Chapter 3: The *Deepwater Horizon* Oil Spill Natural Resource Injury Assessment

3.1 Introduction

The Trustees described the status of natural resource damage assessment activities pertaining to the Spill as part of the Final Phase III ERP/PEIS (see Chapter 4), released to the public in June 2014. Below, the Trustees update that description based on the status of natural resource damage assessment activities.

The Trustees are in the process of assessing injuries caused by the Spill to natural resources and the services provided by these resources. The assessment extends from the deep ocean to the highly productive coastal habitats and estuaries along the five Gulf States, and includes a broad array of fish and shellfish species, rare deep sea corals, plankton and invertebrates that serve as prey for larger organisms, coastal vegetation, birds, sea turtles, and marine mammals. Additionally, impacts to recreational use of these resources and habitats, such as recreational fishing, boating, and other shoreline activities are also being assessed.

The Trustees have developed and implemented hundreds of scientific assessment studies focused in areas ranging from deep sea sediments, through the water column, to the nearshore and shoreline. In so doing, the Trustees have worked with technical teams including scientists from state and federal agencies, academic institutions, and BP. This cooperative approach to injury assessment is strongly encouraged by the OPA NRDA regulations, with the goal of creating a common set of data for quantifying injury.

The Trustees have established websites to provide the public with access to work plans and data related to the injury assessment.[1] In addition, in April 2012 the Trustees published an NRDA status update to provide the public with an overview of the potential impacts to resources in the Gulf of Mexico ecosystem caused by the spill; it also outlined the activities undertaken by Trustees to assess the injury.[2]

Many aspects of the injury assessment phase are ongoing. Information presented in this chapter remains subject to revision based on additional data or analysis.

3.2 The Injury Assessment Process: Assessing Injuries in a Complex, Interconnected Ecosystem

Oil from the Spill spread, through a variety of different pathways, over a large area of the Gulf of Mexico environment. Oil and gas released from the wellhead was transported at depth or rose from the wellhead to the surface of the water and was volatized to the atmosphere or moved with surface waters (Camilli et al. 2010). Some of the oil and gas dissolved into the water, some oil was dispersed into tiny oil droplets, and some adsorbed onto particles in the water. Surface oil was transported by natural

[1] As NRDA work plans and data are made public, they are posted to www.doi.gov/deepwaterhorizon/adminrecord/ www.gulfspillrestoration.noaa.gov, www.fws.gov/home/dhoilspill, and http://la-dwh.com.

[2] Natural Resource Damage Assessment April 2012 Status Update for the Deepwater Horizon Oil Spill, http://www.gulfspillrestoration.noaa.gov/wp-content/uploads/FINAL_NRDA_StatusUpdate_April2012.pdf

processes such as wind and waves, eventually reaching Gulf shorelines (Benton et al. 2011). An array of habitats and associated biological communities and organisms were exposed to the oil and/or gas, including, deep water soft bottom sediments, deep water coral reefs, and mesophotic coral reefs; water column; and nearshore and shoreline habitats such as submerged aquatic vegetation (SAV), intertidal and subtidal reefs, marshes, and beaches (OSAT 2010 and White et al. 2012). Oil and dispersant vapors also were present in the atmosphere in some areas (Middlebrook et al. 2012 and OSHA 2014).

The Gulf of Mexico ecosystem includes a complex and interconnected web of organisms (individual species, populations, and communities), habitats, and natural processes and functions. Consequently, natural resources may be adversely affected by oil by direct exposure or indirectly – for example, through loss of spawning and nesting habitat or reductions in prey availability caused by lost primary and secondary productivity. When natural resources are injured, cascading indirect ecological effects can also occur, including changes in ecological structure (such as increasing rates of shoreline erosion) and ecological functions (such as reducing habitat suitability for foraging).

In designing the injury assessment, the Trustees have undertaken studies to evaluate potential Spill-related impacts on species and habitats of particular legal, management and/or ecological concern. However, because of the diversity and complexity of the Gulf of Mexico ecosystem, the vast area of the northern Gulf of Mexico that was affected by the Spill, and the practical challenges of performing scientific studies in some habitats such as the deep ocean, it is impossible to study every species, habitat, location, and ecological process that was potentially affected. Therefore, the Trustees have focused the injury assessment on representative species, habitats, and locations. In this way, the Trustees can then use the results of individual studies to make reasonable scientific inferences about natural resources that were not explicitly studied, based on an understanding of ecological relationships and processes.

Oil and/or dispersants can adversely impact natural resources and natural resource services through a variety of pathways and modes of action (for example smothering or chemical toxicity). Several examples are provided in the following sections of this chapter. In addition, while efforts to protect biota and habitats from oiling and/or to remove oil from the environment are necessary and critical, such cleanup or response actions can themselves cause natural resource injuries. For example, adverse impacts to habitats and/or biota can be caused by:

- Installation, maintenance, and removal of a wide range of types of physical barriers constructed to prevent oil from entering shoreline habitats;
- Manual and mechanical activities required to remove oil from shoreline, nearshore, and substrate habitats (including staging areas and access areas); and/or
- The release of freshwater from diversion structures to keep oil from moving into nearshore habitats.

In their assessment of natural resource injuries from oil and/or dispersants and other response related injuries, the Trustees are applying a combination of field, laboratory, and numerical modeling approaches. Field studies have been performed to document environmental conditions, evaluate exposure, and assess the condition of biological resources. In some circumstances, field-based enumeration of affected biota (e.g., oiled birds) can be undertaken and used to inform estimation of the magnitude and severity of certain types of spill impacts. However, because of the enormous spatial scale affected by the Spill, detecting changes in some natural resources by observing or counting organisms in the field can be difficult and/or impractical. The Trustees are increasing the interpretive power of their assessment by combining field studies with controlled laboratory studies designed to study the effects of oil on Gulf of Mexico biota. As appropriate, field and laboratory data are combined in mathematical computer models to enable interpretation and quantification of injuries at the broad spatial and ecological scale necessary for the NRDA.

3.3 Injuries to Natural Resources

The following subsections of this chapter provide an update for several areas of the Trustees' natural resource damage assessment, including:

- Laboratory toxicity testing
- Deep benthic environments
- Water column fish and invertebrates
- Marine mammals
- Sea turtles
- Birds
- Oysters
- Marsh and mangrove habitat
- Beach habitat
- Un-vegetated nearshore sediment
- Submerged aquatic vegetation
- Recreational use

The information provided in this chapter is not intended to provide a comprehensive review of the status of all assessment activities. Rather, it provides an appropriate level of background and context for the task of considering the proposed Phase IV Early Restoration projects that are the subject of the remaining chapters in this document.

3.3.1 Laboratory Toxicity Testing Program

The Trustees have undertaken a comprehensive laboratory toxicity testing program to evaluate the adverse effects of oil and dispersant on marine organisms of the Gulf of Mexico. The testing program is designed to determine the nature of toxic effects that occurred to different organisms in different habitats, the concentrations of oil and dispersant at which such effects occur, and how exposure to oil in a range of weathering states can adversely affect the viability of organisms in various stages of their life histories. Laboratory toxicity test results are being published as they are completed. Some examples include: Brette et al. 2014, Incardona et al. 2014, and Mager et al. 2014. Additionally, Trustees are mindful that the scientific community has undertaken extensive testing and research regarding the Spill. Trustees continue to stay abreast of current research, which may impact the understanding of ecological injury in the northern Gulf of Mexico.

The Trustees' aquatic toxicity tests involve exposing test organisms to samples of the released oil in various states of weathering (fresh to very weathered), with and without the presence of dispersant. This process was applied to samples of contaminated sediment as well. A wide variety of representative marine and estuarine species, including fish, shellfish, and invertebrates, are being tested as part of the program. Scientists typically conduct these laboratory toxicity tests by exposing test organisms to a range of oil concentrations under controlled conditions. By conducting the tests in this way, scientists are able to calculate the adverse effects that would be expected to occur at various oil concentrations in specific exposure conditions.

The Trustees' aquatic toxicity testing program includes studies both of the lethal effects of oil and dispersant to determine the concentrations of oil that kill organisms, and the "sub-lethal" impacts of oil to determine concentrations of oil that can cause significant adverse effects on the health, growth, reproduction, or general viability of organisms. For example, some of the sub-lethal effects of oil that have been documented in the Trustees' aquatic toxicity tests to date include:

- Disruptions in growth, development, and reproduction;
- Tissue damage;
- Altered cardiac development and function;
- Disruptions to the immune system;
- Biochemical and cellular alterations; and
- Changes in swimming ability and other behaviors that can adversely affect an organism's viability in the environment.

Overall, the results of the Trustees' aquatic toxicity testing program will provide a means for the Trustees to reach conclusions regarding the nature and extent of different types of adverse impacts to aquatic organisms based on observed, measured, and modeled concentrations of oil and/or dispersant on the surface of the water, in the water column, and in bottom sediments.

Similar to the efforts to assess the adverse effects of oil on marine and estuarine organisms, the Trustees are assessing the adverse effects of oil on avian species that inhabit the Gulf of Mexico. Millions of birds utilize the northern Gulf including, but not limited to, sea birds, colonial nesting birds, shorebirds, waterfowl and passerines. The Trustees are conducting laboratory toxicity tests to determine the types and extent of adverse effects of oil from the Spill on avian species.

3.3.2 Deep Benthic Environments

Deep sea habitats include important reservoirs of biodiversity and also serve vital roles in the recycling of carbon and other building blocks for life in the sea, enabling productivity from the near bottom to surface waters of the ocean (Buhl-Mortensen et al. 2010, Gjerde 2006, Llodra and Billett 2006, Rex and Etter 2010, Ruppert and Barnes 1993, Grassle and Maciolek 1992 and Gage 1996). New species and ecological relationships are regularly discovered with our increased exploration of these remote regions of the sea. This zone is characterized by limited light penetration and is populated by organisms adapted to cold, high-pressure, and dark conditions (Fisher et al. 2007, MacDonald and Fisher 1996). Much of the energy reaching the sea floor is provided in the form of "marine snow," which is a mixture of sediment and biological detritus that, in general, falls from the upper photic zone, through the water column, to the bottom (Alldredge and Silver 1998). The deep environments under investigation pursuant to the NRDA fall into several major habitat types. These include soft bottom sediments, which make up the majority of the ocean floor in the northern Gulf of Mexico; hard bottom rocky patches that can support deep sea coral communities in depths of greater than 650 feet (200 m); and mesophotic coral reefs found at depths of about 160 – 650 feet (50 – 200 m), the deepest zone where light can penetrate.

Studying the deep ocean environment is challenging, and relatively little is known about the ecology of the organisms using these habitats. The Trustees have been working to quantify the nature and magnitude of injuries to these unique and sensitive deep water habitats using remotely operated vehicles, autonomous underwater vehicles, and complex water and sediment sampling devices. Data and analyses available to date have documented injuries to these habitats attributable to the Spill, including but not limited to a large footprint of injury around the wellhead and extending to the southwest, as well as losses at mesophotic coral reefs located to the north and northeast of the wellhead. The footprint of injury around the wellhead includes areas of soft bottom sediment in which diversity of sediment-dwelling animals has been reduced (Montagna et al. 2013) and deep sea coral habitats which have been degraded (White et al. 2012, Hsing et al. 2013, and Fisher et al. 2014). Injuries to mesophotic coral reef habitats include reduced numbers of planktivorous fish species and increased prevalence of injured corals in the affected area compared to reference reefs that were outside the influence of the Spill.

3.3.3 Water Column Fish and Invertebrates

The water column of the Gulf of Mexico supports a wide variety of organisms, including numerous species of fish at different life stages (from fertilized eggs, to larvae, juveniles, and adults), as well as many species of phytoplankton, zooplankton, and bacteria (Mann and Lazier 2006 and Lyczkowski-Schultz et al. 2004). All of these organisms play an important ecological role, including serving as prey for fish, invertebrates, birds, sea turtles, and marine mammals as well as cycling and transporting nutrients between nearshore and offshore areas and between the surface and the deep sea (Felder and Camp 2009). Many fish and invertebrate species support robust commercial and recreational fisheries.

To help understand the fate, chemical weathering, transport, and toxicity of the oil, the Trustees have collected data to document physical and chemical water conditions in and around the spill area. These data include currents and physical properties of the water column in the vicinity of the wellhead; dissolved oxygen data to help assess the effect of microbial degradation of the oil and to track the fate of the oil; and data on suspended sediments, chlorophyll concentrations, and other physical measurements. Trustees are accounting for temporally variable surface water oiling in calculations of exposure and injury. Concentrations of oil components are calculated for multiple depth intervals. To help evaluate impacts to water column organisms, the Trustees have gathered and analyzed information on the density and abundance of organisms that live in the water column, including variations in their distribution over space and time. Animals exposed in the water column include small and large pelagic fish, demersal fish that live near the bottom of the ocean, invertebrates, and planktonic organisms in both the nearshore and offshore environment. Preliminary Trustee analysis suggests that tens of thousands of square miles of surface waters were affected by oiling and that hundreds of cubic miles of surface water may have contained petroleum compounds at concentrations associated with mortality to sensitive aquatic organisms. This indicates that injuries to water column organisms were widespread, both spatially and in terms of the diversity of organisms and life stages that were affected.

3.3.4 Marine Mammals

Marine mammals that reside in the Gulf of Mexico include 21 species of cetacean (whales and dolphins) and one sirenian (manatee) (Waring et al. 2010). All are protected under the Marine Mammal Protection Act, 16 U.S.C. §§ 1361 *et seq.* (MMPA). Sperm whales (*Physeter macrocephalus*), the West Indian manatee (*Trichechus manatus*) North Atlantic right whales (*Eubalaena glacialis*), fin whales (*Balaenoptera physalus*), and humpback whales (*Megaptera novaeingliae*), are listed as endangered under the Endangered Species Act (ESA). Based on life histories and habitat preferences of these species, and on observations of oil within marine mammal habitats, the Trustees divided marine mammals into three functional groups for the purposes of injury assessment: oceanic marine mammals (targeting primarily sperm whale, Bryde's whale, striped dolphin and Risso's dolphin), coastal dolphins, and estuarine bottlenose dolphins.

Available information suggests that thousands of marine mammals were exposed to oil from the Spill. Recently published NRDA studies (Schwacke et al. 2014) indicate the presence of adverse health outcomes resulting from this exposure. For example, data from 2011 health studies indicate that bottlenose dolphins in Barataria Bay (which suffered heavy and prolonged exposure to oil) demonstrated signs of severe ill health, with many dolphins sampled in Barataria Bay given a ”guarded,” ”poor” or ”grave” prognosis. Symptoms included low body weight, anemia, impaired stress response, and lung disease (Schwacke et al. 2014). These impacts are consistent with expected effects of exposure to oil or petroleum-related chemicals reported in the literature. Data analysis for the marine mammal assessment in the Mississippi Sound and in other areas of the Gulf of Mexico has been underway, as has been collection and evaluation of data relevant to the assessment of the type and magnitude of injury to marine mammals attributable to the Spill.

In addition to live animal studies, the Trustees are analyzing data collected from the high number of dead stranded marine mammals (>1,300, primarily bottlenose dolphins) since 2010. These strandings have resulted in the declaration of an Unusual Mortality Event (UME) under the Marine Mammal Protection Act. This UME is larger and has lasted longer than any other dolphin mortality event in the Gulf on record (Litz et al 2014). A recent publication identifies four distinct spatial and temporal patterns within the ongoing UME, three of which occur during and after the spill and in areas exposed to the oil (Venn-Watson et al 2015). A UME was also declared in Texas between November 2011 and March 2012. The body conditions of some of the dolphins from the Texas UME were similar to some of the animals that are included in the larger Gulf UME.

The Trustees also investigated non-oil factors that may have contributed to the observed health effects or have been causes of previous UMEs, such as disease (morbillivirus), biotoxins from harmful algal blooms and other contaminants. Researchers have determined that these factors are unlikely to be associated with the current UME.

Dolphins are long-lived species that are slow to mature and reproduce, and it could be many years before the full effects of the *Deepwater Horizon* spill on dolphin populations are realized.

3.3.5 Sea Turtles

There are five species of sea turtles living in the Gulf of Mexico and all are listed as threatened or endangered under the ESA: Kemp's ridley (*Lepidochelys kempii*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*) and hawksbill (*Eretmochelys imbricata*). Sea turtles can nest on any beach with suitable conditions throughout the Gulf, from Mexico to Florida. All five species of sea turtles are migratory and thus have a wide geographic range. Sea turtles were exposed to oil in open water, in *Sargassum* habitat, or on nesting beaches, either through ingestion of oil, direct contact with oil, and/or inhalation of volatile oil and dispersant-related compounds. In addition, response activities, such as collecting and burning oil at sea, skimmer operations, boom deployment, berm construction, increased lighting at night near nesting beaches, beach cleanup operations and boat traffic may have injured sea turtles directly or by blocking access to turtle nesting beaches and changing their reproductive behavior.

The Trustees are using a variety of information to evaluate injuries to sea turtles, including stranding records; response recovery operation records; aerial surveys from aircraft; analysis of open ocean areas, including *Sargassum* habitat, where oceanic juvenile turtles are found; baseline turtle densities; veterinary examination of oiled turtles; necropsies of dead turtles, including tissue analyses; studies on the toxicological effects of oil; and analysis of nesting and hatching success. Preliminary findings include:

- More than 500 oceanic juvenile turtles were recovered during attempts to rescue sea turtles from oil and oiled *Sargassum* in the summer of 2010. Most were visibly oiled. Oil was often found within the mouth, pharynx, and esophagus in oral exams of live turtles and necropsies of dead turtles that were visibly, externally oiled upon recovery;

- More than 2,000 sea turtles (of all life stages) were found stranded dead in the northern Gulf of Mexico from 2010 to 2013. Causes of these strandings are being investigated.

- Broad-scale aerial surveys conducted in 2010 are yielding density, abundance, and exposure estimates of juvenile and adult turtles in neritic waters (less than 100 m depth) that were sighted within the footprint of surface oiling; and

- Nearly 15,000 hatchling sea turtles emerged from nests translocated from Gulf of Mexico beaches in Florida and Alabama and were released on the Atlantic coast of Florida to prevent exposure to oil. Sea turtles typically return to their natal beaches (the beach where they were hatched) to nest. The effects of the translocation to the Atlantic may have disrupted this natal homing behavior.

Sea turtles live for many decades and the full extent of impacts to the five affected species of sea turtles may not be apparent for many years.

3.3.6 Birds

The northern Gulf of Mexico is important to a variety of birds that depend on its diverse and productive habitats. Approximately 500 species use the northern Gulf at some point in their life cycle. The varied habitats include beaches, mudflats, dunes, bars, bay and barrier islands, emergent (marsh) and forested (mangrove) wetlands, and shallow bay and marine open water. Species of conservation concern and that have regional importance using these habitats for breeding include American oystercatcher, snowy plover, Wilson's plover, gull-billed tern, black skimmer, reddish egret, black rail, and brown pelican. Colonial waterbird rookery islands along the Gulf provide some of the most diverse and concentrated bird nesting sites in the nation. The northern Gulf also supports nearly half of the southeastern population of brown pelican. The northern Gulf of Mexico is critically important for migration and overwintering habitat for a variety of migratory birds. In addition, Gulf Coast marshes are important to many marsh birds, including but not limited to seaside sparrows, black rail, clapper rail, king rail, Virginia rail, sora, least bittern, and American bittern. The Gulf Coast also supports protected bird species, such as the piping plover and red knot, which are federally listed under the ESA. At least 70 percent of all piping plovers winter on the shores of the Gulf of Mexico.

Seabirds, colonial waterbirds, coastal marsh birds, and shorebirds are particularly susceptible to impacts from the oil. Oiled birds can lose the ability to fly, dive for food, or float on the water, which can lead to drowning. Oil and dispersants interfere with the water repellency of feathers and can lead to problems of thermoregulation (e.g., hyper- or hypothermia). In addition, birds may ingest or inhale oil while cleaning (preening) their feathers, by consuming contaminated vegetation or prey, or by incidental ingestion of contaminated sediment. This exposure can kill the bird, leave it susceptible to predation or lead to long-term physiological, metabolic, developmental, and/or behavioral effects, which can in turn lead to reduced survival and/or reproduction. Exposure to oil also can reduce the hatching of eggs and survival of hatchlings. Examples of direct and indirect avian injury can include, but are not limited to, mortality, productivity loss, decline in reproductive success, sub-lethal effects, and reduced body fitness due to loss of prey resources and habitat for nest building.

The Spill injured avian resources throughout the northern Gulf through a variety of mechanisms, including but not limited to exposure to oil, disturbance from response activities, cleaning in rehabilitation facilities, and degradation of habitat. Approximately 8,500 live impaired and dead birds were collected in the northern Gulf of Mexico as part of wildlife rescue and NRDA operations during and following the Spill. These birds represent over 100 species collected in all five Gulf Coast states. Due to the inability to search all areas and recover all affected birds, collected birds represent a fraction of the total number of birds that were killed or impaired as a result of the Spill. Additionally thousands of photographs were taken of birds that showed external exposure of oil on feathers. This exposure could have potential short-term and long-term effects on individual and offspring survivorship.

The Trustees are conducting a broad spectrum of studies to fully evaluate the impact of the Spill on avian species, including incident-specific avian toxicity studies and evaluations of potential impacts experienced by oiled birds collected from the northern Gulf. This approach allows for controlled laboratory testing of the oil to specifically identify adverse effects and for confirmation that these effects are observed in oiled, wild birds.

3.3.7 Oysters

The eastern oyster (*Crassostrea virginica*) forms an integral component of nearshore coastal ecosystems and local economies along the Gulf of Mexico (Eastern Oyster Biological Review Team 2007). Oysters provide numerous ecological services to estuarine systems, including production of biomass, filtering water to remove organic and inorganic particles, and improving water quality and clarity. Oyster reefs provide habitat for numerous other shellfish, crabs, and finfish. Oysters are also a valuable commercial and recreational fishery resource (Eastern Oyster Biological Review Team 2007). Oysters in the Gulf of Mexico are present in both intertidal and sub-tidal areas (Eastern Oyster Biological Review Team 2007). Commercial oysters are harvested from sub-tidal areas, but intertidal oysters may be important as a source of larvae to maintain populations of both intertidal and sub-tidal oysters.

In response to the Spill, large volumes of freshwater from Mississippi River diversion structures in Louisiana were released as part of a set of response actions designed to reduce the movement of oil into sensitive marsh and shoreline areas. The volume and duration of the low salinity water from these response actions adversely affected oysters. Analyses of 2010 data suggest oysters in areas affected by lowest salinity water experienced substantial mortality in Louisiana. Oyster abundance and biomass in 2010 was low in many areas.

Oyster gametes and larvae float to the surface after spawning and remain at the surface for the early part of their planktonic period. They can travel up to 40 miles in surface waters. Oyster eggs, sperm, and larvae were exposed to oil and potentially dispersants through direct contact with water. PAHs are toxic to oyster gametes, embryos, larvae, juveniles and adults and result in lethal and sub-lethal effects (e.g., impaired reproductive success). Intertidal adult oysters were also likely exposed to oil droplets and oil on suspended sediment and detritus.

Fall 2010 sample results suggest oyster larvae were rare or absent in many of the samples collected across the northern Gulf of Mexico. Oyster spat recruitment was extremely low or zero in 2010 over large areas of subtidal oyster habitat along the northern Gulf coast. There was also low spat recruitment through the spring and fall of 2011 and the fall of 2012.

3.3.8 Marsh and Mangrove Habitat

The high productivity of coastal marsh vegetation provides an ideal nursery ground that supports a wide variety of finfish, shrimp, and shellfish (Mitsch and Gosselink 2007, Daily et al. 1997, and Minello and

Webb 1997). Many bird species are dependent on marshes for foraging, roosting and nesting, and marshes are also critical to both migratory and wintering waterfowl (Mitsch and Gosselink 2007). The marsh edge also serves as a critical transition between the emergent marsh and open water. This area serves as the gateway for the movement of organisms and nutrients between intertidal and subtidal estuarine environments. Additionally, marsh edge has been found to be the most productive area of the marsh for many organisms (English et al. 2009).

The highly productive black mangrove (*Avicennia germinans)* occurs in association with smooth cordgrass (*Spartina alterniflora*) in many locations of the northern Gulf of Mexico and is important for maintaining shoreline protection and stabilization (Carlton 1974 and Massel et al. 1999). It is an essential feeding and nursery habitat for juvenile fish such as snapper (Coleman et al. 2000 and Mumby et al. 2004). The roots of mangroves that emerge from the water and soil provide excellent habitat for small organisms. Some species of colonial waterbirds, such as herons, egrets, and pelicans, build nests in mangroves and forage in the mangroves or nearby (Davis et al. 2005).

Declines in marsh vegetative health have been observed in oiled marshes relative to reference marshes. Key measurements illustrating adverse effects of oil on marsh vegetation included reductions in live plant cover, total vegetation cover, and above ground biomass. These effects generally are more pronounced along the highly productive marsh edge. Moreover, shorelines with more significant oiling tended to experience greater adverse effects.

In addition to vegetation impacts, impacts on animals that live in the marsh have been demonstrated. For example, researchers have documented a lower abundance of *Littoraria* snails (a typically abundant marsh organism that is an important source of prey in intertidal habitats) in heavily oiled areas relative to un-oiled areas more than a year after the Spill began.

3.3.9 Beach Habitat

Beaches are vital both ecologically and economically (Schlacher et al. 2008 and United Nations Millennium Assessment 2005). Ecologically, beaches provide habitats for numerous migratory birds, invertebrates, and terrestrial wildlife. Organic material such as sea grass that is cast up onto the beach by the surf, tides, and wind provides foraging opportunities and shelter for breeding and wintering shorebirds (Dugan et al. 2003). Colonial nesting gulls, terns, and skimmers nest on open beaches. The sand beaches of the northern Gulf Coast, including various state and federal parks, are also important recreational destinations and tourist attractions that support local and regional economies (e.g., Parsons et al. 2009, Mobile Area Chamber of Commerce 2010, Gulf Coast Business Council Research Foundation 2012, and Houston 2013).

Preliminary estimates indicate that about 600 linear miles of sand beach habitat were oiled as a result of the Spill. At the peak of the Spill, beaches were oiled from Texas to the Florida Panhandle. Many of these beaches were oiled repeatedly over an extended time period. A significant effort to remove oil from beaches was launched across the northern Gulf of Mexico. Oiling of beaches can have a variety of effects on the physical and biological communities of the beach and near shore habitats. Shoreline protection and clean up related to the Spill affected biological communities as well. At least 400 miles of oiled beaches also experienced some level of impairment due to response activities.

3.3.10 Unvegetated Nearshore Sediment

The unvegetated nearshore benthic sediments and tidal flats of the Gulf of Mexico serve as an important and diverse habitat for many species. Crabs, shrimp, fish, shorebirds, waterfowl and terrestrial wildlife feed on the rich populations of organisms living on and in the nearshore sediments (e.g., McTigue and Zimmerman 1998, Perry and McIlwain 1986, Fox et al. 2002, and Gabbard et al. 2001). This sediment-based system notably includes the major shrimp species in the Gulf of Mexico, including white and brown shrimp (Muncy 1984, Bielsa et al. 1983, Lassuy 1983, also see www.fishwatch.gov). Three key commercial species of crabs in the Gulf of Mexico region also are supported by sediment-based ecosystems: blue crab, Gulf stone crab, and stone crab (Lindberg and Marshall 1984, Perry and McIlwain 1986, also see www.fishwatch.gov). Gulf sturgeon (threatened under ESA) also forage on the bottom of the bays and estuaries of Florida, Alabama, Mississippi, and Louisiana, eating invertebrates such as mollusks, worms and crustaceans (Fox et al. 2002, USFWS and NMFS 2009).

As part of the evaluation of the magnitude and extent of oil that stranded and persisted in the shoreline and nearshore environment, nearshore sediment was sampled within one kilometer of the shoreline in 2010 and 2011. These sediment samples have been analyzed for polycyclic aromatic hydrocarbons (PAHs) and other parameters to evaluate the potential for injury to nearshore species. Analysis of over 2,500 sediment samples has revealed the presence of PAHs in many nearshore sediments, with highest concentrations occurring adjacent to heavily oiled vegetated shorelines. Field and laboratory toxicity studies are being conducted to evaluate the implications of this contamination for nearshore fish and invertebrates.

Overall, the Trustees' assessment of injury to nearshore sediment habitat indicates that shallow water sediments were contaminated with oil following the Spill and that the degree of contamination was sufficient to cause a range of adverse effects on survival, reproduction, health of organisms and overall ecosystem productivity within this important habitat.

3.3.11 Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) refers collectively to a group of rooted plants that grows up to the water surface. Various seagrasses grow in marine water, and other species live in fresh and brackish habitats of the Gulf of Mexico. SAV is a highly productive habitat in the northern Gulf of Mexico which provides food and shelter for fish, shellfish, crustaceans, and other invertebrates (Gulf of Mexico Program 2004). It also is an important foraging habitat for sea turtles and resident and migrating birds (USFWS 2012 and Gulf of Mexico Program 2004). It serves as nursery habitat for many species, produces oxygen in the water column as part of the photosynthetic process and enhances water quality by filtering water and removing excess nutrients. SAV also stabilizes sediment and is vital to keeping barrier islands intact (Fonseca et al. 1998 and Porrier 2007).

Sampling was performed to evaluate oil exposure at a number of sites in the northern Gulf of Mexico. Oil was detected in samples at several SAV sites, and preliminary information suggests that at least 10 square miles of SAV beds were oiled and/or adversely affected by a variety of response activities.

3.3.12 Recreational Use

The Gulf of Mexico provides a wide range of recreational opportunities to local residents and visitors from across the nation. These include recreational fishing, boating, visiting beaches, and other activities. The Spill resulted in closures of beaches, fishing areas, publicly owned and managed areas, and waterways, preventing access to these areas by both local and more distant recreational users. In addition to these direct closures, the Spill also caused some recreational users to change the type of recreational activities they would otherwise engage in. Other users cancelled their planned recreational visits or traveled to alternate locations because of the threat of oiling (or because of actual oiling that did not result in beach closures), or visited oiled beaches and therefore suffered from degraded, lower quality trips. Other coastal recreational activities would likely have been disrupted as a result of the Spill.

For each broad type of injury (shoreline use, boating/boat based fishing trips, and shore-based fishing), Trustee experts developed a sampling and analysis plan to estimate the change in recreational use in the assessment area resulting from the Spill. Each of these approaches is described in more detail below. These assessment activities provide estimates of recreational use including counts of recreational users over time and information on the type of activities in which users engaged. By comparing recreational use during the spill period with the counts during a baseline period, and adjusting for other non-spill related differences between the two periods, the Trustees can estimate the number of lost recreation user days in the assessment area. In addition, the Trustees are evaluating recreational use data from a variety of sources and surveys for determining potential impacts in other coastal areas where the data described above are unavailable.

One major category of injury is shoreline use, which includes any recreational visitation to beach sites in the assessment area, such as sunbathing, swimming, birding or other wildlife viewing, walking, and running. Aerial over-flights and on-the-ground fieldwork on beaches that began in the weeks following the Spill provide a measure of recreational use along the Gulf Coast shoreline.

Another major category of injury is boating and boat-based fishing trips, which includes any recreational users who would have engaged in recreational fishing or pleasure boating in the assessment area during and after the Spill period. This assessment does not include those fishing for commercial purposes since losses to commercial enterprises are not part of an NRDA claim. Assessment teams started counting departures at public boat ramps in the assessment area shortly after the Spill at publicly accessible sites. As boating and boat-based fishing also occurs from non-public locations, such as backyards, private marinas, and other sites, Trustees also conducted surveys to assess impacts upon this recreational user group. Together, these data collection efforts provide measures of the level and types of boating and boat-based fishing along the coastal waters of the Gulf of Mexico.

Another major category of injury that required a significant assessment effort is shore-based fishing, which includes fishing from beach locations as well as fishing from piers and jetties or other similar structures. Assessment teams conducted field counts of users engaged in this activity type beginning shortly after the Spill.

Preliminary Trustee review of recreational use data indicates that over ten million recreational user days were lost or otherwise adversely affected by the Spill.

3.4 Use of Assessment Data to Inform Early Restoration Project Selection

Throughout the Early Restoration process, the Trustees have used preliminary results from the assessment to inform and guide the selection of Early Restoration projects. As noted above, the assessment work to date has clearly demonstrated areas of extensive oiling of coastal and nearshore habitats from Texas to the Florida Panhandle. Preliminary results also make clear that the oiling has had significant adverse impacts on coastal and nearshore habitats, including species using the open Gulf of Mexico. In addition, initial results from the Trustees' assessment clearly show that oiling caused very large reductions in coastal recreation from Texas to Florida. Analysis of recreational data assembled by the Trustees indicates that more than 10 million user-days of beach, fishing and boating activity were lost due to the spill.

Early Restoration reflects the Trustees' programmatic approach to focus on injury categories for which the nature of the adverse impacts is reasonably well understood. A future damage assessment and restoration plan will be developed to address all assessed injuries and losses, taking into account Offsets provided by the Early Restoration program.

3.5 References

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