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OVERVIEW

Effects of the *Deepwater Horizon* oil spill on protected marine species

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ABSTRACT: The *Deepwater Horizon* (DWH) incident was the largest offshore oil spill in the history of the United States, contaminating surface waters, the water column, deep-sea corals and benthos, nearshore and coastal ecosystems, and natural resources across 5 states and an ocean area of more than 112 000 km^2 in the Gulf of Mexico (GoM). Protected marine species — sea turtles and marine mammals, in particular — were a main focus of the DWH Natural Resource Damage Assessment (NRDA). The DWH spill overlapped in time and space with sea turtle and marine mammal habitats and life stages throughout the northern GoM. Thus, the DWH NRDA Trustees (2016; www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan/) performed several activities to assess adverse effects of oil exposure on sea turtles and marine mammals to quantify the full extent and nature of the impacts to these taxa across the region. A synopsis of the Trustees' assessment activities and conclusions is presented in the DWH NRDA Programmatic Damage Assessment and Restoration Plan (DWH NRDA Trustees 2016). This Theme Section presents several of these specific sea turtle and marine mammal assessment activities and associated findings. This Overview provides a context for the Theme Section papers, introduces basic NRDA concepts and discusses generally why and how protected marine species were assessed in the DWH NRDA.

KEY WORDS: *Deepwater Horizon* oil spill · Natural Resource Damage Assessment · Oil spills · Sea turtles · Marine mammals

INTRODUCTION TO THE THEME SECTION

On April 20, 2010, the *Deepwater Horizon* (DWH) mobile drilling unit exploded and eventually sank in the northern Gulf of Mexico (GoM), nearly 64 km from mainland Louisiana, USA. In addition to the tragic loss of 11 human lives and 17 injured people, approximately 3.19 million barrels of oil were released into the ocean over 87 days following the initial explosion (DWH NRDA Trustees 2016 [Section 2]). The spill contaminated over 112 000 km^2 of surface waters and 2100 km of shoreline, and affected a wide diversity of biotic and abiotic natural resources in the GoM marine ecosystem (DWH NRDA Trustees 2016). This extensive oiling contaminated vital foraging, migratory, and breeding habitats of protected marine species (e.g. sea turtles and marine mammals) at the surface, in the water

column, and on the ocean bottom throughout the northern GoM.

The unprecedented size, duration, and remote, offshore location of the DWH spill required different assessment and response approaches than those used in previous spills that occurred closer to shore and in smaller, more confined areas. US federal and state agencies charged with stewardship of natural resources (i.e. the Trustees) performed numerous assessment activities to determine and quantify the full extent of adverse effects of oil exposure and their consequences for protected marine species under the DWH Natural Resource Damage Assessment (NRDA). The papers in this Theme Section of *Endangered Species Research* describe some of these assessment activities and highlight the comprehensive interdisciplinary approaches needed to evaluate and quantify the nature and magnitude of exposures to oil and the resulting impacts on populations of protected species (i.e. sea turtles and marine mammals). The complete injury assessment — including assumptions, methods, results, and implications — is contained in the DWH Programmatic Damage Assessment and Restoration Plan (PDARP) and Programmatic Environmental Impact Statement (PEIS) (DWH NRDA Trustees 2016).

BACKGROUND ON NATURAL RESOURCE DAMAGE ASSESSMENT

Under the Oil Pollution Act of 1990 (OPA), the Trustees are entitled to monetary damages to restore natural resources that were harmed by the oil spill. The process of assessing the impacts and quantifying the damages is called Natural Resource Damage Assessment (NRDA). The primary goal of OPA is to restore natural resources and services lost due to oil pollution. Under OPA regulations in the US Code of Federal Regulations (CFR), a loss or adverse impact to a natural resource is called an 'injury,' defined as 'an observable or measurable adverse change in a natural resource or impairment of a natural resource service caused by an oil spill incident' (15 CFR § 990.30). The NRDA is the process of identifying and quantifying injuries to natural resources exposed to the oil pollution, and then developing and implementing adequate restoration to compensate for the natural resource losses. The compensation should return injured natural resources to the conditions they would be in if the oil spill had not occurred ('baseline conditions'), while also compensating for losses incurred from the time the injury started until

the time that the resources are fully restored ('interim losses;' 15 CFR § 990).

The DWH NRDA involved federal and state natural resource Trustees, contractors, and subcontractors, who collaboratively evaluated the nature, extent, and degree of exposures and injuries to natural resources caused by the DWH oil spill. In compliance with OPA regulations, the DWH NRDA Trustees completed and published online the DWH PDARP/ PEIS, along with all technical reports and associated documents used in the NRDA (DWH NRDA Trustees 2016). The Trustees assessed injuries to a wide variety of natural resources, including the water column and biota therein; benthic resources; the nearshore marine ecosystem, including coastal marsh and shorelines; and lost recreational use. In addition, the Trustees focused assessment efforts on specific taxa including birds, sea turtles, and marine mammals. Because all sea turtles and marine mammals are protected by US federal statutes, and all are strictly marine species, they are the focus of this special Theme Section.

WHY PROTECTED MARINE SPECIES WERE ASSESSED

Adverse physical and toxic effects of oil exposure on wildlife, including sea turtles and marine mammals, have been documented extensively (e.g. Piatt & Ford 1996, Shigenaka 2003, Helm et al. 2015). The DWH oil was no exception: exposure to DWH oil caused a variety of harmful effects on a wide range of species native to the northern GoM (e.g. Fallon et al. 2014, Schwacke et al. 2014, Brown-Peterson et al. 2015).

Sea turtles and marine mammals occupy various habitats throughout the northern GoM for growth and reproduction, and they presently face numerous anthropogenic threats (Bolten et al. 2011, Reeves et al. 2013). Sea turtles and marine mammals are usually slow-growing, late-maturing, and long-lived, and generally do not reproduce every year, making populations particularly vulnerable to declines and slow to recover when threats are reduced (Musick 1999). Offshore areas in the GoM host several sea turtle and marine mammal species, including leatherback turtles and small, surface-pelagic juvenile loggerheads, Kemp's ridleys, green turtles, and hawksbills, as well as large cetacean species such as spinner dolphins, striped dolphins, Bryde's whales, sperm whales, dwarf and pygmy sperm whales, and Cuvier's beaked whales. Continental shelf and nearshore/coastal areas

provide habitats for large, 'neritic' juvenile and adult sea turtles and several cetacean stocks (e.g. Atlantic spotted dolphins, 3 common bottlenose dolphin stocks). Inshore areas such as bays, sounds, and estuaries host juvenile and/or adult Kemp's ridleys, loggerheads, and green turtles, as well as 9 stocks of bottlenose dolphins. Loggerheads, and, to a lesser extent, Kemp's ridleys and green turtles, nest on sand beaches in the northern GoM. See DWH NRDA Trustees (2016 [Sections 4.8 and 4.9]) for summaries of sea turtle and marine mammal distributions in the northern GoM.

All sea turtle and marine mammal species are protected by federal law in the USA. The northern GoM hosts 5 sea turtle species and 57 marine mammal stocks from 22 different species (21 cetaceans and 1 sirenian). All sea turtle species that occur in the GoM are listed under the Endangered Species Act, as are sperm whales; all marine mammal species are also protected under the Marine Mammal Protection Act. Many sea turtle and marine mammal species and stocks are also listed or protected under international conservation treaties and agreements, e.g. Inter-American Convention for the Protection and Conservation of Sea Turtles, Convention for Migratory Species (i.e. the Bonn Convention), Convention on International Trade in Endangered Species, International Union for the Conservation of Nature Red List of Threatened Species™. These listings generally mean that these taxa are considered to be in danger of extinction if current threats are not reduced, and that their conservation and continued existence are valued across international borders.

Sea turtles and marine mammals fulfill unique ecological roles as long-lived, large-bodied animals that move through several habitats during their lives, and they are often focal species in assessments of marine ecosystem health and function (Bjorndal & Jackson 2003, Moore 2008). In addition, sea turtles and marine mammals are also valuable natural resources to humans, including both use value (e.g. ecotourism) and non-use value (e.g. existence value). Consequently, considering the federal statutes protecting sea turtles and marine mammals, the important ecological roles that these taxa play, and their value to humans, the DWH NRDA evaluated the effects of the DWH oil on sea turtles and marine mammals across geographic areas and life stages to quantify the full extent of injuries from the time of the spill into the future. The injury assessments informed the development of a portfolio of restoration approaches designed to address primary threats to these taxa, thereby restoring them to their baseline conditions

prior to the DWH spill (DWH NRDA Trustees 2016 [Section 5]).

HOW PROTECTED MARINE SPECIES WERE ASSESSED

The pervasive and prolonged nature of the DWH spill and the related cleanup response activities overlapped in time and space with sea turtle and marine mammal distributions throughout the northern GoM, from offshore areas, across the continental shelf, in nearshore and inshore areas, and on beaches (DWH NRDA Trustees 2016 [Section 4]). Thus, DWH necessitated different response and assessment approaches than those used in previous spills (e.g. *Exxon Valdez*, Peterson et al. 2003; *Prestige*, Munilla et al. 2011) that occurred closer to shore in smaller, more confined areas over shorter time periods. To comprehensively assess DWH oil exposure and injury to sea turtles and marine mammals throughout the northern GoM, the Trustees performed a suite of activities, including boat-based and aerial surveys, rescues, veterinary assessments, satellite tracking of live animals during and after the spill, and recovery and examination of stranded animals (DWH NRDA Trustees 2016 [Sections 4.8 and 4.9]). Planning and execution of the NRDA studies involved an expansive and multidisciplinary team of researchers, many of whom are co-authors on papers published in this Theme Section.

Direct observations of oil on sea turtles and marine mammals represented only a small fraction of the scope and scale of oil exposure and injuries. Factors that restricted the Trustees' ability to perform complete surveys included the vast expanse of the search area (112 000 km^2) and distance from shore of the source of the spill (>64 km); safety considerations associated with ongoing response actions during the spill; and inherent challenges to studying highly mobile, protected marine animals (e.g. located in remote areas, difficult to find and capture at sea, time spent below the surface). For these reasons, both the sea turtle and marine mammal technical working groups (TWGs), which were established to perform injury assessments for each taxon, also used expert opinion about oil toxicity (Mitchelmore et al. 2017, this Theme Section), surface oiling maps (Aichinger Dias et al. 2017, Wallace et al. 2017, both this Theme Section), veterinary assessments (Stacy 2012, Smith et al. 2017, this Theme Section), and statistical approaches (Hornsby et al. 2017, Kellar et al. 2017, McDonald et al. 2017a,b, Schwacke et al. 2017, all

this Theme Section) to estimate the total injuries within the entire footprint and period of the DWH oil spill (DWH NRDA Trustees 2016 [Sections 4.8 and 4.9]).

Differences in the available data and analyses warranted distinct approaches to the respective assessments of DWH oil exposure and injury determination and quantification for the 2 taxa. For example, surface oiling in offshore areas that contain vital habitat for small, surface-pelagic juvenile sea turtles presented a unique and acute risk of severe exposure to DWH oil (Stacy 2012, McDonald et al. 2017a, Wallace et al. 2017). In recognition of this threat, the NOAA–National Marine Fisheries Service and other agency and nongovernmental partners conducted rescue operations in offshore convergence areas to document and rescue sea turtles exposed to surface oil (Stacy 2012, McDonald et al. 2017a). These rescue efforts provided direct evidence of the degree of oil exposure and allowed veterinarians to evaluate over 300 oiled turtles for adverse physical and physiological effects (Stacy 2012, Stacy et al. 2017, this Theme Section). Other types of information that the Trustees used in the sea turtle assessment included:

• Observations of sea turtles during aerial surveys (Garrison 2015)
• Satellite tracking of live sea turtles (Hart et al. 2014)
• Chemical analyses of oil samples collected from live and dead turtles recovered during the DWH spill (Ylitalo et al. 2017, this Theme Section)
• Recovery and post-mortem examination of stranded turtles (Stacy 2012)
• Monitoring of nesting sea turtles and their eggs and hatchlings to estimate effects of deterrence of nesting females related to beach clean-up activities (Lauritsen et al. 2017, this Theme Section)
• Historical and published information (DWH NRDA Trustees 2016 [Section 4.8])
• Various statistical techniques to quantify the full extent of injuries to sea turtles caused by the DWH oil spill (Garrison 2015, DWH NRDA Trustees 2016 [Section 4.8], McDonald et al. 2017a)
• Laboratory exposure of surrogate freshwater turtles to DWH oil (Mitchelmore & Rowe 2015).

Ultimately, the observations made during offshore boat-based rescues of oiled turtles were a foundational dataset for determining oil exposure and its effects, and for determining and quantifying injuries to sea turtles caused by the DWH oil throughout the northern GoM (McDonald et al. 2017a, Wallace et al. 2017). In addition, large numbers of non-visibly oiled, beachcast stranded turtles were found during

and in the years following the oil spill (Stacy 2012, 2015). Following intensive post-mortem examinations, many were concluded to most likely have died as a result of bycatch in commercial fisheries, highlighting the importance of multiple anthropogenic threats within the region (Stacy & Schroeder 2014, Stacy 2015).

In contrast, the primary component of the marine mammal injury assessment focused on long-term, post-DWH evaluations of live-captured and dead stranded small cetaceans (i.e. bottlenose dolphins *Tursiops truncatus*) in areas close to shore in the northern GoM, especially bays, sounds, and estuaries (DWH NRDA Trustees 2016 [Section 4.9], Takeshita et al. 2017, this Theme Section). To determine exposure and injury to whales and dolphins, the marine mammal TWG synthesized data from several sources, including:

• Stranded carcasses (Litz et al. 2014, Colegrove et al. 2016; and Hohn et al. 2017, Rosel et al. 2017, Thomas et al. 2017, Wilkin et al. 2017, all this Theme Section)
• Estimates of home ranges, densities, reproductive success, and survival (Kellar et al. 2017, McDonald et al. 2017b, Wells et al. 2017, all this Theme Section)
• Long-term assessments of various health parameters (Schwacke et al. 2014, Venn-Watson et al. 2015a; and Fauquier et al. 2017, Smith et al. 2017, both this Theme Section) in inshore areas with documented DWH oil contamination (e.g. Barataria Bay, Louisiana; Mississippi Sound, Mississippi)
• Historical data on marine mammal populations (DWH NRDA Trustees 2016 [Section 4.9])
• NRDA toxicity studies (DWH NRDA Trustees 2016 [Section 4.9]).

The marine mammal TWG concluded that exposure to DWH oil caused a constellation of adverse health effects (e.g. reproductive failure, organ damage) (Kellar et al. 2017, Smith et al. 2017), and that animals killed by these adverse effects contributed to the largest and longest marine mammal unusual mortality event ever recorded in the GoM (Litz et al. 2014, Venn-Watson et al. 2015b, Colegrove et al. 2016). Based on the degree to which oceanic cetacean stocks were exposed to DWH oil compared with exposure of the well-studied Barataria Bay and Mississippi Sound bottlenose dolphin stocks, these conclusions about adverse health effects were then applied to oceanic stocks to estimate total injuries to all likely exposed marine mammal species in the GoM (Takeshita et al 2017).

Despite the differences between approaches, both assessments quantified significant injuries to sea tur-

tles and marine mammals across the northern GoM; detailed descriptions of results and conclusions for both taxa are presented in DWH NRDA Trustees 2016, Sections 4.8 and 4.9. Briefly, the Trustees estimated that DWH effects caused the loss of approximately 10 to 20 % of all the 1 and 2 yr old Kemp's ridley turtles alive during the DWH oil spill (DWH NRDA Trustees 2016 [Section 4.8]), and up to 51 and 62 % reductions in total abundance of Barataria Bay and Mississippi Sound bottlenose dolphin stocks, respectively (DWH NRDA Trustees 2016 [Section 4.9], Schwacke et al. 2017).

Considering their long lifespans and generation time — including slow maturation times and low reproductive rates — and wide distributions over which resource availability and impacts of threats can vary greatly (Musick 1999), the Trustees concluded that full recovery of GoM sea turtle and marine mammal populations of both taxa from these losses will take decades and will require extensive restoration efforts (DWH NRDA Trustees 2016 [Sections 5.5.10 and 5.5.11]). To restore these lost natural resources, the Trustees developed integrated portfolios of restoration approaches that were designed to address all species, stocks, and life stages injured by the DWH spill. These restoration approaches are described in detail in Section 5 of the PDARP (DWH NRDA Trustees 2016).

CONCLUSION

This *Endangered Species Research* Theme Section presents a synthesis of more than 5 years' worth of data collection, analysis, and interpretation, as well as countless hours spent in discussion, all with the singular goal of quantifying the full extent of injuries to protected species — sea turtles and marine mammals — caused by the DWH oil spill in the northern GoM. Each paper in the Theme Section is a unique and critical piece of the overall story that the DWH NRDA Trustees have assembled to support achievement of the goal to assess injuries to natural resources and to inform restoration of those resources to make the GoM ecosystem and the public whole. However, we emphasize that the papers that comprise this Theme Section do not represent the complete compendium of assessment documents, nor do they collectively describe the complete injury assessment for either sea turtles or marine mammals. Please see the injury assessment section of the PDARP (DWH NRDA Trustees 2016 [Section 4]) for the complete sea turtle and marine mammal injury assessments, and the Administrative Record for all supporting documentation (https://www.doi.gov/deepwaterhorizon/adminrecord).

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