4.9 Marine Mammals

What Is in This Section?

Executive Summary

The *Deepwater Horizon* oil spill resulted in the contamination of prime marine mammal habitat in the estuarine, nearshore, and offshore waters of the northern Gulf of Mexico. In order to determine the exposure and injury to whales and dolphins due to the *Deepwater Horizon* oil spill, the Trustees synthesized data from specific NRDA field studies, stranded carcasses collected by the Southeast Marine Mammal Stranding Network, historical data on marine mammal populations, NRDA toxicity testing studies, and the published literature. Tens of thousands of marine mammals were exposed to the *Deepwater Horizon* surface slick, where they likely inhaled, aspirated, ingested, physically contacted, and absorbed oil components. The oil's physical, chemical, 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. Animals that succumbed to these adverse health effects contributed to the largest and longest lasting marine mammal unusual mortality event (UME) on record in the northern Gulf of Mexico. The dead, stranded dolphins in the UME included near-term fetuses from failed pregnancies. Similarly, in the 5 years after the oil spill, more than 75 percent of pregnant dolphins observed within the oil spill footprint failed to give birth to a viable calf.

Based on the Trustees' scientific findings, the *Deepwater Horizon* oil spill is the most likely explanation for the injuries to marine mammals observed since May 2010 in the oil spill footprint. The increases in mortality, reproductive failure, and specific adverse health effects were seen in animals within the oil

spill footprint and were not observed in animals outside of the footprint. The injuries were most severe in the year immediately following the spill and have improved slightly over time (but not completely disappeared) since the well was capped. The types of injuries observed are consistent with both the known routes of exposure and the toxic effects reported in the oil toxicity literature, and were identified in both living animals and dead, stranded dolphins. For example, marine mammals that inhale or aspirate oil components are likely to experience physical and chemical damage in the lungs, which is consistent with the increased prevalence of lung disease in live animals and of bacterial pneumonia in stranded animals within the oil spill footprint (Venn-Watson et al. 2015a).

In the absence of active restoration, marine mammal stocks in the northern Gulf of Mexico will require decades to recover from the effects of the *Deepwater Horizon* oil spill. Nearly all of the stocks that overlap with the oil spill footprint have demonstrable, quantifiable injuries. The remaining stocks (for which there is no quantifiable injury) were also likely injured, but there is not enough information to make a determination at this time. The Barataria Bay and Mississippi Sound bottlenose dolphin stocks were two of the best-studied populations, with 51 percent and 62 percent, respectively, projected maximum reductions in their population sizes. Without any active restoration, these populations will take approximately 40 to 50 years to fully recover. While smaller percentages of the oceanic stocks were exposed to *Deepwater Horizon* oil, these stocks still experienced increased mortality (as high as 17 percent), reproductive failure (as high as 22 percent), and adverse health effects (as high as 18 percent).

The Trustees have determined that marine mammals in the northern Gulf of Mexico were exposed to *Deepwater Horizon* oil and were injured as a result of the spill. Without active restoration, these protected, at-risk populations will suffer from the effects of the *Deepwater Horizon* oil spill for decades to come.

4.9.1 Introduction and Importance of the Resource

Key Points

- There are 22 species of marine mammals in the northern Gulf of Mexico, including manatees in coastal seagrasses and cetaceans (dolphins and whales) in estuarine, nearshore, and offshore habitats.
- There is a wide diversity of cetacean species, including animals that differ in size and physiology, feeding habits, and life histories. Many of the species are apex predators that rely on a wide variety of resources in the marine ecosystem.
- For the purposes of tracking populations, marine mammal species in U.S. waters are delineated into stocks based on a variety of data. There are bottlenose dolphin stocks in each bay, sound, and estuary system and in coastal waters; there are dolphin stocks that live over the continental shelf; and there are dolphin and whale stocks that live in the deeper, oceanic waters.
- Marine mammal populations have been severely impacted by human activities, including commercial and recreational fisheries, pollution, industrial activities, vessel strikes, and intentional harm. To address declining populations, all marine mammals are now protected under the Marine Mammal Protection Act, which prohibits individuals from harassing, harming,

or disturbing marine mammals. Some, including sperm whales and manatees, are also protected under the Endangered Species Act.

- In order to investigate the *Deepwater Horizon*-related injuries to northern Gulf of Mexico cetaceans, scientists navigated a variety of regulatory, ethical, and logistical challenges common for research on cetaceans.

4.9.1.1 What Are Marine Mammals?

Like most mammals, marine mammals are warm-blooded, give birth to live young, nurse their young, and breathe air. In contrast, however, they spend significant periods of their lives under the water. There are 22 marine mammal species found in the northern Gulf of Mexico representing two classes of marine mammals: cetaceans (21 species), which include whales and dolphins; and sirenians (1 species), which include manatees (Table 4.9-1). Manatees primarily inhabit the coastal waters of Florida, but can occasionally be found in seagrass habitats as far west as Texas. In contrast, cetaceans have adapted to a wide variety of habitats in the marine environment and can be found throughout the northern Gulf of Mexico (Rosel & Mullin 2015). They feed at all trophic levels, consuming foods ranging from invertebrates to large fish. Cetaceans are agile, efficient swimmers, and some species have been known to submerge for more than an hour. They are also highly intelligent, capable of self-recognition, have developed sophisticated communication strategies, and form complex social structures. Due to their long lives, unique physiology, and the fact that many feed at high trophic levels, researchers often consider marine mammals as sentinel species for marine ecosystem health (Bossart 2011; Moore 2008; Reddy et al. 2001; Ross 2000; Wells et al. 2004).

Table 4.9-1. Twenty-two marine mammal species are found in the northern Gulf of Mexico.

Common Name/Species	Specific Name
Atlantic spotted dolphin	*Stenella frontalis*
Blainville's beaked whale	*Mesoplodon densirostris*
Bryde's whale	*Balaenoptera edeni*
Clymene dolphin	*Stenella clymene*
Common bottlenose dolphin	*Tursiops truncatus*
Cuvier's beaked whale	*Ziphius cavirostris*
Dwarf sperm whale	*Kogia sima*
False killer whale	*Pseudorca crassidens*
Fraser's dolphin	*Lagenodelphis hosei*
Gervais' beaked whale	*Mesoplodon europaeus*
Killer whale	*Orcinus orca*
Melon-headed whale	*Peponocephala electra*
Pantropical spotted dolphin	*Stenella attenuata*
Pilot whale (short-finned)	*Globicephala macrorhynchus*
Pygmy killer whale	*Feresa attenuata*
Pygmy sperm whale	*Kogia breviceps*
Risso's dolphin	*Grampus griseus*
Rough-toothed dolphin	*Steno bredanensis*
Sperm whale	*Physeter macrocephalus*
Spinner dolphin	*Stenella longirostris*
Striped dolphin	*Stenella coeruleoalba*
West Indian manatee	*Trichechus manatus*

Whales and dolphins have suffered from their interactions with humans, including detrimental effects from unsustainable hunting, entanglements in fishing gear, chemical contaminant pollution, vessel noise pollution, incidental vessel strikes, and overfishing of prey species (Read et al. 2006; Reeves et al. 2013).

Biologists and policymakers realized that without intervention to reduce such practices, many species of marine mammals would be driven to extinction. With the passage of the U.S. Marine Mammal Protection Act (MMPA) in 1972, all species of marine mammals in U.S. waters were granted protection. MMPA includes strict prohibitions against any "take" of a marine mammal, meaning it is unlawful to harass, hunt, capture, or kill, or attempt to do so. Several northern Gulf of Mexico stocks are listed as strategic under the MMPA, meaning they are particularly at risk of unsustainable population numbers. The Endangered Species Act (ESA) was passed in 1973 and further protects those species at high risk of extinction. While the MMPA and the ESA have helped to stabilize some marine mammal populations, sperm whales in the Gulf of Mexico are still at risk and are listed as endangered by the ESA (35 FR 18319, December 2, 1970) as are West Indian manatees (32 FR 4001, March 11, 1967). As demonstrated both by acts of legislation and by consensus within the field of marine biology/ecology, any threat to the well-being of marine mammals, as individuals or to populations, is a serious and detrimental activity that could have repercussions for the entire ocean ecosystem (Bossart 2011; Moore 2008; Reddy et al. 2001; Ross 2000; Wells et al. 2004).

4.9.1.2 Marine Mammal Stocks

Marine mammals live everywhere in the Gulf of Mexico, including within bays, sounds, and estuaries (BSEs); along the coast (coastal); over the continental shelf (shelf); and in deeper waters (oceanic) (Rosel & Mullin 2015). While most species reside in the oceanic habitat, the Atlantic spotted dolphin is found over the continental shelf, and the common bottlenose dolphin (referred to as "bottlenose dolphin" throughout this chapter) inhabits oceanic, shelf, coastal, and BSE waters (Figure 4.9-1; (Rosel & Mullin 2015)). Although they are all the same species, bottlenose dolphins in the northern Gulf of Mexico can be separated into demographically independent populations called stocks.

A stock of bottlenose dolphins generally shows a strong attachment (i.e., site fidelity) to a geographic area, exhibiting low levels of immigration and emigration. Therefore, the population level of a given stock is generally assumed to be unaffected by population fluctuations in other stocks. For example, the Sarasota Bay bottlenose dolphin stock, which has been studied since 1970, has up to five concurrent generations of animals that have mostly spent their entire lives within the same bay (Wells & Scott 2009).

There are currently 37 stocks of bottlenose dolphins in the northern Gulf of Mexico, 13 of which (9 BSE stocks, 2 coastal stocks, 1 shelf stock, and 1 oceanic stock) are found in areas within the *Deepwater Horizon* oil spill footprint. The other 20 species of whales and dolphins in the northern Gulf of Mexico are each managed as a single, Gulf-wide stock; the ranges of 18 of these stocks overlap with the *Deepwater Horizon* oil spill footprint. There are not enough data to make a determination about the overlap between the spill footprint and the ranges of killer whales or Fraser's dolphins (Table 4.9-1). While the distribution of West Indian manatees overlap with the *Deepwater Horizon* oil footprint, none were sighted in oil, and are not considered further in this assessment. (Throughout the rest of this document, the term "marine mammal" refers to section headings and general references that would include non-cetaceans; references to "cetaceans" are specific to cetaceans.).

For the purposes of the *Deepwater Horizon* NRDA, the Trustees have considered the impact of the oil spill on the many different species and stocks of cetaceans whose ranges coincide with and/or overlap with the *Deepwater Horizon* oil spill footprint. Figure 4.9-1 illustrates the ranges of these stocks and species, and the extent of their coincidence and/or overlap with the spill footprint.

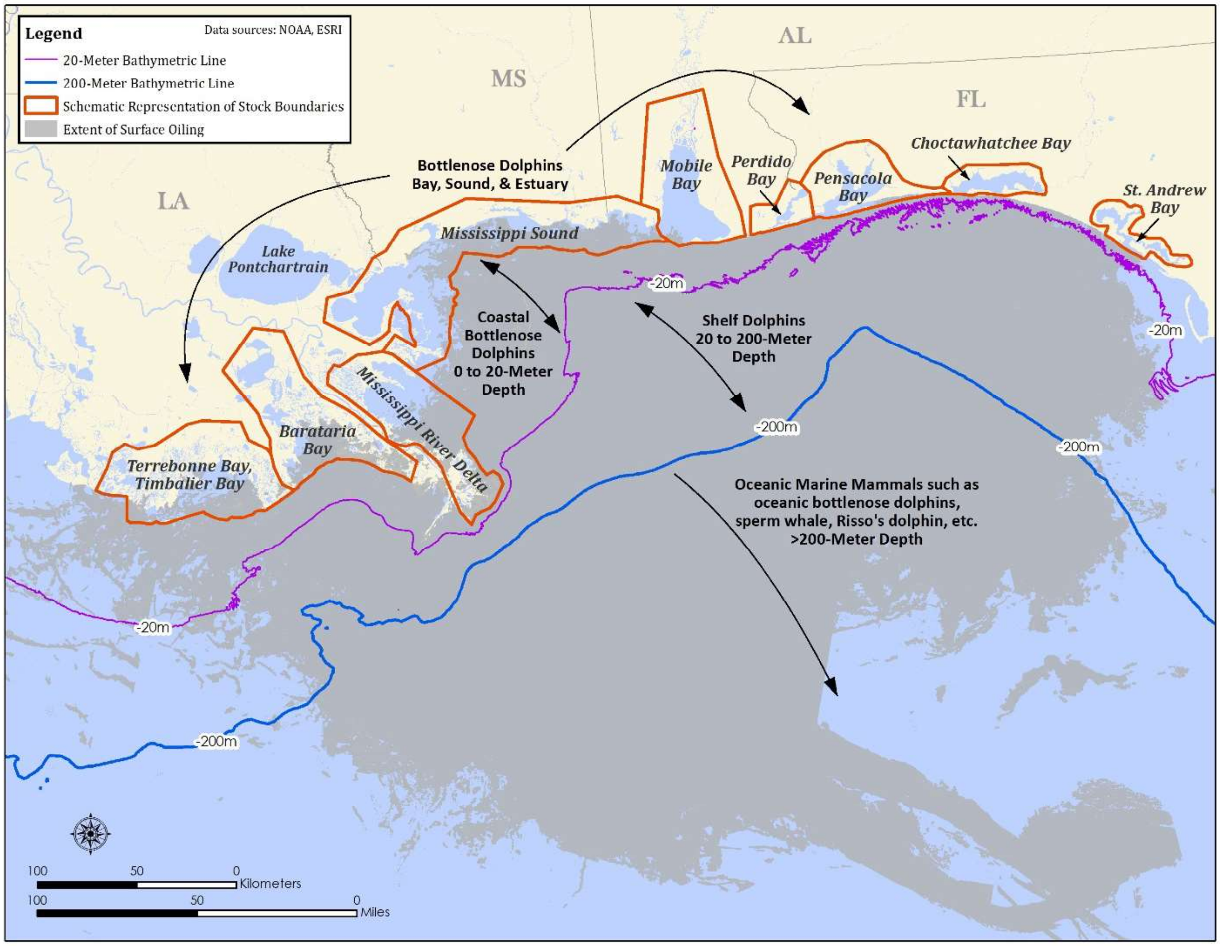


Figure 4.9-1. Thirteen common bottlenose dolphin stocks are found within the cumulative surface oiling footprint from the *Deepwater Horizon* oil spill, including BSE, coastal, continental shelf, and oceanic stocks. In addition, 18 other oceanic species of marine mammals are found within the oil footprint.

4.9.1.3 Life Histories and Habitats

Cetaceans share many traits, but the 21 species of dolphins and whales in the northern Gulf of Mexico (see Table 4.9-1) have adapted strategies to exploit most of the habitats within the Gulf of Mexico marine ecosystem (Dias 2015; Rosel & Mullin 2015). While cetacean behavior can vary greatly, most species generally spend time at the ocean surface to breathe, rest, socialize, and play. When feeding, however, dolphins and whales will swim and dive to various depths throughout the water column, and some feed in sediments on the ocean floor. Cetacean population numbers depend on the quality of habitat, including the quantity and quality of food, weather and environmental conditions, and natural and anthropogenic stressors. Many cetacean species are predators at the top of the food chain (apex predators) that depend on a wide variety of resources within a given habitat. To provide some general description of the physical characteristics, habitat preferences, and life history characteristics of northern Gulf of Mexico cetaceans, two species are described in detail in the following sections. Additional life history information for the other northern Gulf of Mexico cetacean species can be found in *Cetacean Species in the Gulf of Mexico* (Rosel & Mullin 2015).

4.9.1.3.1 Common Bottlenose Dolphins (*Tursiops truncatus*)

Common bottlenose dolphins are large and robust dolphins, averaging 1.9 to 3.8 meters in length with a substantial size variation across populations—in the Gulf of Mexico, most measure 2.7 meters or less (Würsig et al. 2000).

Source: *Fotosearch/Getty Images.*

Figure 4.9-2. Common bottlenose dolphins inhabit estuarine, nearshore, and offshore habitats throughout the Gulf of Mexico. Bottlenose dolphins are protected under the MMPA.

Shown in Figure 4.9-2, bottlenose dolphins are found worldwide in temperate, subtropical, and tropical waters. They can inhabit deep, oceanic waters; nearshore coastal waters; and BSE waters. BSE dolphins demonstrate strong site fidelity. For example, tagged bottlenose dolphins in Barataria Bay exhibit a high degree of site fidelity to relatively small home ranges within the bay (Wells 2014; Wells & Balmer 2012; Wells et al. 2014a; Wells et al. 2014b).

While bottlenose dolphins in U.S. waters are not listed as threatened or endangered under the ESA, all bottlenose dolphin stocks are protected under the MMPA, and several stocks in the Gulf of Mexico are listed as strategic under the MMPA. Bottlenose dolphins are at risk from entanglement in nets from commercial and recreational fisheries (e.g., shrimp, menhaden, and blue crab); therefore, researchers monitor injuries and deaths from fishery interactions and implement mitigation whenever possible. Bottlenose dolphins are also at risk from illegal feeding and harassment, pollutants, habitat loss and degradation, and intentional harm/injury. However, total human-caused mortality and serious injury is unknown for many stocks. The northern and western coastal stocks are considered strategic due to an ongoing UME (described in Box 1). Certain Gulf of Mexico BSE stocks are also listed as strategic due to unknown (but likely small) stock sizes, as well as

potential impacts from the ongoing UME affecting stocks along the coasts of Louisiana, Mississippi, Alabama, and western Florida (Waring et al. 2013).

Box 1: Unusual Mortality Events and the Northern Gulf UME

The MMPA defines an unusual mortality event (UME) as an event that involves a collection of stranded marine mammals that is unexpected, involves a significant die-off of any marine mammal population, and demands an immediate response (16 U.S.C. 1421h). There are seven criteria used to determine if a mortality event is "unusual" (http://www.nmfs.noaa.gov/pr/health/mmume/criteria.htm). UMEs are declared based upon comparisons of a stranding event with historical data, review and recommendation by a federally appointed Working Group for Marine Mammal Unusual Mortality Events (UME Working Group), and input from the NOAA National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS).

From February through April 2010, there was an increase in the number of bottlenose dolphin strandings along the northern Gulf of Mexico coastline: 114 strandings compared to the historical average of 37 for this area during the same time period (http://www.nmfs.noaa.gov/pr/health/mmume/cetacean_gulfofmexico.htm). The increase was particularly notable within Lake Pontchartrain, Louisiana, which had 26 strandings. In March 2010, NMFS consulted the UME Working Group to investigate the increased strandings in the northern Gulf of Mexico, largely motivated by the bottlenose dolphin mortalities in Lake Pontchartrain. The Working Group requested that NMFS reevaluate all cetacean strandings and resubmit their request for consultation.

This consultation with the UME Working Group was subsequently put on hold when the *Deepwater Horizon* well exploded on April 20, 2010, causing NMFS staff and the stranding network to focus on the crisis at hand and support marine mammal response efforts. After the *Deepwater Horizon* response phase for cetaceans ended, consultation was reinitiated. On December 13, 2010, the UME Working Group concluded that the high number of cetacean mortalities in the northern Gulf of Mexico in 2010 met the criteria for a UME, or perhaps multiple UMEs. The UME investigation has lasted more than 5 years and, as of August 2, 2015, includes over 1,400 cetacean strandings, of which 86 percent are bottlenose dolphins. Most (94 percent) of the animals stranded dead.

Although the current UME started prior to the *Deepwater Horizon* incident, most of the strandings (above the historical average) prior to the incident occurred from March to May 2010; were limited to Lake Pontchartrain, Louisiana, and western Mississippi; and were most likely caused by prolonged exposure to cold temperatures and low salinity. Most strandings outside of this March to May 2010 cluster occurred after the *Deepwater Horizon* blowout, were focused in areas exposed to *Deepwater Horizon* oil, and could not be attributed to prolonged cold temperatures or low salinity (Litz et al. 2014; Mullin et al. 2015; Venn-Watson et al. 2015c).

Generally females reach sexual maturity between 5 and 13 years of age and males between 9 and 14 years of age (Wells & Scott 2009). Females typically give birth every 3 to 6 years (Wells & Scott 2009). Researchers have identified females up to 57 years old and males up to 48 years old (Wells & Scott 2009).

Prey preferences for bottlenose dolphins are highly variable and depend on their habitat. BSE and coastal animals eat primarily fish (e.g., drums, mullets, and tuna) and some shrimp and crab, while the oceanic animals typically eat fish and squid (Wells & Scott 2009; Würsig et al. 2000; Wynne & Schwartz 1999). Bottlenose dolphins exhibit adaptable feeding behaviors and many different foraging strategies (Krützen et al. 2005). For example, some dolphins root in the sand for submerged prey, burying themselves nearly to their pectoral fins (Rossbach & Herzing 1997).

4.9.1.3.2 Sperm Whales (*Physeter macrocephalus*)

The sperm whale is the largest toothed-whale species (Figure 4.9-3). Adult females can reach 11 to 12 meters in length, while adult males are much larger, measuring as much as 16 to 18 meters in length (Jefferson et al. 1993; Whitehead 2009). Researchers have reported that Gulf of Mexico sperm whales are smaller than those from other areas (Jochens et al. 2008).

Source: *James R.D. Scott/Getty Images.*

Figure 4.9-3. Sperm whales inhabit offshore habitats in the Gulf of Mexico. Sperm whales are protected under the MMPA and ESA.

Sperm whales are listed as endangered under the ESA. A Final Recovery Plan for sperm whales was published and is in effect (NMFS 2010). Sperm whales in the Gulf of Mexico are also listed as strategic under the MMPA. The best available abundance estimate for the northern Gulf of Mexico sperm whales is 763 (coefficient of variation [CV] = 0.38; (Waring et al. 2013)). The current levels of human-caused mortality and serious injury for this stock are not known (Waring et al. 2013).

Sperm whales are distributed in deep waters worldwide from the ice edge to the equator (Whitehead 2009). The sexes differ in habitat usage with females distributed primarily in tropical and warm-temperate waters, while adult males have larger ranges and may move from the equator to the ice edge (Whitehead 2009). Sperm whales are found year-round in the northern Gulf of Mexico along the continental slope and in oceanic waters (Waring et al. 2013). There are several areas between Mississippi Canyon and De Soto Canyon where sperm whales congregate at high densities, likely because of localized, highly productive habitats (Biggs et al. 2005; Jochens et al. 2008).

Female sperm whales reach sexual maturity at about 8 to 9 years old, and they give birth about every 5 to 7 years; gestation is 14 to 16 months (Whitehead 2009; Würsig et al. 2000). Males are larger and do not start breeding until their late 20s (Whitehead 2009). Sperm whales consume a wide variety of deep-water fish and cephalopods; their primary prey is squid. They forage during deep dives that routinely reach depths of 600 meters and last for about 45 minutes (Whitehead 2009), but they are capable of

diving to depths of over 3,200 meters for over 60 minutes (Würsig et al. 2000). After a long, deep dive, sperm whales come to the ocean surface to breathe and recover for approximately 9 minutes (Whitehead 2009).

4.9.2 Approach to the Assessment

In order to investigate the *Deepwater Horizon* oil spill-related injuries to northern Gulf of Mexico cetaceans, scientists navigated a variety of regulatory, ethical, and logistical challenges that are common for research in cetaceans, including their protection under the MMPA. Evidence of causation was derived by integrating studies from the literature and data from *Deepwater Horizon* oil spill NRDA field studies and laboratory tests, and critically evaluating alternative potential causes of injury.

Key Points

- Researchers used historical sightings data and conducted surveys in the *Deepwater Horizon* oil spill footprint to determine the number of animals exposed to *Deepwater Horizon* oil. Biologists and veterinarians determined the potential routes of exposure of *Deepwater Horizon* oil to the tissues and organ systems of marine mammals, in order to ascertain potential adverse health effects.
- Separate from the NRDA, the federal government declared a marine mammal UME, now the largest and longest UME on record for the northern Gulf of Mexico. Marine mammal scientists from the NRDA worked with the UME investigators to critically evaluate the stranding data to identify the relationship between the increased number of strandings and the *Deepwater Horizon* oil spill.
- Researchers temporarily captured dolphins living in Barataria Bay, Louisiana, and in Mississippi Sound (Mississippi and Alabama) to collect medical data on individuals in *Deepwater Horizon* oil-contaminated habitat. They compared their findings to animals living in areas that did not experience *Deepwater Horizon* oil contamination, as well as to pathology data from dead, stranded dolphins.
- Scientists conducted surveys to compare survival and reproductive success in dolphin populations living within versus outside of *Deepwater Horizon*-oil contaminated habitat.
- Researchers analyzed their data in the context of the *Deepwater Horizon* oil spill and other potential drivers of marine mammal UMEs, in order to determine the likelihood that the injuries observed were caused by the *Deepwater Horizon* spill.
- Marine mammal scientists synthesized data from *Deepwater Horizon* field studies and the literature to characterize the adverse effects on the studied populations and extrapolate the magnitude of injury to other populations.

4.9.2.1 Rationale

As oil spilled into the Gulf of Mexico and reached coastlines, response workers rushed to contain the inevitable injuries to Gulf of Mexico resources, and researchers quickly mobilized to characterize injuries in real time. Responders, researchers, and media reports released striking images of cetaceans

swimming in the *Deepwater Horizon* surface oil slick (Figure 4.9-4) and a disturbingly large number of dead cetaceans stranded on coastlines affected by the spill.

Although studies on marine mammals following oil spills are limited, both laboratory and field studies, including research conducted in the wake of the *Exxon Valdez* oil spill, have documented the adverse effects of oil to marine mammals and other wildlife species and their habitats (Peterson 2001; Peterson et al. 2003). Because of the widespread distribution of oil across prime cetacean habitats in the northern Gulf of Mexico, the Trustees developed a suite of studies to assess the extent of *Deepwater Horizon* oil exposure to northern Gulf of Mexico cetaceans and to identify and characterize potential injuries to these animals as a result of the oil spill.

Source: *Mandy Tumlin, Louisiana Department of Wildlife and Fisheries.*

Figure 4.9-4. A bottlenose dolphin with oil residue on its head swims through a *Deepwater Horizon* oil surface slick in Barataria Bay, Louisiana (August 5, 2010, authority of section 109h MMPA).

4.9.2.2 Known Risks of Oil to Marine Mammals

While data are sparse, both field and laboratory studies have shown that cetaceans exposed to oil can suffer impaired health, and potentially die, as a result of that exposure. Inference about the impacts of oil exposure on the health of cetaceans is more commonly drawn from the results of laboratory studies on the effects of oil in other marine mammals (e.g., pinnipeds, a group of marine mammals which includes seals, sea lions, and walruses) and surrogate mammalian species. Mink are often used as surrogates for other mammals because they are readily raised in captivity; for example, they have been used as surrogates for sea otters because they have a semi-aquatic life style in the wild. The evidence for injury to cetaceans as a result of exposure to oil is briefly summarized below; presented first is evidence from field studies, followed by evidence from laboratory studies of cetaceans, as well as pinnipeds, mink, and other mammals.

There are only a handful of studies that report on the health or survival of cetaceans following oil spills. Most notably, in the 18 months following the *Exxon Valdez* oil spill, one resident pod and one transient pod of killer whales present in Prince William Sound at the time of the spill experienced an unprecedented number of deaths (30 to 40 percent mortality; Matkin et al. 2008). None of the killer whale carcasses were recovered. As of 2012, NOAA concluded that the pod of resident killer whales still had not reached its pre-spill numbers, while the oil-exposed transient pod numbers have continued to

decrease– so much so that they have been listed as a "depleted stock" under the MMPA. Meanwhile, other killer whale populations in southeast Alaska have grown since the mid-1980s (Matkin et al. 2008).

In addition, following the *Exxon Valdez* oil spill, 37 carcasses of other cetaceans were found, which represented the largest number of cetacean strandings ever observed in the region. The cause of death of these stranded animals could not be determined, and the extent to which increased vessel activity might have contributed to increased observations of stranded cetaceans is not known. There is also one report of gray whales showing altered respiratory behavior (increased blow rates) in the presence of surface oiling off the coast of California (Geraci & St. Aubin 1982; Geraci & St. Aubin 1985).A small number of studies have exposed cetaceans to oil (reviewed in Englehardt 1983). Effects from these exposures included the following:

- Liver damage in captive bottlenose dolphins that had oil added to their tank.
- Skin lesions in a number of captive delphinid species where oil was applied to their skin.
- Skin lesions after oil was applied to the skin of a live, stranded sperm whale.

Additional studies in which pinnipeds were exposed to oil via ingestion, inhalation, or application to their fur have shown a wide range of effects, including lung inflammation, increased respiratory rates, respiratory failure, abnormal nervous system function, liver and kidney damage, reproductive impairment, and death (reviewed in Englehardt (1983).

Controlled oil exposure studies with mink documented liver, adrenal, and hematological effects over several months (Mazet et al. 2000; Schwartz et al. 2004). Exposed pregnant mink also had a decrease in the number of live-born offspring (Mazet et al. 2000; Mazet et al. 2001). Subsequent studies confirmed findings of adrenal effects and also determined that the adrenal stress response was impaired in mink chronically exposed to oil (Mohr et al. 2008).

In summary, while data on the effects of oil exposure in cetaceans are scarce, available data point towards the possibility of injury and death following oil spills. Findings from experimental studies in pinnipeds and mink (as a surrogate for marine mammals) also suggest that cetaceans exposed to oil will likely experience adverse health effects and possibly death.

4.9.2.3 Conceptual Model and Studies to Support the Assessment

The Trustees developed a general conceptual model to support the injury assessment (Figure 4.9-5). In order to assess injuries to marine mammals due to the *Deepwater Horizon* oil spill, the Trustees evaluated the pathways and exposures of marine mammals to *Deepwater Horizon* oil, characterized the injuries (including death, reproductive failure, and other adverse health effects) associated with *Deepwater Horizon* oil exposure, and quantified the magnitude of those injuries across northern Gulf of Mexico marine mammal populations. The following subsections describe the Trustees' approach to the assessment, including how scientists across the NRDA-designed studies analyzed NRDA and non-NRDA datasets, and synthesized the results with the published literature, in order to determine marine mammal exposure and injury due to the *Deepwater Horizon* oil spill.

Figure 4.9-5 illustrates the Trustees' approach.

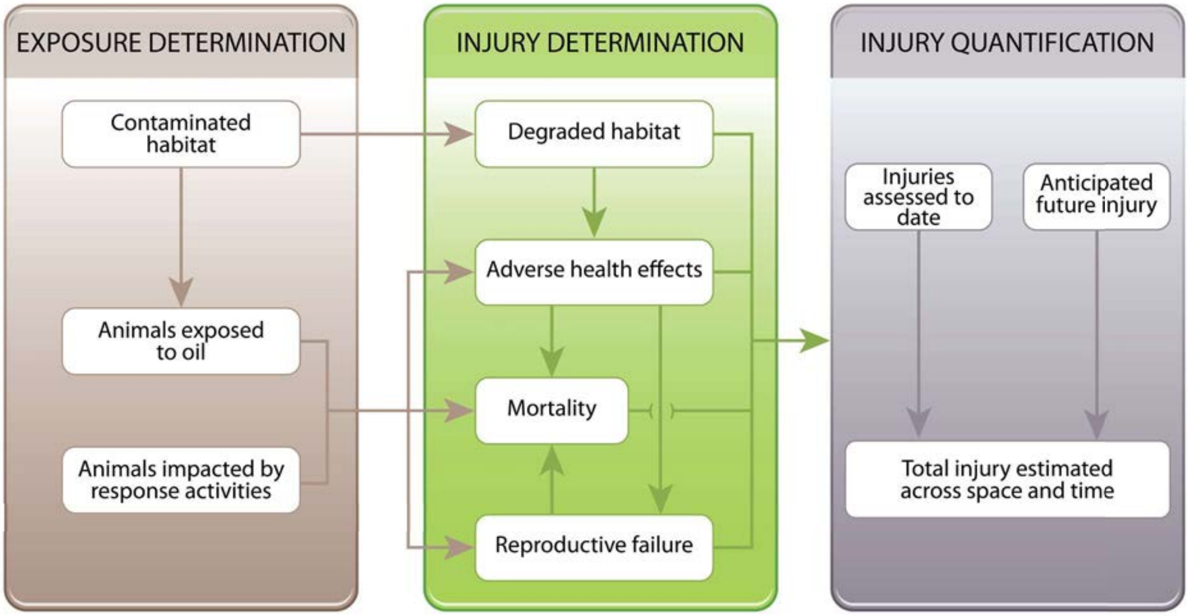


Figure 4.9-5. The Trustees quantified injuries to northern Gulf of Mexico marine mammal populations based on the widespread exposure of marine mammals to *Deepwater Horizon* oil and the observed injuries documented in the field.

4.9.2.3.1 Exposure Determination

In order to determine the exposure of marine mammals to *Deepwater Horizon* oil, the Trustees considered the following:

- Biologists conducted aerial and vessel surveys to document and estimate the number of marine mammals within the *Deepwater Horizon* oil spill surface slick. Researchers also compared marine mammal population distributions and behaviors (based on tracking animals with radio and satellite tags, acoustic tracking of oceanic animals, aerial and vessel-based surveys, and historical data) to the transport of *Deepwater Horizon* oil (see Section 4.2, Natural Resource Exposure).

- *Deepwater Horizon* responders reported observations of marine mammals, living or dead, in the surface slick. Stranding response teams collected photographs of any stranded animals with oil on their skin and swabs of the oil for chemical analysis. Some internal tissues (e.g., lung tissue) were also analyzed for *Deepwater Horizon* oil components.

- Biologists and veterinarians identified and characterized the potential routes of exposure, including inhalation, aspiration, aspiration of oil-induced vomitus, ingestion, and dermal absorption, for *Deepwater Horizon* oil to various marine mammal tissues and organs. Scientists also identified literature that described the adverse health effects when test organisms encountered oil via these exposure routes.

4.9.2.3.2 Injury Determination

In order to determine the injuries to marine mammals as a result of exposure to *Deepwater Horizon* oil, the Trustees considered the following:

- In collaboration with researchers studying the ongoing northern Gulf of Mexico marine mammal UME (Box 1), NRDA scientists studied trends in stranding rates over time and geographic space. For example, although the current UME started prior to the *Deepwater Horizon* incident, most of the strandings (above historical averages) prior to the incident were limited to Lake Pontchartrain, Louisiana, and western Mississippi, and were most likely caused by prolonged exposure to cold temperatures and low salinity. In contrast, most strandings outside of this March to May 2010 cluster occurred after the *Deepwater Horizon* blowout, were focused in areas exposed to *Deepwater Horizon* oil, and could not be attributed to prolonged cold temperatures or low salinity (Mullin et al. 2015; Venn-Watson et al. 2015c).

- Veterinary pathologists analyzed tissues from stranded carcasses to understand the health of each animal leading up to its death and potential causes of death (whenever possible, depending on decomposition rates). They compared the results to findings in dolphins that stranded in other areas of the southeastern United States that were unaffected by the *Deepwater Horizon* oil spill (Venn-Watson et al. 2015a).

- Marine mammal scientists characterized the survival and reproductive success of populations in Barataria Bay, Louisiana, and Mississippi Sound in Mississippi and Alabama (two areas with documented *Deepwater Horizon* oil contamination) using a combination of photo-identification surveys, mark and recapture analysis, and pregnancy determination via ultrasound or blubber hormone levels.

- In addition to measuring dolphin density/abundance and reproduction, veterinarians and biologists also captured

Box 2: Sarasota Bay and Other Reference Populations

The Trustees compared mortality rates, reproductive parameters, and health indicators for bottlenose dolphins in areas of the northern Gulf of Mexico affected by the *Deepwater Horizon* oil spill to data from well-studied bottlenose dolphin stocks from other BSEs in the southeastern United States. Researchers have studied bottlenose dolphins extensively at several BSE sites and have documented a common basis of biology, behavior, ecology, and health across sites (Reynolds III et al. 2000; Wells & Scott 1990).

The Trustees used information on mortality and reproduction available from reference sites in Texas, Mississippi, Florida, and South Carolina (Fernandez & Hohn 1998; Mattson et al. 2006; Stolen & Barlow 2003; Wells & Scott 1990).

The Trustees compared dolphin health data with data from Sarasota Bay, Florida, where scientists have conducted health studies for decades, as well as with health data from other long-term studies or repeated, standardized health assessments on BSE dolphins near St. Joseph Bay, Florida; Charleston, South Carolina; Beaufort, North Carolina; and Indian River Lagoon, Florida (Schwacke et al. 2009; Schwacke et al. 2010; Wells et al. 2004).

and released live animals in Barataria Bay and Mississippi Sound to conduct health assessments. They analyzed a suite of medical parameters, including pulmonary health, hormone levels, body condition, blood chemistry, and reproductive status, among many others. Data from these studies were compared to the results from dolphins in Sarasota Bay, Florida, and other similar habitats in the southeastern United States that were unaffected by the *Deepwater Horizon* oil spill (Schwacke et al. 2014; Smith et al. 2015) (Box 2).

- Scientists specifically designed their studies and analytical methods to account for other factors, such as biotoxins from harmful algal blooms, infectious disease outbreaks, human/fishery interactions, environmental factors, and other chemical contaminants. Whenever possible, researchers evaluated the plausibility, specificity, consistency, and strength of association between the observed adverse effects and oil exposure (or other potentially harmful activities associated with the response to the *Deepwater Horizon* oil spill). This provided the scientific basis for establishing causality (Venn-Watson et al. 2015b).
- The Trustees found it unrealistic to investigate the health of marine mammals across the entire area of the northern Gulf of Mexico affected by the *Deepwater Horizon* oil spill. Instead, scientists focused their health assessments on dolphin populations in Barataria Bay and Mississippi Sound to 1) examine potentially sublethal effects in cetaceans exposed to *Deepwater Horizon* oil, and 2) use these BSE populations as case studies for extrapolating to coastal and oceanic populations that received similar or worse exposure to *Deepwater Horizon* oil. In addition, marine mammal biologists could compare the injuries identified in health assessments and photo-identification surveys with the pathology findings and statistics from the dead, stranded dolphins in the ongoing UME investigation.

4.9.2.3.3 Injury Quantification

In order to quantify the injuries to marine mammals as a result of exposure to *Deepwater Horizon* oil, the Trustees considered the following:

- Scientists used data from stranded animals, photo-identification surveys, and live dolphin health assessments to characterize the adverse effects within the observed populations in Barataria Bay and Mississippi Sound, and extrapolated the magnitude of the injury to other populations present within the oil footprint (DWH MMIQT 2015).
- Marine mammal biologists used models that synthesized the extent of oiling over the geographic area and timeline of the spill, the likelihood of lingering adverse health and reproductive effects, and the specific population dynamics of each cetacean species to characterize the effect of the *Deepwater Horizon* oil spill on cetacean populations.

4.9.2.4 Summary

The Trustees developed a suite of laboratory and field studies to determine the extent of exposure across the northern Gulf of Mexico, characterize the types of injuries suffered by marine mammals, and quantify the total injuries across the marine mammal stocks in the Gulf of Mexico. The results of those studies are presented in the following sections, with interpretations informed by non-NRDA studies and the pre-existing literature.

4.9.3 Exposure

Key Points

- The Trustees have determined that marine mammals were exposed to chemical contaminants resulting from the *Deepwater Horizon* oil spill in the northern Gulf of Mexico.
- *Deepwater Horizon* oil contaminated every type of habitat that northern Gulf of Mexico marine mammals occupy.
- During response activities and surveys, workers observed over 1,100 marine mammals in the *Deepwater Horizon* surface slick. The Trustees estimate that tens of thousands of marine mammals were exposed to *Deepwater Horizon* oil based on population abundances and the extent of the oil footprint.
- Chemists identified *Deepwater Horizon* oil on the skin of dead, stranded dolphins and also found constituents consistent with what would be in the breathing zone vapor above oil slicks in the lung tissue of one dead, stranded dolphin.
- Cetaceans were likely exposed to *Deepwater Horizon* oil via inhalation of contaminated air and/or aspiration of liquid oil. These routes of exposure are consistent with the types of adverse health effects documented in living and dead, stranded dolphins (e.g., effects on the lungs).
- Cetaceans may also have been exposed to *Deepwater Horizon* oil via ingestion of contaminated sediment, water, or prey, or dermal absorption after contact with contaminated water or sediment.

The Trustees have determined that marine mammals were exposed to chemical contaminants resulting from the *Deepwater Horizon* oil spill in the northern Gulf of Mexico. As demonstrated in this section, as well as in Section 4.2, Natural Resource Exposure; Section 4.4, Water Column; and Section 4.6, Nearshore Marine Ecosystem, sufficient amounts of oil were present, and persisted, in the oil spill footprint to expose marine mammals and their supporting habitats. *Deepwater Horizon* oil impacted over 112,000 square kilometers of the ocean surface,

Source: *NOAA. Photo taken under NMFS permit.*

Figure 4.9-6. Stenellid dolphins swim through oil on April 29, 2010.

over 2,100 kilometers of shoreline, at least 1,000 square kilometers of the deep-sea floor, and plumes of deep ocean water that extended over 400 kilometers from the wellhead. While the surface oil and plumes dissipated following the capping of the wellhead, contaminated sediments persisted at least into 2014 ((Hayworth et al. 2015); Section 4.2, Natural Resource Exposure). Critical pathways of exposure include the contaminated water column, where marine mammals swim and capture prey; the surface slick at the air:water interface, where marine mammals breathe, rest, and swim; and contaminated sediment, where marine mammals forage and capture prey.

Source: *NOAA. Photo taken under NMFS permit.*

Figure 4.9-7. A group of rough-toothed dolphins swim through thick oil offshore on June 16, 2010.

4.9.3.1 Overlap of Marine Mammal Populations and the Surface Oil Footprint

Whether in the area contaminated by the deep-sea plume, at the surface, or in BSE habitats, a variety of cetacean species rely upon the habitat and resources within the *Deepwater Horizon* oil spill footprint, as shown in Figure 4.9-6 (Dias 2015; Jefferson & Schiro 1997; Waring et al. 2013). Population distributions (as defined by tracking with radio or satellite tags or via acoustic monitoring, aerial and vessel surveys, and historical survey data) demonstrated that the *Deepwater Horizon* oil spill footprint overlapped with the known ranges of 31 stocks of northern Gulf of Mexico marine mammals (Dias 2015; Waring et al. 2013).

During the spill, response workers and Trustees documented, photographed, and recorded videos of marine mammals present in areas contaminated by oil ranging from light sheen to thick, heavy oil (Dias 2015). Figure 4.9-4, Figure 4.9-6, and Figure 4.9-7 document some of these animals swimming in oil. Between April 28 and September 2, 2010, the Trustees conducted marine mammal surveys in the northern Gulf of Mexico and around the *Deepwater Horizon* oil spill site. Vessel and aerial marine mammal surveys, as well as reports from response monitoring activities, documented over 1,100 marine mammal sightings of at least 10 cetacean species swimming in oil. Table 4.9-2 and Figure 4.9-8 present the findings from these reports and surveys. In addition, between May 2010 and as late as February 2012, 14 stranded marine mammals were found with *Deepwater Horizon* oil on their skin (as confirmed by analytical chemistry (Stout 2015a)).

Table 4.9-2. Response workers and scientists observed over 1,100 marine mammals in *Deepwater Horizon* surface oil during response activities and as part of NRDA boat and helicopter surveys (Dias 2015).

Species	Individuals Seen in Oil
Atlantic spotted dolphin	71
Common bottlenose dolphin	277
Cuvier's beaked whale	1
Dwarf/pygmy sperm whale	2
Pantropical spotted dolphin	205
Risso's dolphin	127
Rough-toothed dolphin	74
Sperm whale	35
Spinner dolphin	108
Striped dolphin	156
Unidentified dolphin	130
Unidentified mammal	7

4.9.3 Exposure

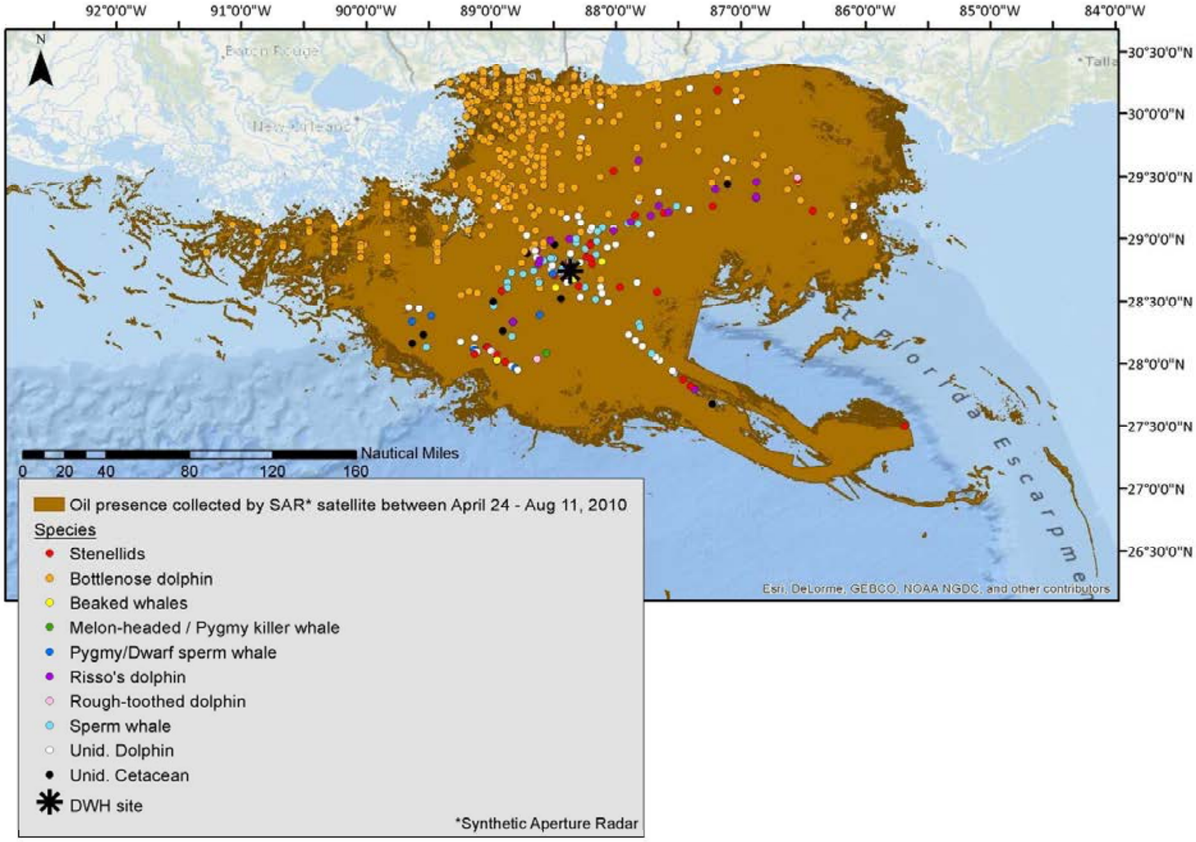


Figure 4.9-8. Marine mammals of at least eight cetacean species were sighted within the *Deepwater Horizon* oil spill footprint during vessel and aerial surveys between April 28 and August 10, 2010. Individual points can represent more than one animal. Surveys continued through September 2, 2010, but those data are not shown here.

4.9.3.2 Routes of Exposure

Due to the long timeframe and expansive area of the *Deepwater Horizon* oil spill, marine mammals may have experienced different exposures depending on their intersection(s) with the oil transport pathways. Oceanic animals near the wellhead were likely exposed to fresher oil for longer periods of time, while BSE bottlenose dolphins were exposed to intermittent, but lingering, doses of more weathered oil (see Section 4.2, Natural Resource Exposure). Near the wellhead, rising oil was relatively fresh and contained a wide range of toxic components, including polycyclic aromatic hydrocarbons (PAHs, e.g., naphthalene, phenanthrene, and benzo[a]pyrene). In the nearshore, however, oil could have spent days to weeks in the subsurface mixing zone and on the surface before moving into the nearshore environment and exposing the BSE bottlenose dolphins. This oil may have contained a more weathered PAH profile (Stout 2015b, 2015c). Thus, marine mammals would have experienced a heterogeneous set of exposure scenarios.

Marine mammals encountering *Deepwater Horizon* oil would have experienced multiple routes of exposure that could result in injuries through inhalation, ingestion, ingestion leading to secondary aspiration, direct aspiration, and dermal absorption. Response workers and scientists routinely saw marine mammals swimming in surface oil both offshore and nearshore, like the rough-toothed dolphins

pictured in Figure 4.9-7. These animals would likely have inhaled contaminated air, ingested contaminated water, aspirated liquid oil, and contacted oil with their skin and mucus membranes.

4.9.3.2.1 Exposure Through Inhalation

When cetaceans surfaced to breathe within the footprint of the *Deepwater Horizon* oil surface slick, they would have likely inhaled toxic volatile and aerosolized oil components (see Section 4.2, Natural Resource Exposure). When taking a breath, cetaceans break the surface of the water and exhale/inhale through their blowhole near the air:water interface. If they are surfacing after a long dive, they may breathe at the surface for a long period of time in order to replenish their oxygen supply. During long dives, oceanic marine mammals may retain inhaled toxic chemicals for as long as an hour, allowing for long exposures to lung tissue or absorption into the blood when their lungs collapse, a typical physiological response during long dives (Piscitelli et al. 2010; Ponganis 2011).

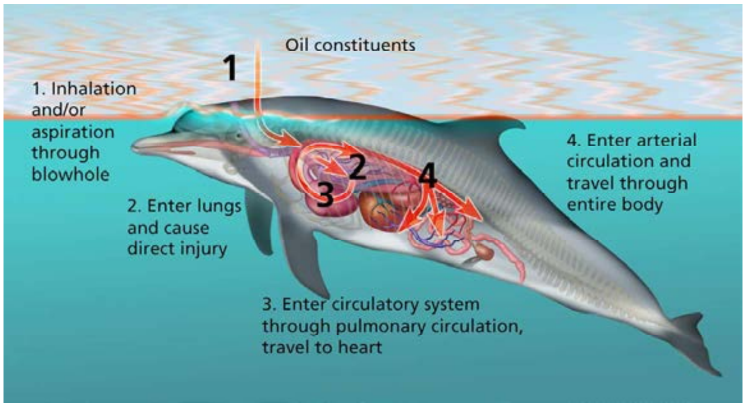
The chemical components of oil will escape from a surface slick (at various rates depending on the compound and its concentration) and become available to cetaceans in a variety of forms. In surface slicks, they may escape as volatile organic compounds (VOCs), intermediate volatile organic compounds (iVOCs), or semivolatile organic compounds (sVOCs) (de Gouw et al. 2011; Stout 2015a) and be suspended in the air column (de Gouw et al. 2011; Haus 2015; Murphy et al. 2015). Chemical components may also enter small seawater droplets that can become indefinitely suspended in the air column due to the breaking of waves, wind, raindrops, animals breaking the surface, or other disruptions to the air:water interface (primary aerosols). Finally, volatiles and particles in the air column can undergo chemical transformations and coalesce to form suspended particulates (secondary aerosols) (de Gouw et al. 2011; Haus 2015; Murphy et al. 2015).

Inhalation exposures were a concern for any organism near the *Deepwater Horizon* surface slick, including response workers, birds, sea turtles, and marine mammals. For health and safety purposes, *Deepwater Horizon* spill responders were required to wear dosimetry badges to document their potential inhalation exposure to oil compounds. Chemical analyses of these badges demonstrated that some of these workers inhaled oil compounds and suffered adverse respiratory effects (Groth et al. 2014; Ramachandran et al. 2014; Sandler et al. 2014; Stenzel et al. 2014).

Inhaled contaminant exposure and lung injury to cetaceans were likely amplified compared to other mammals and wildlife because cetaceans breathe at the air:water interface where volatile contaminants would be at their highest concentrations; lack nasal structures that filter air prior to reaching the lung; have deep lung air exchange (80 to 90 percent of lung volume compared to 10 to 20 percent for humans); have extended breath hold time; and have an extensive, rich blood supply in their lungs (Green 1972; Irving et al. 1941; Ridgway et al. 1969; S.H. 1972). As shown in Figure 4.9-9, all of these factors would facilitate the transport of inhaled contaminants into the blood, directly to the heart, and then throughout the body, without first going through the liver (which is a major organ involved in metabolizing toxicants absorbed via ingestion).

The Trustees were able to directly document inhalation exposure to *Deepwater Horizon* oil vapors in a deceased bottlenose dolphin stranded on May 24, 2010, near Barataria Bay. This dolphin had *Deepwater Horizon* oil on its exterior, and its lung tissue contained volatile petroleum constituents. The lung tissue data strongly suggest that the dolphin inhaled *Deepwater Horizon* oil vapors prior to death (Stout

2015a). Researchers ruled out aspiration of liquid or aerosolized oil due to the absence of nonvolatile PAHs and biomarkers in the lung tissue (see Section 4.2, Natural Resource Exposure).

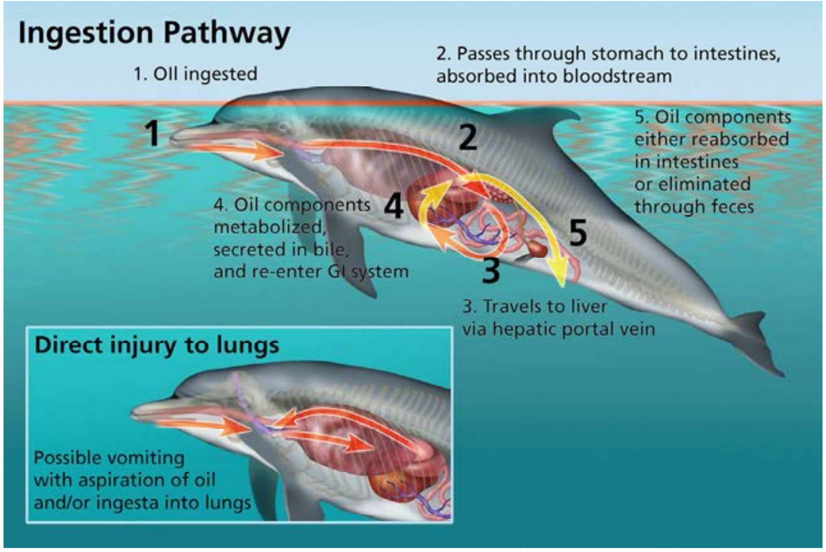


Source: Kate Sweeney for NOAA.

Figure 4.9-9. Chemical components become available to cetaceans through inhalation and aspiration exposure pathways.)

4.9.3.2.2 Exposure Through Ingestion

Depending on the species, habitat, and prey, marine mammals can use many different feeding techniques, from baleen whales straining large volumes of water for krill, to bottlenose dolphins foraging in shallow, turbid BSE waters. In the presence of oil-contaminated resources, it is inevitable that animals will inadvertently ingest oil from water, sediment, or prey. Some specific examples of such ingestion include suction feeding, where animals quickly suck water and prey into their mouths, and crater feeding, where dolphins burrow into the sediment with their rostrum (sometimes as far as their pectoral fins) in search of submerged prey (Rossbach & Herzing 1997). Contaminated water, sediment, and prey will transit from the oral cavity to the esophagus and the rest of the gastrointestinal tract, where oil can cause mucosal irritation, vomiting, and regurgitation ((Edwards 1989; Rowe et al. 1951); see Section 4.7, Birds, and Section 4.8, Sea Turtles). Figure 4.9-10 illustrates these ingestion pathways. Oil components can transit to the bloodstream (and then to the rest of the body) from the gastrointestinal tract, but chemicals that make it to the liver will likely be metabolized. Ingested toxicants will affect a variety of organs, including the adrenal glands and the reproductive tract, but the detoxification pathway associated with ingestion is likely to reduce any potential effect to the lungs except through vomiting and aspiration. Bodkin et al. (2012) reported long-term effects from the *Exxon Valdez* oil spill on sea



Source: Kate Sweeney for NOAA.

Figure 4.9-10. Cetaceans become exposed to chemicals through ingestion of contaminated water, soil, or prey. After ingestion, some animals can become nauseous and vomit, presenting an opportunity for aspiration of oil-contaminated oil and/or ingesta into the lungs.

otters *(Enhydra lutris)* in Alaska. The pathway for these long-term effects was attributed to oil exposure via ingestion during intertidal foraging and the presence of oil near otter foraging pits (the authors ruled out exposure by inhalation).

Animals that ingest petroleum are likely to experience nausea and vomiting; after vomiting, they are at risk of aspirating the vomitus (a collection of food, petroleum, and stomach acids) into the lungs (Coppock et al. 1995; Coppock et al. 1996; Lifshitz et al. 2003; Siddiqui et al. 2008). The aspiration of vomitus results in pneumonias that can eventually lead to lung abscesses and secondary infections (Coppock et al. 1995; Coppock et al. 1996). In regions of the world where children frequently mistake bottles of kerosene for water during hot summer months, numerous reports have documented that kerosene ingestion leads to aspiration pneumonia (Lifshitz et al. 2003; Sen et al. 2013; Siddiqui et al. 2008). Although aspiration pneumonia is considered rare in dolphins, a recent study from stranded animals in the northern Gulf of Mexico has documented aspiration pneumonia (Venn-Watson et al. 2015a).

4.9.3.2.3 Exposure Through Aspiration

When cetaceans surface, some water remains around the blowhole, or water droplets may be splashed onto the blowhole just prior to or during a breath. In oil-contaminated waters, when marine mammals surface to breathe, they can aspirate (i.e., draw in liquid via suction) oily water or droplets directly into their blowhole, through the larynx and trachea, and potentially into their lungs. Figure 4.9-11 shows a spray of oily water droplets from exhalation, which could lead to the animal's aspiration of oily water. Aspiration of liquid oil results in physical injuries, where oil damages tissues and membranes along the respiratory tract and lungs. Exposure to toxic oil components will results in chemical injury to tissues, as well as delivery of oil components to the blood, and then throughout the body (Coppock et al. 1995; Coppock et al. 1996; Prasad et al. 2011). Aspiration of petroleum products in cattle most commonly leads to a severe inflammatory response and lung disease, including pneumonia, fibrosis, and pulmonary dysfunction (Coppock et al. 1995; Coppock et al. 1996).

Source: *NOAA. Taken under NMFS permit.*

Figure 4.9-11. A rough-toothed dolphin surfaces through an oil slick during the *Deepwater Horizon* oil spill (June 16, 2010). The spray of oily water droplets is generated from the animal's exhalation, leading to the potential for inhalation of contaminated aerosols and aspiration of oily water.

4.9.3.2.4 Exposure Through Dermal Contact

Cetaceans have developed a thick epidermis that prevents absorption and leakage, which is critical in a high salinity environment. Their thick skin is thought to protect against oil absorption. However, if *Deepwater Horizon* oil-exposed animals had any skin lesions, cuts, rake marks, or abrasions, or were in low salinity water

for a period of time, oil could be absorbed more readily and delivered into the bloodstream. In addition, in areas of skin ulceration, direct exposure to oil could damage the exposed tissues. Oil can also irritate and erode mucous membranes, for example, in the eyes and mouth (Dutton 1934; Hansborough et al. 1985)

4.9.3.3 Summary

Deepwater Horizon oil contaminated marine mammal habitats throughout the northern Gulf of Mexico, resulting in the exposure of 31 stocks of dolphins and whales. Cetaceans would have been exposed to toxic oil components through inhalation, aspiration, ingestion, and dermal exposure. Similar routes of exposure have been characterized in field and laboratory studies of a variety of species and resulted in physical and toxicological damage to organ systems and tissues, reproductive failure, and death. However, unlike in laboratory exposures, cetaceans exposed in the northern Gulf of Mexico would have suffered from multiple routes of exposure at the same time, over intermittent timeframes and at varying rates, doses, and chemical compositions of oil, thus complicating the severity and combinations of injuries.

4.9.4 Injury Determination

Key Points

- The Trustees determined that exposure to *Deepwater Horizon* chemical contaminants resulted in death, reproductive failure, and adverse health effects in northern Gulf of Mexico marine mammal populations.
- The adverse health effects include lung disease, adrenal disease, and poor body condition. Other factors contributing to poor health include tooth loss, anemia, and liver injury.
- In addition to injuries from direct exposure to *Deepwater Horizon* oil, marine mammal habitat was degraded.
- Marine mammals were affected by *Deepwater Horizon* oil spill response activities.
- The Trustees ruled out other potential causes of the observed injuries and have concluded that the impacts from the *Deepwater Horizon* oil spill are the only reasonable cause for the suite of observed adverse health effects and the patterns of observed reproductive failure and mortalities.

The Trustees have determined that exposure to *Deepwater Horizon* chemical contaminants resulted in death, reproductive failure, and adverse health effects in northern Gulf of Mexico marine mammal populations. The determination is based on the integrated analysis of field-based studies of marine mammal health and reproduction, Gulf-wide stranding numbers, histopathology analysis of tissues from dead dolphins, and oil toxicity literature from field and laboratory studies. The nature of the adverse health effects in living marine mammals, the lesions identified in stranded marine mammals, and the spatial extent and timing of marine mammal injuries are consistent 1) across the *Deepwater Horizon* marine mammal injury determination studies; 2) with known toxic effects described in the literature and

Section 4.3, Toxicity; and 3) with the timing and pathway of oil and chemical contaminants during and after the *Deepwater Horizon* oil spill.

Oil toxicity exerts a variety of negative effects on marine mammals (Geraci 1990; Loughlin 2013), including molecular, cellular, and developmental effects; tissue and organ malfunction; reproductive failure and death; impacts on population dynamics; and secondary effects from the oil's harm on critical marine mammal habitats. Oil is a complex chemical mixture, and oil toxicity will likely manifest differently in each individual. In laboratory and field studies with a variety of taxa (including fish, birds, invertebrates, and turtles), *Deepwater Horizon* oil exposure resulted in anemia, immunosuppression, growth inhibition, hormone dysregulation, reproductive failures, and many other adverse effects, often in various combinations depending on dose, species, and other factors (see Section 4.3, Toxicity). In this section, the Trustees describe the marine mammal injuries from the *Deepwater Horizon* spill and discuss how the adverse effects to each tissue or organ can influence marine mammal fitness and survival.

While marine mammals in the northern Gulf of Mexico face a variety of pathogens, environmental insults, and anthropogenic stressors on a routine basis, the likely cause of the suite of adverse effects described in this section is exposure to *Deepwater Horizon* oil (Venn-Watson et al. 2015b). Marine mammal scientists and veterinarians designed field studies and conducted data analysis so as to explicitly examine other potential explanations for marine mammal injuries, including biotoxins from harmful algal blooms, infectious diseases that have been implicated in previous marine mammal UMEs, human and fishery interactions, and other potential contaminants unrelated to the *Deepwater Horizon* oil spill (Venn-Watson et al. 2015b). Based on the results of these analyses, the scientists ruled out each of these other factors as a primary cause for the high prevalence of adverse health effects, reproductive failures, and disease in stranded animals. When all of the data are considered together, the *Deepwater Horizon* oil spill is the only reasonable cause for the full suite of observed adverse health effects.

4.9.4.1 Effects on Habitat

Marine mammals live for decades and use a wide range of behaviors and feeding strategies to exploit available resources. Oiled marine mammal habitats in the northern Gulf of Mexico include the shallow embayments with fringing wetlands and beaches, coastal and shelf waters, and oceanic habitats including the deeper waters used by deep divers such as sperm whales. Thus, any detrimental impacts on their habitat will most likely have some negative effect on their typical behavior, especially as interpreted through the lens of the MMPA (which prohibits the "disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering"). Herbivorous/planktivorous marine mammals will suffer from the effects of *Deepwater Horizon* oil on seagrass and plankton populations (see Section 4.3, Toxicity, and Section 4.4, Water Column). Carnivorous cetaceans such as dolphins and sperm whales which are typically apex predators, will suffer from *Deepwater Horizon* oil's effects on fish and invertebrate populations. At a more subtle, but still crucial, level, the summed negative effects of the *Deepwater Horizon* oil spill on the Gulf of Mexico ecosystem across resources, up and down the food web, and among habitats, will especially impact marine mammals due to their long lives and their strong dependence on a healthy ecosystem (Bossart 2011; Moore 2008; Reddy et al. 2001; Ross 2000; Wells et al. 2004).

4.9.4.2 Response Injury

In addition to direct impacts to habitat, response activities (including removal of oil from the environment, use of dispersant, response vessel activity, and protection of shorelines and other critical areas) may have had unintended negative consequences for marine mammal habitats and marine mammals themselves. Oceanic animals that were proximate to response activities would have been at risk for:

- Breathing in smoke from burning surface slicks (enriched in the higher molecular weight pyrogenic PAHs and particulate matter).
- Blocked habitat from skimming and burning operations.
- Disturbance by increased vessel traffic and noise.
- Increased bioavailability and mobilization of PAHs by dispersant application.
- Direct breathing and dermal exposure to aerially applied dispersants.
- Increased inhalation and aspiration of dispersed oil at the air:water interface.
- Increased noise from seismic and other assessment or drilling activities near the wellhead.

For deep-diving whales, subsurface dispersant application at the wellhead likely had negative impacts on prey resources and habitat, and may have led to incidental ingestion of dispersant.

Similarly, response activities adversely affected BSE and coastal dolphin habitat, including:

- Disturbance of shallow feeding and resting habitat by containment boom (including boom deployment, stranded boom, and boom maintenance).
- Introduction of dispersants to the habitat (particularly off Grand Isle and Chandeleur Sound, Louisiana, but also in Barataria Bay, where a pilot was forced to release a full load of dispersant during an emergency).
- Increased vessel traffic and noise associated with response operations.

BSE and coastal animals were also at increased risk of entanglement and entrapment in boom and sampling gear.

Overall, the large and varied efforts initiated in response to the spill impacted marine mammals and their habitats and may have contributed to injury.

4.9.4.3 Mortality from Oil Exposure

Starting in 2010, the number of stranded cetaceans (primarily bottlenose dolphins) along the coastlines of Louisiana, Mississippi, and Alabama increased dramatically (Litz et al. 2014; Venn-Watson et al. 2015c). The ongoing, high rate of dead, stranded animals in the region prompted a federally declared northern Gulf of Mexico UME (see Box 1; Litz et al. 2014). The long duration, high number of strandings, and large area affected suggest that the overall event could include multiple overlapping incidents or

one incident with multiple contributing factors. To investigate the potential lethal effects of the *Deepwater Horizon* oil spill on northern Gulf of Mexico marine mammals, researchers analyzed the stranding data in the context of *Deepwater Horizon* oil transport and conducted surveys to track the survival of animals in BSEs exposed to *Deepwater Horizon* oil (Lane et al. [In Press]). Based on the combined results of these studies, the Trustees have determined that the *Deepwater Horizon* oil spill resulted in the death of marine mammals and is the primary underlying cause of the persistent, elevated stranding numbers and reduced survivorship in the northern Gulf of Mexico.

More than 1,000 cetaceans stranded in Alabama, Mississippi, and Louisiana from 2010 to 2014 (an average of more than 200 per year) compared to an average of 54 per year prior to 2010 for the same region (Figure 4.9-12).

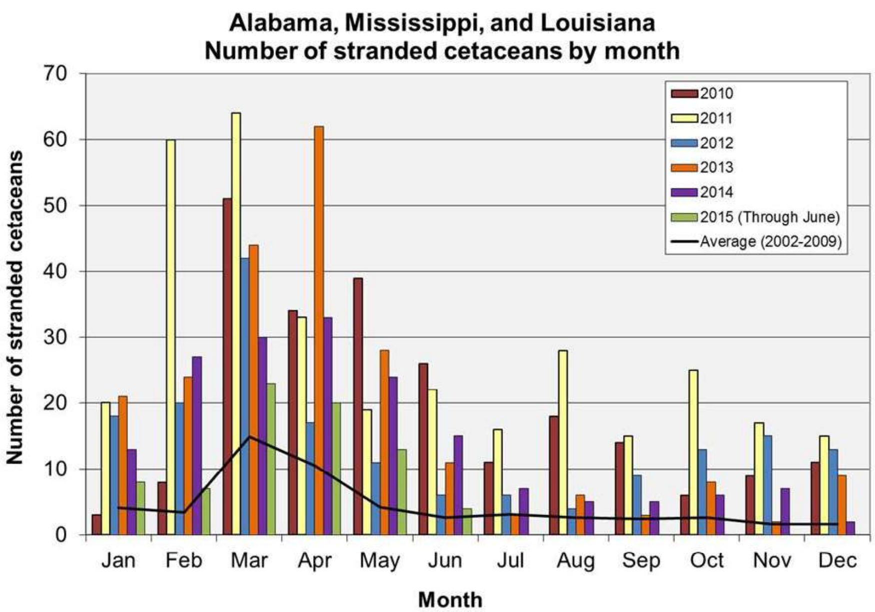


Figure 4.9-12. The *Deepwater Horizon* oil spill contributed to a large increase in monthly marine mammal strandings in the northern Gulf of Mexico. The number of monthly cetacean strandings along the coastlines of Louisiana, Mississippi, and Alabama from January 2010 to June 2015 is compared to the average number of strandings from 2002 to 2009 (solid line). Stranding data for this figure were extracted from the NOAA Marine Mammal Health and Stranding Response Program Database on August 24, 2015.

The majority of stranded cetaceans were common bottlenose dolphins (87 percent), and more than 95 percent were dead (Venn-Watson 2015). The geographic and temporal patterns of the elevated strandings overlap with the *Deepwater Horizon* oil footprint. The largest increase in stranding rates occurred in Barataria Bay, which sustained the longest period of consecutive months with unusually high numbers of stranded dolphins (August 2010 through December 2011). The numbers of stranded animals in 2010 and 2011 in Louisiana were the highest in recorded history; 2011 was also one of the highest stranding years for both Mississippi and Alabama. In contrast, beaches in Florida and Texas did not see a similar sustained increase in the number of dead, stranded dolphins (Venn-Watson et al. 2015c). Although there were elevated strandings in western Mississippi and outside of Lake Pontchartrain before the *Deepwater Horizon* oil spill, the Trustees' analyses show that these are likely due to a cold winter and mortality among dolphins from Lake Pontchartrain (DWH MMIQT 2015; Mullin et al. 2015; Venn-Watson et al. 2015c). Barataria Bay did not have elevated pre-spill strandings (Venn-Watson et al. 2015c).

The total number of stranded animals is likely an underestimate. The detection of marine mammal carcasses is very low, because many carcasses do not make it to shore and those that do may not be found or reported to stranding networks (DWH MMIQT 2015). For offshore animals, currents and time of drift preclude the beaching of a carcass onshore, where they are more likely to be reported to a stranding network than in the open ocean (DWH MMIQT 2015).

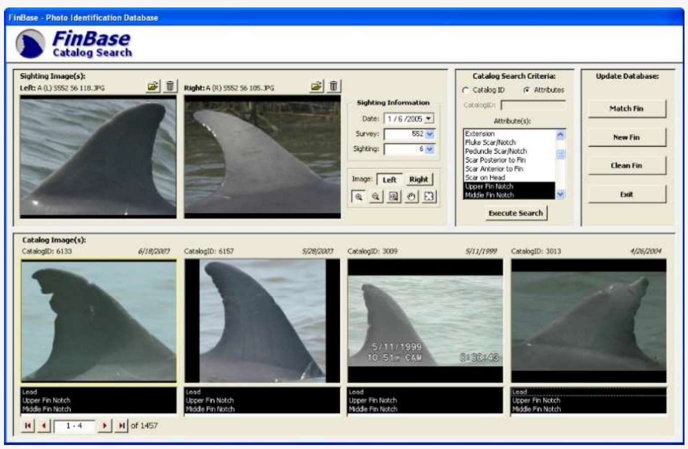
Consistent with the increased number of strandings in heavily oiled coastal locations, researchers conducting photo-identification studies observed high apparent mortality (i.e., unexplainable disappearances) among dolphin populations in Barataria Bay and Mississippi Sound (27 percent per year; confidence interval of 22 to 33 percent) in the year following the *Deepwater Horizon* spill (DWH MMIQT 2015). (Box 3 describes and illustrates the use of photo-identification studies, also known as photo-ID studies.) This mortality is referred to as "apparent," because photo-ID studies can only document the loss of individuals from the population, and both mortality and permanent emigration may contribute to those losses. These apparent mortality rates, however, are very high compared to those reported for other populations from the southeast U.S. coast measured using similar photo-ID study methods (3.9 and 4.9 percent per year for Sarasota Bay and Charleston, South Carolina stocks, respectively; (Speakman et al. 2010; Wells & Scott 1990)). Furthermore, dolphin satellite tracking data obtained in the years following the spill did not indicate long-range movements from either Barataria Bay or Mississippi Sound (Wells & Balmer 2012; Wells et al. 2014a; Wells et al. 2014b), making it unlikely that a significant number of dolphins were emigrating from these areas. Furthermore, a variety of marine mammal species suffered increased mortality rates after the *Exxon Valdez* oil spill, including sea otters, harbor seals, and killer whales (Frost et al. 1999; Garrott et al. 1993; Matkin et al. 2008).

In summary, the Trustees have determined that *Deepwater Horizon* oil exposure resulted in increased mortality to marine mammals. While UMEs can be caused by a variety of factors, including infection, biotoxins, cold stress, and other anthropogenic toxin exposures, researchers have ruled out these alternative hypotheses and determined that the most likely causes of the increased strandings and the observed high mortality rates are the adverse health effects caused by the *Deepwater Horizon* oil spill (Venn-Watson et al. 2015b).

Box 3: Photo ID Studies and Apparent Mortality

Source: *NOAA.*

Dolphins naturally acquire nicks and notches on their dorsal fins. These markings, along with unique fin shapes, can be used to identify individual animals. Photo-identification (photo-ID) studies use dorsal fin photographs to recognize and track individual animals over time. The data from photo-ID studies can be used to estimate survival rates and track reproductive events for females with marked fins. In addition, a mark-recapture model (a type of statistical model) can be used to estimate population size based on the re-sighting of previously identified dolphins relative to sighting of dolphins that had not been previously identified.



Source: *NOAA.*

FinBase is a customized Access database that allows photo-ID researchers to search an existing catalog of identifiable dorsal fins to find matches for newly photographed fins. Fins are assigned attributes such as "upper fin notch" that allows FinBase to present the existing dorsal fins in a sorted order to improve the searching efficiency.

4.9.4.4 Reproductive Failure

Marine mammal reproductive traits vary from species to species, the best understood being those of the bottlenose dolphin. Female bottlenose dolphins reach reproductive maturity between 5 and 12 years old and typically give birth every 3 to 5 years until they are as old as 48 years (Wells 2014). Gestation lasts about 380 days, and the mother, along with potentially other socially associated females, are critical for the successful recruitment of the calf into the population (Wells 2014). Stressors and injuries that affect the reproductive success of female marine mammals can have deleterious effects at the individual and population levels.

Twenty-two percent of all bottlenose dolphins that stranded between January 2010 and December 2013 were perinates, that is, pre-birth or very young newly born animals (Venn-Watson et al. 2015c). These dead animals showed a higher prevalence of fetal distress, failure of their lungs to inflate with air, and *in utero* pneumonia (not due to lungworm infection), when compared to reference perinates from outside the spill footprint.

During health assessments in Barataria Bay and Mississippi Sound, researchers identified a number of pregnant females, but their reproductive success (measured through follow-up surveys at and after the birth due date) was unusually low (DWH MMIQT 2015; Smith et al. 2015). Only 19.2 percent of pregnant females studied in Barataria Bay and Mississippi Sound between 2010 and 2014 gave birth to a viable calf. In contrast, dolphin populations in Florida and South Carolina have a pregnancy success rate of 64.7 percent (DWH MMIQT 2015). Pregnant females within the *Deepwater Horizon* oil spill footprint were more likely to abort a calf (due to infection or other factors), and if a calf was born, it was less likely to survive more than a few weeks (Smith et al. 2015). Figure 4.9-13 shows a Barataria Bay female with a dead near-term or newly born calf. The poor reproductive success was seen over successive years, not just for females that were pregnant during the spill (DWH MMIQT 2015; Smith et al. 2015).

Source: *Jeremy Hartley, Louisiana Department of Wildlife and Fisheries.*

Figure 4.9-13. In August 2011, a female dolphin (Y01) was examined in Barataria Bay and found pregnant with an expected due date in May 2012. In March 2013, just 10 months after her due date, she was seen supporting a dead calf. The timing and size of the dead calf (which appears to be near- or full-term) suggests that Y01 must have lost the calf due in 2012, become pregnant again, and suffered a second loss. Seventy-eight percent of pregnant females in Barataria Bay lost their calves, either as fetuses, neonates, or calves less than 1 year old.

The reproductive failure in *Deepwater Horizon* oil-exposed animals is consistent with field and laboratory study results present in the literature. After the *Exxon Valdez* oil spill, sea otters suffered from high rates of maternal, fetal, and neonatal loss (Tuomi & Williams 1995). In laboratory studies in which mink were exposed to bunker C oil, mothers had fewer offspring and neonates were less likely to survive (Mazet et al. 2001). Oil exposure has also been linked to spontaneous abortions and infant mortality in rats, mink, and humans (Mazet et al. 2001; Merhi 2010; Thiel & Chahoud 1997).

The *Deepwater Horizon* oil spill is the most plausible explanation for the overall reproductive failure effects seen in dolphins exposed to *Deepwater Horizon* oil (Venn-Watson et al. 2015b). Evidence of *in utero* deaths and poor reproductive success was found in both live and dead dolphins within the *Deepwater Horizon* oil spill footprint (Colegrove et al. 2015; DWH MMIQT 2015). The confirmed high prevalence of adult dolphins with hypoadrenocorticism, moderate to severe primary bacterial pneumonia, and poor body weight–all adverse health effects attributed to *Deepwater Horizon* oil

exposure ((Schwacke et al. 2014; Venn-Watson et al. 2015b); Section 4.3, Toxicity)–were the most likely primary causes for the high rates of failed pregnancies in dolphins living within the oil spill footprint. Other potential causes of the reproductive failures, such as other contaminants, infectious diseases, or harmful algal toxins, were ruled out as primary causes for all of the failed pregnancies across the oil spill footprint. However, the effects of these stressors may have been exacerbated by the oil spill (particularly infectious pathogens such as *Brucella* that are known to cause abortions) (Colegrove et al. 2015; Smith 2015; Venn-Watson et al. 2015b).

The Trustees have determined that *Deepwater Horizon* oil exposure resulted in increased reproductive failure for marine mammals. There is also evidence that the prevalence of poor reproductive success in live dolphins is persisting 4 years after the *Deepwater Horizon* oil spill (DWH MMIQT 2015; Schwacke et al. 2014).

4.9.4.5 Adverse Health Effects

The toxic components of oil, including, but not limited to, PAHs, cause a variety of adverse health effects (Figure 4.9-14). Toxic effects may manifest in different ways in different species, or even individuals. Thus, the Trustees relied upon a combination of field-based studies, analyses of tissues from stranded animals, and the toxicity literature in order to determine and characterize the injuries to marine mammals in the northern Gulf of Mexico. The *Deepwater Horizon* NRDA studies revealed a suite of adverse health effects that are both injuries in and of themselves (symptoms that will affect the quality of life for animals) and health effects that will lead to decreased survival and/or reproductive failure in northern Gulf of Mexico marine mammals.

Source: *Kate Sweeney for NOAA.*

Figure 4.9-14. Bottlenose dolphins within the *Deepwater Horizon* oil spill footprint had a variety of oil-related health issues, including lung disease, adrenal system disruption, poor body condition, and reproductive failure, including fetal/neonatal loss. These health effects were seen in dead, stranded bottlenose dolphins; in health assessments conducted on live bottlenose dolphins in 2011, 2013, and 2014; and in reproductive follow-up studies conducted in 2012, 2014, and 2015.

Based on data from the live health assessments and post-mortem analyses of stranded animals, researchers have identified three primary adverse health effects that are the main contributors to the increased prevalence of sick animals, dead animals, and reproductive failure within the *Deepwater Horizon* oil spill footprint: lung disease, abnormal stress response, and poor body condition. They also identified a suite of other adverse health effects that compound the primary injuries, including anemia, liver disease, and dental disease. This section will describe each adverse health effect in further detail and put it into the context of an overall clinical prognosis for an animal's survival and reproductive potential.

4.9.4.5.1 Lung and Respiratory Impairments

The cetacean respiratory system is critical for individual fitness; reduced lung capacity will lead to less effective foraging, swimming, and diving. Since cetaceans breathe at the ocean surface, they are particularly at risk from exposure to the toxic chemicals in oil surface slicks via inhalation of volatiles and aerosols, as well as aspiration of liquid oil (see Section 4.9.3.2). The lungs of cetaceans, more than those of humans, are designed to maximize surface area to allow for efficient oxygen uptake and to expand diving capability. Physical disruptions, whether from oil coating tissues and membranes or organ/cellular damage due to chemical toxicity, can result in serious effects on animal health, including infections (Coppock et al. 1995; Coppock et al. 1996).

Through post-mortem examinations, marine mammal pathologists identified unusually high numbers of bottlenose dolphins with primary bacterial pneumonia and severe pneumonias (Venn-Watson et al. 2015a). Similarly, researchers found evidence of lung damage and disease in dolphins in Barataria Bay and Mississippi Sound during live dolphin health assessments (Schwacke et al. 2014).

From 2010 to 2012 (data beyond 2012 are not yet available), the prevalence of primary bacterial pneumonia was higher in animals that stranded within the footprint of the *Deepwater Horizon* oil spill (22 percent) than in animals that stranded outside of that footprint (2 percent) (Venn-Watson et al. 2015a). Many of these pneumonias were unusual in severity and caused or contributed to death (Venn-Watson et al. 2015a). Several types of bacteria were responsible for the large numbers of pneumonia cases, making it unlikely that all of these dolphins succumbed to a single infectious disease outbreak (Venn-Watson et al. 2015a). More likely, oil exposure weakened their lung health and systemic immune functions, resulting in infection by whatever bacteria could exploit the injury in each individual.

In 2011, 2013, and 2014, marine mammal veterinarians performed ultrasound examinations on dolphins captured for health assessments. They found unusually high rates of moderate to severe lung disease in dolphins from Barataria Bay and Mississippi Sound compared to animals from Sarasota Bay (Schwacke et al. 2014). Specifically, dolphins in areas contaminated with *Deepwater Horizon* oil were three to six times more likely to have moderate to severe lung disease compared to those in the Sarasota Bay reference site (Schwacke et al. 2014; Smith et al. 2015). Severe cases of lung disease were only found in oiled locations, and the severity and prevalence of lung disease decreased from 2011 to 2014 (Smith et al. 2015).

The lung injuries affecting animals in the *Deepwater Horizon* oil spill footprint were consistent with those reported in the human and mammalian oil toxicology literature, including research on inhaled, aspirated, and ingested oil and other chemicals (Akira & Suganuma 2014; Franzen et al. 2013; Lifshitz et al. 2003). In humans, inhalation exposure to the *Prestige*, *Heibei Spirit,* and *Tasman Spirit* oil spills resulted in increased respiratory symptoms (Carrasco et al. 2006; Janjua et al. 2006; Jung et al. 2013; Sim et al. 2010; Suarez et al. 2005; Zock et al. 2007; Zock et al. 2012), and *Deepwater Horizon* response workers reported increased respiratory symptoms (Sandler et al. 2014). Ingestion of oil, followed by aspiration of petroleum products, has led to pneumonia in both animals and humans (Bystrom 1989; Coppock et al. 1995; Coppock et al. 1996; Edwards 1989; Lifshitz et al. 2003; Sen et al. 2013). These studies are consistent with the exposure and injuries to northern Gulf of Mexico marine mammals as a result of the *Deepwater Horizon* oil spill. Lung disease in exposed dolphins likely contributed to the increased mortality within the *Deepwater Horizon* oil spill footprint, as well as to some of the other

adverse health effects reported here, including poor body condition and reproductive failure. The lung disease seen in marine mammals is also consistent with the adverse health effects reported in other wildlife species exposed to *Deepwater Horizon* oil, including cardiac dysfunction, poor body condition/growth, anemia, immune system abnormalities, decreased flight/swimming performance in birds and fish, and reproductive failure (see Section 4.3, Toxicity). Based on the consistency between *Deepwater Horizon* marine mammal studies, *Deepwater Horizon* toxicity studies, and the literature, the Trustees have determined that *Deepwater Horizon* oil exposure likely caused lung disease in cetaceans, which contributed to the adverse health effects, mortality, and reproductive failure observed in exposed northern Gulf of Mexico marine mammals.

4.9.4.5.2 Adrenal Gland Impairments

The adrenal glands, part of the endocrine system, are responsible for secreting hormones (e.g., cortisol and aldosterone) into the blood stream that are essential for mounting an appropriate response to stress, maintaining glucose and electrolyte levels, modulating the immune system, and altering behavior. Hypoadrenocorticism is a disease state resulting from a deficiency in adrenal gland hormones (Klein & Peterson 2010), which, if left untreated, greatly increases an animal's risk of death from adrenal crisis, particularly during times of stress, such as illness or pregnancy. Toxigenic chemicals, including PAHs, have been shown to affect the adrenal gland in vertebrates (Nichols et al. 2011; Ribelin 1984). Therefore, dolphins within the *Deepwater Horizon* oil spill footprint were examined for evidence of adrenal disease and dysfunction.

Marine mammal veterinarians and pathologists found evidence of adrenal gland disease in bottlenose dolphins that stranded within the *Deepwater Horizon* oil spill footprint, and evidence of hypoadrenocorticism in live bottlenose dolphins from Barataria Bay and Mississippi Sound. Specifically, stranded dolphins had adrenal cortical atrophy (Venn-Watson et al. 2015a), and live dolphins had low cortisol and aldosterone hormone levels (Schwacke et al. 2014; Smith et al. 2015). Adrenal cortical atrophy (thinning of the cortex) is sometimes associated with adrenal insufficiency, or low hormone levels (Capen 2007).

An unusually high number of dead dolphins (33 percent) stranding in Louisiana, Mississippi, and Alabama between 2010 and 2012 had a low corticomedullary ratio (indicating a thin cortex); 50 percent of these animals stranded within Barataria Bay (Venn-Watson et al. 2015a). Approximately 7 percent of reference dolphins (outside the spill area) had a low corticomedullary ratio. A specific cause of death could not be identified for many of the dolphins with a thin adrenal cortex; the dolphins likely died of an adrenal crisis (Venn-Watson et al. 2015a). Histological evaluation of the adrenal glands in dead, stranded dolphins did not produce evidence of other possible causes of adrenal cortical atrophy (Venn-Watson et al. 2015a).

Normally, blood concentrations of cortisol are expected to increase following the initiation of a stressor, for example, the chase-capture process used in the health assessments (Thomson & Geraci 1986). This was not the case, however, for dolphins living in Barataria Bay and Mississippi Sound. Cortisol concentrations were lower than expected in dolphins captured in Barataria Bay (Schwacke et al. 2014; Smith et al. 2015). In fact, nearly half (44 percent) of the dolphins captured in Barataria Bay in 2011 had cortisol measures that were lower than the minimum values previously measured in other dolphin populations (Schwacke et al. 2014). Abnormal cortisol concentrations were also seen in Mississippi

Sound dolphins in 2013, and continued to be seen in Barataria Bay dolphins in 2013 and 2014, although the number of individuals affected was lower than the number observed in 2011 (Smith et al. 2015). These findings are consistent with hypoadrenocorticism (Klein & Peterson 2010). Some bottlenose dolphins from Barataria Bay suffered from low blood sugar, high potassium, and/or low sodium, which are symptoms likely associated with hypoadrenocorticism (Schwacke et al. 2014).

The results from both the live and stranded bottlenose dolphin studies are unprecedented in terms of previous observations with marine mammals and consistent with literature concerning the effects of oil exposure on other species. Preliminary *Deepwater Horizon* NRDA studies using Gulf toadfish (*Opsanus beta*) and human adrenal cell lines demonstrated that *Deepwater Horizon* oil can disrupt stress hormone pathways (see Section 4.3, Toxicity; Takeshita et al. 2015). Laboratory studies exposing animals to other crude oils have demonstrated impaired stress responses and poorly functioning adrenal glands (Lattin et al. 2014; Mohr et al. 2008). The adrenal hormone abnormalities observed among Barataria Bay and Mississippi Sound dolphins were unexpected and significantly different than normal when compared to reference intervals, a reference site, and other dolphins previously sampled in the southeastern United States (Hart et al. 2015; Schwacke et al. 2014; Smith et al. 2015). Prior to this investigation, adrenal cortical atrophy had not been described in free-ranging cetaceans (Clark et al. 2005).

If left untreated, hypoadrenocorticism is life threatening and can lead to adrenal crisis and death in mammals (Arlt & Allolio 2003). Adrenal crises may have caused death in dolphins with damaged adrenal glands and contributed to death in dolphins exposed to factors to which a healthy dolphin would have otherwise adapted. Thus, adrenal cortical atrophy leading to adrenal insufficiency likely contributed to the increased mortality in areas affected by the *Deepwater Horizon* oil spill (Smith et al. 2015; Venn-Watson et al. 2015a; Venn-Watson et al. 2015c). It also likely contributed to other marine mammal adverse health effects, including reproductive failure in pregnant females (Colegrove et al. 2015); liver enzyme, glucose, potassium, and sodium imbalances; and poor body condition (Schwacke et al. 2014). The adrenal injury in marine mammals is also consistent with the injuries to other *Deepwater Horizon* oil-affected wildlife, including impaired stress response, immunosuppression, poor body condition/growth, and glucose/electrolyte imbalances (see Section 4.3, Toxicity; Section 4.7, Birds; and Section 4.8, Sea Turtles).

Based on the measures of adrenal function in health assessments, adrenal cortical thinning in dead dolphins, and a review of the available literature, the Trustees have determined that adrenal gland impairment is a result of exposure to *Deepwater Horizon* oil and likely contributed to the adverse health effects, mortality, and reproductive failure observed in exposed northern Gulf of Mexico marine mammals.

4.9.4.5.3 Body Condition

Many factors can be measured to assess the health of wildlife, but the fitness of an animal can be represented effectively and with little effort by assessing body condition, as measured by the ratio between weight and length. Poor body condition could be a symptom of many types of stressors, including exposure to toxins, illness, low feeding success, poor diet quality, or detrimental changes in behavior. Any increase in the severity or duration of decreased body condition will result in further reductions in the animal's fitness, including its ability to feed, reproduce, and deal with other environmental stressors, and, in the worst scenarios, will eventually lead to death.

Dolphins exposed to *Deepwater Horizon* oil were more likely to be underweight than dolphins outside the oil spill footprint (Schwacke et al. 2014). In 2011, 25 percent of live animals captured in Barataria Bay had a low mass-to-length ratio, compared to only 4 percent of Sarasota animals. Furthermore, dolphins with poor body condition from Barataria Bay were more severely underweight, especially males, than the underweight animals from Sarasota Bay. The most likely cause of the low mass-to-length ratio in Barataria Bay dolphins was illness, in particular, the lung disease or hypoadrenocorticism associated with *Deepwater Horizon* oil exposure (Venn-Watson et al. 2015b).

The decreased body condition in dolphins exposed to *Deepwater Horizon* oil is consistent with the oil toxicity studies described in Section 4.3 (Toxicity) and with other adverse health effects observed in the marine mammal health assessments. In laboratory studies of *Deepwater Horizon* oil exposures, birds, fish, and invertebrates all suffered from reduced growth rates (Section 4.3, Toxicity).

A low mass-to-length ratio, depending on its severity, would likely contribute to the increased prevalence of reproductive failure and mortality in marine mammals exposed to *Deepwater Horizon* oil. Poor body condition is a possible effect of lung disease and adrenal disease.

Based on the poor body condition of animals in Barataria Bay and the prevalence of decreased body condition in oil-exposed wildlife in the literature, the Trustees have determined that poor body condition as a result of exposure to *Deepwater Horizon* oil likely contributed to the adverse health effects, mortality, and reproductive failure observed in exposed northern Gulf of Mexico marine mammals.

4.9.4.5.4 Other Adverse Health Effects

In addition to the adverse health effects described above, marine mammal veterinarians and biologists also documented the following:

- **Anemia**. While health assessments in 2011 showed that 13 percent of dolphins in Barataria Bay were anemic, no dolphins in Sarasota Bay showed signs of anemia (Schwacke et al. 2014). Anemia was also seen in birds and fish exposed to *Deepwater Horizon* oil, and is well documented in field and laboratory studies of oil exposure on a variety of species (Section 4.3, Toxicity; Section 4.7, Birds; (Bursian et al. 2015a; Bursian et al. 2015b; Dorr et al. 2015; Harr et al. 2015)).

- **Tooth loss.** Some of the bottlenose dolphins in Barataria Bay had excessive tooth loss. Three animals had fewer than half of their teeth remaining, and three animals had lost all or nearly all of their teeth (eight, two, and zero teeth remaining) (Schwacke et al. 2014). Bottlenose dolphins typically have 76 to 108 teeth. All of these animals suffered from overgrown tissue in their gums. Beluga whales and pinnipeds exposed to toxic chemicals in the St. Lawrence estuary and the Baltic, respectively, exhibited tooth loss (Beland et al. 1993; Bergman et al. 1992). Laboratory exposures of rodents to PAHs resulted in inflammation, hyperplasia, and cell proliferation in the mouth (Brandon et al. 2009; Guttenplan et al. 2012; Wester et al. 2012). Mink exposed to chemical toxicants that act by a similar toxic mechanism to PAHs demonstrated bone loss, extreme tooth loss, and lesions in the jaw (Haynes et al. 2009; Render et al. 2000).

- **Liver damage.** Some Barataria Bay dolphins had signs of liver injury, including increased liver enzyme concentrations in the blood (Schwacke et al. 2014). Similar hepatic dysfunction was seen in sea otters following the *Exxon Valdez* spill and in laboratory exposures with mammals (Mazet et al. 2000; Rebar et al. 1995; Schwartz et al. 2004). Captive bottlenose dolphins exposed to oil showed signs of liver damage (Englehardt 1983). Abnormal liver function can lead to decreased fitness and, importantly in the context of exposure to *Deepwater Horizon* oil, reduce an animal's ability to cope with exposure to toxic chemicals.

4.9.4.5.5 Overall Prognosis

For each animal captured during the Barataria Bay and Mississippi Sound health assessments (as well as those captured during the health assessments for the Sarasota Bay reference site), veterinarians synthesized the results from the physical examinations, ultrasounds, hematology, and serum chemistry in order to generate an overall prognosis (Schwacke et al. 2014; Smith et al. 2015). Dolphins could be assigned one of the following prognoses: good (favorable outcome expected), fair (favorable outcome possible), guarded (outcome uncertain), poor (unfavorable outcome expected), or grave (death considered imminent). Dolphins examined in Barataria Bay in 2011, 1 year following the *Deepwater Horizon* oil spill, had a high prevalence of guarded or worse prognosis scores (48 percent) when compared to animals sampled in Sarasota Bay in 2011 (7 percent) or over both survey years (2011 and 2013) in Sarasota Bay (11 percent). In the years following, the prevalence of guarded or worse prognoses in Barataria Bay decreased but remained elevated (37 percent in 2013, 28 percent in 2014). Dolphins examined in Mississippi Sound, an area also impacted by *Deepwater Horizon* oil, had a higher prevalence of guarded or worse prognoses scores (35 percent in 2013) as well. Unfortunately, health assessments could not be conducted in earlier years for Mississippi Sound. Thus, it is not surprising that the constellation of adverse health effects documented in marine mammals exposed to *Deepwater Horizon* oil happened synchronously with the increased number of marine mammal strandings in the northern Gulf of Mexico.

4.9.4.6 Causation

The Trustees have determined that exposure to *Deepwater Horizon* -related petroleum products caused a suite of adverse health effects, including lung disease, adrenal disease, reproductive failure, mortality, and poor body condition, in bottlenose dolphins. This conclusion was based on the overlap of observed disease conditions with the *Deepwater Horizon* oil spill footprint (in terms of time, space, and severity), the consistent evidence of abnormalities in both live and dead animals, the coherence and interconnectedness of the particular adverse health effects observed (Figure 4.9-15), and the elimination of other plausible causes (Venn-Watson et al. 2015b).

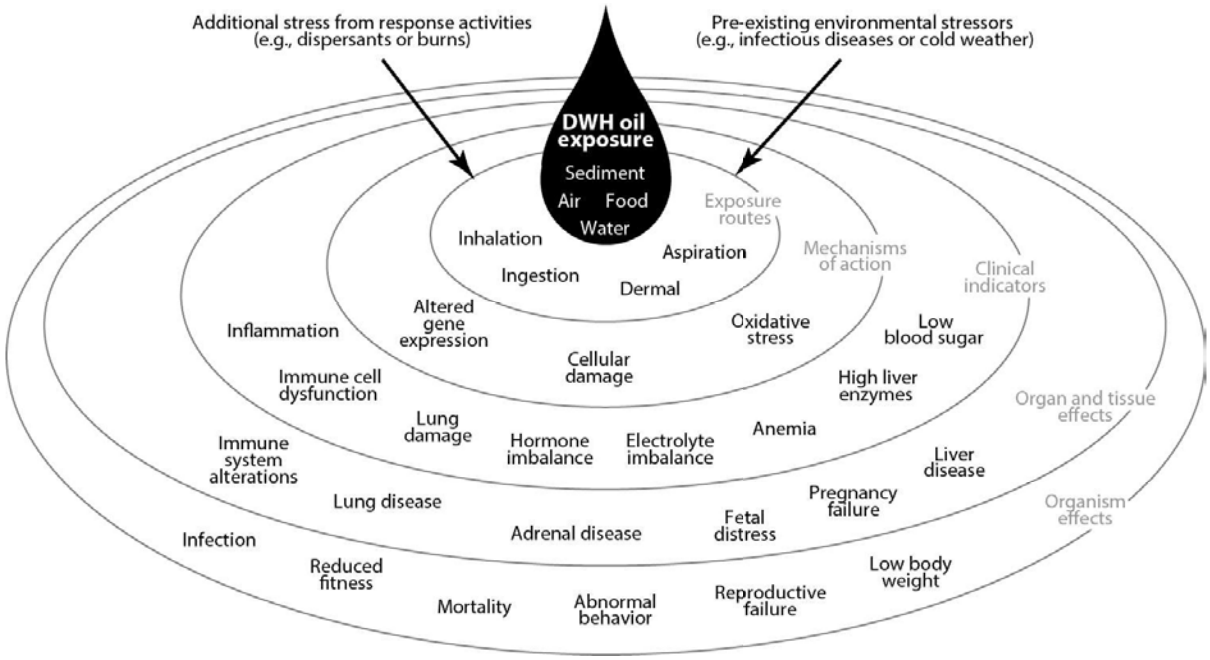


Figure 4.9-15. This conceptual model shows the interactions among oil exposure, exposure routes, mechanisms of action, clinical indicators, organ and tissue effects, and organism effects in marine mammals within the *Deepwater Horizon* oil spill footprint. Oil toxicity will manifest differently in each exposed individual, leading to different combinations of the outcomes listed in this diagram. The diagram includes information from *Deepwater Horizon* NRDA studies, as well as from the literature.

Very few factors can cause the suite of adverse health effects observed, and the most likely cause is exposure to *Deepwater Horizon*-related petroleum products. Researchers ruled out a variety of alternative explanations for the observed injuries, including morbillivirus, brucellosis, biotoxins, environmental stressors (e.g., cold temperatures or salinity changes), and fisheries/human interactions (Venn-Watson et al. 2015b). In addition, the adverse health effects seen in affected dolphins were consistent with what has been reported in other animal species experimentally exposed to petroleum and petroleum-associated products. These health effects, if left untreated, greatly increase an animal's risk of death, particularly during times of stress, illness, or pregnancy. Therefore, this constellation of adverse health effects almost certainly contributed to the poor survival rate and high reproductive failure of dolphins living in heavily oiled Barataria Bay and to the high stranding rates within the *Deepwater Horizon* oil spill footprint (DWH MMIQT 2015; Venn-Watson et al. 2015c).

Based on these findings and on the extent of exposure to *Deepwater Horizon* oil in the northern Gulf of Mexico, the Trustees concluded that it is reasonable to expect that marine mammals from oil-exposed species or stocks suffered similar effects as observed in Barataria Bay and Mississippi Sound.

4.9.5 Injury Quantification

Key Points

- The Trustees synthesized *Deepwater Horizon* NRDA exposure and injury data with the existing scientific literature to quantify the magnitude of injuries across the marine mammal populations in the northern Gulf of Mexico.
- The Trustees have determined that the majority of cetacean stocks within the *Deepwater Horizon* oil spill footprint were injured by some combination of increased mortality, increased reproductive failure, and/or adverse health effects, leading to reduced populations that will take decades to recover naturally.
- The injury quantification presented here builds from the measured injuries in Barataria Bay and Mississippi Sound bottlenose dolphins to other BSE stocks of bottlenose dolphins, and then to the coastal and oceanic stocks of bottlenose dolphins and other cetacean species within the *Deepwater Horizon* oil spill footprint.
- The Trustees quantified injuries to four BSE stocks: Barataria Bay, Mississippi River Delta, Mississippi Sound, and Mobile Bay. For example, in the Barataria Bay bottlenose dolphin stock, the *Deepwater Horizon* oil spill caused 35 percent (confidence interval of 15 to 49 percent) excess mortality, 46 percent (confidence interval of 21 to 65 percent) excess failed pregnancies, and a 37 percent (confidence interval of 14 to 57 percent) higher likelihood that animals would have adverse health effects (DWH MMIQT 2015).
- Shelf and oceanic stocks were generally less affected than BSE stocks. Of these stocks, Bryde's whales were the most impacted, with 17 percent (confidence interval of 7 to 24 percent) excess mortality, 22 percent (confidence interval of 10 to 31 percent) excess failed pregnancies, and an 18 percent (confidence interval of 7 to 28 percent) higher likelihood of having adverse health effects (DWH MMIQT 2015).
- To more completely quantify the injury to each stock, statisticians and biologists used a population modeling approach to capture the overlapping and synergistic relationships among the three injuries, and to quantify the entire scope of *Deepwater Horizon* marine mammal injury to populations into the future.
- Based on the results of the population model, the Barataria Bay stock of bottlenose dolphins suffered 30,347 (confidence interval of 11,511 to 89,746) lost cetacean years due to the *Deepwater Horizon* oil spill. In the absence of active restoration, the population will take 39 (confidence interval of 24 to 80) years to recover. This represents a 51 percent (confidence interval of 32 to 72 percent) maximum reduction in the population size due to the *Deepwater Horizon* oil spill (DWH MMIQT 2015).

The *Deepwater Horizon* oil spill resulted in an increased number of dead, stranded marine mammals on the shorelines of Louisiana, Mississippi, and Alabama; reduced survival and increased reproductive failure in bottlenose dolphins surveyed in Barataria Bay and Mississippi Sound; and a constellation of adverse health effects, including lung disease, adrenal disease, and poor body condition in bottlenose

dolphins examined in Barataria Bay and Mississippi Sound. Given the severity of these observed injuries and the wide distribution of marine mammals throughout the *Deepwater Horizon* oil spill footprint, the Trustees quantified the degree, and spatial and temporal extent, of marine mammal injuries within the entire footprint.

In the wake of the *Deepwater Horizon* oil spill, and in the midst of the northern Gulf of Mexico UME, the bottlenose dolphin stocks in Barataria Bay and Mississippi Sound offered an opportunity to study the effects of *Deepwater Horizon* oil exposure on cetaceans, in a situation that could be both logistically feasible (given the difficulties studying dolphins and whales in the open ocean) and serve as a reasonable case study for other cetacean species (with adjustments for differences in behavior, anatomy, physiology, life histories, and population dynamics among species). Thus, the injury quantification presented here builds from the measured injuries in Barataria Bay and Mississippi Sound bottlenose dolphins to other BSE stocks of bottlenose dolphins, and then to the coastal and oceanic stocks of bottlenose dolphins and other cetacean species within the *Deepwater Horizon* oil spill footprint.

A total of 31 cetacean stocks (9 BSE, 2 coastal, 2 shelf, and 18 oceanic) overlap with the oil spill footprint. As a first step, scientists used stranding data to calculate excess mortality above baseline for the BSE stocks (DWH MMIQT 2015). Two oceanic stocks, Fraser's dolphins and killer whales, were not considered; though they are present in the Gulf of Mexico, sightings are very rare and there were no historical sightings in the oil spill footprint on the surveys used in the quantification. Four BSE stocks (Perdido Bay, Pensacola Bay, Choctawhatchee Bay, and St. Andrews Bay) did not show evidence of excess mortality based on the quantification approach described in Section 4.9.5.1, despite some oiling along beaches and barrier islands of these stock areas. As a result, injury quantification was not pursued for these four BSE stocks. Table 4.9-3 presents a list of all marine mammal stocks that the Trustees considered for injury quantification in the assessment and, for those that were not included, an explanation of why they were not included.

Table 4.9-3. Thirty-two marine mammal stocks, 31 cetacean and 1 sirenian, were considered for injury quantification.

Common Name/Species	Stock	Injury Quantified?	Explanation
BSE			
West Indian manatee	Gulf-wide	No	Exposure unlikely
Common bottlenose dolphin	Terrebonne-Timbalier Bay	No	Unable to distinguish between injury due to *Deepwater Horizon* oil versus cold temperatures
Common bottlenose dolphin	Barataria Bay	Yes	Included
Common bottlenose dolphin	Mississippi River Delta	Yes	Included
Common bottlenose dolphin	Mississippi Sound	Yes	Included
Common bottlenose dolphin	Mobile Bay	Yes	Included
Common bottlenose dolphin	Perdido Bay	No	No excess strandings attributed to *Deepwater Horizon* oil using regression model

Common Name/Species	Stock	Injury Quantified?	Explanation
Common bottlenose dolphin	Pensacola Bay	No	No excess strandings attributed to *Deepwater Horizon* oil using regression model
Common bottlenose dolphin	Choctawhatchee Bay	No	No excess strandings attributed to *Deepwater Horizon* oil using regression model
Common bottlenose dolphin	St. Andrews Bay	No	No excess strandings attributed to *Deepwater Horizon* oil using regression model
Coastal			
Common bottlenose dolphin	Western coastal	Yes	Included
Common bottlenose dolphin	Northern coastal	Yes	Included
Shelf			
Atlantic spotted dolphin	Gulf-wide	Yes	Included in "Shelf dolphins" summation*
Common bottlenose dolphin	Gulf-wide	Yes	Included in "Shelf dolphins" summation*
Oceanic			
Blainville's beaked whale	Gulf-wide	Yes	Included in "Beaked whales" summation*
Bryde's whale	Gulf-wide	Yes	Included
Clymene dolphin	Gulf-wide	Yes	Included
Common bottlenose dolphin	Gulf-wide	Yes	Included
Cuvier's beaked whale	Gulf-wide	Yes	Included in "Beaked whales" summation*
Dwarf sperm whale	Gulf-wide	Yes	Included in "Pygmy/Dwarf sperm whales" summation*
False killer whale	Gulf-wide	Yes	Included
Gervais' beaked whale	Gulf-wide	Yes	Included in "Beaked whales" summation*
Melon-headed whale	Gulf-wide	Yes	Included
Pantropical spotted dolphin	Gulf-wide	Yes	Included
Pygmy killer whale	Gulf-wide	Yes	Included
Pygmy sperm whale	Gulf-wide	Yes	Included in "Pygmy/Dwarf sperm whales" summation*
Risso's dolphin	Gulf-wide	Yes	Included
Rough-toothed dolphin	Gulf-wide	Yes	Included
Pilot whale (short-finned)	Gulf-wide	Yes	Included
Sperm whale	Gulf-wide	Yes	Included
Spinner dolphin	Gulf-wide	Yes	Included
Striped dolphin	Gulf-wide	Yes	Included

*It can be difficult to distinguish between species during vessel and aerial surveys. Thus, for the purposes of the injury quantification, some species were grouped together.

Marine mammal biologists, veterinarians, and statisticians worked together to integrate *Deepwater Horizon* NRDA exposure and injury data with the existing scientific literature to most appropriately quantify the magnitude of injuries across the marine mammal populations in the northern Gulf of Mexico. The Trustees have determined that the majority of cetacean stocks within the *Deepwater Horizon* oil spill footprint were injured by some combination of increased mortality, increased reproductive failure, and/or adverse health effects—leading to reduced populations that will take

decades to recover naturally. In the Terrebonne/Timbalier Bay stock (one of the stocks for which the Trustees did not quantify injury), it is still likely that *Deepwater Horizon* oil exposure resulted in injuries; however, there are not enough data about the populations and injuries before and after the spill to make a determination at this time.

The quantification approaches are summarized more thoroughly in the *Deepwater Horizon* Marine Mammal Injury Quantification Team Technical report (DWH MMIQT 2015). Summaries are tabulated in Table 4.9-12 and Table 4.9-13 at the end of Section 4.9.5.4.

4.9.5.1 Mortality

The Trustees have determined that *Deepwater Horizon* oil exposure resulted in the increased number of dead cetaceans in the northern Gulf of Mexico following the *Deepwater Horizon* blowout. The numbers of deaths were above the expected baseline mortality. These significantly increased mortality rates in cetaceans exposed to *Deepwater Horizon* oil will have a negative impact on each population stock for years to come (Table 4.9-4 and Table 4.9-6).

Statistical analysis of data from photo-ID surveys conducted from 2010 to 2013 in Barataria Bay and from 2010 to early 2012 in Mississippi Sound estimated the proportion of each stock that succumbed to the effects of *Deepwater Horizon* oil exposure. Statisticians estimated the annual mortality rates in the 3 years in Barataria Bay and 1 year in Mississippi Sound following the *Deepwater Horizon* oil spill and compared them to previously reported annual mortality rates from other southeast U.S. dolphin populations (hereafter referred to as baseline or expected mortality). They used these comparisons to estimate excess mortality attributable to the *Deepwater Horizon* oil spill (hereafter referred to as excess mortality). Excess mortality was calculated as the difference between the expected annual mortality and the estimated annual mortalities for Barataria Bay and Mississippi Sound, and the differences were then summed over the multiyear period. Based on these calculations, there was 35 percent (confidence interval of 15 to 49 percent) excess mortality in Barataria Bay and 22 percent (confidence interval of 13 to 29 percent) excess mortality in Mississippi Sound (DWH MMIQT 2015).

Table 4.9-4. The *Deepwater Horizon* oil spill caused the deaths of BSE and coastal bottlenose dolphins throughout the surface slick footprint. This table presents the estimated percentage of each stock that died due to the *Deepwater Horizon* oil spill (above baseline).

Bottlenose Dolphin Stock	Population Killed (%)	95% CI
Barataria Bay	35	15-49
Mississippi River Delta	59	29-100
Mississippi Sound	22[a]	13-29
Mobile Bay	12	5-20
Western coastal	1	1-2
Northern coastal	38	26-58

[a] Based on 1 year of surveys; all other stocks based on 3 years of observations.

For the other five potentially affected BSE and two coastal bottlenose dolphin regions, statisticians used a linear regression model to compare the actual monthly strandings for each region during and after the spill to the predicted monthly strandings in a scenario assuming the oil spill never took place. This "no oil spill" scenario is modeled based on the average historical monthly strandings and weather/environmental conditions during and after the spill (DWH MMIQT 2015). Statisticians then calculated the number of excess strandings above baseline for the 3 years following the spill for each region exposed to *Deepwater Horizon* oil, after accounting for other potential contributing factors, such as cold temperatures. Stranded dolphins were tested using genetics and stable isotopes to determine if they belonged to a BSE or coastal stock. Once it was determined what percentage of the strandings came from the BSE or adjacent coastal stock, the number of strandings was scaled to estimate the number of mortalities for each stock, including those that did not wash ashore or were not detected. Based on these calculations, the Mississippi River Delta stock experienced 59 percent (confidence interval of 29 to 100 percent) excess mortality, and the Mobile Bay stock had 12 percent (confidence interval of 5 to 20 percent) excess mortality attributable to the *Deepwater Horizon* spill (DWH MMIQT 2015).

The Terrebonne-Timbalier Bay stock had higher stranding rates in the spring and summer of 2010 compared to baseline, but the statistical model could not distinguish mortalities due to oil exposure from mortalities due to cold weather. In addition, the marshy habitat in Terrebonne Bay is remote, and many strandings in the estuarine system may not be found and therefore go unreported. Thus, it was not possible to distinguish excess strandings from baseline in Terrebonne-Timbalier Bay, and the Trustees did not perform further injury quantification for this stock.

For the other BSE stocks (Perdido Bay, Pensacola Bay, Choctawhatchee Bay, and St. Andrews Bay), there was no evidence of excess mortality in the post-spill period, based on the results of the linear regression model (DWH MMIQT 2015). *Deepwater Horizon* oil reached the coastal shores of these Florida bays, but with intermittent frequency (especially compared to the Louisiana, Mississippi, and Alabama coastal areas), and the oil did not penetrate very far into the estuarine waters.

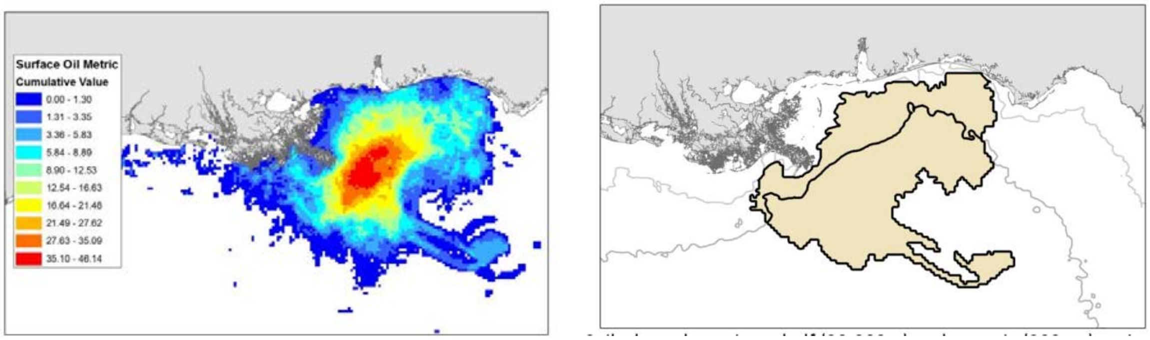


Figure 4.9-16. Marine mammals in coastal, shelf, and oceanic communities in waters with equal or greater *Deepwater Horizon* surface oiling (measured in days with at least a thin sheen) than in Barataria Bay would be subject to equal or greater *Deepwater Horizon* oil toxicity (DWH MMIQT 2015). **Figure 4.9-16a** (left) shows the entire oil footprint with a metric presenting comparative surface oiling across the Gulf of Mexico on the days of imaging. Based on the average of this metric in Barataria Bay, Barataria Bay mortality rates and reproduction rates were applied to areas of the shelf/oceanic area that had at least the same amount of oil. In **Figure 4.9-16b** (right)**,** the polygon shows the area of shelf (20 to 200 meters isobaths) and oceanic habitats (less than 200 meters isobaths) that exceed Barataria Bay oiling metric.

To calculate the increase in percent mortality for the shelf and oceanic marine mammal stocks, the Barataria Bay percent mortality was applied to the percentage of animals in each stock that was exposed to oil (DWH MMIQT 2015). For the purposes of calculating the percentage of the population exposed, this quantification assumes that animals experiencing a level of cumulative surface oiling similar to or greater than that in Barataria Bay (Table 4.9-5) would have been likely to suffer a similar or greater degree and magnitude of injury (Figure 4.9-16). For example, Barataria Bay dolphins experienced 35 percent excess mortality; 47 percent of the spinner dolphin stock range in the northern Gulf of Mexico experienced oiling equal to or greater than Barataria Bay, and, therefore, would have experienced at least a 35 percent mortality increase. Thus, the entire northern Gulf of Mexico spinner dolphin stock experienced a 16 percent mortality increase (0.35 x 0.47 = 0.16). The results of these calculations for each shelf and oceanic stock are presented in Table 4.9-6.

Table 4.9-5. This table presents estimates of pre-spill abundance and percentage of population exposed to *Deepwater Horizon* oil for each northern Gulf of Mexico cetacean stock with quantifiable injury (DWH MMIQT 2015). Cetaceans experiencing a level of surface oiling similar to or greater than that experienced by bottlenose dolphins in Barataria Bay would likely have suffered a similar or greater degree and magnitude of injury.

Cetacean Stock	Pre-spill Abundance Estimate	95% CI	Population Exposed to Oil (%)	95% CI
Bottlenose dolphin Barataria Bay	2,306	1,973-2,639	NA	NA
Bottlenose dolphin Mississippi River Delta	820	657-984	NA	NA
Bottlenose dolphin Mississippi Sound	4,188	3,617-4,760	NA	NA
Bottlenose dolphin Mobile Bay	1,393	1,252-1,535	NA	NA
Bottlenose dolphin western coastal	20,161	14,482-28,066	23	16-32
Bottlenose dolphin northern coastal	7,185	4,800-10,754	82	55-100

Cetacean Stock	Pre-spill Abundance Estimate	95% CI	Population Exposed to Oil (%)	95% CI
Continental shelf dolphins [a]	63,361	42,898-87,417	13	9-19
Bottlenose dolphin oceanic	8,467	4,285-16,731	10	5-20
Sperm whale	1,635	1,132-2,359	16	11-23
Bryde's whale	26	12-56	48	23-100
Beaked whales [b]	1,167	643-2,117	12	7-22
Clymene dolphin	3,228	1,558-6,691	7	3-15
False killer whale	316	121-827	18	7-48
Melon-headed whale	1,696	709-4,060	15	6-36
Pantropical spotted dolphin	33,382	25,489-43,719	20	15-26
Short-finned pilot whale	1,641	710-3,790	6	4-9
Pygmy killer whale	281	131-601	15	7-33
Pygmy/dwarf sperm whales [c]	6,690	3,482-12,857	15	8-29
Risso's dolphin	1,848	1,123-3,041	8	5-13
Rough-toothed dolphin	2,414	964-6,040	41	16-100
Spinner dolphin	6,621	3,386-12,947	47	24-91
Striped dolphin	2,605	1,537-4,415	13	8-22

[a] Continental shelf dolphins is a combination of shelf bottlenose dolphins and Atlantic spotted dolphins.

[b] Beaked whales is a combination of Blainville's beaked whales, Cuvier's beaked whales, and Gervais' beaked whales.

[c] Pygmy/dwarf sperm whales is a combination of pygmy sperm whales and dwarf sperm whales.

For coastal stocks, the excess mortality estimates are 1 percent (confidence interval of 1 to 2 percent) and 38 percent (confidence interval of 26 to 58 percent) for the western and northern coastal stocks, respectively (DWH MMIQT 2015). The increase in mortality due to *Deepwater Horizon* oil exposure in the shelf and oceanic stocks ranges from 2 to 17 percent of each population (DWH MMIQT 2015).

Table 4.9-6. The *Deepwater Horizon* oil spill caused the deaths of shelf and oceanic cetaceans throughout the surface slick footprint. This table presents the estimated percentage of each stock that died due to the *Deepwater Horizon* oil spill (above baseline).

Cetacean Stock	Population Killed (%)	95% CI
Continental shelf dolphins [a]	4	2-6
Bottlenose dolphin oceanic	3	1-5
Sperm whale	6	2-8
Bryde's whale	17	7-24
Beaked whales [b]	4	2-6
Clymene dolphin	2	1-4
False killer whale	6	3-9
Melon-headed whale	5	2-7
Pantropical spotted dolphin	7	3-10
Short-finned pilot whale	2	1-3

Cetacean Stock	Population Killed (%)	95% CI
Pygmy killer whale	5	2-8
Pygmy/dwarf sperm whales [c]	5	2-7
Risso's dolphin	3	1-4
Rough-toothed dolphin	14	6-20
Spinner dolphin	16	7-23
Striped dolphin	5	2-7

[a] Continental shelf dolphins is a combination of shelf bottlenose dolphins and Atlantic spotted dolphins.

[b] Beaked whales is a combination of Blainville's beaked whales, Cuvier's beaked whales, and Gervais' beaked whales.

[c] Pygmy/dwarf sperm whales is a combination of pygmy sperm whales and dwarf sperm whales.

4.9.5.2 Reproductive Failure

The Trustees have determined that *Deepwater Horizon* oil exposure resulted in the increased number of dead, stranded perinates and the unexpected number of unsuccessful pregnancies documented during Barataria Bay and Mississippi Sound surveys. The numbers of reproductive failures in these health assessment studies were above the expected baseline failures, based on historical monthly perinate stranding averages and reproductive failure rates in the bottlenose dolphin reference stocks in the southeastern United States. The increased reproductive failure rates in pregnant females exposed to *Deepwater Horizon* oil will have a negative impact on each population stock.

From 2011 to 2014, researchers tracked the numbers of pregnant females and successful pregnancies identified during health assessments and by measuring hormone levels in blubber biopsies (DWH MMIQT 2015). The Trustees pooled data from Barataria Bay and Mississippi Sound to achieve a reasonable sample size. Researchers found an excess of 46 percent (confidence interval of 21 to 65 percent) failed pregnancies in Barataria Bay and Mississippi Sound compared to the expected rate of reproductive failure based on reported observations from the Charleston, South Carolina; Indian River Lagoon, Florida; and Sarasota Bay, Florida, bottlenose dolphin populations (DWH MMIQT 2015). In other words, exposure to *Deepwater Horizon* oil caused 46 percent of pregnant females in Barataria Bay and Mississippi Sound to lose their calves. No reproductive failure data are available for other stocks exposed to the *Deepwater Horizon* oil spill. Thus, the percentage of females with reproductive failure in Barataria Bay and Mississippi Sound (46 percent) is the best estimate of excess failed pregnancies for marine mammals in the oil spill footprint (Table 4.9-7; (DWH MMIQT 2015)).

The quantification of reproductive failure in coastal, shelf, and oceanic stocks is analogous to the percent mortality calculations described in the previous section. The reproductive failure rate from the Barataria Bay and Mississippi Sound stocks (46 percent) is applied to the percentage of each stock that experienced levels of *Deepwater Horizon* oil exposure similar to or greater than animals in Barataria Bay. The increase in percentage of failed pregnancies due to *Deepwater Horizon* oil exposure in the two coastal stocks ranged from 10 to 37 percent, and in the shelf and oceanic stocks from 3 to 22 percent of each stock (Table 4.9-7) (DWH MMIQT 2015).

Table 4.9-7. The *Deepwater Horizon* oil spill caused reproductive failure in cetaceans throughout the surface slick footprint. This table presents the estimated percentage of females in each stock that suffered from reproductive failure due to the *Deepwater Horizon* oil spill (above baseline).

Cetacean Stock	Females with Reproductive Failure (%)	95% CI
Bottlenose dolphin Barataria Bay	46	21-65
Bottlenose dolphin Mississippi River Delta	46	21-65
Bottlenose dolphin Mississippi Sound	46	21-65
Bottlenose dolphin Mobile Bay	46	21-65
Bottlenose dolphin western coastal	10	5-15
Bottlenose dolphin northern coastal	37	17-53
Continental shelf dolphins [a]	6	3-8
Bottlenose dolphin oceanic	5	2-6
Sperm whale	7	3-10
Bryde's whale	22	10-31
Beaked whales [b]	5	3-8
Clymene dolphin	3	2-5
False killer whale	8	4-12
Melon-headed whale	7	3-10
Pantropical spotted dolphin	9	4-13
Short-finned pilot whale	3	1-4
Pygmy killer whale	7	3-10
Pygmy/dwarf sperm whales [c]	7	3-10
Risso's dolphin	3	2-5
Rough-toothed dolphin	19	9-26
Spinner dolphin	21	10-30
Striped dolphin	6	3-9

[a] Continental shelf dolphins is a combination of shelf bottlenose dolphins and Atlantic spotted dolphins.

[b] Beaked whales is a combination of Blainville's beaked whales, Cuvier's beaked whales, and Gervais' beaked whales.

[c] Pygmy/dwarf sperm whales is a combination of pygmy sperm whales and dwarf sperm whales.

4.9.5.3 Adverse Health Effects

The Trustees have determined that *Deepwater Horizon* oil exposure resulted in the constellation of adverse health effects documented in health assessments of bottlenose dolphins in Barataria Bay and Mississippi Sound. Veterinarians assigned a general prognosis to each individual animal (based on its various combinations of adverse health effects) in order to characterize the dolphin's likely future outcome. The percentage of the populations within a given prognosis category is meaningful and predictive. For example, two dolphins that were given a grave prognosis in August 2011 died within 6 months, and the percentage of the population with the two lowest prognoses (17 percent poor and

grave) essentially predicted the percentage of dolphins that disappeared and presumably died the following year based on photo-ID surveys (17 percent, confidence interval of 14 to 21 percent) (DWH MMIQT 2015). To quantify the magnitude of animals with adverse health effects in each stock, the Trustees used the overall prognosis to encapsulate the various combinations and severities of adverse health effects in each individual. In other words, they asked, what is the likely outcome for dolphins exposed to *Deepwater Horizon* oil compared to unexposed animals?

Table 4.9-8. The *Deepwater Horizon* oil spill caused adverse health effects in BSE and coastal bottlenose dolphins throughout the surface slick footprint. This table presents the estimated percentage of each stock that suffered adverse health effects due to the *Deepwater Horizon* oil spill (above baseline).

Bottlenose Dolphin Stock	Population with Adverse Health Effects (%)	95% CI
Barataria Bay	37	14-57
Mississippi River Delta	37	14-57
Mississippi Sound	24	0-48
Mobile Bay	24	0-48
Western coastal	8	3-13
Northern coastal	30	11-47

In Barataria Bay and Mississippi Sound, the percentage of the population with a guarded or worse prognosis was 37 percent and 24 percent higher, respectively, compared with dolphins sampled in Sarasota Bay (DWH MMIQT 2015). Biologists applied these numbers to the Mississippi River Delta and Mobile Bay stocks, respectively, based on the similar habitat and exposure levels in each pair (Table 4.9-8). (The Mississippi River Delta stock is most similar to the Barataria Bay stock; the Mobile Bay stock is most similar to the Mississippi Sound stock.) The quantification of adverse health effects for coastal, shelf, and oceanic stocks uses the same logic as the reproductive failure quantification: the Barataria Bay adverse health effects metric (37 percent) is applied to the percentage of each stock that experienced a level of *Deepwater Horizon* oil exposure equal to or greater than the stock in Barataria Bay. The percentage range for each of these stocks that suffer from an increase in adverse health effects is 2 to 30 percent (Table 4.9-9; (DWH MMIQT 2015)).

Table 4.9-9. The *Deepwater Horizon* oil spill caused adverse health effects in shelf and oceanic cetaceans throughout the surface slick footprint. This table presents the estimated percentage of each stock that suffered adverse health effects due to the *Deepwater Horizon* oil spill (above baseline).

Cetacean Stock	Population with Adverse Health Effects (%)	95% CI
Continental shelf dolphins [a]	5	2-7
Bottlenose dolphin oceanic	4	1-6
Sperm whale	6	2-9
Bryde's whale	18	7-28
Beaked whales [b]	4	2-7
Clymene dolphin	3	1-4
False killer whale	7	3-11
Melon-headed whale	6	2-9
Pantropical spotted dolphin	7	3-11
Short-finned pilot whale	2	1-3
Pygmy killer whale	6	2-9
Pygmy/dwarf sperm whales [c]	6	2-9
Risso's dolphin	3	1-4
Rough-toothed dolphin	15	6-23
Spinner dolphin	17	6-27
Striped dolphin	5	2-8

[a] Continental shelf dolphins is a combination of shelf bottlenose dolphins and Atlantic spotted dolphins.

[b] Beaked Whales is a combination of Blainville's beaked Whales, Cuvier's beaked Whales, and Gervais' beaked Whales.

[c] Pygmy/dwarf sperm whales is a combination of pygmy sperm whales and dwarf sperm whales.

4.9.5.4 Overall Effects on Populations

The increases in mortality, reproductive failure, and adverse health effects represent a snapshot of how *Deepwater Horizon* oil exposure impacted each northern Gulf of Mexico population stock from 2011 to 2013. They do not, however, capture the overlapping and synergistic relationships among the three injuries, and fail to quantify the entire scope of the *Deepwater Horizon* oil spill injury to marine mammal populations into the future. To more completely quantify the injury to each stock, statisticians and biologists used a population modeling approach. Cetaceans are long-lived, slow maturing species. Thus, populations have difficulty recovering from the loss of reproductive adults, whether from illness, death, or a decrease in reproductive success. A population model allows consideration of long-term impacts resulting from individual losses, adverse reproductive effects, and persistent impacts on survival for exposed animals (Figure 4.9-17).

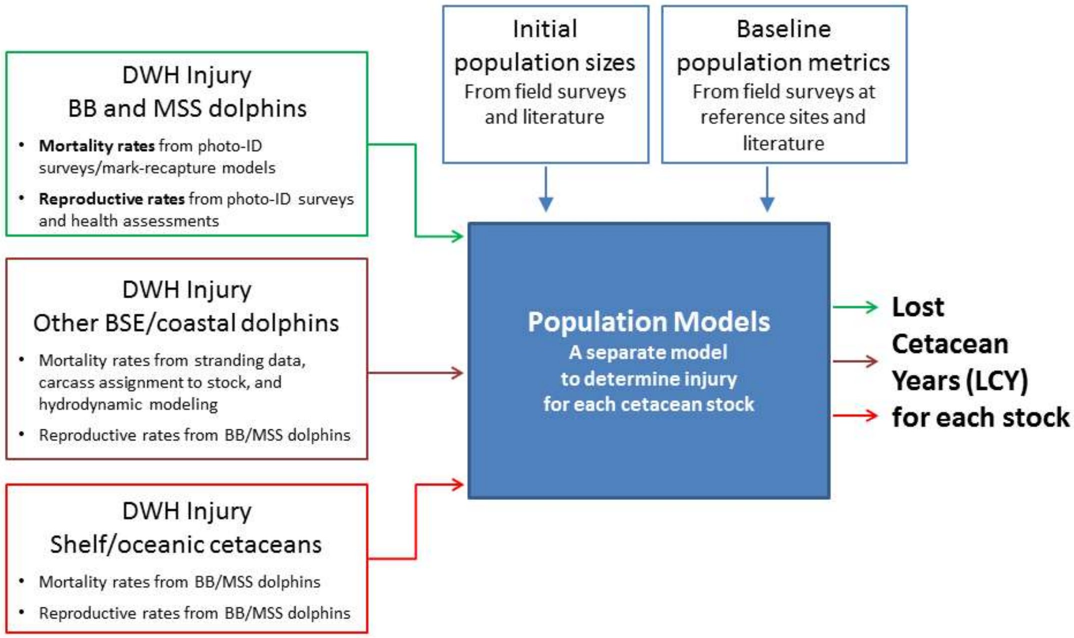


Figure 4.9-17. Population models were used to calculate the number of lost cetacean years (for each stock) due to the *Deepwater Horizon* oil spill. A lost cetacean year (LCY) is analogous to production foregone. Marine mammal scientists ran a separate population model for each stock; however, for convenience, we use the term lost cetacean years to describe the output of each model.

The model for the *Deepwater Horizon* marine mammal injury quantification (DWH MMIQT 2015) is run using baseline mortality and reproductive parameters to determine what the population trajectory of each stock would have been if the *Deepwater Horizon* spill had not happened. The same model is then run a second time, with estimates for excess mortality, reproductive failures, and adverse health effects due to the *Deepwater Horizon* oil spill. Figure 4.9-18 shows the result of a population model for an example cetacean population. The number of years predicted for the *Deepwater Horizon* oil-impacted population to recover (without active restoration) is the number of years until the *Deepwater Horizon* oil-injured population trajectory catches up with the baseline population trajectory, reported as years to recovery (YTR). In addition, the difference between the two trajectories summed over the years until the *Deepwater Horizon* oil-impacted population recovers is the total number of lost cetacean years (LCY) due to the *Deepwater Horizon* oil spill. This measure of LCY is the sum of all of the years of life lost, from animals that died earlier than they would have to animals that were never born due to reproductive failure. The output from the population model also predicts the largest proportional decrease in population size (i.e., the difference between the two population trajectories when the *Deepwater Horizon* oil-impacted trajectory is at its lowest point).

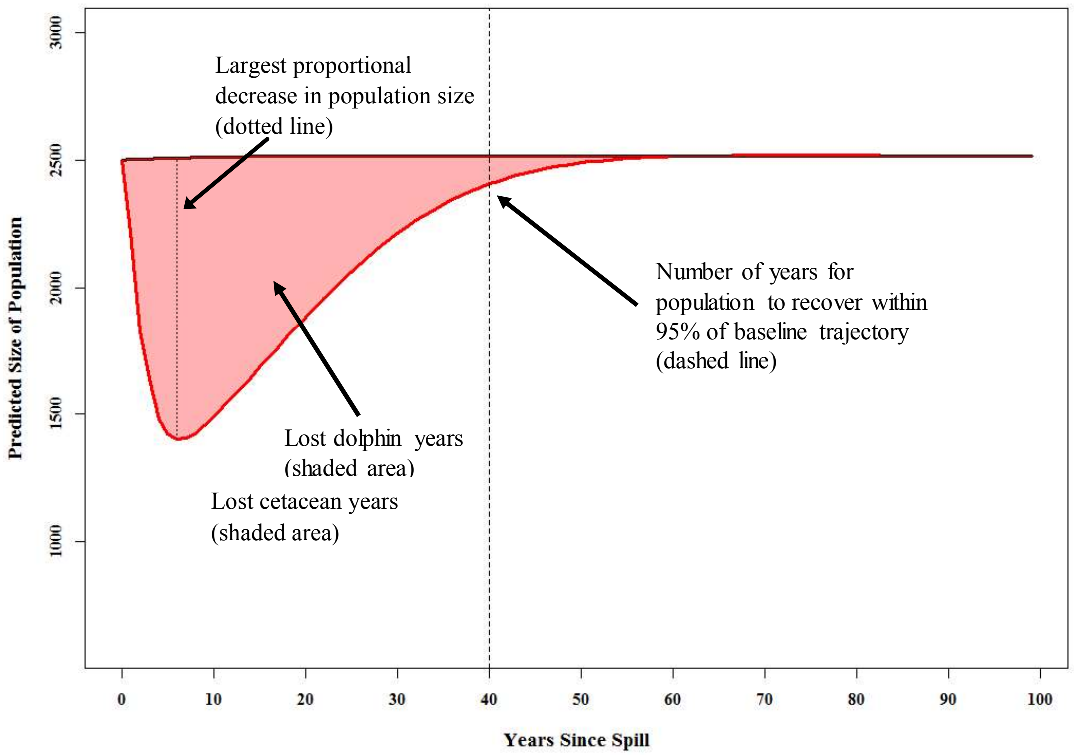


Figure 4.9-18. Assuming a stable baseline population size, this population model demonstrates that this example cetacean population will continue to decline for approximately 7 years, then will begin a slow recovery period lasting approximately 40 years. To quantify injury to each cetacean stock, the Trustees report the years to recovery (YTR) as the time it takes for the population to recover to 95 percent of the baseline trajectory (dashed line); the lost cetacean years (LCY) as the summed difference between the two trajectories (shaded area); and the maximum reduction in population size as the largest population difference in the two trajectories (dotted line).

A separate population model is run for each cetacean stock (Table 4.9-13). The inputs for the population models are restricted to the available data for each stock. For inputs without empirical data, the values are extrapolated from other stocks or incorporate additional modeling efforts (DWH MMIQT 2015). The Barataria Bay and Mississippi Sound population models mostly rely upon empirical data from the health assessments and population surveys.

The Barataria Bay stock of bottlenose dolphins suffered 30,347 LCY (confidence interval of 11,511 to 89,746) due to the *Deepwater Horizon* oil spill (Table 4.9-10; (DWH MMIQT 2015)). In the absence of active restoration, the population will take 39 YTR (confidence interval of 24 to 80). This represents a 51 percent (confidence interval of 32 to 72 percent) maximum reduction in the population size due to the *Deepwater Horizon* oil spill. The Mississippi Sound bottlenose dolphin stock experienced 78,266 LCY (confidence interval of 38,858 to 219,602), with 46 YTR (confidence interval of 27 to 89) and a 62 percent (confidence interval of 43 to 83 percent) maximum reduction in the population size due to the

Deepwater Horizon oil spill. The higher range of LCY in Mississippi Sound is due to the higher abundance of animals in Mississippi Sound compared to Barataria Bay (Table 4.9-10; (DWH MMIQT 2015)).

Table 4.9-10. The *Deepwater Horizon* oil spill negatively impacted BSE and coastal bottlenose dolphin stocks throughout the surface slick footprint. This table presents the results of population models for each stock.

Bottlenose Dolphin Stock	Lost Cetacean Years	95% CI	Years to Recovery [a]	95% CI	Maximum Population Reduction (%)	95% CI
Barataria Bay	30,347	11,511-89,746	39	24-80	-51	32-72
Mississippi River Delta	20,065	4,896-62,355	52	27-106	-71	40-97
Mississippi Sound	78,266	30,858-219,602	46	27-89	-62	43-83
Mobile Bay	9,362	3,429-32,356	31	18-65	-31	20-51
Western coastal	19,041	6,869-64,245	NA	NA	-5	3-9
Northern coastal	92,069	36,427-264,716	39	23-76	-50	32-73

[a] It was not possible to calculate YTR for stocks with maximum population reductions of ≤ 5% (see DWH MMIQT 2015 for details).

The Mississippi River Delta stock of bottlenose dolphins suffered 20,065 LCY (confidence interval of 4,896 to 62,355) due to the *Deepwater Horizon* oil spill, including a 71 percent (confidence interval of 40 to 97 percent) maximum population reduction (Table 4.9-10; (DWH MMIQT 2015)). In the absence of active restoration, the population will take 52 YTR (confidence interval of 27 to 106). The Mobile Bay bottlenose dolphin stock experienced 9,362 LCY (confidence interval of 3,429 to 32,356), with 31 YTR (confidence interval of 18 to 65 years) and a 31 percent (confidence interval of 20 to 51 percent) maximum reduction in population (Table 4.9-10; (DWH MMIQT 2015)).

The values for LCY for the shelf and oceanic stocks varied widely due to differences in population sizes and proportions of the populations impacted by *Deepwater Horizon* oil (Table 4.9-11; (DWH MMIQT 2015)). For the two stocks with the greatest abundances, the shelf dolphins lost 359,996 cetacean years and pantropical spotted dolphins lost 363,780 cetacean years. Of the two, the pantropical spotted dolphins had the greatest change in population size with a 9 percent maximum decrease requiring 39 years to recover. The shelf dolphins experienced a 3 percent maximum decline in population size; this decline was not significantly lower than 95 percent of the original population size and so years to recovery could not be determined (Table 4.9-11; (DWH MMIQT 2015)).

Spinner dolphins, rough-toothed dolphins, pygmy and dwarf sperm whales, and oceanic bottlenose dolphins had LCY values ranging between 37,688 and 188,713 (Table 4.9-11; (DWH MMIQT 2015)). Spinner dolphins and rough-toothed dolphins had the highest maximum reductions in population size at 23 percent (105 YTR) and 17 percent (54 YTR). As with the shelf dolphins, several oceanic stocks had declines of less than 5 percent of the original population size, so YTR could not be determined (Table 4.9-11; (DWH MMIQT 2015)).

Table 4.9-11. The *Deepwater Horizon* oil spill negatively impacted coastal and oceanic cetacean stocks throughout the surface slick footprint. This table presents the results of population models for each stock.

Cetacean Stock [a]	Lost Cetacean Years	Years to Recovery [e]	Maximum Population Reduction (%)
Continental shelf dolphins [b]	359,996	NA	-3
Bottlenose dolphin oceanic	37,668	NA	-4
Sperm whale	13,197	21	-7
Bryde's whale	705	69	-22
Beaked whales [c]	7,838	10	-6
Clymene dolphin	12,167	NA	-3
False killer whale	3,422	42	-9
Melon-headed whale	14,887	29	-7
Pantropical spotted dolphin	363,780	39	-9
Short-finned pilot whale	5,304	NA	-3
Pygmy killer whale	2,501	29	-7
Pygmy/dwarf sperm whales[d]	49,100	11	-6
Risso's dolphin	6,258	NA	-3
Rough-toothed dolphin	50,464	54	-17
Spinner dolphin	188,713	105	-23
Striped dolphin	18,647	14	-6

[a] Confidence intervals for shelf and oceanic animals were not calculated (see DWH MMIQT 2015 for details).

[b] Continental shelf dolphins is a combination of shelf bottlenose dolphins and Atlantic spotted dolphins.

[c] Beaked whales is a combination of Blainville's beaked whales, Cuvier's beaked whales, and Gervais' beaked whales.

[d] Pygmy/dwarf sperm whales is a combination of pygmy sperm whales and dwarf sperm whales.

[e] It was not possible to calculate years to recovery (YTR) for stocks with maximum population reductions of ≤ 5% (see DWH MMIQT 2015 for details).

Two species of particular concern are the endangered sperm whales and Bryde's whales. For sperm whales, *Deepwater Horizon* oil exposure resulted in 13,197 LCY and a 7 percent maximum decline in population size, requiring 21 YTR (Table 4.9-11; (DWH MMIQT 2015)). For Bryde's whales, 48 percent of the population was impacted by *Deepwater Horizon* oil, resulting in an estimated 22 percent maximum decline in population size that will require 69 YTR. Due to the very small Bryde's whale population size (26 animals, confidence interval of 12 to 56), the number of LCY is only 705. These results, however, should be interpreted with caution, for Bryde's whales, in particular. Small populations are highly susceptible to stochastic, or unpredictable, processes and genetic effects that can reduce productivity and resiliency to perturbations. The population models do not account for these effects, and, therefore, the capability of the Bryde's whale population to recover from this injury is unknown (Table 4.9-11; (DWH MMIQT 2015)).

Table 4.9-12. This table summarizes the injuries to northern Gulf of Mexico cetaceans caused by the *Deepwater Horizon* oil spill, including the percentage of each stock killed, the percentage of each stock with reproductive failure, and the percentage of each stock with adverse health effects.

Cetacean Stock	Pre-spill Abundance Estimate	95% CI	Population Exposed to Oil (%)	95% CI	Population Killed (%)	95% CI	Females with Reproductive Failure (%)	95% CI	Population with Adverse Health Effects (%)	95% CI
Bottlenose dolphin Barataria Bay	2,306	1,973-2,639	NA	NA	35	15-49	46	21-65	37	14-57
Bottlenose dolphin Mississippi River Delta	820	657-984	NA	NA	59	29-1	46	21-65	37	14-57
Bottlenose dolphin Mississippi Sound	4,188	3,617-4,760	NA	NA	22 [d]	13-29	46	21-65	24	0-48
Bottlenose dolphin Mobile Bay	1,393	1,252-1,535	NA	NA	12	5-20	46	21-65	24	0-48
Bottlenose dolphin western coastal	20,161	14,482-28,066	23	16-32	1	1-2	10	5-15	8	3-13
Bottlenose dolphin northern coastal	7,185	4,800-10,754	82	55-100	38	26-58	37	17-53	30	11-47
Continental shelf dolphins [a]	63,361	42,898-87,417	13	9-19	4	2-6	6	3-8	5	2-7
Bottlenose dolphin oceanic	8,467	4,285-16,731	10	5-10	3	1-5	5	2-6	4	1-6
Sperm whale	1,635	1,132-2,359	16	11-23	6	2-8	7	3-10	6	2-9
Bryde's whale	26	12-56	48	23-100	17	7-24	22	10-31	18	7-28
Beaked whales [b]	1,167	643-2,117	12	7-22	4	2-6	5	3-8	4	2-7
Clymene dolphin	3,228	1,558-6,691	7	3-15	2	1-4	3	2-5	3	1-4
False killer whale	316	121-827	18	7-48	6	3-9	8	4-12	7	3-11
Melon-headed whale	1,696	709-4,060	15	6-36	5	2-7	7	3-10	6	2-9
Pantropical spotted dolphin	33,382	25,489-43,719	20	15-26	7	3-10	9	4-13	7	3-11
Short-finned pilot whale	1,641	710-3,790	6	4-9	2	1-3	3	1-4	2	1-3
Pygmy killer whale	281	131-601	15	7-33	5	2-8	7	3-10	6	2-9
Pygmy/dwarf sperm whales [c]	6,690	3,482-12,857	15	8-29	5	2-7	7	3-10	6	2-9

Cetacean Stock	Pre-spill Abun-dance Estimate	95% CI	Popula-tion Exposed to Oil (%)	95% CI	Popula-tion Killed (%)	95% CI	Females with Repro-ductive Failure (%)	95% CI	Population with Adverse Health Effects (%)	95% CI
Risso's dolphin	1,848	1,123-3,041	8	5-13	3	1-4	3	2-5	3	1-4
Rough-toothed dolphin	2,414	964-6,040	41	16-100	14	6-20	19	9-26	15	6-23
Spinner dolphin	6,621	3,386-12,947	47	24-91	16	7-23	21	10-30	17	6-27
Striped dolphin	2,605	1,537-4,415	13	8-22	5	2-7	6	3-9	5	2-8

[a] Continental shelf dolphins is a combination of shelf bottlenose dolphins and Atlantic spotted dolphins.

[b] Beaked whales is a combination of Blainville's beaked whales, Cuvier's beaked whales, and Gervais' beaked whales.

[c] Pygmy/dwarf sperm whales is a combination of pygmy sperm whales and dwarf sperm whales.

[d] Based on 1 year of surveys; all other stocks based on 3 years of observations.

Table 4.9-13. This table summarizes the injuries to northern Gulf of Mexico cetaceans caused by the *Deepwater Horizon* oil spill, including lost cetacean years, years to recovery, and maximum population reductions.

Cetacean Stock	Lost Cetacean Years	95% CI [e]	Years to Recovery [f]	95% CI [e]	Maximum Population Reduction (%)	95% CI [e]
Bottlenose dolphin Barataria Bay	30,347	11,511-89,746	39	24-80	-51	32-72
Bottlenose dolphin Mississippi River Delta	20,065	4,896-62,355	52	27-106	-71	40-97
Bottlenose dolphin Mississippi Sound	78,266	30,858-219,602	46	27-89	-62	43-83
Bottlenose dolphin Mobile Bay	9,362	3,429-32,356	31	18-65	-31	20-51
Bottlenose dolphin western coastal	19,041	6,869-64,245	NA	NA	-5	3-9
Bottlenose dolphin northern coastal	92,069	36,427-264,716	39	23-76	-50	32-73
Continental shelf dolphins [a]	359,996	NA	NA	NA	-3	NA
Bottlenose dolphin oceanic	37,668	NA	NA	NA	-4	NA
Sperm whale	13,197	NA	21	NA	-7	NA
Bryde's whale	705	NA	69	NA	-22	NA
Beaked whales [b]	7,838	NA	10	NA	-6	NA

Cetacean Stock	Lost Cetacean Years	95% CI [e]	Years to Recovery [f]	95% CI [e]	Maximum Population Reduction (%)	95% CI [e]
Clymene dolphin	12,167	NA	NA	NA	-3	NA
False killer whale	3,422	NA	42	NA	-9	NA
Melon-headed whale	14,887	NA	29	NA	-7	NA
Pantropical spotted dolphin	363,780	NA	39	NA	-9	NA
Short-finned pilot whale	5,304	NA	NA	NA	-3	NA
Pygmy killer whale	2,501	NA	29	NA	-7	NA
Pygmy/dwarf sperm whales [c]	49,100	NA	11	NA	-6	NA
Risso's dolphin	6,258	NA	NA	NA	-3	NA
Rough-toothed dolphin	50,464	NA	54	NA	-17	NA
Spinner dolphin	188,713	NA	105	NA	-23	NA
Striped dolphin	18,647	NA	14	NA	-6	NA

[a] Continental shelf dolphins is a combination of shelf bottlenose dolphins and Atlantic spotted dolphins.

[b] Beaked whales is a combination of Blainville's beaked whales, Cuvier's beaked whales, and Gervais' beaked whales.

[c] Pygmy/dwarf sperm whales is a combination of pygmy sperm whales and dwarf sperm whales.

[d] Based on 1 year of surveys; all other stocks based on 3 years of observations.

[e] Confidence intervals for shelf and oceanic animals were not calculated (see DWH MMIQT 2015 for details).

[f] It was not possible to calculate years to recovery (YTR) for stocks with maximum population reductions of ≤ 5% (see DWH MMIQT 2015 for details).

4.9.5.5 Qualitative Considerations

Due to the scope of the spill, the magnitude of potentially injured populations, and the difficulties and limitations of working with marine mammals (e.g., MMPA regulations), it is impossible to quantify injury without uncertainty. In evaluating these injuries, however, the Trustees have considered the following:

- Marine mammals were clearly observed in *Deepwater Horizon* oil.
- Population boundaries (i.e., stock ranges) overlap with the spill.
- Oil has negative physiological effects on wildlife, including marine mammals.
- The Trustees documented negative physiological effects on live dolphins examined in Barataria Bay and Mississippi Sound and dead, stranded dolphins from Louisiana, Mississippi, and Alabama.

The Trustees have additionally supplemented these observations and findings with the best available scientific literature, as well as their professional judgment and expert opinions in identifying the most appropriate assumptions and extrapolations to characterize the magnitude of injury (for each species and the temporal and spatial extent of the spill). Wherever possible, the quantification results presented herein represent ranges of values that encapsulate the uncertainty inherent in the underlying datasets. However, a variety of qualitative information cannot be captured in uncertainty estimates or ranges.

Even taking into account the inevitable uncertainty associated with assumptions and extrapolations, as well as the protected status of all marine mammals under the MMPA (and sperm whales under the ESA), the Trustees believe that the results of the injury assessment conducted over the past 5 years, coupled with the professional judgment used in quantifying these injuries, provides sufficient basis for identifying restoration activities. These restoration activities will appropriately compensate the public for injuries to marine mammals as a result of the *Deepwater Horizon* oil spill.

The Trustees have determined that estimating the total number of lost cetacean years, or LCY, for each stock is the best metric of the damage to marine mammals in the northern Gulf of Mexico resulting from the *Deepwater Horizon* oil spill. This value best reflects the long-term injury to each stock. A single calculation of dead dolphins could be misconstrued to represent injuries that occurred in a narrow time frame and, therefore, could be restored in a narrow time frame. The population model outputs best represent the temporal magnitude of the injury and the potential recovery time from the injury. As is evident from these calculations, some stocks will suffer from the effects of the spill for decades.

The quantification of injury is based on the extent of surface oiling across the Gulf of Mexico, because 1) many of the adverse health effects and causes of death for stranded animals were likely related to inhalation or aspiration of oil components in the surface slick, and 2) little is known about the fate and transport of *Deepwater Horizon* deep-sea oil plumes in relation to deep diving marine mammals such as sperm whales. The characterization of marine mammal exposures to contaminated sediments, both nearshore and offshore, is similarly uncertain.

4.9.6 Conclusions and Key Aspects of the Injury for Restoration Planning

Immediately following the *Deepwater Horizon* blowout, it was clear that the oil spill would jeopardize the marine mammal communities in the northern Gulf of Mexico. The Trustees developed a suite of studies and analyses to assess the exposure and injuries to dolphins and whales from the *Deepwater Horizon* oil spill. Response workers and scientists observed marine mammals swimming in the *Deepwater Horizon* surface slick, but animals would have also been exposed via contaminated air and sediments, as well as oil in the water column. After inhaling, ingesting, aspirating, and potentially absorbing oil components, animals suffered from physical damage and toxic effects to a variety of organs and tissues. Marine mammals living in areas contaminated with *Deepwater Horizon* oil suffered from lung disease, adrenal disease, poor body condition, and a suite of other adverse health effects. Unsurprisingly, at the same time as veterinarians were documenting these illnesses, NOAA declared and was investigating the largest and longest Gulf of Mexico cetacean UME on record. In the years following the spill, many of these stranded animals were fetuses from unsuccessful pregnancies, and more than 80 percent of cetacean pregnancies in Barataria Bay and Mississippi Sound were unsuccessful (DWH MMIQT 2015).

Based on their scientific findings, and after carefully ruling out other potential causes for the unprecedented number of dead, stranded marine mammals, , the Trustees concluded that the *Deepwater Horizon* oil spill is the most likely explanation for the combination of injuries and mortalities seen across the marine mammal populations in the northern Gulf of Mexico. The routes of exposure, adverse health effects, increased mortality, reproductive failure, and causes of death for stranded animals form a coherent pathological narrative, consistent with the chemistry and toxicity of oil transport and exposure, and the relationship between the levels of oil exposure and the severities of injuries across the spatial and temporal extent of the *Deepwater Horizon* oil spill event.

Common bottlenose dolphins in the Barataria Bay, Mississippi River Delta, Mississippi Sound, and Mobile Bay BSE stocks suffered some of the most severe injuries to both individual animals and their populations going forward. The northern and western coastal bottlenose dolphin stocks and most of the shelf and oceanic marine mammal stocks suffered quantifiable injuries. Other bottlenose dolphin stocks, including the Terrebonne-Timbalier Bay stock, which saw extensive *Deepwater Horizon* oiling, and the Perdido Bay and Pensacola Bay stocks, which saw less oil, but were within the *Deepwater Horizon* oil spill footprint, were likely injured, but data were too sparse to determine the relationship between *Deepwater Horizon* oil exposure and potential injuries.

In summary, the injury assessment found that:

- The *Deepwater Horizon* oil spill resulted in the contamination of prime marine mammal habitat in the estuarine, nearshore, and offshore waters of the northern Gulf of Mexico.
- Nearly all of the marine mammal stocks that overlap with the *Deepwater Horizon* oil spill footprint have demonstrable, quantifiable injuries. The remaining stocks within the footprint were also likely injured, but there is not enough information to make a determination at this time.

- The Barataria Bay and Mississippi Sound bottlenose dolphin stocks were two of the most severely injured populations, with a 51 percent and 62 percent maximum reduction in their population sizes, respectively. Dolphins are long-lived animals, and slow to reach reproductive maturity, and these stocks will take approximately 40 to 50 years to recover, without any active restoration (DWH MMIQT 2015).

- Smaller percentages of the oceanic stocks were exposed to *Deepwater Horizon* oil. However, they still experienced increased mortality (as high as 17 percent), reproductive failure (as high as 22 percent), and other adverse health effects (as high as 18 percent) (DWH MMIQT 2015).

The Trustees considered all of these aspects of the injury in restoration planning, and also considered the ecosystem effects and recovery information described below.

4.9.6.1 Ecosystem Effects

Carnivorous cetaceans such as dolphins and sperm whales, which are typically apex predators, will suffer from *Deepwater Horizon* oil's effects on fish and invertebrate populations. At a more subtle, but still crucial, level, the summed negative effects of the *Deepwater Horizon* oil spill on the Gulf of Mexico ecosystem across resources, up and down the food web, and among habitats, will especially impact marine mammals due to their long lives and their strong dependence on a healthy ecosystem (Bossart 2011; Moore 2008; Reddy et al. 2001; Ross 2000; Wells et al. 2004).

4.9.6.2 Recovery

In the absence of active restoration, marine mammal stocks across the northern Gulf of Mexico will take many years to recover. Whales and dolphins are slow to reach reproductive maturity, only give birth to a single offspring every 3 to 5 years, and are long lived (with lifespans up to 80 years). Therefore, it will take decades for the Gulf of Mexico stocks to recover from losses following the spill. The ability of the stocks to recover, and the length of time required for that recovery, are tied to the carrying capacity of the habitat, and to the degree of other population pressures. The fact that not enough is known about the pressures, or stressors such as human impacts and natural events, that may adversely affect these animals makes understanding the time frame required for stocks to recover even more challenging.

4.9.6.3 Restoration Considerations

As described in Chapter 5 (Section 5.5.11), the Trustees have identified an integrated portfolio of restoration approaches that collectively address all stocks, species, and geographies that were injured by the spill, taking into account the long-lived nature of these animals and the stressors that adversely affect them. The restoration portfolio for marine mammals will also include robust monitoring, analysis, and scientific support for an adaptive management approach to restoration planning and implementation to ensure that restoration goals are met.

4.9.7 References

Akira, M. & Suganuma, N. (2014). Acute and subacute chemical-induced lung injuries: HRCT findings. *European Journal of Radiology, 83*(8), 1461-1469

Arlt, W. & Allolio, B. (2003). Adrenal Insufficiency. *Lancet, 361*, 1881-1893

Beland, P., DeGuise, S., Girard, C., Lagace, A., Martineau, D., Michaud, R., Muir, D., Norstrom, R., Pelletier, E., Ray, S., & Shugart, L. (1993). Toxic Compounds and Health and Reproductive Effects in St. Lawrence Beluga Whales. *Journal of Great Lakes Research, 19*(4), 9

Bergman, A., Olsson, M., & Reiland, S. (1992). Skull-bone lesions in the Baltic grey seal (*Halichoerus grypus*). *AMBIO: A Journal of the Human Environment, 21*(8), 517-519

Biggs, D.C., Jochens, A.E., Howard, M.K., DiMarco, S.F., Mullin, K.D., Leben, R.R., Muller-Karger, F.E., & Hu, C. (2005). Eddy Forced Variations in On- and off-Margin Summertime Circulation Along the 1000-m Isobath of the Northern Gulf of Mexico, 2000–2003, and Links with Sperm Whale Distributions Along the Middle Slope. *Circulation in the Gulf of Mexico, 161*(71)

Bodkin, J.L., Ballachey, B.E., Coletti, H.A., Esslinger, G.G., Kloecker, K.A., Rice, S.D., Reed, J.A., & Monson, D.H. (2012). Long-term effects of the 'Exxon Valdez' oil spill: sea otter foraging in the intertidal as a pathway of exposure to lingering oil. *Marine Ecology Progress Series, 447*, 273-287

Bossart, G.D. (2011). Marine mammals as sentinel species for oceans and human health. *Veterinary Pathology, 48*(3), 676-690

Brandon, J.L., Conti, C.J., Goldstein, L.S., DiGiovanni, J., & Gimenez-Conti, I.B. (2009). Carcinogenic Effects of MGP-7 and B[a]P on the Hamster Cheek Pouch. *Toxicologic Pathology, 37*(6), 733-740

Bursian, S., Harr, K., Cunningham, F., Link, J., Hanson-Dorr, K., Cacela, D., & Dean, K. (2015a). *Draft Report - Phase 2 FWS DWH Avian Toxicity Testing: Double Crested Cormorant (Phalacrocorax auritus) Oral Dosingduction Study (M22)*.

Bursian, S., Harr, K., Shriner, S., Horak, K., Link, J., Cacela, D., Pritsos, C., & Dean, K. (2015b). *Draft Report Phase 2 FWS DWH Avian Toxicity Testing: Laughing Gull (Leucophaeus atricilla) Oral Dosing Study (C23)*. (AV_TR.12). DWH Birds NRDA Technical Working Group Report.

Bystrom, J.M. (1989). *Study of the Acute Toxicity of Ingested Crude Petroleum Oil to Cattle.* University of Saskatechewan, Saskatoon, Saskatchewan.

Capen, C.C. (2007). Endocrine Glands. In: M.G. Maxie (Ed.), *Jubb, Kennedy, and Palmer's Pathology of Domestic Animals.*(5th ed.). Edinburgh: Elsevier Saunders.

Carrasco, J.M., Lope, V., PérezGómez, B., Aragones, N., Suarez, B., Lopez-Abente, G., Rodriguez-Artalejo, F., & Pollan, M. (2006). Association between health information, use of protective devices and occurrence of acute health problems in the Prestige oil spill cleanup in Asturias and Cantabria (Spain): A crosssectional study. *BMC Pub Health, 6*(1)

Clark, L.S., Pfeiffer, D.C., & Cowan, D.F. (2005). Morphology and histology of the Atlantic bottlenose dolphin adrenal gland with emphasis on the medulla. *Anatomia, Histologia, Embryologia, 34*, 132-140

Colegrove, K.M., Venn-Watson, S., Litz, J., Fougeres, E., Ewing, R., & Rowles, T.K. (2015). *Pathologic Findings in Perinatal Bottlenose Dolphins (Tursiops truncatus) Stranding During the Northern Gulf of Mexico Unusual Mortality Event*. (MM_TR.04). DWH Marine Mammal NRDA Technical Working Group Report.

Coppock, R.W., Mostrom, M.S., Khan, A.A., & Semalulu, S.S. (1995). Toxicology of oil field pollutants in cattle: A review. *Veterinary and Human Toxicology, 37*(6), 569-576

Coppock, R.W., Mostrom, M.S., Stair, E.L., & Semalulu, S.S. (1996). Toxicopathology of oil field poisoning in cattle: A review. *Veterinary and Human Toxicology, 38*, 36-42

de Gouw, J.A., Middlebrook, A.M., Warneke, C., Ahmadov, R., Atlas, E.L., Bahreini, R., Blake, D.R., Brock, C.A., Brioude, J., Fahey, D.W., Fehsenfeld, F.C., Holloway, J.S., Le Henaff, M., Lueb, R.A., McKeen, S.A., Meagher, J.F., Murphy, D.M., Paris, C., Parrish, D.D., Perring, A.E., Pollack, I.B., Ravishankara, A.R., Robinson, A.L., Ryerson, T.B., Schwarz, J.P., Spackman, J.R., Srinivasan, A., & Watts, L.A. (2011). Organic aerosol formation downwind from the Deepwater Horizon oil spill. *Science, 331*(6022), 1295-1299. doi:10.1126/science.1200320

Dias, L.A. (2015). *Evidence of marine mammals' direct exposure to petroleum products during the Deepwater Horizon Oil Spill in the Gulf of Mexico.*: DWH Marine Mammal NRDA Technical Working Group Report.

Dorr, B.S., Hanson-Dorr, K.C., Dean, K., Harr, K., Horak, K., Link, J., Cacela, D., McFadden, A., & Bursian, S. (2015). *Deepwater Horizon Avian Toxicity Phase 2: Double-Crested Cormorant (Phalacrocorax auritus) External Oiling Scoping Study (M23)*. (AV_TR.14). DWH Birds NRDA Technical Working Group Report.

Dutton, W.F. (1934). Petroleum Dermatitis. *Med. Rec, 140*, 550-552

DWH MMIQT (Deepwater Horizon Marine Mammal Injury Quantification Team). (2015). *Models and analyses for the quantification of injury to Gulf of Mexico cetaceans from the Deepwater Horizon oil spill*. DWH Marine Mammal NRDA Technical Working Group Report.

Edwards, W.C. (1989). Toxicology of oil field wastes. Hazards to livestock associated with the petroleum industry. *Food Animal Practice.*(Vol. 5, pp. 363-374).

Englehardt, F.R. (1983). Petroleum Effects on Marine Mammals. *Aquatic Toxicology, 4*(3), 199-217. doi:10.1016/0166-445X(83)90018-8

Fernandez, S. & Hohn, A.A. (1998). Age, growth, and calving season of bottlenose dolphins, *Tursiops truncatus*, off coastal Texas. *Fishery Bulletin, 96*, 357-365

Franzen, D., Kohler, M., Degrandi, C., Kullak-Ublick, G.A., & A., C. (2013). Fire eater's lung: retrospective analysis of 123 cases reported to a national poison center. *Respiration, 87*(2), 98-104

Frost, K.J., Lowry, L.F., & Ver Hoef, J.M. (1999). Monitoring the trend of harbor seals in Prince William Sound, Alaska, after the Exxon Valdez oil spill. *Marine Mammal Science, 15*, 494-506

Garrott, R.A., Eberhardt, L.L., & Burn, D.M. (1993). Mortality of sea otters in Prince William Sound following the Exxon Valdez oil spill. *Marine Mammal Science, 9*, 343–359

Geraci, J. (1990). *Sea Mammals and Oil: Confronting the Risks.* Elsevier.

Geraci, J.R. & St. Aubin, D.J. (1982). *Study of the effect of oil on cetaceans*. Prepared for Department of Interior.

Geraci, J.R. & St. Aubin, D.J. (1985). *Expanded studies of the effects of oil on cetaceans: Final report*. University of Guelph.

Green, R.F. (1972). Observations of the anatomy of some cetaceans and pinnipeds. In: S.H. Ridgeway (Ed.), *Mammals of the sea: biology and medicine.*(pp. 247–297). Springfield, IL: Charles C. Thomas Publishers.

Groth, C., Banerjee, S., Huynh, T., Ramachandran, G., Stenzel, M., Stewart, P.A., Blair, A., Engel, L., Sandler, D.P., & Kwok, R.K. (2014). The NIEHS Gulf Study: Correlations of Concentrations Between Various Oil Chemicals and Total Hydrocarbons. Paper presented at the International Epidemiology in Occupational Health (EPICOH) Conference, Chicago, IL.

Guttenplan, J.B., Kosinska, W., Zhao, Z.L., Chen, K.M., Aliaga, C., DelTondo, J., Cooper, T., Sun, Y.W., Zhang, S.M., Jiang, K., Bruggeman, R., Sharma, A.K., Amin, S., Ahn, K., & El-Bayoumy, K. (2012). Mutagenesis and carcinogenesis induced by dibenzo[a,l]pyrene in the mouse oral cavity: a potential new model for oral cancer. *International Journal of Cancer, 130*(12), 2783– 2790

Hansborough, J.F., Zapata-Sirvent, R., Dominic, W., Sullivan, J., Boswick, J., & Wang, X.-W. (1985). Hydrocarbon contact injuries. *Journal of Trauma and Acute Care Surgery, 25*(3), 250-252

Harr, K.E., Deak, K., Murawski, S.A., & Takeshita, R.A. (2015). *Anemia in Red Drum (Sciaenops ocellatus) Caught at Locations in Coastal Louisiana Contaminated by DWH Oiling*. (WC_TR.29). DWH Water Column NRDA Technical Working Group Report.

Hart, L.B., Wells, R.S., Kellar, N., Balmer, B.C., Hohn, A.A., Lamb, S.V., Rowles, T., Zolman, E.S., & Schwacke, L.H. (2015). Adrenal Hormones in Bottlenose Dolphins (Tursiops truncatus): Influential Factors and Reference Intervals. *PLoS One, 10*(5). doi:10.1371/journal.pone.0127432

Haus, B. (2015). Laboratory observations of spray generation over fresh, salt and oiled water in very high winds. (Abstract). Paper presented at the Gulf of Mexico Research Initiative.

Haynes, J.M., Wellman, S.T., Beckett, K.J., Pagano, J.J., Fitzgerald, S.D., & Bursian, S.J. (2009). Histological lesions in mink jaws are a highly sensitive biomarker of effect after exposure to TCDD-like chemicals: field and literature-based confirmations. *Archives of Environmental Contamination and Toxicology, 57*, 803- 807

Hayworth, J.S., Prabakhar Clement, T., John, G.F., & Yin, F. (2015). Fate of Deepwater Horizon oil in Alabama's beach system: Understanding physical evolution processes based on observational data. *Marine Pollution Bulletin, 90*(1-2), 95-105. doi:10.1016/j.marpolbul.2014.11.016

Irving, L., Scholander, P.F., & Grinnell, S.W. (1941). The respiration of the porpoise, *Tursiops truncatus*. *Journal of Cellular and Comparative Physiology, 17*, 145–168

Janjua, N.Z., Kasai, P.M., Nawaz, H., Farooqui, S.Z., Khuwaja, U.B., ul-Hassan, N., Jafri, S.N., Lutfi, S.A., Kadir, M.M., & Sathiakumar, N. (2006). Acute health effects of the Tasman Spirit oil spill on residents of Karachi, Pakistan. *BMC Pub Health, 6*(84)

Jefferson, T.A., Leatherwood, S., & Webber, M.A. (1993). *FAO Species Identification Guide. Marine Mammals of the World*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Jefferson, T.A. & Schiro, A.J. (1997). Distribution of cetaceans in the offshore Gulf of Mexico. *Mammal Review, 27*(1), 27-50

Jochens, A., Biggs, D., Benoit-Bird, K., Engelhaupt, D., Gordon, J., Hu, C., Jaquet, N., Johnson, M., Leben, R., Mate, B., Miller, P., Ortega-Ortiz, J., Thode, A., Tyack, P., & Würsig, B. (2008). *Sperm whale seismic study in the Gulf of Mexico: Synthesis report*. (OCS Study MMS 2008-006). New Orleans, LA: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region.

Jung, S.C., Kim, K.M., Lee, K.S., Roh, S., Jeong, W.C., Kwak, S.J., Lee, I.J., Choi, Y.H., Noh, S.R., Hur, J.I., & Jee, Y.K. (2013). Respiratory effects of the hebei spirit oil spill on children in taean, Korea. *Allergy, Asthma and Immunology Research, 5*(6). doi:10.4168/aair.2013.5.6.365

Klein, S.C. & Peterson, M.E. (2010). Canine Hypoadrenocorticism: Part 1. *The Canadian Veterinary Journal, 51*(1), 63-69

Krützen, M., Mann, J., Heithaus, M.R., Connor, R.C., Bejder, L., & Sherwin, W.B. (2005). Cultural transmission of tool use in bottlenose dolphins. Proceedings of the National Academy of Sciences of the United States of America. Paper presented at the National Academy of Sciences of the United States of America.

Lane, S.M., Smith, C.R., Balmer, B.C., Barry, K.P., McDonald, T., Mitchell, J., Mori, C.S., Mullin, K.D., Rosel, P.E., Rowles, T.K., Speakman, T.R., Townsend, F.I., Tumlin, M.C., Wells, R.S., Zolman, E.S., & Schwacke, L.H. ([In Press]). Reproductive Outcome and Survival of Common Bottlenose Dolphins (Tursiops truncatus) Sampled in Barataria Bay, Louisiana, USA Following the Deepwater Horizon Oil Spill. *submitted to [missing journal name]*

Lattin, C.R., Ngai, H.M., & Romero, L.M. (2014). Evaluating the stress response as a bioindicator of sub-lethal effects of crude oil exposure in wild house sparrows (*Passer domesticus*). *PLoS One, 9*(7)

Lifshitz, M., Sofer, S., & Gorodischer, R. (2003). Hydrocarbon poisoning in children: a 5-year retrospective study. *Wilderness and Environmental Medicine, 14*(2), 78-82

Litz, J., Baran, M.A., Bowen-Stevens, S.R., Carmichael, R.H., Colegrove, K.M., Garrison, L.P., Fire, S.E., Fougeres, E.M., Hardy, R., Holmes, S., Jones, W., Mase-Guthrie, B.E., Odell, D.K., Rosel, P.E., Saliki, J.T., Shannon, D.K., Shippee, S.F., Smith, S.M., Stratton, E.M., Tumlin, M.C., Whitehead, H.R., Worthy, G.A., & Rowles, T.K. (2014). Review of Historical Unusual Mortality Events (UMEs) in the Gulf of Mexico (1990–2009): Providing Context for the Multi-Year Northern Gulf of Mexico Cetacean UME Declared in 2010. *Diseases of Aquatic Organisms, 112*, 161-175. doi:doi: 10.3354/dao02807

Loughlin, T.R. (2013). *Marine Mammals and the Exxon Valdez.* Waltham, MA: Academic Press.

Matkin, C.O., Saulitis, E.L., Ellis, G.M., Olesiuk, P., & Rice, S.D. (2008). Ongoing population-level impacts on killer whales Orcinus orca following the 'Exxon Valdez' oil spill in Prince William Sound, Alaska. *Marine Ecology Progress Series, 356*, 269-281

Mattson, M.C., Mullin, K.D., Ingram, G.W., & Hoggard, W. (2006). Age structure and growth of the bottlenose dolphin (Tursiops truncatus) from strandings in the Mississippi sound region of the north-central Gulf of Mexico from 1986 to 2003. *Marine Mammal Science, 22*(3), 654-666

Mazet, J.A., Gardner, I.A., Jessup, D.A., Lowenstine, L.J., & Boyce, W.M. (2000). Evaluation of Changes in Hematologic and Clinical Biochemical Values after Exposure to Petroleum Products in Mink (*Mustela vison*) as a Model for Assessment of Sea Otters (*Enhydra lutris*). *American Journal of Veterinary Research, 61*(10), 7

Mazet, J.K., Gardner, I.A., Jessup, D.A., & Lowenstine, L.J. (2001). Effects of Petroleum on Mink Applied as a Model for Reproductive Success in Sea Otters. *Journal of Wildlife Diseases, 37*(4), 686-692

Merhi, Z.O. (2010). Gulf Coast oil disaster: impact on human reproduction. *Fertility and Sterility, 94*(5), 1575-1577

Mohr, F.C., Lasley, B., & Bursian, S. (2008). Chronic oral exposure to bunker C fuel oil causes adrenal insufficiency in ranch mink (*Mustela vison*). *Archives of Environmental Contamination and Toxicology, 54*(2), 337-347. doi:10.1007/s00244-007-9021-5

Moore, S.E. (2008). Marine Mammals as Ecosystem Sentinels. *Journal of Mammalogy, 89*(3)

Mullin, K.D., Barry, K., Sinclair, C., Litz, J., Maze-Foley, K., Fougeres, E., Mase-Guthrie, B., Ewing, R., Gorgone, A., Adams, J., & Tumlin, M. (2015). *Common Bottlenose Dolphins (Tursiops truncatus) in Lake Pontchartrain, Louisiana: 2007-mid 2014*. (MM_TR.23). DWH Marine Mammal NRDA Technical Working Group Report. Retrieved from *http://docs.lib.noaa.gov/noaa_documents/NMFS/SEFSC/TM_NMFS_SEFSC/NMFS_SEFSC_TM_673.pdf*.

Murphy, D.W., Li, C., d'Albignac, V., Morra, D., & Katz, J. (2015). Splash behavior and oily marine aerosol production by raindrops impacting oil slicks. *Journal of Fluid Mechanics, In Press* Retrieved from *https://sites.cns.utexas.edu/utmsi.dropps/publications/splash-behavior-and-oily-marine-aerosol-production-raindrops-impacting-oil*

Nichols, J.W., Breen, M., Denver, R.J., Distefano, J.J., Edwards, J.S., Hoke, R.A., Volz, D.C., & Zhang, X. (2011). Predicting chemical impacts on vertebrate endocrine systems. *Environmental Toxicology and Chemistry, 30*, 39-51

NMFS (National Marine Fisheries Service). (2010). *Recovery Plan for the Sperm Whale (Physeter macrocephalus)*. Silver Spring, MD: National Marine Fisheries Service.

Peterson, C.H. (2001). The Exxon Valdez oil spill in Alaska: Acute, indirect and chronic effects on the ecosystem. *Advances in Marine Biology, 39*, 1-103

Peterson, C.H., Rice, S.D., Short, J.W., Esler, D., Bodkin, J.L., Ballachey, B.E., & Irons, D.B. (2003). Long-term ecosystem response to the Exxon Valdez oil spill. *Science, 302*(5653), 2082-2086. doi:10.1126/science.1084282

Piscitelli, M.A., McLellan, W.A., Rommel, S.A., Blum, J.E., Barco, S.G., & Pabst, D. (2010). Lung size and thoracic morphology in shallow-and deep-diving cetaceans. *Journal of Morphology, 271*(6), 654-673

Ponganis, P.J. (2011). Diving Mammals. *Comprehensive Physiology*

Prasad, R., Karmakar, S., Sodhi, R., & Karmakar, S. (2011). Bilateral hemorrhagic pleural effusion due to kerosene aspiration. *Lung India: Official Publication of Indian Chest Society, 28*(2), 130-132

Ramachandran, G., Huynh, T., Groth, C., Banerjee, S., Stenzel, M., Blair, A., Sandler, D.P., Engel, L.S., Kwok, R.K., & Stewart, P.A. (2014). The Gulf Study: Estimate of workersexposures through the inhalation route on four rig vessels. Paper presented at the International Epidemiology in Occupational Health (EPICOH) Conference, Chicago, IL.

Read, A.J., Drinker, P., & Northridge, S. (2006). Bycatch of Marine Mammals in U.S. and Global Fisheries. *Conservation Biology, 20*(1), 163-169. doi:10.1111/j.1523-1739.2006.00338.x

Rebar, A.H., Lipscomb, T.P., Harris, R.K., & Ballachey, B.E. (1995). Clinical and clinical laboratory correlates in sea otters dying unexpectedly in rehabilitation centers following the Exxon Valdez oil spill. *Veterinary Pathology, 32*, 346-350

Reddy, L.M., Dierauf, L.A., & Gulland, F.M.D. (2001). Marine mammals as sentinels of ocean health. *CRC Handbook of Marine Mammal Medicine: Health, Disease and Rehabilitation.*(pp. 3-13).

Reeves, R.R., McClellan, K., & Werner, T.B. (2013). Marine Mammal Bycatch in Gillnet and Other Entangling Net Fisheries, 1990 to 2011. *Endangered Species Research, 20*, 71–97

Render, J.A., Aulerich, R.J., Bursian, S.J., & Nachreiner, R.F. (2000). Proliferation of maxillary and mandibular periodontal squamous cells in mink fed 3,3′, 4, 4′, 5-pentachlorobiphenyl (PCB 126). *Journal of Veterinary Diagnostic Investigation, 12*, 477-479

Reynolds III, J.E., Wells, R.S., & Eide, S.D. (2000). *The Bottlenose Dolphin: Biology and Conservation.* Gainesville, FL: University Press of Florida.

Ribelin, W.E. (1984). The effects of drugs and chemicals upon the structure of the adrenal gland. *Fundamentals of Aquatic Toxicology, 4*, 105-119

Ridgway, S.H., Scronce, B.L., & Kanwisher, J. (1969). Respiration and deep diving in the bottlenose porpoise. *Science, 166*, 1651–1654

Rosel, P.E. & Mullin, K.D. (2015). *Cetacean Species in the Gulf of Mexico*. (MM_TR.21). DWH Marine Mammal NRDA Technical Working Group Report.

Ross, P.S. (2000). Marine mammals as sentinels in ecological risk assessment. *Human and Ecological Risk Assessment, 6*(1), 29-46

Rossbach, K.A. & Herzing, D.L. (1997). Underwater observations of benthic-feeding bottlenose dolphins (Tursiops truncatus) near Grand Bahama Island, Bahamas. *Marine Mammal Science, 13*(3), 498-504

Rowe, L.D., Dooahite, J.W., & Camp, B.J. (1951). Toxicity of two crude oils and kerosene to cattle. *Journal of the American Veterinary Medical Association, 162*, 61–66

S.H., R. (1972). *Mammals of the Sea: Respiration System.* Charles C. Thomas, Springfield, Illinois.

Sandler, D.P., Engel, L.S., Rose, K., Payne, J., Curry, M., Ekenga, C.C., Miller, A., Birnbaum, L., Blair, A., & R.K., K. (2014). Respiratory Symptoms in Oil Spill Clean-up Workers Participating in the Gulf Study. Conference Abstract. Paper presented at the International Society for Environmental Epidemiology, Seattle, WA.

Schwacke, L.H., Hall, A.J., Townsend, F.I., Wells, R.S., Hansen, L.J., Hohn, A.A., Bossart, G.D., Fair, P.A., & Rowles, T.K. (2009). Hematologic and serum biochemical reference intervals for free-ranging common bottlenose dolphins (Tursiops truncatus) and variation in the distributions of clinicopathologic values related to geographic sampling site. *American Journal of Veterinary Research, 70*, 973-985

Schwacke, L.H., Smith, C.R., Townsend, F.I., Wells, R.S., Hart, L.B., Balmer, B.C., Collier, T.K., De Guise, S., Fry, M.M., Guillette, L.J., Lamb, S.V., Lane, S.M., McFee, W.E., Place, N.J., Tumlin, M.C., Ylitalo, G.M., Zolman, E.S., & Rowles, T.K. (2014). Health of common bottlenose dolphins (*Tursiops truncatus)* in Barataria Bay, Louisiana, following the Deepwater Horizon oil spill. *Environmental Science and Technology, 48*(1), 93-103. doi:10.1021/es403610f

Schwacke, L.H., Twiner, M.J., De Guise, S., Balmer, B.C., Wells, R.S., Townsend, F.I., Rotstein, D.C., Varela, R.A., Hansen, L.J., Zolman, E.S., Spradlin, T.R., Levin, M., Leibrecht, H., Wang, Z.H., & Rowles, T.K. (2010). Eosinophilia and biotoxin exposure in bottlenose dolphins (Tursiops truncatus) from a coastal area impacted by repeated mortality events. *Environmental Research Letters, 110*(6), 548-555

Schwartz, J.A., Aldridge, B.M., Lasley, B.L., Snyder, P.W., Stott, J.L., & Mohr, F.C. (2004). Chronic fuel oil toxicity in American mink (Mustela vison): systemic and hematological effects of ingestion of a low-concentration of bunker C fuel oil. *Toxicology and Applied Pharmacology, 200*(2), 146-158. doi:10.1016/j.taap.2004.04.004

Sen, V., Kelekci, S., Selimoglu Sen, H., Yolbas, I., Günes, A., Abakay, O., & Fuat Gurkan, M. (2013). An evaluation of cases of pneumonia that occurred secondary to hydrocarbon exposure in children. *European Review for Medical and Pharmacological Sciences, 1*(912)

Siddiqui, E.U., Razzak, J.A., Naz, F., & Khan, S.J. (2008). Factors associated with hydrocarbon ingestion in children. *Journal of Pakistan Medicine Association, 58*(11), 608-612

Sim, M.S., Jo, I.J., & Song, H.G. (2010). Acute health problems related to the operation mounted to clean the Hebei Spirit oil spill in Taean, Korea. *Marine Pollution Bulletin, 60*(1). doi:10.1016/j.marpolbul.2009.09.003

Smith, C. (2015). *Individual dolphin veterinary reports: Technical Report*.

Smith, C., Townsend, F.I., Rowles, T.K., Hart, L.B., Zolman, E.S., Wells, R.S., Balmer, B.C., Quigley, B., Speakman, T., McFee, W., Wu, Q., Ivančić, M., & Schwacke, L.H. (2015). *Health Data and Prognosis Determination of Live Bottlenose Dolphins (Tursiops truncatus) Examined in the Aftermath of the Deepwater Horizon Oil Spill.*: DWH Marine Mammal NRDA Technical Working Group Report.

Speakman, T.R., Lane, S.M., Schwacke, L.H., Fair, P.A., & Zolman, E.S. (2010). Mark-recapture estimates of seasonal abundance and survivorship for bottlenose dolphins (Tursiops truncatus) near Charleston, South Carolina, USA. *Journal of Cetacean Research and Management, 11*(2), 153-162

Stenzel, M., Stewart, P.S., Blair, A., Engel, L., Kwok, R., Banerjee, S., Cherrie, J., Groth, C., Huynh, T., & Sandler, D.P. (2014). The NIEHS Gulf Study: Recalculation of Exposure Measurement Data Between The Limit Of Detection (LOD) Reported By The Laboratory and the Analytical Methods'

LODs. Paper presented at the International Epidemiology in Occupational Health (EPICOH) Conference, Chicago, IL.

Stolen, M.K. & Barlow, J. (2003). A model life table for bottlenose dolphins (Tursiops truncatus) from the Indian River Lagoon System, Florida, USA. *Marine Mammal Science, 19*(4), 630-649

Stout, S.A. (2015a). *Chemical Fingerprinting Assessment of Exposure of Dolphins to Macondo Oil During and After the Deepwater Horizon Oil Spill*. (CHEM_TR.13). Seattle, WA. DWH Natural Resource Exposure NRDA Technical Working Group Report.

Stout, S.A. (2015b). *Distribution and Weathering of Macondo Oil Stranded on Shorelines in 2010 Based on Chemical Fingerprinting*. (CHEM_TR.08). Seattle, WA. DWH Natural Resource Exposure NRDA Technical Working Group Report.

Stout, S.A. (2015c). *Range in Composition and Weathering Among Floating Macondo Oils During the Deepwater Horizon Oil Spill*. (CHEM_TR.06). Seattle, WA. DWH Natural Resource Exposure NRDA Technical Working Group Report.

Suarez, B., Lope, V., PerezGomez, B., Aragones, N., Rodriguez-Artalejo, F., Marques, F., Guzman, A., Viloria, L.J., Carrasco, J.M., Martin-Moreno, J.M., Lopez-Abente, G., & Pollan, M. (2005). Acute health problems among subjects involved in the cleanup operation following the Prestige oil spill in Asturias and Cantabria (Spain). *Environmental Research Letters, 99*, 413–424

Takeshita, R., Morris, J.M., Forth, H.P., & Dean, K. (2015). *Range-Finding Studies on the Effect of Deepwater Horizon oil on the Human Adrenal Cell Line H295R*. (TOX_TR.29). Boulder, CO. DWH Toxicity NRDA Technical Working Group Report.

Thiel, R. & Chahoud, I. (1997). Postnatal development and behaviour of Wistar rats after prenatal toluene exposure. *Archives of Toxicology, 71*, 258-265

Thomson, C.A. & Geraci, J.R. (1986). Cortisol, aldosterone, and leucocytes in the stress response of bottlenose dolphins, Tursiops truncatus. *Canadian Journal of Fisheries and Aquatic Sciences, 43*, 1010-1016

Tuomi, P.A. & Williams, T.M. (1995). *Rehabilitation of pregnant sea otters and females with newborn pups. In Emergency Care and Rehabilitation of Oiled Sea Otters: A Guide for Oil Spills Involving Fur-Bearing Marine Mammals.* Fairbanks, AK: University of Alaska Press.

Venn-Watson, S. (2015). *Deepwater Horizon causation analysis*. DWH Marine Mammal NRDA Technical Working Group Report.

Venn-Watson, S., Colegrove, K.M., Litz, J., Kinsel, M., Terio, K., Saliki, J., Fire, S., Carmichael, R., Chevis, C., Hatchett, W., Pitchford, J., Tumlin, M., Field, C., Smith, S., Ewing, R., Fauquier, D., Lovewell, G., Whitehead, H., Rotstein, D., McFee, W., Fougeres, E., & Rowles, T. (2015a). Adrenal Gland and Lung Lesions in Gulf of Mexico Common Bottlenose Dolphins (*Tursiops truncatus*) Found Dead Following the Deepwater Horizon Oil Spill. *PLoS One, 10*(5). doi:10.1371/journal.pone.0126538

Venn-Watson, S., Colegrove, K.M., Litz, J., Kinsel, M., Terio, K., Saliki, J., Fire, S., Fauquier, D., Fougeres, E., Quinlan, J., Garrison, L., & Rowles, T. (2015b). *Morbidity & Mortality in Bottlenose Dolphins: Summary of Alternative Hypotheses*. DWH Marine Mammal NRDA Technical Working Group Report.

Venn-Watson, S., Garrison, L., Litz, J., Fougeres, E.M., Mase, B., Rappucci, G., Stratton, E.M., Carmichael, R.H., Odell, D.K., Shannon, D.K., Shippee, S.F., Smith, S.M., Staggs, L., Tumlin, M.C., Whitehead, H., & Rowles, T. (2015c). Demographic Clusters Identified within the Northern Gulf of Mexico Common Bottlenose Dolphin (Tursiops truncates) Unusual Mortality Event: January 2010-June 2013. *PLoS One, 10*(2). doi:e0117248

Waring, G.T., Josephson, E., Maze-Foley, K., & Rosel, P.E. (2013). *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2012*. (NOAA Technical Memorandum NMFS-NE-223).

Wells, R.S. (2014). Social structure and life history of bottlenose dolphins near Sarasota Bay, Florida: Insights from four decades and five generations. In: J. Yamagiwa & L. Karcmarski (Eds.), *Primates and Cetaceans: Field Research and Conservation of Complex Mammalian Societies, Primatology Monographs.*(pp. 149-172). Japan: Springer.

Wells, R.S. & Balmer, B.C. (2012). *Assessing Potential Sublethal and Chronic Health Impacts from the Mississippi Canyon 252 Oil Spill on Coastal and Estuarine Bottlenose Dolphins*. (MM_TR.25). DWH Marine Mammal NRDA Technical Working Group Report.

Wells, R.S., Balmer, B.C., Barleycorn, A., & Wilkinson, K. (2014a). *2013 Barataria Bay and Mississippi Sound Dolphin Tracking*. (MM_TR.26). DWH Marine Mammal NRDA Technical Working Group Report.

Wells, R.S., Barleycorn, A., & Wilkinson, K. (2014b). *2014 Barataria Bay Dolphin Tracking – Final Report*. (Order No: AB133C-11-CQ-0050).

Wells, R.S., Rhinehart, H.L., Hansen, L.J., Sweeney, J.C., Townsend, F.L., Stone, R., Casper, D.R., Scott, M.D., Hohn, A.A., & Rowles, T.K. (2004). Bottlenose dolphins as marine ecosystem sentinels: developing a health monitoring system. *EcoHealth, 1*, 246–254

Wells, R.S. & Scott, M.D. (1990). Estimating bottlenose dolphin population parameters from individual identification and capture-release techniques. In: P.S. Hammond, S.A. Mizroch, & G.P. Donovan (Eds.), *Individual Recognition of Cetaceans: Use of Photo-Identification and Other Techniques to Estimate Population Parameters. Report of the International Whaling Commission.*(Vol. 12, pp. 407-415). Cambridge, UK.

Wells, R.S. & Scott, M.D. (2009). Bottlenose Dolphin *Tursiops truncatus*. In W.F. Perrin, B. Würsig, & H.G.M. Thewissen (Eds.), *Encyclopedia of Marine Mammals* (pp. 249-255). San Diego, CA: Academic Press.

Wester, P.W., Muller, J.J.A., Slob, W., Mohn, G.R., Dortant, P.M., & Kroese, E.D. (2012). Carcinogenic activity of benzo[a]pyrene in a 2 year oral study in Wistar rats. *Food and Chemical Toxicology, 50*(3-4), 927-935

Whitehead, H. (2009). Sperm Whale Physeter macrocephalus. In W.F. Perrin, B. Würsig, & H.G.M. Thewissen (Eds.), *Encyclopedia of Marine Mammals* (pp. 1093-1097). San Diego, CA: Academic Press.

Würsig, B., Jefferson, T.A., & Schmidly, D.J. (2000). *The marine mammals of the Gulf of Mexico.* College Station, TX: Texas A&M University Press.

Wynne, K. & Schwartz, M. (1999). *Guide to marine mammals and turtles of the U.S. Atlantic and Gulf of Mexico.* Alaska Sea Grant, University of Alaska Fairbanks.

Zock, J.P., G., R.-T., Pozo-Rodriguez, F., Barbera, J.A., Bousa, L., Torralba, Y., Anto, J.M., Gomez, F.P., Fuster, C., H., V., & SEPAR-Prestige Study Group (2007). Prolonged respiratory symptoms in cleanup workers of the Prestige oil spill. *American Journal of Respiratory and Critical Care Medicine, 176*, 610-616

Zock, J.P., Rodriguez-Trigo, G., Rodriguez-Rodriguez, E., Espinosa, A., Pozo-Rodriguez, F., Gomez, F., Fuster, C., Castano-Vinyals, G., Anto, J.M., & Barbera, J.A. (2012). Persistent respiratory symptoms in clean-up workers 5 years after the Prestige oil spill. *Occupational and Environmental Medicine, 69*(7), 508-513. doi:10.1136/oemed-2011-100614