4.11 Injury Assessment: Summary and Synthesis of Findings

What Is in This Section?

- **Introduction (Section 4.11.1):** What events led to development of the injury assessment conclusions presented in Section 4.11?
- **Exposure to Oil and Response Activities Resulted in Extensive Injuries to Multiple Habitats, Species, Ecological Functions, and Geographic Regions (Section 4.11.2):** After assessing injury from the *Deepwater Horizon* incident to representative habitats, processes, communities, resources, and services of the northern Gulf Coast ecosystem, what did the Trustees find?
- **Use of Inference to Assess Natural Resource Injuries Not Directly Measured by Trustees (Section 4.11.3):** How did the Trustees assess injury to natural resources not studied?
- **The Scope of Adverse Effects from the *Deepwater Horizon* Incident Constitutes an Ecosystem-Level Injury (Section 4.11.4):** What findings led the Trustees to conclude that the effects of the *Deepwater Horizon* incident constitute an ecosystem-level injury?
- **Treatment of Unquantified Injuries (Section 4.11.5):** How did the Trustees' injury assessment and restoration plan account for injuries they could not quantify?
- **References (Section 4.11.6)**

4.11.1 Introduction

The April 20, 2010, explosion, subsequent fire, and sinking of the *Deepwater Horizon* mobile drilling unit triggered a massive release of oil and other substances from the BP Macondo well. For 87 days after the explosion, the well continuously released oil into the northern Gulf of Mexico, ultimately releasing 3.19 million barrels (134 million gallons) of oil into the Gulf of Mexico.

The scope of the oil spill was unprecedented; it was the largest offshore oil spill in U.S. history. As the oil rose from the well, it spread over the sea surface. Carried by wind, wave, and tidal action, oil reached shoreline areas where it polluted beaches, bays, estuaries, and marshes from eastern Texas to the Florida Panhandle.

Source: *NASA (2010).*

Figure 4.11-1. The *Deepwater Horizon* oil spill was the largest offshore oil spill in U.S. history, releasing more than 3 million barrels (134 million gallons) of oil into the northern Gulf of Mexico over an 87-day period. This satellite image, taken on May 24, 2010, shows the spreading surface slick of oil approximately 50 miles off the Louisiana coast.

The *Deepwater Horizon* Trustees—the U.S. Department of Commerce; the U.S. Department of the Interior; the U.S. Environmental Protection Agency; the U.S. Department of Agriculture;[1] and designated agencies representing each of the five Gulf states (Alabama, Florida, Louisiana, Mississippi, and Texas)—undertook a natural resource damage assessment, or NRDA, to evaluate the nature and extent of adverse effects of the *Deepwater Horizon* incident on natural resources and their services. This assessment forms the basis of the Trustees' programmatic restoration plan.

As a result of this extensive, multi-year NRDA, the Trustees concluded that the *Deepwater Horizon* oil spill and related oil spill response actions caused a wide array of injuries to natural resources and the services they provide throughout a large area of the northern Gulf of Mexico (Sections 4.2 to 4.10). These conclusions were based on the scientific findings of the studies performed by the Trustees as part of the NRDA and on data collected during the oil spill response, together with supplemental findings published by the scientific community.

This section of the Draft PDARP/PEIS summarizes the Trustees' injury assessment conclusions, which provide the basis for the programmatic restoration plan presented in Chapter 5.

Key Points

- The *Deepwater Horizon* spill resulted in a surface slick ultimately covering approximately 43,300 square miles (112,115 square kilometers), an area larger than the state of Virginia.
- Oil was pushed toward the shorelines of the Gulf states by currents, winds, and wave action. At least 1,300 miles (2,100 kilometers) of shoreline were exposed to oil from the spill. The extent of shoreline oiling exceeded the distance by road from New Orleans to New York City.
- The oil released into the environment was found to be toxic to a wide range of organisms, including fish, invertebrates, plankton, birds, and mammals, causing a wide array of toxic effects including death, disease, reduced growth, impaired reproduction, and physiological impairments that reduce the fitness of organisms (their ability to survive and reproduce).
- Concentrations of oil found to cause toxicity were exceeded in surface waters, sediments, and marsh habitats in many locations in the northern Gulf of Mexico. The degree and extent of these exceedances of toxic concentrations varied by location and time. The extent and degree of such exceedances has declined substantially from 2010 to the present.
- Natural resources were exposed to oil and other contaminants released from the *Deepwater Horizon* incident over a vast area. Exposure to oil and response activities resulted in extensive injuries to multiple habitats, species, ecological functions, and geographic regions.

[1]The Department of Defense (DOD) also is a trustee for natural resources associated with DOD-managed land on the Gulf Coast, which is included in the ongoing NRDA.

- The *Deepwater Horizon* incident resulted in injuries to marsh habitats, including marsh plants and associated organisms; to shoreline beaches and sediments and organisms that live on and in the sand and sediment; to fish and invertebrates that live in the water; to a wide range of bird species; to floating *Sargassum* habitats offshore and submerged aquatic vegetation; to deep sea and nearshore ocean-bottom habitats, including to rare, deep water corals; to all five species of endangered sea turtles that live in the Gulf of Mexico; and to dolphins and other marine mammals.

- The spill directly reduced the public's use of popular recreational activities such as boating, fishing, and beach-going between May 2010 and November 2011. The injuries caused by the *Deepwater Horizon* incident affected such a broad array of linked resources and services over such a large area that they cannot be adequately described at the level of a single species, a single habitat type, a single set of services, or even a single region. Rather, the effects of the *Deepwater Horizon* incident constitute an ecosystem-level injury. Consequently, the Trustees' restoration plan employs an ecosystem-level approach to address ecosystem-level injuries.

4.11.2 Exposure to Oil and Response Activities Resulted in Extensive Injuries to Multiple Habitats, Species, Ecological Functions, and Geographic Regions

The scale of the *Deepwater Horizon* spill was unprecedented, both in terms of the area affected and the duration of the spill. Due to the enormous scope of this incident, evaluation of all potentially injured natural resources in all potentially oiled locations at all times remains cost-prohibitive and scientifically impractical. The Trustees therefore undertook an ecosystem approach to injury assessment that included the evaluation of representative (see Section 4.1.3.1) habitats, ecosystem processes and linkages, ecological communities, specific natural resources, and human services. A summary of the Trustees' findings for these representative habitats and resources follows.

Key finding: Natural resources were exposed to oil and other contaminants released from the *Deepwater Horizon* incident over a vast area. (Section 4.2)

As described in Chapters 2 and 4, the release into the Gulf of Mexico of 3.19 million barrels of oil and 1.84 million gallons of dispersant resulted in extensive exposure of natural resources. For 87 days, BP's Macondo well released an average of nearly 37,000 gallons of fresh oil each day into the ocean. This is essentially equivalent to a substantial oil spill occurring every day for nearly three months.

- Combining direct observations, remote sensing data, field sampling data, and other lines of evidence, the Trustees documented that oil flowed within deep ocean water currents hundreds of miles away from the blown-out well; and that it moved upwards and across an area of the ocean surface. This movement resulted in observable slicks that covered an area of approximately 43,300 square miles (an area greater than the State of Virginia), affecting water quality and exposing aquatic biota. Oil was deposited onto at least 400 and possibly more than 700 square miles of the sea floor and washed up onto least 1,313 miles of shoreline, a distance greater than the road mileage between New Orleans and New York City.

- The estimated average daily volume of contaminated water under surface oil slick was 15 trillion gallons—approximately 40 times the average daily discharge of the Mississippi River at New Orleans.
- Natural resources were exposed to oil and dispersants across a broad range of habitats, including the deep sea, about 5,000 vertical feet of water column, the sea surface, and nearshore habitats such as beach, marsh, mangrove, and submerged aquatic vegetation.
- A wide variety of biota—ranging from those at the base of the food web to upper-level predators such as fish, sea turtles, marine mammals, and birds—were exposed to oil throughout the northern Gulf of Mexico. Natural resources were exposed through various pathways, including direct exposure to oil and dispersant, as well as contact with water, air, and sediments containing the contaminants.
- Despite being subject to natural weathering processes over the past five years, oil persists in some northern Gulf habitats, where it continues to expose species of natural resource value to residual contaminants.

Key finding: **Water column resources,** including fish, invertebrates, and *Sargassum*, were injured as a consequence of exposure to oil floating on the ocean surface; to oil mixed into the upper water column by wind and wave action and the addition of chemical dispersants; to oil as it moved from the wellhead to the surface; and to oil mixed into the deep sea. (Section 4.4)

- This exposure to oil at or near the surface occurred in an area of high biological abundance and high productivity during a time of year (spring and summer) that corresponds with peaks in seasonal productivity in the northern Gulf of Mexico.
- The Trustees determined that developing fish larvae exposed to the surface slick suffered almost 100 percent mortality, and during the time period oil was present, oil concentrations in three water column zones—the (1) nearshore and offshore sea surface and upper mixed layer of the water column; (2) rising cone of oil from the wellhead; and (3) deep sea—exceeded levels known to cause mortality and sublethal effects to fish. Sublethal toxic effects can reduce an organism's health, fitness, and ability to reproduce and survive. These toxic effects were not uniform over the entire spill area; rather, they varied by location and time.
- Using information on oil toxicity and environmental exposures, the Trustees quantified the direct kill and production foregone of larval fish and invertebrates exposed to oil in the water column. The Trustees estimate that 2 trillion to 5 trillion larval fish and 37 trillion to 68 trillion invertebrates were killed in the surface waters as a result of floating oil and mixing of that oil into the upper water column. With respect to the deep waters, the Trustees' assessment showed that exposure to *Deepwater Horizon* oil resulted in the death of 86 million to 26 billion fish larvae and between 10 million and 7 billion planktonic invertebrates. Of these totals, 0.4 billion to 1 billion larval fish and 2 to 6 trillion invertebrates were killed in estuarine surface waters. This translates into a loss from millions to billions of fish that would have reached age one. Additionally, the larval fish that were killed but would not have survived to age 1 are a

significant loss; they are an energy source for other components of the ecosystem. The Trustees estimated that the lost larvae of just nine of the more than one thousand known fish species in the Gulf of Mexico would have developed into thousands of tons of adult fish had the spill not occurred.

- Available information indicates that the injuries, although substantial during the time oil was present, have not resulted in any apparent system-wide population crashes to surveyed fish or water column invertebrate species. However, while the populations of directly affected species appear not to have suffered a lasting impact, the death of such large numbers of larval fish and invertebrates represents a substantial short duration loss to the water column food web (see Section 3.6.1).

- In addition to the lethal injuries quantified by the Trustees, injuries to shelf-reef fish and fish communities were observed at a number of locations and over a range of benthic habitats. Injuries included reductions in abundance and changes in community composition. Although these various injuries cannot be explicitly quantified at this time, the Trustees concluded that fish and fish communities suffered physiologically and demographically important injuries in hard-bottom habitats along portions of the continental shelf. Species-specific data for red snapper, a key recreational and commercial species and a focus of intensive fisheries management effort, indicate growth reductions, shifts in diet, and increased prevalence of lesions.

- The Trustees determined that *Sargassum,* a floating brown algae that creates essential habitat for invertebrates, fish, birds, and sea turtles, was injured as a result of exposure to oil. Trustees quantified both the loss of *Sargassum* resulting from direct oiling and also the area of *Sargassum* foregone due to lost growth. Based on this analysis, the Trustees determined that up to 23 percent of the *Sargassum* in the northern Gulf of Mexico was lost due to direct exposure to *Deepwater Horizon* oil on the ocean surface. In addition, foregone *Sargassum* area from lost growth due to exposure to this oil was estimated to be as large as 3,600 square miles.

Key finding: **Benthic resources** were injured over a variety of habitats and depths from the deep sea to the coastline. (Section 4.5)

Benthic resources live on, in, and in association with the bottom of the ocean. A wide variety of benthic organisms were injured as a result of the *Deepwater Horizon* incident, including hard and soft corals, small invertebrates, crabs, and fish that rely on benthic habitats.

- The Trustees documented a footprint of over 770 square miles around the wellhead within which different types and levels of injury to benthic resources were observed. This is greater than 20 times the size of Manhattan or nearly two-thirds the size of Rhode Island.

- The most severe injuries were observed closest to the wellhead, in an inner zone representing an area of approximately 11 square miles, where there was coral mortality and reduction of infauna diversity and abundance. These injuries were caused by a combination of smothering by drilling muds and other debris materials, as well as exposure to oil, dispersants, and oil-

associated marine snow. Exposure was confirmed through measurement of oil constituents (polycyclic aromatic hydrocarbons—PAHs) in megafauna collected from the deep sea floor. Further, injury was confirmed with laboratory toxicity tests conducted with a deep sea benthic organism (an amphipod, *Leptocheirus*). These tests showed that oil constituent concentrations (PAHs) measured in sediment samples collected within the inner zone exceeded levels sufficient to cause mortality to deep sea benthos.

- The second and third concentric zones (covering areas of 75 and 306 square miles, respectively) exhibited different severities of injury, ranging from coral mortality at scattered hardground sites, to reductions in the diversity of sediment-dwelling animals that were significant, though less dramatic than the reductions observed in the innermost zone. The second concentric zone, for example, experienced reductions in diversity in sediment-dwelling biota and coral mortality, but less extensively than in the innermost zone. Within the third zone, injuries were more patchy, but still ecologically significant. For example, injuries to 600- to 1,000-year-old hardground corals manifested over time, but injuries to sediment-dwelling biota were less severe than observed in zone 2. While the ecosystem functions of these unique deep ocean corals are not well understood, their vertical structure likely covers and protects mobile biota seeking refuge from predators, and provides habitat for species to live and breed—similar to key ecological functions provided by other fan-like coral species growing in shallower habitats.

- In the fourth zone, the chemical quality of the seafloor habitat was adversely affected by contamination over 490 square miles. Specifically, sediments at some locations in this zone had PAH concentrations that exceeded values sufficient to cause mortality to amphipods that live in the deep sea benthos. Further, some resident species such as red crabs had tissues contaminated with *Deepwater Horizon* oil hydrocarbons, which represents a degradation of food quality for organisms that prey on red crabs. Hence, while the magnitude of impact within this outer fourth zone is difficult to quantify, due to the uneven deposition of oil and floc throughout the area, the Trustees determined that injury had also occurred within this fourth zone.

- Significant losses to resident corals and fish were documented within approximately 4 square miles of mesophotic reef habitat along the continental shelf edge. It can be reasonably inferred that ecological functions provided by this biologically rich and important habitat were impaired. Exposure and spill impacts may also have occurred in a larger area, approximately 3,600 square miles in size, that extends beyond and between the areas where the Trustees quantified injury.

- Injury to tall soft corals on the mesophotic reefs reduced the amount of habitat important to fish and other smaller invertebrates.

- Harmful effects on individuals, colonies, and communities can degrade overall ecosystem health and function. Effects caused by the *Deepwater Horizon* incident that may have broader ecosystem ramifications include degradation of coral colony size and surface area, reduction in colony numbers, shifts in species dominance, and reductions in the diversity of benthic infauna. While the ecosystem-level impacts of the individually described injuries have not been directly

documented, their occurrence can reasonably be scientifically inferred from the nature and extent of the confirmed injuries.

Key finding: A wide variety of **nearshore and shoreline resources** were injured over hundreds of miles of coastline of the northern Gulf of Mexico. (Section 4.6)

The Trustees found injuries to multiple shoreline habitats over hundreds of miles of oiled shoreline of the northern Gulf of Mexico, including to estuarine coastal wetland habitats such as mainland salt marsh, sand beaches, submerged aquatic vegetation, and oyster reef habitats, as well as to plants and animals that live in these habitats. Water column injuries to fish and invertebrates also occurred in nearshore waters.

Specific injuries documented by the Trustees included reduced plant cover and vegetative (aboveground) biomass, and harmful reductions in the abundance, survival, growth, reproduction, and fitness of a number of important marsh animals. The Trustees also documented substantial reductions in nearshore oyster abundance and percent cover of nearshore oyster habitat, and an increase in marsh edge erosion rates. In some areas, oil is still present and injuries are ongoing.

- Injury to the estuarine coastal wetlands shoreline was observed over hundreds of miles, with more severe and broader injuries documented along more heavily oiled shorelines. Coastal marsh and mangroves are habitats critical to the overall health of the northern Gulf of Mexico. They provide invaluable spawning, nursery, and feeding grounds for the many commercial and recreational fish and shellfish species that depend on the physical protection offered by these habitats to complete their life cycles. They also help to protect water quality by capturing suspended sediment and removing excess nutrients and pollutants brought in from upland environments. The marsh edge, where the most acute injuries occurred, serves as a highly productive and critical transition zone between the emergent marsh vegetation and open water for the movement of organisms and nutrients between intertidal and subtidal estuarine environments.

- Animals that use the marsh edge for refuge and forage were exposed to oil through contact with oiled plants, soil, bottom and suspended sediments, detritus on the marsh surface, and water. Exposure occurred as the marshes flooded with the tide, as well as through ingestion or contact with oil entrained in submerged sediments near the marsh edge. Toxicity testing conducted with marsh sediment containing *Deepwater Horizon* oil demonstrates that PAH concentrations in soil and sediment found in oiled marsh areas are toxic to many marsh species. Cleanup and oil removal activities at the edge of marshes smothered, crushed, or removed animals in oiled areas.

- Substantial decreases in secondary production occurred along heavily oiled marshes for representative marsh species, including marsh periwinkles, brown and white shrimp, Gulf killifish, and southern flounder.

- Injuries to both subtidal and nearshore oysters were documented, causing a loss of ecological services that these organisms provide. Oysters play a unique role in the coastal ecosystem. They

serve not only as an exploitable resource, but also as habitat for other aquatic organisms such as shrimp, crabs, and finfish. They provide filtration services that improve water quality and clarity. Oyster reefs adjacent to marshes reduce marsh erosion; when these reefs were injured, erosion increased.

- Salinity control structures were opened as part of response actions intended to reduce the movement of oil into sensitive marsh and shoreline areas. Unlike the sediment diversions the State of Louisiana uses for coastal restoration, the structures opened in response to the *Deepwater Horizon* incident have been historically used for releasing river water into surrounding embayments to maintain estuarine conditions. As such, they are normally opened during specific times of the year, for limited durations, and with controlled flow rates to effect targeted impacts to salinity levels. In contrast, when used for response to the *Deepwater Horizon* incident, these structures were opened at or near maximum capacity for extended time periods to repel the approaching oil. The highly atypical flow of river water over a sustained period greatly reduced salinity levels in Louisiana coastal areas during spill response. These resulting salinity reductions caused collateral injuries to estuarine organisms such as oysters and brown shrimp.

- The Trustees concluded that reduced salinity dramatically reduced the abundance of subtidal oysters in coastal Louisiana, whereas nearshore oysters were primarily injured by exposure to oil and the impacts of response activities (potentially in combination with reduced salinity in some locations). Annual NRDA sampling of both oyster settlement and abundance has shown that the initial injuries severely impaired oyster reproduction in the years following the spill, limiting their recovery. With reduced numbers of juvenile and adult oysters in subtidal areas in 2010, fewer larvae were produced in 2011 and subsequent years. Reduced oyster cover in nearshore areas contributed to recruitment decline and limited recovery throughout the region. Diminished recruitment has continued at least into 2014 and is compromising the long-term sustainability of oyster reefs in some areas.

- Beaches and dunes are ecologically and recreationally important shoreline habitats that serve as important breeding, nesting, wintering, and foraging habitats for nearshore and dune-dwelling biota. Injuries from response activities on beaches and dunes included:

    - Direct mortality and persistent behavior modification of nocturnal animals, such as beach mice and ghost crab, and destruction of dune vegetation.

    - Reductions in abundance, species richness, and diversity of small beach-dwelling organisms, such as crabs, snails, and shrimp, occurred due to physical crushing, desiccation, and smothering and to the removal of wrack (decomposing vegetation washed up on shore by surf) that is an important habitat and food source for many beach organisms.

- An estimated 1,100 to 3,600 federally listed threatened Gulf sturgeon were potentially exposed to *Deepwater Horizon* oil in nearshore areas, representing a large proportion (an estimated 27 to 100 percent) of the populations of six of the eight natal rivers systems (Pearl, Pascagoula, Escambia, Blackwater, Yellow, Choctawhatchee). The Trustees found evidence of genotoxicity

and immunosuppression at the molecular, cellular, and organ levels in sturgeon resulting from oil exposure, although the degree and consequences of exposure could not be quantified.

- Submerged aquatic vegetation (SAV) provides highly productive coastal habitat, including food, and shelter for birds, fish, shellfish, invertebrates, and other aquatic species. SAV was injured across the northern Gulf of Mexico due to oiling and the physical effects of vessels responding to the *Deepwater Horizon* incident. The Trustees' assessment documented 9,429 square feet of vessel scars and blowholes in Florida seagrass beds, of which 5,404 square feet were within the boundaries of Gulf Islands National Seashore, Florida District.

- SAV coverage totaling 60 acres along the Lake Cataouatche shoreline in Jean Lafitte National Historical Park and Preserve was reduced by approximately 83 percent as a result of river water releases during oil spill response actions (Section 4.6.8.2.3).

- Oil from the *Deepwater Horizon* spill injured SAV in the Chandeleur Islands, Louisiana. From 2010 to 2012, seagrass spatial distribution decreased along the shallow shelf west of the Chandeleur Islands. A total of 112 acres of seagrass beds were identified as "persistent loss" (defined as loss for two consecutive mapping intervals), and 160 acres were classified as "delayed loss" (areas where seagrass was present in 2010 and 2011, but lost in 2012).

Key finding: Exposure to oil and response actions injured a large number of **bird species** occupying different habitats, from offshore to nearshore, and including coastal marshes. (Section 4.7)

The Trustees confirmed that many tens of thousands of birds were killed by oil exposure, including offshore sea birds, shore birds, waterfowl, marsh birds, and colonial nesting birds. Many other birds were injured through sublethal effects of oil exposure, loss of habitat, or displacement by response actions, as well as through reproduction foregone due to loss of breeding adult birds. As described below, these injury estimates do not include mortality estimates for all birds that likely were exposed and died due to the *Deepwater Horizon* incident.

- For those bird species and habitats for which mortality was quantified, 51,600 to 84,500 birds died as a result of the spill, and mortality likely is closer to the upper end of this range, due to factors that could not be quantified, such as birds within the interior marsh that were not captured by the models, or mortality in colonies that was not recorded. Species with high mortality estimates included brown pelicans, laughing gulls, terns, skimmers, and northern gannets.

- Adult birds that died between May 2010 and April 2011 as a result of the oil spill were not available to produce or sustain young during the breeding season following their death, leading to lost reproduction amounting to 4,600 to 18,000 fledglings during that breeding season.

- The Trustees did not quantify mortality to other types of bird species, particularly marsh birds and colonial nesting birds, because of practical difficulties in field observation and sampling.

- Coastal marsh and small barrier island restoration, through the ecosystem approach, will benefit the bird species whose injuries could not be quantified.

Key finding: Four species of federally endangered or threatened **sea turtles** (Kemp's ridleys, green turtles, loggerheads, hawksbills) were injured by exposure to oil and as a consequence of response activities. The Trustees estimated that exposure to oil resulted in up to 166,000 deaths to small juvenile turtles living offshore. Thousands of larger sub-adult and adult turtles were killed in shallower waters closer to the shoreline. Tens of thousands of sea turtle hatchlings were displaced by response actions and lost from the Gulf of Mexico ecosystem. The number of sea turtles nesting along northern Gulf beaches declined after the spill. (Section 4.8)

- Sea turtles and their habitats were exposed to *Deepwater Horizon* oil in the open ocean, across the continental shelf, and into nearshore and coastal areas, including beaches. Sea turtles were exposed to oil when swimming through oil at or near the surface and in the water column; breathing oil droplets, oil vapors, and smoke; and ingesting oil-contaminated water and prey. Response activities and shoreline oiling also directly injured sea turtles, and disrupted or deterred sea turtle nesting in the Gulf.

- The Trustees' quantification of sea turtle injuries caused by the *Deepwater Horizon* incident showed that sea turtles from all life stages were lost from the northern Gulf ecosystem. In particular, hundreds of thousands of small juvenile turtles died from oil exposure and response activities. Overall, the Trustees estimated that response activities injured nearly 35,000 hatchling sea turtles (loggerheads, Kemp's ridleys, and green turtles), and that the *Deepwater Horizon* incident killed 56,000 and up to 166,000 small juvenile sea turtles (Kemp's ridleys, green turtles, loggerheads, hawksbills, and hardshelled sea turtles not identified to species) and 4,900 and up to 7,600 large juvenile and adult sea turtles (Kemp's ridleys, loggerheads, and hardshelled sea turtles not identified to species). In addition, the Trustees estimated tens of thousands of Kemp's ridley and loggerhead hatchlings as potential reproduction foregone since 2010 due to the loss of breeding-age turtles killed on the continental shelf by the *Deepwater Horizon* incident.

- As noted above, *Deepwater Horizon* oil caused significant losses of *Sargassum* habitat on which small, oceanic-stage juvenile turtles rely, further compounding impacts on sea turtles and their ability to recover.

Key finding: Coastal and oceanic **marine mammals**—dolphins and whales—were injured by exposure to oil from the *Deepwater Horizon* spill. Injuries included elevated mortality rates, reduced reproduction, and disease. Without active restoration, these populations will require decades to recover from these injuries. (Section 4.9)

- Tens of thousands of federally protected marine mammals were exposed to the *Deepwater Horizon* surface slick, where they inhaled, aspirated, ingested, and came into contact with oil components. The oil's physical and toxic effects damaged tissues and organs, leading to a

constellation of adverse health effects, including reproductive failure, adrenal disease, lung disease, and poor body condition in bottlenose dolphins.

- Animals that succumbed to these adverse health effects contributed to the largest and longest marine mammal unusual mortality event (UME) on record in the northern Gulf of Mexico. The dead, stranded dolphins in this UME included near-term fetuses from failed pregnancies. More than 75 percent of pregnancies in Barataria Bay and Mississippi Sound were unsuccessful.

- Barataria Bay and Mississippi Sound bottlenose dolphins were some of the most severely injured populations, with a 51 percent and 62 percent maximum reduction in their population sizes, respectively. Northern and western coastal populations of bottlenose dolphins and all of the shelf and oceanic marine mammal populations that overlap with the *Deepwater Horizon* oil spill footprint also suffered injuries. Dolphins are long-lived animals and slow to reach reproductive maturity. Without active restoration, these populations will require decades to recover from the injuries caused by the *Deepwater Horizon* incident.

- Smaller percentages of the marine mammals that live in deeper oceanic waters were exposed to *Deepwater Horizon* oil. However, they still experienced increased mortality (as high as 17 percent), increased reproductive failure (as high as 22 percent), and a higher likelihood (as high as 18 percent) of other adverse health effects.

Key finding: The oil spill reduced human uses of shoreline and coastal resources, resulting in **lost use** valued at hundreds of millions of dollars. (Section 4.10)

The Gulf of Mexico is a popular destination for many types of recreation, including beach-going, boating, and fishing. The spill directly reduced recreational use of these coastal resources across the northern Gulf of Mexico.

- The U.S. public lost almost 17 million user days of boating, fishing, and beach-going experiences between May 2010 and November 2011 (Section 4.10.6). This number does not include losses to private or commercial enterprises or municipalities, which are not compensable under the NRDA regulations in the Oil Pollution Act (OPA).

- The Trustees estimated the public value of these lost uses to be $693 million (due to uncertainty, the actual value may range from $528 million to $859 million).

4.11.3 Use of Inference to Assess Natural Resource Injuries Not Directly Measured by Trustees

The injuries to natural resources and services documented by the assessment are likely not the only injuries that occurred:

- The vast scale of the *Deepwater Horizon* incident precluded studying all individual components of all affected ecosystems in all affected locations over the full time period of potential effects.

For this reason, the Trustees' designed their injury assessment to evaluate *representative* locations, habitats, species, and injury types.

- As with any ecosystem, Gulf natural resources are inter-linked through fundamental ecological relationships (e.g., habitat-community-species interactions, predator-prey relationships, nutrient transfer and cycling, and organism migration and behavior). Therefore, resources not directly exposed to oil or other consequences of the incident could be exposed indirectly through their ecological links to exposed resources.

In their injury assessment, and as reflected in the key findings described in Sections 4.11.2 and 4.11.4, the Trustees considered not only directly observed or measured injuries, but also injuries that could not be directly studied. To assess injury to natural resources not studied, the Trustees used scientific inference to extend their conclusions beyond the resources and locations they did observe or sample directly. Scientific inference involves using data, observations, and knowledge to make reasonable conclusions about things that were not directly observed. For example, observations and data supporting a conclusion that sufficient amounts of oil can smother wetland plants may be used to infer that similar plants that are similarly oiled would also be smothered, even when this effect was not directly observed. Similarly, existing knowledge can support reasonable scientific inferences. For example, if certain species of organisms are known to depend on marsh plants, scientists can reasonably infer that eliminating those marsh plants would harm the dependent organisms.

This section describes four types of ecosystem inferences considered by the Trustees in developing conclusions from the injury assessment. Not all these inferences apply to every injury category.

4.11.3.1 Inference Based on Food-Web Relationships

Impacts to a specific resource can indirectly affect both predators and prey:

- "Bottom-up" trophic impacts can occur when an important food resource species is impacted. For example, brown shrimp were injured because the incident adversely affected their invertebrate prey. Marsh periwinkles, terrestrial insects, amphipods, and Gulf killifish all are important prey for larger fish and birds, thus injuries to these food sources could also injure their predators. Similarly, larval fish and invertebrates injured in the water column are an important source of prey for larger fish. Birds are highly responsive to variation in their prey. Prey reductions, when they occur, can have cascading effects on both larger species and older life stages. Animals in the wild live in a dynamic relationship with their environment and available resources, balancing energy expenditures and nutritional uptake in order to survive, remain healthy, and reproduce. Any impact that shifts that balance by diminishing food resources or requiring unusual expenditures of energy—whether to acquire prey, avoid predators, fight disease and infection, or successfully reproduce—is inherently harmful to the species. Such harm is "an adverse change in a natural resource or impairment of a natural resource service," constituting an injury as defined in OPA regulations (15 CFR 990.30).

- Alternatively, impacts to a species higher on the food chain (such as dolphins) can reduce predation pressure on their prey, resulting in potential changes to the prey's community structure, as well as changes to dynamic relationships within a species and among multiple

species. For example, injuries to tall soft corals not only reduce the structural complexity of mesophotic reef habitats that attracts other animals, but also affect populations of invertebrates that graze on polyps. Birds are also known to exert top-down effects on the number and distribution of prey species.

4.11.3.2 Inference Based on Cascading Ecological Effects

The northern Gulf of Mexico ecosystem is a network of diverse habitats and species and functions linked through important ecological processes. Consequently, injury to natural resources can cause cascading ecological effects**,** including changes in trophic structure (such as altering predator-prey dynamics as mentioned above), community structure (such as altering an area's species composition), and ecological functions (such as altering nutrient flow and organic production), as illustrated by the following examples.

- **Water column cascading impacts.** Ecological processes in the water column affect the flows of organic matter and nutrients that, in turn, influence ecological processes on the deep sea floor or in shallow nearshore habitats. Many animals living on the sea floor or in nearshore habitats spend early parts of their lives drifting in the water column.

- **Shoreline and nearshore cascading impacts.** Injuries to shoreline and nearshore ecosystems also have cascading effects on offshore ecosystems, including changes in the sequestration of sediments and nutrients in coastal wetlands; reduced capacity for intertidal oysters to serve as a source of oyster larvae for regional subtidal reefs; and reduced capacity for supporting juveniles of offshore species that use these habitats as nurseries.

- **Impacts to ecosystems beyond the Gulf.** Many bird species move across and beyond the Gulf's ecosystems. In addition to their role in food webs, birds transfer nutrients between marine and terrestrial biomes, disperse seeds, and provide other ecological functions. The ramifications of bird injury resulting from the *Deepwater Horizon* incident are not necessarily limited to the ecosystems of the northern Gulf, as many birds migrate to other areas of North America, where impaired performance or reduction in numbers can have radiating effects on the ecosystems there. Reduced populations of sea turtles, too, can have significant effects on the ecosystems to which they migrate.

4.11.3.3 Inference Based on Reasonable Analogy from More- to Less-Studied Ecosystems

Ecosystem scientists routinely make inferences by analogy from more- to less-studied ecosystems. For example, as described in Section 4.5 (Benthic Resources), injuries to hardground corals caused by the *Deepwater Horizon* incident manifested over time in the form of broken coral branches and reduced colony size and health. The ecosystem functions of these unique hardground corals are less well understood in the deep ocean; however, scientists do know that the substantial vertical structure of other fan-like coral species in shallower habitats provides cover and protection to mobile marine life seeking places to live and breed and refuge from predators**.** It is reasonable to infer that fan-like corals in the deep sea would provide similar ecological services.

4.11.3.4 Inference to Unstudied Resources and Locations Based on Representative Studies

Environmental scientists routinely use representative sampling to make statistically based inferences from sampled locations to locations that could not be sampled. For example, the Trustees used information collected at representative coastal wetland vegetation sampling sites to estimate the extent of injury to other wetland habitats in a statistically unbiased manner.

4.11.4 The Scope of Adverse Effects from the *Deepwater Horizon* Incident Constitutes an Ecosystem-Level Injury

The injuries caused by the *Deepwater Horizon* incident affected such a broad array of linked resources and services over such a large area that they cannot be adequately described at the level of a single species, a single habitat type, a single set of services, or even a single region. Rather, the effects of the *Deepwater Horizon* incident constitute an ecosystem-level injury. As described below, an ecosystem-level injury can reasonably be scientifically inferred from the demonstrated injuries across all trophic levels, across all northern Gulf of Mexico habitats, and from impacts to ecological communities and ecosystem functions.

Key finding: Injuries occurred at **all trophic levels.**

Based on the NRDA injury studies, and additional non-NRDA studies published in the literature, the Trustees determined that the *Deepwater Horizon* incident injured virtually every trophic level in the northern Gulf ecosystem, from bacteria, to primary producers (plants), to secondary producers such as zooplankton, to top-level predators such as bottlenose dolphins. Within coastal marshes, for example, a wide array of organisms—from microbes to large animals and including primary producers, animal consumers, and top predators—were injured in addition to the marsh plants themselves. Injured organisms included the very small meiofauna and microalgae inhabiting marsh soil; larger invertebrates such as amphipods, periwinkle snails, and fiddler crabs; and Gulf killifish. Important resource species, such as shrimp, flounder, and bottlenose dolphins, that live in adjacent waters and feed on affected invertebrates and small fish were also injured.

Key finding: Injuries occurred to **virtually all marine and estuarine habitats** that came in contact with oil, from the deep sea to the shoreline.

The *Deepwater Horizon* incident affected resources throughout virtually every known marine and estuarine habitat in its trajectory in the northern Gulf of Mexico, from the deep sea to the shoreline, although the injuries were not uniform in severity or location. Oil in the deep sea injured both **soft-bottom habitats** and rare deep sea corals. Toward the shoreline, important mesophotic reef habitats and associated communities were injured, as were benthic fish in shallow reef communities. Injuries were also observed in fish that live along the continental shelf habitat, such as red snapper.

In other benthic areas, however, injuries did not occur. For example, the Trustees conducted dozens of sampling trips to shallow water coral reefs in the Florida Keys and Flower Gardens reef areas and

documented no evidence of exposure to *Deepwater Horizon* oil, dispersants, or disruptive response activities (DWH Trustees 2012).

Water column resources were injured in the open ocean, in coastal waters, and in nearshore waters and estuaries over approximately 43,300 square miles when oil was present. The injuries to water column resources occurred at the ocean surface, to organisms living in the mixed layer beneath the ocean surface, and to the extensive floating *Sargassum* habitats that support a wide variety of organisms, such as invertebrates, fish, and juvenile sea turtles. Water column resources also were injured in deep, colder waters as a result of exposure to both the rising cone of oil from the wellhead and the deep water plume of oil that formed at a depth of over 3,600 to 4,600 feet below the ocean's surface.

The northern Gulf of Mexico supports a wide array of **nearshore and shoreline habitats**, including estuarine coastal wetlands, such as marsh and mangrove habitat, submerged aquatic vegetation, subtidal and intertidal oyster reefs, barrier islands, and sand beaches. Injuries occurred to each of these habitats. In addition, these nearshore and shoreline habitats and biological resources are linked to both **coastal and offshore habitats** and resources through ecological and physical relationships, such as food web dynamics, organism movements, nutrient and sediment transport and cycling, and other fundamental ecosystem processes. As a result of these interactions, injuries to nearshore resources can have cascading impacts throughout the ecosystem, and injuries to nearshore and shoreline resources influence the overall health and productivity of the Gulf ecosystem.

Because the *Deepwater Horizon* incident injured diverse habitats, injury was not confined to a single set of species or ecosystem functions. Rather, the incident likely impacted important linkages across all Gulf habitats and resources.

Key finding: Injuries occurred to **species, communities, and ecosystem functions.**

In addition to the direct injuries to specific species observed by the Trustees (for example, injury to bottlenose dolphins or brown shrimp), the Trustees determined that adverse effects had occurred to ecological communities and ecosystem functions.

The multiple species and trophic levels injured within salt marsh communities, discussed above, are one example of **community-level injury**. In another example, benthic communities in areas where deposited oil had contaminated deep sea sediments experienced decreased species diversity, indicating effects on multiple invertebrate species. Similarly, multiple components of the mesophotic reef community were injured, from tall soft corals to bottom-dwelling fish.

Ecosystem functions were also injured. For example:

- Marsh plants contribute several important ecosystem functions and services. They produce biomass through photosynthesis and form the basis of wetland and estuarine food webs. They help stabilize shorelines by holding, retaining, and accumulating marsh sediments. They also contribute to coastal flood protection by reducing storm surge and waves, and they provide critical structural habitat (as refuge and forage) for a wide variety of organisms. Injuries to

marsh vegetation resulted in losses of these important ecosystem functions and associated services.

- The Trustees documented accelerated erosion rates along heavily oiled marsh shorelines in Louisiana where injuries to vegetation and intertidal oysters were observed. This increased erosion exacerbates Louisiana's already critical coastal erosion problem.

- Other examples of ecosystem function injuries include: impaired cycles of organic matter and nutrients from the water column to oil-contaminated bottom sediments; altered transfer of energy and nutrients from coastal to offshore ecosystems where estuarine-dependent fish and shrimp were injured; and water filtration and nutrient cycling where oysters were injured.

4.11.5 Treatment of Unquantified Injuries

The Trustees could not fully quantify all direct and indirect injuries resulting from the *Deepwater Horizon* incident due to the vast geographical and ecological scope of impacts. However, they did document evidence of a number of injuries that could not be explicitly quantified. As detailed in Chapter 5, the Trustees' damage assessment and restoration plan accounts for unquantified injuries in several ways:

- The plan addresses injuries that could be determined, but not actually quantified, by directing restoration at ecosystem components that are similar in location or type or connected to ecosystem components with quantified injuries. Also, many species will benefit from habitat-level restoration (e.g., restoration of shoreline marsh or improvements to water quality), regardless whether their injury status is known. In this manner, restoration projects can benefit both resources known to have been injured, as well as analogous or related resources for which injury information was not available or could not be quantified.

- In some cases where the Trustees have documented that injury has or likely has occurred, the potential long-term effects or consequences are less well quantified because of environmental complexities in ocean systems and because future environmental conditions that may influence organisms (such as temperature and precipitation) are unknown. The Trustees have decided that waiting for a better understanding of recovery from injury is not the best way to compensate for these potential ongoing injuries. Rather, they have proposed to start work now to achieve offsetting environmental benefits. By emphasizing both resource- and habitat-based restoration, the Trustees can provide a wide range of beneficial ecosystem services, which will reduce the likelihood of further injuries.

- For many unquantified injuries, additional time and more study is not likely to substantially change the Trustees' understanding of the nature or extent of injuries. The inherent difficulties in studying many oceanic systems limit the degree to which some conclusions can be reached with numerical precision, and additional study likely will not result in information that will substantially alter the Trustees' current conclusions. Further, confounding factors can arise over time, making injury quantification even more difficult as time passes. Therefore, the Trustees have decided that best way to address unquantified losses is to initiate restoration now rather than delay in the hope that further study will enhance quantification.

Despite these uncertainties that are inherent in any NRDA, the information gathered and analyzed are sufficient to adequately allow the Trustees to form reasonable scientific conclusions about the nature and scope of the injuries.

4.11.6 References

DWH Trustees (Deepwater Horizon Natural Resource Damage Assessment Trustees). (2012). *Natural Resource Damage Assessment April 2012 Status update for the Deepwater Horizon oil spill*. Retrieved from *http://www.doi.gov/deepwaterhorizon/upload/FINAL_NRDA_StatusUpdate_April2012-2.pdf*.

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