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# 18

# OVERVIEW OF EFFECTS OF OIL SPILLS ON MARINE MAMMALS

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## 18.1 INTRODUCTION

The 1989 *Exxon Valdez* oil spill (EVOS) in Alaska killed tens of killer whales, hundreds of harbor seals, thousands of sea otters, and hundreds of thousands of birds (sea birds, shorebirds, and marine-associated birds), greatly impacting marine habitats that contain the forage fish and marine invertebrates that fuel higher trophic levels [1–4]. These numbers represent the documented deaths from that spill, which undoubtedly killed many more animals. More than 20 years after the EVOS, long-term individual effects (e.g., impaired health and reproduction) and population impacts (e.g., delayed recovery of population size, especially in the nearshore ecosystem) are most evident for killer whales, sea otters, and some marine birds. The ongoing effects and slow recovery of some species are attributed to long-term exposure to spilled oil sequestered in nearshore habitats and, in the case of the social killer whale, possibly the legacy of key pod member mortalities from the oil [5–9].While apparently not as devastating to marine mammals as the EVOS, there is evidence the massive MC-252 Deepwater Horizon (DWH) oil spill in 2010 impacted reproduction and health of coastal bottlenose dolphins in the northern Gulf of Mexico [10].

Considering that marine mammals are common, highly visible, charismatic, and potentially vulnerable to oil, it is somewhat surprising that we know relatively little about the effects of oil on individuals and populations. The majority of what has been published in books and peer-reviewed journals comes from a handful of laboratory experiments and the investigations on marine mammals that followed the EVOS.

Oil spills can affect marine mammals through a variety of direct and indirect pathways. Direct pathways include inhalation, ingestion, and dermal exposure, each of which can initiate a suite of physiological responses with health and long-term survival and/or reproduction consequences.

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Likely, the most serious acute health threat is severe damage to the respiratory system through inhalation of the volatile and highly toxic aromatic components of oil. Ingestion of oil through grooming or consumption of contaminated prey would harm various internal organs (e.g., liver, kidney, and intestines) and organ systems (e.g., digestive and urogenital). Mild dermal exposure would cause at least short-term injuries to mucus membranes, eyes, and other external soft tissue areas, while severe oiling could result in death by smothering. For those species that rely on fur for insulation, external oiling can be life threatening due to extreme hypothermia. Perhaps equally important, but less well understood, are indirect effects of oil spills. These can include:

1. Short-term reductions in prey availability
2. Long-term injury to prey habitats, prey populations, and prey availability
3. Selective mortality disrupting social bonds
4. Reduced reproduction within structured subpopulations
5. Cumulative effects on individuals, populations, and the ecosystem

In this chapter, we examined what is known about the individual effects and population impacts of spilled oil on marine mammals. We divided marine mammals into five groups (sea otters; seals and sea lions; sea cows; polar bears; and whales, dolphins, and porpoises) to allow a more complete discussion of the pertinent literature for each group and to highlight the wide differences in our understanding of the effects of oil spills and oil-related activities across groups. Most marine mammals are large animals that range widely well out to sea. They are relatively difficult to maintain in captivity for detailed study and few individuals and populations have been followed during and after an oil spill. Thus, our understanding of how oil exploration, development, production, transportation, and spills impact marine mammals is spotty. We know most about species that can be maintained in captivity or spend the majority of their life in the nearshore environment. However, even for those species, many questions persist such as:

1. Do exploration and development activities (e.g., noise and associated human activities, temporary structures, small chronic releases, and transportation infrastructure) have significant effect on individuals?
2. What are the short- and long-term effects on individuals from acute exposure to the most toxic volatile components of oil?
3. What are the long-term health effects on individuals from chronic exposure?
4. Do oil dispersants reduce or increase oil constituent exposure and related effects to individuals?
5. Do spills or development activities cause measurable impacts at the population or subpopulation level?
6. Are ecosystem-wide effects following a large spill sufficiently widespread to impact marine mammals at the population level?

Despite our limited understanding of these important questions, it remains clear that oil spills can, and frequently do, harm at least some individuals of certain species of marine mammals. The insatiable need of modern industrialized societies for large volumes of oil to drive their economies is resulting in exploration, production, and transportation of oil in heretofore unexploited areas, such as the deep ocean and the Arctic. These areas have long been sanctuaries for many marine mammals and the increase in oil-related activities in these areas significantly increases their vulnerability to potentially catastrophic impacts from a large spill or many spills over time. While other forms of energy may replace oil in the future, we expect that oil will remain a primary source of fuel for decades to come. We must be engaged with reducing long-term impacts of oil on marine mammal populations, which will also prepare us for engaging in reducing population impacts from other forms of fuel in the future.

The short synopses below provide some highlights from the taxa-specific sections that follow. For brevity, these synopses do not contain references to foundational literature, which is presented in the taxa-specific discussions.

### 18.1.1 Sea Otters

Sea otters (*Enhydra lutris*; Mustelidae) are among the most vulnerable marine mammals to an oil spill because they rely on fur for insulation and spend most of their time nearshore on the sea surface where oil and the most toxic components of oil accumulate. Unlike most marine mammals, the physical effects of external oil contamination to sea otters may be as damaging as the toxicological effects. For example, during the EVOS, moderately to heavily oiled sea otters suffered from permanent injury to their eyes, pinna, and pelage from the oil and the excessive grooming they did in an attempt to remove the oil. Even small amounts of external oil fouls the insulating fur covering of sea otters and significantly increases the food required to maintain core body temperature. This is a serious health challenge for an animal that normally consumes about 25% of their body weight each day. To stave off hypothermia, oiled sea otters must consume more food and spend more time grooming. In river otters, hypothermia results in (i) short- and long-term injury to the lungs, liver, kidneys, and brain from hypoxia and ischemic necrosis and (ii) reductions in foraging dive times and depths. If this is also true for oiled sea otters, then at a time when their energy needs are extreme their foraging ability is likely impaired and their internal organs are suffering permanent damage.

Long-term monitoring of moderately to heavily oiled adult sea otters kept in captivity following the EVOS demonstrated extended life-threatening problems. For example, necropsies of these otters showed that nearly 75% had persistent interstitial emphysema and 50% had liver necrosis. The accumulation and persistence of oil in nearshore habitats preferred by sea otters, and certain seals and sea lions, result in prolonged human disturbance during the spill cleanup phase, an extended period of acute exposure, years of low-level chronic exposure, and ongoing impacts to prey resources.

### 18.1.2 Seals and Sea Lions

Unlike otters, our understanding of the effects of oil on seals and sea lions (pinnipeds) is surprisingly limited. Although there have been more than two dozen documented examples in which oil has contacted free-ranging pinnipeds, the difficulty in obtaining data on exposed animals has resulted in small sample sizes and limited knowledge. Due to their similar anatomy and physiology, it can be safely assumed that, except for metabolic concerns related to how these species maintain their core body temperatures, pinnipeds would respond to acute and long-term chronic exposure to oil similarly to sea otters. The mucous membranes, eyes, ears, external genitalia, and internal organ systems exposed to oil would be negatively affected. However, the magnitude of the harm and its long-term consequence to individuals and local populations remain unknown. For those pinnipeds that rely primarily on blubber for insulation, such as most sea lions, seals, and the walrus, it appears that external oiling does not significantly impact their ability to maintain their core body temperature. The vulnerability of seals and sea lions to an oil spill probably will be determined by the degree and time course of exposure. Those species that range widely and do not congregate in nearshore waters except to breed and molt, such as elephant seals, likely would be less vulnerable. In contrast, some age and sex classes of sea lions and other seals that spend most of their time nearshore and in estuaries and river mouths, likely would be more vulnerable. Fur seals, like sea otters, rely mostly on fur rather than blubber for insulation and likely would face a serious challenge in maintaining their core body temperature if oiled. Not only are individual fur seals vulnerable to spilled oil, but population-level impacts likely would occur if oil was spilled near the rookeries where these seals annually mass to breed. An ill-timed large spill in the vicinity of a fur seal breeding colony could be devastating.

### 18.1.3 Sea Cows

The four extant species of sea cows or sirenians, which are unique among the marine mammals in being aquatic herbivores with a limited tropical to subtropical distribution, are all considered vulnerable to extinction by the International Union for Conservation of Nature. Although their warm water distributions overlap with some of the world's major areas of oil development, extraction, shipping, and refining, there is scant evidence oil has affected sea cows. The single published study that examined sirenian tissue did not find any petroleum aromatic hydrocarbons (PAH). However, since vertebrates typically rapidly metabolize PAHs, this finding is not unexpected. Sirenians would be affected if spilled oil contaminated sea grasses, their primary food, or the sea grasses were destroyed during cleanup operations. However, even this effect is somewhat unlikely as oil has not been shown to persist in and severely impact tropical sea grass beds.

### 18.1.4 Polar Bears

Polar bears primarily rely on their fur to protect them from the extreme arctic temperatures, and, like sea otters and fur seals, they are vulnerable to hypothermia if oiled during a spill. Similar to sea otters, polar bears are known to groom themselves regularly to maintain the insulating properties of their fur and an oiled bear would be expected to ingest significant quantities of oil during grooming. Laboratory observations of two polar bears forced into a pool with oil for 15 min demonstrated that indeed these marine mammals expended considerable effort to remove the oil from their body and the ingestion of that oil during grooming resulted in critically severe to terminal effects on their gastrointestinal tract, kidneys, liver, blood, and respiratory systems. Those oiled bears also showed hair loss, anemia, anorexia, acute inflammation of the nasal passages, increased metabolic rates, elevated skin temperatures, marked epidermal responses, and stress. In addition, the ingestion of oil by polar bears likely would not be confined to grooming as hungry bears scavenge oiled wildlife and have been observed to directly consume refined oil products.

The increasing exploration, development, and transportation of oil and gas in the arctic, combined with the decreasing amount of permanent ice and frozen permafrost, suggests that polar bears, their preferred seal prey, and the oil industry soon will be squeezed closer together. It seems inevitable that a significant oil spill from a ship, pipeline, or production platform will greatly impact polar bear populations through direct mortality and impaired health of survivors. In addition, the processes of acquiring and transporting oil likely will disturb and/or displace bears and their seal prey. The risk faced by polar bears and their prey will be greatest in fall or spring during the formation or breakup of ice when bears concentrate in prime feeding areas over the continental shelf. At that time, oil would accumulate in open leads and polynyas, areas of high activity for polar bears and seals. Nevertheless, over the past 30 years there is little evidence that oil production and development in the arctic has affected polar bears.

### 18.1.5 Whales, Dolphins, and Porpoises

Very little is known about the effects of oil on whales, dolphins, and porpoises, collectively known as cetaceans. There are few published accounts of wild cetaceans in oiled water and few necropsies of cetaceans that have been oiled. Oil does not adhere to their relatively slick skin and it would not be expected to accumulate in or around the eyes, mouth, blow hole, or other potentially sensitive external areas. Insulation is provided by a layer of blubber rather than hair or fur, so it is unlikely oil would compromise the thermoregulatory system of cetaceans. These marine mammals do not drink large volumes of sea water, do not groom, and likely would not scavenge oil-contaminated prey. Thus, it seems unlikely they would ingest significant quantities of oil. Probably the greatest risk to most cetaceans from an oil spill would occur if they surface to breathe in an oil slick and inhale oil and toxic petroleum vapors.

For certain species that frequent or live in nearshore waters, a spill may pose significant risk. For example, populations of coastal-oriented dolphins likely would be impacted by a spill oiling nearshore waters because they show strong site fidelity to restricted nearshore habitats. If those habitats were oiled, the dolphins could experience both acute and chronic exposure through their respiratory system and through ingestion of contaminated prey. Other coastal-oriented cetaceans, such as gray whales, could be affected by a spill if the oil sank to the bottom, as these whales scoop up significant quantities of bottom sediments during feeding. Still, other species may be at risk from the oil and the oil cleanup operations disrupting important but fragile social bonds.

## 18.2 SEA OTTERS

Behavior, morphology, physiology, and natural history conspire to make sea otters exceptionally vulnerable to the effects of oil contamination. Morphologically, this species is unique among marine mammals due to their small body size and primary reliance on air trapped in their fur for insulation [11]. Both characteristics make thermoregulation in water challenging for sea otters even under normal circumstances [12]. During an oil spill, these same characteristics present a liability that leads to comparatively high levels of mortality. Coupled with a natural history that includes a reliance on nearshore habitats where oil can accumulate and persist and prolonged periods of time on the water surface for resting, feeding, grooming, and caring for young, this marine mustelid represents a species of great concern during an oil spill.

This recognition of acute vulnerability has led to numerous studies and the compilation of considerable information regarding the effects of oil exposure on sea otter health. Controlled studies have examined the impact of crude oil on sea otter fur and physiology [13–16]. Extensive field monitoring and rehabilitation of wild sea otters following the EVOS provide a remarkable resource of information for understanding the effects of acute oiling [5,6,9,17,18], as well as for treating oiled otters [19,20]. Long-term effects of subacute initial oiling and chronic exposure to oil included reduced survival [4,5,8], leading to protracted recovery of affected populations [6,9].

During the EVOS, 357 sea otters were treated at rehabilitation centers and over 100 were necropsied. These efforts resulted in a unique data set detailing the physiological and behavioral responses of a marine mammal to oil contamination (See [19] for further details). The following is based largely on this data set that involved Prudhoe Bay crude oil spilled in cold Alaskan waters. Because crude oils can vary markedly in petroleum hydrocarbon composition and toxicity, it is important to know the chemical makeup of released oil to anticipate and effectively address the likely impacts on otters. The nature of the impact, especially in terms of toxicity to animals, will differ between spills and within an individual spill as the oil weathers. Environmental factors such as air and water temperatures as well as water action will alter the composition of spilled oil and the threat it poses to otters and the environment. Shoreline habitats strongly influence the potential for oil to be sequestered in nearshore sediments and present a long-term exposure threat.

### 18.2.1 External Exposure

As with most marine mammals, exposure of sea otters to petroleum hydrocarbons in crude oil can occur through several routes. The most common are (i) ingestion, (ii) inhalation, and (iii) dermal absorption (Fig. 18.1). Since sea otters spend considerable time on the water surface, the first contact with an oil slick generally results in external contamination of the fur and inhalation of volatile petroleum hydrocarbons. External contamination leads to transdermal absorption of hydrocarbons, which is accompanied by ingestion of oil during grooming and feeding. These quickly lead to widespread internal contamination, which will impact many organ systems, especially those involved in detoxification and excretion [22].

In some ways, the physical effects of external oil may be as damaging to sea otters as the toxicological effects. Depending on the chemical composition of the oil, irritation of sensitive tissues including the interdigital webbing of the hind flippers, as well as membranes around the eyes, nose, mouth and urogenital areas occurs rapidly. In extreme cases, sea otters contaminated with fresh crude oil will bite irritated areas and groom excessively thereby causing permanent damage to the cornea of the eyes, tips of the pinnae, and pelage [23]. In addition, sea otters actively spread even small amounts of oil across their entire body during grooming, thereby exacerbating the problem.

The absence of an insulating blubber layer makes external oil contamination especially problematic for sea otters. Disruption of the air layer in the fur due to contact with oil destroys the heat retaining properties of the pelage and exposes the otter's skin to water. Because water transfers heat 24–25 times faster than air at the same temperature, hypothermia quickly results [24]. The typical daily fluctuations in core body temperature of wild sea otters [2] are intensified when an animal becomes oiled and rectal temperatures of oiled sea otters can fluctuate markedly during all phases of

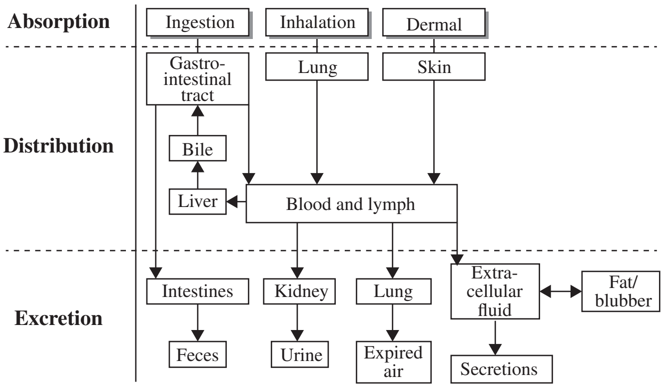


**FIGURE 18.1** Major pathways for petroleum hydrocarbon movement in oiled sea otters. Following initial absorption, the chemical constituents of oil can be distributed throughout the body via the skin, gastrointestinal tract, and pulmonary and vascular systems. Petroleum hydrocarbons may be subsequently stored in the fat or blubber layers or excreted through several organ systems. Redrawn from Klaassen and Rozman [21] and presented in Williams and Davis [19].

oiling and rehabilitation activities [15,20]. For example, during the EVOS, more than 36% of the sea otters arriving at rehabilitation facilities were hypothermic, with the lowest recorded body temperature reaching 8.4°C below normal levels [19]. Conversely, 27% of the arriving oiled otters were hyperthermic due to excessive grooming and hyperactivity after being removed from the water for rehabilitation.

In addition to direct mortality associated with low core body temperatures, hypothermia can instigate long-term organ damage and dysfunction in association with a general collapse of the cardiovascular system and related organ congestion. The severity of vascular congestion and tissue damage in sea otters is correlated to the degree of external oiling. The resultant reduction in blood flow to organs can lead to hypoxia and ischemic necrosis in the lungs, liver, kidneys, and brain with the former two organs showing the greatest injury [19].

The extent of the tissue damage during hypothermia will depend on a variety of factors including the duration and severity of vascular collapse, with some oxygen-sensitive organs never recovering. Consequently, while an oiled sea otter may survive a hypothermic event it may suffer permanent or long-term impaired organ function as a result of hypoxic damage. All of this may occur in the absence of internal contamination or toxic insults from the oil. Thus, responders to an oil spill should be prepared for sea otters that range widely in both internal and external levels of contamination from lightly oiled animals with high levels of internal tissue damage to heavily oiled animals that need more than washing. The level of external contamination should not be considered an accurate predictor of internal contamination [19].

### 18.2.2 Internal Exposure

Oiled sea otters display a suite of medical disorders related to the toxicity of the oil encountered (Table 18.1). As might be expected, heavily oiled otters contaminated early in a spill show the severest medical problems and consequently, the highest rate of mortality. As the oil dissipates and the level of PAHs declines with weathering, the severity of disorders diminishes. Four commonly diagnosed disorders in oiled otters requiring immediate veterinary intervention are (i) hypothermia and hyperthermia as discussed earlier, (ii) hypoglycemia, (iii) subcutaneous and interstitial emphysema, and (iv) gastrointestinal injury.

**TABLE 18.1 Medical disorders of oiled sea otters during the early (toxic) phase and later (nontoxic) phase of an oil spill**

| |
|---|
| **Early phase** |
| 1. Thermoregulatory disorders (hypothermia, hyperthermia) |
| 2. Petroleum hydrocarbon toxicosis |
| 3. Respiratory injury/interstitial and subcutaneous emphysema |
| 4. Hypoglycemia |
| 5. Shock/seizures |
| **Late phase** |
| 1. Gastrointestinal disorders |
| 2. Hepatic dysfunction |
| 3. Renal dysfunction |
| 4. Anemia |
| 5. Stress |

Category designations are based on the level of PAHs present in the oil and the assumption that crude oil will weather over time.

Wild sea otters compensate for their exceptionally high metabolic demands by relying on a predictable schedule of food intake for thermoregulation [12]. If feeding is impaired, as can occur during a spill, sea otters are prone to hypoglycemia (abnormally low blood glucose levels). Underlying reasons for the development of this condition vary and may involve an inability to forage or find prey in a spill zone, impaired liver function or intestinal absorption following contamination, fasting during capture and transport for rehabilitation purposes, or stress/shock. Regardless of the cause, hypoglycemia will contribute to thermoregulatory and metabolic problems as well as seizures in oiled sea otters.

Respiratory distress is a common finding in oiled sea otters and was especially apparent during the first 3 weeks of the EVOS (Fig. 18.2). Injury to respiratory tissues ranges markedly in severity from irritation of the nasopharyngeal membranes and sinusitis to bullous subcutaneous and interstitial emphysema. The subcutaneous emphysema is characterized by air pockets detected on palpation below the skin along the axillary region, and in the most severe cases along the sides of the neck, thorax, and spine [19]. Postmortem examination of oiled sea otters has demonstrated that the air forming subcutaneous emphysema bullae may originate from ruptured membranes in the lungs.

The pathogenesis of emphysema in oiled sea otters is not completely understood. Several contributing factors have been identified and include weakening of the respiratory mucosa by petroleum hydrocarbon exposure coupled with forcible inhalation/exhalation. Ventilatory exertion, as may occur with respiratory distress or with pre- and postdive periods during foraging, has been implicated in the development of spontaneous emphysema in diving humans [25]. A similar mechanism may explain the development of this condition in oiled sea otters. In addition, the incidence of both interstitial and subcutaneous emphysemas during the initial weeks of the EVOS (Fig. 18.2) suggests that the inhalation and dermal absorption of volatile petroleum hydrocarbons were the underlying causes.

Chemical composition of the oil and environmental factors associated with oil weathering will obviously alter the timeline for respiratory injury in sea otters. Lighter aromatic hydrocarbons (i.e., benzene, toluene, xylene, and ethylene) may evaporate over a period of days to weeks in an acute spill depending on water and air temperatures. In some cases, as in Alaska following the EVOS, toxins from unweathered oil have persisted for decades [4].

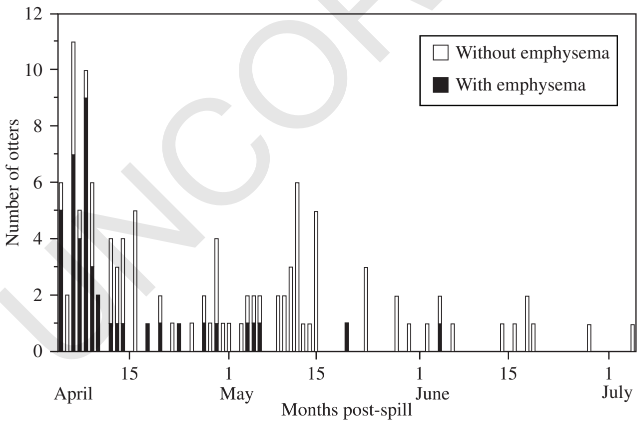


**FIGURE 18.2** The incidence of interstitial and subcutaneous emphysema in sea otters in relation to date following the March 24 EVOS. Height of the bars indicate the total number of otters with (black bars) and without (white bars) evidence of emphysema following necropsy. Note the decrease in occurrence of emphysema 3 weeks after the spill. From Williams and Davis [19].

Such chemical compounds are considered the most toxic of the major classes of petroleum hydrocarbons in crude oil and are known to cause damage to the lungs and mucous membranes of the airways [26]. In Alaska, more than 80% of the documented cases of emphysema in sea otters occurred within 14 days of the grounding of the *Exxon Valdez*. During this period, nearly 70% of the sea otters that died exhibited some form of interstitial emphysema. In contrast, continued release of fresh crude oil in a chronic event such as the DWH spill in the Gulf of Mexico will prolong the period of exposure to tissue damaging chemical compounds. Clearly, the acute or chronic nature of a spill must be considered in assessing potential impacts on the respiratory system as well as other organs and organ systems.

The last of the four major disorders, gastrointestinal injury, is a common problem in oiled sea otters throughout rehabilitation, and affects the ability of the animals to process food. Focal hemorrhaging and ulceration are most evident in the stomach (Fig. 18.3) rather than the intestines, suggesting a hypothermic event rather than toxic lesions per se [27]. Gastrointestinal erosions also occur in stressed sea otters whether the animal has undergone a hypothermic event or not. Based on these findings, Lipscomb et al. [17,18] concluded that the combined effects of hypothermia, stress, shock, captivity during rehabilitation, and overall oil contamination rather than oil ingestion are the primary factors leading to gastrointestinal injury in oiled sea otters.

In addition to these major disorders, oiled sea otters may display a variety of behavioral problems and symptoms. Seizures, lethargy, hyperactivity, labored breathing, and anorexia have all been documented for sea otters with different degrees of external oiling. Many of these are symptomatic of underlying organ damage. For example, liver dysfunction associated with tissue necrosis due to vascular congestion and oil toxicity has been reported for heavily oiled sea otters. While impairing the animal's ability to assimilate food, damage to the liver also impedes its role in

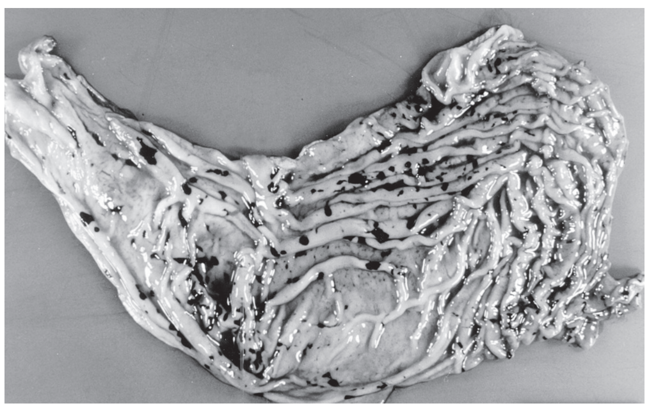

**FIGURE 18.3** Internal surface of the stomach of an oiled sea otter showing areas of focal hemorrhage. Although similar in color, the dark areas are hemorrhage sites not ingested crude oil. From Williams and Davis [19].

detoxifying and excreting foreign chemicals, such as oil. Acute renal insufficiency due to injury to the kidneys can also impair the ability of the animal to excrete toxicants [19].

Adrenal hyperplasia, immunosuppression, and anemia have been identified as potential problems for other oiled wildlife, particularly during rehabilitation processes [28–30]. Of these, anemia can be a long-term problem for oiled sea otters and will dictate the timing of release from rehabilitation programs due to impaired diving capabilities associated with this condition. The combined effects of stress and oil toxicosis instigate many of these conditions and illustrate the range of insults that may affect the health of sea otters during an oil spill event and affect the success of its reintroduction to the wild following rehabilitation. Furthermore, the effects may persist beyond the lifetime of individuals and as such affect more than a single generation of animals (see Section 18.2.3).

### 18.2.3 Long-Term Effects

The incidence and duration of injury to various organ systems following oil contamination will differ in sea otters according to the toxicity of the oil, duration of exposure, original health of the animal, environmental conditions, and organ-specific recovery rates [19]. It is also important to note that there is no "typical" clinical, macroscopic, and microscopic profile for oiled sea otters. Not all otters will exhibit the same symptoms or spectrum of lesions and recover along the same timeline. In addition, as noted earlier, AQ1 the response to acute and chronic exposure to oil will differ. Despite these caveats, several noteworthy trends regarding tissue damage have been observed.

Interstitial and subcutaneous emphysema, gastrointestinal lesions, and severe organ congestion associated with hypothermia are most likely to occur in the presence of volatile petroleum hydrocarbons characteristic of fresh crude oil. The incidence and severity of these injuries are often limited to the first few weeks of a catastrophic spill and are most evident in heavily oiled otters. Organ dysfunction concomitant with vascular congestion may persist for several months and in some cases will result in permanent damage to kidney and liver function in sea otters.

Anemia is another long-term condition that may develop days to weeks after the original exposure to oil. The condition may persist for over 3 months in severely oiled otters and can hinder release back to the wild. This prolonged anemia represents a challenge for the foraging animal because oxygen stores in the blood are important for supporting aerobic diving by sea otters [31]. For another species of otter, the North American river otter, anemia associated with oiling resulted in fewer dives and a potential decrease of 64% in the capture rate of prey [32]. Thus, the severity and duration of anemia associated with oil exposure may ultimately dictate the ability of contaminated as well as rehabilitated sea otters to survive in the wild.

Lastly, long-term monitoring of moderately to heavily oiled adult sea otters that were placed in aquariums following the EVOS has demonstrated several conditions that can remain lifelong problems. Nearly 75% of these captive otters showed evidence of persistent interstitial emphysema upon necropsy 10 years later. Liver necrosis was found in half of the animals (T.M. Williams, unpublished data). Either condition would have challenged the survival of the otters in the wild had they been released.

Continued observation of wild sea otters in the oil spill zone of Prince William Sound has demonstrated the exceptional persistence of crude oil and oiling effects across decades and generations of sea otters [6]. Specifically, elevated mortality across age classes, including those born after the spill, has resulted in decreased survival compared to unexposed populations and coincident long-term population effects [5]. These effects have persisted for more than two decades with chronic mortality losses approaching or exceeding the acute mortality of sea otters immediately following the oil spill. Exposure rates to lingering oil approached over 24 contact times per year for some individual sea otters in 2011–2012 [9]. Overall, the results of recent studies suggest that residual oil can affect wildlife populations on time scales much longer than previously believed and that the cumulative chronic effects can be as significant as acute effects [8].

In summary, sea otters are one of the most vulnerable mammalian species to the impacts of oil contamination. This is evident from the wide variety of medical problems encountered following experimental and accidental oiling, and the protracted period of recovery. The EVOS was the first oil spill to impact large numbers of sea otters, and neither the response nor the wildlife community were adequately prepared to fully address the suite of problems that ensued. With knowledge gained during the EVOS and advancements in treatments, response capabilities and resources following the passage of the Oil Pollution Act of 1990, wildlife personnel are actively working to improve the survivorship of oiled sea otters following the inevitable future marine spill as well as acquiring the data to better understand population-level effects. However, this species' unique biology, behavioral patterns, and nearshore distribution ensures that the sea otter will remain a species at risk to oil.

## 18.3 SEALS AND SEA LIONS

Seals and sea lions, collective called pinnipeds, are marine mammals of the order Carnivora. They are distributed from the poles to the tropics and are the most amphibious marine mammal group. Pinnipeds spend hours to months at sea foraging and return to land or ice to rest, molt, and reproduce. This group includes three families and 36 species: the Otariidae comprises 16 fur seal and sea lion species; the Phocidae, or true seals, contains 19 species; and the Odobenidae is represented by a single species, the walrus.

Our understanding of the impact oil has on pinnipeds is surprisingly limited. Oil has been documented to come in contact with free ranging pinnipeds at least 30 times, but small sample sizes and difficult field conditions have precluded any definitive conclusions about the effect of the oil [33]. Researchers have followed oiled and unoiled animals of two species after a spill, but have not been able to detect a difference in survival between the oiled and unoiled individuals [34,35]. Further, while some animals were found dead with oil on them, it was not possible to clearly identify the cause of death [34,35]. Even the well-studied EVOS produced equivocal results. For example, 81% of the 585 harbor seals (*Phoca vitulina*) observed during or after the EVOS were reported to have been oiled, and based on data from subsequent aerial and boat surveys, investigators concluded that 302 harbor seals died as a result of the spill [36]. However, subsequent studies found that harbor seals are more mobile than previously assumed and suggested that the missing individuals may have migrated out of the affected area and were not necessarily dead [37]. Finally, observations of Steller sea lion (*Eumetopias jubatus*) colonies within the spill zone were not able to detect an effect on that species [38]. While definitive impacts have been hard to document, the limited amount of data precludes distinguishing between no effect versus an effect that we were unable to document. Furthermore, while acute impacts of oil contamination are the most obvious and easiest to quantify, the persistence of hydrocarbons in the environment can result in continued exposure for many years after an oil spill [4,9,39]. This chronic exposure can lead to both direct effects on the health of the individual animal, as well as to the indirect effects of chronic contamination that reduces prey availability. Together these effects can cause a reduction in population viability and/or recovery such as has been reported for sea otters after the EVOS [9,39].

### 18.3.1 Direct Effects

Direct contact with oil can impact pinnipeds in a variety of ways. Oil can coat all or portions of their body surface, they can inhale hydrocarbons, and they can ingest oil directly or in oil-contaminated prey [33]. As sea lions and seals rely on blubber for insulation, their thermoregulatory ability does not seem seriously hampered by contact with oil [40]. However, observations suggest that some individuals have become so encased in oil that they were not able to swim and subsequently drown [36,41]. Studies designed to mimic the small amounts of oil that might be ingested by animals in the wild have been carried out with harp (*Pagophilus groenlandicus*) and ringed (*Pusa hispida*) seals [42,43]. Ingested oil was passed in the feces and the exposed animals were more vocal than control animals. Some changes in liver enzyme levels were noted, but upon euthanasia no relevant organs lesions were observed. Ringed seals placed in a seawater pen with the surface covered with crude oil for 24 h did not ingest the oil, but did exhibit changes in their respiratory epithelium consistent with inhalation of oil fumes [44]. Some of the oil-exposed seals exhibited liver and kidney pathologies. The eyes, oral cavity, respiratory surfaces, and anal and urogenital surfaces were particularly sensitive to prolonged contact with oil [33]. Behavioral studies have shown that while pinnipeds should be able to detect oil through vision and/or smell they apparently do not avoid oil [33]. They are therefore likely to come in contact with oil if it comes into their habitat. Of the pinnipeds, fur seals, which rely almost entirely on their fur for insulation, are far more sensitive than other species to oiling [40]. Heat transfer doubled in fur seal pelts after oiling, whereas pelts from California sea lions (*Zalophus californianus*), bearded (*Erignathus barbatus*), and Weddell (*Leptonychotes weddellii*) seals showed no change [40]. Further, juvenile northern fur seals (*Callorhinus ursinus*) exhibited a 50% increase in heat loss in water after one-third of their body surface was contaminated with Prudhoe Bay crude oil [45].

### 18.3.2 Vulnerability and Risk

The potential impact of an oil spill on an organism results from the intersection between the probability of coming in contact with the oil and the sensitivity of the species. A population of a sensitive species may never be seriously impacted if its distribution and life history patterns result in very low contact with an oil spill, whereas a population of a relatively insensitive species may be seriously impacted if it is consistently exposed. The worst-case scenario would be for a sensitive species to have a life history pattern or distribution that increases the probability that the majority of the species' entire population could come into contact with oil [46,47]. This is the scenario facing northern fur seals, a relatively sensitive pinniped species to oiling in which much of their breeding population becomes concentrated on a few breeding colonies. During the months of June through November, with a peak in late June and early July, this species aggregates on their breeding colonies on the Pribilof Islands (St. Paul and St. George) [48]. During that time, over 80% of the population is on and around the shorelines of these two islands. A moderate-to-large oil spill during the breeding season in the vicinity of these islands could be catastrophic, potentially decimating this species [48]. The various Antarctic fur seal species (*Arctocephalus* spp.), which like their northern cousins rely on air trapped in their fur for insulation, are equally sensitive to the effects of oiling. However, they are not as vulnerable because their breeding colonies are much more widely distributed around the Southern Ocean. Nevertheless, any single population could be seriously impacted if a spill occurs during the breeding season when the seals are concentrated at their colonies.

McLaren [47] provided an excellent overview of the timing of breeding patterns and general distribution of pinnipeds in the context of a potential oil spill. For many species, little has changed in our understanding of their migratory and habitat utilization patterns in the two decades since

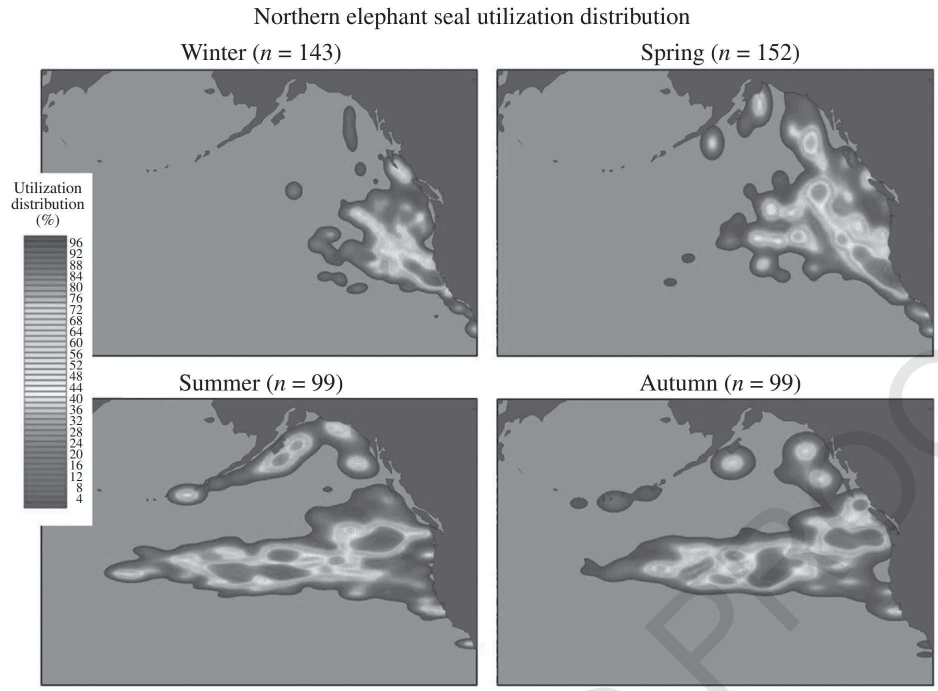


**FIGURE 18.4** The seasonal distribution of female northern elephant seals based on movement of ARGOS satellite tagged individuals. It is predicted that these seals will be least vulnerable to an oil spill during summer and autumn when they range most widely offshore.

McLaren published. However, for elephant seals and some fur seals and sea lions there has been a significant increase in our knowledge of their movements and habitat utilization patterns [49–55]. In particular, we have sufficient data to show that the seasonal distribution of female northern elephant seals (*Mirounga angustirostris*) is quite variable with some regions of their preferred habitat completely unoccupied during certain seasons (Fig. 18.4). While an analysis of the migratory and habitat utilization patterns of pinnipeds is beyond the scope of this chapter, we can describe the broad general patterns that exist. Pinnipeds can be classified into migratory and nonmigratory and ice versus land breeding. These differences are further constrained by differences in the breeding biology of the different families.

Unlike cetaceans, pinnipeds are constrained by the need to breed on land or ice, which conflicts with the need to forage at sea. The separation between breeding and feeding habitats has led to the evolution of two general life history patterns. Many phocid (true seals) mothers remain with their pups throughout lactation fasting from birth to weaning. Some phocids, most notably harbor, ringed, and Weddell seals, feed during lactation. Weaning is abrupt and occurs after a minimum of 4 days of nursing for hooded seals (*Cystophora cristata*) to a maximum of 7 weeks for Weddell seals. In contrast, otariid (sea lions and fur seals) mothers stay with their pups for only the first week or so after parturition and then periodically go to sea to feed, returning to suckle their pup on the rookery. Feeding trips vary from 1 to 7 days depending on the species, and shore visits to the fasting pup last 1–3 days. Pups are weaned from a minimum of 4 months in the subpolar fur seals and northern fur seal and up to 3 years in the equatorial Galapagos fur seal (*Arctocephalus galapagoensis*). The remaining otariids breed in temperate climes. In these species, pups are usually weaned within a year of birth, although weaning age can vary both within and between species as a function of seasonal and site specific variations in environmental conditions. For walruses (*Odobenus rosmarus*), lactation can last up to 3 years, and the calves stay with or in the vicinity of the mother while she feeds on the benthos [56]. Overall, the breeding characteristics of phocid mothers and their pups make them less, and otariid mothers and their pups more, susceptible to a coastal or near colony oil spill.

The feeding and movement pattern of pinnipeds directly affects their susceptibility to an oil spill. For example, northern elephant seals forage hundreds to thousands of kilometers offshore, while a nursing California sea lion remains relatively close to the coast moving only tens to hundreds of kilometers (Fig. 18.5). Susceptibility is also complicated by differences in the seasonal migratory patterns. During the breeding season, northern and Antarctic fur seals are restricted to a discrete area near the colony, but once the 4-month lactation interval is over, they are highly pelagic, foraging hundreds to thousands of kilometers from their breeding colonies. In contrast, other sea lions and fur seals tend to forage in the coastal zone along the continental shelf [56]. While highly migratory species are likely to leave the area of an oil spill, resident nonmigratory animals will be more susceptible to both the acute and chronic effects of an oil spill. Long-term chronic effects result from direct impacts on their health as

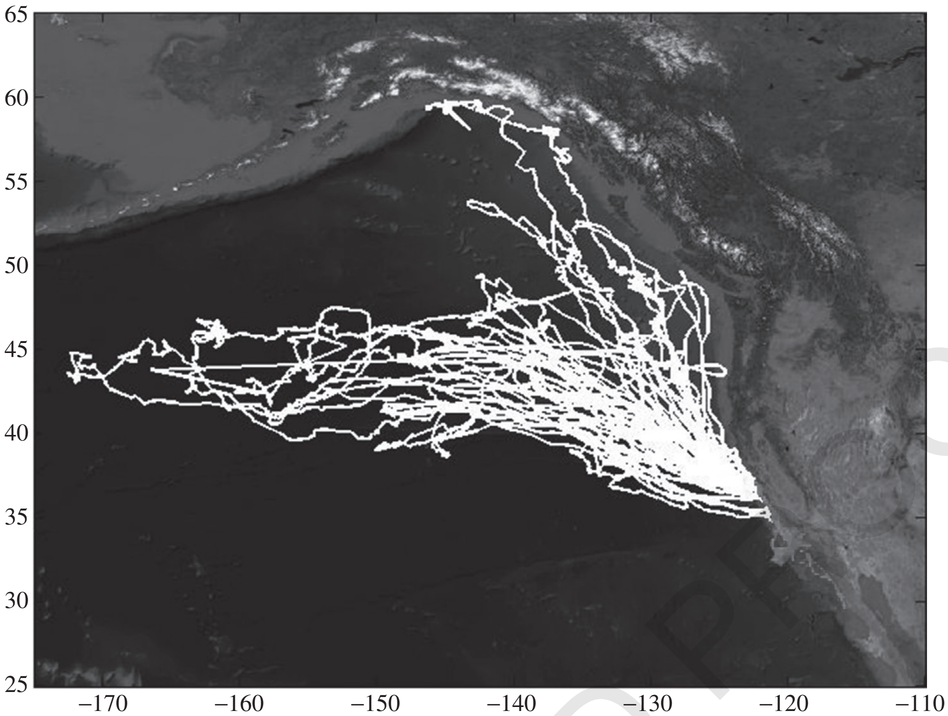


**FIGURE 18.5** ARGOS satellite tracks of foraging trips of capital breeding female northern elephant seals (in white) compared to foraging trips of lactating California sea lions (in red). Elephant seals were foraging from the Año Nuevo colony, California [57], and sea lions from colonies on San Miguel Island, Southern California (Robinson and Costa, unpublished). These foraging patterns strongly indicate California sea lions are more vulnerable than northern elephant seals to an oil spill off the California coast.



well as indirect effects associated with alterations in marine food webs, which may result in reductions in prey or increases in predation [4,9,39]. Differences in foraging behavior will also result in differences in exposure after an oil spill. Populations of sea otters and sea ducks have been slow to recover in areas that were oiled compared to areas that were not oiled. The slow recovery is thought to be associated with the continued exposure to oil that has persisted in the sediments years after the EVOS [9,39]. Thus, organisms that feed on nearshore benthic prey are likely to be at greater risk than species that feed in the water column. As such, we might speculate that as a benthic forager, walruses and bearded seals would be, like sea otters, likely to suffer from chronic exposure if there was an oil spill in their foraging grounds.

In summary, pinnipeds are a diverse taxonomic group that is quite variable in their vulnerability to oil contamination. Fur seals are the most vulnerable, with seals and sea lions less sensitive to direct contamination. However, all pinnipeds are likely to be effected by persistent exposure to hydrocarbons consumed in their prey as well as to any reductions in prey availability associated with an oil spill.

## 18.4 SEA COWS

Sea cows, in the mammalian order Sirenia, includes three species of manatees (family Trichechidae) and the dugong (family Dugongidae). Unlike all other marine mammals, the extant sirenians are aquatic herbivores limited to tropical and subtropical waters. All four species are of considerable conservation concern and are categorized by the International Union for Conservation of Nature as "vulnerable," indicating a high risk of extinction in the wild. Recent comprehensive reviews of the ecology, evolution, and conservation of the Sirenia are available elsewhere [58,59]. The dugong (*Dugong dugon*) is exclusively marine and is found in shallow nearshore waters of the Indo-Pacific, the West African manatee (*Trichechus senegalensis*) is euryhaline and occupies coastal and inland waters of the tropical Atlantic coast of Africa, the Amazonian manatee (*Trichechus inunguis*) occupies freshwater habitats of the Amazon Basin and the euryhaline West Indian manatee (*Trichechus manatus*) is found in coastal bays and inland rivers from coastal Brazil to the southeastern United States.

The warm waters within the ranges of the sirenians include some of the world's major areas of oil development, extraction, shipping, and refining. Examples include facilities in the Gulf of Arabia (dugongs), the Gulf of Mexico and the Orinoco Petroleum Belt of Venezuela (West Indian manatees), oil fields in the Amazon Basin (Amazonian manatees), and offshore development in Nigeria and Angola (West African manatees). Despite this juxtaposition of sirenians and oil development, there has been very limited documentation of effects of oil spills on sirenians.

### 18.4.1 Direct Effects

There have been no published accounts that provide conclusive documentation linking deaths of sirenians to oil spills. There is circumstantial evidence suggesting that about 150 dugongs died as a result of the 1983–1984 Nowruz oil spill in the Arabian Gulf, one of the largest oil spills in history [60,61]. Dugong deaths were noted coincident with this event (37 dead strandings on shores of Saudi Arabia and Bahrain), but no necropsy data were gathered [60–62]. Similarly, in 1991, 14 dugongs were seen dead in the region encompassed by the Gulf War oil spill [63]. No West Indian manatee deaths due to oil or dispersants were confirmed during the 2010 DWH spill in the Gulf of Mexico.

Both the immediate and the long-term chronic effects of exposure to oil are unknown for sirenians. The only published study that examined sirenian tissues for the presence of PAHs and related compounds did not find any of these chemicals [64], which is not surprising as vertebrates are known to efficiently metabolize aromatic hydrocarbons [65, 66]. Additionally, this study was not conducted during a major spill nor did it involve sirenians suspected of being exposed to oil. Similarly, no information exists related to potential sublethal effects of exposure to oil on sirenians. Toxic effects of oil and associated vapors on the eyes and respiratory system would likely be similar to those seen in other marine mammals [26,67,68]. The skin of sirenians has a thick dermis and lacks a pelage coat. However, the sparsely distributed sensory hairs may have a function in orientation [69,70] that could be negatively affected if coated in oil. Sirenians spend considerable time with muzzles in the sediment while feeding, and manatees feed on shoreline vegetation [58], so ingestion of residual oil and associated dispersants can be expected in areas impacted by oil spills. While the effects of oil ingestion on sirenians are undocumented, it seems likely they would respond like other large mammalian herbivores. Horses, like sirenians, are hindgut digesters and seem to be more tolerant of oil ingested in water than ruminants. In contrast, horses seen to be more susceptible to oil ingestion from soil than ruminants [71]. Sirenians can be very susceptible to collisions with boats and entanglement in ropes and lines [58,72]. When spills occur in areas frequented by sirenians, response personnel must take extra care to avoid collisions with manatees or dugongs and regularly monitor potential shoreline entanglement hazards resulting from oil recovery efforts.

### 18.4.2 Indirect Effects

An oil spill could have substantial impact on sirenians by reducing the abundance and quality of their food. Oil has been experimentally shown to cause mortality and sublethal harmful effects on freshwater aquatic vegetation consumed by manatees in the Amazon and elsewhere [73], and oil spills have impacted sea grass meadows in areas used by dugongs or manatees [60,61,74]. In addition, major diebacks of sea grass beds and multiple short-term toxic effects of oil and dispersants on aquatic vegetation have been documented from oil spills [75–77]. However, the effects of oil on sirenian food resources in tropical climates may not persist for long periods as evidenced by the substantial recovery of sea grasses in the Gulf of Arabia 1 year after the Gulf War spill [78].

Faced with a substantial reduction in food quantity or quality, some sirenians may move to other feeding sites. However, this option may not be available to all individuals given the considerable heterogeneity in scales of movement exhibited by sirenians and the degree of an individual's familiarity with potential alternative unimpacted feeding areas [79,80].

## 18.5 POLAR BEARS

Polar bears (*Ursus maritimus*) occur throughout the Arctic. There are 19 recognized subpopulations with a total population of 20,000–25,000. About 60% of the bears occur in Canada [81]. In Alaska, they have been observed as far south in the eastern Bering Sea as St. Matthew Island and the Pribilof Islands, but they are most commonly found within 180 mi of the Alaskan coast of the Chukchi and Beaufort seas, from the Bering Strait to the Canadian border. Two stocks occur in Alaska the Bering–Chukchi seas stock without a reliable population estimate and the southern Beaufort Sea stock with an estimated 1526 bears [82].

### 18.5.1 Direct and Indirect Effects

Polar bears primarily rely on their fur to protect them from the extreme arctic temperatures. Oil significantly reduces the insulating value of fur and, if not removed, an oiled bear would be unable to survive the resulting heat loss [83]. Polar bears are known to groom themselves regularly to maintain the insulating properties of their fur and an oiled bear would be expected to ingest significant quantities of oil during the grooming process [84]. In 1981, three polar bears were involuntarily forced into a pool of oil for 15–50 min and observed [83]. Immediately upon exiting the pool, the bears began licking oil from their paws and forelegs, and for the next 5 days, they regularly groomed their fur attempting to remove the oil. After 26 days, one bear died, another was euthanized 3 days later, and one recovered. Necropsies of the two bears that died revealed gastrointestinal fungus-containing ulcers, degenerated kidney tubules, low-grade liver lesions, biochemical changes indicative of stress, depressed lymphoid activity, and liver and kidney failure [83]. Other observed affects included loss of hair, anemia, anorexia, acute inflammation of the nasal passages, increased metabolic rates, elevated skin temperatures, marked epidermal responses, and stress [85,86]. A bear living and feeding near a recent oil spill likely would be exposed to the toxic volatile components of a spill and may suffer substantial damage to the respiratory and central nervous systems and mucus membranes.

Polar bears are curious and are likely to investigate oil spills and oil-contaminated wildlife [84,85]. Hungry bears are likely to scavenge oil-contaminated seals, as they have shown no aversion to eating and ingesting oil [85,86]. Polar bears may even be attracted to oil as some bears have chosen to consume various refined hydrocarbon products such as antifreeze and hydraulic fluids, which in some instances resulted in death [87].

Polar bears feed on ringed (*Pusa hispida*) and bearded seals (*E. barbatus*), and it seems likely that a large oil spill in the vicinity of these seals would have the same effect on them as the EVOS had on harbor seals (*P. vitulina*) [8, 88–91], but see Ref. [37]. The spill would either result in high mortality of the seals and a glut of easily available toxic prey or the seals would leave the area and create a prey shortage for the bears. Even if high mortality resulted in an initial glut of prey, that bounty would soon become a prey shortage if the spill was sufficiently large or potent [14,92].

### 18.5.2 Vulnerability and Risk

The Arctic distribution of polar bears overlaps with many active and planned oil and gas operations within 25 mi of the coast or offshore. Although no major oil spills in the marine environment have occurred within the range of polar bears, terrestrial pipeline spills have occurred in the vicinity of polar bear habitat and denning areas (e.g., Komi Republic, Russia 1994) [93]. The largest terrestrial Alaskan oil spill came from a corroded pipeline leak in the North Slope oil fields in March 2006. This leak released an estimated minimum 4785 barrels of oil. There were no known impacts to polar bears [94]. Despite numerous safeguards to prevent spills, an average of 70 oil and 234 oil waste product spills occurred each year between 1977 and 1999 in the North Slope oil fields [91]. The Bureau of Ocean Energy Management (formerly the Minerals Management Service) [95] estimated there was an 11% chance that the Beaufort Sea Multiple Lease Sale would result in a marine oil spill greater than 1000 barrels.

Expansion of Arctic circumpolar oil and gas development, coupled with expansions in shipping and development of offshore and land-based pipelines, increases the probability that an oil spill will negatively affect polar bears and/or their habitat [91,96,97]. Future declines in the Arctic sea ice are likely to result in increased tanker traffic in high bear use areas, which would increase the chances of an oil spill from a tanker accident, ballast discharge, or discharges during the loading and unloading of oil [98]. The additional open water ship traffic also may disturb the movement patterns of polar bears and their prey [99]. A 5912-barrel oil spill scenario, the largest spill thought possible from a pipeline in polar bear habitat from the Northstar offshore oil production facility in the southern Beaufort Sea, was modeled [100]. For the purposes of the scenario, it was assumed that a polar bear would die if it came in contact with the oil. The study estimated that 0–27 bears could potentially be oiled during the open water conditions in September and from 0 to 74 bears during the mixed ice conditions in October. The number of polar bears affected would be highest if the spill spread to areas of seasonal polar bear aggregations in the fall, such as the area near Kaktovik, Alaska, and could result in a significant impact to the southern Beaufort Sea population.

Spills in fall or spring during the formation or breakup of ice present the greatest risk to polar bears because of difficulties associated with cleanup during these periods and the presence of bears in their prime feeding areas over the continental shelf. The release of oil trapped under the ice from an underwater spill during the winter or from incomplete cleanup of a spill during the previous year could be catastrophic during spring breakup [101]. During the autumn freeze-up and spring breakup periods, it is expected that any spilled oil in the marine environment would concentrate and accumulate in open leads and polynyas, areas of high activity for polar bears and seals, and both would be oiled [84,100,101]. In autumn, bears are not only found in more vulnerable areas but they are also two to five times more abundant nearshore compared with summer [102]. This trend has been increasing in recent years in the Beaufort Sea [103].

During the summer open water season, most polar bears remain offshore in the pack ice and are not typically present in high vessel traffic areas. Barges and vessels associated with industry activities travel in open water and avoid large ice floes. During the ice-covered season, mobile, nondenning bears would have a higher probability of encountering oil or other production wastes than the nonmobile, denning females.

Documented direct impacts on polar bears by the oil and gas industry during the past 30 years are minimal and the mortality that has occurred has been associated with human–bear interactions as opposed to a release of oil. However, oil and gas activities are increasing as development continues to expand throughout the U.S. Arctic and internationally, including in polar bear terrestrial and marine habitats. Disturbance from activities associated with oil and gas development could result in direct or indirect effects on polar bears and their habitat. Direct disturbances include displacement of bears or their primary prey due to the movement of equipment, personnel, and ships through polar bear habitat. Female polar bears tend to select secluded areas for denning, presumably to minimize disturbance during the critical period of cub development. Direct disturbance may cause abandonment of established dens before cubs are fit to leave. For example, expansion of the network of roads, pipelines, well pads, and infrastructure associated with oil and gas activities may force pregnant females into marginal denning locations [104,105]. The potential effects of human activities are much greater in areas where there is a high concentration of dens such as Wrangel Island, Russia. Although bear behavior is highly variable among individuals and sample sizes are small, some denning bears have shown a degree of tolerance to human activity [106].

It is reasonable to assume that full-scale industrial activities in the waters off the North Slope will have a cumulative negative impact on polar bears. Such cumulative effects would be expected to displace bears and ringed seals from preferred habitats, increase mortality, and decrease reproductive success. When the predicted effects of climate warming are also factored in, the cumulative impacts on polar bears and ringed seals are likely to result in serious population-level concerns [92]. However, others believe that given the limited geographical scope of industrial activities when combined with proper management controls, the potential for catastrophic population-level effects on polar bears from oil and gas exploration and development activities is probably low [104–106]. Regardless, increased industrial activities in the Arctic marine environment coupled with increasing vessel traffic will require ongoing vigilant monitoring and increased preparedness to reduce the potential risk to polar bears and other Arctic marine mammals.

## 18.6 WHALES, DOLPHINS, AND PORPOISES

Whales, dolphins, and porpoises, collectively known as cetaceans, are marine mammals of the order Cetartiodactyla. These animals are restricted to aquatic habitats for their entire lives. The group includes about 88 species of toothed and baleen whales. The 74 species of toothed whales, the Odontoceti, include sperm whales, pygmy and dwarf sperm whales, beaked whales, narwhals, belugas, dolphins, river dolphins, and porpoises. The 14 species of baleen whales, the Mysticeti, include right whales, gray whales, and rorquals such as blue, fin, and minke whales.

Cetaceans can be exposed to crude and weathered oils through direct contact with the skin, eyes, mouth, and blowhole(s), and they can also inhale volatile petroleum fractions at the water's surface, ingest oil directly, and consume oil components in food [84, 107]. They are thought to be at risk from oil in marine and some freshwater environments because they lack the ability to leave the water to avoid oil, their fish and invertebrate prey can become oiled, and cetaceans must surface periodically to breathe, potentially bringing them into contact with floating oil and volatile toxic components. Nevertheless, comparatively little is known about the effects of oil on cetaceans, as there have been few oil exposure experiments, only a small number of reported observations of wild cetaceans in or near oil, and little published information from necropsies of carcasses of cetaceans known to have been exposed to oil.

Based in part on the scant records of cetacean mortalities associated with oil spills from 1969 to 1989, Geraci [108] suggested that an oil spill may only affect small numbers of cetaceans. Other reasons proffered for their potentially low vulnerability are that cetaceans appear to be able to detect oil. They lack hair or fur so oil does not compromise their insulation, their skin is nearly impermeable to the components of oil, they do not drink large volumes of sea water and would not ingest much oil, their foraging strategies likely do not include scavenging on oil-killed prey, and the toxic volatile components of oil dissipate quickly so exposure to toxins through inhalation may be minimal.

### 18.6.1 Direct Effects

Oil does not readily penetrate cetacean skin, which is characterized by tight intercellular bridges and an unusually thick epidermis, 10–20 times that of humans [107]. Experimental direct application of various petroleum fractions to dolphin skin resulted only in subtle histological changes, which were reversed within a week of exposure [26]. The absence of hairs and the frequent sloughing of skin cells provide little opportunity for oil to adhere to cetacean bodies.

Few surveys have evaluated the presence and nature of petroleum constituents in cetaceans [107]. Low concentrations of PAHs were detected in muscle of 26 harbor porpoises in the United Kingdom [109]. Low concentrations of low molecular weight PAHs were found in the blubber of seven stranded sperm whales (*Physeter macrocephalus*) in the southern North Sea and in muscle from five species of cetaceans from the Northwest Atlantic, including beluga (*Delphinapterus leucas*), sperm whale (*P. macrocephalus*), minke whale (*Balaenoptera acutorostrata*), common dolphin (*Delphinus delphis*), and white-sided dolphin (*Lagenorhynchus acutus*) [110,111]. Large variations in PAH concentrations were found in gray whale (*Eschrichtius robustus*) stomachs [112].

Cetaceans primarily feed on live invertebrate or vertebrate prey. They are not scavengers, so it is not likely they will consume petroleum compounds in food that has died from oil exposure. However, it is possible that cetaceans could capture prey contaminated with oil, but which had not died, or they might ingest oil inadvertently while digging into sediments in search of prey.

Potential indirect impacts of oil on feeding of baleen whales were investigated through exposure of baleen plates to oil. The structural and chemical integrity of isolated baleen plates of seven species of whales were reported to remain intact when they were soaked in crude oil, gasoline, or tar over long periods. When plates were exposed to oil in continuous-flow flumes, minor decreases in filtration rates due to fouling were observed, with variation in impairment based on the type of oil [26]. Based on findings from harbor seals during the EVOS, marine mammals probably metabolize hydrocarbons rapidly and efficiently, mediated through the induction of mixed-function oxidases [107]. This is supported by the absence of firm evidence of contamination of tissues or toxicological effects for cetaceans from the EVOS [113]. In addition, no clinical, hematological, or biochemical effects were noted in a captive bottlenose dolphin (*Tursiops* sp.) dosed daily with 5 ml of machine oil for 99 days, suggesting captive dolphins can tolerate small amounts of ingested oil [26].

The few laboratory experiments on the potential impact of oil on cetacean physiology have produced mixed results. The renal cells of spotted dolphins (*Stenella* spp.) were exposed to No. 1 fuel oil to determine the toxicity of the oil and elucidate some of the mechanisms of cytopathology in a standardized preparation [114]. Cell survivability was reduced in a dose-dependent manner and early morphologic changes reflecting cytotoxicity were revealed by transmission electron microscopy. Programmed cell death (apoptosis) studies of the dolphin renal cells exposed to fuel oil for 12, 24, and 48 h showed that the number of cells undergoing early apoptosis increased after 24 h, clearly demonstrating a dose response to No. 1 fuel oil for cultured cells. Although it had been speculated that PAHs induced tumors in St. Lawrence River estuary belugas through the formation of DNA adducts, DNA adducts occurred at similar levels in livers of belugas from remote locations without significant PAH contamination [107,115,116].

Several authors suggest that the threat of most immediate concern to cetaceans is inhalation of volatile toxic fractions at the air–water interface, rather than from ingesting contaminated prey or absorbing oil through skin [84,108,117,118]. This risk is greatest near the source of a fresh spill because volatile toxic vapors disperse relatively quickly. When concentrated vapors are inhaled, mucous membranes may become inflamed, lungs can become congested, and pneumonia may ensue [119]. Inhaled fumes from oil may accumulate in blood and other tissues, leading to possible liver damage and neurological disorders [117]. Respiratory intervals vary between cetacean species, ranging from minutes to more than an hour, but all have the potential to expose cetaceans to toxic fumes from oil spills. Geraci [108] concluded: "…it is clear that for the short time they persist, vapors are one feature of an oil spill that can threaten the health of a cetacean."

Würsig [120] suggested that the prospect of oil disrupting reproductive behavior is remote for offshore species, but more of a concern for inshore reproducers such as gray whales, humpback whales (*Megaptera novaeangliae*), narwhals (*Monodon monoceros*), belugas, or resident populations of dolphins or porpoises. For highly social species, the disruption of social groups from loss of some key individuals could potentially impact reproductive success. Potential support for this hypothesis comes from studies of Prince William Sound killer whales (*Orcinus orca*) before and after the EVOS. Two killer whale pods photo-identified 5 years prior to the spill were followed by photo-identification for 16 years after the spill [7]. These two pods suffered losses of 33 and 41% in the year following the spill, with losses of adult females from these maternally organized groups leading to suppressed reproduction [4,7,113]. After 16 years, one pod had not recovered to prespill numbers, and the other has continued to decline and is now listed as depleted under the Marine Mammal Protection Act.

### 18.6.2 Vulnerability and Risk

Based on available knowledge of cetacean life history and ecology, Würsig [120] evaluated hypothetical risks to different taxa of cetaceans, ranked within five subjective criteria: (i) range (large to small), (ii) habitat (oceanic to coastal, ice dwelling, and riverine), (iii) prey diversity (diverse to limited diet), (iv) behavioral flexibility (adaptable to sensitive to stress), and (v) population size (abundant to endangered). He concluded that baleen whales may be at highest risk because of their small populations, their specialized feeding patterns and structures (baleen), and their selected localized habitats for feeding and reproduction. In general, he noted that exposure to oil is likely to be most problematic for species inhabiting restricted habitats or those with restricted ranges, and that feeding locations within the water column may also affect exposure. Many cetacean species inhabiting offshore or open coastal waters are highly mobile and range widely, so their contact with an oil spill may be relatively brief. In contrast, some species have very specific habitat requirements for feeding and/or reproduction, and annually move between specific locations [120,121]. For example, baleen whales such as gray whales and humpback whales engage in long annual migrations between specific inshore feeding and breeding areas. These movements are timed to optimize the availability of appropriate food supplies or conditions for successful calving and breeding. Disruptions from oil spills and associated response actions at either terminus could place individuals, and possibly populations, in jeopardy. Species that have more restricted ranges or strong habitat requirements may experience prolonged exposure if they do not shift their ranges to avoid oil. Freshwater dolphin species such as the boto (*Inia geoffrensis*) or tucuxi (*Sotalia fluviatilis*) in South American rivers and the Ganges River dolphin (*Platanista gangetica*) and riverine populations of the Irrawaddy River dolphin (*Orcaella brevirostris*) in southern Asia face extreme restrictions of their ranges to river courses and would be unable to avoid upstream oil spills. Ice-edge species such as narwhals would be similarly vulnerable to spills in their limited habitat.

Strong site fidelity to restricted habitats may place certain species at risk for prolonged exposure to oil [120]. For example, in many parts of the species range, bottlenose dolphins (*Tursiops truncatus*) are long-term residents of specific bays, sounds, and estuaries [122]. Along the west coast of Florida, year-round resident populations have been studied for more than four decades, and currently span up to five generations of related dolphins [123]. The long-term persistence of these localized populations despite epizootic disease events, catastrophic harmful algal blooms that decimate prey fish stocks, major hurricanes that alter physiography and create high levels of pollution, and intensive and increasing human activities, has led to the hypothesis that these animals live in "ecological cul-de-sacs" where they either cannot or will not shift their ranges in response to major environmental changes and this would potentially include oil spills [124].

Cetacean diets and feeding locations within the water column contribute to defining potential exposure to oil [120]. Cetaceans with limited diets or that take advantage of seasonally abundant or geographically restricted food would be most affected by an overlapping oil spill. The occurrence and magnitude of nutritional effects would depend on the intensity and spread of the oil and its impact on possible alternative prey. The trophic level of cetacean food also might affect their exposure to oil and dispersants, with some feeding on aggregations of small invertebrates such as krill, copepods, and mysids or schools of small fish, and others preying on larger fish, squid, and mammals. Each trophic level has a specific potential to retain and transfer petroleum hydrocarbon residues. Some benthic invertebrates concentrate these compounds in their tissues, whereas teleost fishes and most other invertebrates metabolize and rapidly excrete them [120].

Spilled oil spreads across the water's surface, attaches to particles and sinks to the seafloor or is broken by dispersants into very small droplets that scatter in the water column [84]. There are no data or models indicating how much dispersant or dispersed oil a cetacean may ingest, but it is likely that bottom feeders could inadvertently ingest significant quantities of oil and surface feeders also might engulf a mouthful of oil. Baleen whales exhibit a variety of surface feeding patterns, such as skim feeding performed by right (*Eubalaena* spp.) and bowhead (*Balaena mysticetus*) whales, bubble net feeding by humpback whales, and lunge feeding performed by a number of rorqual whales (Balaenopteridae), that have the potential for ingesting oil and/or fouling baleen plates used for filtering food from the large quantities of water that pass through them [121]. Gray whales, which feed by ingesting mats of invertebrates on the seafloor, might be at risk for ingesting settled oil. Most toothed whales would not face these problems, except possibly when dolphins drive prey schools to the surface [120].

Few published observations of cetaceans feeding in the presence of oil exist. Goodale et al. [125] reported humpback whales, fin whales (*Balaenoptera physalus*), and Atlantic white-sided dolphins feeding in the slick from the vessel *Regal Sword* that sank in 1979 off the east coast of the United States. The authors also cited a personal communication by William Watkins about having seen gray whales probably feeding in natural oil seepage around Santa Barbara, CA, USA.

Avoidance by cetaceans of oil at the water's surface requires that they be able to detect the oil, and that the spill is not so large that it cannot be avoided. Captive bottlenose dolphins can visually discriminate between oil and uncontaminated water, and they can detect oil with an optical density greater than 0.20–0.34 (corresponding to a 1 mm thick film) [108]. Geraci [108] suggested that the skins of both toothed and baleen whales are capable of receiving cutaneous signals from contact with oil. Geraci and colleagues [108, 126] have concluded that free ranging dolphins would be able to detect the thicker concentrations of oil that occur near a spill and weathered fractions forming "pancakes" of much thicker viscous oils, but the lighter fractions that disperse into sheens and lightly colored refined products such as gasoline, diesel fuel, and solvents that rapidly disperse into thin films likely would not be detected easily, if at all. They also suggested that a dolphin's ability to detect the more transparent substances may, in part, depend on prior exposure.

Experiments with captive bottlenose dolphins showed they avoided oil on the surface of the water [127]. When presented with a dark-colored, nontoxic oil slick confined to a portion of the seawater holding pen, these dolphins detected the oil and hesitated to swim beneath it, and they startled in their few contacts with the oil. Subsequent experiments under day and night light conditions using clear mineral oil, dark-tinted mineral oil, and refined motor oil found that dolphins avoided oil during both day and night, but the response broke down when the oil was a thin sheen, particularly at night, suggesting a threshold for the dolphins' ability to detect oil or their inclination to avoid it [128]. The conclusions reached from these experiments were that dolphins relied on tactile clues to detect and avoid oil and they likely would not be unknowingly subjected to prolonged or repeated exposure to oil in the wild. Indirect support for this conclusion comes from the 1991 Gulf War oil spill in which live dolphins and carcasses were not observed in the aftermath of the spill, but they were observed back in the spill zone by 1992 [129].

Würsig [120] hypothesized that because groups of toothed whales (Odontoceti) are constantly communicating, enhanced sensory integration may allow them to more efficiently detect oil, and therefore avoid it as a group. However, avoidance of oil by wild dolphins does not occur under all circumstances. Bergey [130] reported that unidentified "porpoises" rode at the bow of his research vessel in areas of heavy oiling from the 1979 Ixtoc spill off Mexico, without indications of avoiding oil other than veering to avoid tar balls. Preen [131] observed bottlenose dolphins and Indo-Pacific humpback dolphins (*Sousa chinensis*) surfacing in oil sheen following the 1991 Gulf War spill. Bottlenose dolphins in Texas waters have been observed on multiple occasions swimming though extensively oiled areas despite the presence of less-oiled waters nearby [118,132–134]. Harvey and Dahlheim [135] observed cetaceans in Prince William Sound, Alaska, following the EVOS, and reported that none of the animals altered their behaviors in areas of oil. They noted only a single oiled cetacean, a Dall's porpoise (*Phocoenoides dalli*), which appeared stressed because of labored breathing.

The most detailed observations published to date of the behavior of dolphins near oil come from the 1990 *Mega Borg* spill off Galveston, TX [118]. Aerial observations of nine bottlenose dolphin groups over a total of 5.6 h were conducted 6–9 days after the initial spill of 109,000 barrels of light-grade Angolan crude oil. Surface oil was classified as sheen, slick, or mousse, with dolphins apparently detecting the latter two, but not the sheen. In contrast to the consistent avoidance demonstrated in the captive dolphin experiments described earlier, wild dolphins hesitated and milled briefly upon encountering an oil slick, but eventually, they dove under or in small oil patches, and they swam through more extensive areas of oil. However, these free ranging dolphins consistently avoided mousse by swimming under or around it, and group integrity was altered. The observers concluded that bottlenose dolphins may respond to thick oils by tightening their ranks, decreasing respiration rates, and by increasing dive durations and heading changes. Smultea, Würsig, and others [118,136,137] suggested that these alterations in behavior may represent attempts by cetaceans to minimize contact with surface oil and noted their own similar observations of bottlenose dolphins from the 1990 *Apex* oil spill near Galveston, TX, USA, and reports of gray whales decreasing surface time and respiration rates and changing swimming speeds through natural oil seep slicks. The authors expressed concern that the detection, but lack of consistent avoidance of slicks and the apparent lack of detection of sheen may increase risk of exposure to harmful petroleum fractions.

Outside of the 1989 EVOS and the 2010 DWH spill, systematic studies addressing the population-level impact of a large oil spill on cetaceans are rare. Only a few anecdotal cetacean behavioral observations are available from the very large 1979 Ixtoc spill in the Gulf of Mexico [130]. Preen [131] reported that 79 cetaceans were known to have died in Saudi and Bahraini waters during the 1991 Gulf War, but no obvious link to oil was noted. Ridoux et al. [138] performed spatiotemporal comparisons of mortality, population structures, diets, and concentrations of vanadium, nickel, and porphyrines in small delphinids, seals, and otters from the French Atlantic coasts following the 1999 *Erika* oil spill and found no measurable effect of the spill on dolphins.

Limited data on the impact of the DWH spill on cetaceans has been made available on the U.S. National Oceanic and Atmospheric Administration (NOAA) natural resource damage assessment (NRDA) website [10] and a few scientific papers have addressed the health of two Gulf of Mexico bottlenose dolphin populations examined after the spill [139,140]. In 2011, comparative bottlenose dolphin capture–release health assessments were performed by NOAA scientists in Barataria Bay, Louisiana, which was heavily oiled for a prolonged time during the DWH spill, and in an area that was not oiled, Sarasota Bay, FL, USA, where health assessments have been performed on long-term resident dolphins for decades [141–143]. While quantitative information on the amount of DWH oil that entered Barataria Bay has not been published, Grand Isle, Louisiana, which is immediately adjacent to Barataria Bay andnear to where the animals were captured for the health assessments, showed a 45-fold increase in the bioavailable concentration of PAHs after the DWH spill [144].

The Barataria Bay dolphins exhibited severe health problems that were not seen in dolphins from the Sarasota area and have not been seen in previous studies of dolphins from other sites along the Atlantic coast or the Gulf of Mexico (Table 18.2) [139]. Many of the Barataria Bay dolphins were underweight, had low hormone and blood sugar levels, and some showed signs of liver and/or lung damage. The disease conditions observed are uncommon in dolphins, but consistent with those seen in other marine mammals exposed to oil [17,18,83]. The NOAA NRDA suggested that the dolphins of Barataria Bay were potentially exposed to oil by inhaling vapors at the water's surface, ingesting oil from sediments or the water while feeding, eating fish harboring chemical contaminants from oil, and/or via absorption through their skin.

Many of the serious health conditions found during assessments of Barataria Bay dolphins are suggestive of exposure to oil from the DWH spill, but comparative health data on these dolphins from before the spill are not available. Therefore, it is possible that environmental conditions in Barataria Bay before the spill increased the vulnerability of the resident dolphin population to the DWH spill or these dolphins were already unhealthy prior to the spill. Schwacke et al. [139,140] concluded it was highly unlikely that the

**TABLE 18.2 Summary comparison of bottlenose dolphin health measures in 2011 from Barataria Bay, LA (heavily oiled by DWH), and Sarasota Bay, FL (unoiled), based on findings of Schwacke et al. [139, 140]**

| Health measure | Barataria Bay, LA (heavily oiled) | Sarasota Bay, FL (not oiled) |
|---|---|---|
| Body condition (below reference values relating mass to length) | 25% of animals | 4% of animals |
| Extensive tooth loss | 19% of animals | None |
| Inflammation indicators (elevation of one or more of neutrophils, lymphocytes, eosinophils, monocytes, and basophils and/or increased serum globulin or decreased albumin) | 41% of animals | 8% of animals |
| Hypoglycemia (glucose below low reference limit) | 22% of animals | None |
| Iron panel (elevation of two or more of serum iron, total iron binding capacity, % saturation of transferrin) | 22% of animals | None |
| Hepatobiliary (abnormal value for two or more enzymes: ALT, AST, GGT, or LDH) | 19% of animals | None |
| Moderate to severe lung disease (as evidenced by alveolar–interstitial syndrome, masses in the lungs, and pulmonary consolidation) | 34% of animals | 7% of animals |
| Cortisol levels (below minimums measured elsewhere) | 44% of animals | None |
| Aldosterone levels (below assay detection limit) | 53% of animals | 8% of animals |
| Prognosis in 2011 | 48% guarded or worse; 17% poor or grave, with little expectation of survival | 7% guarded; all others good or fair |

severity and prevalence of disease they observed would have gone unnoticed and they pointed out that the Barataria Bay dolphins ranked very low in concentrations of a large suite of pesticides and other chemicals when compared with dolphins from 14 other coastal sites. Regardless, findings released over the next few years by NOAA scientists and others from the numerous as yet unpublished DWH studies conducted following this spill, including follow-up health assessments in Barataria Bay in 2013 and 2014 and Mississippi Sound in 2013, should greatly improve our understanding of the impacts of oil on cetaceans.

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