# 4.8 Sea Turtles

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## Executive Summary

Sea turtles are irreplaceable natural resources in the Gulf of Mexico because they serve unique ecological roles and are highly valuable to the public. All five sea turtle species that occur in the Gulf are listed as threatened or endangered under the U.S. Endangered Species Act (ESA). The Gulf provides critically important habitats for sea turtle reproduction, feeding, migration, and refuge, including extensive *Sargassum* habitat that small, oceanic juvenile turtles depend on for survival.

Because the DWH spill footprint overlapped in time and space with sea turtles throughout the northern Gulf of Mexico, all five sea turtle species and their habitats were exposed to DWH oil in the open ocean, across the continental shelf, and into nearshore and coastal areas, including beaches. Sea turtles were exposed to oil when in contaminated water or habitats; breathing oil droplets, oil vapors, and smoke; and ingesting oil-contaminated water and prey. Response activities and shoreline oiling also directly injured sea turtles, and disrupted or deterred sea turtle nesting in the Gulf. The pervasive and prolonged nature of the DWH spill and related response activities meant that sea turtle exposures to DWH oil and resulting injuries were inescapable for many turtles.

The Trustees performed several activities to assess oil exposure and injury to sea turtles from the DWH oil spill in the various geographic areas that sea turtles occupy, including surface habitats in the open ocean, across the continental shelf, and on nesting beaches. Activities included boat-based rescues and veterinary assessments, aerial surveys, satellite tracking of live sea turtles, recovery of stranded sea turtles, and monitoring of nesting sea turtles and their nests. Approximately 1,800 sea turtles, across all

life stages, were directly observed within the cumulative DWH oil footprint. Nearly 600 of these were directly assessed for degree of oil exposure, and more than 300 were rehabilitated and eventually released. Oil collected from rescued and stranded turtles, and in tissues of dead turtles, was confirmed to be DWH oil. In addition, the Trustees assessed sea turtle injuries caused by response activities, such as increased boat traffic, dredging for berm construction, increased lighting at night near nesting beaches, and oil cleanup operations on nesting beaches.

Based on these studies, the Trustees concluded that sea turtles in offshore areas, continental shelf areas, and on nesting beaches suffered adverse effects from DWH oil exposure and response activities throughout the northern Gulf of Mexico. External and internal oiling were clearly documented and demonstrated that sea turtles were exposed to DWH oil by multiple pathways. Among all exposure pathways evaluated, veterinarians and sea turtle biologists concluded that the most acute physical and physiological adverse effects resulted from direct contact with surface oil, which mired and killed turtles. All turtles must spend time at the surface to breathe, rest, bask, and feed, and these fundamental behaviors put turtles at continuous and repeated risk of exposure anywhere the ocean surface was contaminated by DWH oil. Toxicity resulting from inhalation and ingestion of oil also may have significantly contributed to injury; however, these effects are not as well understood.

Not only are sea turtles required to come to the surface to breathe, but they also must come ashore to lay their eggs. The latter requirement puts nesting sea turtles and their eggs and hatchlings at risk of exposure to oil and effects of cleanup response activities on nesting beaches. Indeed, DWH response actions undertaken to remove oil from the beaches and the ocean and to prevent hatchlings from entering the Gulf during the oil spill resulted in direct injuries to turtles, including decreased nesting and loss of sea turtle hatchlings, in all areas of the northern Gulf of Mexico.

Direct observations of the effects of oil on turtles obtained by at-sea captures, sightings, and strandings (dead or debilitated turtles that wash ashore or are found floating close to shore) were only partial samples that did not represent the full scope of the injury. The vast expanse of the search area and distance from shore significantly limited the proportion of the spill area that could be physically searched for sea turtles. For example, the area surveyed during rescue operations was less than 10 percent of the total footprint of more than 38,000 square miles (100,000 square kilometers) and search efforts did not occur during the entire spill period. Further, due to safety considerations associated with ongoing response actions, these search efforts were not centered close to the wellhead where effects were likely the greatest. Inherent challenges to studying highly mobile marine animals (i.e., they are typically located in remote areas that are difficult for researchers to access, they are difficult to find and capture at sea, and certain life stages spend most of their time below the surface) further restricted the Trustees' survey efforts. For these reasons, the Trustees used expert opinion, surface oiling maps, and statistical approaches to apply the directly observed adverse effects of oil exposure to turtles in areas and at times that could not be surveyed. This produced estimates of the total number of sea turtles that were injured within the entire footprint and period of the DWH oil spill.

The Trustees estimated that between 4,900 and up to 7,600 large juvenile and adult sea turtles (Kemp's ridleys, loggerheads, and hardshelled sea turtles not identified to species), and between 56,000 and 166,000 small juvenile sea turtles (Kemp's ridleys, green turtles, loggerheads, hawksbills, and

hardshelled sea turtles not identified to species) were killed by the DWH oil spill. Nearly 35,000 hatchling sea turtles (loggerheads, Kemp's ridleys, and green turtles) were also injured by response activities.

Despite uncertainties and some unquantified injuries to sea turtles, the Trustees conclude that this assessment adequately quantifies the nature and magnitude of injuries to sea turtles caused by the DWH oil spill and related activities. Restoration approaches should address different life stages and geographic areas to ensure that sea turtles will be able to fulfill their unique ecological role in the Gulf of Mexico ecosystem in the future.

## 4.8.1 Introduction and Importance of the Resource

**Key Points**

- Five species of sea turtles inhabit the Gulf of Mexico: loggerhead *(Caretta caretta)*, Kemp's ridley *(Lepidochelys kempii)*, green turtle *(Chelonia mydas)*, hawksbill *(Eretmochelys imbricata)*, and leatherback *(Dermochelys coriacea)*. All sea turtle species in the Gulf of Mexico are listed under the ESA.
- Sea turtles occupy unique ecological roles as long-lived, large-bodied animals that rely on both marine and terrestrial ecosystems to support their life history.
- Sea turtles require long-term, consistent, effective protection to prevent further population declines and possible extinction.
- Given the extensive nature of the DWH oil spill, it is key to understand how different life stages are distributed, and how different species of sea turtles use habitats in these different areas, in order to assess impacts of the DWH oil spill. Consequently, the Trustees assessed injury to sea turtles by species and life stage.



### 4.8.1.1 Resource Description

#### 4.8.1.1.1 What Are Sea Turtles?

Sea turtles' unique biology and life history, as well as their status as easily recognizable icons of the oceans, make them flagship species for the health of marine ecosystems and for marine conservation efforts globally (Frazier 2005). Like salmon and migratory birds, turtles have evolved extremely accurate homing and navigational systems that allow them to migrate between distinct feeding areas and breeding areas (Lohmann et al. 1997), including returning to nest on the beaches where they were born (i.e., natal beaches) (Lohmann et al. 1997). Sea turtles return to their natal beaches as breeding adults decades, rather than years, after imprinting on those areas as tiny hatchlings.

Despite their marine nature, sea turtles remain inexorably tied to sand beaches for reproduction. Female sea turtles return to dry land to dig their nests and lay their eggs, just like freshwater turtles and tortoises. Eggs remain buried below 0.3 to 1 meter of sand for the duration of incubation, and embryos obtain all the oxygen, water, and heat from the surrounding sand that they need to develop into hatchlings. After 45 to 60 days of incubation, hatchlings emerge from their nests, quickly crawl to the surf, and begin a marathon swim to reach offshore areas, find refuge, and begin their lives as truly

*marine* turtles. After decades in offshore and then continental shelf areas, sea turtles reach adulthood and begin to reproduce, beginning again a lifecycle that has been occurring unchanged for hundreds of millions of years (see Section 4.8.1.1.4, Sea Turtle Life Stages and Habitat Use).

#### 4.8.1.1.2 Ecological Roles of Sea Turtles and Their Values to the Public

Sea turtles occupy unique ecological roles as long-lived, large-bodied animals that move through several habitats during their lives. For example, different sea turtle species show unique dietary specialization: hawksbills eat sponges, leatherbacks eat jellyfish, and green turtles eat mainly seagrass and algae. Loggerheads and Kemp's ridleys are carnivores, but their diets vary regionally depending on available prey species (Bjorndal 1997).

Because sea turtles rely on both marine and terrestrial habitats to support their life history, they connect ocean to land in ways that few species do. Sea turtles transport marine nutrients to terrestrial environments through the eggs that they lay in sandy beach habitats (Bouchard & Bjorndal 2000), and also serve as important prey resources for many predators and scavengers (Heithaus 2013). Until sea turtles reach large body sizes, they are vulnerable to predation by predators that depend on them for food (Bolten 2003). Therefore, reductions in the number of small sea turtles mean a loss of valuable resources for marine predators, as well as scavengers and decomposers (Heithaus 2013).

In addition to serving important ecological roles, sea turtles are also extremely valuable natural resources to humans as subjects of wildlife-viewing activities, whether through formal ecotourism or informal enjoyment of nature. In nearly every country in the world where sea turtles are present, particularly where they nest, people make efforts to observe sea turtles in the wild. This is especially true in the United States, including in Gulf states.

#### 4.8.1.1.3 Status of and Threats to Sea Turtles in the Gulf of Mexico

At present, there are seven species of sea turtles worldwide, most of which have global distributions, with nesting beaches restricted to the tropics and subtropics, and marine ranges extending into high latitudes, and cold water (typically 10–15°C/50–60°F), as in the case of the leatherback turtle (Wallace et al. 2010). Five species of sea turtles inhabit the Gulf of Mexico: Kemp's ridley (*Lepidochelys kempii*), loggerhead (*Caretta caretta*), green turtle (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), and leatherback (*Dermochelys coriacea*) (Figure 4.8-1). Kemp's ridleys, loggerheads, green turtles, and

***Source:*** *Dawn Witherington.*

**Figure 4.8-1.** Five species of sea turtles inhabit the Gulf of Mexico: (clockwise from top left) Kemp's ridley *(Lepidochelys kempii),* loggerhead *(Caretta caretta),* green turtle *(Chelonia mydas),* hawksbill *(Eretmochelys imbricata),* and leatherback *(Dermochelys coriacea).* Note: species not shown to scale.

hawksbills are in the Cheloniidae family (i.e., hard shells), and leatherbacks are in the Dermochelyidae family. Kemp's ridleys, hawksbills, and leatherbacks are listed as "Endangered" under the U.S. Endangered Species Act (ESA). Green turtles are listed as "Threatened" except for the Florida and Pacific Mexico breeding populations which are listed as "Endangered." Due to the inability to distinguish the breeding population origin of individuals away from the nesting beaches, green turtles are considered "Endangered" wherever they occur in U.S waters of the Atlantic, Gulf of Mexico, and Caribbean. Loggerheads in the Gulf of Mexico belong to the Northwest Atlantic Ocean DPS and are listed as "Threatened" under the ESA. In addition to their ESA listing status, several international conservation treaties and agreements (e.g., Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC), Convention on International Trade in Endangered Species (CITES), International Union for the Conservation of Nature (IUCN) *Red List of Threatened Species*™) reflect their status as species considered to be in danger of extinction if current threats are not reduced.

Although sea turtles have survived threats to their existence over their millions of years on Earth, are geographically widespread, and are seemingly abundant, human threats have significantly reduced many sea turtle populations in less than a century (Bjorndal & Jackson 2003). Sea turtles are particularly susceptible to anthropogenic threats because their life history traits (e.g., slow-growing, late-maturing, long-lived, do not reproduce every year) increase their vulnerability at the population level (Musick 1999). Turtles frequently become accidentally entangled, ensnared, and hooked in fishing gear, including in trawls, nets, traps/pots, and on hook and line, and many of these interactions are fatal (Lewison et al. 2013). Humans consume turtle eggs, meat, and other products for subsistence and commercial purposes (Wallace et al. 2011). Coastal development can alter or destroy sea turtle nesting habitat, thereby hindering nesting, as well as reducing embryo and hatchling survival (Wallace et al. 2011). This combination of threats from humans and the unique life history traits of sea turtles makes their populations prone to rapid declines with slow recoveries from significant negative impacts. For these reasons, sea turtles require long-term, consistent, effective protection to prevent further population declines and possible extinction.



#### 4.8.1.1.4 Sea Turtle Life Stages and Habitat Use

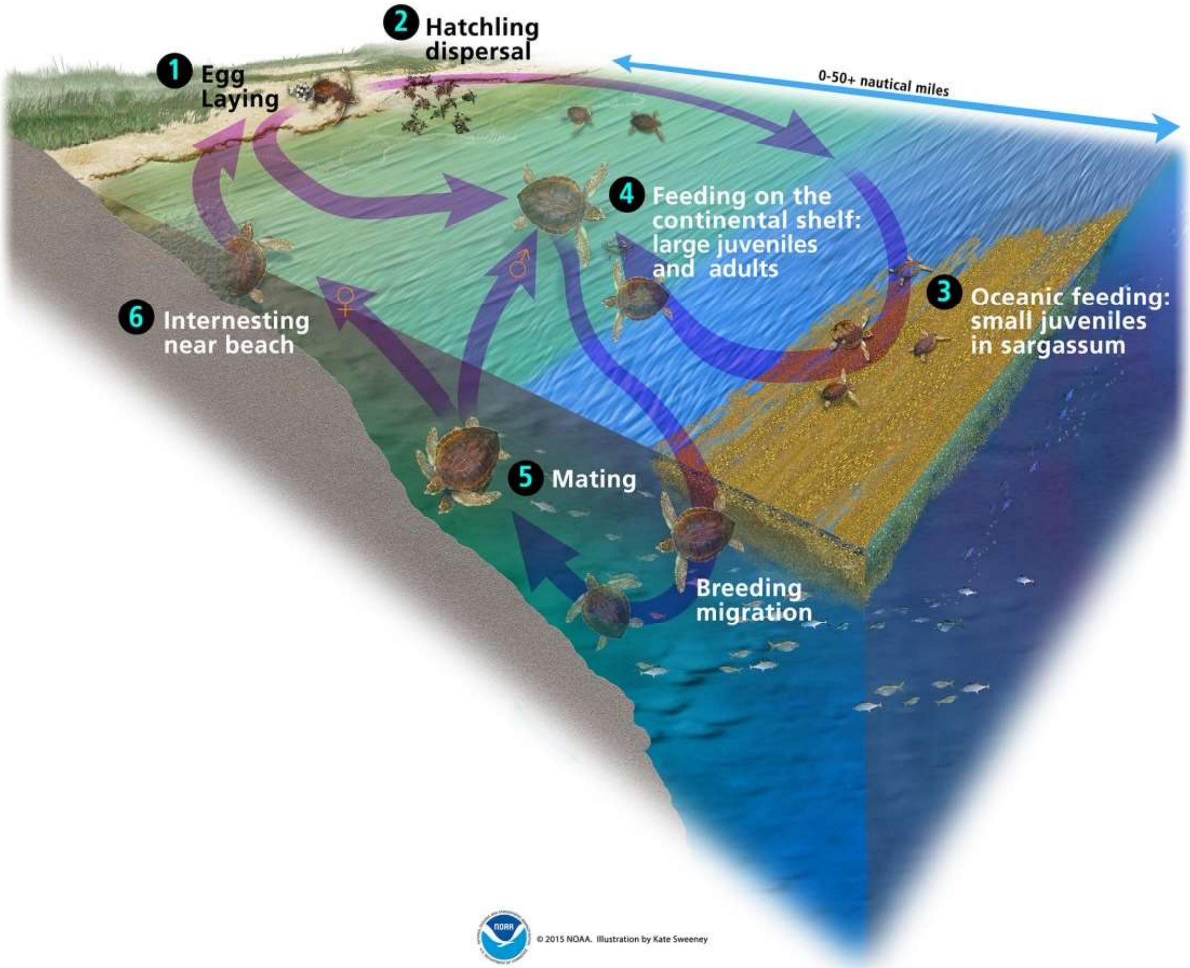
Within their expansive ranges, sea turtles occupy different habitats based on life stages and breeding phase. In order to carry out their multi-decadal lifecycle, different sea turtle life stages require vast areas of different types of marine habitats. Threats can differentially affect specific sea turtle life stages depending on where they overlap in space and time (Bolten et al. 2011). Therefore, given the extensive nature of the DWH oil spill, it is critical to understand how different life stages are distributed, and how different species of sea turtles use habitats in these different areas, in order to assess impacts of the DWH oil spill. Consequently, the Trustees assessed injury to sea turtles by species and life stage. This approach is also most appropriate for developing restoration approaches to compensate for the full extent of the injury across species, life stages, and geographic areas, and restoring sea turtles to their role in the Gulf of Mexico ecosystem.

The sea turtle lifecycle (Table 4.8-1; Figure 4.8-2) begins at egg laying on nesting beaches, followed by hatchling emergence and entry into the ocean, and continues as small juvenile turtles associate with convergence zones in open-ocean areas, where they feed, grow, and evade predation for several years (Bolten 2003). Turtles in this life stage remain at or near the surface, associated with floating material,

specifically *Sargassum* habitats (Witherington et al. 2012). After this open-ocean (i.e., oceanic) phase, turtles recruit to continental shelf (i.e., neritic) areas, where they continue growing to larger sizes over several additional years, even decades, as in the case of loggerheads, green turtles, and hawksbills (Bolten 2003). Turtles mostly remain in continental shelf areas for the rest of their lives. Leatherback turtles are an exception and continue to frequent both the continental shelf and distant offshore waters. Apart from adult females, which come ashore approximately every two or three years to lay eggs several times in a season, sea turtles remain at sea for their entire lives, showing site-fidelity to selected foraging grounds (Hart et al. 2014; Shaver et al. 2013). A summary of the sea turtle lifecycle and habitat use by different life stages is presented in Bolten (2003).Oil exposures documented in these areas inhabited by different life stages are described in Section 4.8.3 (Exposure).

**Table 4.8-1.** Summary of sea turtle life stages and habitats discussed in this section.

| Life stage | Habitat | Description of Turtles in This Stage |
|---|---|---|
| **Nesting females, eggs, hatchlings** | Northern Gulf of Mexico sandy beaches mainly in Florida, Alabama, Texas, and Mexico | Nesting female turtles; embryos develop while buried in sand; hatchlings emerge and enter the ocean |
| **Small juveniles** | "Oceanic": open ocean; surface habitats throughout the northern Gulf of Mexico | Spend more than 80 percent of their time at or near the sea surface; limited diving ability; tend to associate with floating *Sargassum*; drift and swim to remain in surface currents |
| **Large juveniles and adults** | "Neritic": Continental shelf; nearshore and inshore habitats | Use the entire water column, from surface to bottom; active swimmers; dive frequently and typically deeper than 20 meters; spend on average 10 percent of time at the surface; consistently use the same breeding and foraging areas; actively migrate to breed (adults) |




***Source:*** *Kate Sweeney for NOAA.*

**Figure 4.8-2.** Generalized sea turtle lifecycle**.** The lifecycle starts with egg laying 1). Hatchlings then leave nesting beaches and swim away from the coast to reach oceanic (i.e., offshore, depths typically > 200 meters) areas 2), where they remain for several years associated with *Sargassum* and other surface habitats 3). After growing to larger body sizes, they move onto the continental shelf and closer to shore 4) until reaching adulthood. Adults perform breeding migrations to the areas where they were born 5), sometimes across oceanic areas, to find mates. Adult male turtles return to foraging areas after mating, while adult females remain during nesting seasons 6) that can last 1–2 months for each female. Hatchlings emerge from eggs laid on sandy beaches, which initiates a new cycle.

## 4.8.2 Approach to the Assessment

**Key Points**

- The Trustees focused their assessment in areas that sea turtles must use to fulfill their physiological and life history requirements (e.g., sea surface, nesting beaches).
- To assess injuries to sea turtles caused by the DWH oil spill, the Trustees:
  1. Conducted surveys to document sea turtles in oil throughout the northern Gulf of Mexico.
  2. Characterized exposure pathways and the severity of exposure.
  3. Estimated total numbers of turtles exposed.
  4. Determined that adverse effects from exposure caused injuries.
  5. Estimated the total numbers of turtles injured by oil exposure.
  6. Estimated the total numbers of turtles injured by response activities.
  7. Summed all injuries to sea turtles caused by the DWH oil spill.

### 4.8.2.1 Rationale: Why the Trustees Assessed DWH Impacts on Sea Turtles

Sea turtles occupy various habitats throughout the northern Gulf of Mexico for growth and reproduction, and they presently face all of the threats described in Section 4.8.1.1.3 (Conant et al. 2009; NMFS et al. 2011). It is in this context that the DWH disaster—the largest offshore oil spill in U.S. history—occurred, during which oil moved far and wide throughout the Gulf. Oil impacted over 110,000 square kilometers of the ocean surface, over 2,100 kilometers of shoreline, more than 1,030 square kilometers of deep-sea sediments, and deep-sea water within a plume that extended more than 400 kilometers from the failed well (see Section 4.2, Natural Resource Exposure).

This extensive oiling contaminated vital foraging, migratory, and breeding habitats at the surface, in the water column, and on the ocean bottom throughout the northern Gulf of Mexico for Kemp's ridleys, loggerheads, green turtles, hawksbills, and leatherbacks, across geographic areas used by different life stages. In fact, DWH oil contaminated areas designated as "Critical Habitat" under the ESA for loggerhead sea turtles in the northern Gulf of Mexico. The pervasive and prolonged nature of the DWH spill, particularly at the air-water interface where all sea turtles must go to breathe, made exposure to oil inescapable for many sea turtles, and caused significant injuries to sea turtle populations in the northern Gulf of Mexico.

Adverse physical and toxic effects to wildlife exposed to oil have been documented extensively (e.g., Helm et al. 2015; Leighton 1993; Munilla et al. 2011; Peterson et al. 2003; Piatt & Ford 1996; Shigenaka 2003). DWH oil was no exception, as discussed in Section 4.3, Toxicity. Exposure to DWH oil caused a variety of negative effects, including mortality, on a wide range of species native to the northern Gulf of Mexico. The remote location of the wellhead within deep waters distant from shore meant that organisms such as sea turtles that inhabit offshore areas were vulnerable to DWH oil exposures. This necessitated different assessment and response approaches than those used in previous spills that occurred closer to shore and in smaller areas.

Although oiling and mortality of sea turtles have been documented during previous spills in various locations around the world, detailed information, especially with regard to adverse effects of oil, is

generally sparse (Shigenaka 2003). The DWH oil spill overlapped with vital habitats for sea turtles, particularly those of small juvenile turtles that are restricted to ephemeral habitats offshore, at or near the surface (i.e., *Sargassum* habitats and associated floating material; described in Section 4.8.1.1.4, Sea Turtle Life Stages and Habitat Use). The Trustees recognized that surface oil would accumulate in these convergence zones (i.e., areas where surface currents come together), which also brings together anything floating at the surface, such as *Sargassum*, sea turtles, and oil—and therefore would pose a significant risk to turtles in this life stage. As the spill progressed and oil moved into continental shelf and nearshore areas, the Trustees recognized that larger, older sea turtles in these areas, and sea turtle nesting beaches, would also be exposed to DWH oil.

In general, the Trustees focused assessments in areas that sea turtles must use to fulfill their physiological and life history requirements. The remainder of this section summarizes the overall approach that the Trustees followed to determine exposure and injury to sea turtles and to quantify those injuries.

#### 4.8.2.2 Conceptual Model of the Approach to the Sea Turtle Injury Assessment

To assess injuries to sea turtles caused by the DWH oil spill, the Trustees evaluated exposures of sea turtles to DWH oil (described in Section 4.8.3), determined adverse effects caused by oil exposure (described in Section 4.8.4), and quantified the magnitude of injuries to sea turtles across life stages and geographic areas in the northern Gulf of Mexico (described in Section 4.8.5). The conceptual model of the approach to the sea turtle injury assessment is presented in Figure 4.8-3.

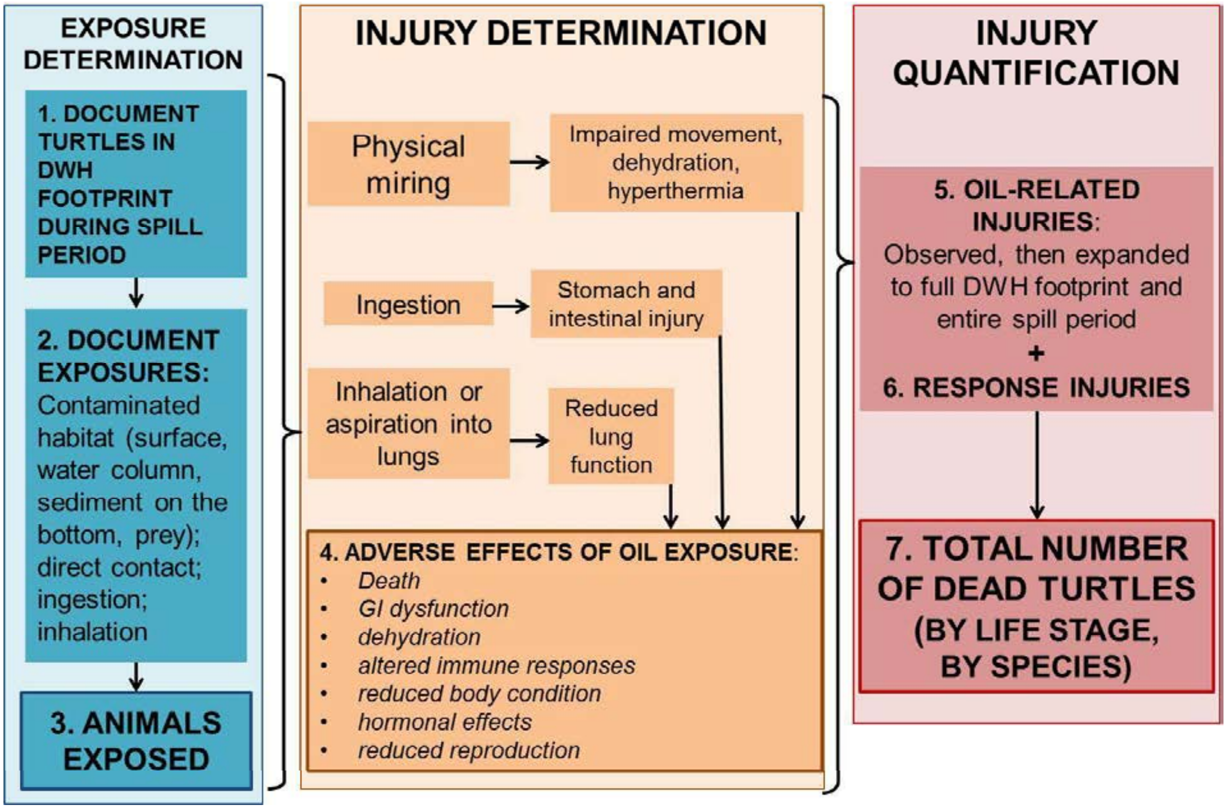



**Figure 4.8-3.** Conceptual model of the approach to the sea turtle injury assessment. Details for each box are provided in the sections below.

#### 4.8.2.2.1 Exposure Determination

The Trustees conducted rescue and survey operations at sea, from the air, and on the ground to document and evaluate sea turtle exposures to DWH oil.

1. **To document turtles in the DWH footprint** during the spill period, the Trustees:

    - Performed boat-based rescue operations of juvenile turtles in offshore convergence zones (Figure 4.8-2). These efforts involved more than 1,200 transects that covered nearly 200 square kilometers of search area (McDonald et al. 2015).

    - Conducted aerial surveys to document large juvenile and adult sea turtles in relation to oil throughout continental shelf areas in the northern Gulf of Mexico. Nearly 250 transects covered approximately 6,600 square kilometers within the DWH oil spill footprint and on the continental shelf (Garrison 2015).

    - Deployed satellite transmitters on adult female turtles to track their movements and habitat use after the nesting season ended to identify overlaps between high-use areas and the DWH oil spill footprint (Hart et al. 2012; Hart et al. 2014; Shaver et al. 2013).

    - Monitored coastlines in search of stranded turtles, and performed necropsies on dead, stranded turtles for signs of oil exposure (Stacy 2012, 2015; Stacy & Schroeder 2014).

- Monitored beaches for female turtles, nests, eggs, and hatchlings to document potential exposure to DWH oil. Evaluations included chemical analyses of blood from nesting female loggerhead and Kemps ridley sea turtles to determine possible exposure to DWH oil as well as monitoring of sea turtle nests on impacted beaches for the presence of oil on or in nests and eggs (Hooper & Schmitt 2015).

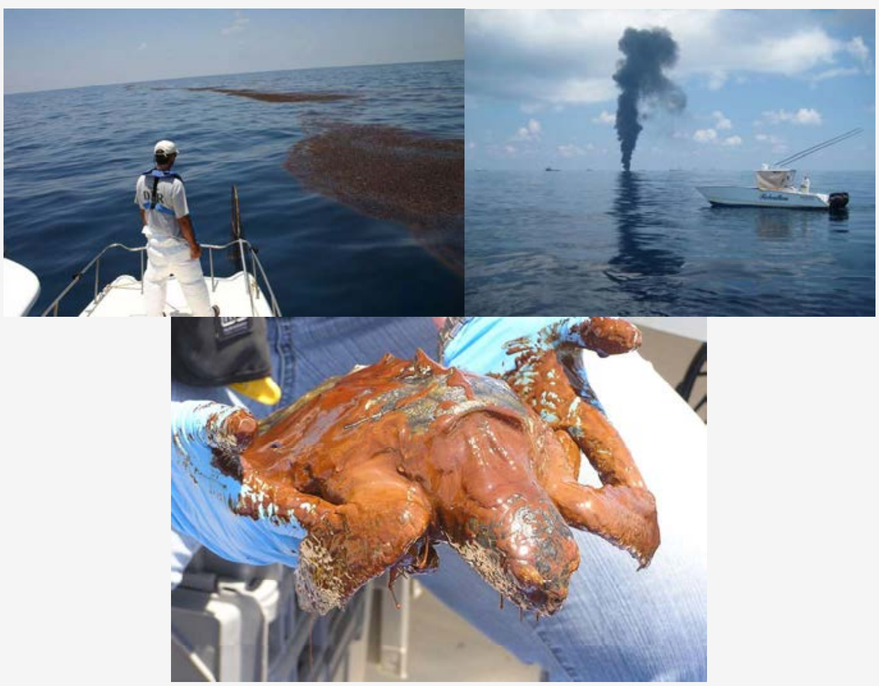
2. **To document sea turtle exposures,** the Trustees characterized exposure pathways and severity of exposure. Veterinarians assessed the conditions of turtles rescued from the Gulf during the spill and assigned turtles to oiling categories based on the extent of external and internal oiling. Toxicologists analyzed tissues from oiled turtles rescued at sea or found as beach-cast strandings, as well as nesting females and their eggs and hatchlings, for signs of oil exposure. The Trustees analyzed composition and concentration of polycyclic aromatic hydrocarbons (PAHs) in liver, lung, stomach and colon content and tissues, and bile collected from turtles captured during rescue efforts and from stranded turtles.

3. **To estimate sea turtles exposed during the DWH spill,** the Trustees used statistical techniques to estimate the magnitude of sea turtle exposures and injuries in both marine and terrestrial environments. Extrapolations were necessary because the field-based observations represent only a sample of the full extent of space and time in which sea turtles occurred and were exposed to oil.

## Offshore Rescue Operations Documented Oil Exposure of Hundreds of Sea Turtles

Between May 17 and September 9, 2010, the Trustees undertook rescue operations in an effort to save sea turtles in the spill area (Stacy 2012). Observers in aircraft aided boat-based efforts by communicating locations of oil and *Sargassum*. Boat-based rescue crews searched lines of floating material with oil at low speeds in search of turtles. Crews searched nearly 250 transects totaling nearly 200 square kilometers. Searched areas typically included floating petroleum, emulsified oil, *Sargassum*, and flotsam such as marsh reeds and plastics (Figure 4.8-4). Turtles were either removed from the oil or water using a dip-net, or evaded capture by diving, often beneath surface oil and *Sargassum*. Once turtles were brought aboard, they were examined, the oil was sampled and partially cleaned from the eyes and body, and photographs were taken (Figure 4.8-4).

From May through the beginning of August 2010, turtles that were rescued were taken to rehabilitation facilities for further health assessments, treatment, and monitoring (Stacy & Innis 2012). The Trustees examined more than 300 turtles and characterized any potentially abnormal medical conditions or physiological abnormalities. More than 90 percent of the turtles that were admitted to rehabilitation centers eventually recovered and were released (Stacy 2012). However, long-term condition and survival of oiled turtles treated in rehabilitation centers are not representative of outcomes for oiled turtles in the wild that did not benefit from rescue and treatment (Stacy & Innis 2012). See Section 4.8.4 (Injury Determination) for details about clinical assessments of rehabilitated turtles.



***Source:*** *B. Witherington (top left), M. Dodd (top right), T. Hirama (bottom).*

**Figure 4.8-4.** Boat-based efforts during the DWH oil spill focused on offshore areas that are inhabited by small juvenile sea turtles. Photos: (top left) Trustees searched convergence areas, which accumulate floating material, typically *Sargassum* and associated fauna, including sea turtles, as well as DWH oil; (top right) responders performed boat-based operations in offshore areas to rescue small juvenile sea turtles that inhabited convergence areas affected by the oil; (bottom) a heavily oiled, small juvenile Kemp's ridley turtle rescued during the spill.

#### 4.8.2.2.2 Injury Determination

The Trustees combined veterinary assessments of oiled turtles that were rescued and rehabilitated with various data sources related to physical and toxicological adverse effects of oil exposure on sea turtles to determine the extent and severity of injuries related to oil exposures caused by oil.

1. **To determine adverse effects of oil exposure** on sea turtles, the Trustees conducted studies and synthesized information on physiological, toxicological, and laboratory studies, as well as veterinary assessment of recovered live and dead turtles to quantify mortality estimates for turtles based on the degree of oil exposure.

#### 4.8.2.2.3 Injury Quantification

Direct observations of turtle exposures in DWH oil only covered a small portion of the entire oil spill footprint and spill period. Therefore, the Trustees combined these direct observations and injury determination with statistical techniques to extrapolate from surveyed areas and times to the entire footprint and spill period to estimate the full magnitude of sea turtle injuries.

2. **To determine the magnitude of oil-related injuries,** biologists, geospatial analysts, and statisticians constructed models to quantify total sea turtle injuries within the entire spill area and for the full duration of the spill. As with exposure, these models were necessary because direct observations represented only a small portion of the large area affected by the DWH oil spill. These approaches allowed the Trustees to calculate the total numbers of turtles killed by oil exposure.

3. **To determine the number of response injuries,** the Trustees also quantified injuries due to response activities that directly injured turtles or deterred reproduction in marine and terrestrial areas.

4. **To quantify the total injuries, by life stage and by species,** the Trustees summed injuries to sea turtles caused by exposure to DWH oil and caused by DWH response activities to produce an overall estimate of turtle injuries by life stage (i.e., geographic area) and by species. These quantification metrics facilitate effective restoration of sea turtles in the northern Gulf of Mexico.

### 4.8.2.3 Summary of Approach to the Assessment

The remote location and pervasive nature of the DWH oil spill required the Trustees to undertake several methods to assess sea turtle exposures to oil and injuries caused by oil throughout the spill footprint and response activities. The Trustees combined direct observations obtained by various types of surveys and studies (e.g., vessel-based, aerial, ground-based, veterinary, toxicological) with statistical extrapolation techniques to assess and estimate the full magnitude of the DWH oil spill effects on sea turtles. In the next section, we describe results from Trustees' efforts to document sea turtle exposure to DWH oil.

### 4.8.3 Exposure

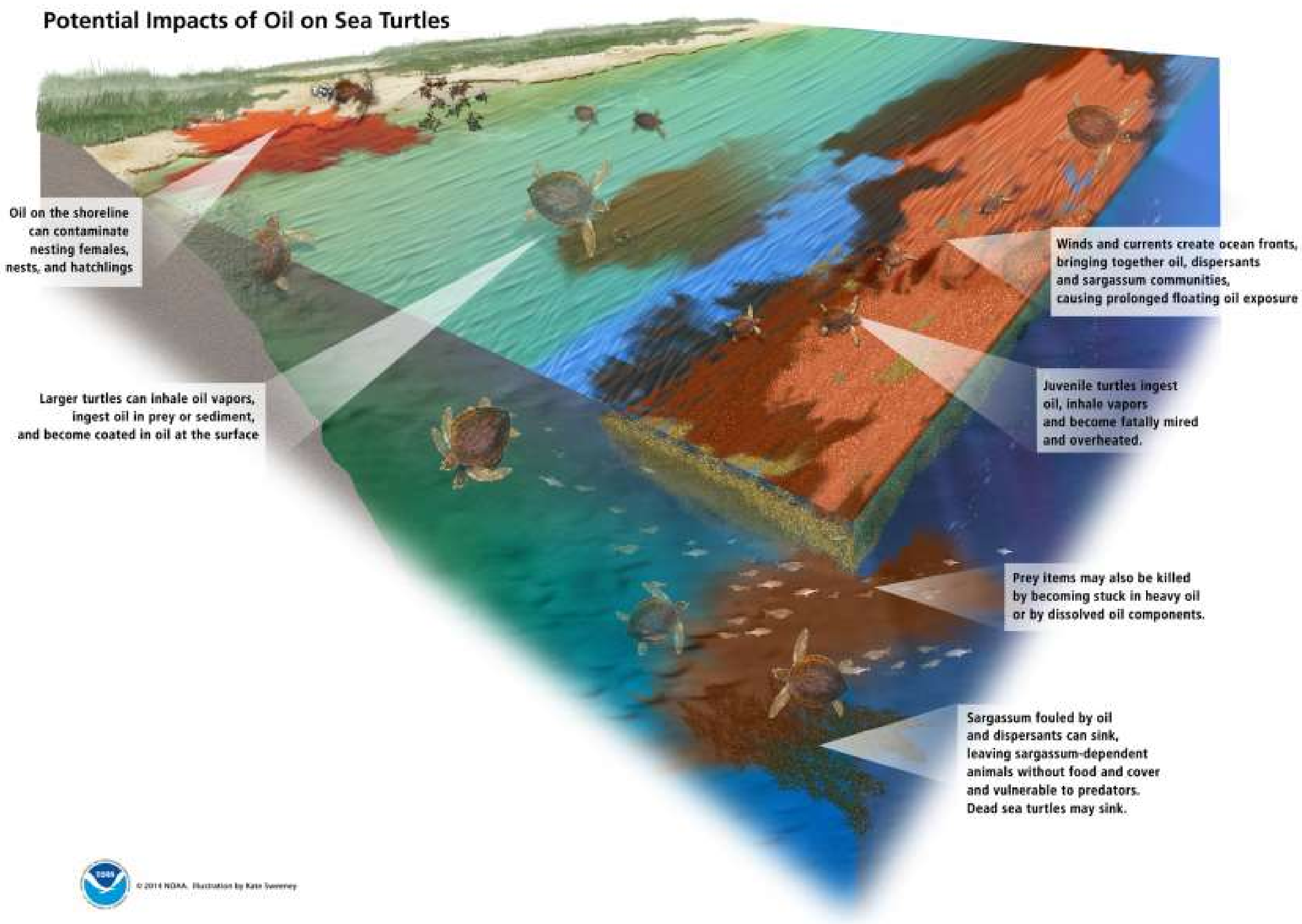
**Key Points**

- The DWH oil spill contaminated critical turtle habitats throughout the northern Gulf of Mexico, especially the sea surface, for extended periods of time.
- Sea turtles likely were exposed to oil through a variety of pathways:
  - Direct contact with oil when swimming at or near the surface, and on nesting beaches.
  - Inhalation of oil, oil vapors, and smoke.
  - Ingestion of oil-contaminated water and prey.
  - Transfer of oil compounds from adult females to their developing embryos.
  - Oil contamination of essential turtle habitats.
- The Trustees used a multi-faceted, multi-scale approach to determine the extent of sea turtle exposure to DWH oil.
  - The Trustees observed nearly 1,800 turtles within the DWH oil footprint based on vessel- and plane-based surveys.
  - Turtle exposure to DWH oil was confirmed based on direct observation, analytical chemistry, and surface oiling data obtained by satellites.
  - The Trustees assessed the degree of external oiling of turtles, and developed categories for the degree of oiling for use in the injury determination and quantification.
  - The Trustees observed that turtles that were externally oiled generally had also ingested oil, demonstrating exposure via multiple pathways.

This section describes how sea turtles were exposed to DWH oil as it spilled into the Gulf of Mexico from the area of the wellhead and spread throughout the northern Gulf of Mexico. Utilization of both marine and terrestrial habitats by different life stages resulted in exposure in various habitats and by a variety of external and internal pathways. In marine areas, sea turtles were exposed to surface oil and to oil beneath the surface. In terrestrial areas, turtles were potentially exposed to oil on nesting beaches and potentially by maternal transfer of oil compounds to embryos. Because the DWH oil spill contaminated critical sea turtle habitats throughout the northern Gulf of Mexico, sea turtle exposure to oil was pervasive, severe, long-lasting, and for many turtles, inescapable (Garrison 2015; McDonald et al. 2015; Stacy 2012).

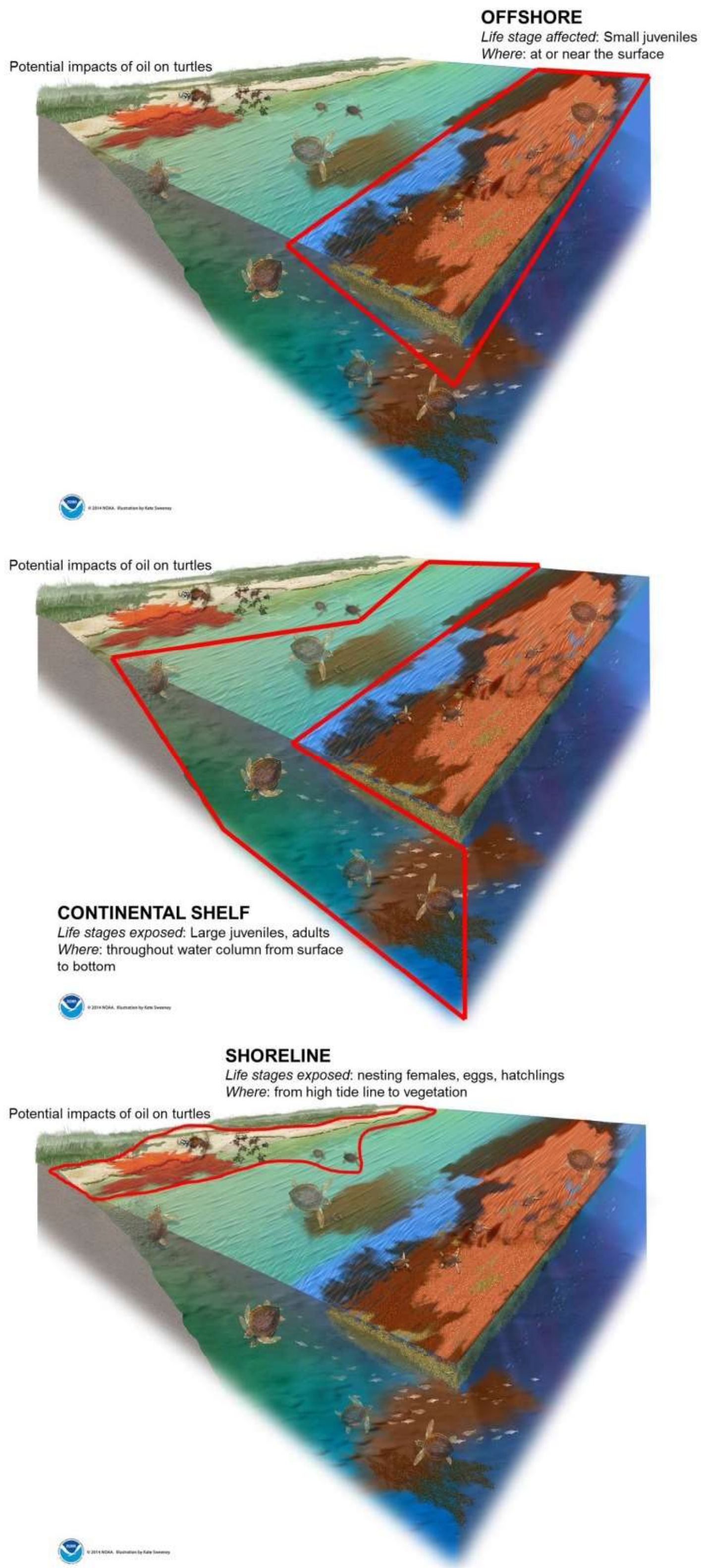
#### 4.8.3.1 Sea Turtle Oil Exposure Followed the Oil Spill Trajectory in the Gulf of Mexico

Figure 4.8-5 shows the potential impacts of DWH oil in the northern Gulf of Mexico. As DWH oil contaminated offshore waters and later spread onto the continental shelf and coast, and into inshore waters, exposure to and potential impacts of oil on sea turtles mirrored the trajectory and advance of the spill. Figure 4.8-6 illustrates the progression of oil and resulting exposures of the different life stages within the sea turtles' predominant habitat. Small juvenile sea turtles were first exposed to oil in offshore areas beyond the continental shelf in the early period of the spill and throughout the duration of the free-release period (Figure 4.8-6, top panel). As the oil moved onto the continental shelf, larger, older neritic turtles were exposed in known foraging, migratory, and breeding areas (Figure 4.8-6, middle panel). When oil came ashore on coastal shorelines, turtle nesting beaches—along with nests and hatchlings—were also potentially exposed (Figure 4.8-6, bottom panel).




***Source:*** *Kate Sweeney for NOAA.*

**Figure 4.8-5**. Potential impacts of DWH oil on sea turtles in the northern Gulf of Mexico. Text boxes highlight specific details about potential exposure pathways and adverse effects to turtles in their different critical marine and terrestrial habitats.




***Source:*** *Kate Sweeney for NOAA.*

**Figure 4.8-6.** Potential impacts of DWH oil on turtles in offshore (top), continental shelf (middle), and shoreline or terrestrial habitats (bottom) in the northern Gulf of Mexico.

#### 4.8.3.2 Potential Exposure Pathways

Sea turtles likely were exposed to oil via several external and internal pathways in marine and terrestrial areas throughout their distribution in the Gulf of Mexico. Surface oil, airborne oil compounds (e.g., volatiles and semi-volatiles, aerosols), oil in the water column, and oil in nearshore sediments were all likely sources of exposure to DWH oil throughout the northern Gulf of Mexico from offshore areas to the shorelines, throughout the duration of the free-release period, and for as long as oil persisted in these areas following the capping of the wellhead. As illustrated in Figure 4.8-5 and Figure 4.8-6, sea turtles in offshore as well as continental shelf waters were exposed to oil by direct contact at or near the surface; ingestion of oil while eating or drinking contaminated food, water, or sediment; and inhalation of oil vapors while breathing at the surface. Turtles also could have been affected via contaminated habitat or reduced prey availability or quality, particularly in sub-surface habitats. Although all of these exposures are probable, some of these pathways could not be specifically incorporated into the assessment due to insufficient available information. Consequently, the exposure assessment focused on the extensive evidence of sea turtle exposures in oil at or near the surface, which were readily observable and clearly documented.

The assessment focused on the following potential exposure pathways:

- **Direct contact.** Turtles came into direct contact with oil when swimming at or near the surface, which caused their bodies to become coated with oil wherever contact occurred. Physical fouling of eyes, nares (i.e., nasal openings), and mouth resulted in ingestion of oil and exposure of sensitive mucus membranes. All life stages are at risk for direct contact exposure due to their inherent need to surface to breathe, although such exposure is especially acute for smaller juveniles that spend nearly all of their time in the top 2 meters of the water column and inhabit ocean convergence fronts formed by wind and currents, which also accumulate oil (Shigenaka 2003). For sea turtles, becoming mired in oil had drastically negative effects, including impeded locomotion and diving ability; and decreased ability to feed and avoid predators; hyperthermia (overheating) in the heavy, dark oil; among others.

  On beaches, nesting turtles and their eggs and hatchlings were potentially exposed to oil through direct contact with oiled substrate on sand beaches. Additionally, oil compounds absorbed by embryos developing in contaminated sand could affect development and survival.

- **Ingestion.** Sea turtles are well-known to ingest petroleum and other anthropogenic material, possibly due to indiscriminant feeding behavior or mistaking such items for prey (Camacho et al. 2013; Witherington 2002). Ingestion of oil or oil-related compounds would have exposed turtles to adverse toxicological effects such as function of vital physiological systems (Lutcavage et al. 1995). These effects could impair turtles' health, growth, and survival.

- **Inhalation.** Turtles rely on oxygen inhaled right above the water's surface, and thus were exposed to inhalation and/or aspiration of oil droplets, oil vapors, and smoke from burning oil when they surfaced to breathe in contaminated areas. Similar to potential effects described for marine mammals (Section 4.9), inhalation exposure would decrease respiratory and cardiovascular function, and thus hinder turtles' abilities to dive efficiently to forage, escape predators, find mates, migrate, etc. This effect could worsen as stressed, oxygen-deprived

turtles surfaced more frequently to breathe, still within surface slicks, thereby becoming exposed repeatedly. Inhalation exposure is a well-recognized concern among spill workers and other air-breathing animals (see Section 4.9, Marine Mammals).

- **Maternal transfer.** Animals that lay eggs have been shown to pass metabolized oil-related compounds onto their offspring, which have the potential to be toxic to developing embryos (Pereira et al. 2009; West et al. 2014). Similarly, adult female turtles could have passed metabolized oil and related products into their eggs, thereby exposing developing embryos. These oil-related contaminants could have impaired the development and survival of embryos.

- **Exposure of turtle habitats.** Oil contamination of essential turtle habitat (e.g., *Sargassum* habitats), nearshore sediments, the water column, and shorelines are also highly relevant to the effects of the DWH spill on sea turtles due to the potential effect on prey items and other marine organisms and implications on the northern Gulf of Mexico food web. In addition, environmental oiling contributes to all of the above routes of exposure. For example, larger turtles feeding on the ocean floor will incidentally consume sediment with food items (Lazar et al. 2011; Preen 1996).



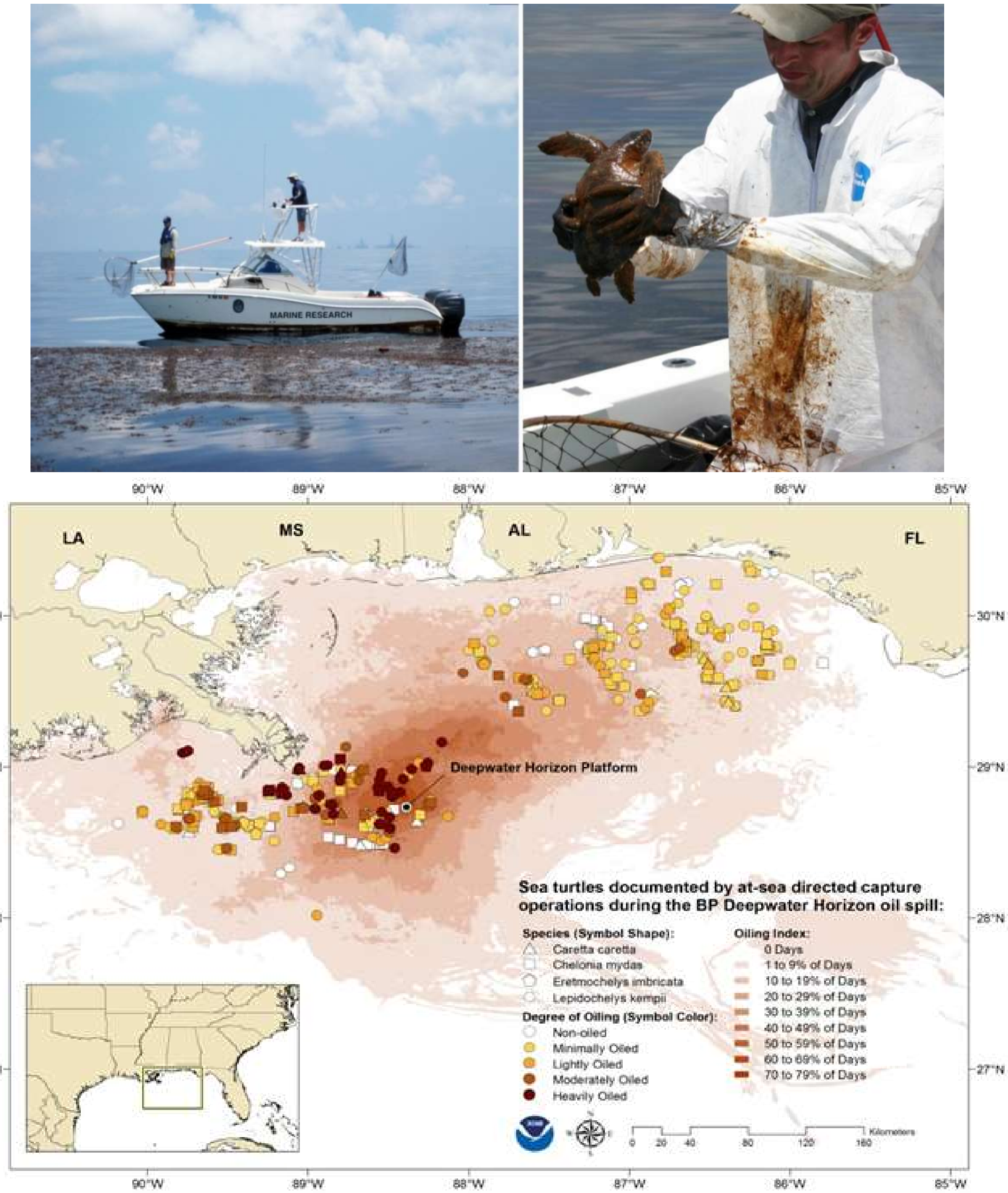
### 4.8.3.3 Sea Turtles Were Observed in Oil Throughout the Northern Gulf of Mexico

The Trustees synthesized results from boat-based rescue efforts, aerial surveys, and other observations with various data sources to document and quantify sea turtle exposure to DWH oil.

#### 4.8.3.3.1 Directed Captures and Observations of Oiling in Offshore Areas

Trustee rescue teams performed active searches on more than 1,200 transects totaling over 4,200 linear kilometers and an area of nearly 200 square kilometers within potential turtle habitats to locate and capture turtles from the ocean surface (Figure 4.8-7). These directed capture efforts primarily targeted oceanic juvenile turtles within offshore convergence zones, which were considered to be under the greatest imminent threat from the spill. More than 900 turtles were sighted, 574 of which were captured and examined for oiling (Stacy 2012). Figure 4.8-7 shows boat-based rescue efforts, assessment of heavily oiled sea turtles, and locations of turtles captured and assessed during rescue operations. Of the turtles captured during rescue operations, 464 (> 80 percent) were visibly oiled (Table 4.8-2), and the quantity of oil collected from 199 oiled turtles was sufficient to identify the material as MC252 oil (Stacy 2012; Stout 2014). This high proportion of captured turtles that were oiled demonstrates the widespread inundation of offshore sea turtle habitat by oil.

From May through the beginning of August 2010, most of the turtles that were rescued were taken to rehabilitation facilities for further medical evaluation, treatment, and monitoring (Stacy & Innis 2012). Five turtles were found dead during directed capture activities, three of which were oiled, and four more were found alive, but died later. Details about clinical evaluation of rehabilitated turtles and postmortem examinations related to assessment of injury are presented in Section 4.8.4.1 (Physical Effects).




***Source:*** *B. Witherington (top left), T. Hirama (top right).*

**Figure 4.8-7.** Boat-based rescue efforts documented more than 900 sea turtles in the DWH spill zone. Photos: (top left) Boat-based rescue efforts on search transects within offshore convergence areas that are known habitats for small juvenile sea turtles; (top right) the NOAA veterinarian assessing the condition of heavily oiled sea turtles rescued from oiled surface habitat; (bottom) Locations of turtles captured and assessed during rescue operations, shown by species and degree of oiling, overlaid upon cumulative oil-days within the overall oiling footprint. Nearly all heavily oiled turtles were found within 90 kilometers of the wellhead, and prior to August 1, 2010.

It is important to note that the turtles documented during rescue operations—especially the number of oiled, dead turtles—underestimate the actual magnitude and degree of oil exposure that affected sea turtles during the DWH oil spill. The underestimation was due to several factors that hindered the ability of field crews to document live and dead turtles during the rescue efforts. Foremost was the vast expanse of the search area and distance from shore, which limited the proportion of the spill area that could be physically searched for small turtles, which are only visible from vessels. Disappearance of carcasses due to sinking of remains, scavenging, and rapid decomposition rates in summer temperatures limited the recovery of dead turtles as did the difficulty of seeing motionless, oiled small turtles among surface material and oil. In addition, rescue crews were restricted from working early in the spill period, during inclement weather, around the wellhead, and in more distant areas due to logistical constraints and safety concerns.

### Assessment of Degree of Oiling

Once turtles were brought aboard rescue vessels, veterinarians and biologists evaluated their general physical condition, photographed the extent of oil coverage, and examined their mouths for oil (Figure 4.8-8). Eighty percent of these animals were visibly oiled to various degrees (Table 4.8-2). To define the relative degrees of visible oil exposure in sea turtles collected during directed capture operations and other activities, veterinarians reviewed field photographs and field notes to evaluate the extent to which turtles' bodies were externally oiled. Based on this evaluation of visible oiling, veterinarians categorized turtles as not visibly, or minimally, lightly, moderately, or heavily oiled based on the extent of oil coverage (Stacy 2012).



***Source:*** *B. Stacy.*

**Figure 4.8-8.** Assessments of externally oiled sea turtles demonstrated that turtles also ingested oil. Photos: (left) Thick crude oil found in the oral cavity and nares of a rescued Kemp's ridley sea turtle; (right) Thick crude oil coats the inside of the esophagus of a deceased heavily oiled turtle found during rescue operations. Sea turtles have cornified papillae (i.e., thorny projections lining the inside of the esophagus) that prevent ingested prey from moving back toward the mouth, and perform the same function when viscous oil is ingested. Responders had already removed some oil from this esophagus prior to taking the photograph.

**Table 4.8-2.** Numbers of sea turtles documented by directed capture operations during the DWH oil spill response by degree of oil coverage, species, and proportion with oil observed in oral cavity (Stacy 2012). "Unknown" turtles did not have sufficient photographic information to be assigned to oiling categories.

| Species | Not Visibly Oiled | Minimally Oiled | Lightly Oiled | Moderately Oiled | Heavily Oiled | Unknown | Total |
|---|---|---|---|---|---|---|---|
| **Kemp's ridley** | 50 | 141 | 47 | 26 | 51 | 2 | 317 |
| **Green** | 49 | 112 | 36 | 17 | 6 | 0 | 220 |
| **Loggerhead** | 6 | 5 | 2 | 3 | 2 | 0 | 18 |
| **Hawksbill** | 5 | 8 | 2 | 1 | 2 | 1 | 19 |
| **Total** | 110 | 266 | 87 | 47 | 61 | 3 | 574 |
| **Oil in oral cavity** | Not evaluated | 49% | 76% | 93% | 97% | | |

Minimally and lightly oiled turtles had relatively little visible oil on their bodies, whereas moderately and heavily oiled turtles were more extensively covered in thicker, tenacious oil. Heavily oiled turtles were essentially completely covered and heavily mired in oil. Among oiled turtles, approximately 58 percent were minimally oiled, 19 percent were lightly oiled, 10 percent were moderately oiled, and 13 percent were heavily oiled (Figure 4.8-9; Table 4.8-2). Nearly all heavily oiled turtles were found within 90 kilometers (straight-line distance) around and to the west of the DWH platform (Figure 4.8-7). The degree of external oiling decreased among captured turtles from the end of July 2010 through cessation of directed capture efforts in September 2010, coinciding with the apparent dissipation of oil from surface habitats following capping of the well and the end of free-release oil discharge into the Gulf.

Furthermore, veterinarians evaluated the amount of oil observed in oral and nasal cavities of live and dead turtles relative to the categories of visible, external oiling (Figure 4.8-8; (Mitchelmore et al. 2015; Stacy 2012)). Ingested oil was found within the mouth, pharynx, and esophagus during oral examinations and necropsies. Oil was ingested via contaminated dietary items or by direct ingestion of aggregated oil that was mistaken for food. Oil adhered to the internal surfaces of turtles' mouths and throats, and required considerable effort to remove in sea turtles brought into rehabilitation centers for de-oiling (Figure 4.8-8). In addition, feces from oiled turtles brought into rehabilitation centers often produced a sheen and included globules of oil-like material.

The extent of oil ingestion was further characterized in dead oiled turtles that were necropsied. Esophagi of these turtles were found to be heavily coated with oil and oil was also found through digestive tracts, consistent with the defecation of oil observed in the live turtles. Oil adhered to the lining of the esophagus was a continuous source of continued exposure for days, possibly longer, following initial ingestion. The percentage of turtles in each oiling category that had oil in their oral cavities, as well as the volume of oil present, increased with the degree of external oiling (Table 4.8-2) (Mitchelmore et al. 2015; Stacy 2012). Even very lightly oiled turtles had an almost 50 percent occurrence of ingestion.

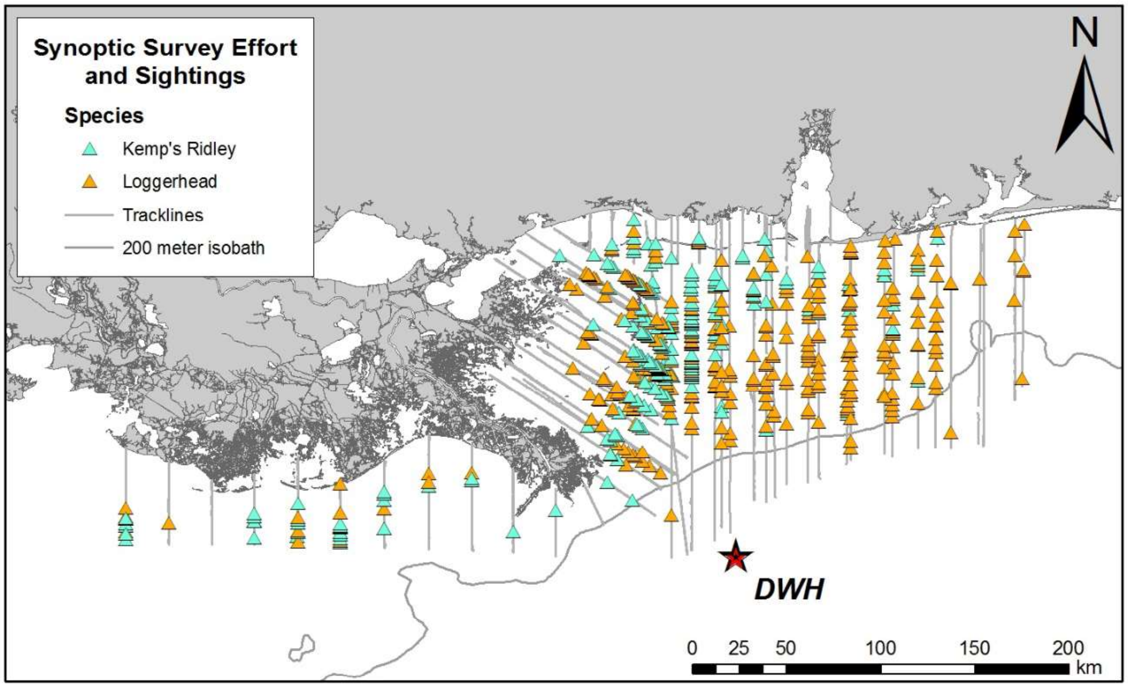

***Source:*** *B. Stacy.*

**Figure 4.8-9.** Photographs of turtles in each oiling category defined by extent of external oiling**.** Percentages of turtles documented in each category relative to all turtles assessed are shown next to representative photograph of each oiling category.

These observations were further corroborated by chemical analyses of turtle tissues. Indicators of PAH exposure were higher in tissues (e.g., liver, lung, esophagus), colon content, stomach content, and feces collected from visibly oiled turtles compared to those collected from non-visibly oiled turtles. PAH compositions were consistent with those of weathered DWH oil (Ylitalo et al. 2014). A chemical constituent of dispersants used for detecting exposure was not found in most analyzed samples, but was observed in high concentrations in ingested oil from a turtle found offshore where most dispersant applications occurred (Ylitalo et al. 2014).

#### 4.8.3.3.2 Observations of Turtles on Continental Shelf and on Beaches

The Trustees conducted aerial surveys throughout the northern Gulf of Mexico on the continental shelf (to the 200-m isobath) in 2010 and again in 2011 to locate and count larger juvenile and adult sea turtles at the surface (Figure 4.8-10; (Garrison 2015)). These surveys were designed to allow for calculation of estimates of turtle abundance across the survey area throughout the study period, and subsequently for calculation of overall abundance estimates. Overall, the Trustees surveyed more than 18,000 linear kilometers along nearly 250 transects, and searched more than 6,600 square kilometers of total area between 28 April and 2 September 2010. In 2011, the Trustees flew approximately 56,000 kilometers and searched nearly 23,000 square kilometers between spring of 2011 and winter of 2012 (Garrison 2015).




***Source**: Garrison (2015).*

**Figure 4.8-10.** The Trustees flew aerial surveys to document locations of sea turtles within the DWH oil spill footprint. Triangles indicate all sightings of Kemp's ridleys (blue; n=287 turtles) and loggerheads (orange; n=529 turtles) along all survey transect lines flown systematically from April through September 2010. The location of the wellhead is indicated by the star symbol.



Aerial survey observers could only see turtles larger than approximately 40 centimeters in length, which omitted small juvenile Kemp's ridleys approximately 3 years of age that inhabit continental shelf areas (Avens & Snover 2013). Because these turtles also would not have been in surface habitats targeted by the vessel operations described in Section 4.8.3.3.1 (Directed Captures and Observations of Oiling in Offshore Areas), an alternative approach was used to estimate their abundance and exposure (see Section 4.8.5, Injury Quantification for details).

More than 800 turtles were documented during aerial surveys in 2010. Turtles were present throughout continental shelf waters from April through September, and consistently within the DWH oil footprint. Observations of loggerheads and Kemp's ridleys declined from spring into summer, and then increased again in the fall. High numbers of observations were documented for both species in the eastern portion of the study area between the Chandeleur Islands (Louisiana) and off the coasts of Mississippi, Alabama, and the Florida panhandle (Figure 4.8-10). An additional area with high numbers of observations for Kemp's ridleys occurred to the west of the Mississippi River Delta (Figure 4.8-10). These areas are generally similar to high-use areas identified by satellite tracking studies of adult female loggerheads and Kemp's ridleys following nesting seasons (Figure 4.8-11; (Hart et al. 2012; Hart et al. 2014; Shaver et al. 2013)), and consistent with observations from surveys in 2011 (Garrison 2015). Turtles were observed and photographed in surface oil slicks during aerial surveys. Density and abundance estimates were calculated using these observational data and environmental habitat models (see Section 4.8.5, Injury Quantification).

Biologists also satellite-tracked dozens of adult female loggerhead and Kemp's ridley turtles across several years, including 2010, to identify high-use areas (Figure 4.8-11; (Hart et al. 2012; Hart et al. 2014; Shaver et al. 2013). Loggerheads that nested in the eastern Gulf of Mexico, including the panhandle of Florida and in Alabama, used foraging areas in the northern Gulf of Mexico throughout 2010, and these were also high-use areas in the years before and after the DWH oil spill (Hart et al. 2012; Hart et al. 2014). Similarly, adult female Kemp's ridley turtles migrated to and from foraging areas throughout the continental shelf of the northern Gulf of Mexico, and demonstrated foraging site fidelity across foraging seasons (Shaver et al. 2013). These results show that areas identified as important and highly used by both species significantly overlapped with areas of known oil presence.

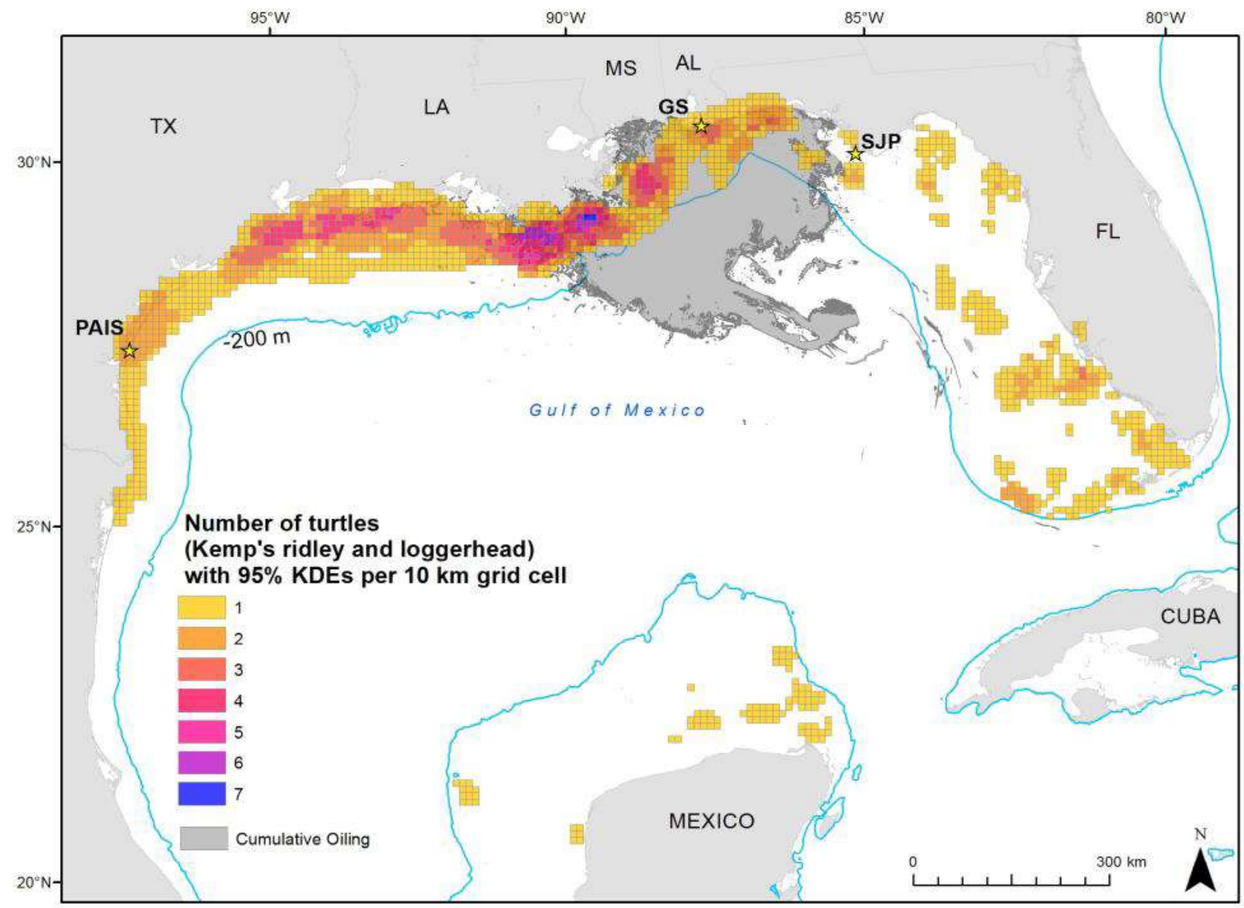



**Figure 4.8-11**. High-use areas of adult female Kemp's ridleys (n=20 turtles) and loggerheads (n=39 turtles) in the northern Gulf of Mexico determined using satellite telemetry overlapped with the DWH oil footprint. High-use areas are defined as 95 percent kernel density estimates, which is a statistical summary of where turtle locations are concentrated in space. Colors indicate the number of turtles per grid cell, and the data include turtles tracked between 2010 and 2013. Tagging locations were nesting beaches indicated by stars: Padre Island National Seashore, Texas (PAIS), Gulf Shores, Alabama (GS) and St. Joseph Peninsula, Florida (SJP).

### Stranded Turtles on Beaches

Surveillance of coastlines for stranded sea turtles was enhanced during and following the DWH spill. Searchers documented stranded turtles and veterinarians performed postmortem examinations to the extent allowed by postmortem condition (Stacy 2012; Stacy & Schroeder 2014). Among the 644 stranded turtles found in 2010, 24 (3.7 percent) were visibly oiled, and 16 oiled stranded turtles (> 66 percent of oiled turtles) were confirmed to have been oiled by MC252 oil (Stacy 2012; Stout 2014). Most of the oiled stranded turtles were small juveniles of the same size class targeted by the directed capture operations (Stacy 2012). The rest of the strandings were mainly larger juvenile turtles (predominantly Kemp's ridleys) (Stacy 2012). Analyses of biological samples collected from a subset of non-visibly oiled stranded turtles did not suggest recent exposure to petroleum or dispersant-associated compounds (Ylitalo et al. 2014).

As further discussed in Section 4.8.5 (Injury Quantification), strandings are a poor indicator of oil exposures that occurred in much of the DWH spill area as they generally are not representative of events occurring further from shore or in areas where turtles were unlikely to be found (e.g., wetlands) (Epperly et al. 1996; Hart et al. 2006; Nero et al. 2013; Williams et al. 2011). Many turtle carcasses may sink and never resurface, decompose, be scavenged, drift away from shore, or reach a coastline, but not be detected by observers (see strandings graphic in Chapter 1, Introduction). The few oiled turtles that were documented as strandings likely represent the very rare occasions where turtles originating from deeper and/or more distant waters reach shore. Of the few that are found stranded, most were too decomposed to determine cause of death (Stacy 2012).



### Potential Exposure of Nesting Turtles, Their Eggs, and Hatchlings

Oil reached Gulf shorelines in early summer 2010, including sand beaches that host nesting female sea turtles and their eggs and hatchlings. Terrestrial life stages of sea turtles were potentially exposed to oil on beaches through direct contact and maternal transfer of oil compounds to developing eggs embryos. As discussed in Section 4.8.4 (Injury Determination), many eggs laid within the spill area were translocated to avoid hatchlings being killed by oil as they swam into the Gulf. Tissue samples were collected from nesting female sea turtles, eggs, and hatchlings in 2010, 2011, and 2012 for chemical and biological analysis to detect exposure and any subsequent physiological, developmental, and toxicological effects. Specifically, the Trustees evaluated PAH concentrations, blood chemistry, sex ratios, and immunological function to determine exposure and impairment of nesting female sea turtles and their eggs and hatchlings. Given the many complexities of response operations and translocation of nests during the oil spill, very little sampling was done during the actual nesting season in 2010. Studies of nesting females, eggs, and hatchlings in subsequent years primarily focused on Kemp's ridleys in Texas and were aimed at detection of ongoing exposure and effects. None of these studies yielded evidence of exposure to DWH oil; however, the limited scale of sampling, uncertainty about application of methods to sea turtles, and the variability in exposure probability among animals that forage in different areas may have prevented detection of possible oil exposure of nesting female sea turtles (Hooper & Schmitt 2015).

#### 4.8.3.4 Summary of Exposure Determination

The Trustees' exposure determination included:

1. Direct observation of approximately 1,800 turtles within the DWH oil spill footprint;
2. Direct observation, analytical chemistry, and remote sensing that confirmed that turtles were exposed to DWH oil;
3. Assessments of exposure pathways based on veterinary examinations and clinical evaluations.

In the next section, we present the Trustees' determinations of the nature and extent of injuries to sea turtles resulting from these exposure pathways.

### 4.8.4 Injury Determination



**Key Points**

- The Trustees concluded that sea turtles throughout the northern Gulf of Mexico suffered adverse effects, including death, from DWH oil exposure and response activities.
- Miring in oil and exposure to oiled surface habitat caused significant harm to sea turtles, including decreased mobility, exhaustion, dehydration, overheating, likely decreased ability to feed and evade predators, and death.
- The Trustees determined that chronic toxic effects of oil and indirect sub-lethal effects on reproduction and health likely resulted in injury, though these effects are less well-understood.
- Response actions undertaken to remove oil from the beaches and the ocean resulted in direct injuries to turtles in all areas of the northern Gulf of Mexico. Translocation of eggs from the Gulf of Mexico to the Atlantic coast of Florida resulted in the loss of sea turtle hatchlings.
- Other response activities, including vessel strikes and dredging also resulted in turtle deaths.

As presented in Section 4.8.3 (Exposure), sea turtles were exposed to DWH oil via several pathways. This section describes the Trustees' assessments of adverse physical and toxicological effects resulting from those exposures. Overall, the Trustees concluded that conditions resulting heavy oiling presented a clear and eminent threat to sea turtles, and increased probability of mortality. This determination is based on the Trustees' conclusions of increased adverse effects from physical fouling in oil, toxicity of oil, and contamination of turtle prey and foraging habitat. The Trustees also determined that turtles were injured by response activities such as cleanup operations on oiled beaches, translocation of eggs from Gulf beaches to the Atlantic coast of Florida, and by activities in marine areas such as dredging and response-related boat traffic.

### 4.8.4.1 Physical Effects

#### 4.8.4.1.1 Physical Fouling

Physical fouling in oil caused significant harm to sea turtles. As observed directly during the rescue of small juvenile turtles from surface oil and described in Section 4.8.3.3.1 (Directed Captures and Observations of Oiling in Offshore Areas), physical fouling had the most readily apparent, immediate effect of oil on sea turtles. The conditions from which heavily oiled turtles were rescued were extremely grave; turtles were unlikely to have survived without intervention (Figure 4.8-12; (Stacy 2012)). Therefore, the Trustees concluded that any turtle that became heavily oiled but was not rescued would have died.


***Source:*** *B. Witherington (top left), B. Stacy (top right, bottom).*

**Figure 4.8-12.** Photographs showing the debilitating effects of physical fouling of oil on sea turtles. Top left: thick, viscous oil on the surface made detection and capture of a small juvenile sea turtles difficult; Top right: This heavily oiled, small juvenile sea turtle would not have survived without rescue and rehabilitation because the heavy, viscous oil impeded its movement and its ability to feed and escape predators; Bottom right: heavily oiled turtles were at risk of aspirating oil as shown in this turtle found stranded in Louisiana. A clump of brown oil is present within the trachea (windpipe); Bottom left: when at the surface to breathe, rest, or feed, sea turtles were exposed to lethally hot temperatures with dark oil present.

Miring in oil impeded movement and diving ability, risking physical exertion and dehydration aggravated by hyperthermia (overheating) from contact with thick, dark, hot oil under summer conditions; these effects are fatal if unabated (Figure 4.8-12). The Trustees documented these in both clinical findings in

live oiled turtles and postmortem observations in dead turtles. Upon admission to rehabilitation facilities, blood abnormalities in oiled turtles included nonspecific metabolic and physiological abnormalities attributable to stress, dehydration, and exertion caused by oiling, capture, and transport (Stacy 2012). As expected, the numbers of recovered oiled, dead turtles found offshore or as strandings were low due to a number of factors (see Section 4.8.3.3, Sea Turtles Were Observed in Oil Throughout the Northern Gulf of Mexico). Those that were found and examined provided additional evidence that conditions resulting in heavy oiling were fatal. Asphyxiation by oil and ingestion of large quantities of oil were observed in these turtles (Stacy 2012). Based on these observations, the Trustees concluded that both external and internal exposure to oil was severe for small oceanic juveniles due to the dependence of these animals on surface habitats where oil accumulated (Stacy 2012; Wallace et al. 2015), and that the probability of death increased with degree of oiling (see Section 4.8.4.4, Mortality Estimates for Turtles Based on Degree of Oiling) (Mitchelmore et al. 2015). Specifically, heavily oiled, small juvenile turtles were expected to die without intervention (Stacy 2012; Wallace et al. 2015). The Trustees also concluded that similar concerns about miring in surface oil were warranted for larger turtles exposed to surface oil based on limited observations of impaired, oiled larger turtles during the DWH spill and previous reports of oiling associated with death or stranding (Camacho et al. 2013; Shigenaka 2003).



### 4.8.4.2 Toxic Effects of Oil on Turtles and their Habitats

Relatively few studies in the scientific literature have described adverse physiological toxic effects of oil on sea turtles in detail (see Shigenaka 2003 for review). Most readily apparent observations of turtles affected by oil have been attributed to physical effects resulting from miring or obstruction of the mouth or digestive system. A laboratory study that examined physiological and health effects of oil on sea turtles found oil in turtles' nares (i.e., external openings of turtles' nasal cavities), mouths, around their eyes, and in feces, indicating that turtles were ingesting oil in addition to coming into direct contact with it. This same study also associated exposure with inflammation and sloughing of skin, decreased red blood cell counts, and salt gland dysfunction (Lutcavage et al. 1995). A recent report from the Canary Islands implicated oiling as the principal cause of the stranding of small and large juveniles, and possibly adults, between 1998 and 2011 (Camacho et al. 2013). However, these animals were not oiled during discrete spills; they are described in the context of general regional oil pollution.

DWH oil caused toxic effects on many species across taxonomic groups (Section 4.3, Toxicity). To examine potential toxicity to sea turtles, toxicologists, veterinarians, and sea turtle biologists synthesized NRDA and non-NRDA data on toxic effects of petroleum products on vertebrates and considered results of blood and tissue analyses performed on sea turtles recovered during the DWH oil spill (see Section 4.8.3.3, Sea Turtles Were Observed in Oil Throughout the Northern Gulf of Mexico) and from surrogate turtle species that were subjects of a controlled laboratory experiment to investigate toxic effects of DWH oil ingestion administered orally (Section 4.8.4.2.2, Laboratory Oil Toxicity Study of Surrogate Turtle Species).

#### 4.8.4.2.1 Observations Related to Oil Toxicity Effects on Rescued and Stranded Turtles

As presented in Section 4.8.3.3.1 (Directed Captures and Observations of Oiling in Offshore Areas), the high frequency of oil ingestion observed in oiled turtles and detection of oil-related compounds in tissues and bile demonstrated internal exposure in sea turtles oiled during the DWH spill (Stacy 2012; Stacy & Innis 2012; Ylitalo et al. 2014). Evidence of damage to red blood cells and impaired salt gland

function, as previously reported in loggerheads exposed to crude oil (Lutcavage et al. 1995), was not found (Stacy 2012). Also, histological evidence of organ injury was not observed in the small number of dead oiled sea turtles that were in suitable condition for detailed examination (Stacy 2012).

Cutaneous and oral exposure was inevitably associated with some degree of inhalation exposure as well, as demonstrated by increased PAH concentrations in lung tissues of oiled turtles compared to lung tissues of non-visibly oiled turtles (Ylitalo et al. 2014). Turtles that surfaced to breathe within oil would have inhaled and/or aspirated oil and oil compounds and smoke from burning oil, similar to the inhalation exposure that marine mammals experienced (see Section 4.9, Marine Mammals). Sea turtles would have been exposed to toxic concentrations of oil at the sea surface where sea turtles surfaced to breathe, particularly in offshore areas near the wellhead where small juvenile turtles live and where volatiles were more likely to occur (see Section 4.2, Natural Resource Exposure). Because turtles must hold their breath while swimming, feeding, and diving, oil compounds inhaled into their lungs would be assimilated into their bodies as they use oxygen in lungs, blood, and muscles to fuel underwater activities. Average turtle dive durations last 5–30 minutes, and longer dives can last 30–45 minutes, as in the case of loggerheads, or over an hour for leatherbacks (Hochscheid 2014; Southwood 2013). In addition to duration, increased pressure with water depth may enhance systemic absorption during prolonged dives (Hochscheid 2014). Concentrated exposure caused by dive depth and duration, particularly for larger turtles that actively dive throughout the water column, could affect respiratory and cardiovascular function, and thus hinder turtles' ability to dive efficiently to forage, escape predators, find mates, migrate, etc. (see Section 4.9, Marine Mammals, for discussion of inhalation effects). Although tissue analyses showed elevated PAH concentrations in lungs of oiled turtles (Ylitalo et al. 2014), determination of adverse effects of inhalation or aspiration of oil products on sea turtles was not possible based on available information.

It is important to note that the dose of oil and duration of exposure in sea turtles that were naturally exposed during the DWH spill were unknown, which complicated comparison of blood values and other data with previously available studies of petroleum toxicity in various taxa.



##### 4.8.4.2.2 Laboratory Oil Toxicity Study of Surrogate Turtle Species

In response to the number of uncertain variables associated with the nature, duration, and extent of exposures that sea turtles experienced in oiled habitats during the DWH oil spill, and the paucity of published data on petroleum toxicity to sea turtles (Shigenaka 2003), the Trustees conducted a laboratory study to evaluate the acute toxicological effects of ingested oil on common species of freshwater turtles using known time and dose exposures. The endangered status of sea turtles necessitated the use of the freshwater surrogate species: red-eared sliders (*Trachemys scripta*) and common snapping turtles (*Chelydra serpentina*) (Mitchelmore & Rowe 2015).

Dose-dependent increases in the levels of biliary PAH metabolites demonstrated uptake and metabolism of oil at levels similar to those of sea turtles oiled during the DWH spill (Mitchelmore & Rowe 2015; Ylitalo et al. 2014). The Trustees observed physiological abnormalities including evidence of dehydration and decreased digestive function and assimilation of nutrients, and some measures of oxidative stress and DNA damage also showed changes that were consistent with PAH exposure. In contrast to some other studies of petroleum toxicity in other vertebrates, mortality and damage to red blood cells were not observed. Two red-eared sliders that had received a high dose of oil showed dysfunction of the

hypothalamic-pituitary-adrenal (HPA) axis, which regulates stress response and other vital functions. When all individuals were compared by oil dose treatment, turtles that had received a consistent oil dose showed a dampened HPA response; however, this dysfunction was not statistically significant due to the high variation among individuals ((Mitchelmore & Rowe 2015). Therefore, the effects of experimental oil exposure on red-eared sliders and common snapping turtles did not clearly indicate HPA dysfunction as reported in minks (Mohr et al. 2008), marine mammals (Schwacke et al. 2014), and marine iguanas (Wikelski et al. 2002).

Overall, turtles orally exposed to DWH oil during the surrogate study did not show severe, life-threatening physiological derangements or mortality. The result was consistent with other observations that effects from physical fouling are the most readily apparent consequence of oil exposure in sea turtles. However, surrogate turtles were not dosed for time periods comparable to other studies where such effects were shown in orally dosed vertebrates (e.g., Mohr et al. 2008). Additional factors that are relevant to exposure during oil spills, such as delayed and longer-term effects of these low-dose oil exposures, as well as exposure via multiple routes, also were not part of the study design due to logistical constraints. Taken together, these experimental constraints limited the application of the surrogate study in estimating mortality of wild sea turtles affected by the DWH oil spill (Mitchelmore & Rowe 2015).



### 4.8.4.3 Potential Adverse Effects from Loss of Prey/Habitat

The Trustees documented evidence of potential impacts to sea turtle habitats. Exposure of *Sargassum* to oil and dispersant can cause it to sink to the ocean floor, thus removing essential habitat for oceanic juvenile sea turtles and numerous other organisms (see Section 4.4, Water Column; (Powers et al. 2013)). Approximately 4,000 to 7,000 square kilometers of *Sargassum* was oiled in relation to the DWH oil spill and determined to have been lost to the northern Gulf of Mexico ecosystem (see Section 4.4, Water Column). This loss was significant for small juvenile sea turtles that were already exposed to DWH oil via multiple pathways because it reduced the availability of already patchy and ephemeral refuge areas, thereby likely increasing transit time and energy costs to turtles between available habitats, as well as making turtles more vulnerable to predation (Witherington et al. 2012).

In continental shelf areas closer to shore, post-mortem evaluation of fat content under the carapaces (i.e., top half of the shell) of juvenile Kemp's ridley turtles that stranded dead revealed that body conditions and available fat stores declined after 2010 (Stacy 2015). This observation suggests that turtles have undergone a general decline in nutritional condition, potentially due to their reduced prey availability or quality, reduced ability to find food, or some unknown health effect. In a separate study, changes in chemical markers in carapacial scutes (i.e., the keratinized covering of turtles' shells) of nesting adult Kemp's ridleys suggested that turtles in 2011 and 2012 foraged in different locations than areas used by turtles in 2010 prior to the DWH spill (Hooper & Schmitt 2015). Although the cause(s) of these observations is unknown at this time, a persistent effect on turtle foraging areas and/or prey availability or quality related to the DWH oil spill cannot be ruled out. Furthermore, because sea turtles tend to use the same foraging areas across years (e.g., Shaver et al. 2013), it is plausible that turtles that foraged in or traveled through the DWH oil spill footprint were exposed to oil.

#### 4.8.4.4 Mortality Estimates for Turtles Based on Degree of Oiling

Mortality estimates were developed to quantify total numbers of injured turtles based on relative degrees of oil exposure. Mortality estimates considered three key elements: 1) veterinary assessment of live and dead oiled turtles; 2) toxicological assessment of affects from oil exposure; and 3) the potential for continued, progressive exposure and oiling. Mortality estimates were developed based on degree of oil exposure and for different life stages of sea turtles with consideration of relative risk of exposure. The high survival rate of oiled turtles that were treated in rehabilitation facilities was not considered reflective of the outcome of oiling without medical intervention (Figure 4.8-12; (Stacy & Innis 2012)). The relatively rapid recovery of many of these animals was consistent with the available evidence indicating that physical fouling was one of the more significant immediate consequences of oiling, and that removal of this threat resulted in a positive survival outcome. Therefore, heavy oiling without medical intervention—which would have been the case for the vast majority of turtles exposed to DWH oil—was considered a primary factor with regard to probability of mortality.

##### 4.8.4.4.1 Mortality Estimates for Heavily Oiled Turtles

Veterinarians with specific sea turtle expertise, toxicologists, and sea turtle biologists concluded that physical effects of miring in heavy oil—as seen in heavily oiled turtles—would likely have been lethal (i.e., 100 percent mortality probability for small juveniles). This probability was based on several factors, as described in Section 4.8.4.1 (Physical Effects) and summarized as follows:

- Small juvenile turtles live, breathe, eat, and seek refuge from predators within the top 2 meters of the water column. Additionally, they are incapable of deep diving, and are not powerful swimmers (Witherington et al. 2012). Therefore, the physical miring that the Trustees observed on heavily oiled turtles would have prevented them from escaping or shedding the thick, sticky, heavy oil (Stacy 2012). This heavily oiled condition would have caused death either acutely or chronically.

- Small juvenile turtles that were heavily oiled were lethargic and palpably warm when rescuers pulled them from the ocean during response efforts, and surface oil temperatures were in excess of 120°F (~ 50°C), which is well above the lethal threshold for sea turtles (Drake & Spotila 2002; Jessop et al. 2000).

- Dead and live-stranded, debilitated heavily oiled turtles that would have died without medical intervention provided direct evidence of the lethality of this condition (Stacy 2012; Wallace et al. 2015).

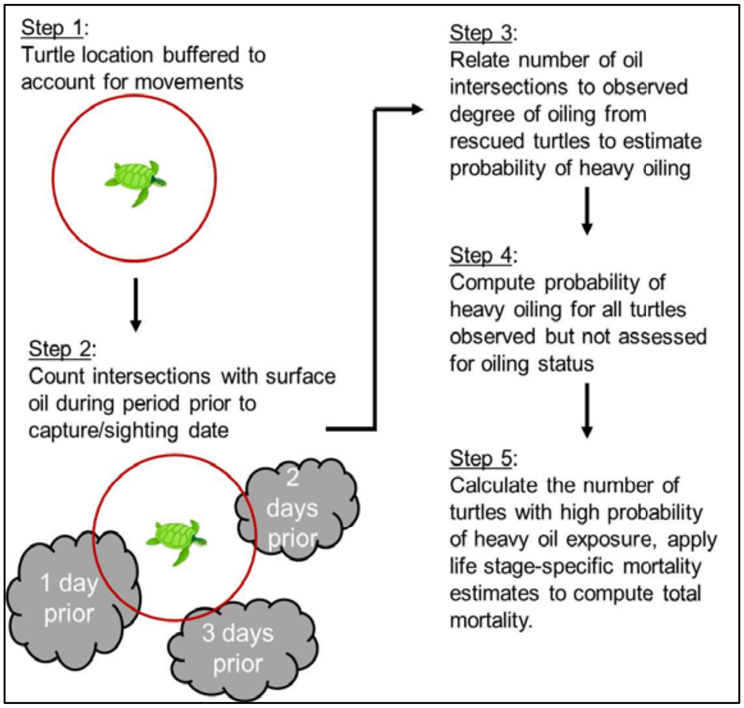
This assessment provided a basis for evaluating mortality estimates for other oiling categories as a function of the probability that they would have become heavily oiled.

###### Probability of Heavy Oil Exposure Based on Spatial and Temporal Proximity to Oil

Field observations and veterinary assessments of small juvenile turtles demonstrated that physical miring in surface oil and oiled surface habitats caused significant harm to sea turtles. Therefore, the Trustees concluded that surface oil conditions in locations and at times when heavily oiled turtles were observed were generally indicative of heavy oil exposure. Therefore, biologists and statisticians developed a model to estimate the probability of turtles being heavily oiled based on remotely sensed

surface oil data in the area around and time preceding a turtle's capture or sighting (Wallace et al. 2015) (Figure 4.8-13).

To calculate these probabilities, each turtle location first was placed within a circle (i.e., a spatially buffered location) to account for the area within which small juvenile turtles presumably moved (Putman & Mansfield 2015) —either while actively swimming or passively drifting in surface currents—during the period prior to being found by searchers. Second, the cumulative number of intersections between a turtle's buffered location and all daily surface oil footprints within three weeks prior to its capture or sighting date was calculated for all turtles. Third, statistical relationships were determined between the surface oil environment in the area and time prior to turtle captures and the observed degree of oiling of those rescued turtles. Fourth, the Trustees then applied this relationship to all turtles that were observed, but not directly assessed, by using surface oil conditions associated with where and when turtles were observed to predict their estimated degrees of oil exposure (Wallace et al. 2015).




***Source**: Wallace et al. (2015).*

**Figure 4.8-13.** Schematic of the modeling approach to estimate probability of heavy oil exposure based on the relationship between surface oil in the area and time prior to turtle captures and their observed degree of oiling. Description of steps appears in the text.

In this way, the number of intersections with surface oil—i.e., proximity in time and space—provided a measure of persistence of surface oil, and thus a relative probability of oil exposure, for a turtle in a certain area at a certain time. This approach has the important advantage of combining ubiquitous, reliable data—i.e., satellite-derived measurements of surface oil and empirical observations of the extent of oiling on sea turtles—to statistically estimate the probability of heavy oil exposure in cases where the former data type is available, but not the latter (Wallace et al. 2015). This approach was used in injury quantification (Section 4.8.5, Injury Quantification) to estimate probability of heavy oiling for turtles and areas within the cumulative DWH footprint.

In the final step, the Trustees computed the numbers of turtles with high probabilities of being heavily oiled for small juveniles captured or sighted during rescue operations (Section 4.8.3.3.1, Directed Captures and Observations of Oiling in Offshore Areas), as well as for large juveniles and adults observed within the DWH oil spill footprint during aerial surveys (Section 4.8.3.3.2, Observations of Turtles on

Continental Shelf and on Beaches). These probabilities of heavy oil exposure were used to estimate the total numbers of turtles that were heavily oiled as a result of the DWH oil spill (see Section 4.8.5, Injury Quantification), and therefore died.

It is worth noting a few important assumptions of this approach that influenced the probability of turtles being heavily oiled. First, the surface oil data used in the model did not include any information about relative thickness of oil in time and space. Therefore, the correlation between proximity of surface oil and the degree of oiling observed on turtles was based solely on the presence of oil on the surface of the ocean in a given place and time. Second, the model counted the number, not the extent or degree, of intersections between a turtle location and surface oil. Third, because the model was fitted to the relationship between surface oil and observed degree of oiling of small juveniles, it also assumed that, when estimating probabilities of heavy oiling for larger turtles, that the processes by which heavy oil exposure occurred were comparable for larger turtles and smaller turtles.

However, the Trustees concluded that these were reasonable assumptions because 1) surface oil and observed degree of oiling showed a significant positive relationship, which indicated that surface oil represented other factors—such as oil thickness— that likely influence turtle oiling (Wallace et al. 2015), and 2) all turtles—regardless of size—must spend significant time at the surface, and while at the surface in areas that also had oil consistently present, turtles would have been exposed.



##### 4.8.4.4.2 Mortality Estimates for Turtles That Were Exposed, But Not Heavily Oiled

The majority of turtles documented were not heavily oiled but were assigned to oiling categories that were less severe, either by veterinary assessment of external oiling or by the model described above. Nonetheless, these turtles were exposed to oil externally and internally ((Stacy 2012); Section 4.8.3.3.1, Directed Captures and Observations of Oiling in Offshore Areas). To estimate the risk of mortality for this group, veterinarians examined various clinical, hematological, and blood chemistry endpoints that have predictive value in terms of survival outcome (Stacy & Innis 2012). Similar prognostic approaches are used in humans and other animals, including sea turtles (Knaus et al. 1985; Koterba & House 1996; Stacy et al. 2013). A series of prognostic scoring models using this approach yielded relatively similar results showing that a substantial proportion of oiled turtles had clinically significant physiological abnormalities with predicted mortality rates between six percent and 22 percent (mean of 14 percent) without treatment based on physiological effects alone (Stacy et al. 2013). This predicted outcome did not include risk of mortality from ongoing exposure to oil and toxicity, which was likely had those turtles not been rescued from their oiled environment (Stacy et al. 2013).

Toxicologists considered potential toxic effects of oil exposure in oiling categories that were less than heavily oiled (Mitchelmore et al. 2015). To develop ranges of mortality estimates for the turtles in lower oiling categories, toxicologists considered the estimated levels of ingested oil in wild juvenile sea turtles, together with scientific literature on the adverse effects of oil exposure to other vertebrate species (e.g., Mohr et al. 2008; Schwacke et al. 2014), and results of the laboratory toxicology study of freshwater turtles (see Section 4.8.4.2.2, Laboratory Oil Toxicity Study of Surrogate Turtle Species; (Mitchelmore & Rowe 2015)). Other factors that were considered included persistent or sub-lethal effects from physical impairment (e.g., reduced fitness and implications on foraging and predator avoidance) and potential chronic toxicological effects resulting from alimentary, dermal, and inhalational exposure to oil that have been demonstrated in well-studied vertebrate taxa (Mitchelmore et al. 2015). The potential

impacts of chemical dispersant applications in the DWH spill zone were considered as an additional, but unknown, toxicological risk for sea turtles. Mortality estimates were developed for each non-heavy oiling category, and then combined into a single estimate for all turtles assigned or estimated to belong to non-heavy oiling categories.

#### 4.8.4.5 Summary of Mortality Estimates

Table 4.8-3 presents a summary of mortality estimates for sea turtles by life stage and by degree of oiling. As described above, heavily oiled, small juvenile turtles were assigned a mortality probability of 100 percent.

**Table 4.8-3.** Summary of mortality estimates for sea turtles by life stage and by degree of oiling (Mitchelmore et al. 2015). Estimate for less than heavily oiled small juveniles is a weighted average of mortality estimates for turtles in all non-heavily oiled categories, including those that were not visibly oiled.

| | Mortality Estimates | |
|---|---|---|
| Sea Turtle Life Stage | Heavily Oiled | Less Than Heavily Oiled |
| Small juveniles | 100% | 30% |
| Large juveniles and adults | 10–20% | 5% |

Small juvenile turtles that were exposed at levels less than heavily oiled were assigned a mortality probability of 30 percent (Table 4.8-3). This value was derived from an assessment by a panel of three toxicologists that used information including the proportion of captured turtles in different oiling categories with oil present in their oral cavities (Table 4.8-2) as well as estimations of the amount of oil in the oral cavities of those turtles (Mitchelmore et al. 2015). These observations were converted to estimated oral doses of oil for turtles in the different oiling categories. The dosing estimations were then used to assess the likelihood of significant injury, primarily to the HPA axis (Mohr et al. 2008; Schwacke et al. 2014), that could result in mortality, depending on the degree of external oiling, and without veterinary intervention. Also considered within this estimate is the mortality range predicted based on the degree of physiological alteration observed in oiled turtles upon admission to rehabilitation facilities (Stacy 2012).

More specifically, the toxicology panel’s consensus was that minimally, lightly, and moderately oiled turtles would have experienced mortality rates of 25 percent, 50 percent, and 85 percent, respectively (Mitchelmore et al. 2015). These percentages were derived from comparisons of the estimated oral doses of oil in wild turtles in different oiling categories to the oral doses of oil that caused severe disruption of the HPA axis in laboratory studies of other vertebrates (primarily mink) (Mohr et al. 2008), and an assumption that such disruption would likely result in mortality in small juvenile sea turtles. Using the numbers of turtles in each of these categories as reported in Table 4.8-2, and assuming that no non-visibly oiled turtles died due to oil exposure, the toxicologists calculated the overall proportion of estimated dead turtles relative to total turtles observed across all non-heavily oiled categories. Following this procedure, the toxicologists estimated that the overall proportion of dead turtles relative to total turtles observed across all non-heavily oiled categories would have been 30 percent. This estimate reflected common areas of concern among experts, similarity of estimates produced by

different approaches under this assessment, and the findings from the surrogate turtle toxicity study (Mitchelmore & Rowe 2015).

Nonetheless, considering 1) that the surrogate turtle toxicity study did not show severe, life-threatening physiological derangements, including HPA dysfunction, or mortality from the levels of oil exposure observed in field-collected turtles (Mitchelmore & Rowe 2015), and 2) oiled turtles that were rescued did not show consistent oil-induced adverse effects upon arrival to rehabilitation centers that could be clearly separated from confounding effects of prolonged transport handling stress (Stacy & Innis 2012), this mortality estimate for non-heavily oiled turtles represents the high end of reasonable values.

To assign mortality estimates to larger juvenile and adult turtles in continental shelf areas, the Trustees concluded that the same processes that could lead to an oceanic turtle becoming heavily oiled would also apply to neritic turtles, and that the methods by which risk of oiling was estimated for oceanic turtles—relationships between surface oil data and direct observations of oiled animals—were also applicable to neritic turtles. Simply stated, probability of oiling was based on spatio-temporal distribution of oil relative to where turtles were either captured or sighted (Wallace et al. 2015). However, the Trustees accounted for behavioral differences between small and large turtles in terms of relative likelihood of exposure to surface oil. Although subsurface exposure was certainly a concern as well, observational evidence of turtle exposure to DWH oil was predominantly related to oil at or near the surface. Small turtles spend more than 80 percent of their time at the surface, whereas large turtles are at the surface roughly 10 percent of the time (Bolten 2003; Garrison 2015; Southwood 2013).



Therefore, mortality estimates applied to small juvenile turtles were scaled lower for larger turtles to reflect this proportional difference in probability of surface oil exposure and resulting mortality (Wallace et al. 2015). Large turtles that were exposed to surface oil conditions similar to those associated with heavy oiling of juvenile turtles were assigned to a high oil exposure category with an associated mortality probability of 10–20 percent. Larger turtles in the lower oil exposure category (i.e., turtles that experienced oil conditions similar to small turtles that had been assigned to intermediate oiling categories) had a mortality probability of five percent (Table 4.8-3; (Wallace et al. 2015)).

These mortality estimates might underestimate the adverse effects of surface oil exposure on large juvenile and adult sea turtles. Reports of stranded, oiled larger turtles indicate that effects can be significant and multi-systemic (Camacho et al. 2013; Shigenaka 2003). Notably, the only heavily oiled neritic juvenile encountered during DWH directed capture operations was found floating with the lateral edge of its carapace and a front flipper above the surface, a condition that did not bode well for survival without intervention (Witherington 2015 personal communication). Furthermore, it is possible that these neritic turtles would also be exposed to oil via numerous exposure routes (e.g., prey ingestion, inhalation, etc.), but also to sub-surface oil and oil/dispersant mixtures, which was an exposure scenario not considered for the oceanic turtles.

On the other hand, the Trustees did not have direct observations of how and to what extent exposure to oil at the surface affected heavily oiled large juveniles and adults (except for the single individual described above). It is possible that large juvenile and adult turtles were less susceptible to adverse effects of heavy oil exposure or to becoming heavily oiled in the first place. For example, in addition to the reduced time that these turtles spend at the surface compared to small juvenile turtles, they are

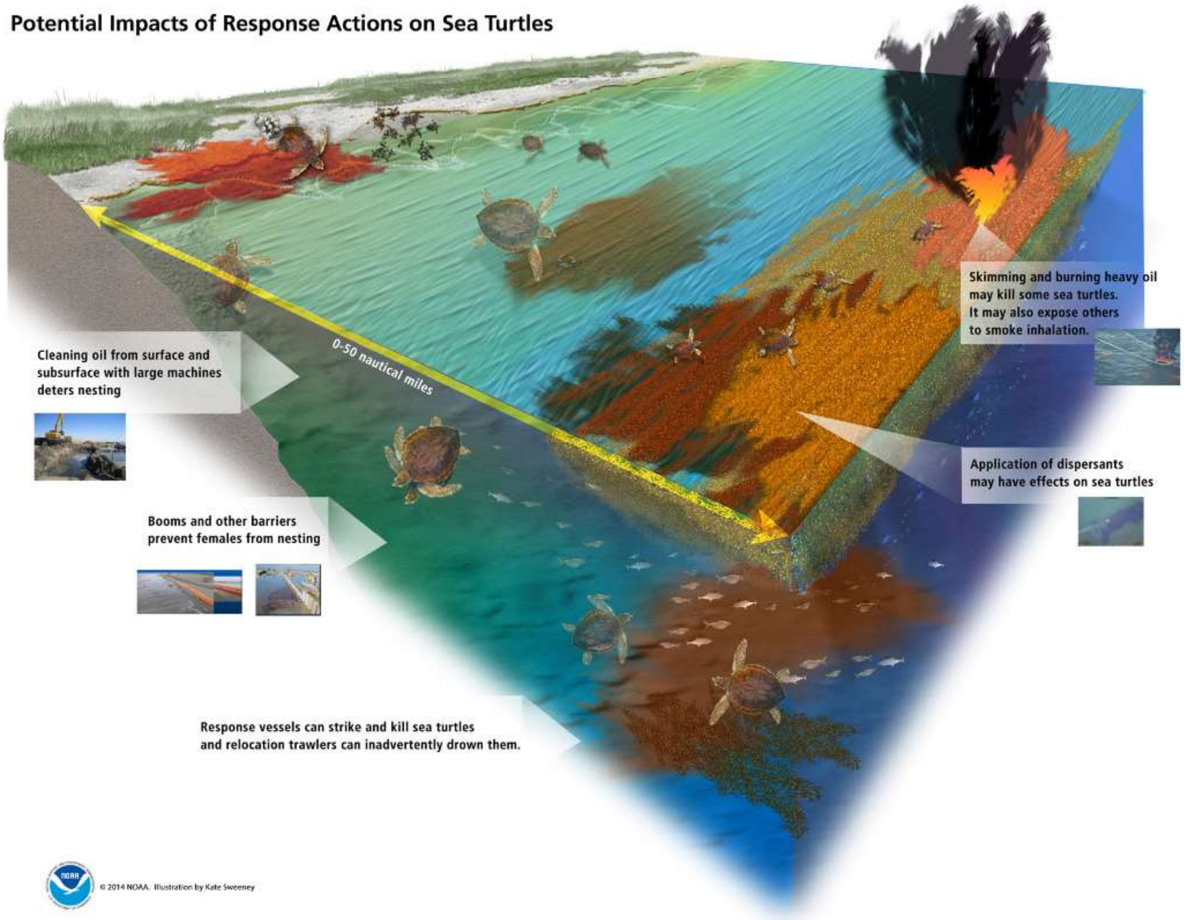
larger in size and stronger swimmers, and therefore were likely more capable of moving away from contaminated areas and potentially avoiding severe oil exposures. These factors might have made large juvenile and adult turtles less susceptible to oil exposure and injury. The Trustees took all of these factors into account, and concluded that the values shown in Table 4.8-3 were reasonable given the strength of evidence about adverse effects related to exposure to surface oil.

#### 4.8.4.6 Injuries to Turtles Caused by Response Activities

The Trustees determined that turtles were injured by response activities that occurred in marine and terrestrial areas (Figure 4.8-14). In marine areas, response activities that injured turtles included relocation trawling, dredging, and response vessel traffic in nearshore areas where turtles were abundant during the spring and summer (Garrison 2015). Injuries resulting from vessel strikes were one of the most common traumatic injuries observed in stranded turtles within the response area (Stacy 2012, 2015; Stacy & Schroeder 2014). In addition, turtles were likely killed during other response activities such as oil skimming and burning operations, which were primarily conducted in more heavily oiled areas and are an additional justification for the high mortality assigned to sea turtles within these areas.

Over 320 kilometers of sand beach coastline that support sea turtle nesting were oiled by the DWH spill or affected by response activities (Michel et al. 2015). Turtles were injured in terrestrial areas by response activities, including beach cleanup operations and associated increased human presence, increased lighting at night on and near nesting beaches, and translocation of nests in the northern Gulf of Mexico to avoid direct contamination of hatchlings (Michel et al. 2015; Provancha & Mukherjee 2011). The DWH oil spill occurred at the onset of the nesting season for sea turtles in the northern Gulf. To prevent hatchlings from emerging from northern Gulf nests and entering oil-filled northern Gulf waters, and to avoid their risk of being killed by beach response activities, sea turtle nests were excavated and eggs were translocated to the Atlantic Coast of Florida. The Trustees determined that hatchlings that emerged from these translocated eggs were injured because it is unknown whether those individuals will return to the Gulf of Mexico and fulfill their role in the Gulf ecosystem (Provancha & Mukherjee 2011).

Additionally, the Trustees determined that fewer loggerhead nests were observed in 2010 in the Florida Panhandle than were expected when compared to previous and subsequent years at those beaches and others outside of the impacted area (see Section 4.8.5.2, Quantification of Sea Turtle Injuries Caused by DWH Response Activities). This decline in loggerhead nesting was attributed to disturbance to nesting female turtles related to response activities on beaches (Cacela & Dixon 2013; Michel et al. 2015).

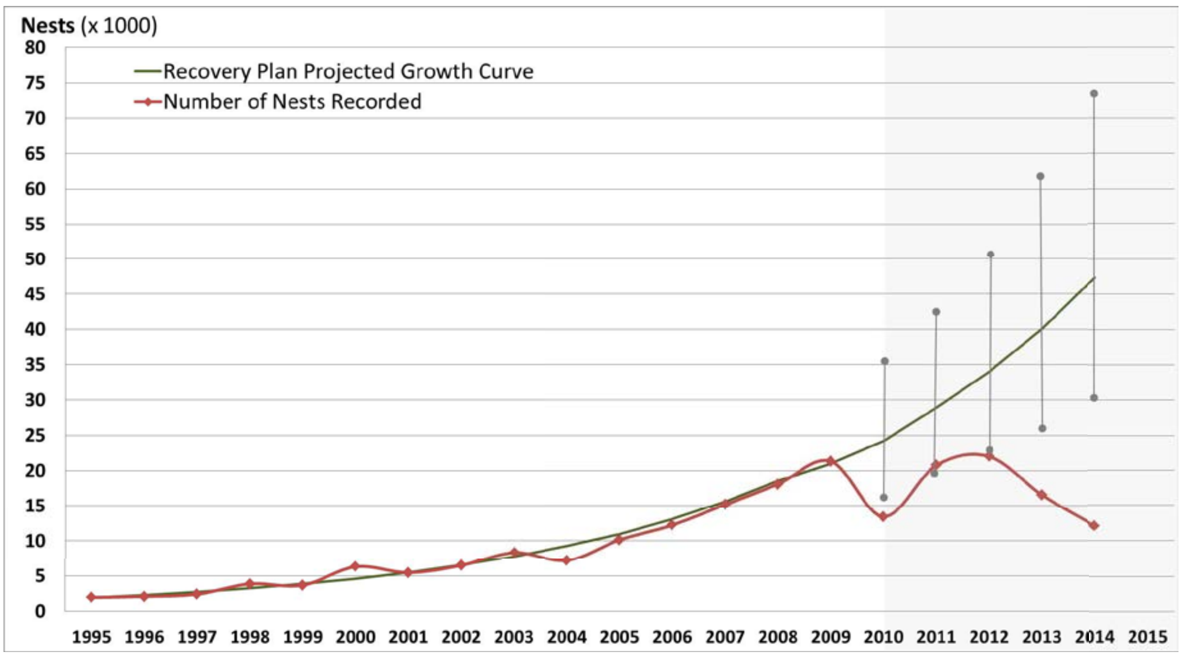



***Source**: Kate Sweeney for NOAA.*

**Figure 4.8-14.** Potential injuries caused by DWH response activities. Text boxes describe specific activities and potential impacts on sea turtles throughout the northern Gulf of Mexico.

### 4.8.4.7 Reduced Kemp's Ridley Nesting Abundance and Hatchling Production

Kemp's ridley turtles are listed as Endangered under the ESA and have the most restricted nesting distribution of all of the sea turtles species (Wallace et al. 2010). Nesting occurs in the western Gulf of Mexico from Veracruz, Mexico, north along the Texas coast to Bolivar Peninsula, but more than 90 percent of annual nesting occurs near Rancho Nuevo in Tamaulipas, Mexico (NMFS et al. 2011). After the population declined from tens of thousands of nesting females in the 1960s to only a few hundred in the 1980s, nest numbers began increasing following intensive conservation efforts. Between 1996 and 2009, numbers of nests increased at approximately 18 percent per year (Figure 4.8-15; (Crowder & Heppell 2011; Gallaway et al. 2013; NMFS et al. 2011)). However, between 2010 and 2014, annual numbers of nests were estimated to be between 8,000 and 35,000 nests lower than expected based on the population trajectory prior to 2010 (Dixon & Heppell 2015). As a result, the Trustees initiated an evaluation of the observed nesting decline and its relationship to the DWH spill.




***Source**: Chip Wood.*

**Figure 4.8-15.** Kemp's ridley annual nest abundance increased exponentially between 1996 and 2009, but has not reached projected abundance since 2010 (Dixon & Heppell 2015). The green line shows the estimated nesting trend from 1996 to 2009 continuing to the present, whereas the red points and line show observed nest abundance for the same time period. Vertical grey bars are 95 percent credible intervals around projected nest numbers. Between 1996 and 2009, annual Kemp's ridley nest abundance increased approximately 18 percent per year due to conservation measures that protected turtles from fisheries bycatch and from human consumption of eggs and nesting turtles. However, starting in 2010, nest abundance failed to reach projections based on the previous increasing trends, and it has remained below projected levels in recent years. Although DWH oil was unlikely to have had an impact on Kemp's ridley nesting abundance in 2010, it is likely DWH oil contributed to some unquantified extent to the observed reduction in projected nesting after 2010.

DWH oil did not arrive on the continental shelf of the northern Gulf of Mexico until late May or early June 2010. By that time, adult Kemp's ridley turtles that were going to breed in 2010 would likely have

already departed the northern Gulf for their breeding and nesting areas in the western Gulf. Therefore, DWH oil was unlikely to have had a direct impact on Kemp's ridley nesting in 2010. However, DWH oil could have contributed to the reduced numbers of nests in subsequent years (2011–2014) through direct and indirect pathways. For example, adult Kemp's ridley turtles that were not breeding in 2010, as well as subadults that would have recruited to the breeding population in 2011–2014, were among the Kemp's ridley turtles present on the continental shelf in 2010 and potentially killed by DWH oil exposure (see Section 4.8.5.1.2, Exposure and Injury Quantification of Large Juvenile and Adult Sea Turtles in Continental Shelf Areas; (Garrison 2015)). The loss of these animals would have affected the overall Kemp's ridley turtle nesting trajectory in subsequent years.

In addition, DWH oil was present in areas that have been identified as vital Kemp's ridley turtle migration and foraging areas (Shaver et al. 2013). Some indirect measures—chemical markers in nesting Kemp's ridley turtle tissues and changes in habitat use (Hooper & Schmitt 2015)—suggest possible behavioral responses to altered foraging area quality, perhaps related to DWH oil. Therefore, it is possible that DWH effects—in addition to other anthropogenic factors and environmental conditions—contributed to the observed reduction in Kemp's ridley turtle nesting, and associated hatchling production after 2010 (Crowder & Heppell 2011; Gallaway et al. 2013). The actual nature and magnitude of a DWH effect on Kemp's ridley turtle nesting abundance requires further evaluation.

#### 4.8.4.8 Summary of Injury Determination

As described in this section, sea turtles were injured by adverse physical effects (e.g., decreased locomotion, decreased ability to feed and evade predators, and hyperthermia) related to miring in oil and exposure to harmful conditions in oiled surface habitat. Contributing to this injury are less understood, but nonetheless concerning, toxicological effects of exposure to oil, dispersants, and oil-dispersant mixtures. These effects are based on a significant body of literature on toxicity in other taxa and involve basic biological and physiological mechanisms present in sea turtles as well. The Trustees identified several additional concerns related to persistent or chronic effects, including those associated with subsurface exposures and unobserved effects on prey or habitat. These factors were insufficiently understood to include in a quantitative assessment.

Mortality probabilities for sea turtles that were subject to different degrees of oil exposure were developed based on relative risk of becoming heavily oiled within the spill footprint and based on a comprehensive assessment of NRDA and non-NRDA data sources relevant to veterinary and toxicological assessment (Table 4.8-3). These mortality estimates were then used in injury quantification to calculate the total numbers of turtles that were killed by DWH oil exposure (see Section 4.8.5, Injury Quantification). In addition, the Trustees determined that sea turtles were injured by response activities in their marine and terrestrial habitats. In the following section, we synthesize exposure and injury determination with estimates of the numbers of turtles exposed to DWH oil to quantify sea turtle injuries caused by the DWH oil spill.

## 4.8.5 Injury Quantification

**Key Points**

- The Trustees quantified sea turtle injuries across life stages and habitats, synthesizing primary information from field-based observations, and veterinary and toxicology assessments.
- The Trustees estimated that between 4,900 and 7,600 large juvenile and adult sea turtles and between 56,000 and as many as 166,000 small juvenile sea turtles were killed by exposure to DWH oil. The Trustees also estimated that nearly 35,000 hatchling sea turtles were injured by response activities associated with the DWH oil spill.
- Due to data limitations and logistical constraints, the Trustees could not quantify the following injuries:
    - Injury to leatherbacks caused by the DWH spill.
    - Injury due to response activities, including impacts from oil skimming and burning operations and collisions with response watercraft.
    - Loss of hatchlings resulting from nests missed during translocation to the Atlantic coast.
    - Reduced Kemp's ridley nesting abundance and associated hatchling production.
- Despite some uncertainties about information and assumptions used in the injury quantification, the Trustees concluded that the assessment adequately quantified the nature and magnitude of the injuries to sea turtles caused by the DWH oil spill.



Previous sections described evidence of sea turtles exposed to oil (Section 4.8.3) and the severity and probable outcomes of those exposures in marine and terrestrial areas (Section 4.8.4). This section describes how the Trustees used these observations and determinations to estimate the total numbers of turtles exposed to and injured by DWH oil.

### 4.8.5.1 Quantification of Turtle Abundance, Exposures, and Injuries Across the DWH Spill Footprint and Time Period

Boat-based, land-based, and aerial surveys provided valuable information about where turtles were distributed in relation to oil and the nature and degree of oil exposures. However, these observations are underestimates of the actual number of turtles that were present and potentially exposed to oil because surveys only sampled small fractions of the overall area within which turtles were present and the time period during which turtles might have been exposed (Section 4.8.3.3, Sea Turtles Were Observed in Oil Throughout the Northern Gulf of Mexico). Therefore, the Trustees applied statistical techniques to empirical data collected during assessment activities to quantify the actual numbers of exposed turtles during the DWH oil spill.

The Trustees extrapolated total sea turtle abundance in the DWH oil spill footprint based on the direct observations of turtles using the following general steps (see Figure 4.8-16 for a schematic representation).

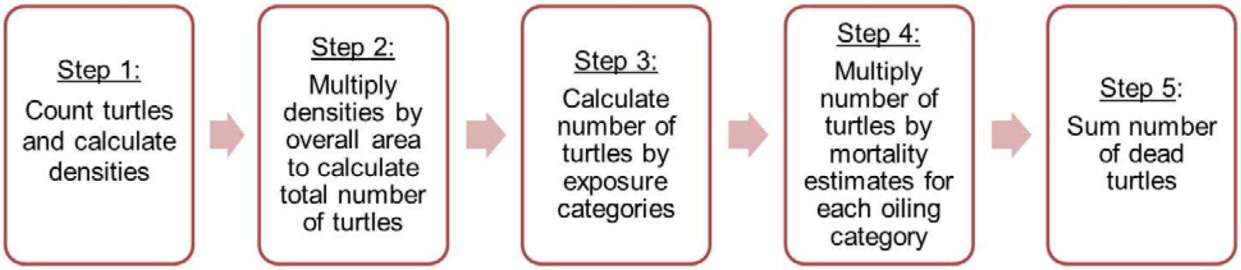



**Figure 4.8-16.** Schematic illustrating the Trustees' process for quantifying total injuries to sea turtles based on the sample of turtles observed within the footprint and time period of the DWH oil spill. Numbered steps correspond to steps described in the text.

1. Statisticians used the rescue and sightings data to estimate turtle densities within areas that were searched by boat-based rescue operations (McDonald et al. 2015) or by aerial surveys (Garrison 2015).

2. Turtle densities were expanded to areas within the DWH oil footprint that were not directly searched based on environmental similarities between searched and unsearched areas. This assumes that environmental conditions of searched areas are associated with observed densities, and thus observed densities could be extrapolated to environmentally similar unsearched areas (see Garrison 2015 for details).

3. The Trustees categorized turtles by observed or estimated degrees of oiling. Observed degrees of oiling were based on veterinary assessments of rescued turtles, as described in Section 4.8.3.3.1 (Directed Captures and Observations of Oiling in Offshore Areas). Estimated degrees of oiling were derived from the modeling approach described in Section 4.8.4.4.1 (Mortality Estimates for Heavily Oiled Turtles) based on an established relationship between observed turtle oiling categories and proximity to surface oil in areas where turtles were documented during the oil spill (Wallace et al. 2015).

4. The total number of turtles in each oiling category was multiplied by mortality estimates for each oiling category.

5. The total number of dead turtles was summed across oiling categories.

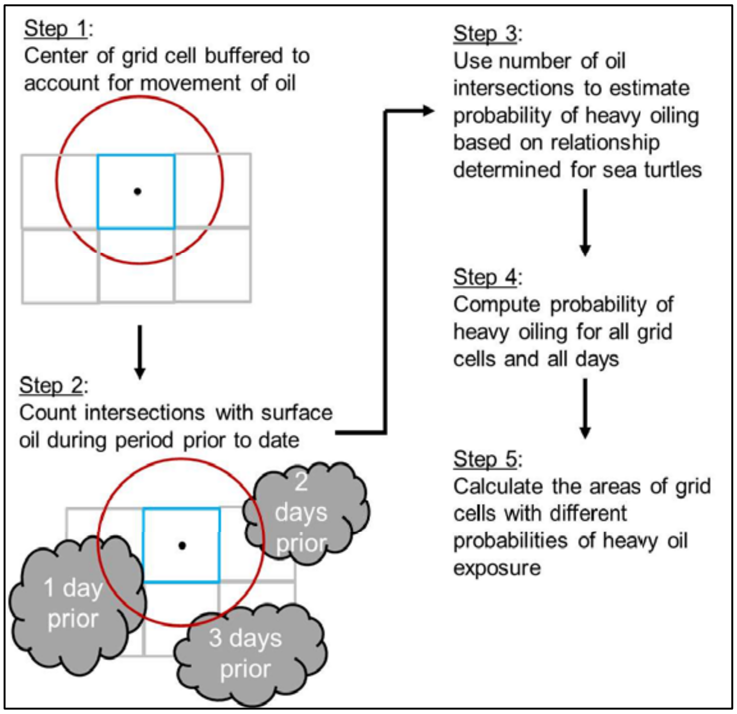
This general approach allowed the Trustees to calculate estimates of turtle abundance and exposures by species for the DWH spill area during the period from May through September 2010. Below, we describe in more detail how the Trustees performed these calculations using data collected during rescue and survey operations.

#### 4.8.5.1.1 Exposure and Injury Quantification of Small Juvenile Turtles in Offshore Areas

To estimate actual abundance and exposures of turtles in open ocean areas, the Trustees first estimated densities of Kemp's ridleys, loggerheads, green turtles, and hawksbills from the boat-based turtle sightings and captures collected along search transects during rescue operations conducted between May and September 2010 (McDonald et al. 2015). These densities were calculated based on turtle capture and sightings data relative to more than 1,200 search transects that covered nearly 200 square

kilometers of habitat for small juvenile sea turtles from May through September 2010. The Trustees used a well-established approach—i.e., distance sampling methodology (Buckland et al. 2001; Buckland et al. 2004)—to estimate the area that was searched during rescue operations, and then to generate turtle densities based on probability of sighting a turtle, distance from the transect line at which it was sighted, and other factors (McDonald et al. 2015).

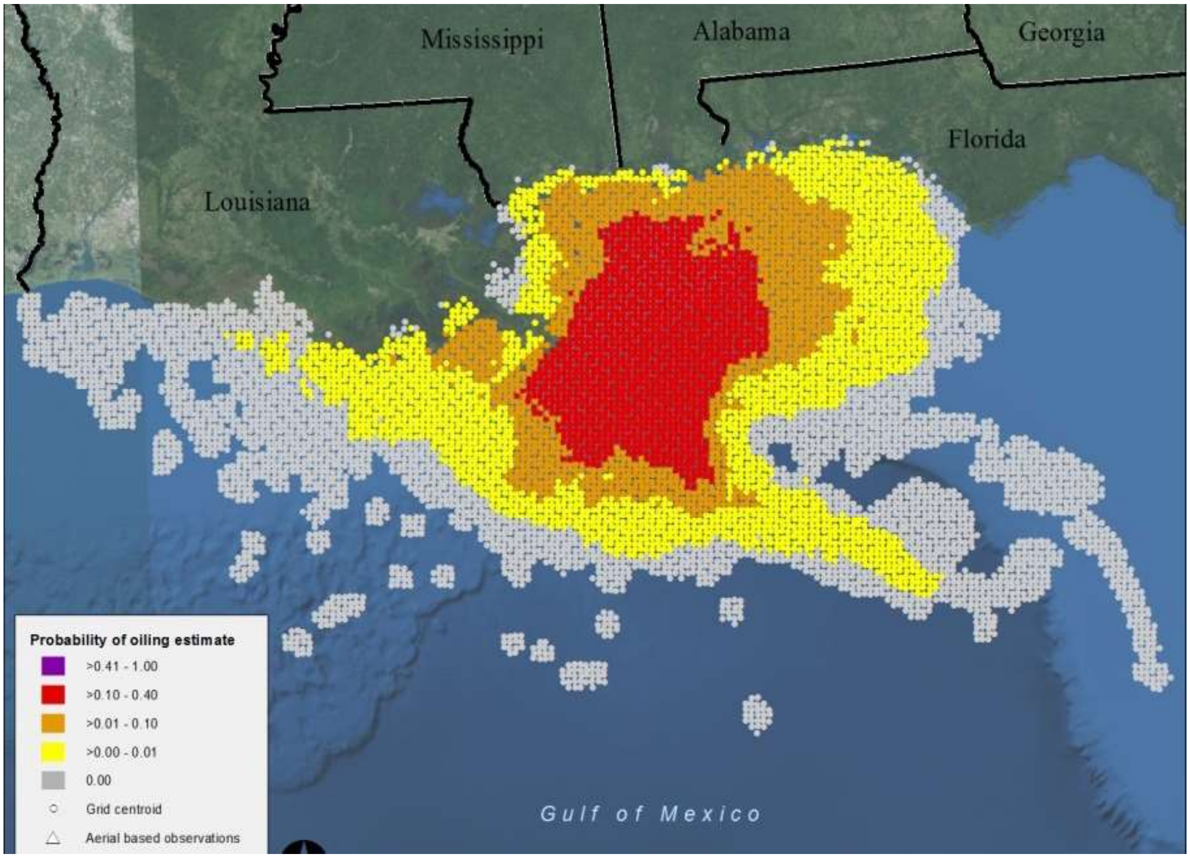
Because the cumulative area accounted for less than 1 percent of the total footprint area (~ 100,000 square kilometers), spatial extrapolations of densities estimated in searched areas were required to estimate the total turtle abundance in the entire DWH oil spill area. To estimate total turtle abundance and the number of turtles in heavy and non-heavy oiling categories, the Trustees estimated the overall area to which the density estimates would apply, i.e., unsearched areas that would be expected to host similar densities of turtles to those observed in searched areas (Wallace et al. 2015). To do this, the Trustees adapted the modeling approach described in Section 4.8.4.4.1 (Mortality Estimates for Heavily Oiled Turtles) to estimate probability of heavy oiling across the cumulative DWH oil footprint. This was done following a similar procedure to how probability of oiling was estimated for turtles (Figure 4.8-13), but with important modifications (Figure 4.8-17; (Wallace et al. 2015)).




*Source: Wallace et al. (2015).*

**Figure 4.8-17.** Schematic of the modeling approach to estimate probability of heavy oil exposure across the cumulative oil footprint using the relationship between surface oil in the area and time prior to turtle captures and their observed degree of oiling described in Section 4.8.4.4.1 (Mortality Estimates for Heavily Oiled Turtles). Description of steps appears in the text.

First, instead of turtle capture/sighting locations and dates, the Trustees calculated the number of intersections between daily surface oil footprints between April 23rd and August 11th, 2010—i.e., the range of days for which satellite derived surface oil was present (see Section 4.2, Natural Resource Exposure)—and points within the cumulative oil footprint that intersected at all with surface oil (Figure 4.8-17 and Figure 4.8-18). Specifically, the cumulative oil footprint was divided into 5 kilometers by 5 kilometers (25 square kilometers) grid cells, and the points used in this procedure were the centers of each grid cell. The extent of the cumulative oil footprint is shown in grey in Figure 4.8-18. The quantification of intersections between surface oil and grid cells used the same spatial and temporal buffering procedure used on the turtle observation data (Wallace et al. 2015).




***Source**: Wallace et al. (2015).*

**Figure 4.8-18.** Mean probabilities of heavy oil exposure across the DWH oil spill zone and period. Values are mean probabilities calculated for the centers of all 5 kilometer x 5 kilometer grid cells of the integrated oil-on-water product (see Section 4.2, Natural Resource Exposure). Turtle densities calculated based on capture and sightings along search transects were multiplied by areas of cells within each probability bin shown above to estimate the number of turtles subject to heavy oil exposure.

Next, the Trustees used the numbers of intersections calculated for each grid cell for each day to calculate probabilities of heavy oil exposure for the entire DWH oil footprint for the duration of the spill period based on the relationship described in Section 4.8.4.4.1 (Mortality Estimates for Heavily Oiled Turtles) between observed degree of oiling of captured turtles and the nearby surface oil environment (Wallace et al. 2015). (See animation of *daily probabilities of heavy oiling for all turtles observed across the cumulative SAR oil footprint:* *https://dwh.nmfs.noaa.gov/TeamCollaborationSites/DARP/Injury%20Volume/4.8%20Sea%20Turtles/Workspace/probability_maps.wmv*.) This step attributed probabilities of heavy oil exposure for every grid cell, for every day between 23 April and 11 August (Figure 4.8-18).

Once exposure areas were calculated, densities of heavily oiled turtles and non-heavily oiled turtles estimated within searched areas were multiplied by the cumulative areas that had non-zero probabilities of heavy oil exposure (i.e., all non-grey cells in Figure 4.8-18; see Figure 4.8-19 for the calculation). This straightforward approach assumed that average densities reflected both spatial and temporal variation in turtle densities, and that the DWH oil footprint encapsulated an average mix of

turtle habitat and non-habitat areas (see Section 4.8.5.4, Uncertainties and Unquantified Injury, for uncertainties related to this assumption; (McDonald et al. 2015)).

This calculation produced abundance estimates of heavily oiled turtles and non-heavily oiled turtles (Figure 4.8-19). The total estimated number of heavily oiled turtles that was based on the observed density of heavily oiled turtles was quantified as dead because the Trustees determined heavily oiled small juvenile turtles to have 100 percent probability of mortality ((Wallace et al. 2015); Section 4.8.4.4.1, Mortality Estimates for Heavily Oiled Turtles).

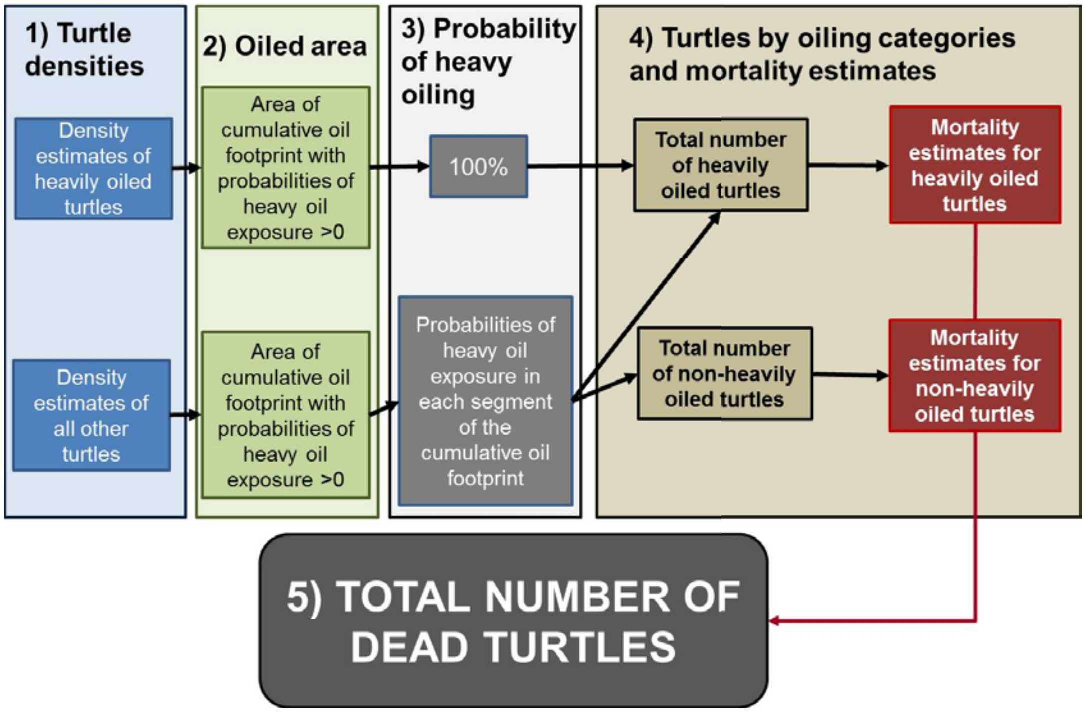


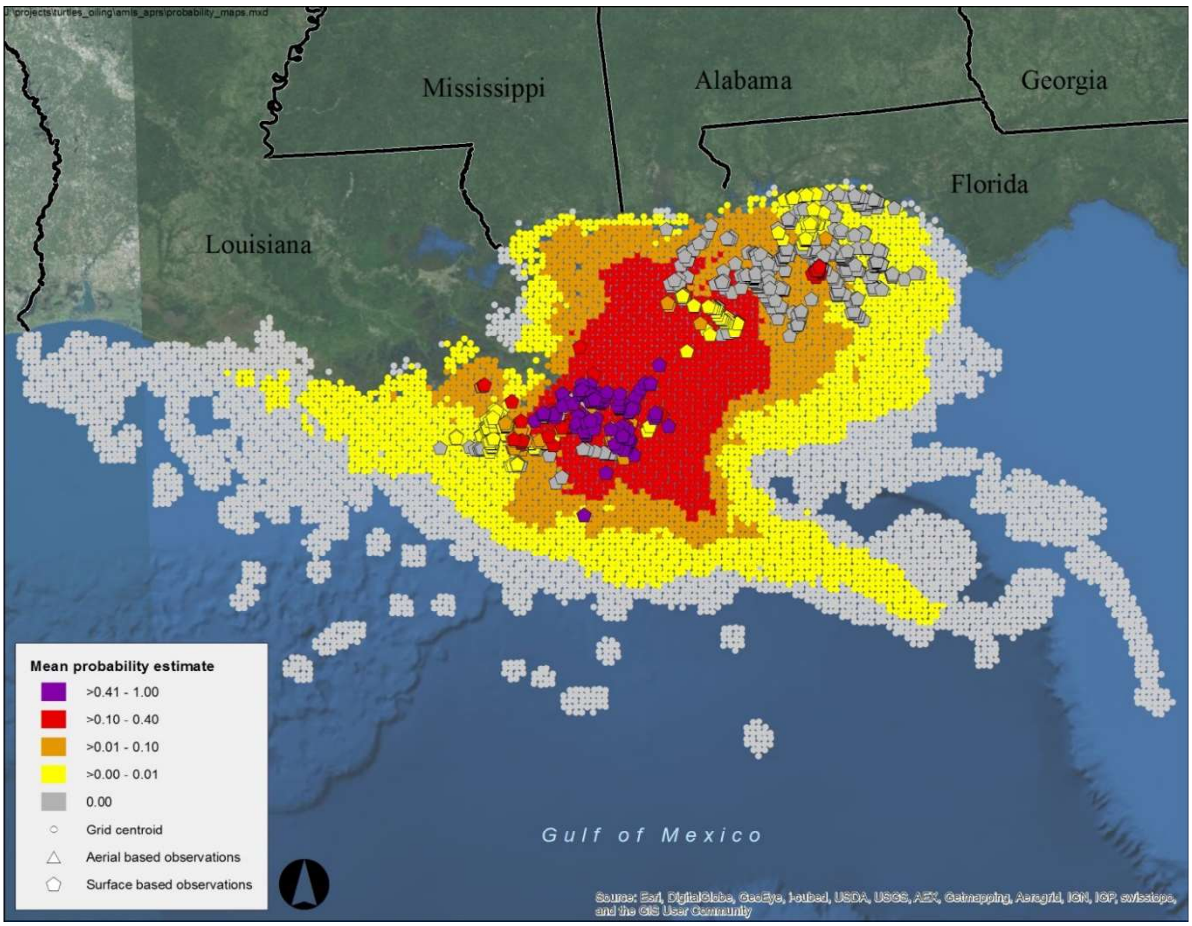

**Figure 4.8-19**. Schematic showing process by which the Trustees quantified injuries to small juvenile sea turtles in offshore areas using density estimates, the area within the cumulative oil exposure footprint, probabilities of heavy oil exposures, and mortality estimates. Descriptions of terms are included in the text.

The Trustees then calculated the total abundance of turtles by multiplying densities of turtles in non-heavily oiled categories by the total area defined above (Figure 4.8-18). Next, the Trustees multiplied this total abundance by the probability values themselves to estimate the number of turtles subject to heavy oil exposure. In this way, the density-area-probability of heavy oiling calculation provided estimates of numbers of turtles with a high probability of heavy oil exposure throughout the spill zone (Figure 4.8-18 and Figure 4.8-19). This number of juvenile turtles was considered heavily oiled, a condition directly linked to 100 percent mortality (Stacy 2012; Wallace et al. 2015).

The remainder of turtles from this calculation—i.e., the difference between total abundance of turtles in a given area and those estimated to be in the heavy oil category—represented turtles subject to less than heavy oil exposure. The mortality estimate for non-heavily oiled turtles (30 percent) (Table 4.8-3; (Mitchelmore et al. 2015)) was applied to this number of turtles to estimate total dead turtles that were

exposed to oil but not heavily oiled. Figure 4.8-19 provides a schematic summary of the calculation that the Trustees used to quantify dead turtles based on density and exposure areas.

To compare this approach with empirical observations of surface oil and degree of oiling on turtles, we assigned a probability of heavy oiling to all turtles captured or sighted during rescue operations, and the capture or sighting locations of these turtles were mapped onto the surface of average probability of heavy oil exposure estimated across the DWH oil footprint (Figure 4.8-20). As with the oiling probabilities across the DWH footprint (Figure 4.8-18), turtles with highest probabilities of heavy oil exposure were limited to areas closest to the wellhead, and probability of heavy oiling decreased with increasing distance from the wellhead (Figure 4.8-20; (Wallace et al. 2015)).




***Source**: Wallace et al. (2015).*

**Figure 4.8-20.** Probabilities of heavy oil exposure of small juvenile sea turtles that were captured or sighted during rescue operations. Probabilities of heavy oiling associated with each turtle sighted or captured during surface-based surveys (i.e., sighted or captured from a boat on the water) overlaid on mean probabilities of heavy oil exposure across the DWH oil spill zone and period. Probabilities were estimated based on the statistical relationship between observed degrees of oiling on turtles and satellite-derived surface oil data in the area and time of turtle sighting or capture (see Section 4.8.4.4.1, Mortality Estimates for Heavily Oiled Turtles).

These results agreed with spatial patterns of degrees of oiling observed on rescued turtles; nearly all heavily oiled turtles were found within 90 kilometers of the wellhead, and turtles found furthest from the wellhead were assigned to the lowest oiling categories (Figure 4.8-20; (Stacy 2012; Wallace et al. 2015)). (See animation of *daily probabilities of heavy oiling for all turtles observed across the cumulative SAR oil footprint:* *https://dwh.nmfs.noaa.gov/TeamCollaborationSites/DARP/Injury%20Volume/4.8%20Sea%20Turtles/Workspace/probability_maps.wmv*.) Given this high level of agreement with the empirical patterns of degree of oiling based on direct observations of turtles in oiled northern Gulf of Mexico habitats, we are confident in the results of the model in estimating degree of oiling for turtles—and surface habitats—that were not directly observed.

To quantify total injuries to small juvenile sea turtles, as described above and shown in Figure 4.8-19, the Trustees combined estimates of turtle density, areas within the oil footprint where turtles were expected to be, probabilities of heavy oil exposure, and mortality estimates for heavily and non-heavily oiled turtles. The Trustees estimated that more than 421,000 small juvenile sea turtles were exposed to DWH oil across more than 100,000 square kilometers of the cumulative oil footprint (Table 4.8-4). The Trustees then applied the mortality estimates presented in Table 4.8-3 to the numbers of turtles exposed in each oiling category to estimate the numbers of turtles killed by oil exposure.

Based on these calculations, approximately 56,000 small juvenile sea turtles were likely killed by heavy exposure to DWH oil. Accounting for potential toxicological and physiological adverse effects associated with less than heavy oil exposure, up to an additional 110,000 turtles were likely killed. Thus, the Trustees estimated that as many as 166,000 small juvenile sea turtles were potentially killed by the DWH oil spill (Table 4.8-4; (Wallace et al. 2015)).

**Table 4.8-4.** Densities, exposures, and estimated mortality of small juvenile sea turtles (Wallace et al. 2015). The Trustees calculated the number of turtles that were heavily oiled, and thus assumed dead (100 percent mortality for heavily oiled turtles), and also calculated the number of turtles exposed to a lesser degree than heavily oiled turtles. To estimate total potential mortality for the latter group, the Trustees applied a mortality rate of 30 percent, which considered potential toxic effects of oil exposure (see Section 4.8.4.4, Mortality Estimates for Turtles Based on Degree of Oiling). The Trustees considered the total number of heavily oiled dead oceanic turtles to be the low end of the range of mortality, and the addition of the number of less-than-heavily oiled dead oceanic turtles to be the high end of the range of total mortality. Exposure and injury estimates shown to three significant digits.

| Species | Density (Turtles/km$^2$) | Total Turtles Exposed | Heavily Oiled, Dead (low end of the range) | Non-heavily Oiled, Dead | Total Dead (high end of the range) |
|---|---|---|---|---|---|
| Kemp's ridleys | 1.70 | 217,000 | 36,200 | 54,100 | 90,300 |
| Loggerheads | 0.25 | 30,800 | 2,140 | 8,590 | 10,700 |
| Greens | 1.22 | 154,000 | 15,700 | 41,600 | 57,300 |
| Hawksbills | 0.07 | 8,850 | 615 | 2,470 | 3,090 |
| Unidentified | 0.08 | 10,700 | 1,360 | 2,800 | 4,160 |
| Total | 3.32 | 421,000 | 56,000 | 110,000 | 166,000 |

*Note: totals may not sum due to rounding.*

### Uncertainties Associated with Quantification of Injuries to Small Juvenile Sea Turtles

There are uncertainties associated with these estimates, as indicated by the wide range of possible injuries to small juvenile sea turtles. Sources of uncertainty in the mortality estimates, particularly those for non-heavily oiled turtles, included several factors that were not empirically observed in sea turtles (e.g., chronic toxic effects on critical physiological functions). These uncertainties could have either underestimated or overestimated mortality, as well as the resulting injury quantification. Calculations of area to which the density estimates were applied might have overestimated the total area where turtles might have been exposed, thus resulting in overestimates of small juvenile sea turtle injuries. However, other sources of uncertainty could have made the injury numbers presented in Table 4.8-4 underestimates. For example, several factors hindered searchers' ability to detect turtles, and rescue efforts covered less than one percent of the cumulative oil footprint. Despite uncertainties (see Section 4.8.5.4, Uncertainties and Unquantified Injury), the Trustees concluded that these injury estimates were reasonable and adequately quantify the magnitude of the injury to small juvenile sea turtles because they were based on the best available information and were quantified using sound technical approaches.



### Putting Injury Estimates in Context

To put these numbers in context and evaluate their reasonableness, we estimated the potential number of small juvenile (one and two year-old) Kemp's ridley turtles present in the Gulf during 2010. Although they occur throughout the northern Gulf of Mexico, one and two year-old Kemp's ridleys primarily inhabit the northern and eastern Gulf of Mexico (Putman & Mansfield 2015; Putman et al. 2013; Witherington et al. 2012). First, we started with numbers of hatchlings produced at the primary nesting beaches in 2008 and 2009 (i.e., nearly 2,000,000 hatchlings released in those two years) (NMFS et al. 2011), and applied the annual survival rate for this age class (0.318) estimated by population modeling (Heppell et al. 2005). Based on this calculation, more than 430,000 small oceanic juvenile Kemp's ridleys (one and two year-old) were estimated to have been in the population. Our exposure estimate of 217,000 Kemp's ridleys would mean that approximately half of these small juvenile Kemp's ridleys would have been exposed to surface oil during the DWH oil spill (Table 4.8-4). Total small juvenile Kemp's ridley mortalities were between 36,000 and 90,000 (Table 4.8-4), or approximately 10–20 percent of all of the one and two year-old Kemp's ridleys alive prior to the oil spill.

We emphasize that this set of calculations is qualitative in nature, and not the result of robust demographic population modeling. For example, age- or stage-specific survival rates vary across years, and can significantly influence modeled population dynamics (Heppell et al. 2005). With this in mind, the results of these calculations demonstrate that our injury estimates, based on extrapolations of turtle densities from searched areas to the DWH footprint, are reasonable (i.e., well within estimates of actual population abundance), and represent a significant loss—perhaps 10–20 percent—of the small juvenile life stage of this endangered species. Although available data were insufficient to conduct similar calculations for loggerheads, green turtles, and hawksbills, we assume that the same approach to the injury estimate for the other sea turtle species has yielded similarly reasonable results, and the significance of the results for Kemp's ridleys apply in principle to the other species in offshore areas.

### 4.8.5.1.2 Exposure and Injury Quantification of Large Juvenile and Adult Sea Turtles in Continental Shelf Areas

To estimate total abundance and exposures of sea turtles in continental shelf waters, the Trustees performed similar calculations to those described above for small juveniles in offshore surface waters, with important modifications (Figure 4.8-21). First, the Trustees combined locations and dates of turtle sightings with environmental variables in the same areas and times to calculate turtle densities for biweekly periods from April to September 2010 (Garrison 2015). To correct for turtles that were submerged and thus not visible to observers performing surveys, the Trustees applied estimates of the time turtles spend at the surface by season to estimate the total number of turtles in a given area at a given time. This procedure accounts for all turtles in a given area based on the proportion that are visible. Additional corrections for detection probability, distance from tracklines, and other factors were also included in a distance sampling approach (Buckland et al. 2001; Buckland et al. 2004), as described above (Garrison 2015).

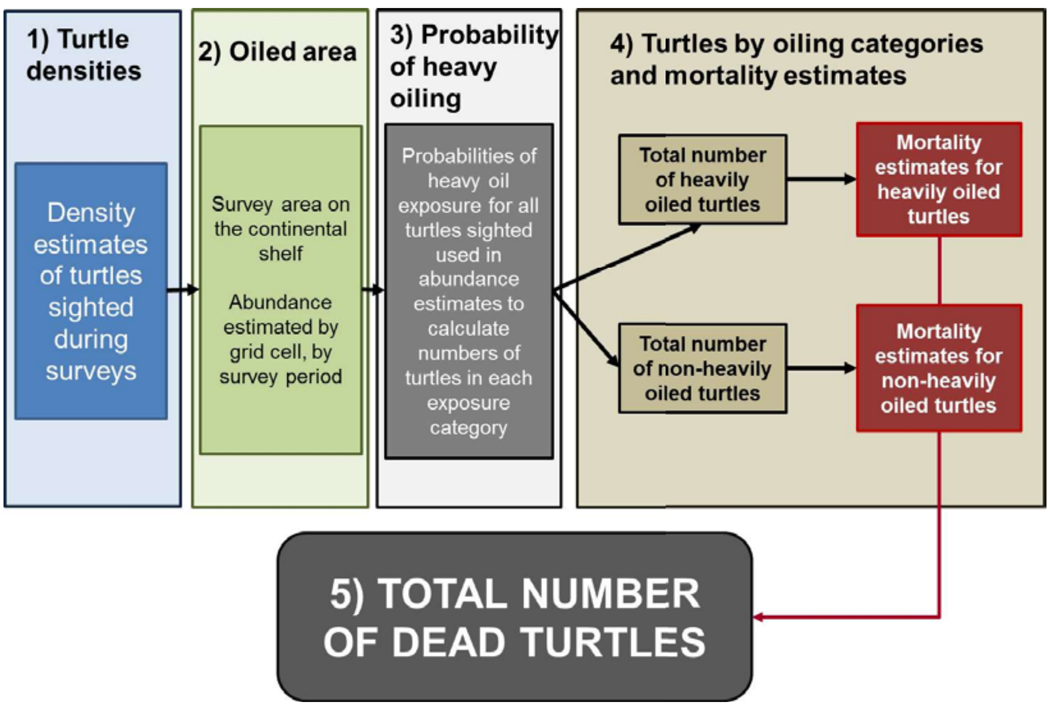
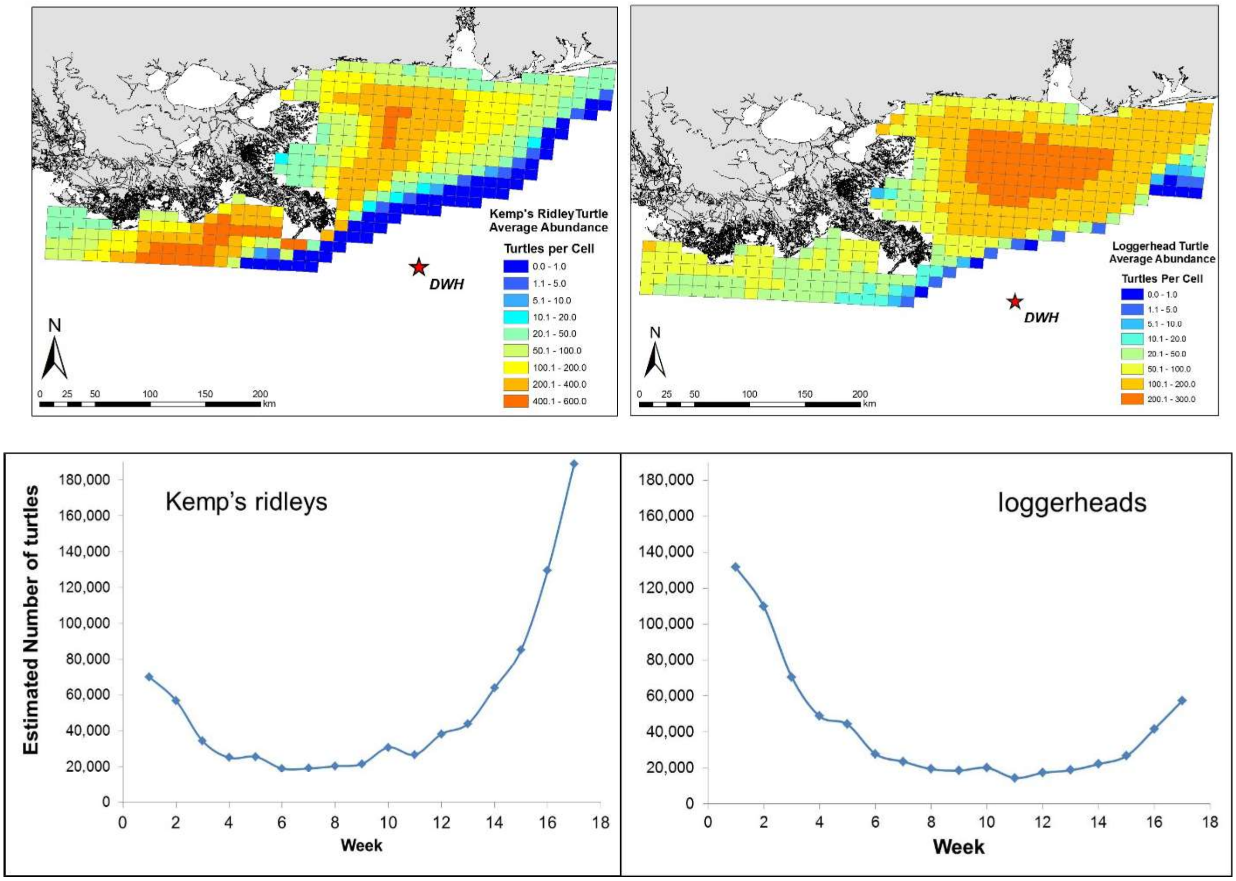



**Figure 4.8-21**. Schematic showing the process by which the Trustees quantified injuries to large juvenile and adult sea turtles on the continental shelf using density estimates, the area within the cumulative oil exposure footprint, probabilities of heavy oil exposures, and mortality estimates. Descriptions of terms are included in the text.

Turtle densities and estimated abundances for both species were highest in early and late summer, with lower abundance in the middle of the summer. However, areas and times of peak abundance, as well as abundance estimates themselves, differed between Kemp's ridleys and loggerheads (Figure 4.8-22; (Garrison 2015)). Loggerheads were in consistently high densities in the eastern area of the survey area, whereas high densities of Kemp's ridleys were estimated both east and west of the Mississippi River Delta (Figure 4.8-22; (Garrison 2015)). Both of these results are consistent with NRDA and non-NRDA satellite tracking studies that showed both migration and residency behaviors of adult female

loggerheads and Kemp's ridleys in the area affected by the DWH oil spill (Figure 4.8-11; (Hart et al. 2012; Shaver et al. 2013)).




***Source**: Garrison (2015).*

**Figure 4.8-22.** Average density (top row) and abundance estimates (bottom row) for Kemp's ridleys (left) and loggerheads (right) on the northern Gulf of Mexico continental shelf during the DWH oil spill based on aerial survey observations and statistical estimates. Densities and abundance were calculated for the survey area shown during the period from April 24 to September 2, 2010.

In contrast to rescue efforts to capture and evaluate oil exposure of small juvenile sea turtles, neritic turtles could not be directly assessed for oiling status or health condition. Therefore, the Trustees estimated the degree of oiling for these animals using the statistical relationship between observed degrees of oiling of rescued turtles and surface oil data derived from remote sensing (i.e., satellite data on daily size and distribution of the oil footprint) described in previous sections (Sections 4.8.4.4.1, Mortality Estimates for Heavily Oiled Turtles, and 4.8.5.1.1, Exposure and Injury Quantification of Small Juvenile Turtles in Offshore Areas) and in Figure 4.8-13 (Wallace et al. 2015). In this way, the Trustees were able first to assign oiling status to turtles that were observed remotely by plane but not assessed directly, and then to quantify oil exposures of turtles in continental shelf areas. This approach provided estimates of numbers of large juvenile and adult turtles in continental shelf waters with a high probability of heavy oil exposure throughout the spill zone. As discussed for small juvenile turtles in

Section 4.8.5.1.1 (Exposure and Injury Quantification of Small Juvenile Turtles in Offshore Areas), the remainder of turtles from this calculation (i.e., the difference between total abundance of turtles in a given area and those estimated to be in the heavy oil category) represented large juvenile and adult turtles subject to less than heavy oil exposures. These calculations provided estimates of turtle abundance by exposure categories (Figure 4.8-21).

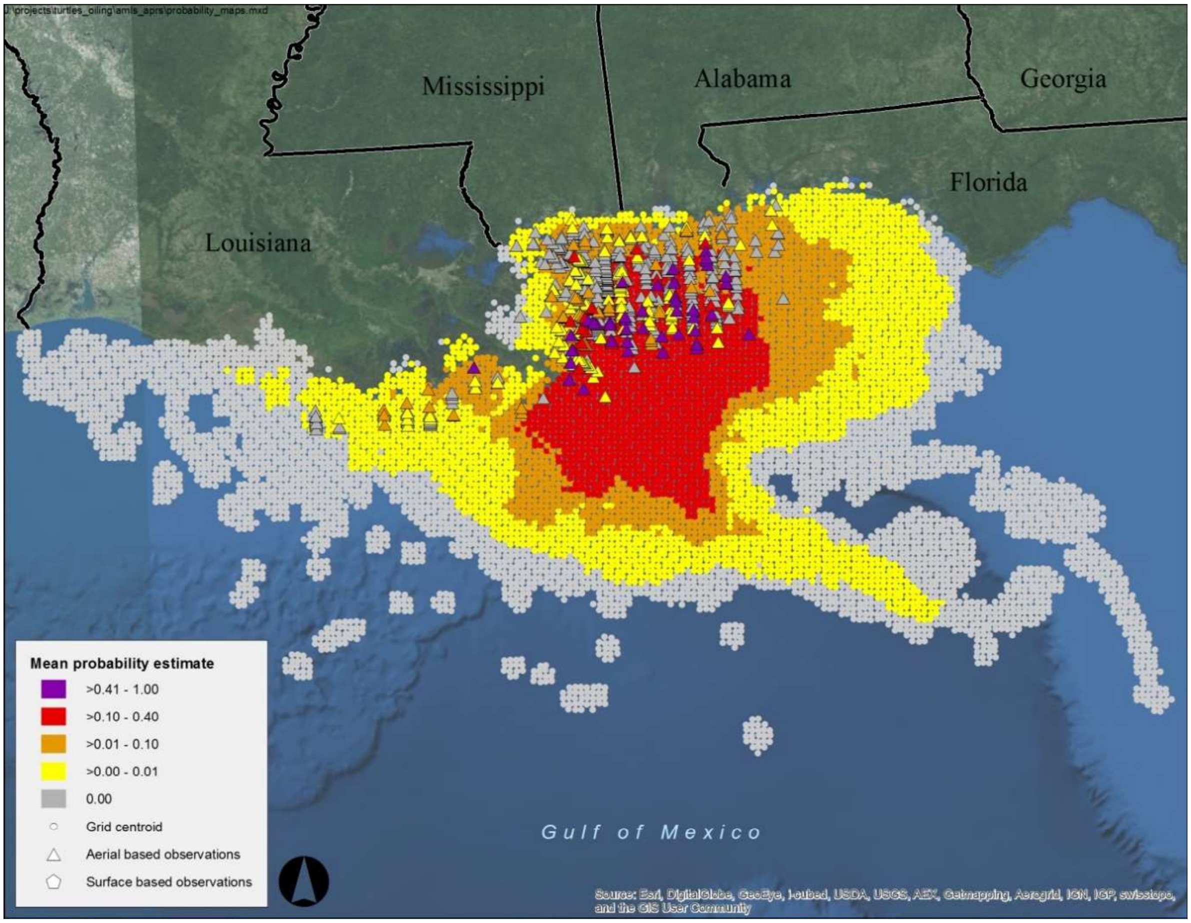
Density estimates were calculated per grid cell per survey, and included the probabilities of heavy oil exposure attributed to individual turtles that were sighted during surveys. In this way, when the Trustees multiplied densities by the survey area to calculate turtle abundances per survey period, they also were able to calculate the number of heavy and non-heavy oil exposures at these spatial and temporal scales (Figure 4.8-21; (Garrison 2015)).

Probabilities of heavy oiling associated with each turtle sighted during aerial-based surveys (i.e., sighted from a plane) were overlaid on mean probabilities of heavy oil exposure across the DWH oil spill zone and period. Although aerial surveys were restricted to water depths of < 200 meters, and the survey area boundaries (Figure 4.8-10) were further westward than areas where rescue operations occurred (Figure 4.8-7), the resulting probabilities of heavily oiled turtles detected by plane-based observers showed a similar relationship with distance from the wellhead; in general, probability of heavy oiling increased with proximity to the wellhead (Figure 4.8-23; (Wallace et al. 2015)). These results were in agreement with several relevant and inter-related patterns, including: 1) directly observed frequencies of degrees of oiling on sea turtles obtained by rescue operations (Figure 4.8-7; (Stacy 2012)); 2) surface oil prevalence (Figure 4.8-18); and 3) estimated probabilities of small juvenile turtles sighted or captured during rescue operations (Figure 4.8-20). (See animation of *daily probabilities of heavy oiling for all turtles observed across the cumulative SAR oil footprint:* *https://dwh.nmfs.noaa.gov/TeamCollaborationSites/DARP/Injury%20Volume/4.8%20Sea%20Turtles/Workspace/probability_maps.wmv*.) In other words, there was broad agreement between observed distributions of oiled turtles and surface oil in space and time, and the established relationship between the two produced reasonable estimates of degree of oiling for all sea turtles observed during NRDA response and survey efforts.

As discussed in Section 4.8.3.3.2 (Observations of Turtles on Continental Shelf and on Beaches), the Trustees identified a size class of young Kemp's ridley juveniles—approximately 25–40 centimeters long, approximately three years old (Avens & Snover 2013)—that were unobserved by vessel-based and plane-based surveys of the DWH spill area. Because the actual distribution of these animals is relatively poorly known, the Trustees estimated their abundance relative to the estimated abundance of all other continental shelf Kemp's ridleys, and assumed that they were uniformly distributed and exposed to oil in similar proportions to turtles that were sighted (Garrison 2015). This allowed the Trustees to estimate the potential number of these small, continental shelf juveniles that were exposed to and killed by the DWH oil spill (Table 4.8-5; (Wallace et al. 2015)).

As described above and shown in Figure 4.8-21, the Trustees combined estimates of turtle density, areas within the oil footprint where turtles were expected to be, probabilities of heavy oil exposure, and associated mortality estimates to quantify total injuries to large juvenile and adult sea turtles in continental shelf areas. Based on these calculations, the Trustees estimated that more than 58,000 large juvenile and adult sea turtles were exposed to DWH oil in continental shelf areas (Table 4.8-5). Finally,

the Trustees applied the mortality estimates for large turtles described in Section 4.8.4.4.2 (Mortality Estimates for Turtles That Were Exposed, But Not Heavily Oiled) to the numbers of turtles exposed in the heavy and non-heavy oil exposure categories. The Trustees estimated that approximately 4,900 large juvenile and adult sea turtles were likely killed by heavy exposure to DWH oil. Accounting for potential toxicological and physiological adverse effects of less than heavy oil exposure, up to an additional 2,600 sea turtles were likely killed. Thus, the Trustees estimated that a total of up to 7,600 large juvenile and adult turtles were potentially killed in continental shelf areas by the DWH oil spill (Table 4.8-5).




*Source: Wallace et al. (2015).*

**Figure 4.8-23.** Probabilities of heavy oil exposure of large juvenile and adult sea turtles that were sighted during aerial surveys overlaid on mean probabilities of heavy oil exposure across the DWH oil spill zone and period. Probabilities were estimated based on the statistical relationship between observed degrees of oiling on turtles and satellite-derived surface oil data in the area and time of turtle sighting or capture (see Section 4.8.4.4.1, Mortality Estimates for Heavily Oiled Turtles).

**Table 4.8-5**. Total exposures and estimated mortality of large juvenile and adult sea turtles killed by the DWH oil spill in continental shelf areas (Wallace et al. 2015). We considered the total number of heavily oiled dead neritic turtles to be the low end of the range of mortality, and the addition of the number of less-than-heavily oiled dead neritic turtles to be the high end of the range of total mortality. Numbers only shown to two significant digits.

| Species | Total Exposures | Heavily Oiled, Dead (low end of the range) | Non-heavily Oiled Exposures | Non-heavily Oiled, Dead | Total Dead (high end of the range) |
|---|---|---|---|---|---|
| Kemp's ridleys, ages 4 + | 21,000 | 1,700 | 19,000 | 950 | 2,700 |
| Kemp's ridleys, age 3 | 990 | 380 | 610 | 30 | 410 |
| *Kemp's, all* | *22,000* | *2,100* | *20,000* | *980* | *3,100* |
| Loggerheads | 30,000 | 2,200 | 28,000 | 1,400 | 3,600 |
| Unidentified | 5,900 | 630 | 5,200 | 260 | 890 |
| Total | 58,000 | 4,900 | 53,000 | 2,600 | 7,600 |
| Note: totals may not sum due to rounding. | | | | | |



### Uncertainties Associated with Quantification of Injuries to Large Juvenile and Adult Sea Turtles

As with injury estimates for small juvenile sea turtles, there are uncertainties associated with these estimates of larger animals that could have either underestimated or overestimated mortality, as well as the resulting injury quantification. Mortality estimates for large juveniles and adults were developed based on strong empirical evidence about physical effects of exposure to surface oil observed in small juvenile sea turtles (Stacy 2012; Wallace et al. 2015), but empirical observations of oiled neritic sea turtles were scarce. Additionally, the Trustees made a simplifying assumption that the "missing size class" of neritic juvenile Kemp's were distributed and exposed equally to oil within the survey area, and that their mortality rates would be similar to those of larger neritic sea turtles. This distribution is unlikely as evidenced by the size classes represented among strandings, which suggests that the smaller turtles are generally more likely to be closer shore and thus less likely to have become heavily oiled (Stacy 2012). However, there was insufficient information with which to more finely resolve size-related differences in distribution that would have been meaningful for incorporation into mortality estimates. Despite these uncertainties (see Section 4.8.5.4, Uncertainties and Unquantified Injury), the Trustees concluded that these injury estimates were reasonable and adequately quantify the magnitude of the injury to large juvenile and adult sea turtles because they were based on the best available information and were quantified using sound technical approaches.

### Putting Injury Estimates in Context

To evaluate the reasonableness and significance of these injury estimates, we conducted a similar procedure to that presented for small juvenile sea turtle injury estimates above (Section 4.8.5.1.1, Exposure and Injury Quantification of Small Juvenile Turtles in Offshore Areas), again using Kemp's ridleys as an example. To estimate the total cohort of large juvenile and adult Kemp's ridleys turtles, which we estimated to correspond to turtles of ages three and older (Heppell et al. 2005), we started with the average number of hatchlings (~ 1,000,000) produced on Kemp's ridley nesting beaches between 2007 through 2009 as a foundation for computing the total number of turtles across age

classes. We then calculated the stable age distribution—i.e., the proportion of animals in each age class in a population—for the Kemp's ridley population with a growth rate of 18 percent per year based on published inputs to a stage-based population model (NMFS et al. 2011 and references therein).

By dividing the actual number of hatchlings by the estimated proportion of hatchlings in the population, we were able to estimate the total number of animals in the population. This number was then multiplied by the proportions of animals in each age class to calculate the number of animals in each age class. This procedure yielded a total estimated abundance of approximately 100,000 animals between three and 12+ years old.

Comparing the injury numbers to this estimate, approximately 22 percent (22,000 turtles) of the Kemp's ridleys in this age range were exposed to oil, and approximately three percent (3,100 turtles) of them died as a result (Table 4.8-5). Taking these calculations a step further to compute the potential number of adult Kemp's injured by the DWH oil spill yields an estimate of between 400 and 600 dead adult Kemp's. Using published sex ratios (i.e., the proportion of females to males) (NMFS et al. 2011) to account for only the females, estimated DWH injuries would equate to nearly 10 percent of the average annual nesting female abundance estimated between 2005 and 2010 (NMFS et al. 2011).



As above, we emphasize that this set of calculations is qualitative in nature, and not the result of robust demographic population modeling. There is variation in all of the parameters used above that is not reflected in the calculations or the results. For example, age at sexual maturity varies in natural populations, but was assumed to be fixed based on the best-fit value from population model results (Heppell et al. 2005). With this in mind, similar to the results presented above for the small juvenile injury estimates, our injury estimates based on extrapolations of turtle densities from searched areas to the DWH footprint are well within estimates of actual population abundance, but also represent a significant loss of the large juvenile and adult life stage for this endangered species. As above, we assume that both the reasonableness and the significance of the results for Kemp's ridleys apply in principle to the other species on the continental shelf.

### 4.8.5.2 Quantification of Sea Turtle Injuries Caused by DWH Response Activities

As mentioned in Section 4.8.4.6 (Injuries to Turtles Caused by Response Activities), the Trustees documented sea turtle injuries caused by activities associated with response to the DWH oil spill. Response injuries occurred in marine and terrestrial habitats.

#### 4.8.5.2.1 Marine Response Injuries

The Trustees conclude that hundreds of sea turtles were likely killed by response activities in marine areas, but the actual number could not be quantified. Counting only those turtles directly observed, the Trustees documented six turtles killed by dredging operations or relocation trawling operations associated with construction of the berm in Louisiana. The Trustees also estimated that hundreds more turtles were killed by collisions with response watercraft based on those that stranded with clear evidence of watercraft collision injuries that coincided with response vessel traffic in nearshore areas throughout the northern Gulf of Mexico (Stacy 2015). In addition, many more turtles were likely killed during other response activities such as oil skimming and burning operations; however, since these activities take place in areas of heavy oiling, these turtles are likely to have been included in the offshore injury quantification (McDonald et al. 2015). Although insufficient data were available to permit a robust

quantification, the Trustees concluded that total injuries caused by response injuries in marine areas were likely to be hundreds of sea turtles, and possibly more.

##### 4.8.5.2.2 Terrestrial Response Injuries: Hatchlings Released in the Atlantic to Avoid Oil in the Gulf of Mexico

Nests from three species—loggerheads, Kemp's ridleys, and green turtles—were excavated prior to emergence and eggs were translocated from Florida and Alabama beaches in the northern Gulf of Mexico between June 6 and August 19, 2010 to a protected hatchery on the Atlantic Coast of Florida. More than 28,000 eggs from 274 nests were translocated, and nearly 15,000 hatchling turtles emerged and were released into the Atlantic Ocean (Table 4.8-6; (Provancha & Mukherjee 2011)). Overall hatching success was 51.6 percent, and ranged from 0 percent to 100 percent among nests. Because these hatchlings entered the Atlantic Ocean and not the Gulf, and because sea turtle hatchlings are thought to imprint on their natal beaches to which they return as breeding adults, it is unknown whether these turtles will return to the Gulf (Provancha & Mukherjee 2011). Therefore, these hatchlings are assumed to be lost to the Gulf of Mexico breeding population as a result of the DWH oil spill.

**Table 4.8-6.** Summary of egg translocation and hatchling release effort to prevent Gulf of Mexico hatchlings from being exposed to DWH oil and response activities (Provancha & Mukherjee 2011).

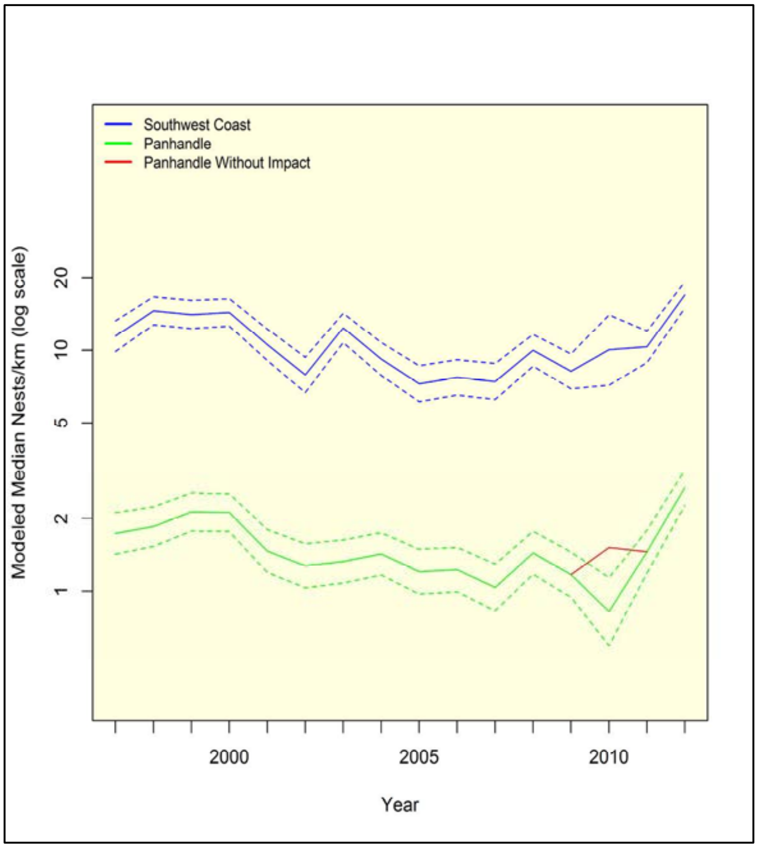
| | Clutches | Egg Count | Hatchlings Released |
|---|---|---|---|
| **Kemp's ridley** | 5 | 483 | 125 |
| **Loggerhead** | 265 | 27,618 | 14,216 |
| **Green** | 4 | 580 | 455 |
| **Totals** | **274** | **28,681** | **14,796** |

##### 4.8.5.2.3 Terrestrial Response Injuries: Disrupted Nesting

The Trustees evaluated nest losses on the panhandle beaches of Florida due to response activities (Cacela & Dixon 2013; Frater 2015). Analyses focused on potential changes in nest densities in 2010 relative to the years before and after the spill on Florida Panhandle beaches compared to southwestern Florida beaches that were outside of the spill zone. These analyses confirmed a significant decrease of approximately 250 loggerhead nests on the Florida Panhandle nesting beaches in 2010 (Figure 4.8-24). The Trustees concluded that this decrease in nest density was related to oil cleanup operations on nesting beaches that deterred adult female loggerheads from coming ashore and laying their eggs. This estimated loss equates to approximately 18,000 unrealized hatchlings from Florida Panhandle nesting beaches in 2010 (Cacela & Dixon 2013).

In addition to the Florida Panhandle, Alabama beaches included within designated Loggerhead Critical Habitat under the ESA were also impacted by both oil and response activities during the 2010 nesting season (Michel et al. 2015). Nesting numbers for the beaches in Baldwin County, Alabama, showed a similar decline as those in the Florida Panhandle in 2010 (Frater 2015). Applying the observed proportional nesting density decrease relative to expected on the Florida beaches (Cacela & Dixon 2013) to the adjacent Alabama beaches, the Trustees estimated that approximately 30 loggerhead nests, or 2,000 loggerhead hatchlings, were lost in Alabama due to DWH response activities (Frater 2015).

Based on the response injury evaluations for Florida Panhandle and Alabama nesting beaches, the Trustees estimated that approximately 20,000 loggerhead hatchlings were lost due to DWH response activities on nesting beaches.




***Source**: Cacela and Dixon (2013).*

**Figure 4.8-24.** Loggerhead sea turtle nest densities in the Florida panhandle were lower than expected due to response activities on beaches. Modeled values of annual nesting densities (nests/kilometer) in the southwest coast (blue lines) and the panhandle (green lines) of Florida. The modeled estimate (red line) of the panhandle nesting rate in the hypothetical absence of response activities in 2010. Dotted lines indicate the 95 percent confidence interval on the modeled median values of nest densities.

### 4.8.5.3 Total Estimate of Sea Turtles Killed by the DWH Oil Spill

Based on all efforts to quantify sea turtle injuries across life stages and habitats, that used observational data collected from land, air, and sea, and synthesized information from veterinary and toxicology assessments, the Trustees estimated that between 56,000 and as many as 166,000 small juvenile sea turtles, between 4,900 and as many as 7,600 large juvenile and adult sea turtles, and approximately 35,000 hatchling sea turtles were likely killed by the DWH oil spill and related response activities (Table 4.8-7). There are sources of uncertainty associated with these estimates, as were described previously and below in Section 4.8.5.4 (Uncertainties and Unquantified Injury). Most important, due to the logistical limitations of searching the vast spatial and temporal expanse of the DWH oil spill footprint, the total injury numbers presented here might underestimate the actual injury to sea turtles in the northern Gulf of Mexico. However, despite uncertainties, the Trustees concluded that the assessment adequately quantifies the nature and magnitude of injuries to sea turtles caused by the DWH oil spill. Furthermore, these uncertainties are best addressed by restoration approaches that are designed to address injuries across life stages and geographic areas.

**Table 4.8-7.** Total estimate of sea turtles killed by the DWH oil spill, shown by life stage and by species. Two estimates of Kemp's ridley hatchling injuries are shown: 1) hatchlings lost due to response injuries, and 2) unrealized hatchling production caused by loss of breeding-age Kemp's ridleys quantified in Section 4.8.5.1.2 (Exposure and Injury Quantification of Large Juvenile and Adult Sea Turtles in Continental Shelf Areas). For more details about these calculations, see Section 4.8.5.4 (Uncertainties and Unquantified Injury). Lower ends of ranges for small juveniles and large juveniles and adults represent estimated injuries to heavily oiled turtles only, and upper ends of ranges represent estimated injuries to heavily oiled turtles plus additional injuries estimated for non-heavily oiled turtles. ND=no data.

| | Species | | | | | |
|---|---|---|---|---|---|---|
| Life Stage | Kemp's Ridley | Loggerhead | Green | Hawksbill | Unidentified Sea Turtle | Total |
| Hatchlings, response injuries | 125 | 34,000 | 455 | ND | ND | 35,000 |
| *Hatchlings, unrealized reproduction* | *65,000–95,000*[a] | | | | | |
| Small juveniles | 36,000–90,000 | 2,100–11,000 | 16,000–57,000 | 620–3,000 | 1,400–4,200 | 56,000–170,000 |
| Large juveniles and adults | 2,100–3,100 | 2,200–3,600 | ND | ND | 630–890 | 4,900–7,600 |

***Note:*** *Totals may not sum due to rounding.*

[a] *This range represents the estimated number of hatchlings that would have been produced by breeding Kemp's ridleys that were killed by the DWH oil spill. These numbers are a part of the total contribution of DWH to the unrealized Kemp's nest abundance observed between 2011 and the present, but do not include potential DWH impacts to reproductive fitness through sub-lethal impacts and impacts to habitat and foraging resources. Quantification of the full nature and magnitude of DWH effects requires further evaluation.*

## 4.8.5.4 Uncertainties and Unquantified Injury

The total numbers of turtles killed by species and life stage shown in Table 4.8-7 include only those injuries that the Trustees could quantify, given available data. Despite the uncertainties and unquantified injuries described below, the Trustees concluded that the results of this injury quantification are reasonable and adequately reflect the nature and magnitude of the full injury to sea turtles caused by the DWH oil spill.

### 4.8.5.4.1 Uncertainty About Turtle Habitat Area

To quantify injuries of small juvenile sea turtles, the Trustees assumed that the entire exposure area of the DWH oil footprint represented potential turtle habitat at some point during the spill. This assumption clearly has a significant effect on the total injury estimate. If potential sea turtle habitat could be better defined in time and space (e.g., using habitat models to estimate the areas in which rescue crews would have searched based on environmental characteristics of areas that they were able to search) it is possible that the total estimated area in which turtles would have been exposed would have been smaller than what we estimated. This scenario would have resulted in lower injury quantification than presented in this assessment.

However, because the dataset of turtle observations that was the basis of the small juvenile abundance and exposure estimates was not based on a structured survey design—like the aerial survey dataset

used to collect observations and estimate abundance of turtles on the continental shelf—statistically describing potential turtle habitat was not feasible. Furthermore, the assumption that average turtle densities could be applied across the cumulative oil footprint is reasonable for multiple reasons. First, given the extensive and constant movement of surface habitat with which these turtles are associated, *Sargassum* and convergence habitat could and does move throughout the northern Gulf of Mexico (see Section 4.4, Water Column). *Sargassum* grows at roughly four percent per day, and is typically entrained in surface currents. Second, although small juvenile sea turtles are also typically entrained in these surface convergence zones, they are also capable of active, directed swimming (Putman & Mansfield 2015), which means that they can cross areas that might not be identified as putative turtle habitats.

On this basis, the Trustees concluded that the injury assessment for small juvenile turtles produced reasonable results that adequately describe the total injuries to this life stage.

#### 4.8.5.4.2 Uncertainty Associated with Mortality Estimates of Non-Heavily Oiled Turtles

As described in detail, the Trustees concluded that heavily oiled small juvenile turtles would likely have died without medical intervention (see Section 4.8.4.4, Mortality Estimates for Turtles Based on Degree of Oiling). This assessment was based on evaluation of physical effects of miring in oil, including ingestion and internal exposure. Furthermore, this conclusion formed the basis of the modeling approach that assigned probabilities of heavy oiling to turtles based on spatial and temporal proximity to surface oil (Wallace et al. 2015). However, the Trustees had less certainty about mortality estimates for turtles that were exposed to oil but to a degree less than that observed for heavily oiled turtles. This was mainly due to the lack of conclusive adverse effects caused by oil exposure observed in 1) clinical parameters measured in oiled turtles brought to rehabilitation centers (Stacy & Innis 2012), and 2) results of the surrogate turtle toxicity study (Mitchelmore & Rowe 2015).

The toxicologist panel developed a 30 percent mortality estimate for non-heavily oiled turtles based on interpreting these studies in the context of existing literature that reported oil-induced physiological abnormalities in other vertebrates (Section 4.8.4.4.2, Mortality Estimates for Turtles That Were Exposed, But Not Heavily Oiled; (Mitchelmore et al. 2015)). Because this mortality rate was applied to all exposed turtles that were not heavily oiled, it had a numerically significant effect on the total injury estimates. Given the uncertainty about toxicological effects of oil exposure on turtles (Section 4.8.4.2, Toxic Effects of Oil on Turtles and Their Habitats; (Mitchelmore & Rowe 2015; Mitchelmore et al. 2015)), the 30 percent mortality rate applied to the non-heavily oiled turtles—and the resulting injury estimates—represents the high end of reasonable values. Nonetheless, it is realistic to conclude that mortality occurred due to exposure to oil at levels that did not reach the heavily oiled category.

#### 4.8.5.4.3 Unquantified Injury to Leatherbacks

Leatherback turtles were sighted within the DWH oil spill footprint during offshore rescue efforts and aerial surveys over the continental shelf during the DWH oil spill. However, several factors prevented the Trustees from being able to quantify leatherback injuries caused by the DWH oil spill. First, because leatherbacks do not typically associate with convergence areas that were the targets of field crews searching for small juvenile turtles of other species (Bolten 2003), densities of leatherbacks could not be estimated within the searched area. Second, too few leatherbacks were seen during aerial surveys to include leatherbacks in abundance modeling conducted for other species. Third, due to logistical constraints related to leatherbacks' massive size and competing resource needs that prevented

allocation of a dedicated effort, the Trustees could not capture leatherbacks to assess their degree of oiling and associated health status.

For these reasons, the Trustees did not estimate leatherback abundance and exposure in the DWH spill area. However, given that the northern Gulf of Mexico is important habitat for leatherback migration and foraging (Turtle Expert Working Group 2007), and documentation of leatherbacks in the DWH oil spill zone during the spill period, the Trustees conclude that leatherbacks were exposed to DWH oil, and some portion of those exposed leatherbacks likely died.

#### 4.8.5.4.4 Strandings on Beaches Are a Poor Indicator of Oil-Caused Mortality of Sea Turtles

As mentioned previously (Section 4.8.3.3.2, Observations of Turtles on Continental Shelf and on Beaches), strandings represent a small fraction of total mortality, and generally are not representative of mortality occurring further from shore or in areas where animals are unlikely to be found (Epperly et al. 1996; Hart et al. 2006; Nero et al. 2013; Williams et al. 2011). To examine the probabilities that animal carcasses would reach coastlines depending on when and where they died and began to drift, the Trustees performed particle drift modeling to simulate how animal carcasses would likely move and possibly strand in the northern Gulf of Mexico (Wirasaet et al. 2015). Results demonstrated that animals that died on the outer portion of the continental shelf and remained floating at the surface would have had an extremely low probability of stranding (< three percent, regardless of date).

Indeed, the vast majority of turtles that the Trustees estimated to have died were located tens of kilometers (or more) from shore (Figure 4.8-20 and Figure 4.8-23), and very few stranded animals had evidence of oil exposure. Animals that died within a few kilometers of shore had a higher probability of stranding, but the strandings simulation model showed that particles appeared to strand in areas where detection was low or non-existent (e.g., Chandeleur Islands).

In summary, turtles that became impaired or died at sea beyond areas very close to shore (< 5–10 kilometers) or stranded within areas where the coastline is predominantly marsh or other relatively inaccessible habitat (e.g., much of the Louisiana coast) were extremely unlikely to have come ashore or to be found even if they did reach shore. Therefore, the Trustees concluded that turtles dying from acute effects of the spill were unlikely to be found on shore as strandings. Further, most animals that are recovered are too decomposed to determine cause of death. For these reasons, strandings were not used to quantify the magnitude of injury to sea turtles caused by DWH oil exposure.

#### 4.8.5.4.5 Turtles That Were Sighted But Not Identified to Species

The Trustees estimated exposed and injured sea turtles that were not identified to species (Table 4.8-4, Table 4.8-6, and Table 4.8-7). These animals were sighted during rescue operations or aerial surveys, but due to various factors, including turtles evading capture attempts by rescue workers, challenging visibility conditions, and others, species identification was not possible. Nonetheless, they were included in quantification of exposure and injury because they represent confirmed locations of sea turtles within the DWH spill footprint and time period. Given the uncertainty about these injuries, restoration approaches to reduce principal threats to sea turtles across geographic areas will be most effective in restoring the full magnitude of sea turtle injuries, including turtles that were not identified to species.

#### 4.8.5.4.6 Unquantified Injury Due to Marine and Terrestrial Response Activities

The Trustees also estimated that hundreds more turtles were killed by collisions with response watercraft. In addition, many turtles were likely killed during other response activities such as oil skimming and burning operations (turtles in the latter group were likely accounted for in the offshore injury quantification). Although insufficient data were available to permit a robust quantification, the Trustees concluded that total injuries caused by marine response injuries were likely to be at least hundreds of sea turtles.

While there was a significant effort to translocate as many eggs as possible in 2010, not all nests were found. Oil eventually did come ashore, and extensive monitoring and cleanup activities were conducted on many of the northern Gulf of Mexico sea turtle nesting beaches. Therefore, there was an unquantified injury to nests (eggs) and/or hatchlings emerging from nests that were missed on nesting beaches where oil came ashore and where response activities took place. These nests (eggs) and/or emergent hatchlings were likely killed.

#### 4.8.5.4.7 Unrealized Kemp's Ridley Reproduction Due to Oil Exposure of Adult Females and Recruitment Failures

As described above in Section 4.8.4.7 (Reduced Kemp's Ridley Nesting Abundance and Hatchling Production), the Kemp's ridley population has gone from high abundance to near extinction to significant recovery over the past 50 plus years, since scientific discovery of the species' primary nesting location in Tamaulipas, Mexico, in 1947 (Gallaway et al. 2013; NMFS et al. 2011). Estimated abundance peaked in the 1940s, but declined to its lowest level in the 1980s. Owing to increased conservation efforts in the 1980s and early 1990s, the nesting population increased exponentially from the mid-1980s through 2009. However, nesting was lower than expected in 2010, and has been lower than expected every nesting season since (Figure 4.8-15; (Dixon & Heppell 2015; Gallaway et al. 2013)). The reduction in expected nests, based on the trajectory of nest counts prior to 2010, continues to be a critical concern and focus of analysis efforts. The DWH oil spill is one potential factor contributing to the observed decline in Kemp's ridley nesting relative to projected abundance increases based on trends from 1996 through 2009 (Crowder & Heppell 2011; Gallaway et al. 2013; NMFS et al. 2011).

The Trustees quantified mortality of Kemp's ridleys on the continental shelf during 2010 (Section 4.8.5.1.2, Exposure and Injury Quantification of Large Juvenile and Adult Sea Turtles in Continental Shelf Areas; Table 4.8-6). Between 400 and 600 adult (ages 12+ years old) and between 300 and 450 sub-adult (approximately 9–11 years old) Kemp's ridleys were killed on the continental shelf during 2010 based on the validation exercise described in Section 4.8.5.1.2 (Exposure and Injury Quantification of Large Juvenile and Adult Sea Turtles in Continental Shelf Areas). These approximately 1,000 animals included reproductive females and sub-adults that would have recruited to the breeding population between 2011 and the present. The loss of these reproductive-stage females would have contributed to some extent to the decline in total nesting abundance observed between 2011 and 2014 (Figure 4.8-15).

Using published sex ratios (i.e., the proportion of females to males) (NMFS et al. 2011) to account for only the females among these dead adult Kemp's ridleys, estimated DWH injuries would equate to roughly 10–20 percent of the average annual nesting female abundance estimated between 2005 and 2010 (NMFS et al. 2011). Using conservative values for sex ratios, clutches per female, egg to hatchling survival, and hatchlings per clutch (NMFS et al. 2011), the estimated number of unrealized Kemp's ridley

nests was between 1,300 and 2,000, which translates to approximately 65,000 and 95,000 unrealized hatchlings (Table 4.8-7).

This unrealized reproduction accounts for less than three percent of the estimated cumulative deficit of approximately 79,000 nests from 2011 to 2014 (Figure 4.8-15; (Dixon & Heppell 2015)). However, the relationship between the injury we quantified here and unrealized reproduction represents a portion, but not all, of the overall potential DWH effect. Sub-lethal effects of DWH oil on turtles, their prey, and their habitats might have delayed or reduced reproduction in subsequent years and also contributed substantially to the observed deviation from projected nest abundance. These sub-lethal effects could have slowed growth and maturation rates, increased remigration intervals, and decreased clutch frequency (number of nests per female per nesting season) of Kemp's ridley turtles, as reported in other sea turtle species when resource availability is reduced (Wallace & Saba 2009). However, the actual nature and magnitude of the DWH effect on reduced Kemp's ridley nesting abundance and associated hatchling production after 2010 requires further evaluation.

Injuries to adult turtles of other species, such as loggerheads, certainly would have resulted in unrealized nests and hatchlings to those species as well. However, we restricted this illustrative calculation of unrealized nests and hatchlings to Kemp's ridleys for several reasons. All Kemp's ridleys in the Gulf belong to the same population (NMFS et al. 2011), so total population abundance could be calculated based on numbers of hatchlings because all individuals that enter the population could reasonably be expected to inhabit the northern Gulf of Mexico throughout their lives. In contrast, other species present in the Gulf that were injured by the DWH oil spill—e.g., loggerheads—come from multiple breeding populations, and not all individuals from all breeding populations inhabit the northern Gulf of Mexico. Therefore, calculating the number of adults and sub-adults was not feasible with available data, and the number of unrealized hatchlings resulting from injuries to breeding turtles could not be verified by evaluation of nesting trends for a particular population. In summary, any injury to adult sea turtles of any species caused by DWH reduced total hatchling production, which would have a negative effect on the overall population.



#### 4.8.5.5 Summary of Injury Quantification

In this section, the Trustees presented quantification of total injuries to sea turtles across life stages and geographic areas based on a synthesis of observations and evaluations of exposure pathways (Section 4.8.3, Exposure) and effects (Section 4.8.4, Injury Determination). Despite uncertainties and unquantified injuries, the Trustees concluded that these injury estimates adequately describe the nature and magnitude of total injuries to sea turtles caused by the DWH oil spill and associated response injuries.

### 4.8.6 Conclusions and Key Aspects of the Injury for Restoration Planning

#### 4.8.6.1 Summary

Based on the Trustees' quantification of sea turtle injuries caused by the DWH oil spill, sea turtles from all life stages and all geographic areas were lost from the northern Gulf of Mexico ecosystem. In particular, up to hundreds of thousands of small juvenile turtles died from DWH oil exposure and response activities. These animals are noteworthy because they belong to a unique, ephemeral community consisting of open-ocean, surface-dwelling fauna (e.g., juvenile fish and invertebrates) and

flora (e.g., *Sargassum*) that is distributed in non-uniform, non-stationary clumps, strips, and patches across the northern Gulf of Mexico. Additionally, DWH oil caused significant losses of *Sargassum* habitat itself, which further compounds the impacts on sea turtles and their ability to recover (see Section 4.4, Water Column).

Specifically, the injury assessment showed that:

- Four species of sea turtles that inhabit the Gulf were injured by the DWH oil spill (Kemp's ridley, loggerhead, green, and hawksbill). A fifth species, the leatherback, was likely exposed to DWH oil in the northern Gulf of Mexico, and some leatherbacks that were exposed likely died; however, quantification of leatherback injury was not undertaken. All of these species are listed as threatened or endangered under the Endangered Species Act (ESA), are long-lived, and travel widely, occupying a variety of habitats across the Gulf and beyond.
- Sea turtles were injured by oil in the open ocean, nearshore, and shoreline environments and resulting mortalities spanned multiple life-stages. The Trustees estimated that between 4,900 and as many 7,600 large juvenile and adult sea turtles (Kemp's ridleys, loggerheads, and hardshelled sea turtles not identified to species), and between 56,000 and as many as 166,000 small juvenile sea turtles (Kemp's ridleys, green turtles, loggerheads, hawksbills, and hardshelled sea turtles not identified to species) were killed by the DWH oil spill.
- Nearly 35,000 hatchling sea turtles (loggerheads, Kemp's ridleys, and green turtles) were injured by response activities, and thousands more Kemp's ridley and loggerhead hatchlings were lost due to unrealized reproduction of adult sea turtles that were killed by the DWH oil spill.
- In addition, the injury assessment included injuries that were determined to have occurred, but were not formally quantified, such as unquantified injuries to leatherback turtles.

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

#### 4.8.6.2 Ecosystem Effects

Sea turtles have been integral and long-term members of marine ecosystems for countless generations. Significant losses of sea turtles remove them from complex inter-species relationships and ecological processes, such as transport of nutrients between marine and terrestrial habitats, likely impacting the northern Gulf of Mexico marine ecosystem (Bjorndal & Jackson 2003). In addition to serving important ecological roles, sea turtles are also extremely valuable natural resources to humans. Sea turtles' protected status under the ESA – as well as their status under international conservation treaties and agreements (e.g., IAC, CITES, IUCN *Red List*) – means that they are considered to be in danger of extinction if current threats are not reduced. In addition, their ESA listed status means that the public values their continued existence as well as efforts to recover and protect them. Sea turtles are also valuable to the public as subjects of wildlife-viewing activities, whether through formal ecotourism or informal enjoyment of nature. In nearly every country in the world where sea turtles are present, particularly where they nest, people make efforts to observe sea turtles in the wild. This is especially true in the United States, including in Gulf Coast states.

### 4.8.6.3 Recovery

Sea turtle populations can recover when primary threats are reduced or eliminated, provided sufficient abundance remains (Dutton et al. 2005; NMFS et al. 2011), and sufficient habitat resources are available (Wallace & Saba 2009). However, the majority of historically depleted sea turtle populations worldwide tend to show slow recovery, and some show no recovery at all, despite decades of conservation management efforts (Williams et al. 2011). Slow recovery is common because sea turtles have decades-long lifespans, overlapping generations, and wide distributions over which resource availability and impacts of threats can vary tremendously. Additionally, the differences in or lack of regulatory regimes among nations complicate and can impede recovery. Therefore, given the combination of sea turtle life history traits and the magnitude of the quantified injuries, recovery of sea turtle populations affected by the DWH oil spill to baseline levels would be expected to take decades if no restoration actions were taken.

The complex and transient nature of the sea turtle population structure and the significant magnitude of the mortality resulting from the DWH oil spill will make complete recovery challenging. This is partly due to the fact that precisely assessing the structure and abundance of sea turtle populations is difficult due to the significant logistical and technical challenges associated with obtaining robust estimates of vital rates, including life stage-specific survivorship and life stage durations. For these reasons, the Trustees conclude that the recovery of sea turtles in the northern Gulf of Mexico from injuries caused by the DWH oil spill will require decades of sustained efforts to reduce the most critical threats and enhance survival of turtles at multiple life stages.

### 4.8.6.4 Restoration Considerations

As described in Chapter 5 (Section 5.5.10 and 5.5.2), the Trustees have identified an integrated portfolio of restoration approaches that can address all species and life stages that were injured by the spill, and takes into consideration key threats to sea turtles.



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