3 Monitor Water Quality at Potential Future Reef Locations

Site-specific water quality data is limited at many sites in Alabama. Much of the available water quality data is limited in temporal scale, in terms of both time series length and temporal resolution and may not be adequately representative of current conditions at a given site throughout the year. Continuous monitoring data for select sites is available through Alabama's Real-time Coastal Observing System (ARCOS) as well as NOAA's National Data Buoy Center. While these sources provide useful data for general purposes, many of the buoys are located in open water areas that would not necessarily be useful for oyster restoration. Additionally, the buoys mainly collect surface data which may not reflect conditions in the benthic zone where oysters occur.

Although Alabama MRD routinely monitors water quality on some existing reefs, additional water quality monitoring is needed and should focus on sites identified as high priority restoration areas based on the results of substrate mapping surveys (discussed in section 4.1.2, *Substrate Mapping and Characterization*). Monitoring water quality in areas where suitable substrates are present would help to identify and prioritize other potentially suitable sites for future oyster restoration activities including construction of new reefs. Conversely, identifying areas with suitable water quality may also inform future decisions regarding placement of new substrate materials. Parameters to be monitored should include, at a minimum: DO, salinity, temperature, and pH. These parameters are most often limiting factors for oyster survival or reef success in Alabama.

Priority sites for future water quality monitoring along the western shore of Mobile Bay include West Fowl River, Mississippi Sound, and potentially Upper Mobile Bay if suitable substrates are identified during substrate mapping surveys. Priority monitoring sites along the eastern shore include the Daphne and Fairhope areas, along with Perdido Bay. Alabama MRD considers water quality monitoring at potential future reef locations to be a high priority restoration need.

5.3.1.4 Assess Potential Water Quality Improvement Activities at High Priority Restoration Sites (Non-Oyster funds)

Oyster restoration efforts may benefit indirectly from water quality improvement projects that have been or may be implemented through restoration funding streams that do not specifically target oyster restoration and recovery. These may include other DWH funding sources such as RESTORE and NFWF GEBF. Various water quality improvement projects funded through RESTORE Buckets 1 and 3 have been implemented in Alabama in recent years. Identifying areas where water quality is a limiting factor for oyster survival and success could be considered in funding decisions for future water quality improvement projects that may be funded through RESTORE Bucket 2 or other non-oyster-specific funding mechanisms, where oyster recovery may be a secondary benefit. Assessment and support of potential water quality improvement projects funded though other sources could include collaboration with municipalities or other state or federal agencies. Assessing water quality improvement activities from other funding sources that may indirectly benefit oyster restoration at high priority sites is dependent on completion of substrate mapping and identification of existing intertidal reef areas. Alabama MRD has identified assessment of potential water quality improvement activities through non-oyster funding sources as a high priority restoration activity.

5.3.1.5 Expand Knowledge of Larval Supply

Larval supply is a key consideration for siting new reefs to increase the likelihood they will be self-sustaining from a recruitment perspective and have adequate connectivity to function within the network of reefs that Alabama MRD seeks to establish. New reefs must be placed in areas with sufficient connectivity to source reefs that can supply larvae and net velocity must be such that larvae are able to settle on the new reef before being transported out of the area. Site-specific recruitment can be assessed using spat settlement plates and flow can be measured using *in situ* flow meters. However, a better understanding of flow dynamics and larval transport throughout the targeted system at large (e.g., Mobile Bay, Mississippi Sound, Bon Secour Bay) would be beneficial for initial site screening and long-term restoration planning purposes. Efforts to expand the current state of knowledge regarding flow dynamics and larval transport in Alabama's coastal and estuarine systems could include modelling studies. These activities are described below in section 5.3.3, *Enhance Understanding of Connectivity Among Existing and Potential Future Oyster Reefs*.

5.3.1.6 Develop Climate Change/Future Conditions Model

Identification and prioritization of sites for future oyster restoration must also consider how climate change and other changing environmental conditions are likely to affect site suitability over the long term. As described in section 3.0, *Overview of Potential Future Environmental Trends*, changing environmental conditions, many of which are associated with climate change, are likely to affect habitat suitability for oysters at some sites. As previously noted, various models have attempted to characterize anticipated environmental changes and predict potential ecosystem responses (Christensen et al. 2007, Biasutti et al. 2012, IPCC 2018). However, more precise modelling is needed to assess how future changes may affect oysters in Alabama.

Currently, Alabama MRD is working with scientists from the University of South Alabama and Dauphin Island Sea Lab to develop a model that is specific to Mobile Bay. The initial model is expected to include considerations such as sea level rise, weather and precipitation patterns, salinity, and other critical metrics for oyster habitat suitability. Upon completion of this effort, additional refinements, further development, or additional data collection may be needed to develop a final model that is suitable for restoration planning purposes. The final model will enhance the predictive capacity for how oysters may respond to changing conditions in specific locations, including existing oyster reefs and potential future restoration sites, across habitat and salinity gradients. Being able to better anticipate changing conditions will allow restoration planners to select sites and methods that are likely to be successful over the long term and ultimately establish a network of reefs that are more likely to be resilient to changing environmental conditions. Alabama MRD has identified completion of the initial model and potential further development to create a final climate change/future conditions model for Mobile Bay as a medium priority restoration need.

5.3.2 Provide Continued Support for Existing Reefs

Continued support for existing oyster reefs in Alabama is critical to the overall success of future oyster restoration efforts. Supporting and enhancing existing reefs will help to maintain their connectivity within the larger network of reefs that Alabama MRD seeks to establish. Alabama MRD would consider the following actions to support and enhance existing oyster reefs:

5.3.2.1 Restore and Replenish Existing Reefs Through Cultch Planting, Oyster Relay, and Spat Deployment

Alabama MRD has supported existing oyster reefs through restoration and enhancement activities, consisting mostly of cultch planting and to a lesser extent placement of relayed oysters, since the early 1970's, as described in section 4.2, *Restoration Implementation,* and detailed in Alabama's Oyster Management Plan (Alabama MRD 2016). In recent years, Alabama MRD has also deployed spat-on-shell to help increase and enhance the oyster density and larval recruitment on existing reefs. As discussed in section 4.3, *Restoration Success and Lessons Learned*, Alabama's oyster populations have not returned to historic levels despite described restoration efforts, prompting Alabama MRD to explore other supplemental techniques to maximize restoration success. Although it has become clear that cultch planting and oyster relaying alone are not sufficient to meet Alabama's restoration needs, it is still critically important to continue to support existing reefs, as they will play a vital role within the network of reefs that Alabama seeks to create.

Priority areas for replenishment along the western shore of Mobile Bay include Cedar Point and Heron Bay reefs. These reefs were last replenished in 2016 and both sites experience relatively heavy harvest pressure. Restoration techniques to be implemented at Cedar Point and Heron Bay could include cultch planting or spat deployment. The acreage and thickness of cultch would be determined based on results of dive surveys, with a focus on areas that are most heavily harvested. Alabama MRD considers enhancement of existing reefs at Cedar Point and Heron Bay to be a high priority restoration need.

Existing reef areas along Mobile Bay's eastern shore that have been identified for restoration or replenishment include Grey Kane (located on Klondike historic reef), Point Clear, Bayou Cour, Weeks Bay, and Oyster Bay. Grey Kane and Point Clear reefs are medium to low priority restoration sites, while Bayou Cour, Weeks Bay, and Oyster Bay are low priority sites in comparison to other reefs.

5.3.2.2 Conduct Additional Water Quality Monitoring at Existing Reef Areas

Alabama MRD routinely collects data at seven existing reef locations but currently only has the capacity to monitor up to five sites at one time. Data sondes must be relocated among sites periodically, so continuous monitoring of all sites is not possible at present. Enhancing Alabama MRD's capacity to conduct water quality monitoring including continuous monitoring at existing sites and increasing the number of sites monitored would provide valuable information about current conditions on Alabama's oyster reefs and inform adaptive management decisions if corrective actions are needed to meet restoration performance goals.

Additional water quality monitoring should also be conducted at existing reef areas in waters that are not currently approved by ADPH for shellfish harvest. Currently, monitoring is limited to conditionally approved shellfish waters, due in part to resource limitation (equipment, staff, budget, etc.). Enhancing Alabama MRD's capacity to monitor water quality could help alleviate nuisance concerns for reefs outside conditionally approved waters and potentially facilitate the opening of new areas for future restoration and enhancement efforts including construction of new reefs in the future. Additional discussion about this issue can be found below in section 5.4.1, *Ability to Locate New Reefs in Areas Where Needed to Achieve Outcome*. Alabama MRD has identified additional/continuous water quality monitoring at existing reef areas as a high priority restoration need.

5.3.2.3 Conduct Additional Harvest Management Activities

Alabama MRD facilitates the sustainable management of existing oyster reefs through harvest management activities that incorporate the principles of shell budgeting, supporting both harvest activities and the realization of restoration goals. Alabama MRD sets its annual oyster harvest goal based on dive surveys conducted each year. Data collected during dive surveys combined with harvest reporting data allows managers to estimate how many oysters can be harvested and from which locations. This information is used to make management decisions such as when to open or close specific reefs areas to harvest, or how much cultch to deploy. Alabama MRD incorporates the principles of shell budgeting, described in Soniat et al. (2012) in its harvest management strategy, and also provides data collected to researchers working to develop a shell budget model to assess oyster populations and management strategies across the region (Soniat et al. 2012). Additional detail about Alabama's current harvest management strategy can be found in the 2016 Alabama Oyster Management Plan (Alabama MRD 2016).

The collection of more refined data is needed to optimize Alabama MRD's harvest management strategy and facilitate harvest management on a finer scale. There is some inherent error associated with current estimates because sampling data must be extrapolated to represent entire populations. Because oyster distribution tends to be patchy, it is difficult to obtain an accurate estimate based on limited sampling data extrapolated across a larger area. Similarly, there is likely error associated with location data because it is reported by oyster harvesters and cannot be easily verified. Alabama MRD's harvest management strategy could be improved by increasing sample size, having a more random spacing of sample locations, and improving the accuracy of location reporting data. The use of patent tongs for sampling can help randomize sampling compared using quadrats. Alabama MRD recently created a new grid system for reporting to help identify harvest locations. Future refinements to this system will improve the accuracy of reporting, providing managers with a more reliable estimate of where harvest is occurring. Alabama MRD has identified additional harvest management activities, including additional data collection and refinement of collection methods, as a medium priority restoration need.

5.3.3 Enhance Understanding of Connectivity Among Existing and Potential Future Oyster Reefs

Understanding reef connectivity in terms of larval supply, transport, sources, and sinks is essential for developing a sustainable and resilient network of oyster reefs in Alabama. As noted above, adequate larval supply is a key consideration for siting new reefs. Understanding larval supply and flow dynamics is also beneficial for identifying and prioritizing restoration and enhancement needs (e.g., cultch planting) at existing reef areas. Although some preliminary studies have been conducted to better understand larval transport in Mobile Bay, as described in 4.1.2, *Substrate Mapping and Characterization*, significant knowledge gaps remain. Alabama MRD would consider the following actions to gain a more robust understanding of reef connectivity.

5.3.3.1 Develop System-wide Flow Model

Flow modelling is a necessary first step to understanding larval transport and reef connectivity. The appropriate study should model flow dynamics throughout the entire Mobile Bay system. This would help determine if connectivity between reef areas on the western and eastern shores could exist under present conditions. The natural flow dynamics of Alabama's coastal systems have been altered by centuries of human activity and development including construction and maintenance of the Mobile Ship Channel which spans Mobile Bay north-to-south, the Gulf Intracoastal Waterway, and the Port of Mobile. Modelling studies should also include Mississippi Sound and Bon Secour Bay at the system level.

Expanding the existing knowledge of flow dynamics in Alabama's coastal and estuarine systems would contribute to the understanding of connectivity among existing oyster reefs and help identify actions that could be implemented to enhance connectivity. Ultimately, results of flow modelling studies would serve as inputs to larval transport models described below. Alabama MRD has identified flow modelling studies as a high priority restoration need.

5.3.3.2 Develop Larval Transport Model

The current understanding of larval transport dynamics in the Mobile Bay system is limited. As noted in section 4.1.2, *Substrate Mapping and Characterization*, previous larval transport modelling and recruitment studies have shown that larvae tend to be transported from north to south in Mobile Bay with limited or no connectivity between populations along Mobile Bay's eastern and western shores (Kim et al. 2013, Kim et al. 2010, Powers et al. 2009). Additional larval transport modelling is needed to better understand larval sources and sinks, how larvae are transported, and how larval transport may be affected by environmental conditions and anthropogenic factors including the Mobile Ship Channel. Better understanding these processes will benefit restoration efforts aimed at increasing larval production, improving recruitment success, and enhancing connectivity among oyster populations. As noted above, larval supply is a key consideration for siting new oyster reefs.

Future larval transport modelling studies could build on existing data from previous studies (Kim et al. (2013, 2010). These studies were limited to mid- and Lower Mobile Bay, where most of Alabama's harvestable reefs are located. Additional studies should include Upper Mobile Bay, Mississippi Sound, and Bon Secour Bay. Additional modelling studies should also include intertidal areas. As noted above under section 5.3.1.2, *Identify and Survey Existing Intertidal Reef Areas*, the contribution of larvae from intertidal oysters, especially in upper Mobile Bay and its tributaries, is largely unknown but could be significant.

Developing a better understanding of larval transport throughout Alabama's coastal and estuarine systems will benefit restoration planning for enhancing existing reefs, constructing new reefs, and improving connectivity among existing and potential future reefs to facilitate a network of reefs that would improve the sustainability and resiliency of Alabama's oyster resources over the long term. Alabama MRD has identified larval transport modelling studies as a high priority restoration need.

5.4 FACTORS INFLUENCING THE LIKELIHOOD OF SUCCESS

The success of the restoration strategy outlined above will be influenced by many factors. Some of the main factors that could influence restoration success include managers' abilities to locate new reefs in desired locations, support from stakeholders and the general public, and the ability to adapt to changing environmental and social conditions. The following sections briefly describe these factors and propose specific actions to address each.

5.4.1 Ability to Locate New Reefs in Areas Where Needed to Achieve Outcome

The likelihood of success for a comprehensive oyster restoration strategy is influenced by various factors, including Alabama MRD's ability to locate new reefs in strategic areas based on the factors described above, which could include areas that are not currently approved for shellfish harvest. Barriers posed by existing policy, jurisdictional conflicts among agencies, and limitation of resources (e.g., monitoring and/or enforcement funding) could prevent Alabama MRD from placing new reefs in some strategic areas that could be key to optimizing restoration success. Alabama MRD would consider the following actions to expand its ability to locate new reefs at preferred strategic locations.

5.4.1.1 Develop Coordination Strategy for Engaging Other Agencies and Partners

The closure of certain areas to harvest due to public health concerns is a potential barrier to Alabama MRD's ability to establish a network of reefs across a gradient of environmental conditions. Currently, enhancement of existing reefs and construction of new reefs in closed waters is not encouraged by the ADPH because there is a concern that illegal harvest could result in oysters that may not be safe for consumption entering the market undetected, creating a risk to public health. There are concerns that enhancing oyster resources or constructing new reefs in closed waters could create an "attractive nuisance" for both public health and law enforcement agencies. This is compounded by concerns about the capacity of enforcement to adequately enforce regulations to prevent illegal harvest with the resources currently available.

Alabama MRD seeks to develop a strategy to collaborate with ADPH to identify ways to mitigate public health risks and nuisance concerns while working toward the overarching goal set of this comprehensive oyster restoration strategy. Alabama MRD seeks to engage with both ADPH and law enforcement to better understand sampling and enforcement capabilities, limitations, and needs, including the need for long-term funding, with the eventual goal of expanding Alabama MRD's ability to locate new reefs where needed to achieve create a resilient and sustainable network of reefs.

Potential approaches to addressing concerns could include conducting additional water quality monitoring, increased sampling capacity, and/or increased enforcement. Currently, Alabama MRD's Enforcement Section is responsible for conducting routine enforcement patrols in shellfish areas. Alabama MRD Enforcement follows a patrol protocol as adopted from NSSP (Appendix B). The ADPH conducts routine monthly sampling of Conditionally Approved waters and additional sampling to determine when harvesting areas can be reopened following closures. The ADPH may also provide information or guidance to marine law enforcement if illegal activities are suspected.

Incorporating newer technologies could benefit enforcement efforts over the long term. Pole-mounted cameras with night vision or heat sensing capabilities are currently used at several public boat launches and other locations in Alabama to aid enforcement efforts. These or similar technologies could be a useful tool in enforcing harvest on closed or restricted oyster reefs. Long-term funding for both ADPH sampling efforts and marine law enforcement would likely be needed to support any potential expansion of open waters that may occur in the future.

Alabama MRD has identified initial discussions between ADPH and Alabama MRD enforcement as a high priority need. Based on those initial discussions, potential future data sharing, management recommendations, policy changes, and funding efforts are a medium priority over the long term.

5.4.1.2 Determine Restoration Site Suitability

To identify the most strategic locations for conducting restoration activities, including construction of new oyster reefs, Alabama MRD would develop a methodology for evaluating site suitability. Potentially suitable sites for restoration activities would be evaluated based on the attributes described above including substrate type, water quality, larval supply, and connectivity to existing reefs. Alabama MRD would use existing data summarized in this document along with additional data from proposed activities including additional water quality monitoring, outputs from the proposed climate change/future conditions model, and results from the proposed larval transport model. Data from these proposed activities would be incorporated as they become available. Alabama's restoration site suitability determination would also consider other factors such as site-specific harvest pressure, harvesting restrictions other regulatory factors, and previous agency experience and knowledge. The purpose of the restoration site suitability determination is to develop a tool for evaluating the overall suitability of potential restoration sites based on multiple quantitative and qualitative factors. Alabama MRD managers would incorporate the output of this tool into the decision-making process along with other considerations to select the final sites for restoration activities. Alabama MRD has identified developing a methodology for determining site suitability as a high priority restoration need.

5.4.2 Support from Stakeholders and General Public

Successful implementation of this oyster restoration strategy is partly dependent on support from various stakeholder groups and the general public. Alabama MRD hopes that through public outreach and education there will be increased awareness of the long-term benefits, both ecological and economic, of enhancing Alabama's oyster population as a whole. Public outreach should be conducted to inform stakeholders and the public about the state of Alabama's past and present oyster resources, restoration needs, and strategies to address those needs as outlined in this strategy document. Public outreach efforts should also aim to inform the general public about the ecological function and importance of oysters and the benefits of oyster restoration. Finally, public outreach efforts should provide opportunities for stakeholders and the public to actively support oyster restoration efforts through collaboration. Overall, public outreach efforts should demonstrate the need for oyster restoration, promote government transparency by demonstrating how Alabama will work on behalf of the public to restore this vital resource, and offer opportunities for public engagement. Alabama MRD would consider the following actions to solicit the support of stakeholders and the general public.

5.4.2.1 Release Coastal Alabama Comprehensive Oyster Restoration Strategy and Conduct Stakeholder Engagement Activities

Alabama MRD plans to conduct a series of meetings with stakeholders, including but not limited to commercial oyster harvesters, non-governmental organizations (NGOs) and conservation groups, and municipal and county governments, to explain the proposed strategy and comprehensive approach to oyster restoration described in this document. Because these various stakeholders play an important role in the conservation of this resource and are directly affected by management decisions, it is important to engage with them early in the process to promote transparency and facilitate mutual understanding. By reaching out directly to these stakeholders, Alabama MRD hopes to enhance the understanding of the elements required to achieve successful restoration of oysters and gain their support. Engaging directly with key stakeholders will also provide an opportunity for members to ask questions or voice concerns directly to managers and decision makers.

In conjunction with stakeholder meetings, Alabama MRD plans to develop outreach materials, such as a printed handout providing information about oyster restoration in Alabama. The handout would provide general information about oyster ecology and the importance of restoration, summarize Alabama's proposed comprehensive oyster restoration strategy, and provide information about NRDA including its purpose and eligible uses for restoration funding. Alabama MRD has identified the release of this Coastal Alabama Comprehensive Oyster Restoration Strategy and associated stakeholder engagement activities as high priority restoration needs.

5.4.2.2 Create and Distribute an Educational Video About Oyster Ecology and Restoration

Alabama MRD would make available to the public an educational short video aimed at promoting awareness of oyster ecology including ecosystem services provided by oysters and the importance of restoration. The goal of this effort is to encourage public support for oyster restoration and promote environmental awareness and stewardship through educational outreach. The educational video may be produced and/or distributed in collaboration with partner organizations such as Alabama-Mississippi Sea Grant. Alabama MRD has identified creating and distributing an educational video about oyster ecology and restoration as a low priority restoration need.

5.4.2.3 Explore Public-Private Partnerships and Opportunities for Collaboration

In addition to directly implementing oyster restoration projects, Alabama MRD would continue to explore opportunities for public-private partnerships. Alabama MRD has collaborated with public and private partners including outside agencies, NGOs, universities and educational institutions, and others to carry out projects that have benefited oyster restoration in Alabama. Examples of past public-private partnerships include the Nature Conservancy's 100-1000: Restore Coastal Alabama living shoreline project, the Alabama Oyster Gardening Program, and the Alabama Oyster Shell Recycling Program. More information about these activities can be found in section 4.2.5, *Other Restoration Efforts*. Other types of public-private partnerships that Alabama MRD may consider in the future include privately funded oyster farms or hatcheries. Alabama MRD has identified exploring partnership and collaboration opportunities as a high priority restoration need.

5.4.3 Ability to Adapt to Changing Conditions

One of the most important factors affecting long-term oyster restoration success and population resiliency is the ability to adapt to changing conditions. This includes changing environmental and ecosystem conditions, changes in the availability of funding and other resources, changing social and political climate, and changes in anthropogenic stressors that are often driven by markets and other socioeconomic factors. The resiliency of Alabama's oyster resources and the success of this comprehensive oyster restoration strategy will be determined by the ability to adapt to these changes.

Some of the proposed restoration activities described above, such as the proposed climate change/future conditions model and restoration site suitability determination process, will provide tools that managers need to anticipate changes, plan projects accordingly, and develop strategies to adapt quickly if corrective actions are needed. Alabama MRD would consider the following actions to enhance its ability to adapt to changing environmental and social conditions.

5.4.3.1 Implement Monitoring and Adaptive Management

Monitoring and Adaptive Management (MAM) will be conducted for all on-the-ground restoration activities (e.g., construction of new reefs, replenishment/enhancement of existing reefs, etc.). This generally consists of monitoring key parameters to reduce uncertainty and evaluate the effectiveness of the restorative action to determine if corrective action is needed to achieve restoration goals and project performance objectives. The types of parameters to be monitored, criteria for determining when to implement corrective actions, and the types of corrective actions that may be implemented are specific to each project.

Restoration projects funded through DWH NRDA are required to have a MAM plan. MAM plans are living documents that identify monitoring activities that will be conducted to evaluate and document restoration effectiveness, including performance criteria for determining restoration success or need for interim corrective action (15 Code of Federal Regulations [CFR] 990.55(b)(1)(vii)). Where applicable, the MAM plan identifies key sources of uncertainty and incorporates monitoring data and decision points that address these uncertainties. It also establishes a decision-making process for adjusting the plan where needed.

DWH NRDA MAM plans have three primary purposes:

- Identify and document how restoration managers will measure and track progress towards achieving restoration goals and objectives.
- Increase the likelihood of successful implementation through identification, before a project begins, of potential corrective actions that could be undertaken if a project does not proceed as expected.
- In a systematic way, capture lessons learned or new information acquired that can be incorporated into future project selection, design, and implementation.

Although restoration actions that are implemented through other funding sources do not require MAM plans, Alabama MRD would take a similar approach to track progress and maximize the success of each action. Monitoring and adaptive management principles would be incorporated into all the restoration activities proposed in this document beginning early in the planning process. In addition to project-specific monitoring data, data that would be collected under the actions described above including water quality monitoring, larval transport modelling, and climate change/future conditions modelling would help managers identify the most appropriate corrective actions, if needed.

While MAM traditionally focuses on adapting to environmental conditions, the ability to adapt to less-tangible factors like changes in the availability of funding and other resources or changes in policy or regulation are equally important for long-term success. Managers can prepare for and adapt to these changes by continuously exploring alternative or supplemental funding streams and pursuing potential partnerships and collaborations with external parties. An important component of MAM for Alabama's

Comprehensive Oyster Restoration Strategy as whole, will be periodic review and update of this document as needed to achieve the overarching restoration goal, as described below in section 5.4.3.3, *Review/Update Coastal Alabama Comprehensive Oyster Restoration Strategy.* Alabama MRD has identified monitoring and adaptive management as a high priority restoration need.

5.4.3.2 Expand Monitoring/Sampling Program

In addition to monitoring new restoration projects, Alabama MRD would build on its existing oyster monitoring/sampling program. As noted in section 4.1.1, *Ongoing Oyster Monitoring*, and detailed in Alabama's 2016 Oyster Management Plan, Alabama MRD regularly monitors existing oyster resources using a variety of techniques (Alabama MRD 2016). Alabama MRD would continue to conduct routine oyster monitoring and expand these efforts in terms of sampling frequency and geographic extent as funding and other resources become available. Enhancing Alabama MRD's monitoring capacity will improve managers' abilities to adapt to changing conditions by providing a robust baseline dataset from which changes can be more easily detected. Alabama MRD has identified expanding its monitoring/sampling program as a high priority restoration need.

5.4.3.3 Review/Update Coastal Alabama Comprehensive Oyster Restoration Strategy

Alabama MRD will also maximize its ability to adapt to changing conditions by reviewing and updating this Coastal Alabama Comprehensive Oyster Restoration Strategy document periodically. This strategy is intended to be a living document that evolves over time as environmental conditions change, restoration actions described herein are implemented, monitoring data are collected, and as new information becomes available. Making regular updates to this document will provide managers with an up-to-date framework to guide restoration efforts to accomplish the overarching goal of this restoration strategy. Alabama MRD has identified periodic review and update of the Coastal Alabama Comprehensive Oyster Restoration Strategy as a high priority restoration need.

5.5 ESTABLISHING A NETWORK OF OYSTER REEFS

Establishing a network of oyster reefs throughout Alabama's coastal waters will ultimately require constructing new reefs and living shorelines that can contribute to larval supply and that range across suitable habitat types and span a gradient of suitable salinities. Constructing new oyster reefs in strategic locations will enhance larval supply, improve connectivity, and increase the resiliency of Alabama's oyster population. The following sections describe key considerations for establishing a network of oyster reefs to achieve the overarching goal of this restoration strategy. Alabama MRD has identified constructing a network of oyster reefs across a gradient of environmental conditions as a high priority restoration need.

5.5.1 Resiliency

As noted in section 4.3, *Restoration Success and Lessons Learned*, strategic restoration of oyster reefs along a gradient of environmental conditions will enhance resiliency by better enabling Alabama's oyster population, as a whole, to withstand changing environmental conditions and stressors. Constructing new reefs across a gradient of environmental conditions will improve the chances of population recovery even if a portion of the population is adversely affected by stressors associated with changing environmental conditions (e.g., salinity, temperature, dissolved oxygen, predation, etc.). Resiliency would increase commensurate with the size of the reef network because new reefs would increase larval supply in the system and enhance connectivity among new and existing reefs, increasing the probability of recruitment success and population recovery if certain reefs or areas experience substantial mortality. To maximize population resiliency, new reefs should be constructed across the broadest feasible range of habitat types, salinities, and geographic locations while considering connectivity via larval transport.

5.5.2 Site selection

Strategic site selection will increase the likelihood that new oyster reefs will not only survive but will achieve the desired outcome of enhancing larval supply and improving larval connectivity among reefs. Sites for new oyster reefs will be selected based on many factors including suitable substrate (as determined by ongoing substrate mapping efforts), acceptable water quality, adequate larval supply, and proximity/connectivity to other oyster resources, as describe above under section 5.4.1.2, *Determine Restoration Site Suitability.* Site selection would also incorporate data from the proposed climate change/future conditions and larval transport models when they become available. Site selection for future reefs will incorporate the best available data to work toward the overarching goal of this restoration strategy document.

Results of the oyster grow-out study, described in section 4.1.5, *Oyster Grow-Out and Restoration Reef Placement Study*, will also provide useful data for identifying optimal sites for placement of new reefs and living shorelines. This project is currently in progress. Data collected during the monitoring phase of this study will provide insight about oyster survival and survival and reproduction at select sites in Grand Bay, Portersville Bay, and Bon Secour Bay.

5.5.3 Design and construction

Along with appropriate site selection, identifying the most appropriate methods for design and construction of new reefs will play a large role in determining the outcome and magnitude of success. There are many ways to construct oyster reefs. The best approaches will depend on specific characteristics and conditions at each site. The size, types of materials used, and configuration can affect the performance of constructed reefs.

Information that will be provided by the ongoing Oyster Cultch Relief and Reef Configuration project described in section 4.1.3, *Reef Configuration Studies*, will be useful to managers in determining the best design parameters for each selected site. This study will assess the effectiveness of different substrate types, reef configurations and orientations, and elevations. Preliminary results suggest that increasing reef elevation can improve oyster survival at sites susceptible to frequent or prolonged hypoxic or anoxic events.

Results of the oyster grow-out study, described in section 4.1.5, *Oyster Grow-Out and Restoration Reef Placement Study*, may also inform project design and construction techniques. This study will investigate the effectiveness of off-bottom restoration techniques which could be incorporated into future project designs.

Ultimately, decisions regarding design and construction methodologies for new restoration reefs will incorporate the best available data from the studies mentioned above, data from Alabama MRD's ongoing monitoring program for existing reefs (Alabama MRD 2016), specific characteristics of each site, cost, and logistical considerations. Alabama MRD will evaluate the cost of various designs compared to the restoration benefit to make the most efficient use of restoration dollars. This will include costs of materials, construction labor, and maintenance requirements for the different options to be considered.

5.5.4 Monitoring

Alabama MRD will monitor the performance of new reefs as described above under section 5.4.3.1, *Implement Monitoring and Adaptive Management*. Pre-deployment sampling and regular post-construction monitoring will allow managers to track restoration success and react quickly if corrective actions are needed to achieve the desired outcomes. Regular monitoring of new reefs will also help managers determine when maintenance is required to maintain project performance.

5.6 SUMMARY OF KEY POINTS: OYSTER RESTORATION GOALS AND IMPLEMENTATION STRATEGY

- The overall goal of Alabama's restoration strategy is to create a network of oyster reefs across a gradient of environmental conditions to improve connectivity and enhance resiliency over the long term.
- To achieve this restoration goal, managers and restoration planners must (1) be able to identify optimal sites for placement of new reefs; (2) continue to support existing reefs, enhancing their connectivity within the network; and (3) understand how existing and potential future reefs would connect within the network.
- Factors that could influence restoration success include the ability to locate new reefs in desired locations, support from stakeholders and the general public, and the ability to adapt to changing environmental and social conditions.
- The actions proposed in Alabama's comprehensive oyster restoration strategy would collectively support Alabama's overall restoration goal by providing managers with the information, tools, and support needed to implement successful oyster restoration throughout Alabama's coastal waters.

Table 2. Oyster Restoration Strategy Quick Reference Table

Activity Type	Activity Description	Implementation Priority
Data collection/ Information gathering	Substrate mapping	High
Data collection/ Information gathering	Identify intertidal oyster resources	High
Data collection/ Information gathering	Water quality monitoring at potential future reef locations	High
Water quality improvements	Assess potential water quality improvement activities using non-oyster funds	High
Data collection/ Information gathering	Larval supply/recruitment studies	High
Data collection/ Information gathering	Climate change/future conditions model	Medium
Restoration and replenishment of existing reefs	Cultch planting, oyster relaying, and spat deployment	High, Medium, Low (depending on site)
Data collection/ Information gathering	Additional water quality monitoring at existing reef areas	High
Harvest Management	Additional harvest management and shell budget activities	Medium
Data collection/ Information gathering	Flow model	High
Data collection/ Information gathering	Larval Transport Model	High
Collaboration and coordination	Develop coordination strategy for engaging other agencies and partners	High, Medium
Data collection/ Information gathering	Restoration site suitability determination	High
Public Engagement/Outreach	Strategy rollout and stakeholder engagement	High

Activity Type	Activity Description	Implementation Priority
Public Engagement/Outreach	Educational video about oyster ecology and restoration	Low
Public Engagement/Outreach	Public-private partnerships	High
Monitoring and Adaptive Management	Conduct monitoring and adaptive management for all new oyster restoration projects	High
Monitoring and Adaptive Management	Expand monitoring/sampling program	High
Monitoring and Adaptive Management	Review/update Comprehensive Oyster Restoration Strategy	High
Construction of new reef areas	Construct new reefs across a gradient of environmental conditions	High

6.0 REFERENCES

Alabama Coastal Birding Trail

2012 Alabama Coastal Birding Trail. Available at: http://www.alabamacoastalbirdingtrail.com/.

Alabama Coastal Foundation (ACF)

2021 Oyster Gardening Program. Available at: https://www.joinacf.org/oyster-shell-recycling-program.

Alabama Cooperative Extension System (ACES)

2019 Mobile Bay Oyster Gardening Program. Available at: https://www.aces.edu/blog/topics/aquaculture/mobile-bay-oyster-gardening-program/.

2020 Alabama Shellfish Aquaculture Situation & Outlook Report: Production Year 2019. Available at: https://www.aces.edu/blog/topics/aquaculture/alabama-shellfish-aquaculture-situation-outlook-report-production-year-2019/.

Alabama Department of Conservation and Natural Resources (ADCNR)

2020 Oyster Harvest Information. Available at: https://www.outdooralabama.com/saltwater-regulations-and-enforcement/oyster-harvest-information.

Alabama Department of Public Health (ADPH)

2017 Vibrio v. and Liver Disease. Available at: https://www.alabamapublichealth.gov/hepatitis/liver-disease.html

Alabama Department of Conservation and Natural Resources, Marine Resources Division (Alabama MRD)

2016 Alabama Oyster Management Plan.

Bannon, S., and J. Herrmann

2020 Side-Scan Mapping of Mobile Bay Relic Oyster Reefs. Alabama Current Connection, Spring 2020, Volume 14, Issue 1, p. 7.

Barnes, T.K., Volety, A.K., Chartier, K., Mazzotti, F.J., and L. Pearlstine

2007 A habitat suitability index model for the eastern oyster (*Crassostrea virginica*), a tool for restoration of the Caloosahatchee Estuary, Florida. Journal of Shellfish Research, 26(4):949-959.

Berger, R.C., and R.A. Boland

1979 Mobile Bay model study. Report 2. Effects of enlarged navigation channel on tides, currents, salinities, and dye dispersion, Mobile Bay, Alabama: hydraulic model investigation.

Bell, J.O.

1952 A study of oyster production in Alabama waters. M.S. Thesis, Texas A & M College, College Station, TX, 81 p.

Boulais, M., Vignier, J., Loh, A.N., Chu, F.L.E., Lay, C.R., Morris, J.M., Krasnec, M.O. and A. Volety

2018 Sublethal effects of oil-contaminated sediment to early life stages of the Eastern oyster, *Crassostrea virginica*. Environmental Pollution, 243:743-751.

Butler, P.A.

1952 Effect of floodwaters on oysters in Mississippi Sound in 1950. U.S. Fish and Wildlife Service Research Report, 31, 20p.

1954 Summary of our knowledge of the oyster in the Gulf of Mexico. In P.S. Galtsoff (editor), Gulf of Mexico. Its origin, waters and marine life. p. 479-489. U.S. Fish and Wildlife Service Bulletin, 55:479-489.

1985 Synoptic Review of the Literature on the Southern Oyster Drill (*Thais Haemastoma floridana*). NOAA Technical Report NMFS, 35.

Cake, E.W.

1983 *Habitat suitability index models: Gulf of Mexico American oyster*. National Coastal Ecosystems Team, Division of Biological Services, Research and Development, Fish and Wildlife Service, US Department of the Interior.

Callam, B.R., and J. Supan

2018 Using Remote Setting to Produce Seed Oysters in Louisiana and the Gulf Coastal Region. Louisiana Sea Grant College Program.

Carmichael, R.H., Walton, W., Clark, H., and C. Ramcharan

2012 Bivalve-enhanced nitrogen removal from coastal estuaries. Canadian Journal of Fisheries and Aquatic Sciences, 69:1131–1149.

Carse, A., and J.A. Lewis

2020 New horizons for dredging research: The ecology and politics of harbor deepening in the southeastern United States. Wiley Interdisciplinary Reviews: Water, 7(6), 16p.

Coogan, J., Dzwonkowski, B., Lehrter, J., Park, K. and R.C. Collini

2021 Observations of dissolved oxygen variability and physical drivers in a shallow highly stratified estuary. Estuarine, Coastal and Shelf Science, 259, p.107482.

Cooley, N.R.

1978 An inventory of the estuarine fauna in the vicinity of Pensacola, Florida. Florida Marine Research Publication, 31, 119 p.

Dalrymple, D.J., and R.H. Carmichael

2015 Effects of age class on N removal capacity of oysters and implications for bioremediation. Marine Ecology Progress Series, 528: 205–220.

Deason, G., Seekamp, E., and C. Barbieri.

2014 Perceived impacts of climate change, coastal development and policy on oyster harvesting in the Southeastern United States. Marine Policy 50: 142-150.

Deepwater Horizon Oil Spill Alabama Trustee Implementation Group (AL TIG)

2018 Final Restoration Plan II and Environmental Assessment: Restoration of Wetlands, Coastal, and Nearshore Habitats; Habitat Projects on Federally Managed Lands; Nutrient Reduction (Nonpoint Source); Sea Turtles; Marine Mammals; Birds; and Oysters. Available at: https://www.gulfspillrestoration.noaa.gov/sites/default/files/2018-09%20AL%20RP%20II%20EA%20and%20Appendices_091318.pdf.

Deepwater Horizon Natural Resource Damage Assessment Trustees (DWH NRDA Trustees)

2014 Deepwater Horizon Oil Spill: Programmatic and Phase III Early Restoration Plan and Early Restoration Programmatic Environmental Impact Statement. Available at: https://www.gulfspillrestoration.noaa.gov/restoration/early-restoration/phase-iii.

2016 Deepwater Horizon Oil Spill: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. Available at: http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan.

2017 Deepwater Horizon Oil Spill Natural Resource Damage Assessment: Strategic Framework for Oyster Restoration Activities. June. Available at: http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan.

DePaolo, A., Nordstrom, J.L., Bowers, J.C., Wells, J.G., and D.W. Cook.

2003 Seasonal Abundance of Total and Pathogenic *Vibrio parahaemolyticus* in Alabama Oysters. Applied and Environmental Microbiology 69(3): 1521-1526.

Dugas R., Joyce, E., and M. Berrigan

1997 History and status of the oyster, *Crassostrea virginica*, and other molluscan fisheries of the U.S. Gulf of Mexico. *In*: The History, Present Condition, and Future of the Molluscan Fisheries of North and Central America and Europe: Volume 1, Atlantic and Gulf Coasts. edited by Mackenzie et al., U.S Dept. Commerce, NOAA Technical Report NMFS 127, September 1997. (A technical report of the Fishery Bulletin).

Ekstrom, J.A., L. Suatoni, S.R. Cooley, L.H. Pendleton, G.G. Waldbusser, J.E. Cinner, J. Ritter, C. Langdon, R. Van Hooidonk, D. Gledhill, and K. Wellman

2015 Vulnerability and adaptation of US shellfisheries to ocean acidification. Nature Climate Change 5:207–214.

Grabowski, J.H., Brumbaugh, R.D., Conrad, R.F, Keeler, A.G., Opaluch, J.J., Peterson, C.H., Piehler, M. F., Powers, S.P. and A.R. Smyth

2012 Economic Valuation of Ecosystem Services Provided by Oyster Reefs. BioScience, 62(10): 900-909.

Gregalis, K.C., Powers, S.P., and K.L. Heck Jr.

2008 Restoration of oyster reefs along a bio-physical gradient in Mobile Bay, Alabama. Journal of Shellfish Research 27.5: 1163-1169.

Gulf Shores and Orange Beach Tourism

2021 The Oyster Trail. Available at: https://www.gulfshores.com/food-trails/the-oyster-trail/.

GSMFC (Gulf States Marine Fisheries Commission)

2012 The Oyster Fishery of the Gulf of Mexico of the United States: A Regional Management Plan.

Higgins, C.B., Tobias, C., Piehler, M.F., Smyth, A.R., Dame, R.F., Stephenson, K., and B.L. Brown

2013 Effect of aquacultured oyster biodeposition on sediment N2 production in Chesapeake Bay. Marine Ecology Progress Series, 473:7–27.

Hofmann, E.E., E.N. Powell, J.M. Klinck, and E.A. Wilson

1992 Modeling oyster populations III. Critical feeding periods, growth and reproduction. Journal of Shellfish Research 11:399– 416.

Intergovernmental Panel on Climate Change (IPCC)

2018 Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

Johnson, M.W., Powers, S.P., Senne, J., and K. Park.

2009 Assessing in Situ Tolerances of Eastern Oysters (*Crassostrea virginica*) Under Moderate Hypoxic Regimes: Implications for Restoration. Journal of Shellfish Research 28(2):185-192.

Kellogg, M. L., Smyth, A. R., Luckenbach, M. W., Carmichael, R. H., Brown, B. L., Cornwell, J. C., Piehler, M.F., Owens, M.S., Dalrymple, D.J., and C.B. Higgins

2014 Use of oysters to mitigate eutrophication in coastal waters. Estuarine, Coastal and Shelf Science, 151:156-168.

Kim, C.K., Park, K., Powers, S.P., Graham, W.M., and K.M. Bayha

2010 Oyster larval transport in coastal Alabama: Dominance of physical transport over biological behavior in a shallow estuary. Journal of Geophysical Research: Oceans 115(C10).

Kim, C.K., Park, K., and S.P. Powers

2013 Establishing restoration strategy of eastern oyster via a coupled biophysical transport model. Restoration Ecology, 21(3):353-362.

Koenig, E.

2018 Can Clams and Oysters Help Clean Up Waterways? Woods Hole Oceanographic Institute. Oceanus, January 22, 2018. Available at: https://www.whoi.edu/oceanus/feature/can-clams-and-oysters-help-clean-up-waterways/#:~:text=Adult%20oysters%20reportedly%20can%20filter,gallons%20of%20water%20a%20day.

La Peyre, M.K., B. Gossman, and J.F. La Peyre

2009 Defining optimal freshwater flow for oyster production: Effects of freshet rate and magnitude of change and duration on eastern oysters and *Perkinsus marinus* infection. Estuaries and Coasts 32(3):522–534.

La Peyre, M.K., B.S. Eberline, T.M. Soniat, and J.F. La Peyre

2013 Differences in extreme low salinity timing and duration differentially affect eastern oyster (*Crassostrea virginica*) size class growth and mortality in Breton Sound, LA. Estuarine, Coastal and Shelf Science 135:146–157.

Lappin, D.M, Jr.

2018 Remote Set of *Crassostrea virginica* as a Potential Means for Public Stock Enhancement in Alabama, and the Assessment of Larval Tank Setting Distributions. Master's Thesis. Auburn University.

Lenihan, H.S., and C.H. Peterson

1998 How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecological applications 8.1: 128-140.

May, E.B.

1971 A survey of the oyster and oyster shell resources of Alabama. Alabama Marine Resources Bulletin 4:1-53.

Meyer, D.L., Townsend, E.C., and G.W. Thayer

1997 Stabilization and erosion control value of oyster cultch for intertidal marsh. Restoration Ecology, 5:93–99.

Moore, H.F.

1913 Condition and extent of the natural oyster beds and barren bottoms of Mississippi Sound. Alabama Department of Commerce and Labor, Bureau of Fisheries Document 769: 60 p.

Mortazavi, B., Ortmann, A.C., Wang, L., Bernard, R.J., Staudhammer, C.L., Dalrymple, D.J., Carmichael, R.H., and A.A. Kleinhuizen

2015 Evaluating the impact of oyster (*Crassostrea virginica*) gardening on sediment nitrogen cycling in a subtropical estuary. Bulletin of Marine Science, 91(3):323–341.

Muth, M., Karns, S., Anderson, D., and B. Murray

2002 Effects of Post-Harvest Treatment Requirements on the Markets for Oysters. Agricultural and Resource Economics Review, 31(2):171-186.

Newell, R.I.E., Fisher, T.R., Holyoke, R.R., and J.C. Cornwell

2005 Influence of eastern oysters on nitrogen and phosphorus regeneration in Chesapeake Bay, USA. The comparative roles of suspension-feeders in ecosystems. NATO Science Series, 47:93–120.

NOAA (National Oceanic and Atmospheric Administration)

2021a Landings Data. NOAA Fisheries. Available at: https://foss.nmfs.noaa.gov/apexfoss/f?p=215:200.

2021b Relative Sea Level Trend. Dauphin Island, Alabama. Available at: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8735180.

Oystergardening.org

2020 Oyster Gardening on the Gulf Coast. Mobile Bay. Available at: https://oystergardening.org/mobile-bay/.

2021 The Oyster Trail. Available at: https://oystergardening.org/the-oyster-trail/.

Patterson, H.K., Boettcher, A., and R.H. Carmichael

2014 Biomarkers of dissolved oxygen stress in oysters: a tool for restoration and management efforts. PLoS One, 9(8): e104440

Peterson, C.H., Grabowski, J.H., and S.P. Powers

2003 Estimated enhancement of fish production resulting from restoring oyster reef habitat: quantitative valuation. Marine Ecology Progress Series, 264:249–264.

Powers, S.P., Peterson, C.H., Grabowski, J.H., and H.S. Lenihan

2009 Success of constructed oyster reefs in no-harvest sanctuaries: implications for restoration. Marine Ecology Progress Series, 389:159-170.

Powers, S.P., S. Rouhani, M.C. Baker, H. Roman, J. Murray, J.H. Grabowski, S. Scyphers, J.M. Willis, and M.W. Hester.

2015 Loss of Oysters as a Result of the *Deepwater Horizon* Oil Spill Degrades Nearshore Ecosystems and Disrupts Facilitation between Oysters and Marshes (NS_TR.30). DWH Oyster NRDA Technical Working Group Report.

Powers, S.P., Peterson, C.H., J. Cebrian, and K.L. Heck Jr.

2017 Response of nearshore ecosystems to the Deepwater Horizon oil spill. Marine Ecology Progress Series, 576:107-110.

Ringwood, A. H., Hoguet, J., Keppler, C., and M. Gielazyn

2004 Linkages between cellular biomarker responses and reproductive success in oysters Crassostrea virginica. Marine environmental research, 58(2-5): 151-155.

Roman, H.

2015 Development of Oyster Nearshore Injury Quantification (NS_TR.04). DWH Oyster NRDA Technical Working Group Report.

Richards, G.P., Watson, M.A., Needleman, D.S., Church, K.M., and C.C. Häse

2015 Mortalities of Eastern and Pacific Oyster Larvae Caused by the Pathogens *Vibrio coralliilyticus* and *Vibrio tubiashii.* Applied and Environmental Microbiology 81(1): 292-297.

Ritter, H.P.

1896 Report on a reconnaissance of the oyster beds of Mobile Bay and Mississippi Sound, Alabama. Bulleting of the United States Fish Commission for 1895: 325-339.

Schecter, V.

1943 Tolerance of the snail *Thais floridana* to waters of low salinity and the effect of size. Ecology 24:493-499.

Shumway, S.E.

1996 Natural Environmental Factors. In Kennedy, V.S., Newell, R.I.E., and A.F. Ebert [Eds.]. The Eastern Oyster: *Crassostrea virginica*. College Park, Maryland: Maryland Sea Grant College. Xvi 734pp.

Shumway, S. E., and R.K. Koehn

1982 Oxygen consumption in the American oyster Crassostrea virginica. Marine Ecology Progress Series 9(1): 59-68.

Sledge, J.

2015 The Mobile River. University of South Carolina Press.

Solomon, J.A., M.J. Donnelly, and L.J. Walters

2014 Effects of sea level rise on the intertidal oyster *Crassostrea virginica* by field experiments. Journal of Coastal Research 68:57–64.

Soniat, T.M.

1985 Changes in levels of infection of oysters by *Perkinsus marinus*, with special reference to the interaction of temperature and salinity upon parasitism. Northeast Gulf Science 7:171–174.

Soniat, T.M. and Brody, M.S.

1988 Field validation of a habitat suitability index model for the American oyster. Estuaries, 11(2):87-95.

Soniat, T.M., Klinck, J.M., Powell, E.N., Cooper, N., Abdelguerfi, M., Hofmann, E.E., Dahal, J., Tu, S., Finigan, J., Eberline, B.S., and J.F. La Peyre

2012 A shell-neutral modeling approach yields sustainable oyster harvest estimates: a retrospective analysis of the Louisiana state primary seed grounds. Journal of Shellfish Research, 31(4): 1103-1112.

Sussarellu, R., Suquet, M., Thomas, Y., Lambert, C., Fabioux, C., Pernet, M.E.J., Le Goïc, N., Quillien, V., Mingant, C., Epelboin, Y., Corporeau, C., Guyomarch, J., Robbens, J., Paul-Pont, I., Soudant, P., and A. Huvet

2016 Oyster reproduction is affected by exposure to polystyrene microplastics. Proceedings of the National Academy of Sciences, 113(9) ;2430-2435.

Tatum, W.M., M.S. Van Hoose, R.W. Havard, and M.C. Clark

1995 The 1995 Atlas of Major Public Oyster Reefs of Alabama and a Review of Oyster Management Efforts 1975 – 1995. Alabama Marine Resources Bulletin. 14:1-15.

The Nature Conservancy (TNC)

2020 Our Living Shorelines. Available at: https://www.nature.org/content/dam/tnc/nature/en/documents/our_living_shorelines_small.pdf.

U.S. Army Corps of Engineers (USACE)

1973 Final Environmental Impact Statement. Permit Application by Radcliff Materials, Inc., Dredging of Dead-Reef Shells in Mobile Bay, Alabama. USACE, Mobile District. February 1973.

U.S. Food and Drug Administration (FDA)

2018 The Danger of Eating Contaminated Raw Oysters. Available at: https://www.fda.gov/food/health-educators/danger-eating-contaminated-raw-oysters.

VanderKooy, S. (editor)

2012 The Oyster Fishery of the Gulf of Mexico, United States: A Regional Management Plan – 2012 Revision. Publication No. 202, Gulf States Marine Fisheries Commission, Ocean Springs, Mississippi.

Vignier, J., Volety, A. K., Rolton, A., Le Goïc, N., Chu, F. L., Robert, R., and P. Soudant

2017 Sensitivity of eastern oyster (*Crassostrea virginica*) spermatozoa and oocytes to dispersed oil: Cellular responses and impacts on fertilization and embryogenesis. Environmental Pollution, 225:270-282.

Virginia Institute of Marine Science (VIMS)

2020 Oyster Diseases of the Chesapeake Bay. Dermo and MSX Fact Sheet. Available at: https://www.vims.edu/_docs/oysters/oyster-diseases-CB.pdf.

Waite, H. R., Donnelly, M. J., and L.J. Walters

2018 Quantity and types of microplastics in the organic tissues of the eastern oyster Crassostrea virginica and Atlantic mud crab *Panopeus herbstii* from a Florida estuary. Marine Pollution Bulletin, 129(1):179-185.

Waldbusser, G.G., E.L. Brunner, B.A. Haley, B. Hales, C.J. Langdon, and F.G. Prahl

2013 A developmental and energetic basis linking larval oyster shell formation to ocean acidification. Geophysical Research Letters 40:2171–2176.

Walthall, J. A.

1980 Prehistoric Indians of the Southeast: Archaeology in Alabama and the Middle South. Tuscaloosa: University of Alabama Press.

Weis, P., J.S. Weis, J. Couch, C. Daniels, and T. Chen

1994 Pathological and genotoxicological observation in oysters (Crassostrea virginica) living on chromated copper arsenate (CCA)-treated wood. Marine Environmental Research 39:275–278.

Wells, H.W.

1961 The fauna of oyster beds, with special reference to the salinity factor. Ecological Monographs 31(3):239-266.

Weng, N. and W.X. Wang

2019 Seasonal fluctuations of metal bioaccumulation and reproductive health of local oyster populations in a large contaminated estuary. Environmental Pollution, 250:175-185.

Wilson, C., L. Scotto, J. Scarpa, A. Volety, S. Laramore, and D. Haunert

2005 Survey of water quality, oyster reproduction and oyster health status in the St. Lucie estuary. Journal of Shellfish Research 24:157–165.

APPENDICIES

APPENDIX A – POTENTIAL FUNDING SOURCES FOR FUTURE OYSTER RESTORATION AND RESEARCH

This section provides a high-level overview of programs funding restoration and restoration science activities across the northern Gulf of Mexico. It is not intended to capture the work of every researcher working on oyster restoration/research, but rather to provide context to the work that the DWH NRDA Trustees will consider funding. For more details on project and research funded through the programs below, please visit the links below or the DWH Project Tracker maintained by the Gulf of Mexico Alliance (GOMA).

DWH NRDA Restoration Program

Natural Resource Damage Assessment is the process by which the DWH Trustees evaluated the type and amount of restoration needed in order to return the Gulf of Mexico to the condition it would have been in before the DHW oil spill and to compensate the public for the natural resource services that were injured or lost. The DWH oil spill resulted in the largest NRDA ever undertaken.

The NRDA for the DWH oil spill began in 2010. In 2011, 1 year after the spill, BP agreed to provide up to $1 billion toward early restoration projects in the Gulf of Mexico.

In 2016, a federal court in New Orleans entered a consent decree resolving civil claims against BP. This historic settlement resolves the U.S. government's civil penalty claims under the Clean Water Act, the governments' claims for natural resources damage claims under the Oil Pollution Act, and also implements a related settlement of economic damage claims of the Gulf States and local governments. Taken together this resolution of civil claims is worth more than $20 billion and is the largest settlement with a single entity in the history of federal law enforcement.

Consistent with the Consent Decree, in 2016, a Trustee Council made up of four federal agencies and trustees from all five Gulf States issued a PDARP/PEIS detailing a specific proposed plan to fund and implement restoration projects across the Gulf for up to $8.8 billion. The PDARP/PEIS describes specific restoration approaches and techniques and monitoring considerations for oyster restoration projects approved and implemented with DWH settlement funds. Building off of the PDARP/PEIS, the DWH Trustees developed a Strategic Framework for Oyster Restoration Activities in 2017 (DWH NRDA Trustees 2017), which provides a summary of the PDARP/PEIS as it relates to oysters, biological information on oysters, an overview of recent and ongoing work associated with oysters in each Gulf State, and considerations for prioritization, sequencing, and selection of restoration projects to best meet the PDARP/PEIS oyster goals. The AL TIG subsequently prepared several Restoration Plans, which tier from the PDARP/PEIS, to analyze and select specific restoration projects for implementation.

Of the $295,589,305 set aside for restoration in the Alabama Restoration Area, at total of $13,329,000 was allocated specifically to oyster restoration in Alabama, including Early Restoration, under the Replenish and Protect Living Coastal and Marine Resources restoration goal. DWH NRDA Restoration funds have been and continue to be an important funding source for oyster restoration in Alabama.

Past and ongoing oyster restoration projects in Alabama funded through the DWH NRDA Restoration program include the following, which are described in additional detail in section 4.0*, Restoration Efforts to Date*:

- Alabama Oyster Cultch Restoration, 2015
- Oyster Cultch Relief and Reef Configuration, in progress (approved 2018)
- Oyster Grow-out and Restoration Reef Replacement, in progress (approved 2018)
- Oyster Hatchery at Claude Peteet Mariculture Center, in progress (approved 2018)
- Side-scan Mapping of Mobile Bay Relic Oyster Reefs, in progress (approved 2018)

Additional information about past and ongoing DWH NRDA oyster restoration projects in Alabama can be found at: https://www.gulfspillrestoration.noaa.gov/restoration-areas/alabama.

Gulf Coast Ecosystem Restoration Council

The Gulf Cost Ecosystem Restoration Council (Council) was established in 2012 under the RESTORE Act with funds from civil and administrative penalties paid under the Clean Water Act following the DWH oil spill. The Council is comprised of governors of the five Gulf states and several federal agencies. The Council is charged with helping to restore the ecosystem and economy of the Gulf Coast region by developing and overseeing implementation of a comprehensive plan and carrying out other responsibilities. The Council distributes funds to the Gulf states and partner entities for projects and programs to restore and conserve habitat, restore water quality, replenish, and protect living marine and coastal resources, and enhance community resilience.

Previously funded projects relevant to oyster restoration in Alabama include:

- Alabama Living Shorelines Program Construction Planning, 2015
- Alabama Living Shorelines Program Implementation, 2015
- Comprehensive Living Shoreline Monitoring Program Planning, 2015
- Comprehensive Living Shoreline Monitoring Program Implementation, 2015 (amended 2020)

Additional information about the Council, previously funded and ongoing projects, and current funding opportunities can be found at: https://www.restorethegulf.gov/.

NOAA's RESTORE Act Science Program

NOAA's RESTORE Act Science Program was established in 2012 under the RESTORE Act. The mission of the program is to carry out research, observation, and monitoring to support, to the maximum extent practicable, the long-term sustainability of the ecosystem, fish stocks, fish habitat, and the recreational, commercial, and charter-fishing industry in the Gulf of Mexico. The program is administered by NOAA in collaboration with USFWS. In carrying out the program, NOAA and USFWS solicit input from key partners and constituents, including the Gulf of Mexico Fishery Management Council, Gulf States Marine Fisheries Commission (GSMFC), the Gulf of Mexico Alliance, academic institutions, federal and state agencies, non-governmental organizations, and other entities across the Gulf region. The program has funded oyster restoration projects, although none have been funded in Alabama to date. The program has, however, funded research and monitoring initiatives that may inform oyster restoration in Alabama.

Previously funded research and monitoring initiatives that may inform oyster restoration in Alabama include:

- Mobile Bay Monitoring Program, 2019 (ongoing)
- Research study entitled, "Use of elemental signatures to detect and trace contaminant entry to the northern Gulf of Mexico coastal food web: managing multiple stressors", 2017 – 2020
- Research study entitled, "Building Resilience for Oysters, Blue Crabs, and Spotted Seatrout to Environmental Trends and Variability in the Gulf of Mexico", 2019 (ongoing; anticipated completion by August 2024)

Additional information about the program, previously funded and ongoing projects, and current funding opportunities can be found at: https://restoreactscienceprogram.noaa.gov/.

National Academies of Science's Gulf Research Program

The National Academies of Science's Gulf Research Program was created in 2013 with $500 million in criminal settlement funds from the BP and Transocean that arose from the DWH oil spill. The Gulf Research Program funds research aimed at supporting a safer, more resilient, and sustainable future for the Gulf Coast. The program focuses on several priority areas including environmental protection and stewardship.

Previously funded projects relevant to oyster restoration in Alabama include:

- Living Shorelines: Synthesizing the Results of a Decade of Implementation in Coastal Alabama, 2015
- Report: Effective Monitoring to Evaluate Ecological Restoration in the Gulf of Mexico, 2017

Additional information about the program, previously funded projects, and current funding opportunities can be found at: https://www.nationalacademies.org/gulf/gulf-research-program.

National Fish and Wildlife Foundation's Gulf Environmental Benefit Fund

The GEBF was established in 2013 using funds from the DWH oil spill settlement. The settlement allocated $2.544 billion dollars to NFWF to fund projects benefiting the natural resources of the Gulf Coast that were impacted by the DWH oil spill. Consistent with the terms of the settlement, funding priorities include, but are not limited to, projects that restore and maintain the ecological functions of coastal habitats, promote resiliency, and replenish and protect living resources, including oysters. Between 2013 and 2018 the GEBF received $356 million for projects in Alabama. Approximately $230 million worth of awards have been funded in Alabama to date.

Previously funded projects relevant to oyster restoration in Alabama include:

- Restoration and Enhancement of Oyster Reefs in Alabama, 2013 (described above in section 4.1.4, *National Fish and Wildlife Foundation Gulf Environmental Benefit Fund Oyster Restoration Studies*)

Additional information about the GEBF, previously funded and ongoing projects, and current funding opportunities can be found at: https://www.nfwf.org/gulf-environmental-benefit-fund.

National Fish and Wildlife Foundation's Gulf Coast Conservation Grants Program

The Gulf Coast Conservation Grants Program, established in 2015, seeks to build and maintain the resilience of the Gulf Coast's ecosystems, living resources and communities by supporting critical gaps in conservation and catalyzing conservation solutions that can be taken to scale. It is a competitive grants program that supports priority conservation needs of the Gulf Coast that are not otherwise expected to be funded under NFWF's GEBF or other funding opportunities associated with the DWH oil spill. To date, no grants have been awarded specifically for oyster restoration in Alabama; however, such projects could be funded in the future.

Additional information about the program, previously funded and ongoing projects, and current funding opportunities can be found at: https://www.nfwf.org/programs/gulf-coast-conservation-grants-program.

Gulf of Mexico Research Initiative

The Gulf of Mexico Research Initiative (GoMRI) was founded in 2010 almost immediately after the DWH oil spill. BP committed $500 million over a 10-year period to create a broad, independent research program to be conducted at research institutions primarily in the US Gulf Coast States. The ultimate goal of GoMRI is to improve society's ability to understand, respond to, and mitigate the impacts of petroleum pollution and related stressors of the marine and coastal ecosystems, with an emphasis on conditions found in the Gulf of Mexico. Knowledge accrued will be applied to restoration and to improvement of the long-term environmental health of the Gulf of Mexico. Although GoMRI does not specifically fund restoration projects, it does fund research that may fill critical data gaps and help to inform oyster restoration planning in Alabama.

Additional information about the GoMRI, previously funded and ongoing projects, and current funding opportunities can be found at: https://gulfresearchinitiative.org/.

Gulf of Mexico Energy Security Act

The Gulf of Mexico Energy Security Act (GOMESA) was enacted by Congress in 2006 and significantly enhances outer Continental Shelf (OCS) oil and gas leasing activities and revenue sharing in the Gulf of Mexico. Among other things, GOMESA provides for enhanced sharing of leasing revenues with Gulf producing states and the Land & Water Conservation Fund for coastal restoration projects. The GOMESA authorizes uses of the proceeds for the following purposes:

a. Projects and activities for the purposes of coastal protection, including conservation, coastal restoration, hurricane protection, and infrastructure directly affected by coastal wetland losses;
b. Mitigation of damage to fish, wildlife, or natural resources;
c. Implementation of a federally approved marine, coastal, or comprehensive conservation management plan;
d. Mitigation of the impact of OCS activities through the funding of onshore infrastructure projects;
e. Planning assistance and the administrative costs.

One previously funded project to benefit oysters is the Auburn University Shellfish Laboratory Oyster Enhancement Project in Little Dauphin Bay. This project will implement Auburn University Shellfish Lab's oyster aquaculture program to attempt to revive the public oyster fishery resource in Little Dauphin Bay on Dauphin Island Alabama.

Additional information about GOMESA in Alabama, previously funded and ongoing projects, and current funding opportunities can be found at: https://outdooralabama.com/.

Public-Private Partnerships

Alabama MRD has collaborated with public and private partners including outside agencies, NGOs, universities and educational institutions, and others to carry out projects that have benefited oyster restoration in Alabama. Examples of past public-private partnerships include the Nature Conservancy's 100-1000: Restore Coastal Alabama living shoreline project, the Alabama Oyster Gardening Program, and the Alabama Oyster Shell Recycling Program. More information about these activities can be found in section 4.2.5, *Other Restoration Efforts*. Other types of public-private partnerships that Alabama MRD may consider in the future include privately funded oyster farms or hatcheries.

APPENDIX B – ALABAMA MARINE ENFORCEMENT PROTOCOL

GUIDANCE DOCUMENT FOR PATROL EVALUATION.

This guidance is being issued to assist Shellfish Specialists during the evaluation of State patrol programs. The new patrol requirements adopted at the 1999 ISSC in New Orleans are included for your use during the FY 00 patrol evaluation.

A. General.

(1) The Authority shall maintain an effective program to control shellstock growing areas and to assure that shellstock are harvested only:

(a) From areas in an open status; and
(b) With approval from areas classified as restricted, conditionally restricted, or prohibited, or in the closed status of the approved or conditionally approved classification.

(2) This program shall include:

(a) The patrol of growing areas;
(b) The licensing of harvesters;
(c) Enforceable legal penalties sufficient to encourage compliance; and
(d) Appropriate identification of harvest areas where shellstock harvest is not allowed.

(3) At the time of issuance or renewal of a harvester's license or a dealer's certification, the Authority shall provide each harvester or dealer with:

(a) Information which explains the public health risk associated with illegal harvesting shellstock in areas classified as restricted, conditionally restricted, or prohibited or in the closed status; and
(b) When requested a current, comprehensive, itemized listing of all harvest areas including their geographic boundaries and their classification.

B. Patrol of Growing Areas.

(1) The Authority shall assure that shellstock are harvested only as provided in this Chapter.

(2) The Authority shall patrol harvest areas classified as restricted, conditionally restricted, or prohibited, or conditionally approved and approved when in the closed status at sufficient intervals to deter illegal harvesting. This patrol activity shall include consideration of the need for night, weekend, and holiday patrols. At a minimum, these growing areas

shall be patrolled at the following frequencies, except as provided in B (3), in order to ensure effective control;

<u>RISK CATEGORY</u>	<u>MIMIMUM FREQUENCY OF PATROL</u>
LOW	Four times per 30 harvestable days
MEDIUM	Eight times per 30 harvestable days
HIGH	Sixteen times per 30 harvestable days

A patrol is accomplished when the majority of an area is monitored. No more than two patrols can be counted in 24-hour period, and each must be a separate deliberate effort.

A harvestable day refers to a day during which tidal, weather and other conditions make it possible to harvest shellfish. When tidal, weather or other conditions prohibit harvesting on a particular day, that day is not included in the 30-day period.

(3) No patrol is required under the following conditions:

(a) There is no shellfish productivity, as demonstrated by one of the following methods:
(i) pH, salinity, temperature, or turbidity are not favorable to the growth of shellfish; or
(ii) the water bottom does not support shellfish growth; or
(iii) the area has been depleted of shellfish by dredging, disease or other means;

(b) Harvest from the area is not economically feasible (i.e., the cost of harvesting exceeds the market value of the product).

(c) The area meets all of the following conditions:
(i) the area is unclassified; and
(ii) there has historically been no interest in commercial harvesting; and
(iii) authority has current evidence that commercial harvesting does not occur. This can be accomplished by information gathered from periodic patrols, or reliable non-patrol sources

(4) The Risk Category for an area shall be determined as follows:

(a) Shellfish Productivity Estimate the abundance of shellfish based on density studies, historical information, and environmental conditions described in B(3)(a). Consider only commercially marketable species. The descriptions below refer to the range of productivity within the state. The area shall be rated based on the highest density in any portion of the growing area.

Low Productivity 1

Medium Productivity 3

High Productivity 5

(b) Ease of Harvest Determine the method used to harvest the shellfish. If multiple harvest techniques are used in an area, select the one with the highest score.

Highly mechanized requiring expensive
equipment, deep water, difficult harvest 1

Restricted access aquaculture,
relatively shallow water dredging 2

Scuba diving, tonging, bullraking 3

Hand collection from a boat 4

Hand collection, no special tools or boat 5

(c) Difficulty of Patrol Determine the difficulty of patrol. If the difficulty varies in an area, select the description with the highest score.

Resource within sight of population and a normal
patrol route. Patrol Officer can observe illegal harvesting from the
patrol vehicle 1

Resource is near a shore and easily visible 2

Moderate difficulty, deliberate effort is required
to provide coverage to the area 3

Long travel time to growing area, large open expanse of harvest area 4

Growing area is a marsh, short sight distance, canals system, extensive shoals 5

(d) Using the values determined in B(4)(a) to (c), calculate the total score for the area as follows:

RISK FACTORS	SCORE (1-5)	WEIGHT	RATING	EXPLAIN RATING (optional)	ADJUSTMENT OF RATING (if needed)
SHELLFISH PRODUCTIVITY (a)		0.40			
EASE OF HARVEST (b)		0.40			
DIFFICULTY OF PATROL		0.20			
			SUB-TOTAL		

The rating for each risk factor is calculated by multiplying the risk factor score by the weight for that factor. The subtotal is calculated by adding all three of the risk factor ratings.

(e) The following criteria should be used to adjust the rating, if warranted:

(i) If a community policing program is in place, the subtotal may be reduced by up to 0.25 points. If such a program leads to frequent citation, the subtotal may be reduced by up to 0.5 points. Community policing may include but is not limited to telephone hot lines, out-reach programs, financial incentives, local law enforcement activities not covered by B(5), or private security arrangements.

(ii) If specialized equipment is available to the patrol agency, the subtotal may be reduced by up to 0.40 points. The actual reduction should be dependent upon the type of equipment that is available and its frequency of use. For example, frequent use of an aircraft can warrant a 0.4 point reduction, and frequent use of night vision or periodic use of aircraft can warrant a 2.0 point reduction.

(iii) If a growing area is conditionally managed or is poorly marked the subtotal may be increased by up to 0.2 points.

The total score is calculated by adding or subtracting the appropriate adjustment(s).

(f) The following risk categories shall be applied to the total score:

TOTAL SCORE	RISK CATEGORY
less than 3	Low
3 to less than 4	Medium
4 or greater	High

(5) The Authority may delegate patrol activity to any State or local enforcement authority. If patrol activities are delegated, the Authority shall:

(a) Develop a memorandum of agreement with the delegated agency to assure that patrol requirements are met; and
(b) Require the delegated agency to maintain and file records of its patrol activities consistent with those required in B(7).

(6) Officers responsible for the patrol of shellfish growing areas shall obtain the following training:

(a) Basic law enforcement training, before assuming their patrol duties;
(b) Training on shellfish control regulations within the jurisdiction of the patrol agency, before assuming independent patrol duties;
(c) In-service training on the shellfish control regulations within the jurisdiction of the patrol agency, when the regulations change.

(7) The Authority shall prepare and revise, as necessary, documentation which records the Authority's patrol organization and its activities to deter illegal shellstock harvesting. This documentation shall include:

(a) Citation of the law providing legal basis for enforcement authority;
(b) Citation of the laws and regulations, including penalties, which are directly related to effective control of illegal harvest activities;

(c) The organizational structure of the unit responsible for patrol activities, including:

(i) Patrol units(s) name, address, and phone number
(ii) The roster and chain of command:
(iii) Area assignments that support the frequencies of patrol delineated in B(2); and
(iv) A listing of specific vessels, vehicles, and equipment that support the frequencies of patrol delineated in B(2);

(d) Summaries of training in shellfish patrol techniques;
(e) The methods used to inform officers of growing area classifications and status, and of any special activities licensed in the area;
(f) A listing of growing areas where patrol is required:
(g) An identification of any patrol problems;
(h) The type and frequency of reporting by patrol personnel;
(i) Copy of agreements with other agencies responsible for shellfish control activities; and
(j) Citations/ summons for the past year. If available, this information may include:

(i) The number of convictions or dismisals;
(ii) Fines in dollar amount;
(iii) Equipment or property confiscations and forfeitures;
(iv) License suspensions or revocations; and
(v) Jail sentences; and
(vi) Written warnings.

(8) Upon request by FDA, the Authority shall provide any available documentation that is used to support the determination that the patrol program was effective in providing the required frequency of patrol. Ordinarily, this does not include providing reports not normally maintained by the Authority.

QUESTIONS AND ANSWERS

1. Can I evaluate more than 15 patrol areas?

-Yes, you may evaluate more than 15 patrol areas as long you complete all of the required compliance activities within the FY 2000 Compliance Program.

2. If a state has one patrol area with multiple NSSP classifications (Approved and/or Conditional), does the Conditional area need to be categorized?

-Yes, a risk category needs to be assigned to all growing waters which are NSSP classified as less than Approved. The actual NSSP classification has no bearing on the risk classification.

3. How long must an officer be in an area to be considered an effective patrol?
   -Long enough for a patrol officer to cover at least 80 % of an area.

4. Do I have to visit each of the fifteen (15) patrol areas to verify the states' risk category?
   -No, you do not have to visit each of the fifteen patrol areas, unless, you feel the necessity to do so. The Shellfish Specialists should be sufficiently familiar with their states' growing waters to make a good decision concerning the proper risk assessment.

5. If a closed patrol area has more than one shellfish species, do I have to do the risk category for each species?
   -Yes, you have to do the risk category for each species, however, for the final categorization of an area, you must select the specie with the highest potential for illegal harvesting.

6. How am I going to assess whether the patrol agency has the resources (transportation, communication, and personnel) to meet required frequencies for each of the fifteen (15) patrol areas.

   - The following questions should be answered for each closed growing area.

     (a) number of patrol officers

     - Is the number of patrol officers adequate to achieve the minimum patrol frequency? Consider:
       - number of personnel conducting field work
       - other patrol obligations (e.g., fin fish, boating safety, search and rescue).
       - administrative down time (e.g., maintenance, courts appearance, leave).
       - other areas patrolled (e.g., officers may cover more than one harvest area).
       - assistance from other units (e.g., inter- and intra-agency agreements).
       - number of overtime hours required to meet the minimum patrol frequency.

     (b) number and type of vessels.

     - Are the vessels suitable and adequate in number to achieve the minimum patrol frequency? Consider:
       - shallow drafts
       - open water/foul weather needs
       - rocky bottom

        - wetland area
        - mangrove area
        - canal
        - marsh area

    - Is the length (size) of each vessel appropriate for the type of water in the area and geographical condition.
        - draft
        - horsepower

(c) number and type of vehicles

- Are the vehicles suitable and adequate in number to achieve the minimum patrol frequency? Consider:
    - vessel towing needs
    - car, trucks, vans
    - motorcycle, mopeds, bicycle

(d) number and type of aircraft

- Are the aircraft suitable and adequate in type to achieve the minimum patrol frequency? Consider:
    - wheel
    - float
    - helicopter

- Are the aircraft suitable and adequate in number to achieve the minimum patrol frequency? Consider:
    - patrol units' access to plane and pilot (e.g., affiliated with a patrol unit or another agency).
    - need for coordination with vessels for apprehension, especially with wheeled plane.
    - other demands on the aircraft (e.g., search and rescue, surveys, transportation).

(e) number and type of radios or other communication equipment.

- Is the communication equipment adequate and suitable to support an effective minimum patrol frequency? Consider:
    - access to 24-hour dispatching.
    - "dead spots" in reception.

(f) number and type of vision enhancement equipment available and adequate in number to achieve the minimum patrol frequency. Consider:

    - binoculars.
    - spotting scopes.
    - night scopes.
    - infrared vision equipment.
    - radar.

- Is the vision enhancement equipment suitable and adequate in number to achieve the minimum patrol frequency? Consider:
    - the ability of some vision enhancement equipment to partially compensate for lower numbers of patrol officers.

(g) number and type of special operations equipment and personnel available to achieve the minimum patrol frequency. Consider:

- How are special operations equipment and personnel used?
- How does the use of special operations equipment and personnel affect patrol requirements?
- Description of delegation of authority to other agencies and how the state patrol agency monitors their performance.