4.7 Birds

What Is in This Section?

Executive Summary

The Trustees documented large-scale and pervasive bird injuries in the northern Gulf of Mexico as a result of the *Deepwater Horizon* oil spill. This chapter describes the work conducted by the Trustees to determine and quantify injuries to birds resulting from the *Deepwater Horizon* spill.

Birds are highly valued and ecologically important components of the northern Gulf of Mexico ecosystem. This region supports a diversity of coastal bird species throughout the year, as nesting grounds during the summer, as a stop-over for migrating species in the spring and fall, and as wintering habitat for numerous species that breed elsewhere. The *Deepwater Horizon* oil spill exposed dozens of species of birds to oil in a variety of northern Gulf of Mexico habitats, including open water, island waterbird colonies, barrier islands, beaches, bays, and marshes. Birds were exposed to oil in several ways, including physical contact with oil in the environment; ingestion of external oil during preening; and ingestion of oil while foraging, through consumption of contaminated prey, water, or sediment.

The Trustees conducted controlled laboratory evaluations of toxicological, metabolic, and physical responses to *Deepwater Horizon* oil exposure. These laboratory studies demonstrated that ingestion and external exposure to *Deepwater Horizon* oil caused an array of adverse effects including anemia, weight loss, hypothermia, heart and liver abnormalities, feather damage, reduced flight capability, and death. These studies indicated the many ways in which birds that were exposed to *Deepwater Horizon* oil were affected, and highlight how exposure led to reduced health and subsequently death for some birds.

The Trustees also conducted a series of studies to quantify bird injury from the *Deepwater Horizon* oil spill. Total quantified bird injury, including both mortality and lost reproduction, was estimated to be between 56,100 and 102,400 individuals of at least 93 species. These quantified injuries represent only a portion of the total bird injury, as these do not reflect all injury thought to have occurred to marsh birds and colonial waterbirds, as well as nonlethal injuries such as impaired health.

Field studies during the spill documented numbers and distributions of thousands of bird carcasses and oil-impaired live birds collected on beaches and marsh edges. Also, thousands of externally-oiled, live birds were observed. In addition, surveys were conducted in offshore, open water habitats (greater than 25 miles [40 kilometers] from shore) to determine birds at risk from oil on the water surface. Based on these data and a series of models that use the data to generate mortality estimates, the Trustees estimated that mortality ranged from 51,600 to 84,500 individual birds. Although these estimates only addressed a portion of the bird mortality, uncertainties associated with the quantification approaches indicate that mortalities for this modeled injury were likely towards the higher end of this range. The Trustees also estimated the reproductive output lost as a result of breeding adult bird mortality; this was estimated to range from 4,600 to 17,900 fledglings that would have been produced in the absence of premature deaths of adult birds as a result of the *Deepwater Horizon* oil spill, after accounting for dead fledglings that were quantified using other methods. The Trustees determined that limitations and uncertainties would likely contribute to an overall underestimate of fledglings lost due to the spill. Given the available information, the results presented here are the best estimate of fledglings lost due to the spill, recognizing that the true loss is likely higher by some unquantifiable amount.

The quantified injury described above captured only a portion of overall injury to birds. *Deepwater Horizon* oil penetrated into marsh, which is important bird habitat. Exposure and mortality of interior marsh birds was not estimated by the Trustees; however, given densities of key species, meaningful injury to marsh birds was very likely to have occurred. Similarly, island waterbird colonies were occupied by hundreds of thousands of breeding birds at the time of the spill. Although some mortality in colonies was included in quantification, the Trustees recognize that these methods were inadequate for fully describing the magnitude of injury at colonies. In addition, bird injury almost certainly occurred in the forms of poorer health, protracted exposure, and delayed effects, none of which were quantified by the Trustees.

Birds are important components of marine ecosystems across the globe. They are highly responsive to variation in prey, and also exert top-down effects on the number and distribution of prey species. They also are abundant and have high metabolic rates, and thus exhibit high food consumption relative to other taxa, which increases their influence on marine communities. Birds also serve as prey for other species, and changes in the prey base could have effects on top level predators. The Trustees, therefore, expect that the loss of birds as a result of the *Deepwater Horizon* oil spill would have meaningful effects on food webs of the northern Gulf of Mexico.

4.7.1 Introduction and Importance of the Resource

Key Points

- Over 150 species of birds occur in waters and wetlands of the northern Gulf of Mexico for at least a portion of their lives; nearly 300 species use either open water, the coast itself, or coastal upland habitats directly adjacent to the Gulf.
- Birds are highly valued and ecologically important components of the northern Gulf of Mexico ecosystem; providing recreational, aesthetic, and economic value and playing vital roles in ecosystems by serving as both predators and prey in many food webs.
- The *Deepwater Horizon* oil spill affected numerous species of birds in four general habitat types in the northern Gulf of Mexico:
    - **Nearshore habitats** (including nearshore waters, beaches, and marsh edge) support a diversity of resident and migratory birds, including shorebirds, waterfowl, wading birds, and many others.
    - **Offshore/ open water habitats** are used by birds that feed on fish and zooplankton near the water surface and by birds that use *Sargassum* mats as resting spots. Offshore birds include boobies, shearwaters, storm petrels and several species of terns.
    - **Island waterbird colonies** are used as nesting areas by a variety of species, including brown pelicans, laughing gulls, and terns. During the breeding season, a substantial proportion of birds in the northern Gulf of Mexico occur in coastal island waterbird colonies.
    - **Interior marshes** support numerous specialized resident and migratory birds, including clapper rails and seaside sparrows.

The *Deepwater Horizon* oil spill released more than 3 million barrels of oil into ecosystems of the northern Gulf of Mexico (Section 4.2, Natural Resource Exposure). Released oil from the spill contaminated extensive areas of nearshore, offshore, coastal island, and marsh habitats that support numerous bird species. As expected in a spill of this magnitude, birds and bird habitats were significantly affected (Figure 4.7-1). This section describes the array of exposure pathways and injuries documented by the Trustees and quantifies some components of injury to birds.

Sources: *U.S. Department of the Interior (top left, top right, bottom left, bottom right) and Louisiana Department of Wildlife and Fisheries (bottom middle).*

Figure 4.7-1. Examples of bird habitat contamination and bird injury resulting from the *Deepwater Horizon* oil spill. Top left: Oiled marsh habitat; Top right: Oiled sandy beach habitat; Bottom left: Oiled open water habitat; Bottom middle: Dead oiled bird on sandy beach; Bottom right: Live oiled bird captured for rehabilitation.

Oil spills are widely understood to injure birds. Examples include: *Exxon Valdez* (Iverson & Esler 2010; Munilla et al. 2011; Piatt & Ford 1996), *Prestige* (Munilla et al. 2011), *Cosco Busan* (Cosco Busan Oil Spill Trustees 2012), *Luckenbach* (Luckenbach Trustee Council 2006), *Kure* (CDFG & FWS 2008), *New Carissa* (DOI et al. 2006), *Apex Houston* (CDFG et al. 2007; USFWS et al. 2011), and *Bean Stuyvesant* (CDFG et al. 2007). Accordingly, the Trustees conducted numerous studies to evaluate bird injuries resulting from the *Deepwater Horizon* oil spill.

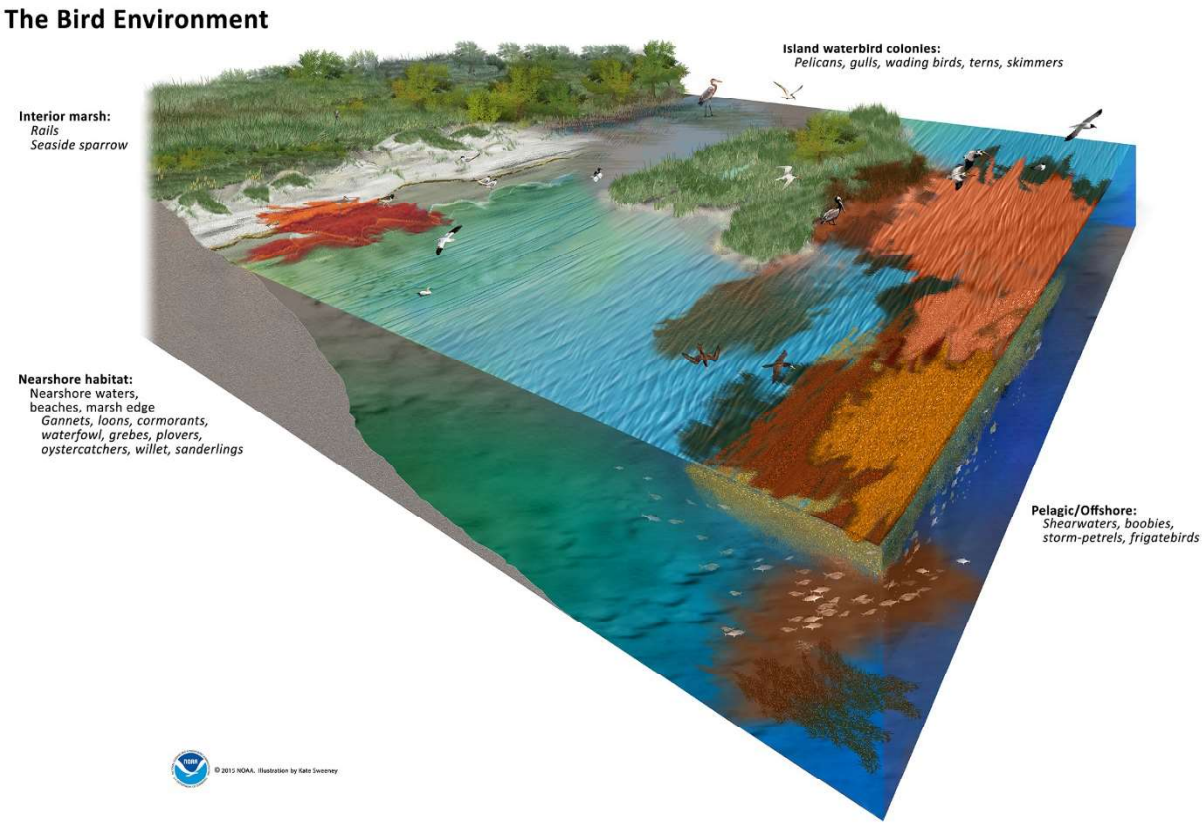
Marine and coastal birds are highly susceptible to oil spill effects because of their use of the water surface, where oil tends to concentrate because of its buoyancy. Bird feathers absorb oil, which leads to ingestion through preening, loss of thermoregulation, and reductions in flight performance. Finally, birds are susceptible to ingestion of oil-contaminated prey, sediment, or water. Densities of birds are particularly high along the coastlines and marshes, where extensive oiling occurred and persisted.

Birds, including those inhabiting the northern Gulf of Mexico, have high societal value. Birds are easily recognized and valued members of coastal ecosystems, and injury to birds following oil spills invariably leads to immediate public demands for bird rehabilitation and restoration. In addition to their appeal to the general public, birds also have significant direct economic contributions. For example, both consumptive (migratory bird hunting) and non-consumptive (bird watching) activities generate billions

of dollars annually in economic activity in the United States (USFWS 2013). In addition to their recreational, aesthetic, and economic values, birds play vital roles in ecosystems, serving as both predators and prey in many food webs.

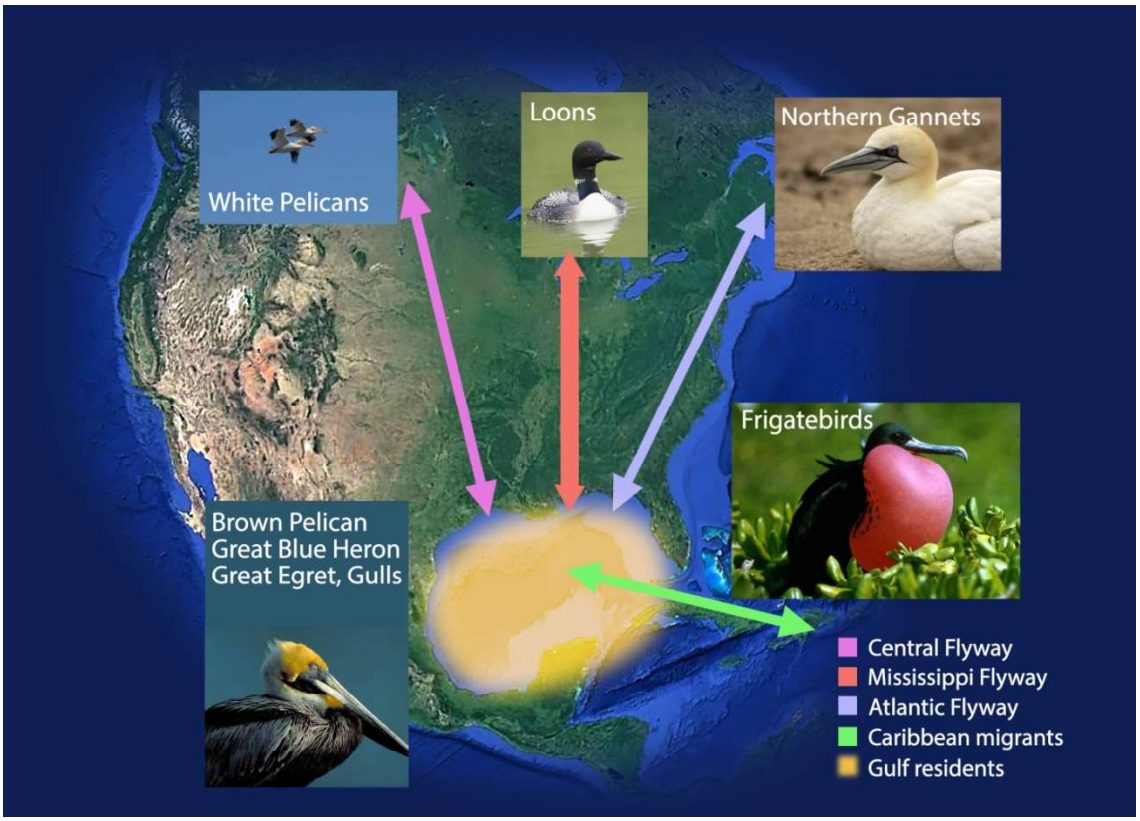
4.7.1.1 Bird Diversity and Habitats in the Northern Gulf of Mexico

The northern Gulf of Mexico consists of a variety of habitats that support a diverse and abundant assemblage of birds (Figure 4.7-2). Approximately 150 species of birds occur in waters and wetlands of the northern Gulf of Mexico for at least a portion of their lives and nearly 300 species use either open water, the coast itself, coastal marshes or coastal upland habitats directly adjacent to the Gulf (e.g., coastal plain, cheniers, etc.). Depending on the species, birds use the northern Gulf of Mexico for their entire life cycle, as a migratory stopover, or as a wintering area. The northern Gulf of Mexico intersects with three of the four major migration flyways in North America, including the Central, Mississippi, and Atlantic Flyways (Figure 4.7-3).



Source: *Kate Sweeney for NOAA.*

Figure 4.7-2. Birds of the northern Gulf of Mexico occur in four general habitat types: nearshore, offshore, coastal islands with breeding colonies, and interior marsh, all of which were affected by the *Deepwater Horizon* oil spill. Examples of birds that occur in these habitats are given.



Source: *Kate Sweeney for NOAA.*

Figure 4.7-3. Where do birds injured by the *Deepwater Horizon* oil spill come from? Species listed are examples within each category.

There are four broad habitat types in the area of the northern Gulf of Mexico affected by the *Deepwater Horizon* oil spill (Figure 4.7-2). Each of these habitats is occupied by somewhat distinct bird assemblages (Table 4.7-1). Within the core impacted spill area, a number of National Wildlife Refuges, National Parks, State Parks, State Wildlife Management Areas and Refuges, and other protected lands provide habitat for both resident and migratory bird species. Some of these public lands, such as Breton National Wildlife Refuge and Isle Dernieres Louisiana State Refuge, were created specifically for protection and conservation of birds.

Table 4.7-1. Bird habitats exposed to *Deepwater Horizon* oil in northern Gulf of Mexico.

Habitat Classification	Examples of Injured Species That Use Each Habitat
Offshore/Open Water	Shearwaters, storm-petrels, frigatebirds, terns
Nearshore	
Nearshore waters	Gannets, loons, cormorants, waterfowl, grebes,
Beaches	Shorebirds, wading birds
Marsh edge	Gulls, pelicans, wading birds, shorebirds, black skimmers
Interior Marsh	Rails, seaside sparrows, waterfowl, wading birds
Island Waterbird Colonies	Pelicans, gulls, wading birds, terns, black skimmers

4.7.1.1.1 Nearshore Habitats

Nearshore habitats (waters, beaches, and marsh edges) of the northern Gulf of Mexico support a diversity of resident and migratory birds, including the federally endangered piping plover and the federally threatened red knot. Birds use multiple nearshore habitats (including shallow waters, beaches, and marsh edge) for nesting, feeding, and resting. Nearshore areas are important migration and wintering habitat for significant numbers of the continental waterfowl populations that use the Atlantic, Mississippi, and Central flyways (Figure 4.7-3). The Southeastern United States Regional Waterbird Conservation Plan identified nearshore habitats as among the most important for colonial birds, especially herons, ibises, pelicans, cormorants, skimmers, terns and gulls, and non-colonial birds such as rails (Hunter et al. 2006). It is also important for gannets, loons, shorebirds, and grebes. Oil from the *Deepwater Horizon* spill affected all nearshore habitats.

The nearshore marsh edge provides habitat for marsh-associated shorebirds, wading birds, gulls, terns, and other bird species. Marsh edge habitat also includes periodically exposed mudflats and tidal flats on the leading edge of marshes, which provide critical foraging areas.

Sandy beach habitats (primarily beaches, dunes, sand bars, and sandy inlet shorelines) provide services to numerous resident and migratory birds. They provide nesting areas for several solitary nesting shorebirds (e.g., American oystercatcher, snowy plover, and Wilson's plover), as well as colonial black skimmers, laughing gulls, and several species of terns.

4.7.1.1.2 Offshore/Open Water Habitat

Offshore birds heavily utilize open water environments. Offshore birds include boobies, shearwaters, storm petrels and several species of terns. Some of these species, such as Audubon's shearwater and masked booby, are frequently found in offshore areas of the northern Gulf of Mexico (Davis et al. 2000; Ribic et al. 1997), but do not nest within the northern Gulf of Mexico. Offshore birds feed in flight on fish and zooplankton as the prey swim to the surface. Free floating mats of *Sargassum* algae are also an important offshore habitat feature (Haney 1986). Offshore birds feed on fish and other organisms that these mats attract and also use *Sargassum* mats as resting spots. In offshore open water areas, birds interacted with and were injured by surface oil from the *Deepwater Horizon* spill (Section 4.2, Natural Resource Exposure).

4.7.1.1.3 Island Waterbird Colonies

Waterbirds use islands as nesting areas; when these birds occur in high densities, the nesting areas are called colonies. During the breeding season, a substantial proportion of birds in the northern Gulf of Mexico occur in colonies; these large aggregations (thousands to tens of thousands of adults, juveniles, and chicks) were susceptible to high levels of injury in cases where *Deepwater Horizon* oil was deposited in or near colonies. Many species, including brown pelicans, gulls, terns, and wading birds, nest colonially on coastal islands or in trees and shrubs over wetlands, and forage in adjacent shallow waters. Brown pelicans, often in mixed aggregations with wading birds, primarily nest on offshore islands where colonies are largely free from predation by terrestrial mammals and free of human disturbance. Wading birds are a diverse group of birds that use their physical adaptations to walk or wade in shallow water. They include the great blue heron, great egret and snowy egret, as well as a number of other herons, egrets and bitterns.

4.7.1.1.4 Interior Marsh Habitat

Coastal marshes, including those within the spill-affected area, support high numbers of birds throughout the year. Marshes are highly productive and serve as nursery habitats for many species of fish, shrimp, and invertebrates. This diversity and availability of prey attracts many bird species. Marsh birds include year-round residents, such as clapper rails, seaside sparrows, pied-billed grebes, common gallinules, least bitterns, marsh wrens, egrets, herons, ibis, and mottled ducks, as well as winter residents such as long-billed curlews, soras, and many species of waterfowl (Woodrey et al. 2012). Oil that occurred on marsh edges, as well as that penetrating deeper into interior marsh habitats (Section 4.6, Nearshore Marine Ecosystem), contaminated habitat used by a variety of interior marsh birds.

4.7.2 Approach to the Assessment

Key Points

- The Trustees collected evidence demonstrating that birds were exposed to *Deepwater Horizon* oil in all coastal and open water habitats in which they occur.
- The Trustees conducted lab studies to evaluate physiological responses of birds exposed specifically to *Deepwater Horizon* oil.
- The Trustees conducted field studies to document numbers and distributions of bird carcasses and oil-impaired live birds.
- The Trustees used a number of methods to estimate bird mortality and lost reproduction as quantified injuries. The Trustees' assessment also included injuries that were not quantified but were significant.
- The Trustees used a "Shoreline Deposition Model" to quantify a portion of the nearshore bird mortality from April 20 to September 30, 2010—roughly when area-wide wildlife operations ceased. Because most dead or dying birds are never found, the model uses correction factors to account for several sources of loss of dead or impaired birds.
- The Trustees estimated bird mortalities in offshore open water habitat using an "Offshore Exposure Model," which determined the overlap between the distribution of oil and offshore birds and then estimated the degree of mortality.
- The Trustees also estimated mortality in areas that were not included in either the Shoreline Deposition or Offshore Exposure Models.
- The Trustees used a "Live Oiled Bird Model," which combined observations of rates and degrees of bird oiling with predictions of likelihood of mortality, to estimate a portion of nearshore bird mortality that occurred after September 30, 2010 for birds exposed to *Deepwater Horizon* oil through March 31, 2011.
- As the means to estimate lost productivity, the Trustees calculated the production of fledglings that would have occurred had breeding-aged birds not died. The Trustees applied species-specific annual productivity rates (average number of fledglings produced per

breeding pair) to the number of breeding-aged birds estimated through quantitative means to have died between April 2010 and April 2011.

- Although some portion of mortality that occurred at Island Waterbird Colonies was quantified, the Trustees recognized that mortality on colonies was substantially higher than the quantified estimates.
- Mortality within marshes was not quantified. Using estimates of densities of key marsh bird species, the Trustees illustrated the substantial scope of potential exposure of marsh birds to oil.

Reflecting the magnitude of the *Deepwater Horizon* oil spill, the Trustees undertook extensive efforts to document and quantify injury to birds. Over the course of the bird injury assessment, thousands of researchers, agency staff, and volunteers conducted a broad range of activities, as illustrated in Figure 4.7-4. These activities occurred across thousands of kilometers of coastline and huge expanses of open water throughout the northern Gulf of Mexico. As a result of these efforts, more than 8,500 dead and impaired birds were collected. More than 3,000 live birds were taken to rehabilitation centers; despite tremendous effort, more than half of these were too compromised to survive. Recognizing that collected birds represent only a fraction of true mortality, significant efforts were directed towards quantifying a portion of the number of birds killed based on the data available. In addition, controlled laboratory studies were conducted to understand the array of avian health effects resulting from exposure to *Deepwater Horizon* oil.

The bird injury assessment following the *Deepwater Horizon* spill can be broken down into three inter-related categories of activities, which are described in detail in Sections 4.7.3, Exposure; 4.7.4, Injury Determination; and 4.7.5, Injury Quantification. First, information was collected confirming that birds were exposed to *Deepwater Horizon* oil (see Section 4.7.3). To evaluate the physiological, metabolic, thermoregulatory, and functional consequences of observed *Deepwater Horizon* oil exposure, a number of controlled laboratory studies were conducted using captive birds (see Section 4.7.4, Injury Determination) (Ziccardi 2015). Field measurements of physiological impairment also were evaluated. The Trustees documented health effects that were likely to result in increased rates of mortality. Using several different modeling approaches (see Sections 4.7.4, Injury Determination; and 4.7.5, Injury Quantification), the Trustees also estimated a portion of the number of bird deaths as a result of the *Deepwater Horizon* oil spill (Table 4.7-2). For the bird mortalities that were quantified, the first year of lost reproduction of those birds was estimated for 2010 and 2011. In addition to quantified mortality and lost reproduction, the Trustees gathered information qualitatively indicating that additional mortality occurred in island waterbird colony and interior marsh habitats.

Table 4.7-2. Methods of assessment of bird mortality by time period and habitat (nearshore vs. offshore). Includes both quantitative and qualitative means of assessing injury.

	20 April to 30 September 2010	1 October 2010 to 31 March 2011
Nearshore	• Shoreline Deposition Model • Excluded Areas • Colony Sweeps • Qualitative Assessment for Interior Marsh • Qualitative Assessment for Colonies (in addition to Shoreline Deposition Model and colony sweeps) • Qualitative Assessment of Response Impacts	• Live Oiled Bird Model
Offshore	Offshore Exposure Model	

Sources: *Louisiana Department of Wildlife and Fisheries (top left) and U.S. Department of the Interior (top right, bottom left, bottom right).*

Figure 4.7-4. Examples of field activities performed by the Trustees as part of the bird injury assessment; Top left: Searching for bird carcasses; Top right: Collecting live, oiled birds; Bottom left: Cataloging collected bird carcasses; Bottom right: Conducting observations of live, oiled birds.

4.7.2.1 Effects of Oil on Birds

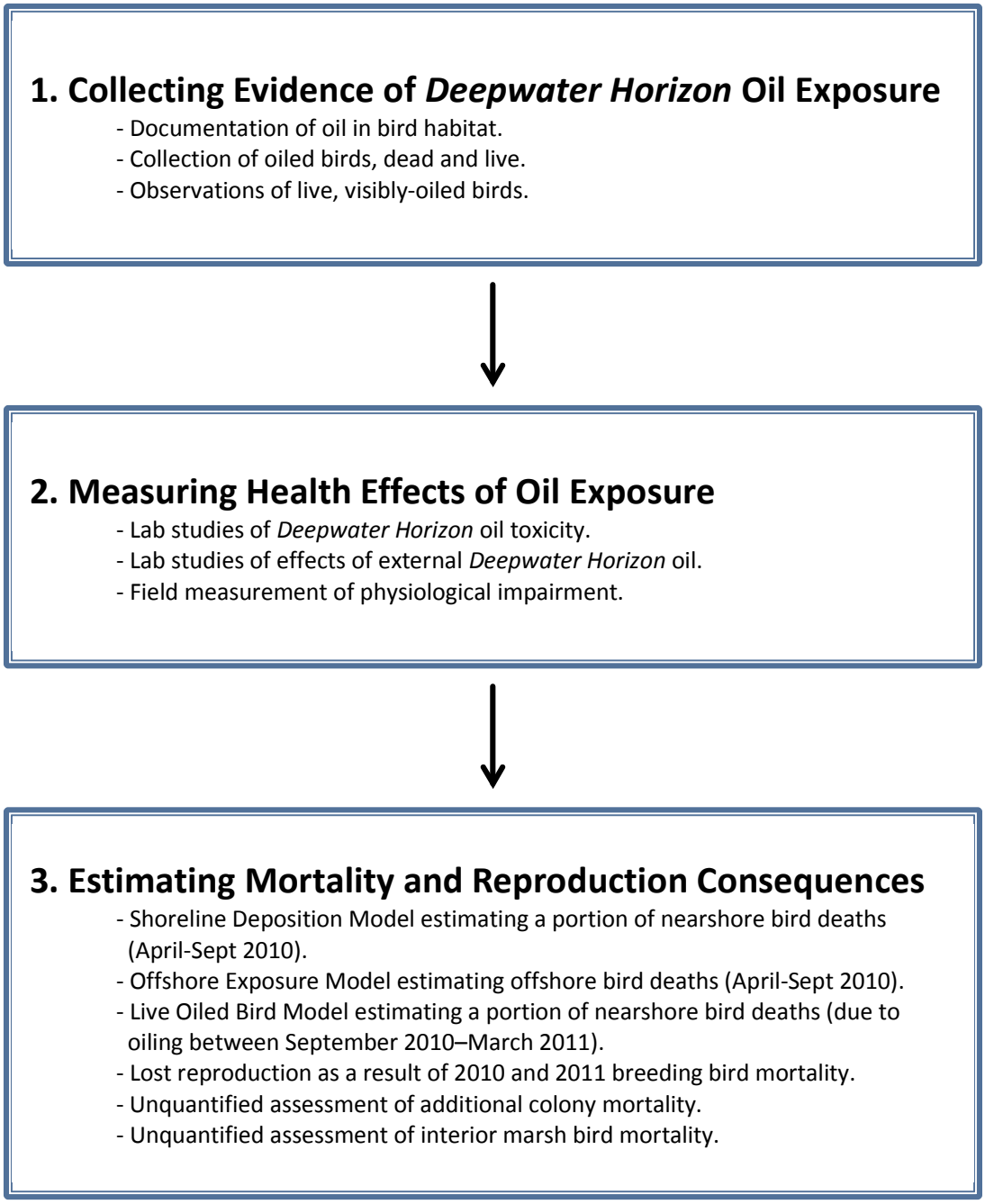
Previous studies have shown that exposure to oil adversely affects birds in a variety of ways; this information informed the approach to bird injury assessment in this case.

Oil can cause feathers to lose their waterproofing and insulating ability, resulting in a bird not being able to swim or float and allowing water to penetrate and wet the skin (Helm et al. 2015). Reduced ability to swim and float increases the energy needed for swimming and diving; these increased energy requirements may not be sustainable. Oil-damaged feathers also impair a bird's ability to fly.

In addition to the physical effects of oil, birds in oiled environments also may consume oil-contaminated food, water, or sediments, ingest oil when preening, and inhale oil fumes (volatile aromatic compounds). Oil ingestion or inhalation can lead to adverse impacts, including inflammation, immune system suppression, and damage to cells (Briggs et al. 1996; Fry et al. 1986; Golet et al. 2002; Leighton et al. 1985). These in turn impact growth, alter organ function, reduce reproductive success, and likely increase risk of disease (Alonso-Alvarez et al. 2007; Briggs et al. 1996; Eppley & Rubega 1990; Esler 2000; Helm et al. 2015). Reproductive effects include adverse hormone changes, delayed egg laying, impaired egg formation, decreased eggshell thickness, and reduced hatchability. Avian embryos, especially very young ones, are very sensitive to crude oil and refined petroleum products when these substances get on egg shells. Oil can be deposited on eggs when adults build nests with oil-contaminated materials or when adults get oil on their feathers and carry it back to the nest. Embryos die not only because the oil covers the shell and suffocates the egg, but also because some of the oil penetrates through the shell and is toxic to the embryo. Numerous examples in the literature indicate high levels of bird mortality caused by oil spills, during both immediate and longer-term periods following spills (e.g., Iverson and Esler (2010); Piatt and Ford (1996).

The Trustees conducted a number of controlled laboratory studies in which exposure to *Deepwater Horizon* oil, both through ingestion and external exposure on feathers, caused a number of adverse effects on bird health and survival (see Section 4.7.3.3, Consequences of Exposure and Ziccardi (2015)). Some effects observed in the laboratory were directly associated with bird deaths, and other documented effects were severe enough that they would be expected to cause increased mortality in wild birds. Understanding specific health effects of exposure provides an important link for understanding mechanisms that lead from oil exposure to mortality and reduced reproduction endpoints (Figure 4.7-5). They also highlight the potential for significant health effects that likely affected numerous birds that did not die during the first year after the spill.

The primary measures of bird injury for this assessment are mortality and reduced reproduction. These are factors known to be consequences of oil exposure experienced by birds following oil spills (see above). Effects of mortality and reduced reproduction can be expressed as numbers of birds removed from the ecosystem or never fledged, in the case of lost reproduction. Bird injury was assessed both quantitatively and qualitatively. Quantified injuries included birds killed in offshore habitats, a portion of the birds killed in nearshore habitats, a portion of the colonial birds that were killed, and reproductive losses in 2010-2011 resulting from the quantified bird mortalities. Unquantified injuries included other island colony birds, interior marsh birds, effects on bird health (including associated reduced survival rates after 2010), and impacts of response activities.



Source: *U.S. Department of the Interior.*

Figure 4.7-5. A description of the types of activities conducted during the bird injury assessment: 1. Collecting evidence of *Deepwater Horizon* oil exposure; 2. Measuring health effects of oil exposure; 3. Estimating mortality and reproduction consequences.

Additional information addressing avian injury following the *Deepwater Horizon* oil spill has been reported independent of the Trustees' assessment activities (Belanger et al. 2010; Bergeon Burns et al. 2014; Finch et al. 2011; Franci et al. 2014; Haney et al. 2014a, 2014b; Haney et al. 2015; Henkel et al. 2012, 2014; Montevecchi et al. 2011; Paruk et al. 2014; Sackmann & Becker 2015; Seegar et al. 2015; Walter et al. 2014). The Trustees have reviewed these publications and considered their findings as part of the bird injury assessment for the *Deepwater Horizon* oil spill.

4.7.3 Exposure

Key Points

- Oil released during the *Deepwater Horizon* oil spill contaminated open water, coastal islands, beaches, bays, and marshes. These habitats are used by more than 150 species of birds.
- Birds were exposed to oil through physical contact with oil in the environment; subsequent ingestion of external oil during preening; and ingestion of oil through consumption of contaminated prey, water, or sediment.
- More than 8,500 dead and impaired birds were collected during and following the spill. Of collected birds, more than 3,000 live individuals were taken to rehabilitation centers; more than half of these were too compromised to survive.
- Over 60 percent of captured, live, impaired birds had evidence of external oiling.
- More than 3,500 uncollected birds were observed with visible external oiling.

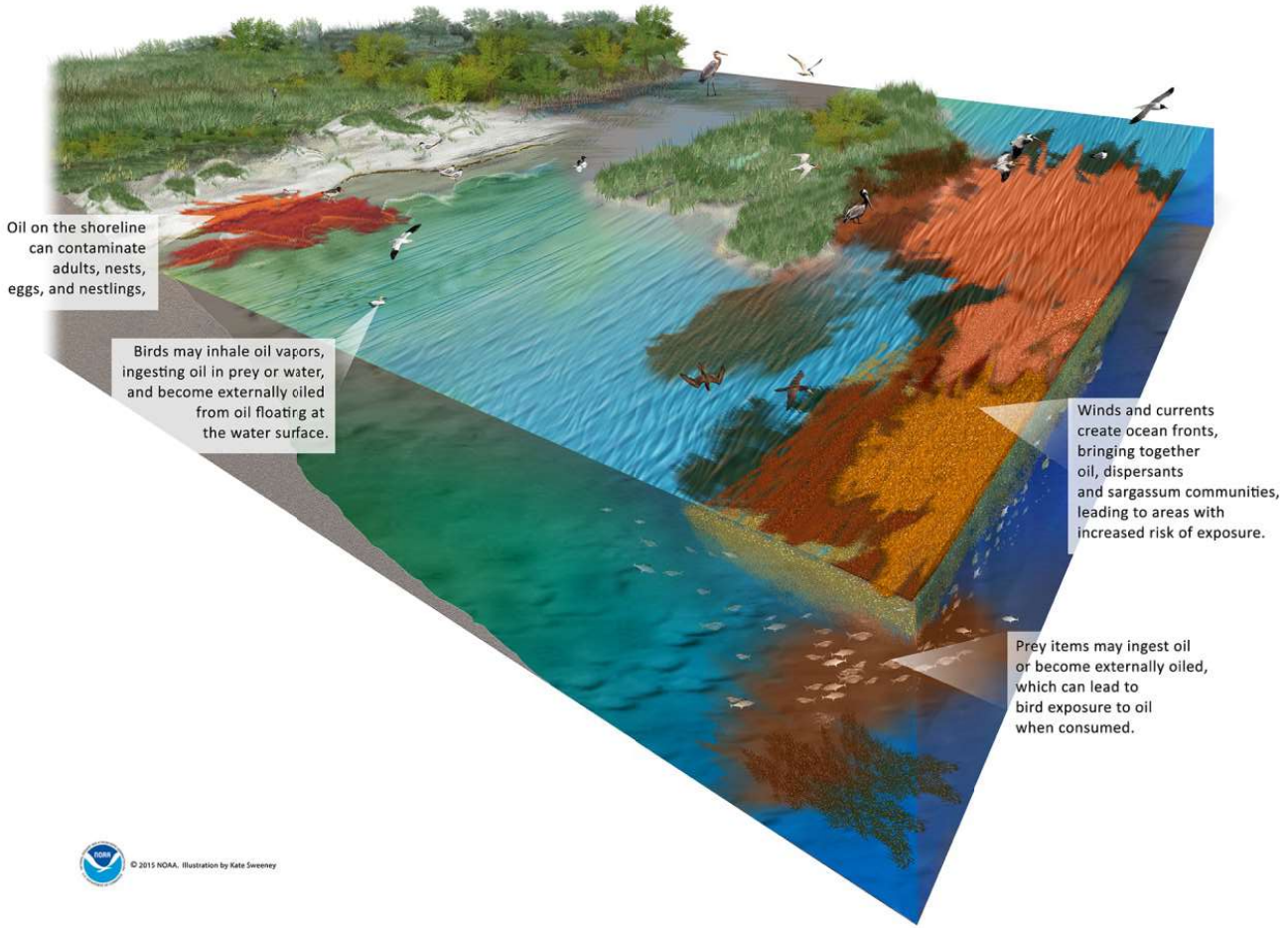
4.7.3.1 Distribution and Duration of *Deepwater Horizon* Oil in Bird Habitats

As described in Section 4.2 (Natural Resource Exposure), *Deepwater Horizon* oil contaminated the water surface (where birds rest and feed), the air (where birds fly and breathe), and various coastal habitats (where birds feed, roost, and nest). Oil was discharged into the environment over 87 consecutive days, resulting in a protracted period of habitat contamination and subsequent bird exposure. All the main bird habitat types described above in Section 4.7.1.1 (Bird Diversity and Habitats in the Northern Gulf of Mexico) were exposed to oil, leading to direct and indirect exposure of associated bird communities. *Deepwater Horizon* oil occurred cumulatively over 112,000 square kilometers of ocean surface during the course of the spill, exposing offshore birds to floating oil and oiled *Sargassum*. As the oil moved into nearshore habitats, a broad suite of birds became exposed. At least 2,113 kilometers of shoreline were estimated to have been oiled (Section 4.6, Nearshore Marine Ecosystem). Oil occurred in all nearshore habitats, including beaches, bays, marsh edges, and island waterbird colonies (Figure 4.7-6). Oil also penetrated into marshes, exposing a variety of bird species.

There were a number of pathways of oil exposure identified for birds (Figure 4.7-7). These included direct contact with oil in contaminated habitats, ingestion of oil during preening of external oil, ingestion of oil when foraging or drinking, as well as inhalation of oil vapors. Based on previous spills, these are well-known routes of exposure that are known to result in significant health and demographic consequences for exposed individuals (Section 4.7.3.3, Consequences of Exposure).

Source: *Louisiana Department of Wildlife and Fisheries.*

Figure 4.7-6. Contamination of island waterbird colony habitat by *Deepwater Horizon* oil. Photo shows royal tern adults and chicks and contaminated shoreline at Queen Bess Island, Louisiana.

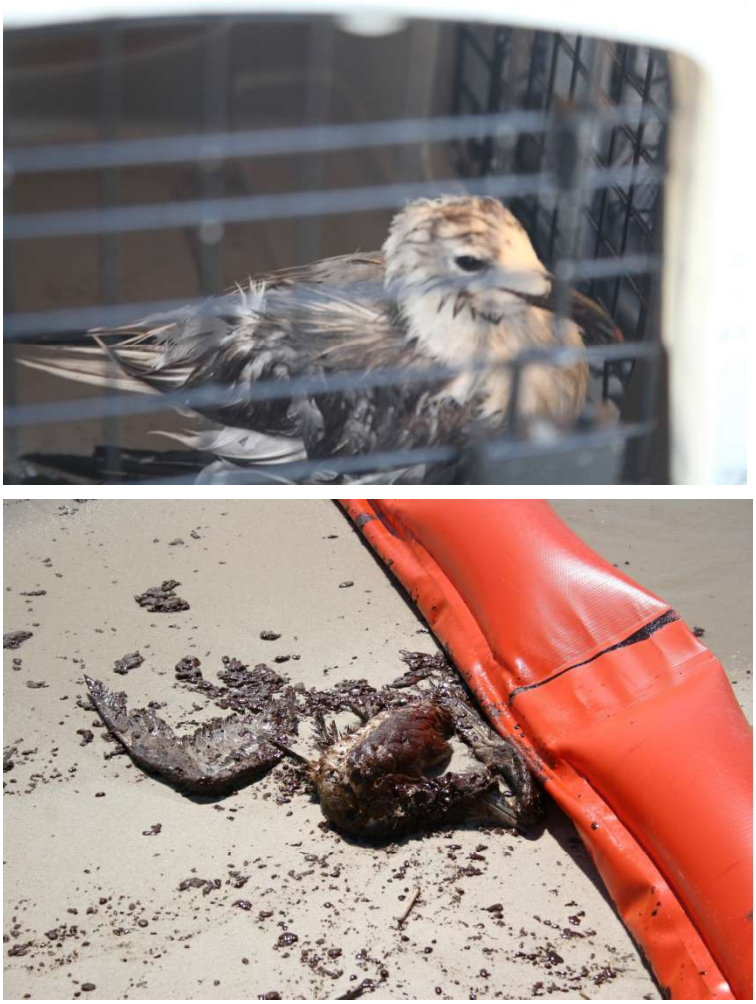


Source: *Kate Sweeney for NOAA.*

Figure 4.7-7. Routes of exposure of birds to *Deepwater Horizon* oil. Text boxes highlight specific details about potential exposure pathways and adverse effects to birds.

4.7.3.2 Evidence of Exposure

In addition to the spatial overlap of *Deepwater Horizon* oil with birds and their habitats described above, evidence of oil exposure included observation and collection of thousands of visibly oiled birds. Of the dead birds collected during the spill, a substantial proportion (greater than 30 percent) were visibly oiled (Figure 4.7-8). Similarly, over 60 percent of captured, live, impaired birds had evidence of external oiling. Collected or captured birds without visible external oiling were still very likely exposed to oil; this could have been the result of oil vapor inhalation, ingestion of contaminated prey, removal of oil by preening prior to collection (as observed in laboratory studies), or simply that external oil was not noted (e.g., on birds with dark plumage). Also, dead birds may have been too decomposed to determine oiling status.



Source: *U.S. Department of the Interior.*

Figure 4.7-8. Examples of live (top) and dead (bottom) oiled birds collected following the *Deepwater Horizon* oil spill.

Along with collection of oiled birds, a significant effort was undertaken to survey birds and document rates of visible external oiling (i.e., the number of birds with visible oil relative to the overall number of birds observed), as well as the degree of visible oiling. These efforts documented over 3,500 individuals

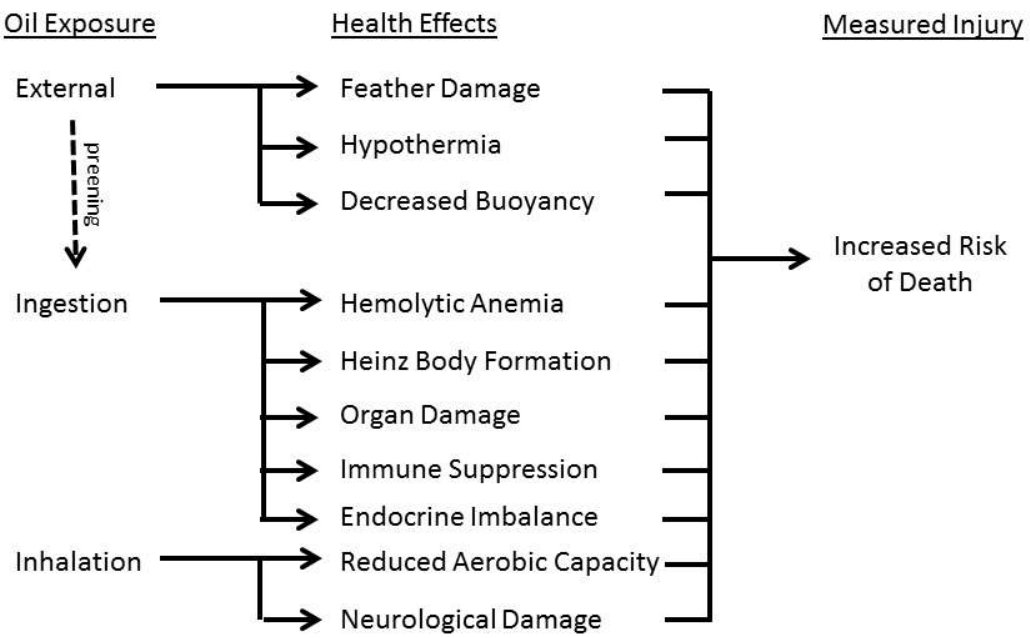
with visible external oiling during the year following the spill (FWS 2015e). Observed external oiling ranged from trace to heavy (Figure 4.7-9). The proportion of birds with observable oil, as well as the intensity of oiling, declined through time after the well was capped.

Source: *U.S. Department of the Interior.*

Figure 4.7-9. Categories of oiling intensity used during surveys to document rates and degree of external oiling of birds in the northern Gulf of Mexico.

4.7.3.3 Consequences of Exposure

As described above, there are multiple ways birds were exposed to *Deepwater Horizon* oil. The flow chart below (Figure 4.7-10) describes examples of adverse health effects resulting from different pathways of exposure, and indicates that each of these can lead to increased mortality and subsequent lost reproduction, which are the primary metrics of bird injury in this assessment. Health effects and injury are described in detail in Sections 4.7.4 (Injury Determination) and 4.7.5 (Injury Quantification).



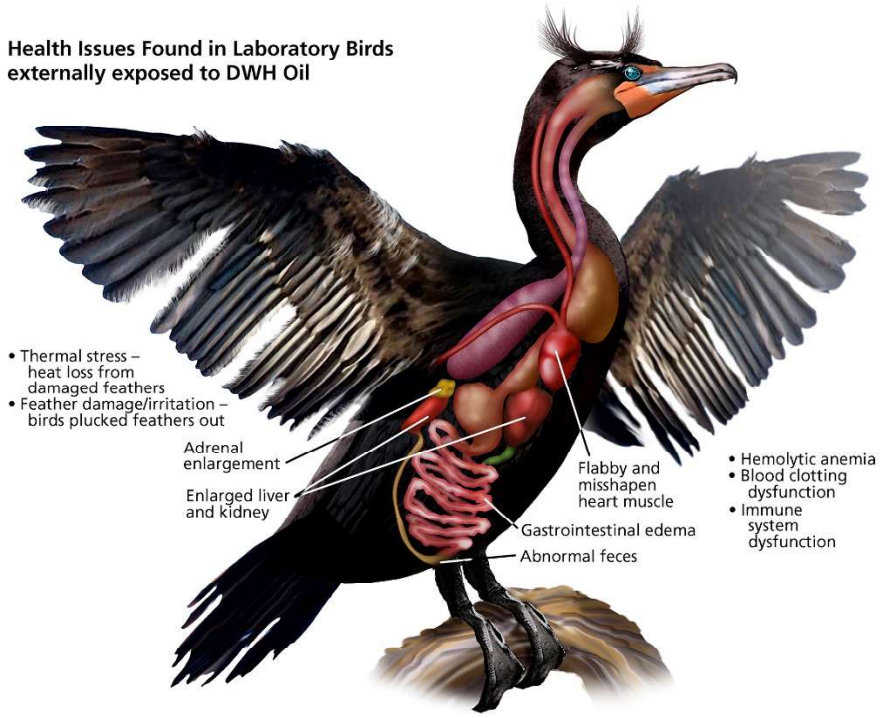
Source: *U.S. Department of the Interior.*

Figure 4.7-10. Conceptual pathways leading from the various types of oil exposure, through associated health effects, to the mortality endpoint used to quantify bird injury following the *Deepwater Horizon* oil spill. This figure does not capture all potential injuries, including sublethal effects, but illustrates ways in which quantified injury may have resulted from exposure.

4.7.4 Injury Determination

Key Points

- The Trustees conducted a number of laboratory studies that demonstrated a suite of negative physiological effects on birds exposed to *Deepwater Horizon* oil (Figure 4.7-11).
    - Physiological effects of ingestion of *Deepwater Horizon* oil included disruption of reproductive function; anemia; changes in immune function; reduced kidney, liver, and gastrointestinal function; and heart abnormalities.
    - Physical effects of plumage oiling included structural damage to feathers, leading to impaired flight capability and behavioral alterations, thermoregulatory impairment, and loss of buoyancy.
- The impairments identified through controlled studies undoubtedly occurred in wild, oil-exposed birds and resulted in increased rates of mortality.
- Elevated mortality in wild birds was abundantly evident by the more than 8,500 dead and oil-impaired birds recovered following the *Deepwater Horizon* oil spill. These recovered birds represent only a fraction of overall mortality. The Trustees used a number of quantitative and qualitative methods to describe the magnitude of bird mortality and associated lost reproduction.



Source: *Kate Sweeney for NOAA.*

Figure 4.7-11. Schematic showing the array of negative effects experienced by birds following external exposure or ingestion of *Deepwater Horizon* oil.

Studies of effects of oil on bird health were conducted for two purposes: 1) to understand the types and degrees of negative effects occurring in wild birds exposed to *Deepwater Horizon* oil, and 2) to use that information to inform estimation of the fate of birds adversely impacted by exposure to *Deepwater Horizon* oil, in particular within the Live Oiled Bird Model (Section 4.7.5.1.2, Avian Mortality After September 2010) and the Offshore Exposure Model (Section 4.7.5.1.1, Avian Mortality Between April and September 2010). These effects are described in a summary report (Ziccardi 2015) and supported by technical reports cited therein (Bursian et al. 2015a; Bursian et al. 2015b; Dorr et al. 2015; Fallon et al. 2014; IEc 2015b; Maggini et al. 2015; Pritsos et al. 2015); information below is a synopsis of that document.

4.7.4.1 Physical Effects of External Oil

Thousands of birds in the northern Gulf of Mexico were externally contaminated by *Deepwater Horizon* oil (Section 4.7.3, Exposure). Conclusions of laboratory studies conducted by the Trustees were consistent with information from the literature, indicating that external oil exposure had significant effects on feather structure and function (Holmes & Cronshaw 1977; Leighton 1993). Because feathers are the primary insulation for birds, breakdown of feather structure can result in thermoregulatory challenges. If birds cannot catch enough food to meet increased energy costs, they will exhaust their energy stores and become hypo- or hyper-thermic, which results in death.

In unoiled birds, feathers form a waterproof layer that traps air and provides buoyancy (Helm *et al*. 2015). When feather damage occurs following external oil exposure, that buoyancy is lost, leading to significantly reduced capacity to swim or float in water, which in turn reduces birds' ability to forage and escape predators (Maggini et al. 2015; Pritsos et al. 2015; Ziccardi 2015).

Trustee laboratory studies demonstrated that damage to feathers associated with external oiling also caused significant alterations in flight ability, manifested by decreased takeoff speed, reduced takeoff angle, decreased endurance during flight, and longer flight times. These alterations in flight capabilities can directly cause a number of harmful outcomes, including an inability to evade predators, reduction in energy stores, and delayed arrival at breeding grounds (Maggini et al. 2015; Pritsos et al. 2015; Ziccardi 2015).

External oil also affects skin, mucus membranes, and other sensitive tissues, causing irritation, burning, and permanent damage or loss of function, manifested by inability to hear or see normally and/or the presence of inflamed, ulcerated, thickened, or sloughing skin (Dorr et al. 2015; IEc 2015b; Ziccardi 2015). These multiple health consequences resulting from external oiling led to increased mortality risk.

4.7.4.2 Physiological Effects of Oil Ingestion and Inhalation

As described in Section 4.7.3 (Exposure) and summarized in Ziccardi (2015), ingestion of *Deepwater Horizon* oil occurred through preening oil from feathers, as well as through feeding or ingestion of contaminated water or sediment. Physiological effects also can result from absorption of toxic components of oil through the skin. The available literature shows that oil ingestion leads to a variety of negative effects for birds, and laboratory studies conducted by the Trustees confirmed those effects and revealed additional, previously unknown, harmful consequences of oil ingestion (Figure 4.7-10 and Figure 4.7-11). Health effects of oil exposure were likely additive, as exposure occurred through multiple pathways for some individuals and multiple health effects were likely induced.

Trustee studies and previously published work document significant alterations to red blood cells upon ingestion of petroleum hydrocarbons, including *Deepwater Horizon* oil (Bursian et al. 2015a; Bursian et al. 2015b; Fallon et al. 2014; IEc 2015b; Leighton 1993; Ziccardi 2015). This results in reductions in oxygen carrying capacity of the blood. In turn, this can have significant effects on bird behavior, constraining their ability to fly, swim, and forage, with subsequent increased risk of death.

White blood cells (leucocytes) also were altered by ingestion of *Deepwater Horizon* oil (Bursian et al. 2015a; Bursian et al. 2015b; Ziccardi 2015). This would be expected to reduce birds' abilities to combat bacterial, fungal, viral, or parasitic infections—increasing energetic costs and risk of death.

Several types of organ damage were observed in Trustee laboratory studies, including liver, kidney, and gastrointestinal systems (Bursian et al. 2015a; Bursian et al. 2015b; Dorr et al. 2015; Ziccardi 2015). In addition, Trustee studies found previously undescribed alterations in heart morphology and function following *Deepwater Horizon* oil ingestion. Overall, disruption of organ physiology and function would contribute to increased mortality rates.

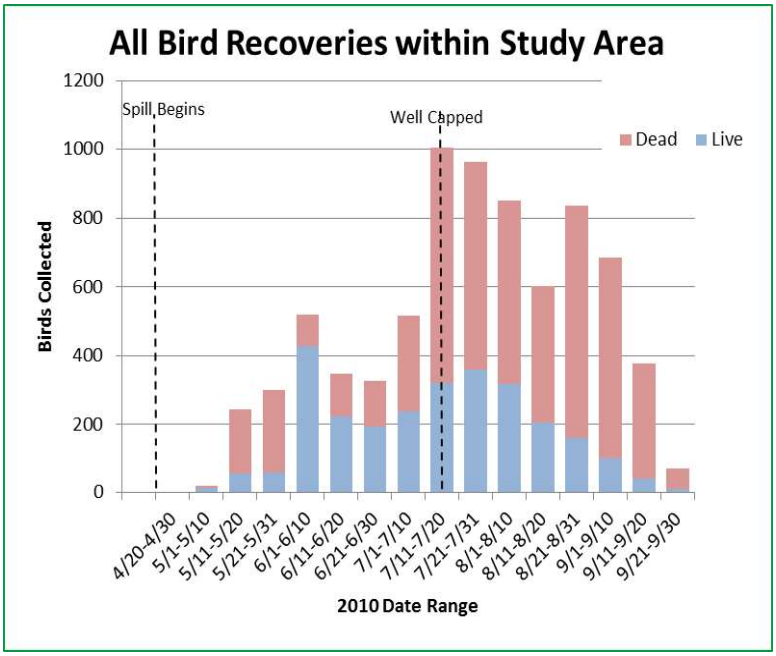
Although the Trustees did not directly evaluate health effects of inhalation by birds of the volatile components of *Deepwater Horizon* oil, the existing literature indicates that PAH inhalation can cause significant alterations in neurological and respiratory function (Helm et al. 2015; IEc 2015b). Resultant

behavioral modifications and constraints on birds' abilities to fly, swim, and dive would increase risk of mortality (Helm et al. 2015; IEc 2015b).

4.7.4.3 Effects of Oil on Bird Survival and Reproduction

Physical and physiological effects on birds exposed to oil, described above, are known to increase risk of death. Extensive bird mortality has been seen in many previous spills. Bird deaths due to the *Deepwater Horizon* spill also were extensive and obvious. Dead birds and oil-impaired live birds (i.e., those that were affected by oil to the point that they were behaving abnormally and, in many cases, could be easily captured) were seen in offshore habitats within 10 days of the initial release of oil. Additionally, dead and oil-impaired birds were found on shorelines prior to the arrival of oil on shore – presumably these birds were oiled offshore and flew or swam to land in an attempt to preen and recover. Dead birds were collected from the time that oil was being released through two months after the well was capped, when intensive search efforts ended. Thousands of dead birds were collected in the spill-affected area, in all of the habitats listed in Section 4.7.1.1 (Bird Diversity and Habitats in the Northern Gulf of Mexico). Numbers of collected dead and oil-impaired birds steadily increased until the well was capped, and then declined over the following two months (Figure 4.7-12).

It is widely recognized that a tally of collected bird carcasses constitutes only a fraction of true mortality (Ford et al. 2006; Henkel et al. 2012; Velando et al. 2005). As described in Section 4.7.5 (Injury Quantification), the Trustees used several methods to estimate the number of birds that were killed as a result of the *Deepwater Horizon* oil spill, as well as qualitative assessments of the magnitude of additional injury that was not captured quantitatively.



Source: *U.S. Department of the Interior.*

Figure 4.7-12. Timing and number of collections of dead and impaired birds during the *Deepwater Horizon* oil spill. Thousands of birds died, and these deaths were spread over a period of months.

Adult birds that died during the course of the oil spill were not available to lay eggs, incubate eggs, or attend to nestlings. Thus, the associated lost reproduction due to deaths of breeding birds represents additional injury caused by the *Deepwater Horizon* oil spill. This is separate from, and in addition to, quantitative and qualitative assessments of mortality. As described in Section 4.7.5 (Injury Quantification), the Trustees estimated the number of fledglings that would have been produced by adult birds that died during 2010 and 2011, as another component of the modeled oil spill injury.

4.7.5 Injury Quantification

Key Points

- The Trustees quantified mortalities representing a portion of bird injury using several approaches that account for deaths in particular habitats during specific time periods (Table 4.7-2). These quantified mortalities were estimated to range from 51,600 to 84,500 individual birds. Uncertainties associated with these methods indicate that quantified mortalities were likely underestimated and the true mortality is closer to the higher end of this range.
- Based on the portion of bird mortality that was quantified, the loss of fledglings due to mortality of their parents was estimated to be 1,700 to 6,300 in 2010 (based on adult mortalities during the 2010 breeding season, after accounting for fledgling mortality quantified using other methods) and 2,800 to 11,600 (based on adult mortalities after the 2010breeding season). Total lost reproduction, in excess of fledgling mortality identified using other methods, was estimated to be 4,600 to 17,900. Uncertainties associated with these methods indicate that the true loss is likely higher by some unquantifiable amount.
- The Trustees recognize that additional, unquantified injury occurred in situations where quantification methods were not applied, particularly in marshes and in island waterbird colonies. Qualitative assessments were used to consider the scope of unquantified injury.
- Quantification that resulted in mortality estimates above was conducted using several non-overlapping methods that were specific to certain habitats and time periods (Table 4.7-2). These are described below:
    - For nearshore birds (those that died within 25 miles [40 kilometers] from shore, including in open water, beaches, marsh edges, and a portion of island waterbird colonies), mortality was estimated using a Shoreline Deposition Model. The Shoreline Deposition Model used records of when and where the thousands of dead and oil-impaired birds were collected, and generated a mortality estimate that ranged from 38,900 to 58,400 for the period 20 April to 30 September 2010.
    - Some areas did not have data useable for inclusion in the Shoreline Deposition Model. Mortality in three areas (Lake Mechant, Vermilion Bay, and the Breton-Chandeleur Islands) was calculated using best estimates of densities of dead birds based on Shoreline Deposition Model results. This resulted in an additional 3,500 to 7,000 birds estimated to have died. Also, some dead birds were collected from colonies where the Shoreline Deposition Model was not applied; from these collections, 636 individuals of 22 species

were added to mortality figures; much more mortality in these colonies went unquantified (see below).

  - Offshore bird mortality (greater than 25 miles [40 kilometers] from shore) during April to September 2010 was estimated using an Exposure Model, based on the spatial overlap between birds and oil. Between 2,300 and 3,100 birds were estimated to have died in this habitat.

  - Mortality that originated with exposure of nearshore birds to oil between September 2010 and March 2011 was quantified using a Live Oiled Bird Model, which combines estimates of the number of birds having external oiling and their fates; resulting mortality was estimated to range between 6,200 and 15,300.

- Considerations of unquantified mortalities centered on island waterbird colonies and marsh.

  - Although some mortality associated with island waterbird colonies was quantified, the Trustees recognize that additional mortality was undetected, due in part to restrictions on access to avoid disturbance. Given the high concentrations of birds within colonies, many of which were known to be oiled, it is likely that additional, meaningful mortality occurred.

- Mortality quantification did not extend beyond the marsh edge. Oil was known to penetrate into marshes, which hold significant densities of specialist marsh species. Although mortality was not estimated, tens of thousands of birds were at risk of oil exposure within this habitat.

4.7.5.1 Quantified Injury: Mortality

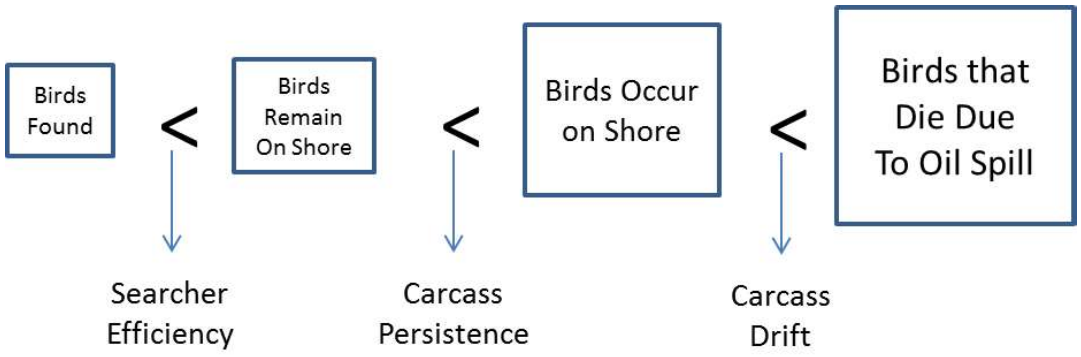
More than 8,500 individuals representing nearly 100 bird species associated with oil-affected habitats were collected dead or impaired throughout the five Gulf Coast states during wildlife rescue response and NRDA operations. More than 3,500 additional birds, across numerous species, were also observed with external oiling. In this section, estimates of mortality are presented for a portion of the bird injury, based on the observations described above. Due to a number of uncertainties within quantification methods, mortality is likely underestimated (see Section 4.7.5.5, Sources of Potential Bias and Uncertainty). In addition, some mortality occurred outside of the scope of quantification (see Section 4.7.5.4, Unquantified Injury), indicating that quantified injury constitutes only a portion of true injury.

Estimates of mortality were generated for two time periods: 1) the initial months between the beginning of the spill (April 2010) and September 2010, and 2) mortality originating from oil exposure between September 2010 through March 2011 (Table 4.7-2). During the first period, when injury was highest, mortality was estimated for a portion of the bird injury using several methods (Section 4.7.2, Approach to the Assessment) to quantify bird injury in different oil-affected habitats. During the latter period, a single method was used for a portion of the bird injuries based on observations of live nearshore birds with external oil (Section 4.7.2, Approach to the Assessment).

4.7.5.1.1 Avian Mortality Between April and September 2010

Mortality in Nearshore Areas: Shoreline Deposition Model

Because it is not practical or possible to collect all birds killed by the *Deepwater Horizon* oil spill, the Trustees estimated bird mortality in a portion of the nearshore habitats through application of a Shoreline Deposition Model for the period 20 April to 30 September 2010 (IEc 2015c). This general method has been used in previous spills, particularly along beach habitats (e.g., Ford et al. (2006). This approach uses the number of dead and impaired birds found on shorelines within the spill zone and estimates the number of birds that died, by accounting for a number of factors that influence the proportion of oil-killed birds discovered on shorelines (Figure 4.7-13).



Source: *U.S. Department of the Interior.*

Figure 4.7-13. Schematic describing several mechanisms that resulted in the number of birds collected from shorelines being less than the total number that died. The Shoreline Deposition Model uses numerical estimates of processes (carcass drift, carcass persistence, and searcher efficiency) necessary to quantitatively estimate the number of birds that died based on the number of birds found along shorelines. This method was applied to estimate a portion of nearshore bird injuries.

Factors that affected the number of birds found on shorelines relative to the number that actually died include: 1) some birds died at sea and sunk before they could wash up on shore or be collected in open water (corrected for by carcass drift factor); 2) some incapacitated or dead birds ended up on a shoreline but did not persist long enough to be found by searchers (corrected for by carcass persistence factor); and 3) some incapacitated or dead birds ended up on shore but were not found by searchers (corrected for by searcher efficiency factor). For the *Deepwater Horizon* oil spill, the Trustees conducted studies to quantify searcher efficiency, carcass persistence, and carcass drift so that an estimate of the total number of birds injured could be calculated for a portion of the bird injury.

Carcass Drift

When birds die during an oil spill, they do not always die on a shoreline. If a bird dies on the water, wind and water currents might push it to either a beach or marsh edge where it could be found by searchers. However, while in the water, a bird carcass also might be eaten or sink. The Trustees conducted studies to estimate carcass drift (IEc 2015c), which is an estimate of the likelihood that birds dying on water would float to a shoreline.

The Trustees placed 248 radio-tagged bird carcasses in numerous locations nearshore and offshore across the northern Gulf of Mexico (Figure 4.7-14). Placement of carcasses corresponded to the distribution of birds at risk of oil exposure. Birds were tracked until they were found on a marsh edge or beach or until the radio signals could no longer be detected within the study area. No radio-tagged bird carcasses released in offshore habitat (greater than 40 kilometers from shore) or carcasses released near the *Deepwater Horizon* well ever made it to shore. Of the 187 carcasses released in nearshore habitats and considered useable, 29 were found on shore. Therefore, the likelihood that birds dying on water (either in open sea or open water in marsh areas) drifted to shore was estimated to be 0.16, or 1 in 6.5.

Source: *U.S. Department of the Interior.*

Figure 4.7-14. A radio-tagged bird carcass prior to release (left) during studies to quantify carcass drift as part of a Shoreline Deposition Model, and a carcass upon discovery along shore (right).

Carcass Persistence

For a bird carcass or oil-impaired bird to be found, it must remain on a beach or along a marsh edge long enough for a searcher to find it. Bird carcasses disappear for a number of reasons, including scavenging, burial, and decomposition. Disappearance of carcasses is accounted for in the Shoreline Deposition Model by using a carcass persistence factor to estimate the likelihood that a carcass along a shoreline would disappear before searchers arrived.

The Trustees conducted studies on beaches and marsh edges to estimate carcass persistence (IEc 2015c). To determine how long the carcasses remained on the shoreline, bird carcasses were placed at known locations along sandy beach and marsh edge transects. Carcass locations were revisited on a nearly daily basis for 11 to 14 days. Bird carcasses disappeared at a faster rate at the beginning of the time period than they did later in the study for both sandy beaches and marsh edges. Bird carcasses also disappeared at a faster rate in marshes than on sandy beaches. The type of marsh was also significant. Carcasses disappeared more quickly in *Phragmites*-dominated marsh habitat compared to *Spartina*-dominated marsh habitat. These sources of variability in carcass persistence were considered when applying persistence values in the Shoreline Deposition Model.

Searcher Efficiency

Searcher efficiency is the probability that a person walking along a beach or riding in a boat near a marsh edge would see a dead or dying bird that is present within the specified search area. The Trustees conducted studies on beaches and along marsh edges to estimate the proportion of birds a searcher is likely to find (IEc 2015c). These studies were conducted by placing bird carcasses in known locations and then having trained searchers try to observe them while following procedures used during the spill to collect dead and dying birds. Not surprisingly, searcher efficiency was different for different habitat types. It was easier for searchers to find bird carcasses on a sandy beach than along a marsh edge. Also, large birds were easier to find than small birds. On sandy beaches, intact carcasses were easier to detect than partially decomposed carcasses.

Spatial and Temporal Extrapolation

Birds for the Shoreline Deposition Model were collected from 12 kilometers east of Cape San Blas, Florida to 18 kilometers southeast of Freeport, Texas, spanning hundreds of kilometers of shoreline. However, all shorelines within this huge area could not be consistently surveyed. Areas without sufficient data coverage to estimate deposition rates needed to be accounted for by spatial extrapolation. Spatial extrapolation is when data from one geographic area are applied to another similar geographic area that does not have data. This process provides an estimate of birds that would have been collected on a shoreline segment if that segment had been searched with sufficient frequency for use in the Shoreline Deposition Model.

The Shoreline Deposition Model estimates the number of nearshore birds that died from the beginning of the spill (April 20, 2010), through the 87 days of oil spilling into the northern Gulf of Mexico (the well was capped July 15, 2010), and until area-wide wildlife operations were generally stopped (about September 30, 2010). However, not all places were searched for bird carcasses through that entire period. Just as spatial extrapolation filled in estimated deposition for places that were not searched, temporal extrapolation was used to fill in time periods that did not have adequate data coverage. Spatial and temporal extrapolations were conducted using the data that most closely corresponded to the area or time with missing data (IEc 2015c). Large areas with little or no useable data for extrapolation are treated as Excluded Regions.

Results of Shoreline Deposition Model

Mortality for this portion of the quantified bird injury is presented as a range of low and high estimates, reflecting estimated variability in input values (Section 4.7.5.4, Unquantified Injury). Using the Shoreline Deposition Model, the Trustees estimated that between 38,900 and 58,410 nearshore birds died between 20 April and 30 September 2010 as a result of the *Deepwater Horizon* oil spill. This represents only part of the overall modeled mortality; methods estimating additional bird mortality are presented below.

Mortality in Nearshore Regions Not Covered by the Shoreline Deposition Model

The Shoreline Deposition Model requires threshold quantities and frequencies of search data to estimate mortality. As was the case for many colonies (see below), search effort at three large areas was

insufficient for modeling purposes: the Breton-Chandeleur Island Chain, Vermillion Bay, and a large portion of Lake Mechant. The observation of oil on the water and shorelines, as well as dead oiled birds collected from these locations, however, indicated that an estimation of bird mortality was required (FWS 2015b).

To approximate bird mortality within these areas, the Trustees used the number of dead birds per kilometer estimated by the Shoreline Deposition Model from similar, nearby habitats as the best approximation of dead bird density in the areas not covered by the Shoreline Deposition Model (FWS 2015b). Using this approach, the Trustees estimated that, for this modeled component of injury, between 3,500 and 7,000 bird deaths occurred in the Breton-Chandeleur Island Chain, Vermillion Bay, and Lake Mechant due to the *Deepwater Horizon* spill.

Mortality in Island Breeding Colonies

The onset of the *Deepwater Horizon* oil spill coincided with the early stages of the nesting season for numerous bird species in the northern Gulf of Mexico. Bird colonies in this area host high abundance and densities of several species and provide vital ecological function for bird populations. Several nesting colonies, including some of the largest nesting island colonies in the northern Gulf, were directly oiled and large numbers of oiled adult and sub-adult birds in and around the affected colonies were documented. Oiled adult birds also were documented in colonies that were not directly oiled.

Some colony mortality was reflected with the Shoreline Deposition Model above. However, this quantified injury is known to underestimate colony injury for reasons described below and in Section 4.7.5.4, Unquantified Injury.

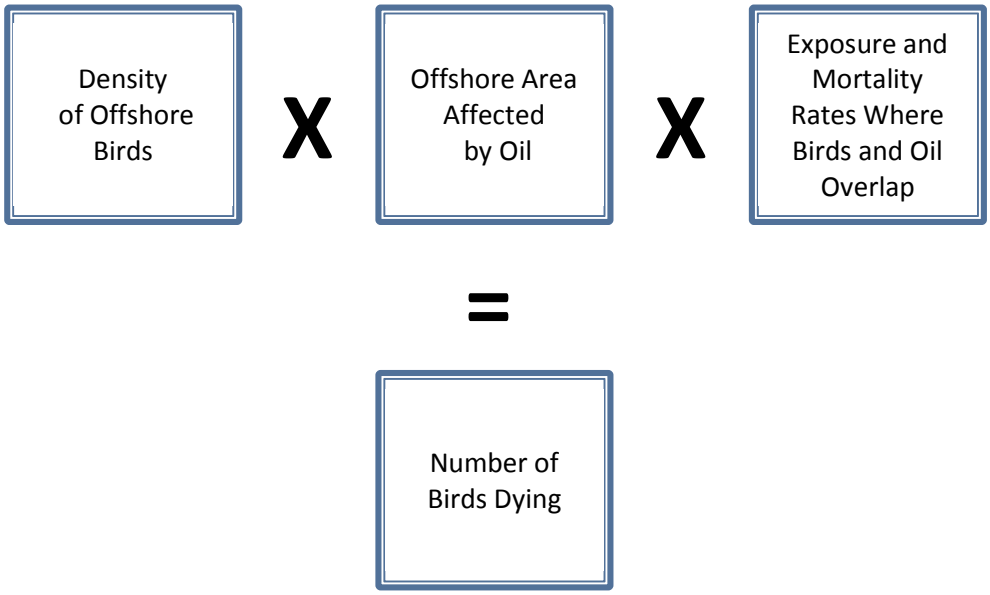
During wildlife response, colonies were handled carefully and protected to minimize disturbance and avoid additional stress being placed on the nesting birds. Consistent monitoring of bird colonies during the spill was limited by restrictions on response workers in an effort to reduce human disturbance. For this reason, search effort for some breeding colonies was not consistent with the search effort criteria required for shoreline deposition modeling. Therefore, some birds collected in colonies were not modeled in the Shoreline Deposition Model. Instead the actual dead bird count from some colonies over a limited time period was considered additional colonial bird mortality (FWS 2015a). A total of 636 dead birds of more than 20 species were collected on colonies in August and September 2010, including over 150 brown pelicans, more than 270 laughing gulls, and 125 black skimmers. The Trustees acknowledge that this is most likely a gross underestimation of mortality in these important bird habitats. Consideration of unquantified mortality within island waterbird colonies is found in Section 4.7.5.4.1.

Mortality in Offshore Open Water Areas

As described in Section 4.7.3.1 (Distribution and Duration of *Deepwater Horizon* Oil in Bird Habitats), oil occurred on surface waters of the open Gulf of Mexico for months. During that time, birds that use offshore habitats were at risk of exposure and mortality. Based on results of carcass drift studies, birds dying more than 40 kilometers from shore would not float to shore, and thus would not be represented in the Shoreline Deposition Model.

The Trustees used an Offshore Exposure Model to estimate mortality of birds in offshore areas (Figure 4.7-16; IEc (2015a). This model first estimates the number of birds potentially affected by oil exposure by multiplying the density of birds in offshore areas (greater than 40 kilometers from shore) by the calculated offshore surface area covered by oil. Bird surveys indicated that offshore densities in water less than 200 meters deep were approximately 1.53 birds per square kilometer and in water greater than 200 meters deep were approximately 0.56 birds per square kilometer. The offshore area where oil occurred was based on the average daily coverage estimated by the Trustees for July 2010, or about 4,930 square kilometers. Estimates of exposure and mortality rates were applied to determine overall mortality. The Trustees assumed all birds occurring in the footprint of the oil slick would be exposed to oil over the 87-day course of these calculations. Because of the lack of data for categorizing degree of bird oiling in the offshore environment, the Trustees distributed the number of estimated oiled birds evenly across the four oiling categories established from all the bird types observed for this case. Ranges of mortality rates corresponding to each oiling category were applied to generate the range of overall offshore mortality (Ziccardi 2015).

Using this approach, the Trustees estimated that between 2,300 and 3,100 offshore birds were killed during the *Deepwater Horizon* oil spill. Most of the mortality occurred in shearwaters, terns, and gulls, but deaths also included members of numerous species of conservation concern to the U.S. Fish and Wildlife Service.



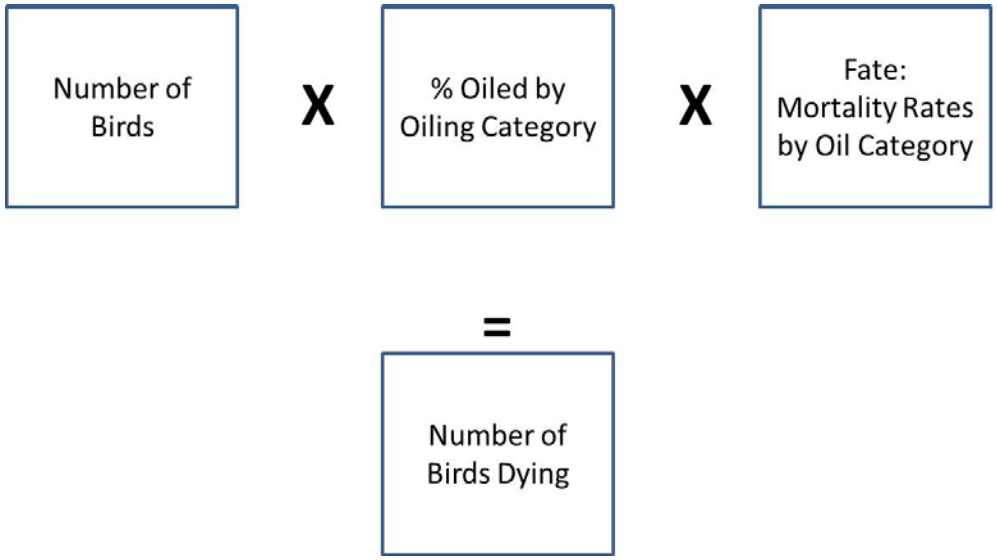
Source: *U.S. Department of the Interior.*

Figure 4.7-15. Exposure model calculation for offshore birds.

4.7.5.1.2 Avian Mortality After September 2010

Birds continued to be exposed to oil from the *Deepwater Horizon* spill past September 2010 when area-wide wildlife operations were generally stopped. To estimate a portion of the mortality that occurred as a result of oil exposure between September 2010 and March 2011, the Trustees used a Live Oiled Bird

Model approach that was based on observations of live, oiled birds and estimations of mortality based on the degree of oiling (Figure 4.7-16). The difference between the Live Oiled Bird Model approach and the exposure model described above for the offshore bird mortality estimate is that these oiling rates are based on visual observations of birds, rather than an estimate of the percentage of birds that are oiled.



Source: *U.S. Department of the Interior.*

Figure 4.7-16. Calculations for a Live Oiled Bird Model used to estimate bird mortality that occurred due to oil exposure from September 2010 to March 2011.

The Live Oiled Bird Model (FWS 2015e) requires three sources of data: 1) the numbers of birds occurring in areas affected by the oil spill (abundance), 2) the incidence and degree to which birds were oiled (oiling rates), and 3) the likelihood a bird would die due to oiling (fate). Fate is further defined as the probability of a bird dying from any cause related to oil exposure, including toxic, thermoregulatory, or other effects. For this estimate, the mortality for each species is provided as a range extending from the first quartile to the third quartile of the fate estimate for each oiling rate.

The Live Oiled Bird Model calculation is a multiplication of the abundance, oiling rate, and fate information (Figure 4.7-16). This was repeated for each species and time period to estimate bird mortality originating from oil exposure during September 2010 through March 2011 (FWS 2015e). More than 2,000 individual birds were observed oiled during Live Oiled Bird Model surveys (Figure 4.7-17). Using this model, the Trustees estimated that between 6,200 and 15,300 nearshore birds were killed by the *Deepwater Horizon* oil spill during the Live Oiled Bird Model period.

Source: *U.S. Department of the Interior.*

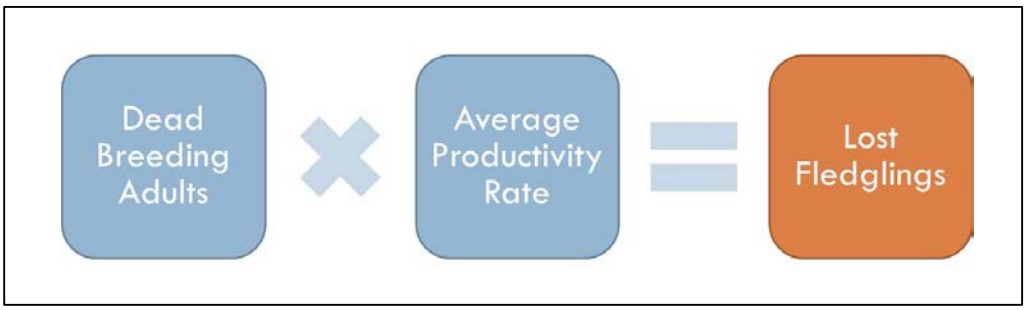
Figure 4.7-17. Examples of live birds that were visibly oiled following the *Deepwater Horizon* oil spill.

4.7.5.2 Quantified Injury: Lost Reproduction

The effects of the *Deepwater Horizon* oil spill overlapped both the 2010 and 2011 bird breeding seasons (March through August) in the northern Gulf of Mexico. The Trustees did not conduct any studies that directly quantified the impacts of the spill on reproductive success of birds nesting in the Gulf of Mexico. Logistical restrictions also prevented the Trustees from measuring reproductive success of birds that migrated through oil-contaminated areas on their way to nesting grounds outside the spill area. Nevertheless, the Trustees estimated numbers of fledglings lost in 2010 and 2011 due to the oil spill using alternative approaches that are based on the quantified mortality estimates described above (FWS 2015c, 2015d). These lost fledglings would have been the first year of progeny of breeding adults that died from the spill.

The approach to estimating the lost fledglings is shown in Figure 4.7-18. Using mortality estimates described in Section 4.7.5.1, the Trustees determined mortality for a portion of the breeding-aged birds.

Had these breeding-aged birds not died, the Trustees assumed they would have produced a number of fledglings consistent with literature on species-specific productivity (i.e., number of fledglings produced per pair). The Trustees also assumed that chicks required both parents to feed and protect them to survive to fledging. Multiplying the number of dead breeding adults by species-specific, average annual productivity values provided an estimate of number of fledglings that were not produced due to the oil spill (FWS 2015c, 2015d).



Source: *U.S. Department of the Interior.*

Figure 4.7-18. Conceptual approach to calculating lost fledglings using the average annual productivity.

The Trustees recognize that this methodology does not produce a comprehensive assessment of the loss of reproductive success in any year. There are other pathways that eggs, chicks, or fledglings could have been injured by the spill, but data were not available to quantify those injuries. Therefore, the results of these calculations are likely underestimates of lost reproduction.

4.7.5.2.1 Lost 2010 Reproduction

Estimation of lost 2010 fledglings was based on mortality ranges generated by the Shoreline Deposition Model and Excluded Areas methodologies. The Trustees estimated that between 8,500 and 12,700 dead birds were of breeding age during the 2010 breeding season, and 4,200 to 12,700 nests would have suffered a complete loss of fledglings in 2010. Using species-specific information on average annual productivity, the Trustees estimated that 4,700 to 14,200 fledglings were lost in 2010. Because a portion of these fledglings were already detected as dead birds in the Shoreline Deposition Model and Excluded Areas outputs, lost reproduction in 2010 is presented as "additional" lost reproduction after subtracting fledgling mortality already captured by mortality estimates in Section 5.1 (FWS 2015c, 2015d). This additional lost reproduction was estimated to be between 1,700 and 6,300 in 2010.

4.7.5.2.2 Lost 2011 Reproduction

The estimation of lost 2011 fledglings is based upon the mortality estimates generated by the Live Oiled Bird Model, the portion of the Shoreline Deposition Model output occurring after the end of the 2010 breeding season (August 8, 2010 to September 30, 2010), and dead birds from colonies. The Trustees estimated that 7,400 to 15,200 of the birds killed by the spill between August 8th to the end of the Live Oiled Bird Model period were of breeding age and that 3,000 to 12,300 nests would not have existed in the 2011 breeding season. Using species-specific information on average annual productivity, the Trustees estimate that 2,800 to 11,600 fledglings were lost in 2011.

Combining additional lost reproduction from 2010 and 2011 results in an estimate of between 4,600 and 17,900 fledglings that would have been produced in the absence of the spill, after accounting for fledglings that died in 2010 and were detected using the various mortality metrics. Limitations and uncertainties would likely contribute to an overall underestimate of fledglings lost due to the spill. Given the available information, the results presented here are the best estimate of fledglings lost due to the spill, recognizing that the true loss is likely higher by some unquantifiable amount.

4.7.5.3 Total Avian Injury Quantification

For the quantified portion of bird mortality, the Trustees estimated a spill-related injury of between 56,100 to 102,400 lost birds (Table 4.7-3). This was comprised of between 51,600 and 84,500 birds that died as a direct result of the *Deepwater Horizon* oil spill (Table 4.7-3), as well as lost reproduction stemming from these mortalities that ranged between 4,600 and 17,900 fledglings. Due to a variety of factors that likely led to underestimation of mortality (Section 4.7.5.4, Unquantified Injury), the quantified portion of true injury is likely closer to the upper range of the estimates.

Ninety-three different bird species associated with oil-affected habitats showed documented injury resulting from the *Deepwater Horizon* oil spill (Table 4.7-3)**.** There were undoubtedly other species that suffered injury that was undetected. Species showing particularly high injury included brown and white pelicans, laughing gulls, Audubon's shearwaters, northern gannets, clapper rails, black skimmers, white ibis, double-crested cormorants, common loons, and several species of terns. The magnitude of the injury and the number of species affected makes the *Deepwater Horizon* oil spill an unprecedented human-caused injury to birds of the region.

Table 4.7-3. Estimates and ranges of bird mortality and lost productivity resulting from the *Deepwater Horizon* oil spill. Mortality estimates were generated using several methods, which are described in detail in the text. Lost productivity refers to fledglings that were not produced due to mortality of breeding-age birds during 2010 and 2011.

Species*	Guild	Shoreline Deposition Model[1]		Excluded Regions[1]		Colony Sweeps[1]	Offshore[1]		Live Oiled Bird Model[2]		Subtotal		Additional Lost Productivity[3]		Combined Totals	
American White Pelican	Pelicans	238	358	22	43				1836	4052	2096	4453	507	2134	2603	6587
Brown Pelican		7105	10663	642	1277	156	12	18	2590	6503	10505	18617	2215	8996	12720	27613
Herring Gull	Gulls	161	241	15	29				36	107	212	377	10	61	222	438
Laughing Gull		19637	29471	1775	3530	273	160	264	146	503	21991	34041	760	2601	22751	36642
Lesser Black-backed Gull		21	31	2	4				11	32	34	67			34	67
Ring-billed Gull		16	23	1	3	1			18	51	36	78	7	41	43	119
Audubon's Shearwater	Seabirds	26	39	2	5		660	887			688	931			688	931
Band-rumped Storm-Petrel							16	22			16	22			16	22
Cory's Shearwater		10	16	1	2		13	17			24	35			2	2
Brown Booby							2	2			2	2			24	35
Great Shearwater		129	194	12	23		18	25			159	242			159	242
Leach's Storm-Petrel		10	16	1	2						11	18			11	18

Species*	Guild	Shoreline Deposition Model[1]		Excluded Regions[1]		Colony Sweeps[1]	Offshore[1]		Live Oiled Bird Model[2]		Subtotal		Additional Lost Productivity[3]		Combined Totals	
Magnificent Frigatebird		73	109	7	13		14	20			94	142			94	142
Manx Shearwater		5	8	0	1						5	9			5	9
Masked Booby		41	62	4	7		6	9			51	78			51	78
Northern Gannet		2527	3793	228	454	1	3	4	26	77	2785	4329	44	160	2829	4489
Parasitic Jaeger							4	6			4	6			4	6
Red-billed Tropicbird							7	9			7	9			7	9
Sooty Shearwater		5	8	0	1						5	9			5	9
White-tailed Tropicbird		5	8	0	1						5	9			5	9
Wilson's Storm-petrel							14	19			14	19			14	19
American Coot	Rail	16	23	1	3	1					18	27			18	27
Clapper Rail		347	521	31	62	2					380	585	324	1054	704	1639
Common Gallinule		16	23	1	3						17	26			17	26
Purple Gallinule		16	23	1	3						17	26			17	26
Sora		16	23	1	3						17	26			17	26
Virginia Rail		5	8	0	1						5	9			5	9
Osprey	Raptor	73	109	7	13						80	122			80	122

Species*	Guild	Shoreline Deposition Model[1]		Excluded Regions[1]		Colony Sweeps[1]	Offshore[1]		Live Oiled Bird Model[2]		Subtotal		Additional Lost Productivity[3]		Combined Totals	
American Avocet	Shore								1	1	1	1			1	1
American Oystercatcher		73	109	7	13	1			1	2	82	125			82	125
Black-bellied Plover		5	8	0	1				10	21	15	30			15	30
Black-necked Stilt		16	23	1	3	1			5	14	23	41			23	41
Dunlin		10	16	1	2				52	138	63	156	29	155	92	311
Killdeer		21	31	2	4						23	35			23	35
Least Sandpiper		5	8	0	1						5	9			5	9
Long-Billed Dowitcher		5	8	0	1				1	1	6	10			6	10
Piping Plover[4]		21	31	2	4				3	6	26	41			26	41
Ruddy Turnstone		83	124	7	15				2	3	92	142			92	142
Sanderling		155	233	14	28				14	36	183	297	6	32	189	329
Semipalmated Plover									7	16	7	16			7	16
Semipalmated Sandpiper		21	31	2	4						23	35			23	35
Short-billed Dowitcher		16	23	1	3				3	6	20	32			20	32
Snowy Plover									0	1	0	1			0	1

Species*	Guild	Shoreline Deposition Model[1]		Excluded Regions[1]		Colony Sweeps[1]	Offshore[1]		Live Oiled Bird Model[2]		Subtotal		Additional Lost Productivity[3]		Combined Totals	
Spotted Sandpiper		5	8	0	1						5	9			5	9
Western Sandpiper									2	5	2	5			2	5
Willet		62	93	6	11	1			8	17	77	122			77	122
Wilson's Plover		16	23	1	3				0	2	17	28			17	28
Black Skimmer	Tern	1015	1523	92	182	125			336	734	1568	2564	23	99	1591	2663
Black Tern		47	70	4	8		745	988			796	1066			796	1066
Bridled Tern		10	16	1	2		46	62			57	80			57	80
Brown Noddy		5	8	0	1		15	21			20	30			20	30
Caspian Tern		119	179	11	21				62	187	192	387	29	178	221	565
Common Tern		166	249	15	30		9	12	58	127	248	418	29	128	277	546
Forster's Tern		269	404	24	48	5	3	4	16	42	317	503	14	54	331	557
Gull-billed Tern		26	39	2	5						28	44			28	44
Least Tern		642	964	58	115	7					707	1086	40	128	747	1214
Royal Tern		2061	3093	186	370	25	306	406	250	708	2828	4602	112	456	2940	5058
Sandwich Tern		513	769	46	92	9	94	124	20	44	682	1038	11	54	693	1092
Sooty Tern		16	23	1	3		167	221			184	247			184	247
Black-crowned Night-heron	Waders	114	171	10	20				10	19	134	210			134	210

Species*	Guild	Shoreline Deposition Model[1]		Excluded Regions[1]		Colony Sweeps[1]			Live Oiled Bird Model[2]		Subtotal		Additional Lost Productivity[3]		Combined Totals	
Cattle Egret		264	396	24	47	1					289	444	152	459	441	903
Great Blue Heron		331	497	30	60	1			4	11	366	569	14	76	380	645
Glossy Ibis		5	8	0	1						5	9			5	9
Great Egret		109	163	10	20	1			46	137	166	321	9	51	175	372
Green Heron		93	140	8	17						101	157			101	157
Least Bittern		26	39	2	5						28	44			28	44
Little Blue Heron		26	39	2	5	3					31	47			31	47
Reddish Egret		21	31	2	4				2	4	25	39			25	39
Roseate Spoonbill		218	326	20	39	3			6	10	247	378	21	80	268	458
Snowy Egret		145	218	13	26	7			6	11	171	262			171	262
Tricolored Heron		249	373	22	45	11					282	429			282	429
White Ibis		36	54	3	7	1			508	1421	548	1483	73	408	621	1891
Yellow-crowned Night-Heron		52	78	5	9						57	87			57	87
Black-Bellied Whistling-Duck	Waterfowl	10	16	1	2						11	18			11	18
Blue-winged Teal		83	124	7	15						90	139			90	139

Species*	Guild	Shoreline Deposition Model[1]		Excluded Regions[1]		Colony Sweeps[1]			Offshore[1]		Live Oiled Bird Model[2]		Subtotal		Additional Lost Productivity[3]		Combined Totals	
Bufflehead		10	16	1	2								11	18			11	18
Canada Goose		10	16	1	2								11	18			11	18
Fulvous Whistling-Duck		5	8	0	1								5	9			5	9
Green-winged Teal		10	16	1	2								11	18			11	18
Lesser Scaup		5	8	0	1								5	9			5	9
Mallard		161	241	15	29								176	270			176	270
Mottled Duck		47	70	4	8								51	78			51	78
Red-Breasted Merganser		10	16	1	2								11	18			11	18
Ruddy Duck		10	16	1	2								11	18			11	18
Surf Scoter		16	23	1	3								17	26			17	26
Double-crested Cormorant	Cormorant	274	412	25	49						62	185	361	646	104	413	465	1059
Neotropic Cormorant		10	16	1	2								11	18			11	18
Belted Kingfisher	Land	5	8	0	1								5	9			5	9
Boat-tailed Grackle		5	8	0	1								5	9			5	9
Red-winged Blackbird		5	8	0	1								5	9			5	9

Species*	Guild	Shoreline Deposition Model[1]		Excluded Regions[1]		Colony Sweeps[1]	Offshore[1]		Live Oiled Bird Model[2]		Subtotal		Additional Lost Productivity[3]		Combined Totals	
Seaside Sparrow		5	8	0	1						5	9			5	9
Common Loon	Loons and Grebes	445	668	40	80				45	64	530	812	31	98	561	910
Pied-billed Grebe		202	303	18	36						220	339			220	339
TOTALS**		**38,918**	**58,410**	**3,506**	**6,999**	**636**	**2,314**	**3,140**	**6,203**	**15,298**	**51,577**	**84,483**	**4,564**	**17,916**	**56,141**	**102,399**

[1] Shoreline Deposition Model, Excluded Areas, Colony Sweeps and Offshore are estimates of adult mortality from April to September 2010.

[2] Live Oiled Bird Model estimates adult mortality from October 2010 to April 2011.

[3] Lost productivity refers to fledglings that were not produced due to mortality of breeding-age birds during 2010 and 2011.

[4] The piping plover is listed as both threatened and endangered (depending on population) under the Endangered Species Act of 1973 (87 Stat. 884, as amended; 16 U.S.C. 1531 et seq.).

* Species listed in bold are listed as federally threatened or endangered, or included as USFWS species of conservation concern (FWS 2008).

** Totals may differ somewhat from values presented in the technical reports due to rounding error because some models (Shoreline Deposition Model, Excluded Areas, Offshore, Lost Productivity) produce a total number of birds that was distributed to the relative bird frequencies in the database and this resulted in fractions being rounded to the nearest integer for presentation.

4.7.5.4 Unquantified Injury

As a result of the immense area affected by the spill, the diversity of habitats involved, and the prolonged nature of the event, there were a number of bird injuries that were not detected or estimated using quantified portions of the Trustees' assessment approach. However, these are important to consider to more completely understand the full scope of bird injuries, as well as the habitats in which these injuries occurred.

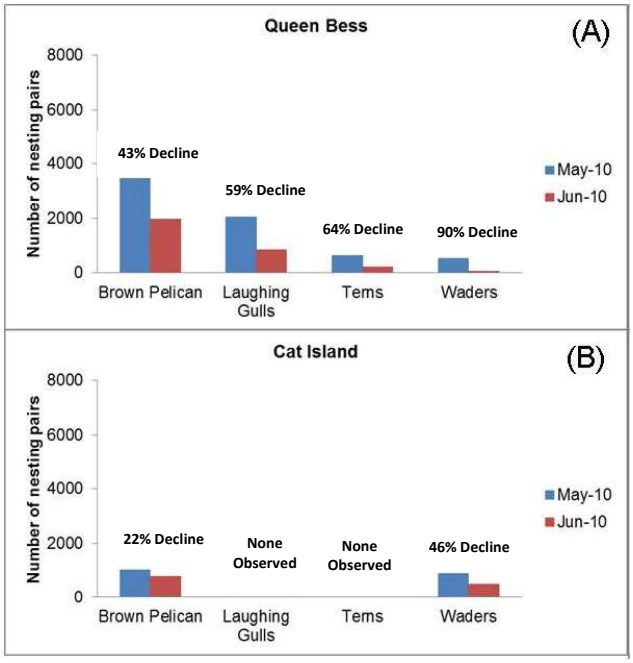
4.7.5.4.1 Island Waterbird Colonies

Some mortality in Island Waterbird Colonies was included in Injury Quantification (see Section 4.7.5.1.1). However, the Trustees recognize that these estimates do not fully capture the total injury that occurred within colonies. There were many time periods and colonies for which neither Shoreline Deposition Model nor colony sweep methods could be used to quantify colony injury, largely due to lack of search effort with the intent of minimizing disturbance of nesting birds. Given the large aggregations of birds that were in colonies at the time of the spill and the occurrence of *Deepwater Horizon* oil contamination at some of these colonies (Figure 4.7-19), lack of completely quantified mortality likely resulted in substantial underestimation of bird injury.

To illustrate potential effects of the *Deepwater Horizon* oil spill on island waterbird colonies, the Trustees evaluated changes in bird abundance at several waterbird colonies during 2010, the year of the spill (Baker et al. 2015). This analysis indicated that reductions in representative colonial breeding bird abundance occurred coincident with oil exposure. For example, (Baker et al. 2015) demonstrated that abundance of Brown Pelicans, Laughing Gulls, terns, and wading birds declined by approximately 50 percent at two colonies in Barataria Bay from May to June 2010 (Figure 4.7-20). This is a period when colony abundance would be expected to increase, under normal conditions. It is unknown whether these observations represent mortality, movement, or both. If the declines included mortality, some of that was likely captured in quantitative methods. However, these highlight the large-scale disruption to birds nesting at affected colonies during the *Deepwater Horizon* event.

Source: *Louisiana Department of Wildlife and Fisheries.*

Figure 4.7-19. Breeding adults as well as their chicks were exposed to *Deepwater Horizon* oil on island waterbird colonies, as shown in the photo above of oiled Brown Pelican chicks at Cat Island colony. Brown Pelican chicks should be covered in white down feathers at this stage of development.



Source: *Louisiana Department of Wildlife and Fisheries.*

Figure 4.7-20. Change in abundance of select bird species at two oil-affected colonies during 2010, the year of the *Deepwater Horizon* oil spill.

4.7.5.4.2 Marsh

Most oil-affected habitats were considered as part of quantitative avian injury assessment. However, birds occurring in marsh habitats suffered injuries that were not quantified. The Shoreline Deposition Model captured mortality that occurred at the marsh edge. It is known that oil penetrated deeper into the marsh (Figure 4.7-21), likely causing bird injury to marsh species that went undetected. In addition, injury that occurred to marsh and nearshore birds would be undetected for individuals that moved deeper into the marsh before dying, a likely response to compromised health for many species.

Source: *Louisiana Department of Wildlife and Fisheries.*

Figure 4.7-21. *Deepwater Horizon* oil contaminated marsh edge and also penetrated into interior marsh habitats. This photo shows oil (dark brown) penetrating beyond the marsh edge (left side of photo) into the marsh interior.

Coastal marshes support an abundance of numerous bird species, such as clapper rails, seaside sparrows, mottled ducks, least bitterns, green herons, common gallinules, willets, pied-billed grebes, marsh wrens, orchard orioles, common yellowthroats, boat-tailed grackles, and red-winged blackbirds. Birds that live strictly in marsh habitats, as well as birds that extensively use coastal marsh habitat, were likely exposed to oil, died within marsh habitats, and were never collected to be quantified by the Shoreline Deposition Model. The Trustees therefore applied methods to estimate the magnitude of numbers of birds potentially exposed to oil, as a qualitative means to evaluate potential injury (Wallace & Ritter 2015).

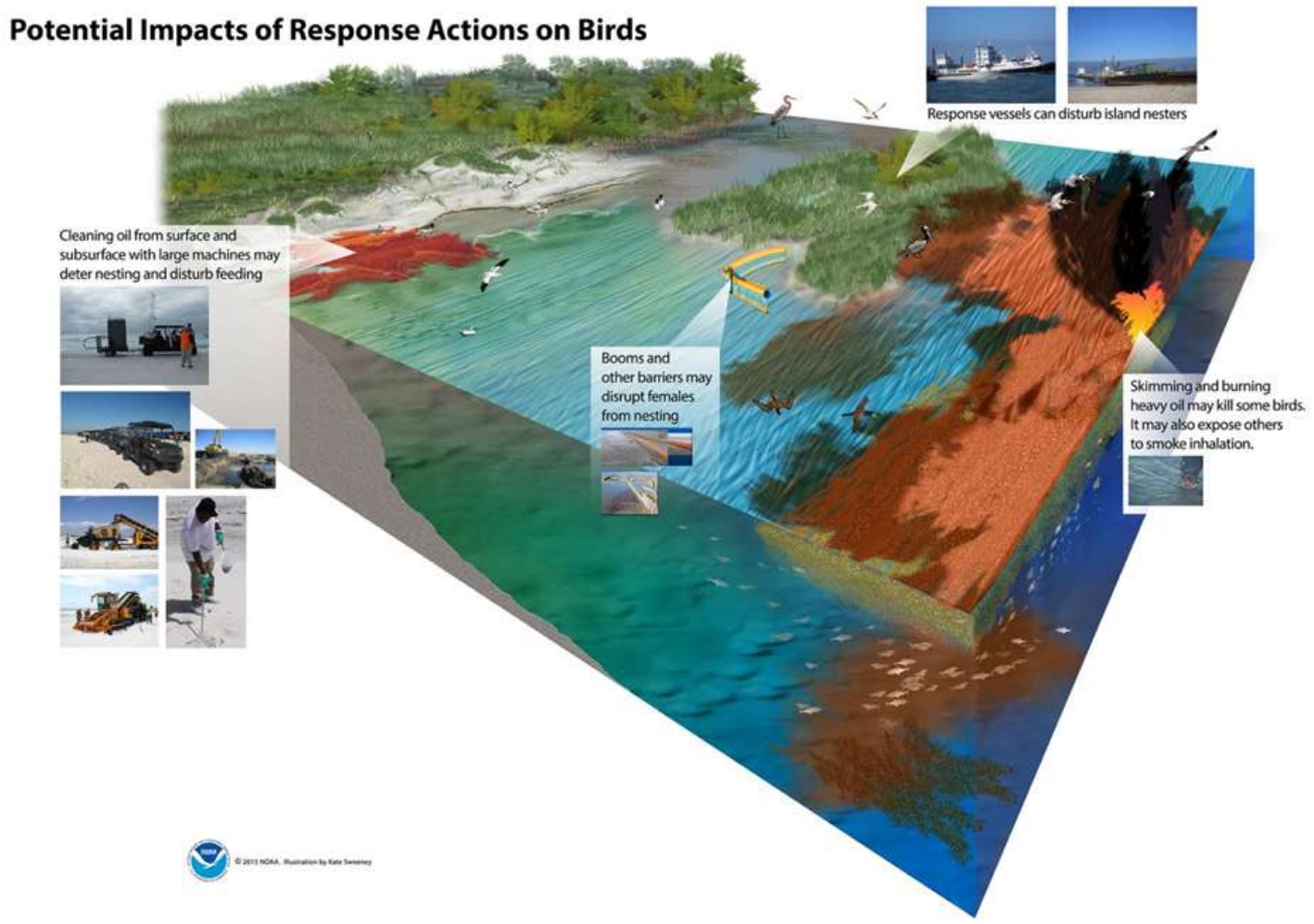
The Trustees collected data on densities of seaside sparrows, clapper rails, least bitterns, and red-winged blackbirds in different marsh habitats (e.g., *Spartina*-dominated and *Phragmites*-dominated); only density values derived from distance sampling models were used (Conroy 2013). Bird densities ranged between 0.05 individuals per hectare (least bitterns in *Spartina* marsh) to 3.4 individuals per hectare (seaside sparrows in *Spartina* marsh). Habitat-specific densities for the four example species were multiplied by the oiled shoreline lengths for each habitat type (Section 4.6, Nearshore Marine Ecosystem), using an assumption that any bird within 100 meters of an oiled shoreline was potentially susceptible to oil exposure.

Based on these methods described above, tens of thousands of individuals from these four bird species were estimated to have been present and therefore potentially exposed to *Deepwater Horizon* oil in oiled marsh habitats in Louisiana (Wallace & Ritter 2015).

The actual exposure and injury are not quantified, but this exercise indicates that substantial injury to marsh birds likely occurred. Heavily oiled marsh areas had extensive oiling on the soil, oil coating the vegetation, and oil contaminated prey; birds that were present in these habitats would have been exposed via multiple pathways. For example, birds would have come into direct contact with oiled vegetation through walking, perching, foraging, hiding from predators, etc.; and would have ingested oil when preening oil from feathers, eating contaminated prey, and ingesting soil or sediment while feeding.

4.7.5.4.3 Response Activities

Actions and activities of people and equipment deployed to control and clean up the oil spill also may have directly and indirectly injured birds, although these were not quantified as part of the avian assessment. Direct response injuries include disturbance of birds while nesting or foraging, crushing of nests or young, and intentional hazing (using propane cannons and other methods) to deter birds from heavily oiled areas. Examples of indirect effects include reduction of food sources, nest abandonment, and loss of habitat. The array of potential response effects is illustrated in Figure 4.7-22. Response activities also may have interfered with collection of carcasses that would have been used in injury assessment. For instance, machines that skimmed oil-contaminated material from sandy beaches or open water may have incidentally collected bird carcasses, and in-situ burning of oil may have destroyed bird carcasses.



Source: *Kate Sweeney for NOAA. Photos from U.S. Department of the Interior.*

Figure 4.7-22. Potential effects of response actions on birds. Text boxes highlight specific details about various response actions and potential adverse effects to birds.

Several response activities took place with the intent of preventing oil from getting to shore and cleaning oiled shoreline. These activities likely affected colonial nesting birds. For example, on many colonies, boom moved into the colonies likely impacting nests, nesting habitat, and chicks (Figure 4.7-23; (Baker et al. 2015).

Source: *Louisiana Department of Wildlife and Fisheries.*

Figure 4.7-23. Containment and sorbent boom washed ashore in a Brown Pelican colony. Boom is wrapped around pelican nests and fledglings on nests in the colony, which likely resulted in injuries to nesting birds, their nests, and their fledglings.

Response activities not only had physical impacts to the colonies, but also likely enhanced oil exposure to colonies and colonial birds. For example, oiled booms were found retaining oil on the water against colonies for several days at a time (Figure 4.7-24). The daily persistence of oil, in combination with tidal fluctuations, likely enhanced oil exposure on shorelines, vegetation, and sediment at colonies. Additionally, lost nesting habitat destroyed by response activities, such as boom removal, could affect nesting success in future years (Baker et al. 2015).

Source: *Louisiana Department of Wildlife and Fisheries.*

Figure 4.7-24. Oil trapped by boom against Cat (or Mangrove) Island colony in Barataria Bay.

4.7.5.4.4 Injury Outside the Domain of Quantified Injury

As demonstrated in the *Exxon Valdez* oil spill, chronic effects to birds and degradation of habitat quality may persist for extended periods (Iverson & Esler 2010). This assessment considered only effects within the first year post-spill, so any subsequent effects were not estimated, likely leading to an underestimation of overall bird injury. Similarly, longer-term health effects to birds exposed to *Deepwater Horizon* oil during the Trustees' period of study may not manifest as shortened life span until years later; that injury would not be captured by this assessment. Also, migratory birds with compromised health or damage to feathers as a direct result of the *Deepwater Horizon* oil spill could suffer depressed reproduction or increased risk of death (Ziccardi 2015) in times outside our period of study and/or in places outside of the northern Gulf of Mexico. These injuries would not be detected using our assessment metrics. Finally, the *Deepwater Horizon* oil spill had significant effects on the entire northern Gulf of Mexico ecosystem (Chapter 3, Ecosystem Setting and Affected Environment). The indirect effects that radiate from a perturbation of that magnitude likely had significant, negative effects on birds. For example, disruptions to food webs, loss of nesting structure, and persistent contamination are all likely mechanisms of injury that would not be detected in this assessment.

4.7.5.5 Sources of Potential Bias and Uncertainty

Within the quantitative methods used by the Trustees to estimate mortality, there are a number of potential sources of bias that likely led to underestimates of injury, including the following:

- Searcher efficiency trials conducted as part of the Shoreline Deposition Model were conducted under ideal conditions, with respect to tides, carcass condition, observer motivation, and other factors. With an oil spill of this geographic and temporal magnitude, the conditions during actual carcass collection were likely less than ideal in many instances, resulting in poorer searcher efficiency and mortality underestimation.

- Carcass persistence along marsh edges may have been overestimated, as the carcasses used in the Trustees' carcass persistence study were fresher and more intact than the average bird found during spill response efforts.

- Based on results of field and lab studies, the Trustees hypothesize that estimates of oiling rates conducted as part of the Live Oiled Bird Model may have been low for birds with dark plumage (e.g., cormorants) due to difficulties in detecting oil on these birds.

- Similarly, some birds that were determined to be unoiled may have been oiled previously but had preened away that oil prior to observation. These birds would still be subject to the detrimental health effects the Trustees documented in our laboratory exposures following external exposure to oil.

- Throughout the multitude of bird surveys conducted during the spill, oiling observations were limited to locations on a bird's body that were visible to observers. Most birds observed were resting, nesting, or loafing—positions that would have limited observers' ability to evaluate oiling on bird breasts and bellies, the body parts where they would be most likely to come in contact with oil on the surface of the water or land.

The Trustees made a conscientious attempt to estimate avian injury as accurately as possible, but recognize that variable and uncontrolled field conditions and factors that were impossible to account for resulted in uncertainty and variability in our estimates. Ranges of mortality are presented for the quantified components of injury, rather than point estimates, to attempt to account for some of that uncertainty and variability. The Trustees consider their estimate of injury to be scientifically reasonable but conservative (i.e., injuries were underestimated). Inherent bias and uncertainties like those described above resulted in underestimation of bird mortality caused by the *Deepwater Horizon* oil spill. Thus it is most likely that true mortality for the quantified components of the injury assessment was closer to the upper estimates presented in Table 4.7-3 than the lower estimates.

4.7.6 Conclusions and Key Aspects of the Injury for Restoration Planning

4.7.6.1 Summary

The Trustees have documented a large-scale and pervasive bird injury in the northern Gulf of Mexico as a result of the *Deepwater Horizon* oil spill. Bird deaths for the quantified component of injury assessment were found to be in the tens of thousands. Injured birds represented nearly every coastal bird guild and the habitats that these birds rely upon, including, islands supporting nesting colonies, beaches, marshes, open water, and *Sargassum* rafts.

Specifically, the injury assessment showed that:

- At least 93 resident and migratory species of birds across all five Gulf Coast states were exposed to *Deepwater Horizon* oil in multiple northern Gulf of Mexico habitats, including open water, barrier islands, beaches, bays, and marshes. Laboratory studies showed that exposure to *Deepwater Horizon* oil led to injuries, including feather damage, abnormal blood attributes, organ damage, and death.

- The total quantified injury was estimated to range from 56,100 to 102,400 lost birds, which included between 51,600 and 84,500 birds that died as a result of the *Deepwater Horizon* oil spill. Further, of those dead birds, breeding age adults would have produced an estimated additional 4,600 to 17,900 fledglings in 2010 and 2011. Due to a number of factors that likely led to underestimation of mortality, true injury is likely closer to the upper ranges than the lower. In addition, unquantified injury in marsh and island waterbird colonies suggests that the total injury is substantially higher.

- The magnitude of the injury and the number of species affected makes the *Deepwater Horizon* spill an unprecedented human-caused injury to birds of the region.

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

4.7.6.2 Ecosystem Effects

Birds are important components of marine ecosystems across the globe. They are highly responsive to variation in prey, and also exert top-down effects on the number and distribution of prey species. They also are abundant with high metabolic rates, and thus exhibit high food consumption relative to other taxa, which increases their influence on marine communities. Birds also serve as prey for other species (e.g., raptors, alligators) and changes in the prey base could have effects on top level predators. The Trustees, therefore, expect that the loss of birds as a result of the *Deepwater Horizon* oil spill would have meaningful effects on food webs of the northern Gulf of Mexico.

Birds serve additional ecological functions, including transfer of nutrients between marine and terrestrial biomes, seed dispersal, and many others. These functions were disrupted as a result of the *Deepwater Horizon* oil spill, due to losses of birds and changes to their behavior.

Ecosystem ramifications resulting from bird injury following the *Deepwater Horizon* spill are not limited to the northern Gulf of Mexico. Many birds that occur in the spill-affected region migrate to areas across North, Central, and South America (Figure 4.7-3) where their impaired performance or reduction in numbers could have radiating effects on ecosystems similar to those described above. These broad effects, although difficult to quantify, may have occurred due to changes in many bird species across many migration and breeding habitats.

4.7.6.3 Recovery

The *Deepwater Horizon* oil spill injured avian resources throughout the Gulf of Mexico through a variety of mechanisms, including but not necessarily limited to exposure to oil, disturbance from response activities, and degradation of habitat. The Trustees estimate that between 56,100 and 102,400 birds were killed by the spill or not produced as a result of the spill, representing dozens of species across all five Gulf Coast states (Table 4.7-3).

Ultimately, the large number of individuals injured by the spill, the diversity of species, specific life history requirements and population structures of different species, spill-related impacts to habitats and prey relied upon by birds, and other factors unrelated to the spill that can affect bird species make the estimation of recovery time challenging. The Trustees documented mortality and reproductive loss over approximately one year following the spill. Injury may have persisted beyond that period for some species. Complete recovery of the tens of thousands of birds lost due to the *Deepwater Horizon* oil spill would take longer relying on natural recovery (no action) than if restoration actions were implemented. To restore the number of birds lost during the spill will require many years of restoration activities.

4.7.6.4 Restoration Considerations

As described in Chapter 5 (Restoring Natural Resources), the Trustees have identified an integrated portfolio of restoration approaches to restore for these avian injuries. The Trustees will consider restoration actions across the Gulf of Mexico, as well as in non-Gulf areas where injured bird species migrate and/or breed, potentially including but not necessarily limited to the upper Midwest, northwest Atlantic, and Caribbean.

4.7.7 References

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