OPERATIONAL SCIENCE ADVISORY TEAM

SUMMARY REPORT FOR FATE AND EFFECTS OF REMNANT OIL REMAINING IN THE BEACH ENVIRONMENT

Annex L: MISCELLANEOUS RECEPTORS

A number of potential receptors to the residual oil identified under the OSAT-2 charter are of importance, but were not included in the other sections of this report. In the supratidal zone, these receptors include the terrestrial plant community, invertebrates, and ghost crabs. In the subtidal zone, there is the potential for marine mammals to be exposed. This section presents a summary of the potential exposure pathways, toxicity, and risks to these miscellaneous receptors and a discussion of the impact of continued remediation activities.

Terrestrial Plant Communities

Terrestrial plants are valued members of beach communities because they stabilize dunes, contribute to nutrient cycling, and provide food, shade, and habitat for birds, mammals, and invertebrates. The primary point of exposure for terrestrial plants is sand dunes, which may contain supratidal buried oil (SBO) or small surface residue balls (SSRBs) transported by wind and waves up into the dunes, which is part of the supratidal habitat. Vegetation is vulnerable to mechanical oil removal. Even without the use of heavy equipment, plants can become damaged by foot traffic and raking. Crews avoid walking on dunes or disturbing the soil around plants, because experience has shown that digging up plants to remove residual oil is more harmful to plant communities than leaving the oil in place. Most vegetation can recover after cleanup (USFWS 2010). The rate of recovery of plant communities that were cleaned up to remove the oil is about equal to or only slightly faster than plant communities where the oil was simply left in place to degrade.

OSAT-2 was tasked to evaluate whether the concentrations of spill-related chemicals in the supratidal beach sands were above literature-derived toxicity thresholds for survival, growth, and reproduction of terrestrial plants and could present unacceptable risk.

The degree of impaired growth or survival in terrestrial plants was evaluated using measured concentrations of total PAHs in near-shore sediment samples and samples of SBO and SSRBs. Samples were chosen that represent supratidal soils to the degree possible, given the limited characterization of some of these areas. Toxicity thresholds to protect plants were obtained from the literature.

Crude oil in soil can be directly toxic to plants. Oil or dissolved oil can affect plants by blocking air exchange through surface pores (Albers 1995). Long-term effects of petroleum on plants can include reduction in germination due to lack of viable seeds, reduced germination, and affects on soil conditions attributed to reduced aeration caused by oil-filled pores (Kisic et al. 2009). Oil pollution can have long-lasting effects on soils by aggregating soil particles, reducing soil porosity, and forming crusts that prevent roots from penetrating (Andrade et al. 2004). Oil mats that become exposed and dry out can form thick crusts through which plant roots cannot penetrate until the mats break up, allowing vegetation to recover (Barth 2001). Spilled oil can disrupt plant-water interactions, affect plant metabolism, cause toxicity to plant cells, and reduce oxygen exchange between the atmosphere and soils (Ko and Day, 2004). Oil decomposing microorganisms compete with plants for nutrients. The microbial degradation of oil can deplete the nutrients in the soil available to plants. The recovery of local plant populations from the effects of oil can take from a few weeks to 5 years, depending on the type of oil, the circumstances of the spill and the species affected (Albers 1995).

Polycyclic aromatic hydrocarbons (PAHs), one of the components of crude oil, can adsorb to leaves or be assimilated into plant tissues and subsequently become a source of exposure to birds and mammals feeding in the dunes. High-molecular weight PAHs, such as found in weathered oil, will accumulate only a small fraction of the concentrations of oil found in soils. The degree that PAHs will accumulate in plant tissues is lessened by the fact that PAHs assimilated by vegetation may be translocated, metabolized, and possibly photodegraded within the plant (Eisler, 1987). High-molecular weight PAHs measured on plant tissues are typically bound to the surface of the plant rather than incorporated into plant tissues, and therefore should not be a mechanism to facilitate exposure from weathered crude oil to receptors that consume fruit and seeds.

Kisic et al. (2009) reported results of a 4-year “pot trial” where unweathered crude oil was mixed with soil the first year and no additional oil was applied. Wheat, barley, and soybeans were sown into the pots according to a typical crop sequence. Soil samples were taken between harvest and sowing the next crop. Concentrations of total PAHs in the treatments were greater than in the controls in all years. The process of weathering depleted the concentrations of many PAH compounds to below analytical detection limits within the first year, after which there was little additional degradation. Despite the fact that most of the oil had degraded, the effects of the oil on the soil properties and crop yields persisted from year to year. Levels of total petroleum hydrocarbons (TPH) less than 5 g/kg were slow to degrade over time. The major effects observed on soil fertility were an increase in the ratio of carbon to nitrogen and an increase in soil pH along with sparser plant density and reduced crop yields.

The authors concluded that TPH concentrations in soils below 5 g/kg, or total PAHs concentrations in soils below 5 mg/kg, were not harmful to plants. They recommended a total PAH concentration in soil of 5 mg/kg as a “warning or emergency value in remediation of hydrocarbons-contaminated soil.” Kisic et al. (2009) cited work by Kyung-Hwa et al. (2004) who reported that 10 g/kg of TPH in soil was toxic to the crops studied but no toxicity to plants was reported at soils containing TPH levels up to 1 g/kg. Because TPH is only a rough measurement that does not consider the variation in the composition of petroleum hydrocarbons in the oil, the results for total PAHs are preferred. The value of 5 mg/kg total PAHs in soil was adopted as a literature-derived no observable effects concentration (NOEC) value for evaluating potential effects of total PAHs on plants exposed to residual MC252 oils.

The results of laboratory analysis of total PAHs in SBO determined that the concentration of total PAHs in the oil was roughly 1,000 mg/kg of oil because the samples of SBO consisted of approximately 80 to 98 percent sand. Using the conservative assumption of 80 percent sand, the concentration of total PAHs in SBO was approximately 200 mg/kg of oiled substrate. The concentration of PAHs in SBO is greater than 5 mg/kg and is high enough to suggest that terrestrial plant communities could suffer risk from exposure to SBO in the root zone. Figure 1 provides an overview of nearshore and beach samples that identify a concentration above 5 mg/kg (or 5,000 micrograms per kilogram [μg/kg]). Concentrations of

SSRBs in dunes surrounding plants would have to occur at a density of about 2.5 percent or greater to cause risk to plants. Therefore, the oil spatial distribution, with respect to potential risks to plants, was evaluated based on three criteria: (1) SBO buried in the root zone, i.e., less than 6 inches below the surface; (2) environmental monitoring data for soils having concentrations of total PAHs greater than 5 mg/kg; and (3) densities of SSRBs in the dunes greater than 2.5 percent.

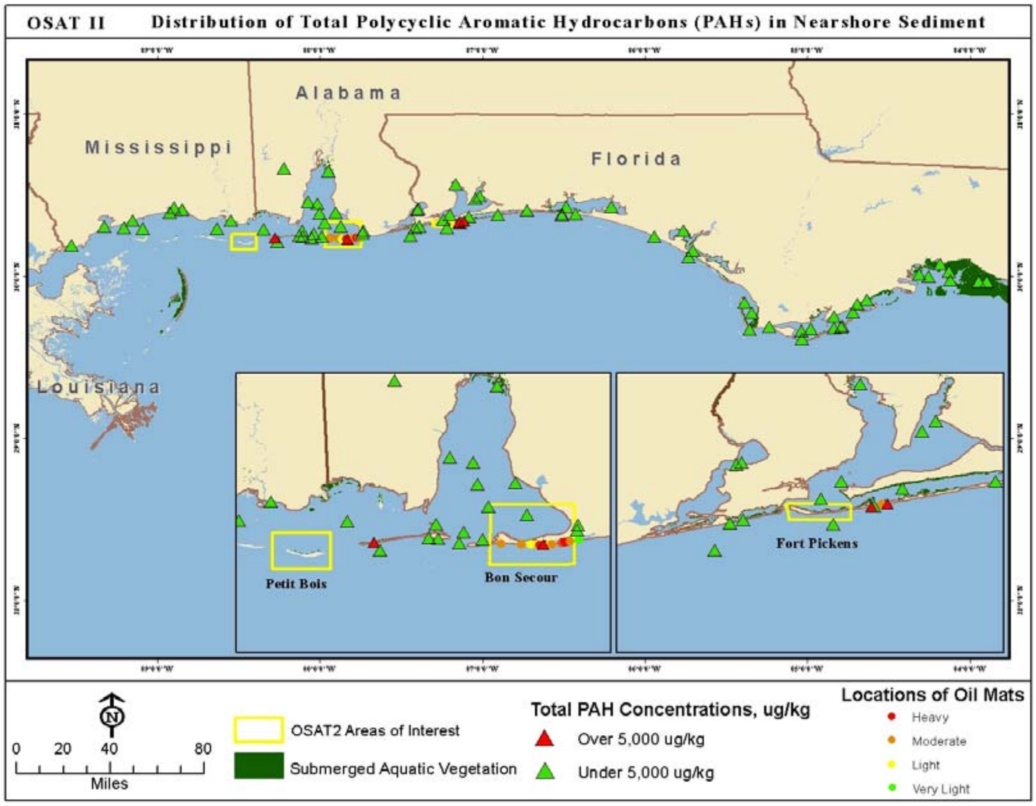

Figure 1 Distribution of total polycyclic aromatic hydrocarbons in nearshore and beach sediments.

There are multiple uncertainties in using a value for total PAHs from the Kisic et al. (2009) study. The relative proportions of different PAHs in the crude oil studied were likely different from those of MC252 oil. The Kisic and et al. (2009) work was based on fresh crude oil applied to soil to simulate the potential impact of a pipeline rupture. Because the MC252 oil had weathered, perhaps by 86 percent, before it was deposited on the beaches, the Kisic et al. (2009) study probably overestimates the toxicity of MC252 oil to plants. In addition, crops were studied by the authors instead of plants native to dunes on the Gulf Coast shorelines. Native plants may be more or less sensitive to oil pollution than the crops studied. Despite uncertainties in the application of this study to the residual oil, the conclusion still holds that in the process of oil degradation, nutrients upon which plants depend will be consumed and soil fertility will likely be reduced.

In summary, the inherent toxicity of oil directly to plants is moderate. Plants can be exposed to SBO through their roots. Plants can also be exposed to SSRBs that wash up into the dunes during storms. Plants will not likely be exposed to SOMs. Although, the spatial distribution of oil in dunes is not well known, it is anticipated some isolated areas occur where plants could be exposed to SBOs above the evaluation criteria. The risk to the terrestrial plant population is deemed low, recognizing that exposure is likely for isolated patches of vegetation.

Plant communities are quite susceptible to damage by foot traffic, digging, or raking. Experience has shown that digging up plants to remove residual oil is more damaging to plant communities than leaving the oil in place. Most vegetation will recover eventually, whether the oil is cleaned up or is left in place to degrade. Therefore, further removal for the protection of the terrestrial plant community is not recommended at this time.

Ghost Crab

The Atlantic ghost crab (*Ocypode quadrata*) is an important part of the supratidal beach community; this crab is largely nocturnal, but its burrows are plainly seen from the high tide line well into the dunes. Burrows may be up to 4 feet deep, and may be closed at the surface on hot days or during cold weather. Largely terrestrial, the ghost crab visits water only occasionally to wet its gills. This may be done on the edge of the surf, or by wicking up groundwater through capillary action set up by fine hairs on the crab's walking legs. The ghost crab feeds by scavenging and by preying on invertebrates in the swash zone; the ghost crab also preys on eggs of loggerhead turtles found by burrowing.

Ghost crabs will contact buried oil while burrowing and may contact or ingest the oil while foraging. No toxicity data are available to evaluate ingested oil or contact with residual oil in terrestrial situations. WAF data would serve as a worse case assumption to evaluate risk, based on aqueous exposure of the gills in the surf and potentially in burrows to within a few millimeters of the edge of SBO. Gill exposure in burrows requires that groundwater, buried oil, and ghost crab burrows occur together. At three case study sampling locations in the eastern spill area, groundwater is at a depth of about 3 feet below the lowest buried oil. Because these case study locations are considered representative of Mississippi, Alabama, and Florida beaches, ghost crab exposure is not likely in these States. Grand Isle, Louisiana, however, has much shallower groundwater nearer the beach surface and the groundwater interacts with the buried oil. Based on the WAF results, ghost crabs burrowing very near buried oil in saturated sand at Grand Isle may be at risk for chronic effects, although a small likelihood of encounter means the 'summed effects assessment' in the NEBA table is *low*. Recent cleanup efforts on Grand Isle will have reduced the level of risk even further.

While the Deepwater Horizon (DWH) spill may not affect ghost crabs in most locations, the crabs may have an effect on the residual oil. Potential exposure to supratidal buried oil (SBO) is possible based on frequently observed "tailings" found around burrow mouths. In fact, cleanup crews on Bon Secour NWR use such observations to locate buried oil. Also, the excavation process appears to help break up the sand-oil matrix, suggesting a role for the crabs in enhancing the weathering of oil.

Effects of oil cleanup operations on ghost crabs are unknown, but deep cleaning operations will destroy burrows, and potentially injure the crabs themselves. Also, night operations are likely to disrupt foraging.

Supratidal Invertebrates

Supratidal invertebrates consist of macroinvertebrates, meiofauna, and micro-organisms. The macroinvertebrates include insects and crustaceans, and inhabit the intertidal and supratidal zones on Gulf of Mexico beaches. Perhaps the most iconic of these is the ghost crab (*Callichirus islagrande*), as discussed previously. Meiofauna are minute macroscopic benthic invertebrates defined by their size range (0.06 - 1.0 mm in length), but more importantly, by their ability to persist in the interstitial matrix of marine and coastal sediments (Kennedy and Jacoby 1999). Meiofauna consist of representatives of at least 20 phyla of animals, and play an important role in beach food webs. Meiofauna enhance the rate of nutrient cycling in shorelines through predation and consumption of detritus produced by larger deposit-feeding invertebrates. Increasingly, meiofauna are used as indicators of pollution and shoreline management (Kennedy and Jacoby 1999). Microorganisms include bacteria, protists, and fungi – both saprophytic and mycorrhizal associates with plants such as sea oats.

Studies that focus on invertebrates in supratidal environments are sparse. Therefore, a complete risk assessment for these receptors could not be conducted for the OSAT 2 report. We can, however, use available information for the supratidal environment and extrapolate from studies of the intertidal zone, as groups, if species are common to both zones and share some similar physiological and ecological roles.

Tunnell, et. al., (1982) identified multiple factors that complicate analyses of impacts of oil spills on shoreline invertebrates. A before and after impact (BACI) survey design was implemented to evaluate effects of oil coming ashore on Texas beaches. But even while implementing a careful design, the ability to distinguish between the effects of oil, storms, natural variability and mechanical cleaning on species abundance metrics was limited. The researchers used multiple lines of evidence (other studies and professional judgment) to identify oiling as the cause of decreases in abundance of subtidal and intertidal organisms. In an analysis of the 2001 *Jessica* oil spill near the Galápagos Islands, Ecuador, a reference-impact approach was applied to evaluate intertidal invertebrates. Although no differences were seen in abundance metrics in the high intertidal, it is difficult to draw any conclusions because this study was limited by few replicates, and population and community dynamics for this community are poorly understood (Gelin, et. al., 2003). It is also important to note that effects on lower trophic levels of shoreline foodwebs were not evaluated, nor were long term community effects.

In the *Prestige* oil spill of 2002, a general decline in polychaetes, insects, semi-terrestrial crustaceans, and other taxonomic groups was observed. However, in some cases the population of some species increased. A decline of up 66.7% species richness was observed at heavily oiled beaches. The most impacted habitats included the swash zone, due to a loss of polychaetes diversity, and dry sand, where a decrease in insects and semi-terrestrial crustaceans was observed. The macroinvertebrate community in the dry sand habitat was likely more impacted by response activities of grooming and cleaning than by the heavy oiling. Fuel, polluted debris and the top centimeters of sand were removed, as well as the algal wrack that is used by the supratidal macrofauna as food and shelter (de la Huz et al., 2005). This study also concluded that community changes could not be explained by seasonal variations, pointing at the combined effect of oiling and cleanup activities.

Some of the conflicting results from these studies speak to the need to understand the chemical as well as physical (coating) effects of oil on beach organisms, and not just higher levels of ecological organization. Other factors to consider when characterizing short or long term impacts on these communities include the type of oil and its weathering state, the extent and frequency of oiling, beach geomorphology, and species assemblages.

Shoreline invertebrates can still be impacted by residual components of weathered oil. In a test to evaluate sand crabs (*Emerita analoga*) as ecological indicators, mortality increased with increased dose of oil compounds generated by a water accommodated fraction (WAF) (Barron, et. al., 1999). In another study, Sverdrup et. al. (2002), studied the effects of 16 PAHs on the survival and reproduction of a soil dwelling springtail *Folsomia fimetaria.* Results were evaluated as a function of PAH-specific molecular properties (water solubility, *n*-octanol-water partitioning). The PAHs included naphthalene, acenaphthene, acenaphthylene, anthracene, chrysene, benz[*a*]anthracene, benzo[*k*]fluoranthene, perylene, benzo[*b*]fluoranthene, benzo[*a*]pyrene, dibenz[*a*,*h*]anthracene and indeno[1,2,3-*cd*]-pyrene, fluorene, phenanthrene, pyrene, and fluoranthene. The results show that PAHs with a low to intermediate lipophilicity (log K_{OW} in the range 3.3-5.2) (i.e., naphthalene, acenaphthene, acenaphthylene, anthracene, phenanthrene, fluorene, pyrene, and fluoranthene) substantially influenced the survival and reproduction of springtail. The LC50 and EC10 values (expressed as molar porewater concentrations) show significant inverse relationships with PAH lipophilicity. For the PAHs with a log $\mathrm{K}_{\mathrm{OW}} \leq 5.2$, toxicity significantly increased with increasing bioavailability. Using this quantitative structure-activity relationship (QSAR) to calculate threshold values for the toxicity of the nontoxic substances (benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, dibenz[a,h]anthracene, benzo[a]pyrene, perylene, and indeno[1,2,3-cd]pyrene), the absence of toxicity could be explained by a limited water solubility, reducing bioavailability. Toxicity is related to concentrations in the pore water. Thus, absence of toxicity could be explained by the low water solubility of specific PAHs. Field assessments are more difficult to interpret because of the range of responses of organisms and populations. Feder, et. al., (1990) found that the abundance of harpacticoid copepods increased in oiled versus unoiled sites, and went on to identify four other studies that showed an increase in invertebrate abundance when exposed to oil and another four that show detrimental effects of oil on invertebrates. These authors suggest possible explanations for increases in copepods. These include access to a new food source (oil and associated bacteria), attraction to oil, reduction in predation, or geochemistry, with the diagenic mobilization of trace metals from the sediments. More specific understanding of the toxicology of weathered oil in the supratidal zone needs to be evaluated for organisms, populations and shoreline food webs.

Borzone and Rosa (2009) were able to conduct a BACI study based on survey work they had initiated before the accidental release of oil from the *Vicuña*, in 2004. They examined the effect of wrack removal on amphipods. Response actions were limited to a range of hand cleanups of surficial oil and wrack. At this particular site, wrack inputs are continual, therefore wrack quantities and amphipod assemblages recovered within months after the cessation of beach cleaning. This finding differs from the current Gulf scenarios, where substantial wrack inputs are less frequent and upon removal of the wrack during beach cleanup efforts, the potential for invertebrate recovery will also be limited. Just surface cleanup on beaches, then, could have broad food web ramifications for organisms that are dependent upon the wrack fauna for food. Meiofauna impacts have also been studied in response to beach cleanings. Single, surficial cleanings can have impacts on meiofaunal metrics, but these effects are usually short lived due to rapid recolonization (Gheskiere et al. 2006). Borzone and Rosa hypothesized that recolonization occurred from migration of organisms from below the cleaned sands, and led them to caution against deep sand cleaning, which could result in greater impacts to sand and sediment communities. Further, there is a high probability that broad scale manipulation of the upper 20 cm of the sand column will result in the loss of sand-dwelling organisms on the beach (A. Todaro, oral communication 2010), Llewellyn and Shackley, 1995) making recolonization a much slower process.

The dynamics of microbe-meiofauna interactions in sediments are ultimately regulated by the amounts of essential nutrients derived from detritus (Alongi 1985). Thus, the maintenance of surface and subsurface habitat structure and quality (natural distribution of shells, organic detritus, and sorted and unsorted mineral particle sizes on beaches) are important in maintaining beach ecosystem species assemblages. Although it is likely that even disturbed beyond natural disturbance levels, meiofauna (and other groups) may recolonize, the principles of community assembly dynamics indicate that recolonization may occur at variable rates and result in an ecological endpoint markedly different from the pre-disturbance state. Moreover, human-induced disturbance (e.g., beach cleaning) followed by natural recolonization increases susceptibility to biological invasion and/or loss of species diversity.

Beaches and their component resources have been injured and ecological services have been disrupted. In these situations, response decision-making should facilitate the most rapid recovery of these resources. It can be interpreted from models used in this report (little movement of chemicals from buried sources, and continued degradation of these buried sources) that toxicity concerns may be more relevant as a chronic issue. While weathered oil occupies subsurface habitat, deep beach cleaning disturbs entire communities and large volumes of habitat. Dynamics of wrack inputs are not clear, and it is not known if sufficient numbers of organisms are available or at what levels organic wrack are required for populations to re-establish. Population recovery following an oil spill and subsequent cleanup activities will depend on the life history traits of each of the key-stone species affected. Species more likely to overcome the resulting impacts include those with high fecundity, short life cycles, smaller body sizes, and efficient larval dispersal. Therefore, understanding the biology and ecology of the species comprising the supratidal community, is critical to quantifying their recovery to baseline conditions. High ecological quality reference beaches should be identified, and metrics for an acceptable range of spatial and temporal measures of invertebrates should be established and monitored to determine recovery of these communities, under all response scenarios.

Marine Mammals

Marine mammals are valued component of the Gulf of Mexico ecosystem. The most familiar marine mammal of the Gulf of Mexico is the bottlenose dolphin. Bottlenose dolphins represent a sentinel species to help predict hazard threshold levels and can serve as an early warning of potential adverse effects on public health from contaminants in the environment (American Association for the Advancement of Science (AAAS) 2010).

The objective of this section is to evaluate how likely marine mammals are to be exposed to the residual oil, and if they are exposed, what is the likely duration of that exposure, what types of adverse effects are possible, and are they likely to occur.

There is limited research on the impact of contaminants from oil on marine mammals. Much of the research involved the study of blood or skin tissues of marine mammals to assess their degree of exposure to chemicals, such as PAHs in the environment. There is limited knowledge of the potential harmful effects of chronic exposure to oil or PAHs. This risk questions were primarily answered through the review of literature on emerging science in the area of dolphin research and research on other marine mammals. Risks were assessed qualitatively due to the lack of data on the concentrations of PAHs in the diet of marine mammals and the lack of numerical threshold values for quantifying risks.

Although there was some opportunity for marine mammal contact with surface oil slicks or oil-in-water emulsions shortly after the spill, direct contact by dolphins with the three types of residual oils is currently unlikely. The main potential routes of exposure to marine mammals are through ingestion of oil-related compounds in the diet or by direct contact with submerged oil mats (SOMs) in shallow near-shore waters. Although the habitat of dolphins is mainly in the open water and not in the shallow waters, dolphins will occasionally fish in shallow waters, where SOMs have been observed. Dolphin pods fish by corralling fish up against the shore, driving them up onto the banks. It is possible, although unlikely, that dolphins could contact submerged oil mats while fishing along the shoreline in this manner. Marine mammals could potentially become exposed to contaminants in surface water released into the water through dissolution of contamination from SOMs. Soluble contaminants released from SOMs could accumulate in the fish that dolphins eat.

The West Indian manatee is present along the Gulf Coast of Florida and has been sighted along the south Texas coast (Geraci and St Aubin, 1988). The direct effects of oil exposure in manatees can only be hypothesized, as knowledge of the effects of oil on manatees is nonexistent. Manatees might come in contact with SOMs while in shallow waters, where they might encounter and ingest oil-contaminated vegetation. There is no overlap, however, between manatee habitat and locations having residual oils. Therefore, risk to manatees from the Gulf of Mexico spill is very low.

The limited amount of information available on potential effects of oil ingestion suggests that marine mammals can tolerate ingestion of small amounts of oil while feeding without acute effects. Harp seal pups experienced no acute effects when they ingested 75 mL of oil in a single dose. Ringed seals dosed orally with 5 mL of crude oil daily, for up to 5 days, cleared residues of oil from their tissues within a week. No clinical, hematological, or biochemical effects were noted in captive bottlenose dolphins dosed daily with 5 mL of machine oil for 99 days (O'Hara and O'Shea, 2001, Geraci and St Aubin, 1990, St. Aubin, 1990, Engelhardt 1983).

Species susceptibility to effects of oil spills can be far more subtle than immediate mortality and other obvious health-related effects (S. Johnson, personal communication as cited in Bejarano 2010). The degree of risk may depend on health status of the population, distribution of the population relative to exposure, and lifestyle factors, such as, foraging behavior and migration patterns. Exposure-related variables, such as exposure route, duration, and oil properties, also come into play (S. Johnson, personal communication as cited in Bejarano 2010).

The largest source of exposure to marine mammals is through the diet. Petroleum hydrocarbons can accumulate in the tissues of prey organisms. Some benthic invertebrates, such as clams and worms, can accumulate petroleum hydrocarbons in their tissues. Fish, and to a lesser extent, crustaceans, however, metabolize and excrete hydrocarbons and so rarely become heavily contaminated (Aubin 1992).

Therefore, marine mammals, such as dolphins, that feed at the top of a food chain are less likely to ingest oil-contaminated food than organisms that feed on clams, worms, or zooplankton at the base of the food chain.

When dolphins are exposed to contamination in the marine food supply, some of the contaminants may accumulate in their tissues. While marine mammals have mixed function oxidase enzyme systems that can detoxify and eliminate PAHs, studies of PAH residues in the tissues of marine mammals have shown that dolphins do accumulate PAHs in their blubber. Effects of the low concentrations accumulated are poorly understood. Dolphins accumulated a median concentration of 29,500 ppb total PAHs in blubber (fresh weight) in a study of free-ranging Mediterranean dolphins (Marsili et al. 2001). An average concentration of 3,010 ng/g lipid was found in the blubber of Charleston Harbor, South Carolina dolphins, while an average concentration of 1,316 ng/g lipid was found in the blubber of Indian River Lagoon, Florida dolphins (Fair et al. 2010). All of the PAHs measured in the U.S. East Coast dolphins were naphthalene or alkylated naphthalene homologs. This fraction is not a substantial portion of the SOM sampled as part of the OSAT-2 study.

Exposure to PAHs from petroleum pollution has been linked to chronic diseases or adverse changes in health or reproductive fitness. Cytogenic, genotoxic, immunotoxic, and carcinogenic effects have been correlated with high PAH levels (National Research Council of Canada (NRCC), 1983). PAHs with more than 4 rings can cause dioxin-like and weak estrogenic responses in mammals (Vrabie et al. 2011; Villeneuve et al., 2002). Necropsies of beluga whales indicated that belugas from the St. Lawrence estuary die younger and strand dead more often than beluga from northwest Alaska. About 18 percent of stranded belugas studied had died from cancer. Higher rates of cancer in belugas were observed in populations in the St. Lawrence and were attributed in part to accumulation of the carcinogenic PAH, benzo(a)pyrene, in the benthic invertebrates in the belugas' diet (Martineau et al. 2002). Beluga whales from Cook Inlet, Alaska, had levels of PAHs in their tissues high enough that scientists could not rule out chemical contamination as a potential factor limiting recovery of populations (Reynolds and Wetzel 2010). Long term ingestion of oil or contaminated prey may lead to organ damage or hormonal disruption (Engelhardt 1987; Fair and Becker 2000). Exposure to PAHs may also increase a marine mammal's susceptibility to disease by damaging the immune system (O Shea et al. 1999; Neale et al. 2005). Compounds produced by metabolism of PAHs within the organism may also accumulate and induce toxic effects (Brunstrom et al., 1991). Consequently scientists who study the effects of oil exposure on marine mammals are moving away from studying short-term acute exposures and are beginning to appreciate long-term effects on populations experiencing compromised health through a combination of chronic chemical exposure and environmental stress (Reynolds and Wetzel 2010).

In summary, the inherent toxicity of oil to marine mammals is low. Marine mammals can possibly be exposed to SOMs through direct contact during feeding behavior, although this exposure is expected to be *de minimis*. The potential for exposure to SOMs though indirect means through the food chain is low. Marine mammals are unlikely to be exposed to SSRBs and by definition will not be exposed to SBOs. The degree of exposure to marine mammals will depend on the spatial extent of SOMs. The primary uncertainty in the evaluation is the inability to assess the degree to which dolphins might be exposed to chemicals released from the SOMs through accumulation in the diet and the inability to link dietary exposures to subtle changes in health. Manatees are unlikely to be exposed to oil from the spill because their habitat is mainly in Florida outside of the spill-impacted area. It not expected that any further remedial action will have a substantial impact on marine mammals.

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