

## Chapter 26

# Impacts of the Deepwater Horizon Oil Spill on Marine Mammals and Sea Turtles



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**Abstract** The Gulf of Mexico (GOM) is one of the most diverse ecosystems in the world (Fautin et al. PLoS One 5(8):e11914, 2010). Twenty-one species of marine mammals and five species of sea turtles were routinely identified in the region by the end of the twenty-first century (Waring et al. NOAA Tech Memo NMFS NE 231:361, 2015), a decrease from approximately 39 species prior to intensive exploitation (Darnell RM. *The American sea: a natural history of the Gulf of Mexico*. Texas A&M University Press, College Station, TX, 2015). Life histories of these megafauna species range from hyperlocal residence patterns of bottlenose dolphins to inter-ocean migrations of leatherback turtles. All species are subject to direct and indirect impacts associated with human activities. These impacts have intensified with major development and extraction efforts since the 1940s. The *Deepwater Horizon* (DWH) oil spill represents a new type of injury to this system: Unlike previous large oil spills, it not only exposed marine megafauna to surface slicks, it also involved an unprecedented release of dispersed oil into deep waters and pelagic habitats, where effects are difficult to observe and quantify. This chapter synthesizes the research conducted following the DWH oil spill to characterize acute and chronic offshore effects on oceanic marine mammals and sea turtles. Marine mammals and sea turtles were exposed to unprecedented amounts of oil and dispersants. Local declines in marine mammal presence observed using passive acoustic monitoring data suggest that the acute and chronic population-level impacts of this exposure were likely high and were underestimated based on coastal observations alone. These population declines may be related to reduced reproductive success as observed in nearshore proxies. Long-term monitoring of oceanic marine mammals is a focus of this chapter because impacts to these populations have not been extensively covered elsewhere. We provide an overview of impacts to sea turtles and

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coastal marine mammals, but other more thorough resources are referenced for in depth reviews of these more widely covered species.

**Keywords** Marine mammal · Sperm whale · Beaked whale · Dolphin · Passive acoustic monitoring · PAM · Sea turtle · Loggerhead · Kemp's ridley · Megafauna · Bottlenose · Barataria Bay · Mammal · Odontocete · Bryde's whale · Spotted dolphin · *Stenella* · *Kogia* · Echolocation · Visual survey · Nesting · Entanglement · Ship strike · Noise · Airgun · UME · Unusual mortality event · Leatherback, Hawksbill · Stranding · Pinniped · HARP · Mississippi Canyon · Green Canyon · *Sargassum* · Green turtle · Trawl · Skimming · Risso's dolphin · Pilot whale · Tag · Aerial survey · Bycatch

## 26.1 Megafauna of the Gulf of Mexico

The Gulf of Mexico (GOM) supports 5 species of sea turtles and at least 21 species of marine mammals including 1 species of baleen whale, 19 species of toothed whales, and 1 species of manatee (Darnell 2015). Gulf marine mammal species fall into several ecological groups: Shallow-dwelling bottlenose dolphins (*Tursiops truncatus*) inhabit coastal waters including bays, sounds, and estuaries, as well as the broad continental shelf regions extending from the coast out to the shelf break. Atlantic spotted dolphins (*Stenella frontalis*) are also commonly found on the continental shelf. The majority of the marine mammal diversity in the GOM is found at or beyond the shelf break, often hundreds of kilometers offshore. Pelagic deep-diving species include sperm whales (*Physeter macrocephalus*), Gervais' and Cuvier's beaked whales (*Mesoplodon densirostris* and *Ziphius cavirostris*), and *Kogia* species, which execute long foraging dives to depths typically exceeding 200 meters. These species feed at depth, primarily on squid and do not typically exhibit diel foraging patterns. At least 13 species of pelagic, shallower diving delphinids (typical diving depths less than 200 m) are also found in the region. These species feed nocturnally on vertically migrating mesopelagic prey in the deep scattering layer. A single baleen whale species, the GOM Bryde's (*Balaenoptera edeni*) whale, is found in the northeastern GOM near Desoto Canyon (Soldevilla et al. 2017).

All marine mammal species currently known to the northern GOM are also found in other oceans; however, little is known about the migration ranges of Gulf populations or the degree to which they mix with populations in the southern GOM and broader Atlantic. The GOM Bryde's whale is thought to be a distinct and isolated subspecies (Rosel and Wilcox 2014). The GOM sperm whale population also appears to be resident in the area (Waring et al. 2009; Jochens et al. 2008). Sperm whale sightings in the GOM often consist of groups of females and juveniles; therefore, the region is thought to serve as a year-round nursing ground for sperm whales. Large solitary males, which are routinely observed in other oceans, are rarely encountered in the GOM, and tag data has shown that males may travel in and out of the Gulf (Jochens et al. 2008).

Leatherback (*Dermochelys coriacea*) and surface-pelagic juvenile loggerhead turtles (*Caretta caretta*) and green (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempii*), and Atlantic hawksbill (*Eretmochelys imbricata*) sea turtles are found in offshore waters in the GOM, while larger neritic juvenile and adult turtles are found in the continental shelf and nearshore/coastal waters; inshore areas host juvenile and adult Kemp's ridleys, loggerheads, and greens (Wallace et al. 2010, 2017). All five species are listed as endangered or threatened under the Endangered Species Act of 1973. Hatchlings emerge from nesting beaches and disperse into surface-pelagic developmental habitats in convergence zones, using *Sargassum* communities as a foraging resource that affords protection from predation and potential thermal benefits (Bolten 2003, Witherington et al. 2012, Mansfield et al. 2014). Foraging strategies differ by species, with the adult diet of green turtles dominated by seagrasses and algae, loggerheads feeding upon a broad range of pelagic and benthic invertebrates, hawksbills specializing primarily on sponges, Kemp's ridleys feeding mostly on crabs, and leatherbacks depending on cnidarians (see Bjorndal 1997 for a comprehensive review).

Loggerheads and to a lesser extent Kemp's ridleys and green turtles nest on northern GOM beaches in spring and summer months, although the Kemp's ridley's primary nesting beaches are found in the western Gulf in Tamaulipas and Veracruz, Mexico.

## 26.2 A Context of Chronic Impacts

The *Deepwater Horizon* (DWH) oil spill is one chapter in a long history of direct and indirect anthropogenic impacts on marine mammal and sea turtle populations in the GOM. The primary sources of stressors are summarized below.

### 26.2.1 Direct Harvest

Exploitation of GOM megafauna dates back to the Maya and Aztecs, who intensively harvested sea turtles and manatees (Lange 1971). Impacts were likely mainly limited to coastal zones until the late 1700s when the American whaling industry reached Gulf waters (Darnell 2015). Whalers primarily targeted sperm whales, with pilot whales as secondary targets, and reported that the waters of the mouth of the Mississippi River constituted one of the most profitable whaling grounds (Reeves et al. 2011). Reports of sightings and takes of "finback" whales taken in the region likely refer to the Gulf Bryde's whale, and these reports indicate that the range of this species included most of the Gulf (Reeves et al. 2011), although the current population appears to be restricted to a small region near Desoto Canyon (Soldevilla et al. 2017).

Sea turtles are threatened by direct harvest both in offshore habitats and on nesting beaches, from egg to adult stages. Adult green turtles were intensively harvested for their meat in the 1880s (Valverde and Holzwart 2017) when landings of that species alone are estimated at 4800 to 6000 animals per year, across the GOM and broader Caribbean (Darnell 2015). Adult loggerheads were harvested in Cuba through the mid-1990s (Gavilan 1998). Harvesting of sea turtles became illegal in the United States under the Endangered Species Act of 1973, and illegal poaching at sea is thought to be rare in the US Gulf of Mexico (NMFS 2011). However, active harvest may still occur outside of the US EEZ. An active illegal trade in hawksbill tortoiseshells persists (NOAA 2013). Poaching of sea turtle eggs from nesting sites continues in the United States and neighboring countries (NMFS 2008, 2011).

### ***26.2.2 Shipping and Vessel Strikes***

Commercial shipping has been a major industry in the GOM since the 1850s, when the port of New Orleans was the second largest in the country (Darnell 2015). In 2016, GOM ports accounted for nearly 50% of total tonnage transferred through American ports (US Army Corps of Engineers). Both marine mammals and sea turtles are at risk of vessel strikes, and these are likely highly underreported for pelagic species (Williams et al. 2011; Epperly et al. 1996).

### ***26.2.3 Anthropogenic Noise***

Offshore human activities also affect megafauna through elevated noise levels and pollution. Oil and gas development took hold in the GOM in 1947 (Darnell 2015), expanding rapidly thereafter. In 2018 over 50 thousand wells and 7 thousand drilling platforms were documented in the GOM (BOEM 2018). Seismic surveys using explosive sound sources (airguns) are used to map subsurface oil and gas deposits. These surveys are nearly continuous in the GOM, and they combine with shipping noise to make average low-frequency ambient noise levels very high in the GOM relative to levels in other ocean regions (Wiggins et al. 2016). Noise is considered a chronic stressor for marine mammals because these species rely on sound to interpret their environment and communicate with one another (e.g., Wright et al. 2007).

### ***26.2.4 Debris Entanglement, Ingestion, and Bycatch***

Commercial fishing efforts in the GOM expanded after WWII, adopting novel technologies including purse seines, longlines, trawls, and gillnets, which increased the occurrence of marine mammal and sea turtle entanglement in fishing gear (Lutcavage

et al. 1997), as well bycatch rates and competition for prey species (Darnell 2015). Sea turtles and marine mammals are incidentally caught and killed in trawl, gillnet, hook-and-line, and longline fishing gear, and fishery bycatch is considered the most serious global threat to marine megafauna (Lewison et al. 2004; Wallace et al. 2010, 2013).

Marine mammals and turtles are affected by entanglement in gear and marine debris, with possible effects including injury and drowning (Walker and Coe 1989; Plotkin and Amos 1990). Loggerhead, green, hawksbill, and Kemp's ridley sea turtles take refuge as juveniles in *Sargassum* rafts and are particularly susceptible to entanglement in trash and ingestion of plastics (Witherington et al. 2012).

### **26.2.5 Oil and Gas Development**

Oil and gas development in the GOM is linked to a variety of chronic impacts including occasional small- and large-scale spills (Asl et al. 2016; SERO n.d.), leaking infrastructure, chemical releases related to extraction activities (Neff 1990; Neff et al. 2011a, b), persistence of weathered oil and related compounds in the environment (Van Vleet and Pauly 1987; Botello et al. 1997; Van Vleet et al. 1984), increased vessel activity, and the construction and removal of offshore platforms (Gitschlag et al. 1995). Some amount of natural crude oil seepage also occurs from an estimated 914 natural seep zones in the GOM (MacDonald et al. 2015). Oil from small-scale releases and seeps weathers and spreads in the pelagic ecosystem, accumulating in offshore convergence zones. These zones, which aggregate drifts of *Sargassum* and other macroalgae species, act as vital habitats for surface-pelagic juvenile turtles, putting them at particular risk for exposure to oil accumulating in these zones (Witherington et al. 2012; Bolten 2003).

### **26.2.6 Nesting Beach Impacts**

Turtle populations have susceptibilities related to their reliance on nesting beaches, which are impacted by coastal development, beach erosion, light pollution, dredging, beach re-nourishment programs and armoring, climate change and sea level rise, as well as native and exotic predators (Lutcavage et al. 1997). Current efforts to protect nesting beaches and rescue nests began in some areas as early as the 1950s, and successful nesting beach conservation efforts can result in rapid local population increases (Troëng and Rankin 2005; Hayes 2004).

### ***26.2.7 Habitat and Environmental Degradation***

Other major chronic impacts to both marine mammals and turtles include hypoxia in the Mississippi River outflow region, which affects prey quality and density in a previously rich foraging ground for GOM megafauna, as well as harmful algal blooms (Magaña et al. 2003). Direct impacts to turtle habitats including loss of nesting beaches, seagrass beds, and coral reefs, are primarily associated with coastal and continental shelf zones. The same suite of chronic impacts that affect GOM marine mammal and sea turtle health may also have some effect on the health and quality of their prey.

## **26.3 Quantifying Impacts on Pelagic Species/Stages and Habitats**

Although occasional reports of various direct impacts to marine mammals and sea turtles including entanglements and ship strikes are reported, they are likely highly underreported (Williams et al. 2011; Epperly et al. 1996) because they occur off-shore and may go undetected. Carcasses are unlikely to strand following pelagic deaths, particularly in regions or seasons where higher water temperatures accelerate decomposition (Nero et al. 2013). Equally difficult to quantify are the cumulative effects of chronic impacts such as pollution, noise, and prey depletion, since these effects likely accumulate gradually at sublethal levels over many years.

One possible indicator of chronic stress is the occurrence, intensity, and length of unusual mortality events (UMEs). A UME is an unexpected stranding event that represents a significant die-off in a marine mammal population. From 1990 to 2104, there were 12 UMEs in the GOM (Litz et al. 2014) with recovered carcass counts ranging from 31 to 1141 animals and lasting from 1 to 52 months (Resources NOoP 2018). Coastal bottlenose dolphins are the predominant species in the stranding record, likely because the bodies of this nearshore species are far more likely to reach beaches. The proximate cause of the majority of these UMEs is typically determined to be morbillivirus, biotoxins, and/or cold weather. However, the causes of some events remain unknown, as in the case of the largest, longest-lasting event that occurred from 2012 to 2014 with 1141 recovered carcasses. The occurrence of these events suggests population-level immunodeficiencies (Di Guardo and Mazzariol 2013) or other susceptibility in populations which are already experiencing chronic stress.

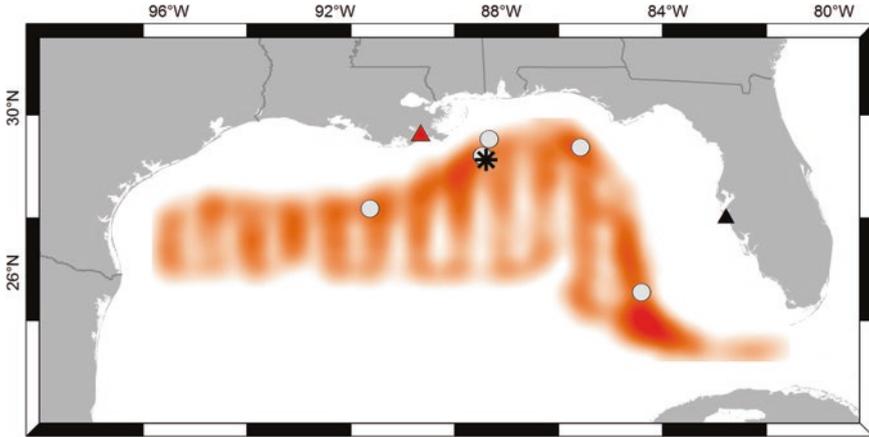
Turtle populations also experience mass stranding events such as cold stunning events (Milton and Lutz 2003). In January 2010, unusually cold temperatures resulted in a cold stunning event of unprecedented magnitude involving over 4500 sea turtles (primarily green turtles) in Florida (Avens et al. 2012). As in the case of marine mammals, chronic stress associated with anthropogenic activity may be acting to decrease overall resilience of turtle populations (Lamont et al. 2012).

One particularly observable anthropogenic impact is the loss of historic nesting beaches to coastal development projects. Female sea turtles generally exhibit high site fidelity to particular nesting beaches, and the availability of natural, undeveloped beaches is dwindling. It is unclear how many nesting beaches may have previously existed in the northern GOM. A 2006 study in the Caribbean estimated that 20% of historic (twentieth century) green and hawksbill nesting beaches in the Caribbean had been lost and that 50% of the remaining beaches were visited by fewer than ten nesting females (McClenachan et al. 2006). Beaches in the northern GOM today have minimal sea turtle nesting relative to the Atlantic regions (except for Kemp's ridleys), although previous nesting density is largely unknown (Hildebrand 1982; Valverde and Holzwarth 2017). Currently, most nesting beaches in the US GOM are in Florida and Texas (see Valverde and Holzwarth 2017 for a thorough account of nesting sites and habitats). However, most Kemp's ridleys found in US waters hatched on Mexican beaches; thus, conservation measures require an international perspective.

The majority of the existing data on population-level effects of oil spills on marine megafauna comes from shallow water spills and their effects on coastal populations. A long-term study of the effects of the Exxon Valdez spill on killer whale populations indicates that two pods suffered acute losses during the event (33% and 41% of their members) and had not returned to pre-spill numbers nearly 20 years later (Matkin et al. 2008). One of the two exposed pods appeared to be headed for extinction at the conclusion of the study (Matkin et al. 2008). Evidence suggests that lipophilic chemical contaminants are often offloaded from mother to calf in marine mammals, including bottlenose dolphins (Irwin 2005) and killer whales (Ylitalo et al. 2001), leading to higher levels of calf mortality.

### ***26.3.1 Study Methods: Pre-DWH***

Marine mammal and sea turtle populations in the offshore GOM have historically been quantified in the offshore GOM using shipboard and aerial visual surveys. Aerial continental shelf surveys began in 1979, initially conducted by the USFWS and then by NMFS. Offshore marine mammal surveys were conducted by NMFS in the spring or summer of 1990–1994, 1996–2001, 2003–2004, and 2009 (Waring et al. 2015; Mullin and Fulling 2004; Mullin 2007) (Fig. 26.1). Major survey efforts in the early to mid-1990s (GulfCet study, supported by the Minerals Management Service) focused on the continental slope region (100–2000 m) and recorded both marine mammals and turtles over eight surveys in all seasons (Würsig et al. 2000). Despite these survey efforts, few species had enough sightings to produce robust population size estimates, and none could be analyzed for long-term population trends due to low precision and infrequent assessments. As a result, little baseline information was available on population trends prior to the DWH spill. The only cetaceans with adequate population data were bottlenose dolphins resident in



**Fig. 26.1** Oceanic monitoring effort in the GOM. Colormap indicates high visual survey effort (red) to low visual survey effort (white) during deepwater (>200 m target depths) NOAA and NOAA-affiliate shipboard surveys 1992–2014. Gray dots indicate GOM HARP monitoring sites, 2010–2017. Asterisk is site of DWH, and triangles are locations of bottlenose dolphin studies in Barataria Bay (red) and Sarasota Bay (black)

selected bays and estuaries, where high-resolution monitoring was based on mark-recapture analysis (Wells 2014).

Offshore turtle surveys using aerial and shipboard methods have limitations because small turtles are difficult to detect and identify using these methods, although using satellite tags to monitor diving behavior to account for sightability may reduce uncertainty in estimates (Thomas et al. 2010; Seminoff et al. 2014). Beach counts of nesting females and clutch sizes are a reliable census method (Schroeder and Murphy 1999), but this approach only surveys adult females nesting in a given year (nesting cycles differ between species). Satellite systems and drones are now being adopted to survey sea turtles, and satellite tags are being used to track their movement over large distances (Rees et al. 2018).

### 26.3.2 Study Methods: Post-DWH

In response to the DWH event, numerous additional studies were initiated in the GOM to understand potential impacts from the spill. The longest-term marine mammal study was the GOM High-frequency Acoustic Recording Package (HARP) program based on passive acoustic monitoring of marine mammal sounds (Hildebrand et al. 2017); an 8 + -year broadband passive acoustic monitoring effort was initiated at five locations in the GOM in 2010 (Fig. 26.1). Three deepwater monitoring locations included a site in Mississippi Canyon near the DWH wellhead (site MC), an eastern site at Green Canyon outside of the DWH surface oil footprint (site GC), and a southern site outside of the oil footprint near the Dry Tortugas (site DT).

HARPs were maintained nearly continuously at these representative oil-exposed and oil-unexposed monitoring sites to detect marine mammal sound production as a proxy for animal presence across the region. Marine mammal species and genera were then distinguished in the long-term passive acoustic recordings based on the characteristics of their sounds. Species monitored include sperm whales, Cuvier's and Gervais' beaked whales, Risso's dolphin, and pygmy/dwarf sperm whales (*Kogia* spp.), delphinids in the genus *Stenella* (Atlantic spotted, pantropical spotted, spinner, striped, and Clymene dolphins), and blackfish (primarily short-finned pilot whales).

Bottlenose dolphin health assessments began in 2011 in Barataria Bay, Louisiana (Schwacke et al. 2013). Health metrics from resident bottlenose dolphins in Barataria Bay, which was heavily oiled by the DWH event (Michel et al. 2013), were compared to an unexposed reference population in Sarasota Bay, Florida (Fig. 26.1).

Shorter-term marine mammal studies following the DWH event included low-frequency passive acoustic monitoring for Bryde's whales on the west Florida shelf in 2010 and 2011 (Rice et al. 2014), satellite tagging efforts aimed at understanding sperm whale distributions (Mate unpublished data), and short-term passive acoustic monitoring near the DWH wellhead site (Ackleh et al. 2012). In the absence of long-term data, various population modeling efforts were also undertaken to try to estimate population-level effects and recovery times based on assumed vital rates (Farmer et al. 2018; Ackleh et al. 2018; Schwacke et al. 2017).

In an effort to mitigate the impact of the spill on sea turtle nesting beaches, 25,000 Kemp's ridley and loggerhead eggs were transported from beaches in the GOM to the Atlantic coast in Florida (Inkley et al. 2013). Following the DWH spill, transect searches were conducted in convergence zones within the spill area to rescue oceanic juvenile sea turtles and to document species composition and oiling status (McDonald et al. 2017). Aerial surveys were conducted on the continental shelf throughout the northern GOM to the 200-m isobath between April and September 2010, documenting the distribution and abundance of neritic sea turtles throughout the DWH spill area (Garrison 2015).

Estimates of the probabilities of oil exposure for sea turtles present within the area of the spill were generated from direct observations of surface-pelagic juvenile sea turtles (Stacy 2012) and satellite-derived surface oil distributions (Wallace et al. 2017). Abundance and source populations for impacted turtles were predicted using ocean circulation and particle tracking simulation models, estimating that 321,401 green, loggerhead, and Kemp's ridley turtles were likely within the spill site, originating primarily from Mexico and Costa Rica (Putman et al. 2015).

## 26.4 Acute Effects

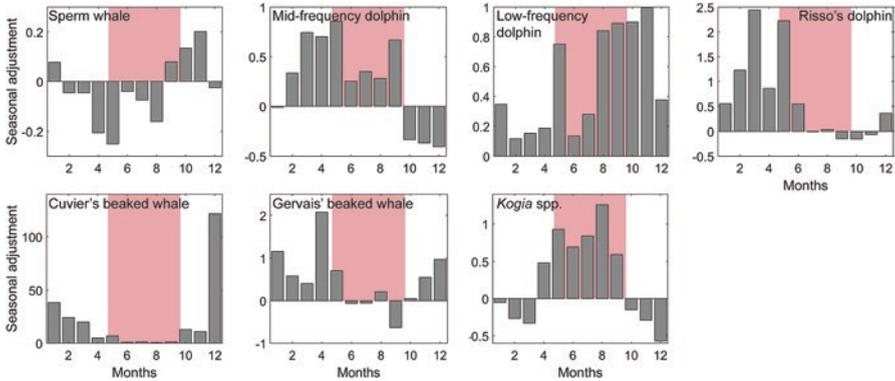
We consider acute effects of the DWH oil spill on marine megafauna as those effects that caused immediate harm during the spill and response. This section focuses primarily on effects experienced in oceanic habitats, as coastal impacts have been reviewed extensively elsewhere. Primary acute effects include immediate injury and death from oil and chemical exposure, response activities, and strandings.

### 26.4.1 *Oil Exposure: Marine Mammals*

In an oil spill, marine megafauna can be exposed to oil and related compounds through surface slicks when breathing or resting at the air/sea interface (Trustees 2016) and through interaction with subsurface plumes during dives and foraging events. Oil compounds can be taken up through the skin, breathed into the lungs, or ingested with prey (Schwacke et al. 2013). Exposure studies conducted in the 1970s focused on polar species including pinnipeds, sea otters, and polar bears and found a range of effects including eye and skin lesions associated with continued exposure, uptake, distribution and accumulation of oil compounds into body tissues and fat reserves through oil ingestion (Engelhardt 1977; Engelhardt 1982), and thermoregulation problems associated with oiling. Marine mammals and turtles were observed in oil-impacted areas during the DWH spill response while the well remained uncapped (Wilkin et al. 2017).

There is limited prior information on the effects of oil spills on marine mammal populations. Early oil spill studies noted that a wide range of marine mammal species including baleen whales, dolphins, and pinnipeds did not appear to avoid oil-contaminated waters (Goodale et al. 1981; Spooner 1967; Geraci 1990a, 1990b) despite the fact that captive bottlenose dolphins could detect and avoid oil in experimental settings (Geraci 1990a). In the case of the DWH oil spill, the acoustic record shows little evidence for near-term avoidance of the wellhead area by marine mammals (see Sect. 26.5).

Marine mammals were exposed to oil at the sea surface but also likely at depth. Deep-diving pelagic species including sperm whales and beaked whales forage at depths of 1000 m or more and likely interacted with the deep plume which formed at approximately 1100 m (Hildebrand et al. 2012). The deep plume formation is largely attributed to dispersant use (Kujawinski et al. 2011) and has not been reported in previous spills; therefore, it likely represents a new route of exposure for deep-diving cetaceans. A large amount of released oil did not reach the surface and likely was eventually deposited on the seafloor (Romero et al. 2017). GOM marine mammal species are not typically benthic foragers; however, bay, sound, and estuary bottlenose dolphins may use benthic hunting tactics (e.g., Lewis and Schroeder 2003; Rossbach and Herzing 1997), which could increase their exposure to deposited oil. In addition, GOM Bryde's whales appear to forage at or near the sea floor



**Fig. 26.2** Seasonal patterns in marine mammal presence at a passive acoustic monitoring site in Mississippi Canyon, located approximately 10 km from the DWH wellhead. The vertical axis indicates the factor by which seasonal presence varies relative to mean presence. Higher values indicate stronger seasonality

(Soldevilla et al. 2017) and, therefore, may also be at risk of exposure to oil deposited in sediments.

Differences in seasonal presence likely played a role in the extent to which marine mammal species were directly exposed to DWH oil and dispersants (Fig. 26.2). Sperm whales, Gervais' beaked whales, *Kogia* species, and mid-frequency dolphins (in the GOM this group primarily consists of species in the *Stenella* genus, categorized based on echolocation click peak frequencies) are found year-round in the region of the oil spill and were likely directly exposed to oil. In particular *Kogia* and mid-frequency delphinid species presence increases in the summer months, increasing the likelihood of exposure to DWH oil and dispersants. Risso's dolphins are seasonally present in spring through summer and therefore likely experienced direct exposure during the first months of the spill but less exposure as the summer progressed. In contrast, Cuvier's beaked whale presence is strongly seasonal near the wellhead with highest occurrence during winter months; therefore, these populations likely experienced minimal direct exposure during the spring spill.

### 26.4.2 Oil Exposure: Sea Turtles

Potential direct impacts to sea turtles from an oil spill differ depending on the life stage, but all stages are vulnerable to acute toxicity from volatile contaminants, exposure through inhalation and ingestion, physical impairment from heavy oiling, and a variety of physiological and clinicopathological impacts of exposure (see review in Shigenaka 2003). Sea turtles are unlikely to detect oil (Odell and MacMurray 1986), and in experimental conditions they showed no avoidance

behavior (Lutcavage et al. 1995). They are continuously exposed by resurfacing to breathe (Milton et al. 2003), and pelagic juveniles are susceptible to floating tar accumulations in ocean convergence zones due to indiscriminate feeding patterns (Witherington 2002; Lutcavage et al. 1997).

In laboratory studies, juvenile loggerheads were adversely affected by short-term exposures to oil in almost all aspects of physiology (e.g., respiration, diving patterns, energy metabolism, salt gland function, oxygen transport, blood chemistry, and red and white blood cell count) (Lutcavage et al. 1995; Lutz et al. 1986). In sea turtles, oil clings to eyes and nares and causes skin to slough off leaving inflamed soft skin exposed to infection (Lutcavage et al. 1995). Skin lesions and necrosis were observed in leatherback oil exposure studies, and skin returned to normal appearance approximately 1 month after the turtles were removed from oil (Lutcavage et al. 1995). Following the Ixtoc 1 oil spill, necropsied sea turtles were found to have ingested large amounts of oil, with indications that the ingestion was eventually lethal (Hall et al. 1983). Effects of oil ingestion in loggerheads dying from oil exposure in the Canary Islands include esophageal impaction, necrotizing dermatitis and gastroenteritis, and necrotizing hepatitis (Camacho et al. 2013).

During the DWH spill, live oiled turtles admitted for rehabilitation exhibited abnormalities including relatively severe metabolic and osmoregulatory derangements resulting from a combination of stress, exertion, exhaustion, and dehydration related to oiling, capture and transport (Stacy et al. 2017). Mortalities were examined for evidence of internal exposure to polycyclic aromatic hydrocarbons (PAHs) and dispersant component dioctyl sodium sulfosuccinate (DOSS) (Ylitalo et al. 2017). Visibly oiled turtles had higher concentrations of PAH than unoiled turtles, which may suggest low-level exposure from other sources, and DOSS levels were below the limit of quantitation in almost all samples (Ylitalo et al. 2017).

Transect searches conducted in convergence zones during rescue operations following the DWH spill documented 937 oceanic juvenile Kemp's ridley, green, loggerhead, and hawksbill turtles in the spill area, and 81% of those captured were visibly oiled (McDonald et al. 2017). Based on these observations, turtle density calculations, and spatial extent of the oil, the total number of pelagic-stage sea turtles exposed to DWH oil was estimated at 402,000, with 54,800 of these heavily oiled, although the majority of the dead turtles were believed to be unobserved and therefore unaccounted for in these estimates (McDonald et al. 2017). Researchers estimated an overall mortality of 30% for oceanic turtles within the footprint of the spill in addition to those presumed dead from heavy oiling (Mitchellmore et al. 2017). Dependence on floating *Sargassum* for shelter and food in convergence zones where oil and tar accumulate makes surface-pelagic turtles particularly vulnerable to ingesting oil and tar (Witherington 2002; Witherington et al. 2012). Stranding data indicated that sea turtle stranding rates were at record levels in 2010 and 2011, increasing as much as 5× after the spill (NMFS data).

Kemp's ridley's principal foraging habitat is in the northern GOM (Seney and Landry Jr 2008; Shaver et al. 2013). Stable isotope analyses conducted on nesting Kemp's showed that 51.5% of turtles sampled had evidence of oil exposure (Reich et al. 2017), indicating that the primary foraging grounds in the northern GOM were

contaminated by oil and that Kemp's ridleys continued to forage in these areas after the spill. Loggerhead foraging sites characterized through satellite tracking demonstrated an overlap with the oil spill footprint, with 32% of tracked individuals taking up year-round residence in the northern GOM foraging habitats (Hart et al. 2014). Stable isotope analysis confirmed that loggerheads returned to the oiled area and did not change foraging patterns after the spill, increasing their risk of chronic exposure to oil and dispersants (Vander Zanden et al. 2016).

Declines in reproductive parameters of loggerheads in the northern GOM were reported (Lamont et al. 2012), although the decline could not be linked directly to the DWH spill. Observed declines in nesting may have been partly due to reduced prey availability and therefore an inhibited ability to allocate resources required for nesting. Colder temperatures in 2010 may have delayed or reduced nesting activity or suppressed the ability of turtles to reach breeding condition (Chaloupka et al. 2008; Lauritsen et al. 2017; Weishampel et al. 2010; Hawkes et al. 2007).

### 26.4.3 Response Activities

Surface skimming and burning of oil slicks during the DWH disaster response may have impacted an unquantified number juvenile turtles living in *Sargassum* (McDonald et al. 2017). Up to 23% of important *Sargassum* habitat was estimated as lost as a result of oil exposure (Trustees 2016).

Response activities related to cleanup efforts, such as mechanical beach cleaning of oiled sand with heavy machinery and the associated disturbance from noise and artificial lighting, impacted sea turtle nesting habitats in the northern GOM (Michel et al. 2013). Enhanced vessel activity and physical barriers (e.g., booms) in near-shore waters may have affected nesting activity as well (Lauritsen et al. 2017). Loggerhead nesting densities in 2010 in northwest Florida were 43.7% lower than expected based on previous data, and an estimated 250 loggerhead nests were lost due to DWH response activities on nesting beaches (Lauritsen et al. 2017).

### 26.4.4 Dispersants

In addition to being exposed to oil, marine mammals and sea turtles were also exposed to dispersants. Impacts of exposure to dispersants or dispersants in conjunction with oil are not well known, as there are few studies for marine mammals and sea turtles. Since oil itself is generally toxic and can be lethal, dispersants may improve short-term survival of marine megafauna by reducing formation of oil slicks, decreasing the probability of heavy oiling, and accelerating the initial degradation of released oil (Neff 1990).

The ramifications of the unprecedented release of high volumes of dispersant chemicals as part of the DWH spill response are widely unknown. Evidence for

cytotoxicity and genotoxicity of Corexit 9527 and Corexit 9500, the two dispersant chemicals used during the DWH spill, to sperm whale skin cells has been demonstrated in a laboratory setting (Wise et al. 2014). These findings were consistent with cytotoxicity and cell survival studies using Corexit 9500 in human and rat cells (Bandelet et al. 2012; Zheng et al. 2014); however, Corexit 9527 was found to be less cytotoxic to whale cells than reported for other species' cells. Cytotoxicity may lead to acute effects, while genotoxicity is expected to lead to delayed effects associated with genetic mutations in somatic and/or germ cells. Mutations in somatic cells from toxic exposure may be associated with cancer in exposed marine mammals (Gauthier et al. 1999), while mutations in germ cells are inherited by offspring.

Effects of dispersants on sea turtles are largely unknown, but dispersants have the potential to interfere with lung function, digestion, and salt gland function (Shigenaka 2003). In an exposure study that investigated the effects of crude oil, dispersant, and a crude oil/dispersant combination on loggerhead hatchlings, significant differences between treatment and nonexposed controls were detected in multiple blood chemistry parameters (Harms et al. 2014). Electrolyte imbalances and hydration challenges were worst in the combined oil/dispersant group, and the failure to gain weight was noted in dispersant and combined exposed hatchlings (Harms et al. 2014). Only one heavily oiled Kemp's ridley showed evidence of DOSS at detectable concentrations (Ylitalo et al. 2017). Recent studies have demonstrated that DOSS degrades more rapidly in surface conditions than under deep-water conditions (Campo et al. 2013; Batchu et al. 2014), suggesting that DOSS exposure was minimized in surface-pelagic turtles (Ylitalo et al. 2017).

### **26.4.5 Mortality Events**

The 2010 marine mammal UME which began prior to the DWH spill complicated measurement of the fatalities from the DWH event itself. It is now thought that the UME was not caused by the spill but was aggravated and potentially prolonged and expanded by the event (Venn-Watson et al. 2015; Antonio et al. 2011). An exponential increase in sea turtle and cetacean mortality was reported beginning 38 days after the initial blowout (Antonio et al. 2011). The relationship between observed strandings and unobserved offshore mortality is difficult to assess, but it has been estimated that strandings accounted for at most 6.2% of the total dead marine mammals in the GOM following the DWH oil spill, depending upon the species (Williams et al. 2011). This study relied on highly uncertain population estimates and mortality rates but strongly suggests that stranded carcass counts are not an adequate means to estimate the total mortality. Similarly, sea turtle carcass stranding rates likely represent a fraction of total at-sea mortality, as carcasses are likely to sink prior to detection (Epperly et al. 1996). Winds, surface currents, and sea temperatures can bias stranding sites with respect to offshore source mortality locations (Nero et al. 2013).

## 26.5 Long-Term Effects

We consider long-term effects of the DWH oil spill on marine megafauna as those occurring after the initial response and cleanup period, extending months to years after the event.

### 26.5.1 Findings of Marine Mammal Passive Acoustic Studies

The GOM HARP project (Frasier et al. 2017; Hildebrand et al. 2015) provides the only long-term time series documenting marine mammal occurrence in oiled and unoiled oceanic habitats during and after the DWH oil spill. Data collected between 2010 and 2016 are discussed here. Mean weekly presence was calculated for each species (or species group) as the weekly average of time per day in which echolocation clicks were detected (Table 26.1). The seasonal component was removed from the weekly presence time series using a monthly seasonal trend decomposition procedure (Cleveland et al. 1990). Long-term trends in deseasoned mean weekly presence were then estimated for each site and species combination using a Theil-Sen regression (Table 26.2) with 5–95% confidence intervals obtained using a bootstrap method. The median slope across 500 pairs of points selected randomly with replacement within each time series was computed 100 times.

On average across the monitoring period, presence of sperm whales (Fig. 26.3) was substantial at the site adjacent to the wellhead (MC, 36.8% of 5-min time windows detected their presence; Table 26.2), slightly less at site GC (13.8% of time windows), and low at site DT (5.1% of time windows). Long-term trend estimates suggest a slow decline in mean presence of sperm whales at site MC ( $5 \pm 1\%$  annual reduction), between 2010 and 2016, and a greater decline at site GC ( $8\% \pm 2\%$  annual reduction). A possible slight increase in the presence of sperm whales was found at site DT ( $5 \pm 5\%$  annual increase); however, encounter rates were low and seasonally variable at this southern GOM location.

**Table 26.1** Mean weekly marine mammal presence (as percentage) including [5th, 95th] percentiles at passive acoustic monitoring sites in the GOM HARP study, 2010–2016

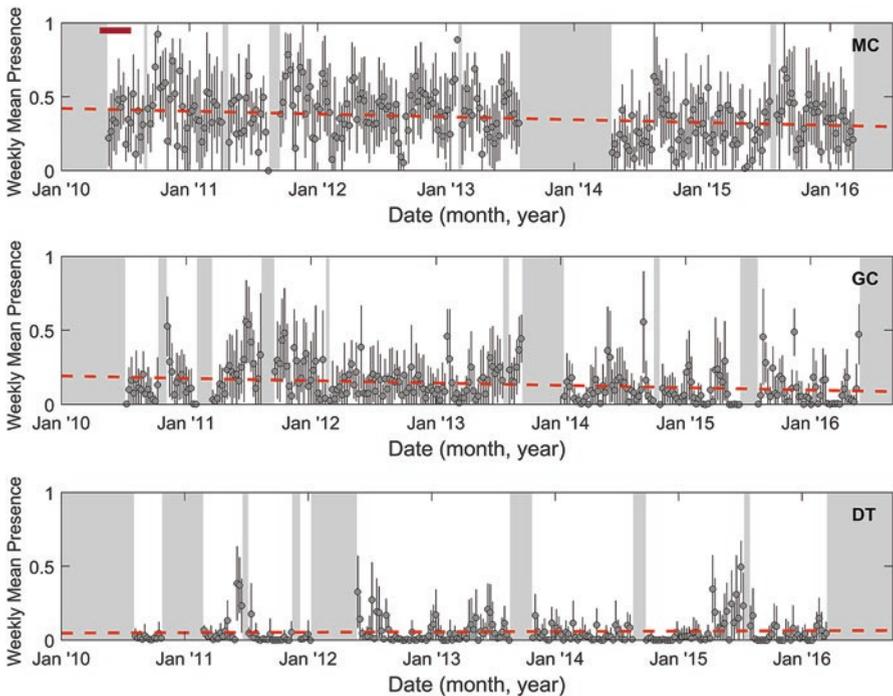
Site	Sperm whale	<i>Kogia</i> spp.	Cuvier's BW	Gervais' BW	Risso's dolphin	<i>Stenella</i> delphinid	Blackfish delphinid
MC	36.8 [11.6, 64.2]	0.5 [0.0, 1.4]	0.1 <sup>a</sup> [0, 0.6]	0.3 <sup>a</sup> [0, 1.1]	1.3 [0, 5.7]	6.3 [0.5, 16.0]	0.6 [0, 2.0]
GC	13.8 [0.2, 38.4]	0.3 [0.0, 0.9]	0.1 [0, 0.5]	0.5 [0.0, 1.1]	0.2 [0, 1.1]	3.0 [0.2, 9.0]	0.4 [0, 1.8]
DT	5.1 [0, 19.5]	0.1 [0.0, 0.2]	3.6 [0.8, 7.2]	1.5 [0.3, 3.9]	4.5 [0, 23.4]	3.1 [0.0, 9.4]	0.4 [0, 2.1]

<sup>a</sup>Indicates subset from 2010 to 2013 was used to calculate the mean

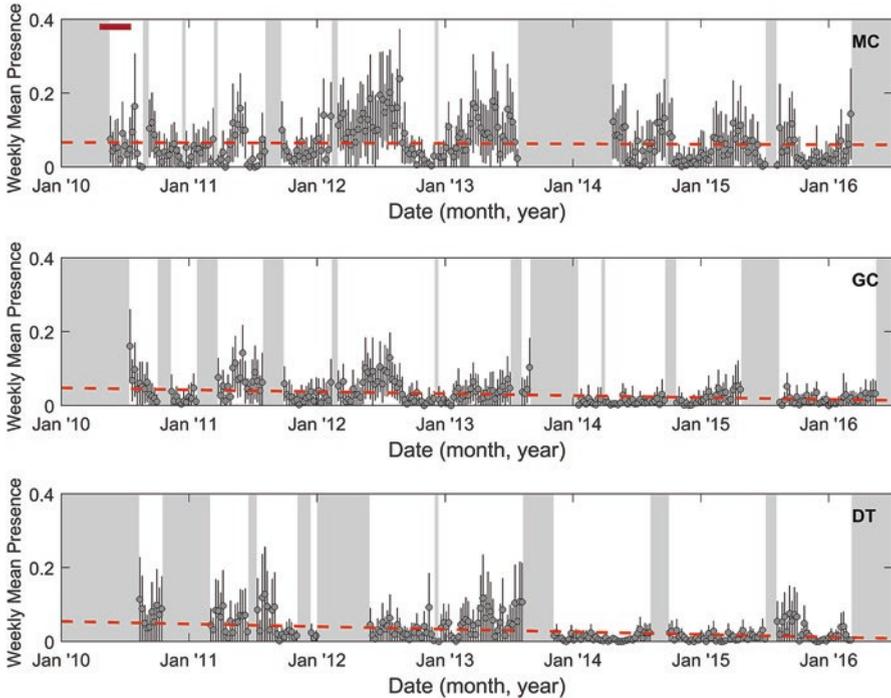
**Table 26.2** Estimated average annual percent change in marine mammal presence including [5th, 95th] confidence intervals at passive acoustic monitoring sites in the GOM HARP study, 2010–2016

Site	Sperm whale	<i>Kogia</i> spp.	Cuvier’s BW	Gervais’ BW	Risso’s dolphin	<i>Stenella</i> delphinid	Blackfish delphinid
MC	−4.5 [−6.0, −3.3]	18.8 [12.9, 26.3]	5.4 <sup>a</sup> [2.0, 8.7]	37.3 <sup>a</sup> [24.3, 52.8]	8.7 [2.1, 19.4]	−1.6 [−3.5, 0.2]	−7.0 [−9.0, −4.6]
GC	−8.3 [−10.0, −6.4]	−15.5 [−16.3, −14.8]	1.0 [−3.0, 6.3]	4.1 [1.4, 7.3]	−5.0 [−9.1, 0.0]	−10.9 [−12.2, −9.7]	−11.1 [−13.5, −9.3]
DT	5.4 [−0.3, 13.6]	−9.0 [−11.8, −5.4]	−9.7 [−11.0, −8.9]	−8.1 [−9.1, −6.6]	4.2 [1.4, 8.1]	−13.0 [−14.2, −11.5]	1.3 [−4.1, 10.2]

<sup>a</sup>Indicates subset from 2010 to 2013 was used to calculate slope



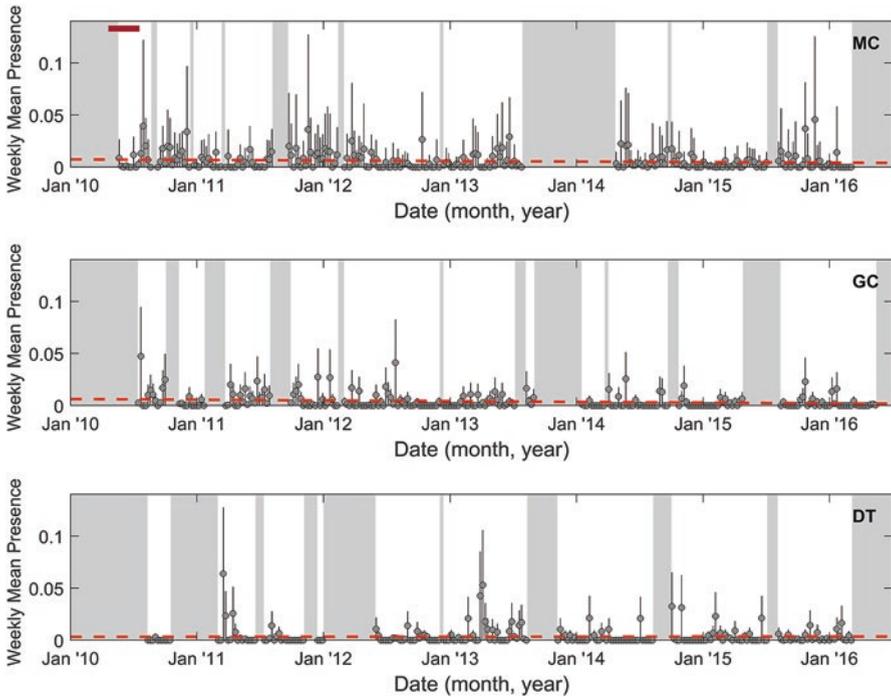
**Fig. 26.3** Sperm whale weekly mean presence (open circles) as fraction of time present at passive acoustic monitoring sites from the GOM HARP study. Error bars indicate standard deviation within each week. Gray rectangles indicate periods without data. Red dashed line indicates estimated trend. Dark red bar on top plot indicates period during which the DWH well remained uncapped



**Fig. 26.4** Weekly mean *Stenella* sp. (mid-frequency delphinid) presence as fraction of time present at passive acoustic monitoring sites from the GOM HARP study. Markings as in Fig. 26.3

*Stenella* species and blackfish (presumably short-finned pilot whales) species were associated with mid- and low-frequency echolocation, respectively. *Stenella* had slightly higher presence at site MC (6.3% for *Stenella*) relative to other sites. Long-term declines in *Stenella* occurrence (Fig. 26.4) were observed at the sites GC ( $11 \pm 1\%$  annual reduction) and DT ( $13 \pm 2\%$  annual reduction) outside of the DWH surface slick footprint, but not at site MC where presence remained nearly constant ( $2 \pm 2\%$  annual reduction). However, relatively higher encounter rates in 2012 may be masking long-term decreases in *Stenella* delphinid presence at site MC. Blackfish presence was low overall (0.4–0.6%), with declines at sites MC and GC ( $7 \pm 2\%$  and  $11 \pm 2\%$  annual reductions, respectively), but no significant change at site DT ( $1 \pm 6\%$  annual change) (Fig. 26.5). Risso's dolphin presence was low (0.2–4.5%) and strongly seasonal at all sites, and their presence increased slightly at site DT ( $4 \pm 4\%$  annual increase) and more strongly at site MC ( $9 \pm 7\%$  annual increase) (Fig. 26.6). A possible decline in Risso's dolphin presence was found at site GC ( $5 \pm 5\%$  annual reduction) where overall presence was low.

Beaked whale presence was highest at site DT for both Cuvier's (4%) and Gervais' (2%) beaked whale, and both were present year round (Figs. 26.7 and 26.8). Presence of both species declined at site DT ( $10 \pm 1\%$  annual reduction for Cuvier's;  $8 \pm 1\%$  annual reduction for Gervais'), but remained constant or increased



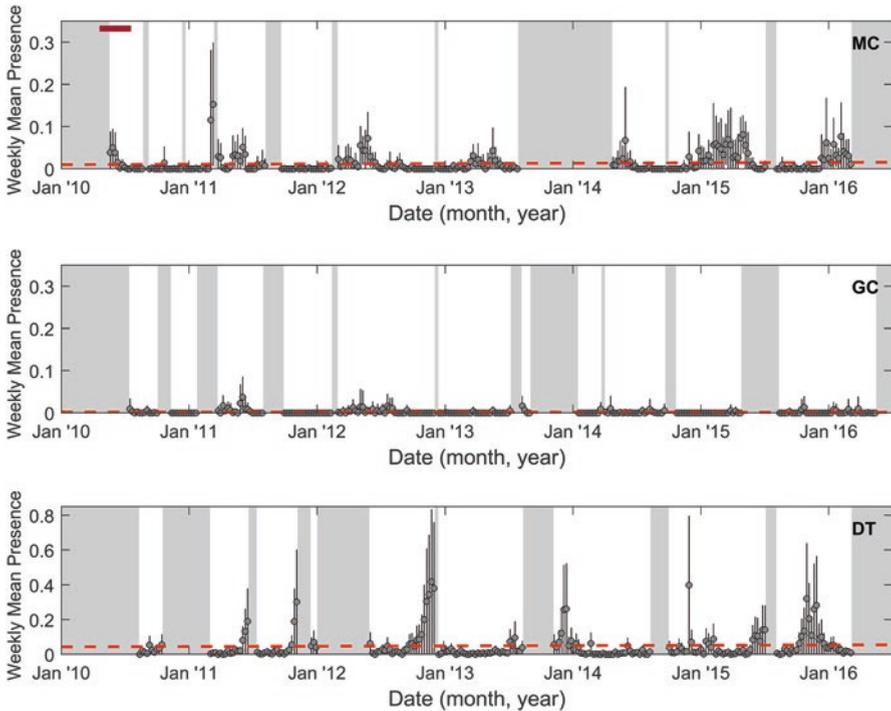
**Fig. 26.5** Weekly mean blackfish (low-frequency echolocation) presence as fraction of time present at passive acoustic monitoring sites from the GOM HARP study. Markings as in Fig. 26.3

at site GC ( $1 \pm 4\%$  annual change for Cuvier's;  $4 \pm 3\%$  annual increase for Gervais'). An increase in beaked whale presence at site MC is observed; however, analysis for beaked whale presence at this site occurred over a limited date range (2010–2013); therefore, trends are less robust.

*Kogia* spp. presence was relatively high (0.3–0.5% occurrence within a short detection range of <1 km) at site MC and GC (Fig. 26.9). Presence of *Kogia* spp. increased at site MC ( $19 \pm 7\%$  annual increase), but presence at site GC decreased strongly after 2013 resulting in a strongly negative long-term trend in mean presence at this site ( $15 \pm 1\%$  annual decrease). Presence also decreased at site DT ( $9 \pm 3\%$  annual decline), although overall encounter rates at that site were low (0.1%) throughout the monitoring period.

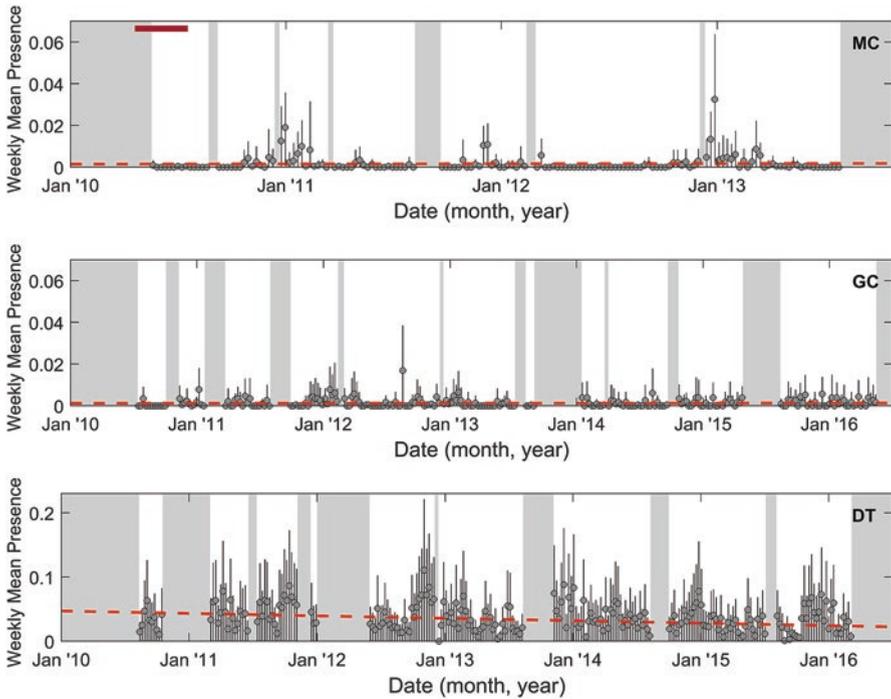
Population movements and declines may be convolved in the trends seen in GOM acoustic monitoring because of the limited number of monitoring locations in the HARP dataset. It is unclear to what degree changes in presence reflect population displacement around the GOM and beyond or rather indicate offshore mortality. Aspects of both processes may be influencing the long-term observed trends.

Population trends may be related to exposure: Based on seasonal trends and encounter rates during the oil spill at site MC, sperm whales, *Stenella*, and *Kogia*



**Fig. 26.6** Weekly mean Risso's dolphin presence as fraction of time present at passive acoustic monitoring sites from the GOM HARP study. Markings as in Fig. 26.3

species are most likely to have interacted with the DWH surface and subsurface footprints for extended periods of time in the spring and summer of 2010. *Stenella* and *Kogia* presence strongly declined at sites GC and DT, *Kogia* presence declined at site MC, and *Stenella* delphinids appear to have declined from 2012 to 2016 following a peak in 2012. Sperm whale presence declined steadily at GC and MC, and while possibly increasing at site DT, this site may not be part of core sperm whale habitat (Jochens et al. 2008) given overall low encounter rates there. Blackfish presence is highly variable at site MC; however, this group appears to have been present during the DWH event based on the acoustic record. Presence of blackfish delphinids has declined at sites MC and GC while remaining approximately constant at site DT. In contrast Risso's dolphins may not have been as strongly exposed to oil in 2010 due to the seasonality of their presence in the northern GOM, and Risso's dolphin encounter rates appear to be increasing at sites MC and DT while decreasing at site GC. Both beaked whale species appear to be declining at site DT, with limited change at site GC. Owing to the seasonality of Cuvier's beaked whales, only the Gervais' beaked whale appears to have been substantially exposed to oil during the DWH spill. The time series for beaked whale presence at site MC may be too short to robustly interpret long-term trends there.



**Fig. 26.7** Weekly mean Cuvier's beaked whale presence as fraction of time present at passive acoustic monitoring sites from the GOM HARP study. Markings as in Fig. 26.3

Population declines in the eastern and southern GOM may be unrelated to the DWH event, since some of the strongest declines are seen at the two sites outside the DWH oil footprint (GC and DT). However, seasonal cycles in the passive acoustic data suggest that these species' distributions shift over time, likely as animals seek out favorable conditions; therefore, many of these pelagic species may not be resident in specific areas throughout the year. The high productivity conditions created by the outflow of the Mississippi River have historically supported higher marine mammal densities than other regions of the GOM (Reeves et al. 2011), and populations may preferentially return to that region. Female sperm whales tagged in the MC region typically had long residence times in the area and appeared to use it as core habitat (Jochens et al. 2008). Declines at other less productive sites may indicate range contraction associated with population-level mortality (Rugh et al. 2010; Worm and Tittensor 2011), or might reflect population shifts in response to other drivers. A broader understanding of migratory patterns on a GOM-wide scale is needed to more confidently interpret site-level trends in the context of the broader GOM ecosystem.

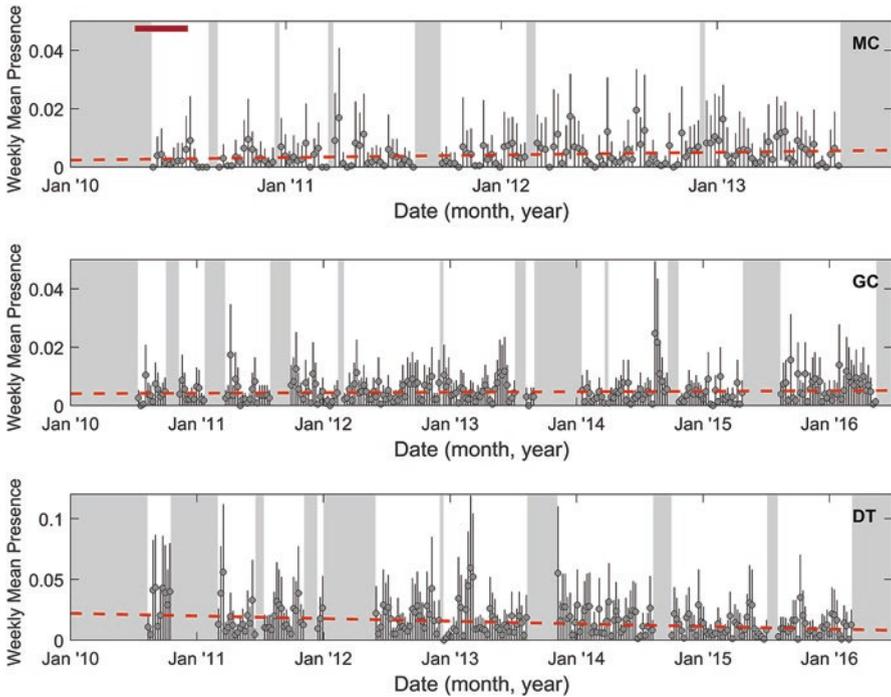
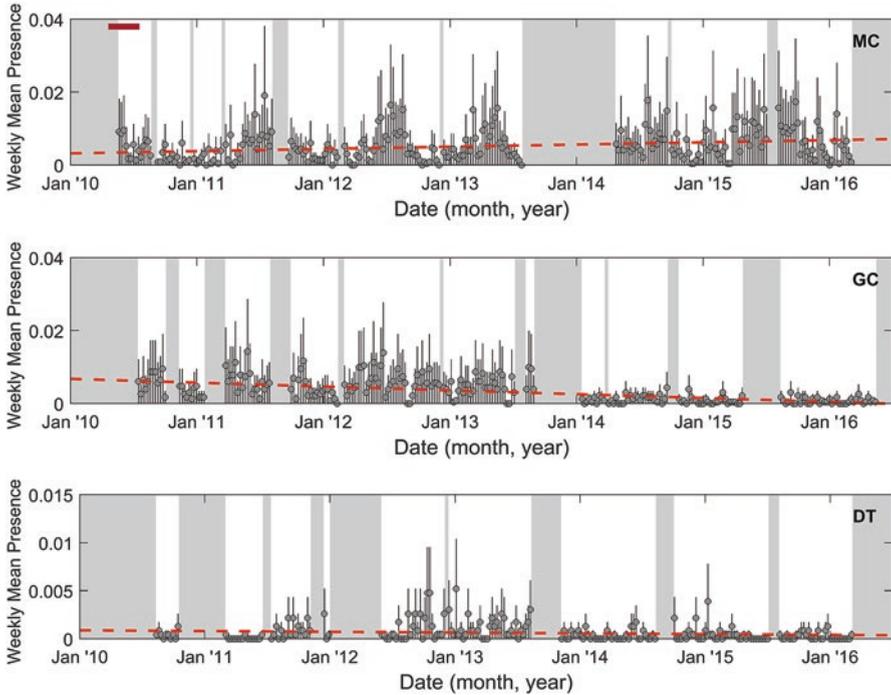


Fig. 26.8 Weekly mean Gervais' beaked whale presence as fraction of time present at passive acoustic monitoring sites from the GOM HARP study. Markings as in Fig. 26.3

### 26.5.2 Additional Marine Mammal Studies

Latent effects of exposure have been examined in the case study of the resident Barataria Bay bottlenose dolphin population. Over 5 years after heavy oiling of the bay during the DWH oil spill, successful calving rates were 20% compared to 83% for an unexposed reference population (Lane et al. 2015). It was unclear whether unsuccessful pregnancies were directly caused by oil exposure or were linked indirectly through poor maternal health (Schwacke et al. 2013). Similar reproductive failures occurring in offshore populations (e.g., Farmer et al. 2018) could explain the observed long-term declines in encounter rates at oceanic monitoring locations. Annual survival rates among adults were also lower (86.8%) than in comparable populations (95.1 to 96.2%; Lane et al. 2015). Bottlenose dolphins in Barataria Bay were five times more likely to have moderate to severe lung disease than a reference population (Schwacke et al. 2013).

A study comparing short-term (7–12-day) PAM recordings before and after the DWH spill at a site near the wellhead indicated possible declines in sperm whale occurrence (Ackleh et al. 2012), with an increase of 25 miles from the site. However, due to the high variability in sperm whale presence at fixed monitoring sites on



**Fig. 26.9** Weekly mean *Kogia* spp. presence as fraction of time present at passive acoustic monitoring sites from the GOM HARP study. Markings as in Fig. 26.3

weekly timescales (Fig. 26.3), it is not possible to determine whether the difference between the two measurements reflects real change or normal variability.

### 26.5.3 Findings of Sea Turtle Studies

The long-term effects of oil exposure and the DWH oil spill on sea turtles are not well understood or quantified (Vander Zanden et al. 2016). The number of Kemp's ridley nests in Tamaulipas, Mexico, in 2010 was below predicted levels and has remained below expected levels every nesting season since (Dixon and Heppell 2015), but the reduction has not been definitively attributed to the DWH spill (Caillouet et al. 2016; Caillouet Jr 2014). Some have speculated that the large-scale oiling of *Sargassum* (Hu et al. 2016) and subsequent loss of developmental/foraging habitat for juvenile turtles may have long-term implications for population recovery.

In response to the DWH oil spill, stage-based spatial matrix models have been developed to simulate oil spills to assess the potential impact of oil spills on loggerhead populations, defining oceanic-stage survival followed by fecundity as the

most sensitive parameters for eliciting changes in population growth (Leung et al. 2012). A geospatial assessment of cumulative stressors to evaluate where combined threats and impacts are greatest was conducted on a GOM-wide scale for Kemp's ridleys and loggerheads following the DWH oil spill (Love et al. 2017). This research showed a range of anthropogenic stressors including incidental bycatch in commercial and recreational fisheries and habitat degradation, and it demonstrated that few areas exist in their terrestrial or marine environment without cumulative impacts from multiple stressors (Love et al. 2017).

## 26.6 Remaining Knowledge Gaps

Efforts to assess the comprehensive immediate and long-term effects of the DWH oil spill on pelagic species are limited by a scarcity of pre-disaster baseline data (Bjorndal et al. 2011; Graham et al. 2011; Trustees 2016). Without the ability to compare pre-and post-spill measurements, many potential impacts are unquantifiable. Further, effects on these long-lived species may continue to play out over the coming decades (Schwacke et al. 2017). The assessment of cumulative impacts must be considered on an ecosystem level, as effects are based on direct mortality, degradation of habitat, quality and availability of prey resources, and sublethal impacts such as reduced foraging or reproductive potential (Love et al. 2017). Developing a better understanding of the spatiotemporal overlap of threats with the distribution and abundance of sea turtle populations will guide managers to develop geographically targeted management strategies to mitigate key stressors and restore injured resources (Love et al. 2017).

No comparable long-term data on marine mammal presence were collected in the period prior to the 2010 spill. At best, visual survey data give decadal-scale abundances that cannot be directly applied to understanding the impact of the spill. In addition, the GOM was not a pristine habitat prior to the 2010 spill; therefore, we cannot assume that pre-spill population levels were stable or attribute observed shifts to the DWH event with great confidence. Although a visual marine mammal survey was conducted prior to the spill in 2009 (Waring et al. 2013), it did not provide the kind of spatiotemporal resolution or precise abundance estimates needed to quantify acute impacts. Passive acoustic sensors were deployed 26 days after the initial blowout, so although they did record during the majority of the 152-day spill, recorders were not in place to capture pre-spill levels, and some immediate effects may have been missed. Further, passive acoustic sensors have limited detection ranges (Frasier et al. 2016), and additional research is needed to determine the spatial scale over which the observations from these monitoring locations can be extrapolated. Efforts to estimate chronic effects by any method have necessarily relied on uncertain assumptions regarding pre-spill population sizes, health, and distributions.

Much of the released oil is thought to have been deposited on the seafloor. Little is known about if and how marine megafauna might be interacting with deep water

benthic oil, either directly or via the pelagic food web (see Pulster et al. 2020). Impacts of the spill on mesopelagic and bathypelagic prey availability remains unclear (Fisher et al. 2016). Different prey types likely have differing abilities to metabolize oil-derived compounds. In particular, cephalopods seem less capable of metabolizing polycyclic aromatic hydrocarbons (PAHs) and more likely to bioaccumulate heavy metals than fish (Reijnders et al. 2009). Trace metals are common in crude oil and may further concentrate in weathered oil (Gohlke et al. 2011). Deep-foraging, squid-eating cetaceans including sperm whales and beaked whales may be at higher risk of long-term exposure to oil-related pollutants through their prey. Toxicity of oil and oil-related compounds to marine mammals and sea turtles remains poorly understood.

Lastly, the unknown spatial ranges and movement patterns of most oceanic GOM marine mammal species and sparse habitat use, abundance, and distribution data for sea turtles result in broad uncertainty regarding exposure and long-term impacts of the spill and subsequent environmental pollution on these populations. It remains unclear to what degree observed animals are resident in or systematically return to affected habitats. Without coordinated, international GOM-wide monitoring efforts, it is not possible to determine whether local declines in encounter rates represent population shifts or population decreases.

## 26.7 Conclusion

The majority of research on the effects of oil spills on marine mammals and sea turtles has focused on nearshore species (coastal bottlenose dolphins, killer whales, and pinnipeds), coastal impacts (coastal strandings, sea turtle nesting beaches), and surface oiling. The DWH event was a large-volume oil spill that occurred offshore, with significant subsurface footprint, in poorly understood habitats, and with sparse baseline data. Long-term offshore monitoring suggests ongoing declines in marine mammal presence, which may be related to reduced reproductive success as observed in nearshore proxies. Oceanic species were most heavily and directly impacted by this spill, but discerning the immediate and long-term effects on oceanic populations requires piecing together a patchwork of sparse observations and studies. It is clear however that marine mammals and sea turtles were directly exposed to unprecedented amounts of oil and dispersants and that the acute and chronic population-level impacts of this exposure were likely high and underestimated based on coastal observations.

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Environmental Studies Program and the National Marine Fisheries Service, Southeast Fisheries Science Center. The analyses and opinions expressed are those of the authors and not necessarily those of the funding entities. The data used for this study are archived by the Gulf of Mexico Research Initiative at <https://data.gulfresearchinitiative.org/data/R4.x267.180:0011> maintained by the Gulf Research Initiative Information and Data Cooperative.

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