Deepwater Horizon Sand Beach Injury Assessment Technical Report

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Table of Contents

List of Figures

List of Tables

ABBREVIATIONS AND ACRONYMS

BLM	Bureau of Land Management
BMP	Best Management Practices
BOP	Buried Oil Program
cm	centimeter
cy	cubic yard
DOD	Department of Defense
DWH	*Deepwater Horizon*
ft	feet
GOM	Gulf of Mexico
km	kilometer
LAASR	Louisiana Augering and Sequential Recovery
LDWF	Louisiana Department of Wildlife and Fisheries
NRA	Natural Resource Advisor
NRC	National Response Center
NWR	national wildlife refuge
OPS	Incident Command Operations Section
P&M	Patrol and Maintenance
RAT	Rapid Assessment Team
READ	Natural Resource Advisor
SCAT	Shoreline Cleanup Assessment Technique
SCCP	Shoreline Cleanup Completion Plan
SIR	Shoreline Inspection Report
SOM	submerged oil mat
STR	Shoreline Treatment Recommendation
SWR	state wildlife refuge
USCG	U.S. Coast Guard
USDOI	United States Department of the Interior
USFWS	United States Fish and Wildlife Service
UC	Unified Command
UTV	utility vehicle

Sand Beach Injury Assessment

1.0 INTRODUCTION AND OBJECTIVES

The *Deepwater Horizon* oil spill (DWH) resulted in the oiling of approximately 600 miles (965 kilometers) of sand beach habitat extending from Florida to Texas (Figure 1; Nixon et al., 2015). Oil first began stranding in May 2010, with shoreline cleanup beginning shortly thereafter. Because oil stranding occurred in discontinuous waves over a period of months, oil became incorporated into the sediments in the supratidal, intertidal, and nearshore subtidal habitats adding to the complexity of the cleanup. This oil distribution and burial required the shoreline cleanup led by the DWH Unified Command (UC) to employ various mechanical and manual treatments to remove oil and to establish specific cleanup endpoints for amenity and non-amenity beaches based on the techniques used. All shoreline cleanup endpoints were defined as the maximum amount of confirmed oil from the DWH spill (MC-252 oil) allowed remaining in the beach habitat. Shoreline cleanup endpoints for amenity beaches in Florida, Alabama, and Mississippi include "no visible MC-252 oil" either on the surface or in the subsurface; in Louisiana, the endpoint for subsurface oil is different: no visible oil above stain. On non-amenity beaches, shoreline cleanup endpoints varied by region and management status but generally include: 1) no oil or oiled debris >1% in distribution on the surface (and no surface residue balls >5 centimeters [cm] in Mississippi, Alabama, and Florida); and 2) no subsurface oil exceeding 3 cm in thickness and patchy (50%) distribution that is greater than oil residue.

As of June 2013, active response operations were deemed complete for the shorelines in Florida, Alabama, and Mississippi. In Louisiana, the active response operations were deemed complete except for six segments on 15 April 2014. Cleanup operations in Texas were completed much earlier, by August 2010. Once a shoreline segment is moved out of response, the U.S. Coast Guard (USCG), states, and BP established a program that was called "Middle R." Under this program, any oil that strands onshore is reported to the National Response Center (NRC), and the USCG sent out an inspection team to determine the oil source (either visually or through chemical fingerprint analysis of a sample). If the oil was determined to match the MC-252 oil and the amount was too large for the USCG team to remove during their inspection, a notice was sent to BP to conduct cleanup; if the oil was not matched to the MC-252 oil, an oil spill response organization under contract to the USCG was called out to conduct cleanup. In late February 2015, the USCG Gulf of Mexico Incident Command Team transitioned from Operations to Documentation, with responsibility for responding to NRC reports of oil on the shoreline returned to USCG Sectors Commanders in the region (Nolan, 2015).

To meet the cleanup endpoints, the response conducted a wide range of shoreline treatment methods as allowed under Shoreline Treatment Recommendations (STRs) that included stringent guidelines, including Best Management Practices (BMPs) and close monitoring to minimize adverse impacts. However, even when the BMPs outlined in the STRs were adhered to, significant impacts to sand beach habitats and their ecological services and functions occurred. Response actions or treatments have directly and indirectly impacted the animals and the habitats that they rely upon for breeding, feeding, and resting, as well as the human users of these habitats. These adverse effects are commonly referred to as response injury and are separate from injury due to oil exposure.

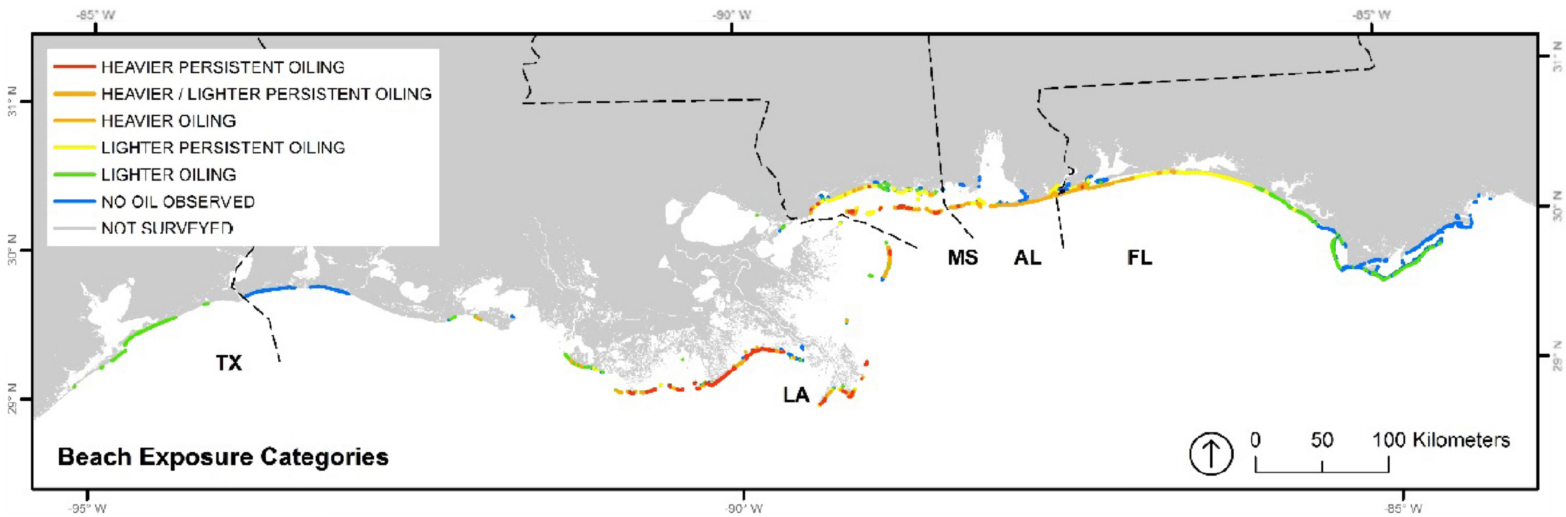

Figure 1. Map of the maximum oiling category for all beaches affected by the DWH oil spill (Nixon et al., 2015).

This assessment was conducted to provide a measure of the extent, degree, and duration of these adverse impacts associated with both oil exposure and response activities on sand beaches affected by the DWH oil spill.

Response-related injury that has and is affecting the sand beach habitats can be divided into the following general categories:

- Shoreline Treatment: Manual and mechanical activities required to remove oil from sand beaches, including staging areas, access areas, vehicular traffic, and other types of disturbances, in addition to sand cleaning and removal of oiled sediments and debris; and
- Shoreline Protection: Installation, maintenance, and removal of a wide range of types of physical barriers constructed to prevent oil from entering more sensitive habitats along sandy shorelines.

In the following sections, the types of injuries to sand beach habitats, the methods and data sources to define and assess these injuries, and the results are briefly described and summarized.

2.0 EXPOSED SAND BEACH HABITATS

2.1 Exposed Sand Beach Structure and Services

Approximately 70% of the land-sea margin globally and the predominate portion of the land-sea margin in the northern Gulf of Mexico (GOM) consists of exposed sand beaches (Rakocinski et al., 1991; Dugan et al., 2010). This generally narrow (<1 km), but ubiquitous landform supports a diverse, but cryptic, biological community that, along with the physical structure of the beach, provides an array of ecosystem services, some of which are widely recognized and exploited commercially, some of which are not.

Exposed Gulf sand beach habitats generally consist of the following components, from the highest to the lowest elevations (Figure 2):

- Supratidal Zone – above spring high tides, divided into sub-components
  - Vegetated dunes – Usually dunes are <4 meters (m) in elevation and composed of fine sand. They can range widely in vegetation density and species; the vegetation type and age are good indicators of the time since the last erosional event. There was strict enforcement of best management practices (BMPs) that prohibited entry into or disturbance of vegetated dunes during the response by cleanup workers and equipment.
  - Washover fans – Low areas between dunes where storm waves have overtopped the island and deposited sand in a fan-shaped area on the back side of the island, often into the backbarrier marsh. These habitats often include a lot of shell material, especially on the surface where the shell accumulates as a lag deposit (where the finer-grained sand is removed by wind erosion).
  - Unvegetated backbeach – High, flat surface that is above spring tides but affected by "normal" storm waves that prevent the formation of mature dunes. There may be incipient dunes forming in the lee of wrack deposited during recent storms. Annual vegetation can be present but sparse; perennial vegetation may be taking root in the incipient dunes.
- Beach face – A relatively steep zone between spring high and low tidal levels. It is often divided into three intertidal zones by dividing the tidal range into thirds: upper, middle, and lower beach face. This part of the beach is exposed to daily inundation by the tides and reworking by wave action. Grain size varies from fine- to medium-grained sand. Shell fragments tend to be coarser but minor components of the sediments.
- Low-tide terrace – A gently seaward-sloping surface at the toe of the beach that is composed of fine-grained sand. Often, this terrace is only exposed during spring low tides or meteorological low tide events.

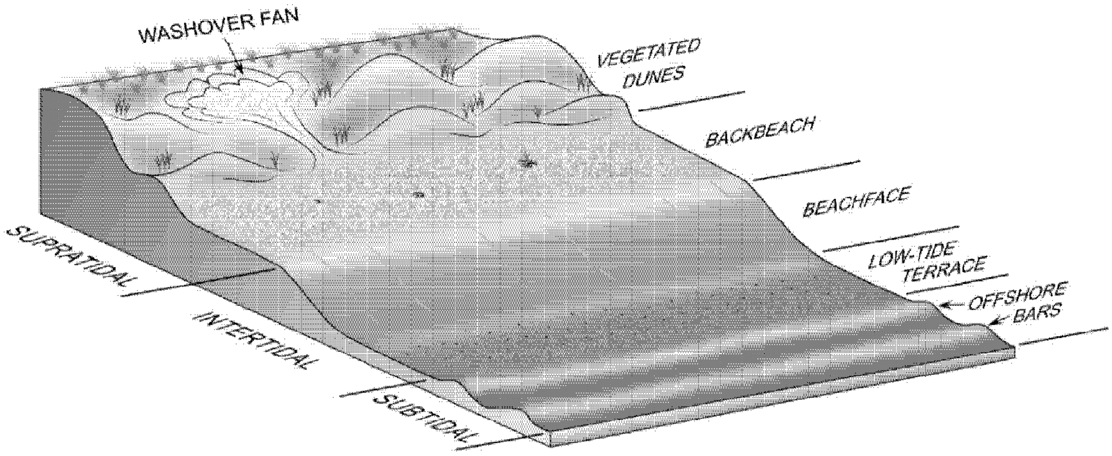

Figure 2. Components of sand beaches in the north-central Gulf of Mexico.

The list of recognized services provided by sand beaches includes: (1) resource mining (sand); (2) recreation (e.g., sunbathing, swimming, bird watching, surf fishing); (3) shoreline protection and storm mitigation; (4) groundwater filtration; (5) nutrient recycling; and (6) carbon (C) transfer from primary producers and decomposers to species of broad public interest, such as birds and fish (Nel et al., 2014). All of these services can be altered, diminished, or destroyed by oiling of the beach. For example, Engel and Gupta (2014) suggest that dramatic increases and persistence in the abundance of hydrocarbon-degrading bacterial species in sand beach microbial communities has altered the pre-spill microbial community structure while providing a new beach service - hydrocarbon degradation. It is not clear how the observed changes in the microbial community would affect nutrient cycling in the beach (service #5 above).

2.2 Threatened and Endangered Species Associated with Sand Beaches

Sand beaches in the north central GOM provide habitat for the following species that are listed as either threatened or endangered under the Endangered Species Act:

- Loggerhead (*Caretta caretta*) – Endangered
- Kemp's ridley *(Lepidochelys kempii*) – Endangered
- Green (*Chelonia mydas*) – Threatened except the Florida breeding population which is listed as endangered
- Leatherback (*Dermochelys coriacea*) – Endangered
- Hawksbill (*Eretmochelys imbricata*) – Endangered
- Perdido Key beach mouse (*Peromyscus polionotus trissyllepsis*) – Endangered
- Alabama beach mouse (*Peromyscus polionotus ammobates*) – Endangered
- Choctawhatchee beach mouse (*Peromyscus poliontus allphyrys*) – Endangered
- St. Andrews beach mouse (*Peromyscus polionotus peninsularis*) – Endangered
- Piping plover (*Charadrius melodus*) – Threatened throughout the winter range
- *Rufa* Red Knot (*Calidris canutus rufa*) – Threatened through its range

In addition, the Santa Rosa beach mouse (*Peromyscus polionotus leucocephalus*) is listed by the state of Florida as a species of special concern.

All sea turtles lay eggs on tropical or semi-tropical sand beaches. Sea turtle nesting occurs along ~229 miles of Florida Panhandle beaches (Escambia County through Franklin County) and on 47 miles of Alabama beaches (Mobile County and Baldwin County). There are no recent reports of sea turtle nesting in Louisiana and Mississippi; however, beaches in these states are known to have nesting by loggerhead turtles (Dow et al., 2007). In the north central GOM, nesting and hatching season extends from late April through early November. Thus, shoreline treatment following the DWH oil spill has spanned at least three sea turtle nesting periods. All nesting occurs at night, and a significant reduction in sea turtle nesting activity has been documented on beaches illuminated with artificial lights (Witherington, 1992), which were commonly used by response operations. Nighttime activity and physical barriers can deter females emerging onto a beach to nest as well.

All subspecies of endangered beach mice have a very limited distribution (Wetlands Science, Inc., 2014). The range of the Alabama beach mouse extends from Gulf State Park to Fort Morgan, though their habitat is highly fragmented. The U.S. Fish and Wildlife Service designated Critical Habitat for the Alabama beach mouse on 30 January 2007 (72 FR 4330). The Perdido Key beach mouse exists throughout private and public lands on Perdido Key, an island that straddles the Alabama and Florida state line. The Choctawhatchee beach mouse occurs in Okaloosa and Walton counties, and the St. Andrew beach mouse occurs in Bay and Gulf counties, all in Florida. Critical habitat for the Perdido Key beach mouse, Choctawhatchee beach mouse, and St. Andrew beach mouse was designated on 12 October 2006 (71 FR 60238).

Beach mice burrow in the dunes and scrub behind the beach. They have been observed foraging on debris in the wrack line. They are nocturnal, feeding at night primarily on seeds and insects. Their foraging behavior can be altered as a result of artificial lights, thus rendering otherwise suitable habitat unusable (Bird et al., 2004). In fact, they most often feed during dark, stormy nights, and reduce feeding forays by up to 70% during full moon (Wolfe and Summerlin, 1989). Thus, like nesting sea turtles, they would be greatly disturbed by nighttime operations.

In a separate study, Wetlands Science, Inc. (2014) determined that direct impacts affected 0.58 acres of beach mouse habitat through loss of dune vegetation related to response actions; and indirect impacts affected 98.98 acres of beach mouse habitat due to increased human activity, increased night-time lighting, use of heavy equipment, and beach driving.

Piping plover are small shorebirds that winter along the Gulf coast, arriving as early as late July and departing as late as the following April. Thus, they spend most of their life history in their "wintering" (more appropriately referred to their non-breeding period) grounds. Studies have shown very high site fidelity and small ranges (usually just a couple of miles) for where they spend their non-breeding period (Drake et al., 2001; Johnson and Baldassarre, 1988). They prefer to loaf and feed on sand beaches, thus the long-term and continuous disturbances during shoreline treatment are of particular concern for this species, with an estimated population of less than 3,000 pairs (http://www.fws.gov/plover/facts.html).

Red knots are small shorebirds that migrate annually between breeding grounds in the Canadian Arctic and several wintering regions, including the southeast U.S. and the northeast GOM. During both the northbound (spring) and southbound (fall) migrations, red knots use key staging and stopover areas to rest and feed. This life history strategy makes this species inherently vulnerable to changes in the timing of quality food and habitat resource availability. Red knots long-distance migrants that must take advantage of seasonally abundant food resources at migration stopovers to build up fat reserves for the next non-stop, long-distance flight. Red knots are specialized molluscivores, eating hard-shelled mollusks, sometimes supplemented with easily accessed softer invertebrate prey, such as shrimp- and crab-like organisms, marine worms, and horseshoe crab eggs (USFWS, 2013).

3.0 SAND BEACH OIL EXPOSURE CATEGORIES

Sand beach oiling exposure categories were developed as described in Nixon et al. (2015). Briefly, the primary source of the shoreline was the shoreline data developed specifically for the DWH incident by the SCAT Program and used to reference SCAT data. In locations where no SCAT surveys had been conducted, the shoreline data were supplemented from the U.S. Geological Survey National Wetlands Inventory (NWI) data or National Oceanic and Atmospheric Administration Environmental Sensitivity Index (ESI) vector shoreline data. For some locations in Louisiana, shorelines were digitized from USGS 2008 4-band 1-m imagery. Vector line data from all these sources were manually compiled and edge-matched. This shoreline was segmented based upon any pre-existing shoreline divisions including SCAT segment ID, operational zone ID, state, and Federal lands.

Surface shoreline oiling degree was primarily derived from the DWH SCAT Program as part of DWH response operations (Michel et al., 2013) with additions from NRDA field data. For Texas, data collected by the Rapid Assessment Teams in the state of Texas were included.

All available observational subsurface oiling data collected by the DWH SCAT Program and by operational cleanup teams in the field were compiled. These data consist of points with attributes describing subsurface oiling conditions collected between May 8, 2010, and March 25, 2014 across the potentially impacted areas within the states of Florida, Alabama, Mississippi, and Louisiana. An additional source of surface and subsurface information is operational material removal mass data collected by operational cleanup teams in the field and maintained by the response. These data consist of monthly counts of cleanup visits, and monthly material removal mass estimates in pounds from 947 operational zones. These data were collected between June 2011 and February 2014 in the states of Florida, Alabama, Mississippi, and Louisiana. Data on volumes of material removed per segment before June 2011 are not currently available, though there are data on total amount removed by state or sometimes by operational division. Because the number of sorties per operational zone and the size of operational zones may vary widely, the total mass in kilograms (kg) removed per kilometer of shoreline per month and for the entire response within each operational zone was computed.

Sand beach oil exposure categories were defined as shown in Table 1, collapsing all categories in Figure 1 into two: heavier and lighter. For subsurface oiling, it was assumed that heavier subsurface oil was likely to have been present, sequestered in the subsurface, since the time oil initially came ashore. To reflect this, the maximum subsurface oiling descriptor for any given month was assigned to all previous months back to the month of initial oiling. Table 2 shows the results of this work, totaling the km of shoreline oiling by the two sand beach oiling categories.

Table 1. Simplified oiling categories used in constructing oiling time series and criteria used to define them for surface oiling, subsurface oiling, and operationally material removal mass.

Oiling Category	Surface Oil: Original category	Subsurface Oil: Cumulative % oiled pits	Operational Removal: kg per km
Lighter	Trace, Very Light, or Light	>0 and <30%	>4 and <10,000 kg
Heavier	Moderate or Heavy	> 30%	> 10,000 kg

Table 2. Miles of shoreline oiling of sand beaches by oil exposure classes and state. Note that miles have been rounded to nearest whole digit and may not total exactly. Summarized from Nixon et al. (2015).

Exposure Category	Lighter Oiling Miles	Heavier Oiling Miles	Total Oiled Miles
FLORIDA	139	38	176
ALABAMA	41	44	84
MISSISSIPPI	86	36	121
LOUISIANA	63	119	182
TEXAS	35	0	35
TOTALS	364	236	600

To determine acres of sand beach habitat, the widths of segments were measured as described in Appendix A.

4.0 SAND BEACH RESPONSE INJURY

Assessment of sand beach response injuries was conducted as follows. First, the shoreline treatment methods used on sand beaches were characterized, and the types of impacts resulting from the use of these methods described. Second, Response Injury impacts based on the expected degree of reduction in ecological services for each type of response method were developed. Third, all available data on shoreline treatments conducted along each sand beach segment within the response were compiled.

4.1 Sand Beach Treatment Methods Assessed

Shoreline treatment consisted primarily of two methods:

Manual Removal, consisting of the following types of activities:
- Surface removal by shovels, rakes, and other hand tools to 6 inches
- Deep removal of oiled sediments that were > 6 inches deep, often using mechanical removal of clean overburden
- Could be conducted daily or under a set frequency (e.g., three times per week bi-weekly) as part of the Patrol and Maintenance (P&M) schedules in STR S4s.

Mechanical Methods, including the following types of equipment and techniques:

- Beach Cleaners and Sifters to depths as great at 18 inches
- Excavators to depths as great at 48 inches
- Tilling
- Augering (for assessment of buried oil and in combination with removal actions)
- Dredging/Surf Washing

All treatment methods involved vehicular traffic on most beaches, and most operations removed or disturbed the wrack for periods of months to years. Response operations increased the human presence in areas where public use is normally not allowed or highly restricted. The different types of manual and mechanical removal methods and equipment, and the associated impacts, are described below.

4.1.1 Manual Removal

Manual removal methods ranged from highly intrusive removal of deeply buried oil to P&M of surface oil on regularly scheduled shoreline visits, using hand tools such as shovels, rakes, sifters, scoops, and nets. It included screening of sand to remove oiled particles using various types of screening devices. In the Eastern States, manual removal was usually limited to the upper 6 inches; in Louisiana, manual methods were used to remove deeply buried oil layers, after mechanical removal of the clean overburden. Manual removal could also include mechanical equipment for hauling of oiled sediments. Figure 3 shows examples of the range of manual methods used during the *Deepwater Horizon* response on sand beaches.

Figure 3. Manual removal methods. Top left: Manual removal of buried mats after mechanical removal of clean overburden, Grand Terre II, LA, 15 Dec 2010. Top right: Manual removal/sifting to 6 inches at Ft. Pickens, FL, 20 Jan 2011; Bottom left: Manual removal at Topsail Beach, FL on 16 Jan 2011. Bottom right: Manual removal on Petit Bois Island, MS, 13 Feb 2011. Photos courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

During manual treatment, it was assumed that there would be 100% loss of biota in sediments physically removed or sifted. During active treatment within a segment, crews would work that segment for multiple days; during P&M treatment, crews would walk through the segment at the assigned frequency, recovering any visible oil. Thus, there would be a difference in the degree of wildlife disturbance between nearly continuous operations in a segment each day, for multiple days, versus periodic transits. Natural Resource Advisors (NRAs or READs) were assigned to all treatment operations, to document compliance (or non-compliance) with the BMPs that were part of the STR. However, following the BMPs only somewhat reduced the impacts to the wildlife and habitats. Crews working on the shoreline disturbed birds, sea turtles, beach mice, and other wildlife, removed sand, wrack, shell, and other materials from the shoreline, and used utility vehicles (UTVs) to transit to the work segments and haul materials and wastes. Traffic corridors were established to avoid the most sensitive habitats; however, these corridors were very heavily trafficked over long periods of time. The intensity and duration of manual removal operations, conducted on hundreds of miles of contiguous sand beaches, resulted in significant disturbances to sand beach habitats and the wildlife that rely on these habitats for food, shelter, and nesting. It is noted that the added effects of some disturbances would be less on amenity beaches because they have more frequent human activity leading to similar types or levels of disturbance.

4.1.2 Mechanical Removal

Beach Cleaners and Sifters

Beach cleaners varied from small, walk-behind "Sandman" units that were similar to lawnmowers in size, to mobile sand cleaning equipment such as the self-propelled Cherringtons and towed Sand Shark and Beach Tech (Figure 4). Most of the towed and self-propelled equipment were capable of excavating down to 18 inches. Oiled debris and sediments were lifted onto conveyors or by other means to feed the sediment through screens of various sizes to filter out the larger, more consolidated oil/sediment particles. The mobile beach cleaners were driven or towed along the beach, either scraping the sand surface to recover surface oiled sediments, or sifting the sand through on-board screens to separate clean sand from the oil particles. The machine(s) would work back and forth until the entire treatment area was covered. Often, the entire dry beach, from the high-tide line to the base of the dunes, was sifted. During the warmer months of 2010, operations were often conducted at night when the oil/sediment particles were cooler and less likely to break up when passing through the screens (Figure 5). Multiple beach cleaners would be lined up, side-by-side, and work a large part of the supratidal zone simultaneously, thus disturbing a wide extent of the sand beach habitat.

Night operations and lighting would affect nocturnal animal behavior, both large and small. Sea turtles come ashore to nest at night and are readily disturbed by such intensive activity. Ghost crabs are largely nocturnal, feeding at night to avoid predators. Many of the small fauna that live under the wrack, such as beetles, amphipods, and insects, are also nocturnal for the same reasons.

Where the subsurface oil was deeper than the operating depth of the mobile beach cleaners (usually 12 inches, but as deep as 18 inches), a different set of equipment and methods was used. Under operations called "Deep Clean" or "Big Dig," stationary sifters such as Power Screens were used extensively for this type of deep cleaning. The types of equipment and processes to treat the deeply buried subsurface oil by sifting are shown in Figures 6-8. This process involved

Figure 4. Mobile beach cleaning operations. Top left: Cherringtons in sifting mode on Grand Isle, LA on 13 Nov 2010. Top right: Four Sand Sharks at Ft. Pickens State Park, FL running in tandem and sifting to 18 inches on 20 Feb 2011. Bottom row: Trench dug and screened oil particles and shell by the Sand Shark at Ft. Pickens State Park, FL on 8 Jan 2011. Photos courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

Figure 5. Mobile beach cleaning night operations. Summer 2010. Photos courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

Figure 6. The "Deep Clean" Operation along the Alabama beaches on 13 Jan 2011. Top left: Long-arm excavators were used to dig down to 4 feet to excavate the oiled sand, stockpile the sand to allow it to dry, then feed it into a screening machine. Top right and lower left: the screened material included both oil/sand particles and shells. Photos courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

Figure 7. Powerscreening operations. Top left: "Big Dig" sifting operations at Pensacola Beach, FL on17 Dec 2010. Top right: Operation "Deep Clean" on West Point Island, AL on 15 Dec 2010. Bottom left: Sifting of piles created by Cherringtons on Grand Terre II, LA on 30 Oct 2010. Bottom right: Sifting operation on Dauphin Island, AL on 14 Feb 2011. Photos courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

Figure 8. Use of excavators. Top left: Excavation of oil mats at Elmers Island, LA on 2 December 2010. Top right: Wet screening of sediments during mat removal at Elmers Island, LA on 7 December 2010. Bottom left: Oil mat removal at Little Lagoon, AL on 13 January 2011. Bottom right: Re-grading of the beach surface after mat removal at Elmers Island, LA on 3 December 2010. Photos courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

excavation of sand in trenches to 3+ feet by a separate piece of equipment, usually a long-arm excavator. The excavated sand had to be stockpiled and dried prior to sifting, resulting in desiccation of animals that normally live in wet sand. The excavations were so deep and quick that most animals would not be able to escape by digging deeper. Any natural wrack materials were moved aside, making it unavailable to shorebirds for feeding.

It is assumed that there was 100% removal and mortality of animals that were larger than the screen size, which varied from 6-25 millimeters (0.2-1 inch). Even for smaller animals, it is likely that there was 100% crushing mortality as the screens agitated the sand through the openings. The screens also removed all of the shell and other natural materials that were larger than the screen size; these materials are important components of the sand beach habitat. For example, Maslo et al. (2011) found that the presence of shells at any coverage was attractive to nesting plovers and most nests were found in areas that had 1-20% shell cover. In fact, they recommended that beach-grooming activities should be eliminated on beaches used by plovers for nesting, and in backshore areas where shells or gravel are lacking, that shells should be added prior to the birds' arrival on the breeding grounds.

Changes in sediment compaction during sifting, excavation, and replacement can increase beach erosion potential, because it increase the drag coefficient, which is one of the key factors in calculating the shear velocity, which affects the rate of aeolian sand transport (Dingler et al., 1992). Aeolian sand transport is an important factor, particularly in Louisiana where the barrier islands have low relief and only partial vegetation of the dunes. Dingler et al. (1992) measured 1.26 m^3/m of sand transport on Trinity Island, Louisiana during four days of strong northerly winds during the passage of a cold front, causing erosion of the backbeach and accretion at the beachface.

The areas around the sifters became heavily trafficked, compacted, almost industrial sites on the shoreline. As can be seen in Figure 6, the operation of stationary sifting involved extensive supporting equipment and vehicular traffic. Compaction increases the bulk density of the substrate, and reduces the interstitial space thereby reducing the capillarity, water retention, permeability and the exchange of gases and nutrients within the substrate matrix (USACE, 1989; Defeo et al., 2009). When moving, vehicles also produce shear forces that can have substantial direct and indirect effects on the fauna and sediment stability. Numerous researchers have documented that vehicle traffic compacts and shears beach sand (to 20 cm deep) and loosens the surface of the beach, thus rendering it more susceptible to aeolian erosion (e.g., Anders and Leatherman, 1981; van der Merwe and van der Merwe, 1991). Vehicle traffic also decreases the rate of decay of organic material by reducing bacterial counts when vehicles pulverized the organic deposits (Leatherman and Godfrey, 1979). During response actions on the heavily trafficked beaches, there was intense disturbance of animals such as birds, sea turtles, beach mice, and ghost crabs.

Once the sand was sifted, bulldozers, excavators, and other heavy equipment were often used to load the sand into dump trucks for hauling back to the excavation site. The upper shoreline became a heavily travelled corridor, where any animals were crushed and dune vegetation prevented from taking root. Bulldozers or other equipment would be used to dump the sand back on the shoreline, spread the sand into the excavated areas, and smooth the beach to its original contour, crushing and burying any animals that had re-occupied the excavation site. The overall impacts of the use of mechanical equipment for sediment excavation and redistribution can be translated into reduced substrate productivity and microhabitat suitability, as Lindquist and Manning (2001) documented on beaches where bulldozing was used to for erosion control.

Furthermore, it would take some time for the sand to return to its pre-excavation and sifting density, particularly for sand placed above the intertidal zone because wave action is the main mechanism by which sand becomes compacted on the shoreline. This change in sediment density would affect burrowing animals such as nesting sea turtles and ghost crabs. Lindquist and Manning (2001) evaluated the impacts of beach nourishment and mechanical redistribution of beach sand (bulldozing) on dominant intertidal macroinvertebrates and found significant declines in the abundance of ghost crabs 6 to 8 months post-bulldozing. Possible explanations for this decline included the substantial changes in the sand composition, which likely impeded the formation of stable burrow structures.

Excavators

Excavators were used on sand beaches to remove large volumes of oiled sediments for disposal, sifting, or wet screening. Figure 8 shows examples of beach treatment operations using excavators, usually long-reach, tracked excavators with solid or screened buckets. The oiled sand removed for off-site disposal was permanently lost from shoreline habitats, and 100% of the animals in these sediments would be lost as well. Injuries and losses from dry sifting are described above. During wet screening, the bucket on the excavator was modified to include a screened bottom, and the scoop of sediments would be rinsed in the surf zone, with the finer clean sand passing through the screens and the larger oil/sediment particles being retained. Wet screening was used both for sediment excavated from the intertidal zone, then rinsed in shallow water, as well as sediment dug from under water farther offshore.

Excavators were also used to remove clean overburden for either manual or mechanical removal of the underlying buried oil layers. The stockpiled, clean sediments would dry out, resulting in crushing and desiccation of animals that normally live in wet sand as previously discussed.

The type and degree of sediment disturbance and biological effects resulting from excavation, stockpiling, and re-distribution during treatment of sand beaches during the DWH oil spill can be equated to the sediment disturbance during beach nourishment projects. Bilodeau and Bourgeois (2004) evaluated the impacts of beach nourishment projects on the ghost shrimp, *Callichirus islagrande,* at two barrier islands of the Isles Dernieres chain of Louisiana (East and Trinity Islands). Two and a half years post-nourishment, these beaches did not have the large densities of ghost shrimp seen at reference sites within the chain of islands, which had generally well-established populations. Only a few juveniles and one ovigerous female were found, indicating that the population did not show any signs of recolonization or recruitment. The lack of recolonization was attributed to changes in the sediment composition.

Peterson et al. (2000) found that both beach nourishment and bulldozing had quantifiable effects on intertidal species 5-10 weeks post treatment compared to control beaches. Nourishment activities reduced the density of two dominant species, mole crab and bivalve mollusks (*Donax* spp.) by 99% and 86%, respectively, possibly by altering the composition of the substrate;

whereas bulldozing reduced the abundance of mole crabs and ghost crabs active burrows by 37% and 65%, respectively, probably by changing the beach morphology enough to reduce the habitat suitability for intertidal macroinvertebrates.

Sand beach nourishment projects on the eastern Atlantic have also shown impacts on dominant members of the intertidal community (Peterson et al., 2000; Lindquist and Manning, 2001; Peterson et al., 2006; Peterson et al., 2013) and that these impacts can persist for years after nourishment (Manning et al., 2014; Peterson et al., 2014). As previously discussed, Lindquist and Manning (2001) found significant declines in the abundance of ghost crabs 6-8 months post-bulldozing. Possible explanations for this decline included the substantial changes in the sand moisture and composition, which likely impeded the formation of stable burrow structures; and/or the timing of the bulldozing (mid-November to March), which may have caused direct mortality through burying as these activities coincided with the season when crabs are permanently below ground.

Tilling

Tilling was conducted extensively in Louisiana (Figure 9), including:

- On much of Grand Isle outside of the Grand Isle State Park in 2010 and 2011;
- Elmers Island (11-18 July 2012, where about 57,000 square feet (ft^2) of supratidal zone at the base of the dunes were tilled);
- South Spit at South Pass in 2010/2011 (tilling proved ineffective at oil removal, thus this area was subsequently dredged); and
- Garden Island, on the north side of South Pass.[1]

Figure 9 shows various tilling equipment and operations used to recover oil from sand beaches. On sand beaches where significant quantities of oil had become deeply buried, harrows were used to bring up the deeply buried oiled sediments to the surface. Mobile shifters such as the Cherrington were then used to remove the exposed oil and sediments. However, harrows and tillers were more commonly used on beaches as a secondary treatment after other treatments to break up the remaining oiled sediments into smaller pieces to speed microbial degradation. Most equipment could reach depths of 18 inches.

Because tilling completely mixes in the upper 18 inches of the biologically active sediments, the tilling activities completely destroyed all burrows, particularly with multiple passes over several days resulting in the complete mortality of the larger infauna of the sand beach. Along with removal of the infauna, tilling also removed the surface wrack even if it was clean, which is an important substrate for animals that birds feed on. Once tilling was completed, the tilled areas could be considered biological deserts, providing little forage for shorebirds and other fauna that feed in these areas.

[1] Incidentally, waves during Hurricane Isaac cut through Garden Bay Island right at the point along the island where extensive evacuation and tilling was conducted.

Figure 9. Tilling operations. Top: Tilling on Grand Isle in July (left) and December (right) 2010 using agricultural equipment. Bottom left: Wet tilling on Garden Island, South Pass in August 2011. Bottom right: Disk tilling on Elmers Island in July 2012.

There were also concerns that tilling would affect beach compaction. As discussed previously, changes in compaction can have impacts on erosion potential. Tilling has been used extensively as a method to loosen the sand placed on nourished beaches in Florida because of concerns that the compacted sand would be harder for sea turtles to excavate during nesting. Nelson and Dickerson (1988) showed that a tilled nourished beach remained uncompacted for up to one year. This change in sediment density would affect burrowing animals such as the ghost crab that lives in the supratidal zone where most of the intensive tilling was conducted on Grand Isle.

Augering

Mechanical augers were used by SCAT and Operations teams to delineate areas for later removal of buried oil above cleanup endpoints. Augering was also used by Operations as part of the Louisiana Augering and Sequential Recovery (LAASR) program where any buried oil above endpoints was removed during the augering delineation. Figure 10 shows different types of augering equipment that was used. Augering was a significant effort, with nearly 38,000 auger holes excavated between November 2012 and August 2013 alone. Figure 11 shows the August 2013 map of augering on Fourchon Beach where it was conducted throughout the intertidal and supratidal zones; Figure 12 shows augering sites on Chaland where specific sites were targeted.

Figure 10. Augering operations for delineation of buried oil on sand beaches. Photos courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

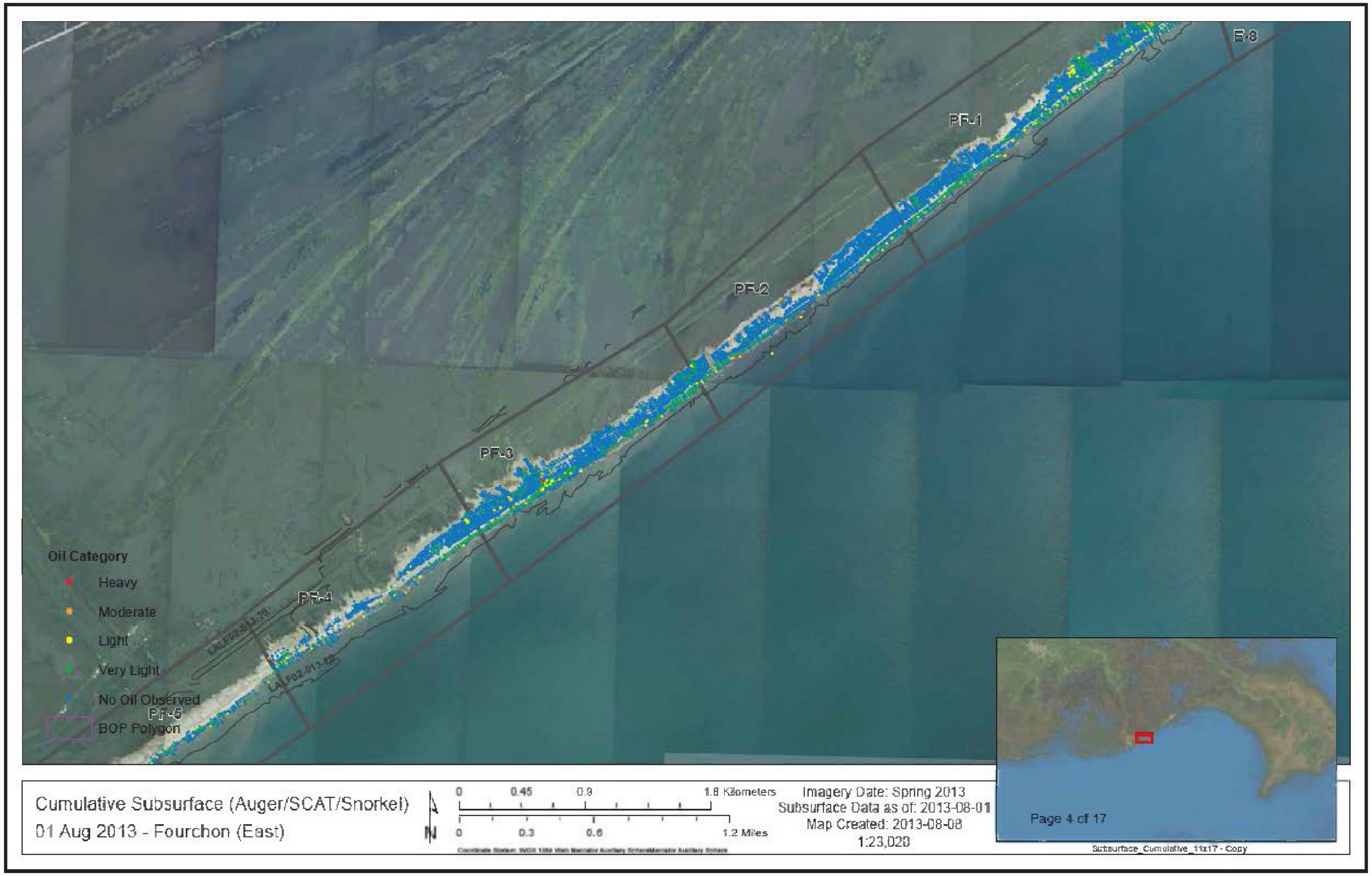

Figure 11. Map of cumulative auger sites in 2013 on Fourchon Beach as of 1 August 2013 showing that the much of the intertidal and supratidal zones were augered. Map courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

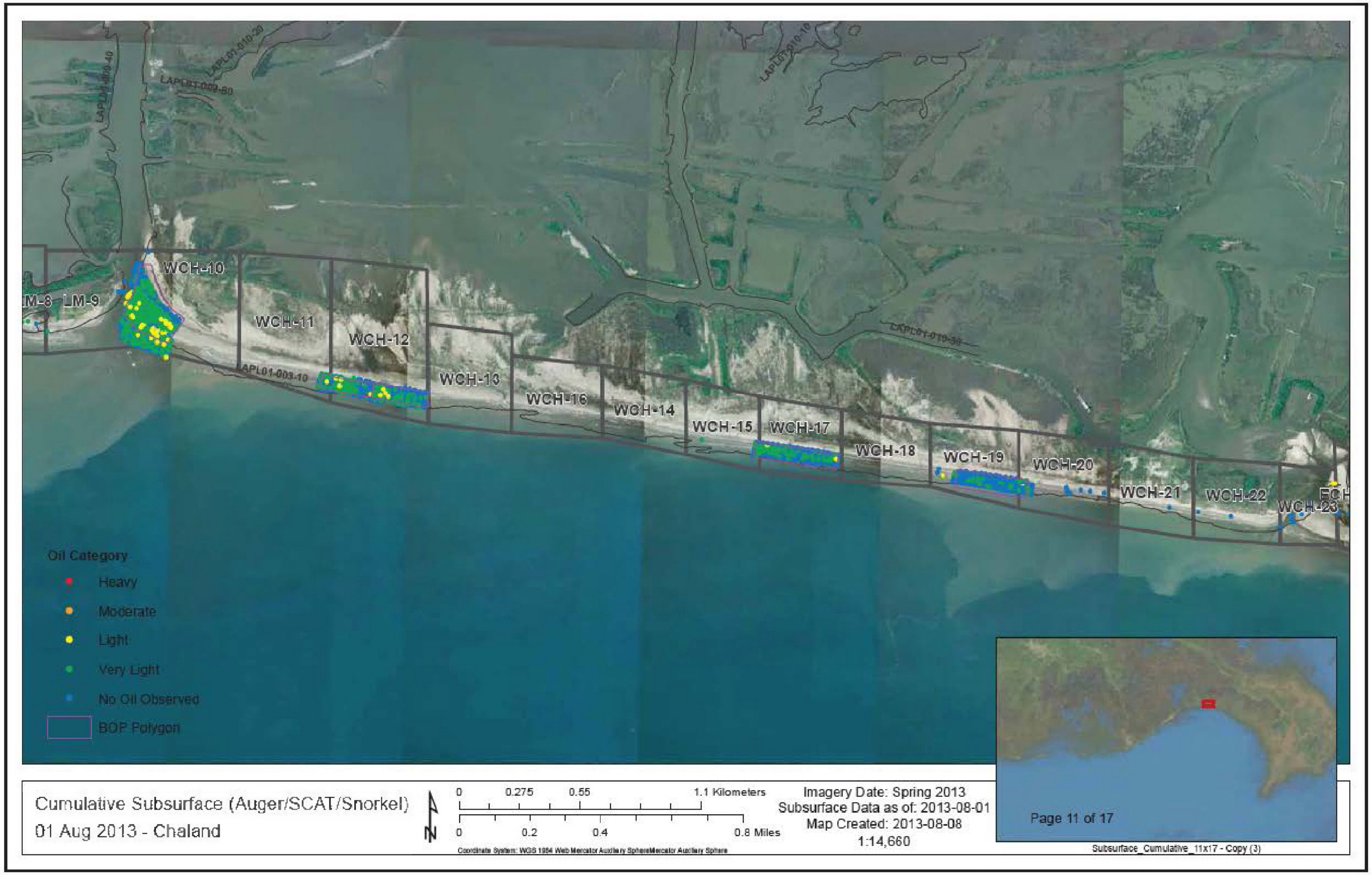

Figure 12. Map of cumulative auger sites in 2013 on Chaland Beach as of 1 August 2013 showing specific areas that were targeted for subsurface oil detection. Map courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

Dredging and Surf Washing

Dredging and surf washing were conducted as shoreline treatment methods for buried oil on South Pass, LA. Four areas at South Pass (Figure 13), covering 556,063 ft^2 (12.77 acres) of supratidal and intertidal habitat, were excavated or bulldozed, resulting in 79,334 yd^3 of oiled sediments pumped via pipeline into the GOM nearshore for re-working by waves (surf washing) and eventual transport back onto the shoreline down current. It was assumed that the oil in the sediment slurry would become dispersed in the surf zone and mixed into the water column. To fill the excavated areas, sand was dredged from a subtidal borrow area and placed back. Figure 13 shows the areas targeted for dredging, the pipeline corridors, and the area where the excavated sediments were discharged into the Gulf side of the barrier for surf washing. There is no "as-built" documentation; however, the areas and volumes listed above were tallied from the daily and final reports submitted by BP for the dredging and surf washing operations. This treatment operation started on 10 August 2011 and was completed on 2 December 2011, a period of nearly four months. Most of the equipment was removed in advance of Tropical Storm Lee in early September 2011 and re-deployed shortly thereafter. Tropical Storm Lee caused extensive erosion and created numerous washover fans in the low, dredged areas because they had not been re-filled at that time.

The South Spit at South Pass is a highly valuable and heavily used area for birds. It is designated as "Critical Habitat" for the piping plover. Dredging, filling, and surf washing occurred along a large percentage of the low, mostly unvegetated habitat that is most valuable for bird feeding, loafing, and nesting. As discussed above, these activities have been shown to reduce the prey on which birds feed.

During dredging, pumping, and discharging into the surf zone, there would be significant loss of the animals in the excavated sediments. The temporary deposition of sand at the discharge point of the pipeline would cause virtually complete mortality of all the benthic invertebrates within the deposition footprint except for some more mobile species at the margins where burial depths are so modest that some mobile polychaetes, gastropods, and other organisms may survive. As discussed above, the re-worked sediments that were eventually deposited on the shoreline would bury the existing biota, although it would likely occur slowly so the motile species could migrate up into the new sediment layers. Peterson et al. (2006) noted mass mortality of benthos after sand deposition on ocean beaches during beach nourishment.

4.1.3 Vehicular Traffic

Nearly all shoreline treatment operations, including manual removal, involved extensive vehicular traffic, which was often very intensive and covered long distances between staging and work areas. Although efforts were made to confine vehicular traffic to established corridors, there were many instances where vehicles traveled throughout all tidal zones.

Off-road traffic on sand beaches (i.e., four-wheelers, cars, and trucks) is an activity that has been studied relatively extensively and is very comparable to treatment activities conducted during the *Deepwater Horizon* response, though less intense than the use of heavy equipment, staging areas,

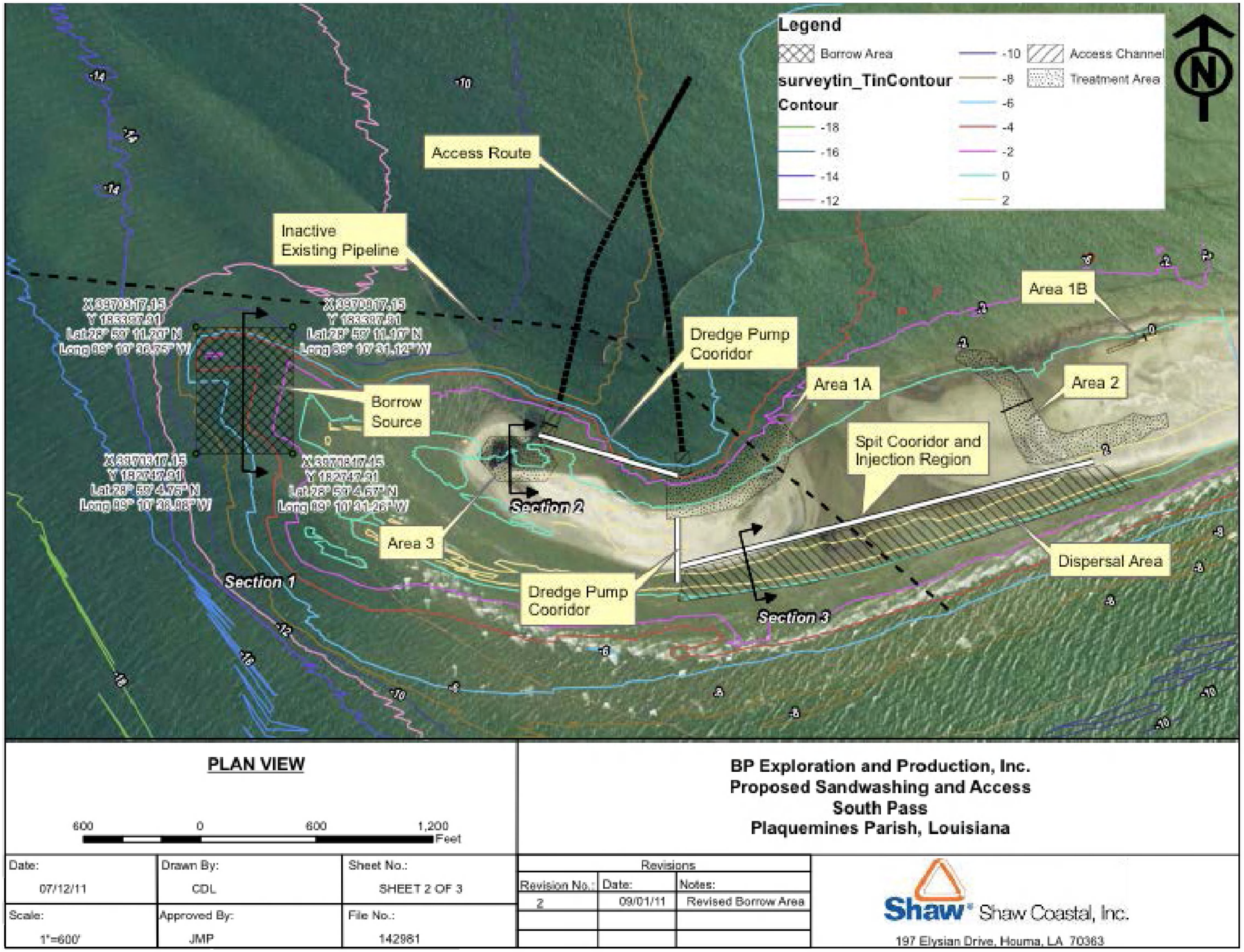

Figure 13. Proposed dredging and surf washing plan for South Pass, LA conducted from 10 August to 2 December 2011. Map courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

and sifting operations during the response. Wolcott and Wolcott (1974) and subsequently Schlacher et al. (2007) found that ghost crabs are frequently crushed by off-road traffic if their burrows are relatively shallow (5 cm), and that this species is particularly vulnerable because of its soft exoskeleton and, in Australia, shallow burrows. Not surprisingly, ghost crab mortality declined exponentially with burrow depth. Schlacher et al. (2007) also found that ghost crab densities were higher in areas subjected to low to moderate traffic, while individuals were smaller in heavily impacted areas, suggesting alterations of the population structure. Beaches with heavy off road traffic also had lower abundance, species richness, and diversity of intertidal macrobenthos, and large changes in the community structure were driven by the low abundances of an isopod *Pseudolana concinna* (Schlacher et al., 2008a). Direct crushing appeared to be the main cause of community changes. Lucrezi and Schlacher (2010) reported that sand beaches impacted by traffic were slightly hotter and had lower moisture content than beaches closed to traffic. Lucrezi and Schlacher (2010) also observed that on vehicle-impacted beaches not only were ghost crabs smaller, but they were constructed much deeper and longer burrows possibly to avoid desiccation.

Vehicular traffic and staging areas often occurred in the supratidal zone between the high-tide line and a buffer away from any dunes present. This part of the beach is also where sea turtles nest. Studies have shown that compacted sand is harder for sea turtles to excavate during nesting (Nelson, 1987). Also, nighttime traffic likely prevented some nesting females from coming ashore to nest.

Aside from direct crushing, heavy traffic decreases invertebrate abundance by reducing food availability (including wrack), increasing species displacement, disrupting the intertidal habitat and the physical properties of the sand substrate, and increasing invertebrate exposure to predators from the continuous maintenance of burrows (Schlacher et al., 2007; Kluft and Ginsberg, 2009).

4.1.4 Wrack Removal

Wrack is the organic material deposited at the high-water level on beaches. In the GOM, it is composed of a wide range of materials including: the brown algae, *Sargassum*, the stems of salt marsh vegetation such as *Spartina*, freshwater vegetation washed down the Mississippi River, seagrasses, driftwood, and other types of plant material. All types of treatment operations on sand beaches during the *Deepwater Horizon* oil spill involved wrack removal or disturbance of wrack when it was moved aside during treatment operations. Although only oiled wrack was supposed to be removed, large amounts of unoiled wrack were removed (based on numerous observations by Shoreline Cleanup Assessment Technique [SCAT] teams).

Wrack is a very important part of the sand beach ecology. Some of the ecological benefits of wrack include erosion control, beach stabilization, enhanced dune plant growth, and dune formation (Williams et al., 2008; Gheskiere et al., 2006). In addition, stranded wrack provides important habitat that supports a rich community of crustaceans and insects (Defeo et al., 2009). Stranded wrack is an important source of carbon and organic material that affects all aspects of the trophic structure of the macrofaunal community on sand beaches (Dugan et al., 2003). The wrack itself is both a food source and a microhabitat refuge against desiccation for many sand beach invertebrates (e.g., ghost crabs, amphipods, isopods). Species richness, biomass, and abundance of primary and secondary consumers, as well as the abundance of higher trophic level species (e.g., shorebirds) are all influenced by the input and fate of wrack (Dugan et al., 2003).

Many invertebrates use the nutrition from particulates and detritus brought in on tides and waves consuming organic matter and recycling nutrients that otherwise would become trapped in the sediments. Amphipods, crabs, and insects convert the energy content of stranded wrack washed onto the beach into forms available for larger animals, including shorebirds, surf zone fish, and other higher trophic level aquatic organisms.

There have been many studies of the effects of wrack removal from periodic grooming of amenity beaches (Dugan et al., 2000; Gheskiere et al., 2005; Weslawski et al., 2000a; Weslawski et al., 2000b), and from oil treatment operations (Chan, 1976; Blaylock and Houghton, 1989; De La Huz et al., 2005; Michel et al., 2008; Borzone and Rosa, 2009). Defeo et al. (2009) indicated that, in general, macrobenthic populations and communities respond negatively to increased human activity levels. Beach grooming activities that remove wrack have significant effects on the community structure of wrack-associated fauna, depressing species richness, abundance, and biomass. Beach grooming has significant ecological consequences, including the substantial reduction of prey for higher trophic levels such as birds and fish (Dugan et al., 2000; Dugan et al., 2003; Defeo et al., 2009) and, depending on the spatial scale of grooming (<1 to 60 miles), the effects could be noticeable at scales ranging from weeks to years (Defeo et al., 2009).

In a study conducted at Padre Island National Seashore, mechanical raking (0-1.25 inches penetration) for wrack removal on the upper intertidal zone lowered the mean density and biomass of all macrofauna within three days post-raking, with effects lasting up to 10 days post raking for Talitrid amphipods and polychaetes when compared to unraked areas (Engelhard and Withers, 1997). European studies (Weslawski et al., 2000a; Weslawski et al., 2000b; Malm et al., 2004; Gheskiere et al., 2005; Gheskiere et al., 2006) have also reported biological and ecological impacts from beach cleaning. At two tourist beaches, removal of wrack with mechanical beach cleaners reduced the total organic matter in the upper beach zone. This caused high community stress and lower invertebrate diversity, taxa richness, and genetic diversity (Gheskiere et al., 2005). These effects in turn caused a shift in species composition to one dominated by opportunist species compared to the more diverse and stable communities found on the non-tourist beaches (Gheskiere et al., 2005). In a related study, the top 2 inches of sand surface was removed with mechanical beach cleaners (Gheskiere et al., 2006); this short-lived disturbance caused significant changes in the total abundance and community structure immediately after cleaning by reducing the abundance of the dominant nematode species and harpacticoid copepods.

In Sweden, beach cleaning caused significant changes in the organic content of sediments (Malm et al., 2004). Cleaned beaches had a much lower level of organic carbon than un-cleaned beaches, with the most intensively cleaned beaches having lower total benthic biomass. Weslawski (Weslawski et al., 2000a; Weslawski et al., 2000b) has extensively documented the effects of beach cleaning in Poland. He suggested that trampling and mechanical cleaning may have contributed to the disappearance of air-breathing amphipods or sandhoppers from the most frequently visited beaches (Weslawski et al., 2000a,b and citations therein). Furthermore, wrack removal from the upper layer of sand and sand sifting through a 5 mm sieve effectively removes important food sources for key species, which are linked to disappearance of macrofauna and the decline of their predators (Weslawski et al., 2000b and citations therein). This author also indicated foot traffic (3,000 steps/10 ft^2 per day) caused sufficient beach fragmentation and mixed debris with sediment down to 4-12 inches.

4.1.4 Foot Traffic

All types of response activities on sand beaches include foot traffic and the construction of temporary shelters where cleanup workers could rest, eat, drink, and muster. Studies have documented reductions in density, abundance, and species richness on sand beaches with heavy beach traffic (including pitching of tents) compared to beaches with lesser beach use; some of these studies were controlled experiments with side-by-side plots with different intensities of foot steps (Moffett et al., 1998; Ugolini et al., 2008; Lucrezi et al., 2009a,b; Schlacher and Thompson, 2012; Viera et al., 2012). Greatest impacts were observed for delicate, shallow burrowing species (such as mysids and juvenile bivalves); however, ghost crab burrow densities and burrow size were reduced by 35 to 88%. Many of the beaches that were treated have relatively low public use because of limited access or restricted access.

4.2 Sand Beach Response Injury Categories

Based on an assessment of the potential degree of impacts to ecological services and functions of sand beaches, Response Injury categories were developed as shown in Table 3.

Table 3. Response Injury categories and descriptions.

Response Injury (RI) Category	Description
RI = 1: Intermittent Manual Treatment/Augering/SOMs removal	Manual only, lower frequency (<20 visits/month), includes vehicle traffic for transport of workers and waste; Mechanical augering; SOMs removal impacts in the intertidal zone
RI = 2: Intensive Manual Treatment	Mostly manual (but includes walk-behind sifters for any duration), higher frequency (>20 visits/month), includes vehicle traffic for transport of workers and waste
RI = 3: Beach Grooming/Tilling/Very Intensive Manual	Treatment at least twice in a month with a mechanical beach groomer that would sift the sand, down to a depth of 12 inches; All tilling operations; Intensive manual removal
RI = 4: Excavation	Treatment at least twice a month with a mechanical device and at least once in the month beach sediment was mechanically removed from the beach and sifted; Mechanical removal of clean sediments for manual removal of oiled sediments
RI = 5: Intensive Mechanical Treatment	Extensive deep (>12 inches) mechanical treatment, staging areas, and dredging

In summary, the parameters that are used for the response injury assessment are:

- Days per month of manual treatment activity on each segment.
- Days per month of mechanical treatment activity on each segment.

- Type of mechanical treatment activity (i.e., towed sifters, remove sift and replace, total removal, bulldozer, backhoes, etc.)

4.3 Information Sources Used to Assign Response Injury Categories

The following sources of information were used to assign response injury categories to each segment.

1. OPS Segment Tracker: Available for the period June 2011-February 2014. This spreadsheet provides a summary by segment of the number of days per month that the segment was visited by Operations workers for treatment and the pounds of oiled waste recovered per month. It is updated weekly. It is used to determine the level of response for manual treatment for the months from June 2011 to the termination of shoreline treatment operations.
2. Florida Branch Consolidated Report: Available for September 2010 to 5 December 2011. This daily report provides detailed information per segment on mechanical and manual treatment conducted, date visited, number of workers, pounds of material recovered, type of mechanical equipment used, hours of mechanical operations, etc.
3. Situation Reports/ICS-209 Forms: Where available, these forms provide detailed information on response operations. However, they are not available for every day of operations for every segment.
4. Shoreline Treatment Recommendations (STRs): These forms are available for all segments where any shoreline treatment was conducted, under Stage 3 and Stage 4 of the response. These are operational permits to work for shoreline treatment, issued by the Unified Command. STRs state allowable treatment methods; however, not all allowable treatment methods were actually used. The status of the STR (dates active) is useful to track start/end of allowable treatments.
5. SCAT OPS Liaison Daily Report: In July 2010, the Shoreline Cleanup Assessment Technique (SCAT) Program instigated the use of technical experts to liaise between the SCAT program and Operations in the field. They were called SCAT OPS Liaisons and worked out of the various Operations Branches. They generated daily reports on their work, including photographs of different operations and locations. These reports are available almost daily from July 2010 to August 2011.
6. U.S. Coast Guard Jefferson Division 1 Shoreline Afternoon Reports: US Coast Guard Monitors submitted daily reports on treatment activities from Elmers Island to Grand Terre III, with short descriptions and representative photographs. These reports are available almost daily from 3 September 2010 to 5 May 2011.
7. Gulf Islands National Seashore Daily Update Debrief (DUD) Reports: Includes information on level of effort, pounds recovered, number of visits by island (not segment) for the time period from June 2010 to February 2012.
8. National Park Service (NPS) Records: Gulf Island National Seashore segments in FL and MS: NPS compiled information on treatment on their lands.

9. Mainland and Islands Ops Tarballs Collected by Segment: Spreadsheets generated by the Operations Branch in Mississippi that reported the pounds of tarballs collected during visits by date for the period 1 April 2011 to 15 July 2011.
10. Coastal Protection and Restoration Authority (CPRA) Daily Reports: for Elmer's Island, Fourchon Beach, Grand Terre II: October 2010 to January 2012. The STRs for these beaches required the presence of a CPRA Monitor, and these are their daily reports.
11. Permits for Installation of Various Types of Barriers, Booms, etc.: Approved permits for Louisiana and Alabama were used to document the type, location, length, etc. for these barriers.
12. SCAT Overflight and Ground Photographs: Geo-referenced photographs are available for every SCAT survey, which were used to document response methods, locate the actual placement of sand bags, Tiger Dam boom, and other barriers, and to select photographs of typical types of response activities.
13. Various Response Reports: During the response, SCAT and Operations generated various reports and documentation that contained information on pounds of material removed, treatment methods, their effectiveness, and durations for specific shoreline treatment areas.

For all states, the Ops Segment Tracker spreadsheet was used to determine the level of response for manual treatment for the months from June 2011 to the termination of shoreline treatment operations. This spreadsheet has a count of how many days each segment was visited during each month. The following assumptions were used unless other data, as indicated in the explanations by state below, were available to indicate a different level of response. For the time period from February 2011 to May 2011 the level of response for each segment was assumed to be the same as for the month of June 2011, because mechanical treatment was mostly terminated by February 2011, particularly for the Eastern States. For the time period from June 2010 to January 2011 the level of response for manual treatment was assumed to be intensive manual removal because cleanup crews were usually out every day (weather permitting) during this period. When no information was available for a segment from May 2010 to June 2011, it was assumed that intensive manual removal was conducted, as a default.

In addition to the Ops Segment Tracker spreadsheet, additional data used for each of the states is described below.

4.3.1 Florida

Florida Branch Consolidated Reports were used to identify the times, segments, and level of mechanical treatment. These reports are available for the months from September 2010 to December 2011. Mechanical treatment was terminated in Florida in March 2011. A Response Injury of 3 was assigned to the months that a sand shark was used. A response injury level of 4 was assigned to the months that any of the power sifters were used. For the overlap time period when both mechanical and manual cleaning was being conducted, the months that had mechanical treatment were subtracted out from the months of manual treatment. Thus, there is no double-counting the months, and the higher injury is assigned to the month based on the mechanical treatment. The data needed to assign Response Injury categories for Florida are considered to be good with nearly complete coverage by location from September 2010 until the end of response. Documentation prior to September 2010 is limited to Operations executive summaries or situation briefs, which provide location information at the beach or division level; however, times and type of treatment were well documented. It was assumed that the treatment indicated was conducted over the entire beach or division identified.

4.3.2 Alabama

Situation Reports/ICS-209 spreadsheets were available for the months from June 2011 to June 2013. These forms detailed the work done on each segment as well as amount of oiled waste removed. Because these forms covered the same period as the Ops Segment Tracker, these data were used to identify the dates and segments where mechanical treatment methods were used. A Response Injury of 3 was assigned to the months when a sand shark or similar beach sifter was used. A Response Injury of 4 was assigned to the months when power sifters were used. The information needed to assign Response Injury categories for Alabama for the period prior to June 2011 was derived various sources. Branch Operation reports were used for Baldwin County from August 2010 to March 2011. There was no additional information for the remainder of Alabama, so it was assumed that crews were deployed to the oiled beaches daily during the first few months of the response.

4.3.3 Mississippi

In addition to the Ops Segment Tracker, data on treatment methods and periods for Mississippi were extracted from the Mainland and Island Ops Tar Balls Collected per Segment spreadsheet from April 2011 to 15 July 2011. The June 2011 data matched the data in the Ops Segment Tracker spreadsheet; therefore, only the months of April and May were used to supplement the Ops Segment Tracker data. There was documentation of mechanical treatment for several mainland segments. The ICS-209 forms for June 2011 to June 2013 were available; they contain detailed information on the treatment operations conducted each day, including equipment used, segments treated, and pounds of oiled waste removed. Much of this information was also available in the Ops Segment Tracker, but the ICS-209 forms were used to determine when and where mechanical treatment methods were used. The Gulf Islands National Seashore Daily Update Debrief (DUD) reports for the time period from June 2010 to February 2012 include information on level of effort, pounds recovered, number of visits by island, not segment. However, Frank Powell, Project Manager at the Gulf Islands National Seashore, provided the number of days per month that each different type of mechanical method (e.g., mechanical auguring, beach cleaners) was used by segment from August 2010 to February 2011, based on his observations and records. The Mississippi Operations Branch generated a Powerpoint presentation that reports the amount of oiled waste removed from the shoreline for the mainland (by county) and the islands (by island) from June 2010 to May 2011. Earlier versions of the ICS 209 forms were also available from June 2010 to April 2011and provided information on response activities at the beach level of resolution. The data needed to assign Response Injury categories for Mississippi are considered to be good with nearly complete coverage over time and by location.

4.3.4 Louisiana

In addition to the Ops Segment Tracker, documentation of mechanical treatment in Louisiana is contained in the CPRA On-site daily reports for Elmers Island, Fourchon Beach, and Grand Terre II (East Grand Terre) from October 2010 to January 2012. These reports were used to determine the days and locations that mechanical treatment was conducted. Injury categories for other months were based on various daily reports from the SCAT Ops Liaisons, U.S. Coast Guard observers, SCAT daily reports, and various other sources. ICS forms for Jefferson Parish from July 2010 to January 2011 and Situation Reports for Elmers from September 2010 to February 2011 were used.

4.4 Response Injury Category Assignment Methods by State

4.4.1 Florida

The Florida Consolidated Report provided daily information for September 2010 to December 2011 and the Ops Segment Tracker provided monthly visit information starting in June 2011. It was assumed that all treatments prior to September 2010 were manual and the frequency was >20 visits per month.

4.4.2 Alabama

Because of incomplete information, some assumptions were made to assign Response Injury categories to sand beaches in Alabama. Therefore, in the following sections, the treatment history as available is described.

Federal Lands (Bon Secour NWR and Gulf Island National Seashore)

The sand beaches of Bon Secour National Wildlife Refuge (NWR) managed by the U.S. Fish and Wildlife Service (USFWS) and several parcels managed by the Bureau of Land Management (BLM) were treated using mostly manual methods, with some mechanical treatment in selected segments based on information from the ICS-209 forms. Little Dauphin Island is part of the Bon Secour NWR, managed by the USFWS. It has very limited access and is designated as critical habitat for the listed piping plover, as well as nesting habitat for the loggerhead sea turtle. Due to the sensitive nature of the habitat and the species present, only manual removal of oil was allowed in 2010 and 2011. Operations crews were monitored by READS and only a limited number of visits by cleanup crews were allowed. Therefore, the same approach described above for the Gulf Islands National Seashore was used for these beaches. That is, the various sources and assumptions were used to determine the number of days per month that manual removal occurred, and Frank Powell, Project Manager at the Gulf Islands National Seashore, provided the number of days per month that each different type of mechanical method (e.g., mechanical auguring, beach cleaners) was used by segment. Periods of environmental hold were treated as days of no work on the segment, and therefore were not added into the days per month of operations on the segment.

Inland Bay Shorelines

For the sand beaches along Terry Cove, Bayou St. John, and Ono Island in Lower Perdido Bay, Alabama, only manual removal methods were used. Therefore, a Response Injury of 1 was assigned to the months when shoreline treatment was conducted, starting in June 2011 based on information in the Ops Segment Tracker.

West Point Island (Gulf Beaches)

West Point Island is only accessible by boat and is a privately owned island, thus it has limited public access and a relatively high quality habitat value. It is also designated critical habitat for piping plover. The Gulf-facing beaches were classified as Heavy oiling during the response.

The Gulf-facing beaches on West Point Island had extensive subsurface oil that posed difficult challenges for its removal. Therefore, these beaches underwent extensive manual and mechanical cleaning, as documented by the list of STRs issued below:

- STR 3-006, October 2010 – mechanical treatment to 6 inches.
- STR 3-029, October 2010 – mechanical treatment.
- STR 3-033, November 2010 – This STR included wording that said: "the strength must be kept on in order to reach NFT[2]" and allowed extensive mechanical treatment.
- STR 3-041, November 2010 – extended Deep Clean to March 2011.
- STR 4-006, August 2011 – mechanical treatment to 6 inches, manual for deeper removal, then P&M visits.
- STR 4-006c, October and December 2012 – Included a Deep Clean Pilot Test, conducted in November 2012, that involved over 1,000 auger holes and test screening with Power Screen sifters. Based on those results, the Federal On-Scene Coordinator issued an authorization to begin Deep Clean Work on West Pelican Island, starting 1 December 2012 and to be completed prior to bird and sea turtle nesting season in 2013.

Figure 6 shows the West Point Island "Deep Clean" Operation on 13 January 2011. Deep cleaning on West Point Island started on 1 January and ended on 7 March 2011, with up to 48 days of operation on various segments. All segments on West Point Island received some level of mechanical treatment based on a poster generated by Operations. From June 2011 to November 2012, Operations reported removing approximately 13,897 pounds (20.6 cubic yards) of oiled waste from the island. However, chronic re-oiling on the island triggered the decision to, conduct a second "Deep Clean" on the beaches, starting in December 2012. Therefore, West Point Island received multiple "Deep Cleaning" operations, which resulted in a significant degree of disturbance to the sand beaches habitat and communities.

West Point Island (North Beaches)

The north side of West Point Island (North beach) had less oiling, thus less intensive treatment, as indicated by the STRs issued in 2010 and 2011:

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[2] NFT means No Further Treatment

- STR 3-003, Oct 2010 – manual treatment.
- STR 3-038, Nov 2010 – manual sifting.
- STR 3-041, Nov 2010 – extensive mechanical treatment allowed, but this type of treatment likely occurred mostly on the Gulf beach.
- STR 4-006, Aug 2011 – mechanical treatment to 6 inches, manual for deeper removal, then P&M visits.

Dauphin Island

Dauphin Island is a high-use amenity beach that is also used by three species of listed or protected sea turtles for nesting. Pelican Island and the western end of Dauphin Island are designated as Critical Habitat for the threatened piping plover, and there are several important bird nesting colonies on the island.

No information is available for treatment operations in summer 2010. In November 2010, an STR was issued allowing mechanical treatment on Pelican Island. In March 2011, mechanical removal of submerged oil mats was allowed on Pelican Island. In April 2011, mechanical treatment to 12 inches was allowed, followed by P&M visits. Figure 7 shows the large-scale sifting operation on Dauphin Island on 14 February 2011. The most intensive treatments appear to have been conducted along the eastern end of the island, which has higher public use. From June 2011 to November 2012, 1,678 pounds (2.5 cubic yards) of oiled waste were removed from Dauphin Island.

All Amenity Gulf Beaches in Baldwin County

Baldwin County Gulf beaches extend from the Florida border to the entrance of Mobile Bay. These beaches are important nesting habitat for four species of sea turtle and are designated as Critical Habitat for the endangered Alabama and Perdido Key beach mouse. Most of these beaches were classified as heavier oiling, with the exception of the beaches on either side of the entrance to Perdido Bay, which were mostly classified as lighter oiling.

The amenity beaches are differentiated from those beaches that are under the management of the U.S. Department of the Interior (DOI) because of the different cleanup endpoints (the endpoint for amenity beaches is no oil observed, whereas the cleanup endpoints for Special Management Area beaches (i.e., Bon Secour) are less than 1% surface oil and no oil particles greater than 1 inch in size); thus, different treatment methods were used to meet these endpoints. Figure 14 shows the typical “Deep Clean” Operations that were used on amenity beaches in Baldwin County, Alabama.

Figure 14. Powerscreen operations at two different locations along Baldwin County amenity beaches in Alabama on 20 January 2011. These operations are highly intrusive and result in removal or crushing of all animals living in the treatment areas. Photos courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

Baldwin County beaches also had many areas with submerged oil mats in the nearshore subtidal zone. The nearshore subtidal zone is defined as that part of the shoreface that is below mean low-low water. Long-arm, tracked excavators are used to remove these oil deposits and sift out the oil from the sand (Figure 15). Table 4 shows the pounds and cubic yards[3] of oiled waste being removed from the Baldwin County amenity beaches, including removal of the submerged oil mats, from June 2011 to June 2013. Mechanical equipment was used to remove the submerged oil mats along the Baldwin County beaches from September 2010 until the segment was moved out of response.

Figure 15. Removal of submerged oil mats from the nearshore subtidal zone along Perdido Key, Alabama on 6 March 2011. Photos courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

[3] A conversion factor of 675 pounds per cubic yard was used.

Table 4. Amounts of oiled waste removed from the STR areas for amenity beaches in Baldwin County, AL from August 2010 to June 2013.

STR Treatment Area	Pounds	Cubic Yards
Orange Beach	348,822	518
Gulf Shores Amenity	1,654,019	2,454
Fort Morgan Amenity	1,008,661	1,497

4.4.3 Mississippi

For the mainland beaches and the privately owned parts of Cat Island in Mississippi, nearly all shoreline treatments were conducted using manual methods. The exceptions were privately owned sections of Cat Island (September and December 2010 and January 2011) and Gulfport beaches (July 2010). These beaches had some limited use of Sandman beach cleaners. The "Mainland and Islands Tarballs Collected by Segment" spreadsheet was used to determine the number of visits in April and May 2011 by cleanup crews conducting manual removal operations for each segment. For the period from June 2011 until the segment was moved out of response, the Ops Segment Tracker provided data on the number of visits per month by segment. To create monthly Response Injury categories prior to April 2011, more generalized ICS 209 forms from June 2010 and extended through March 2011 for all mainland and the privately owned Cat Island beach segments were used. Since these earlier forms did not have segment level detail it was assumed the response action identified was used on all the segments within the area delineated in the form, typically a beach, subdivision, or island. Using this approach, a monthly Response Injury category was created for each segment for the period June 2010 to when the segment was moved out of response.

For the parts of the Gulf Islands National Seashore in Mississippi (East and West Ship Islands, Horn Island, and Petit Bois Island), mostly manual methods were used with the exception of limited mechanical treatment in selected segments. The "Mainland and Islands Tarballs Collected by Segment" spreadsheet was used to determine the number of visits in April and May 2011 by cleanup crews conducting manual removal operations for each segment. For the period from June 2011 until the segment was moved out of response, the Ops Segment Tracker provided data on the number of visits per month by segment. To create monthly Response Injury categories prior to April 2011, more generalized ICS 209 forms from June 2010 and extending through March 2011 were used. No Response Injury was assigned during the months when Operations were not allowed during "environmental holds" to prevent disturbances to nesting birds and sea turtles. Frank Powell, Project Manager at the Gulf Islands National Seashore, provided information on the number of days per month that each different type of mechanical method (e.g., mechanical auguring, beach cleaners) was used by segment. Using this approach, a monthly Response Injury category was created for each segment for the period June 2010 to when the segment was moved out of response.

4.4.4 Louisiana

Because of incomplete information, some assumptions were made to assign Response Injury categories to sand beaches in Louisiana. The Ops Segment Tracker doesn't provide enough information to determine where and when mechanical treatment was conducted. However, there are various sources for some segments that can be used to describe the treatment history and assign Response Injury categories using reasonable assumptions.

In the following sections, the history of shoreline treatment on sand beaches in Louisiana as currently known is described and how Response Injury categories were assigned when possible, from west to east.

Raccoon Island

Raccoon Island is part of the Isles Dernieres Barrier Islands State Wildlife Refuge (SWR) managed by the Louisiana Department of Wildlife and Fisheries (LDWF) that has a high natural resource value and potential for response disturbance. Raccoon Island is the largest rookery in Louisiana and host to thousands of migratory birds in the spring and fall. It is also piping plover Critical Habitat. There is very limited access allowed on the island. During the response, most of the island was classified as light oiling, though there were some areas classified as heavy, moderate, and very light oiling. Due to the sensitive nature of the habitat on Raccoon Island, treatment operations were very restricted and included:

- Manual treatment only in STR S3-000 issued on 4 September 2010.
- There was a narrow treatment window in Fall 2010, to minimize impacts to the many nesting, wintering, and migratory birds present.
- Use of UTVs was not allowed; all treatment operations were conducted by foot.
- Oversight of all operations by staff from the LDWF.
- SCAT teams inspected the three segments that were treated on 14 and 24 October 2010 with a result of No Further Treatment or No Oil Observed.

No information is currently available on the amount of oiled waste removed from the island. Based on the treatment history, Raccoon Island was assigned a Response Injury of 1 for a one-month period spanning September/October 2010.

Whiskey Island

Whiskey Island is part of the Isles Dernieres Barrier Islands SWR, with high natural resource value, including designated piping plover critical habitat, and potential for response disturbance. Like Raccoon Island, Whiskey Island also has very limited public access. Gulf-facing beaches were classified as heavier oiling, thus required more intensive treatment than on other islands in the SWR and are summarized below:

- Manual treatment only was authorized under STR S3-018 issued on 19 October 2010; the SCAT Daily Report indicated that STR Completion Inspections had been conducted by SCAT for this STR prior to 21 November 2010.
- There were strict limitations on use of UTVs for transport of workers, cleanup supplies, and waste materials.
- Oversight of all operations by staff from the LDWF.

- Operations were put on environmental holds because of bird nesting closures for long periods.

The first treatment operations were conducted in October and November 2010. A Response Injury category of 1 was assigned to both months. Information on the amount of oiled waste removed prior to June 2011 is not available. In March-April 2011, 50 cleanup workers removed approximately 81,000 pounds (120 cubic yards) of oiled waste during nine days on the island in March and three days in April. A Response Injury category of 1 was assigned to both months. No oiled waste materials were removed from June 2011-November 2012, and there was only one visit per month from October 2011 to January 2012, and no visits after January 2012. A Response Injury category of 1 was assigned to each month when treatment operations were conducted.

Trinity Island

Trinity Island is part of the Isles Dernieres Barrier Islands SWR, with high natural resource value, including designated piping plover Critical Habitat, and potential for response disturbance. Public access to this island is allowed only in one designated area, so much of the island was not disturbed prior to the DWH oil spill. Most of the Gulf-facing beach was classified as heavier oiling, with some lighter oiling on each end of the island. The supratidal zone on Trinity Island, in particular, was the focus of more intensive treatment starting in March 2011 when it was discovered that large amounts of oil had been exposed by aeolian erosion over the winter. Though the amount of oiled waste removed from the island prior to August 2011 is not known, operations did report 962,290 pounds (1,426 cubic yards) of oiled waste removed from August 2011 through October 2012, the last month of Operations on the island.

Because of the heavier oiling on the island, beach treatment operations were more intensive, as summarized below:

- The first treatment operations were conducted in September-October 2010 under STR S3-002 issued on 6 September 2010. The SCAT Daily Report indicated that STR Completion Inspections had been conducted by SCAT for this STR prior to 21 November 2010.
- Mostly manual removal operations were allowed during that period, though some mechanical methods were used, including walk-behind sifters and chain drags pulled behind UTVs (as described in STR S3-002.r.1 issued on 20 October 2010).
- There were strict limitations on use of UTVs for transport of workers, cleanup supplies, and waste materials.
- There was extensive oversight of all operations by staff from the LDWF.
- Because of extensive oil exposed in the supratidal zone after the 2010/2011 winter, the volume of oiled waste removed March-April 2011 was 723,575 pounds (1,072 cubic yards), with 49-55 workers on the island for eight days in March and twenty days in April; then operations were put on environmental hold May-July 2011 because of bird nesting.
- In August 2011, when the bird-nesting hold was lifted, an addition 227,100 pounds (336 cubic yards) of oiled waste were removed.

- From August 2011 to October 2012, operational teams visited the island 0-2 times per month, removing an additional 11,615 pounds (17.2 cubic yards) of oiled waste. There was an intensive augering efforts during this period to find any buried oil.

Based on this information, Trinity Island was assigned a Response Injury of 2 for September and October 2010 and April and August 2011 and a Response Injury of 1 for March 2011 and whatever months treated until operations were terminated in October 2012.

West Timbalier Island

The Gulf-facing beaches on West Timbalier are designated as critical habitat for piping plover. Most of the western sand beaches were classified as light oiling, with the eastern beaches classified as moderate and heavy oiling. The island was difficult to access, so visits by operational teams were sporadic. The treatment history for West Timbalier Island is summarized below:

- Mostly manual removal operations were allowed on West Timbalier Island under STR #162 issued on 25 August 2010 and STR S3-006 issued on 13 September 2010, though walk-behind sifters were allowed under STR S3-006.r.1 issued on 20 October 2010.
- The SCAT Daily Report indicated that STR Completion Inspections had been conducted by SCAT for this STR prior to 21 November 2010.
- Operations were put on environmental holds because of bird nesting closures for shorter periods, compared to adjacent islands in Louisiana.
- STR S4-005 was issued on 1 March 2011 allowing manual removal only; it was revised on 11 April 2011 to allow mechanical removal using sifters and excavators.
- STR S4-027 was issued on 31 May 2011 for P&M using manual methods only to remove oil at depths no greater than 6 inches. This STR was revised on 26 September 2011 to allow manual removal at depths greater than 6 inches.
- Oiled material removals for the period June 2011-January 2014 for West Timbalier Island are 60,198 pounds (89 cubic yards).
- In June to July 2013 intensive augering was conducted on the western and eastern segments of the island and in the middle of the island where the dredged channel is located, with over 1,000 auger holes excavated.

With mostly manual removal methods used and difficult access to the island, a Response Injury category of 1 was assigned to September-November 2010 for all segments on the island and for the months when cleanup teams worked on the island as documented in the Ops Segment Tracker starting in June 2011 until each segment was moved out of response.

East Timbalier Island

The maximum oiling for the sand beaches on East Timbalier Island ranged from light to heavy. The treatment history for East Timbalier Island is summarized below:

- Mostly manual removal operations were allowed on East Timbalier Island under STR #165 issued on 25 August 2010 and STR S3-027 issued in September 2010, though walk-behind sifters were allowed under STR S3-027.r.1 issued on 11 November 2010 and STR S3-027.r.2 issued on 21 January 2011.

- STR S4-028 was issued on 31 May 2011 for P&M using manual methods only to remove oil at depths no greater than 6 inches. An Operational Pause was issued on 29 June 2011STR S4-028 was revised on 26 September 2011 to allow manual removal at depths greater than 6 inches.
- Oiled material removals starting in June 2011 for East Timbalier Island totaled 2,772 pounds (4.1 cubic yards), with the last reported Operations visit in November 2011.

With mostly manual removal methods used and difficult access to the island, a Response Injury category of 1 was assigned to September 2010 to May 2011 for all segments on the island and for the months when cleanup teams worked on the island as documented in the Ops Segment Tracker starting in June 2011 until each segment was moved out of response.

Miss Lena Island

The maximum oiling for the sand beaches on Miss Lena Island ranged from very light to light. The Gulf-facing beaches on Miss Lena Island are designated as critical habitat for piping plover. Treatment operations on Miss Lena Island were completed by November 2011 in advance of a pending beach nourishment project. The treatment history for East Timbalier Island is summarized below:

- STR S3-022 was issued in early October 2010 and STR S3-022.r.1 was issued on 23 October 2010. SCAT inspected the island on 15 January 2011 and all segments were recommended to move to P&M.
- STR S4-006 was issued on 9 March 2011 for manual removal of oil in the supratidal zone, which was completed by 22 March 2011.
- Access to the island was not allowed during the bird-nesting season starting April to July 2011.
- STR S4-029 was issued on 9 June 2011 for P&M using manual methods only to remove oil at depths no greater than 6 inches. This STR was revised on 20 September 2011 to allow manual removal at depths greater than 6 inches to remove buried oil residue mats.
- Oiled material removals starting in June 2011 for Miss Lena Island totaled 45,097 pounds (66.8 cubic yards), with the last reported Operations visit and recovery in November 2011. Theoil residue mat discovered on the western end of the island was removed August-November 2011, prior to moving the island out of the response so that the planned shoreline restoration project could proceed.

With manual removal methods used and difficult access to the island, a Response Injury category of 1 was assigned to the months of October 2010 to January 2011 and March 2011, and for the months when cleanup teams worked on the island as documented in the Ops Segment Tracker starting in June 2011 until each segment was moved out of response. The construction of the dike for the West Belle Pass Barrier Headland Restoration Project began on 31 December 2011 and beach and dune construction were completed on 19 August 2012 (Coastal Planning & Engineering, 2013).

Fourchon Beach and Elmers Island

Fourchon Beach and Elmers Island were among the most heavily oiled sand beaches affected by the *Deepwater Horizon* oil spill. These beaches had extensive, deep, and persistent subsurface oil that was exposed, buried, and re-exposed over time.

Elmers Island is a SWR, managed by the LDWF. Both islands are designated as critical habitat for the piping plover and least tern nesting colonies. Fourchon Beach also supports a large heron rookery and nesting sites for Wilson's plover. A small part of Elmers Island has direct public access by road and is considered to be an amenity beach.

Fourchon Beach is owned by the Wisner Donation and has some of the highest rates of shoreline erosion and land loss in the U.S. The Wisner Donation only allowed mostly manual methods were used on Fourchon Beach from 2010-2012; however, very heavy vehicular traffic along the beach was required to support these efforts due to the limited access via the Road 3090 entrance on the western end and the public road to Elmers Island. There are several breaches and washovers on Fourchon where roads had to be constructed to provide access for cleanup crews. Several breaches and washover areas were also closed early in the response to prevent oil from washing into the sensitive marshes behind the barrier island, as discussed in the section on response injuries from shoreline protection actions. These breaches became the focus of multiple efforts to remove oil that had become deeply buried around them. In addition, there were several intensive augering events (Buried Oil Program [BOP] and Louisiana Augering and Sequential Recovery [LAASR] on both islands in 2013, with excavation of nearly 6,000 auger holes on Fourchon and nearly 2,000 auger holes on Elmers Island.

Along both beaches, the emulsified oil accumulated as a thick (up to 10 inches) mat overlying the exposed, relict marsh platforms at the toe of the beach. These mats were buried, often deeply, by sand accretion, requiring extensive excavation for their removal. There were fewer restrictions on mechanical removal operations on Elmers Island as compared to Fourchon, and heavy equipment has been used extensively to remove the deeply buried oil mats (see photographs in Figure 8). Tilling was also used on Elmers Island for a specific area in the supratidal zone (Figure 9).

The intensity of treatment operations is reflected in the amounts of oiled waste removed from these beaches. The amount removed prior to June 2011 is not available; however, between June 2011 and February 2014 operations reported: Fourchon Beach = 9,717,556 pounds (14,396 cubic yards), with 2,765,581 pounds (4,097 cubic yards) removed during a big push in December 2013; and Elmers Island = 2,033,228 pounds (3,012 cubic yards). There have been nearly continuous shoreline treatment operations along both beaches since the oil first stranded on them in May 2010. Obviously, intensive treatments were required to remove the extensive volumes of oil from these sand beaches.

In summary, very intrusive shoreline treatments have been conducted nearly continuously on both Fourchon Beach and Elmers Island throughout the response.

The Caminada Headland Beach and Dune Restoration project was completed in two increments. Increment 1 extended from Belle Pass to about 6 miles to the east; this project started in August 2013 at Belle Pass and was completed in December 2014. Increment 2 continued to the west almost to Caminada Pass and started in May 2015 and was progressing as a rate of about 0.8 miles per month (CPRA, 2015).

Grand Isle

Grand Isle is the only barrier island in Louisiana with public access by road. All of Grand Isle is designated as piping plover critical habitat. Nearly all of the beaches on Grand Isle have been classified as heavy oiling. Because of its status as a high-use amenity beach, there have been extensive shoreline protection and treatment activities since the beginning of the response.

Grand Isle, exclusive of the State Park beaches, has undergone extensive mechanical shoreline treatment. Because it had to meet amenity beach cleanup endpoints of no visible oil, many different methods have been used. Surface oil was removed using both manual and mechanical methods. Cherrington beach cleaners were operated in scrapping mode to remove the surface layer of oiled sand and store them in piles for either disposal or treatment. A sand washing plant was constructed in front of the dunes on Grand Isle with the intent to wash the sand for placement back on the beach (Figure 16). It operated from July-November 2010 and treated 22,948 cubic yards of sand. By December 2010, there were approximately 35,000 cubic yards of sand in piles along Grand Isle (FitzGerald and Jepson, 2010).

Figure 16. The MI-Swaco sand washing plant operated on Grand Isle, LA from July to December 2010. Photo courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

Surf washing (dumping the sand into the surf zone for reworking by waves) was tested but never approved. Thus, these piles were screened to remove/break up the oil particles, and the treated sand was spread back on the beach. There was also extensive tilling along Grand Isle (see Figure 9), using agricultural-type equipment that worked in parallel lines and multiple passes over the same area. The goal was to turn over the beach sand to depths of 18 inches, so that the larger oil particles could subsequently be removed by beach cleaning equipment; tilling would also break up the smaller oil pieces and expose the oil to higher rates of weathering.

Grand Isle State Park, on the eastern end of Grand Isle, also had undergone extensive shoreline treatment, with mostly manual removal methods because of limited access for mechanical equipment and the recommendation of the park management. However, the extent of manual removal operations has been extensive. Some of the oil was buried up to 4 feet, requiring extensive excavation for removal. Figure 17 shows an example of the manual removal efforts, with mechanical removal of the clean overburden.

No information is available for the amount of oiled waste removed prior to June 2011; however between June 2011 and February 2014, Operations reported removing 531,111 pounds (787 cubic yards) of oiled waste from Grand Isle beaches. Operations are still active on the eastern part of the island as of the end of February 2014.

Once most of the mechanical treatments were completed, cleanup workers conducted manual P&M visits at four times a week starting in August 2011, with some reductions along certain segments to 1-2 visits per week. In November 2012, the frequencies of P&M visits along the eastern 2/3 of the island were increased to five times per week, to address increased oiling since Hurricane Isaac.

Figure 17. Manual removal operations in Grand Isle State Park on 1 November 2010. Images Map courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

There were several intensive augering events (BOP and LAASR) on Grand Isle in 2013, with nearly 5,000 auger holes excavated and recovery of over 400,000 pounds (593 cubic yards) of oiled waste.

Grand Terre I

Grand Terre I is the first island east of Grand Isle. Ft. Livingston, which is listed on the National Register of Historical Places, is located on the western end of the island. Grand Terre I beaches are designated as piping plover critical habitat. The entire Gulf-facing beach was classified as heavier oiling. Parts of the Gulf beach are narrow at high tide, which limited access for mechanical treatment during high water levels. Bobcats were used to assist in tarmat excavation; forklifts and a swamp crane were used to transport oiled waste to staging areas; tracked long reach excavators were used to locate/remove tarmats in specific zones; and Cherrington sifters and walk-behind Sandman sifters were also used. Auguring was conducted in December 2010 using a large tracked excavator with an auger attachment and a smaller bobcat.

Overall, mechanical treatment methods used smaller equipment and less often, compared with operations on Grand Terre II and III. Also, the main access/staging area on the island was via dock/marina facilities on the back side of the island, so there was limited disturbance to the sand beach habitat at the staging areas. However, there was extensive UTV traffic along the high-tide line. There were several intensive augering events (BOP and LAASR) on both islands in 2013.

No information is available for the amount of oiled waste removed prior to June 2011; however between June 2011 and February 2014, Operations reported removing 271,558 pounds (402 cubic yards) of oiled waste from the island.

Grand Terre II

The sand beaches on Grand Terre II (also known as East Grand Terre) were classified as heavily oiled. They are designated as critical habitat for the piping plover. Grand Terre II supports least tern nesting colonies, an endangered species, and has limited access.

There was an active beach nourishment project on Grand Terre II while the oil was coming ashore; thus, there was potential for deep burial of oil. Manual and mechanical treatment was authorized in June 2010 and continued into early 2011. There was a major staging area set up on the western end of the island (Figure 18). There was extensive mechanical treatment, including tilling, excavation, and Power Screen operations (see photograph in Figure 7). Even during manual removal operations, there was extensive use of UTVs for transport of workers and materials to and from the water-access points on the western end of the islands. No information is available on the amount of oiled waste removed during the early stages of the response. From June 2011 to February 2014, operations reported removing 1,062,481 pounds (1,574 cubic yards) from Grand Terre II.

Figure 18. Grand Terre II staging area. Bottom left photograph taken on 8 January 2011. Photos courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

Of this amount, 52% was removed in March-July 2013 from the eastern end of the island where large mats were found during intensive augering conducted in February and March 2013.

Grand Terre III

Grand Terre III was classified as heavy oiling on both ends of the island, and moderate oiling along its central section. From June 2011 to February 2014, Operations reported removing 124,265 pounds (184 cubic yards) from Grand Terre III. There was mechanical cleanup near the ends of the island in March and April 2011, and augering and intensive manual removal on some segments in 2013 and 2014.

Bay La Mer, Chaland, Bastian Islands

These islands are grouped because they were all treated similarly, using mostly manual removal of surface oil and limited mechanical removal of buried mats in 2010 through early 2011. The islands were difficult to access, so visits by operational teams were sporadic. These islands were treated out of the Venice Operations Branch, and there is little documentation available on actual treatment areas, methods used, and amounts of oiled waste removed during the active cleaning period prior to June 2011.

On Bastian Island, Operations reported removal of 12,628 pounds (18.8 cubic yards) between June and November 2011. Shoreline treatment ended in November 2011, and all segments were moved out of the response in April 2012.

On Bay La Mer, Operations reported removal of 1,059 pounds (1.6 cubic yards) between June and November 2011. Shoreline treatment ended in November, and all segments were moved out of the response in May 2012.

On Chaland, Operations reported removal of 38,913 pounds (57.6 cubic yards) between June 2011 and September 2013 when shoreline treatment was completed. An intensive augering effort was conducted in June and July 2013 with 312 auger holes excavated in targeted areas under the Buried Oil Program and recovery of 5,685 pounds of oiled waste.

There are no readily available sources of information on which to determine the type of mechanical treatment by segment by month for the sand beaches on Bay La Mer, Chaland, and Bastian Island prior to June 2011. Because of the difficulty of accessing the island, a Response Injury category of 1 was assumed. The Ops Segment Tracker was used to assign Response Injury categories based on the number of visits per month, with the assumption that only manual removal and augering operations were conducted as of June 2011 until operations were terminated.

Southwest Pass

The sand beach at Southwest Pass is located on the eastern side of the pass. The oiling classification varied from heavy to light. UTVs were used to transport workers and materials from the only access point on either side of the channel between the river and the bay throughout the response. The treatment history for Southwest Pass sand beaches is summarized below:

- STR #11, 112, and 114 were issued on 9 July for manual removal of pooled oil.
- STR S3-009 was issued on 22 September 2010 and allowed only manual removal.
- STR S4-030 was issued on 1 June 2011 for P&M at bi-weekly intervals, using manual methods though walk-behind sifters were used as well.
- Because of nesting birds at the access points to both North and South Island, Environmental Holds prevented operations in spring 2011.
- On Southwest Pass beaches, Operations reported removal of 86,504 pounds (128 cubic yards) between June and December 2011. Shoreline treatment ended in December, and all segments were moved out of the response in May and June 2012.

With only manual removal methods used (including use of a walk-behind sifter), a Response Injury category of 1 was assigned to July 2010 to March 2011 for all segments on the island and for the months when cleanup teams worked on the island as documented in the Ops Segment Tracker starting in June 2011 until each segment was moved out of response.

Cowhorn Island, South Pass

The oiling on Cowhorn Island at South Pass was classified as very light to heavy. The flat, narrow beaches on Cowhorn Island are designated as critical habitat for the piping plover. They are also part of the Pass a Loutre State WMA, managed by the Louisiana Department of Wildlife and Fisheries. The initial treatment of Cowhorn Island was conducted under STR #110 issued on 28 June 2010 for removal of oil residue mats. Subsequent treatment operations were conducted on Cowhorn Island as part of STR S3-003 issued for South Pass on 18 October 2010, of which there were seven revisions. Manual removal methods only were allowed, and only one UTV was allowed to support operations during removal actions. Operations reported removal of 600 pounds (about 1 cubic yard) of oiled waste from June 2011 to November 2012. Some segments were moved out of the response in mid to late 2012. SCAT teams dug pits on Cowhorn Island in 2013 as part of the Buried Oil Program, with no areas requiring removal of subsurface oil.

It is assumed that Operations conducted cleanup on Cowhorn Island at less than 20 visits per month from June to September 2010. A Response Injury category of 2 was assigned from October 2010 to January 2011, a category of 1 was assigned for the months when cleanup teams worked on the island as documented in the Ops Segment Tracker starting in June 2011 until each segment was moved out of response.

Bird and Garden Islands, South Pass

Bird and Garden Islands are located on the northeast side of South Pass. The sand beaches are designated as critical habitat for piping plover. They are also part of the Pass a Loutre State WMA, managed by the LDWF. Most of the Gulf-facing sand beaches were treated using manual methods only during very sporadic visits, and use of UTVs was not allowed. Starting in June 2011, Operations reported removal of 205 pounds in two visits in December 2011, with no additional removal operations after that date. There are no readily available sources of information on which to determine the months of manual removal for the sand beaches on Garden Island prior to June 2011; however, only manual removal methods were used during that period and visits were likely less than 20 visits per month. Therefore a Response Injury category of 1 was assumed

Over five days in July 2011, SCAT teams conducted augering using hand augers in two washover areas to delineate the distribution of buried oil mats. Treatment of these buried mats in the two washover areas was conducted using manual and mechanical removal, in-situ wet and dry tilling, and flushing, starting in December 2010 and ending in September 2011. These segments were assigned a Response Injury category of 3 for those months.

South Spit, South Pass

South Spit is located on the southwest side of South Pass. It is part of the Pass a Loutre State WMA, managed by the LDWF. It is a high-use area for birds, with numerous shorebirds, terns, and pelicans. South Spit was very heavily oiled early in the response. Due to the very dynamic and changing shoreline due to wave and tidal conditions, much of the stranded oil quickly became buried.

Manual removal methods were allowed under STR #118 issued on 10 July 2010 and STR S3-003 issued on 17 October 2010. However, the extent of buried oil that released sheens on intertidal flats triggered the decision to conduct intense scraping, raking, tilling, and flushing under STR S3-003.r.1 issued on 21 December 2010, which proved to be ineffective. Because of the importance of the area for birds, it was ultimately decided to remove the buried oil layers by dredging, which started in August 2011 and was completed in December 2011, over a period of four months. Four areas, covering 556,063 ft^2 (12.77 acres) of supratidal and intertidal habitat, were excavated or bulldozed, with 79,334 yd^3 of sediments pumped via pipeline into the GOM nearshore for re-working by waves (surf washing) and eventual transport back onto the shoreline down current. To fill the excavated areas, sand was dredged from a subtidal borrow area and placed back into the dredged areas on the island. Figure 13 shows the areas proposed for dredging, the pipeline corridors, and the dispersal area. Because of these very intensive treatment methods, the western one-third of South Spit was assigned a Response Injury Level of 5 for August to December 2011.

The eastern two-thirds of South Spit was classified as heavy oiling with light oiling on the eastern end. Because most of the oil at South Spit was buried, a Response Injury category of 1 was assigned for the period of May 2010 to June 2011. After June 2011, there were two response visits in October and November 2011, and only 50 pounds were recovered in October 2011.

Chandeleur Islands

The Chandeleur Islands are part of the Breton NWR, managed by the USFWS. It is the second oldest NWR, established in 1904. The Chandeleur Islands are designated as critical habitat for the piping plover. The degree of shoreline oiling varied widely throughout the island chain, from heavy to very light. The islands are only accessible by boat, and cleanup crews were only able to conduct treatment operations during a few visits in 2010 because of weather and sea conditions.

Treatment was always under the close supervision of staff from the Breton NWR. STR S3-049 was issued on 25 February 2011 allowing manual removal. There was a major push to complete treatment operations in 2011, with removal of 662,175 pounds (981 cubic yards) of oiled waste along 11,726 feet of beach during 33 visits to treatment zone A, 4 visits to treatment zone B, 10 visits to treatment zone C, and one visit to treatment zone D from 19 March-30 May 2011. All visits were less than 20 per month. Note, however, zone A was deemed to be only 76% complete as of 30 May 2011, and there are no entries in the Ops Segment Tracker for this STR. The USFWS supervised all removal operations on the island, and asked that all Breton NWR lands be moved out of the response without further treatment in April 2012.

There are no readily available sources of information on which to determine the months of manual removal for the sand beaches on the Chandeleur Islands prior to March 2011.

4.4.4 Texas

In Texas, Rapid Assessment Teams (RAT) documented the extent of shoreline oiling, and Nixon et al. (2015) used these data to determine that 36.1 miles of sand beaches were classified as Trace (less than 1%) oiling. Texas General Land Office reported all oiled beaches had manual treatment operations, including use of UTVs for crew access and transport. Treatment operations were conducted over two months (July-August) in the summer of 2010 along 95 miles of shoreline. No response injury is assessed for treatment operations in Texas.

4.5 Amount of Oiled Waste Removed from Sand Beaches

For many spills, one indicator of the intensity of shoreline treatment is the amount of oiled waste removed during treatment operations. While this is true for some of the beaches oiled from the *Deepwater Horizon* oil spill, other beaches (i.e., amenity beaches) required a higher degree of effort to meet stricter cleanup guidelines specified under the different shoreline treatment plans. Information on removal amounts was used to support the assessment of response injury in combination with other information on levels of effort as previously discussed. Operations only started reporting (in the "Ops Tracker" spreadsheet) removal quantities in a comprehensive manner in June 2011. This information was reported weekly either by shoreline segment (Florida to Mississippi) or Ops Zone (Louisiana). Mississippi Operations put out a report on 15 May 2011 in which they reported the pounds of material recovered on the islands and the mainland in Mississippi. Otherwise, data on removal quantities prior to June 2011 are scattered on individual daily reports. Table 5 lists the available information on removal quantities compiled to date by State and time period for sand beach segments/zones. These amounts total 98,738,428 pounds or 49,369 tons. However, Nolan (2105) reported the following summary on removal amounts:

> "The total product collected in 2010 was 86,274 tons (85% of all collections; in 2011, 9,292 tons (9%) of all collections; in 2012, 3,275 tons (3%); and in 2013, 3,068 tons (3%). The product collected in 2014 (16 tons) represents less than 0.02% of the total collections. Collection numbers early in the response included significant amounts of oily waste solids, such as vegetation, protective clothing, and beach trash (e.g., cans, glass, paper).

The amounts of oiled wasted materials reported by Nolan (2015) total 203,850,000 pounds or 101,925 tons, which are over twice as much as documented in Table 5.

Table 5. Pounds of oiled waste removed from sand beaches based on available data.

State	Prior to June 2011 (pounds)	June 2011 – February 2014 (pounds)
Texas	17,454[a]	
Louisiana	76,062,800	15,176,296
Mississippi	3,886,415 (total) 3,423,049 (islands) 454,366 (mainland)	113,061
Alabama	2,569,200 (Oiled Debris to July 2011)	930,656
Florida	Not available	66,276

[a] Equates to 10% of the total volume of oily solids disposed of by contractors (Texas Unified Command Memo, 2011).

Reported removal quantities from the Ops Trackers for June 2011 through February 2014 were plotted using a 3D format to show the amount of oiled waste removed monthly from each segment. It is important to note that the segment lengths for the Eastern States are very uniform and about 480 m long. In contrast, the Ops zone lengths in Louisiana vary widely, making it difficult to compare within Louisiana and with the other states.

Figures 19 and 20 show plots for segments in Florida, from west to east. It is important to note that the y-axis scale varies for each; that is, for Figure 19 covering Okaloosa and Washington Counties, the y-axis is 0-70 pounds; for Figure 20 covering Escambia County, the y-axis is 0-2,000 pounds. In each figure, the x-axis shows the response segments for those counties. The quantity of oiled waste removed from the sand beach each month is shown along the y-axis, with each month plotted along the z-axis. Looking at Figure 19, in June 2011, oiled wastes were removed from nearly every segment, with most of the removal amounts occurring in central Walton County. Monthly, removal quantities steadily decreased in Walton County after June 2011. A very different pattern was observed for Escambia County where higher quantities were removed (Figure 20). The discovery of submerged oil mats (SOMs) along the shoreline of Escambia County contributed to the overall higher amount of oil removed in these segments. After storms moved through the area and broke up the SOMs, there were re-oiling pulses that increased the removal quantities. These events continued in September and October 2012, as can be seen from peaks in the pounds removed after strong storms moved through the area.

A similar response can be observed in Baldwin County, Alabama (Figure 21) where the long-term efforts to remove SOMs and buried oil mats has extended the shoreline treatment. On this figure, waste oil removal approached as much as 5,000 pounds per month at some segments. In Mobile County, Alabama (Figure 22), the intensity of the efforts to remove oil from West Point Island since June 2011 was much lower and corresponded to the duration and degree of oiling these segments received.

The mainland beaches of Mississippi (Figure 23) were protected by the barrier islands and received lower levels of oiling, which reduced the amount of oiled wastes removed. On the barrier islands, which caught most of the stranded oil, environmental holds and access limitations resulted in periods of no activity followed by higher activity and removals (Figure 24).

For Louisiana, Figure 25 shows the amounts of oiled waste removed from the sand beaches on the Mississippi River delta, from Southwest Pass and South Pass. Most of the treatments at South Pass and South Spit were in-situ with relatively low removal quantities reported. Along the outer beaches from Trinity Island to Chaland/Bay La Mer Islands, reported oil waste removal approached 50,000 pounds per month. Fourchon and Elmers Island received heavy oiling and intensive treatments as can be seen in the increased amount of oiled waste removal in Figure 26. The Grand Terres also had significant increases in oiled waste removal and treatment after on-going removal of mats and re-exposed oil efforts were increased after Tropical Storm Lee in September 2011 and Hurricane Isaac in August 2012.

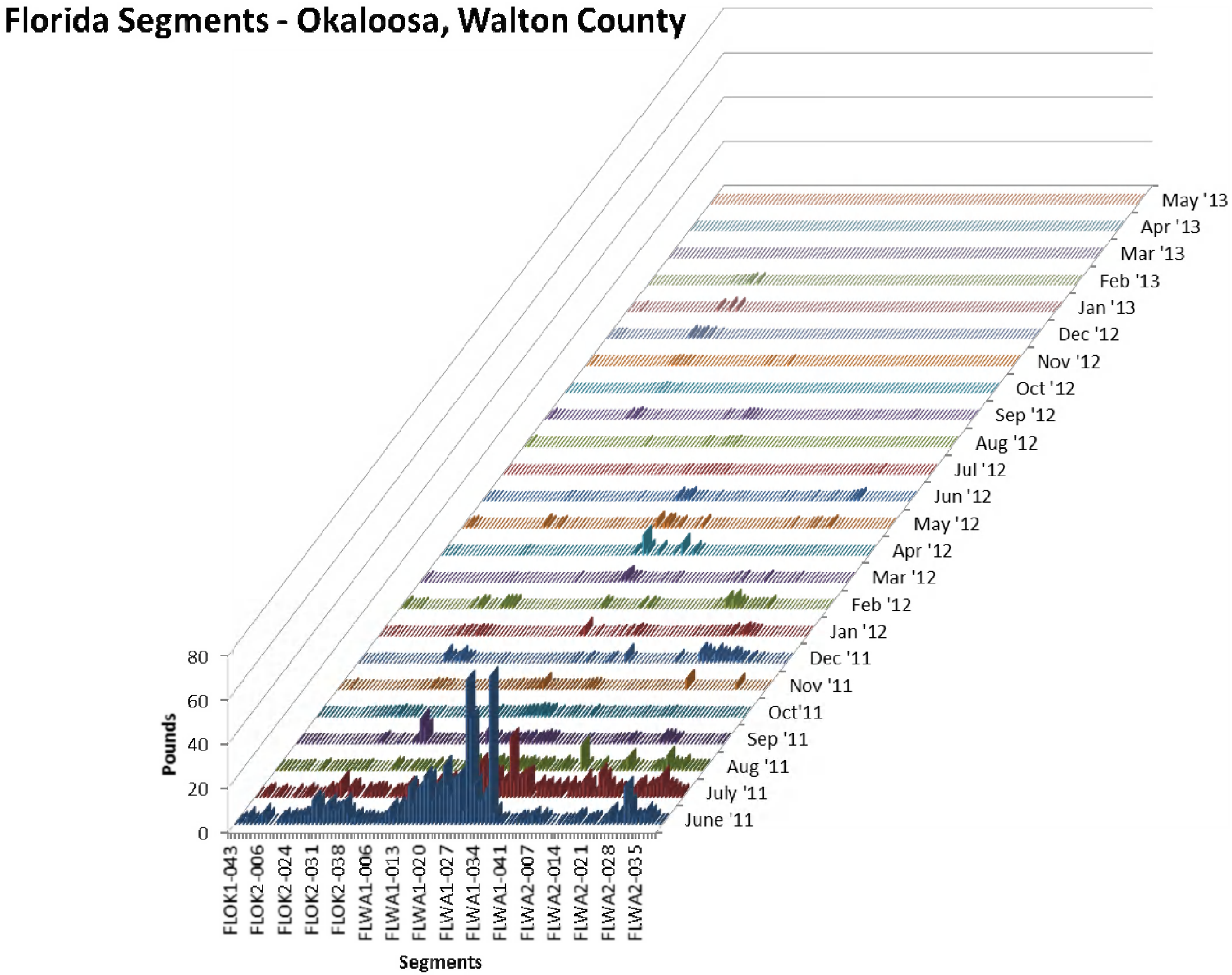

Figure 19. Pounds of oiled waste removed from sand beaches in Okaloosa and Washington Counties, FL Jun 2011-May 2013. **Note differences in the pounds scale for all these types of plots.**

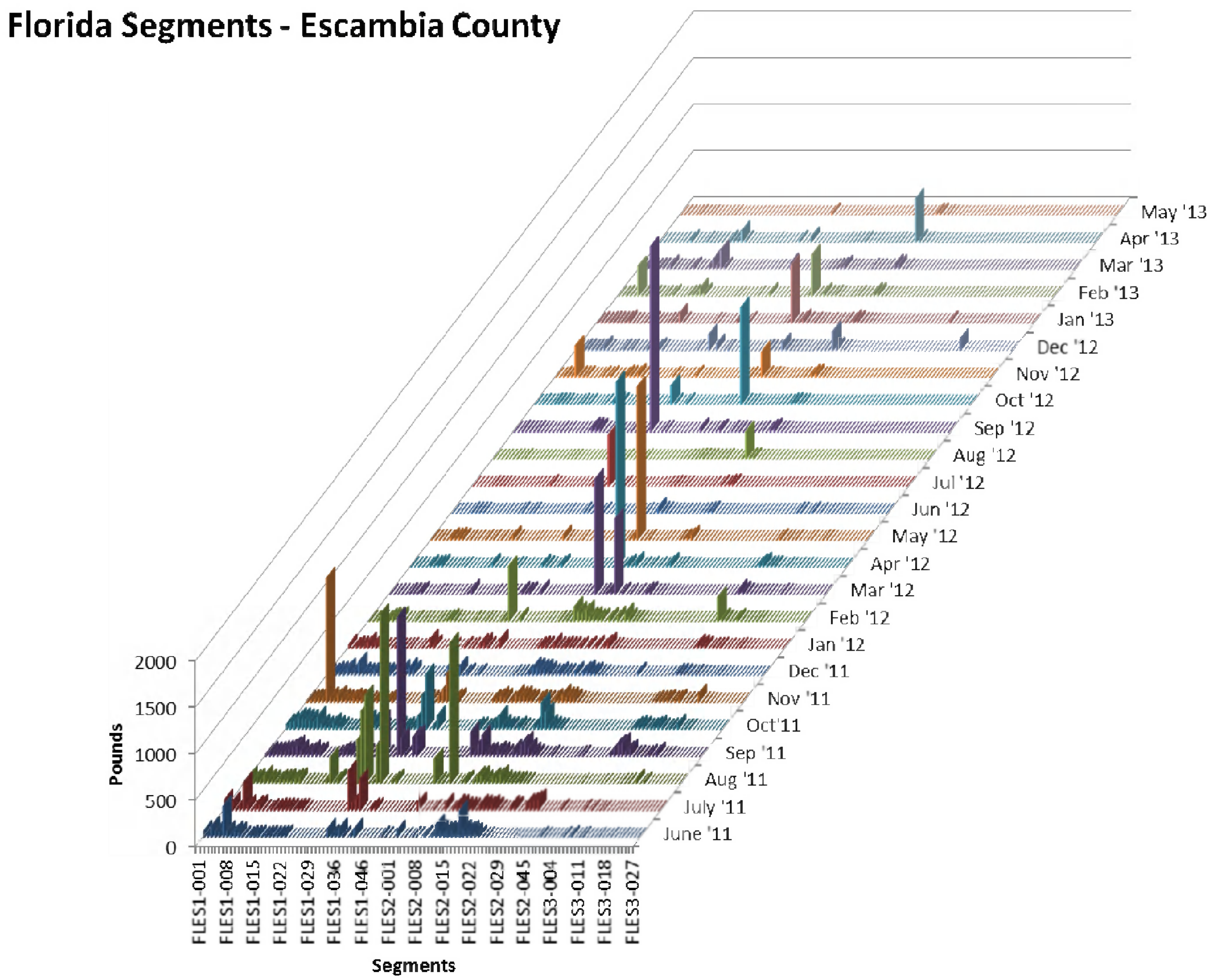

Figure 20. Pounds of oiled waste removed from sand beaches in Escambia County, FL Jun 2011-May 2013.

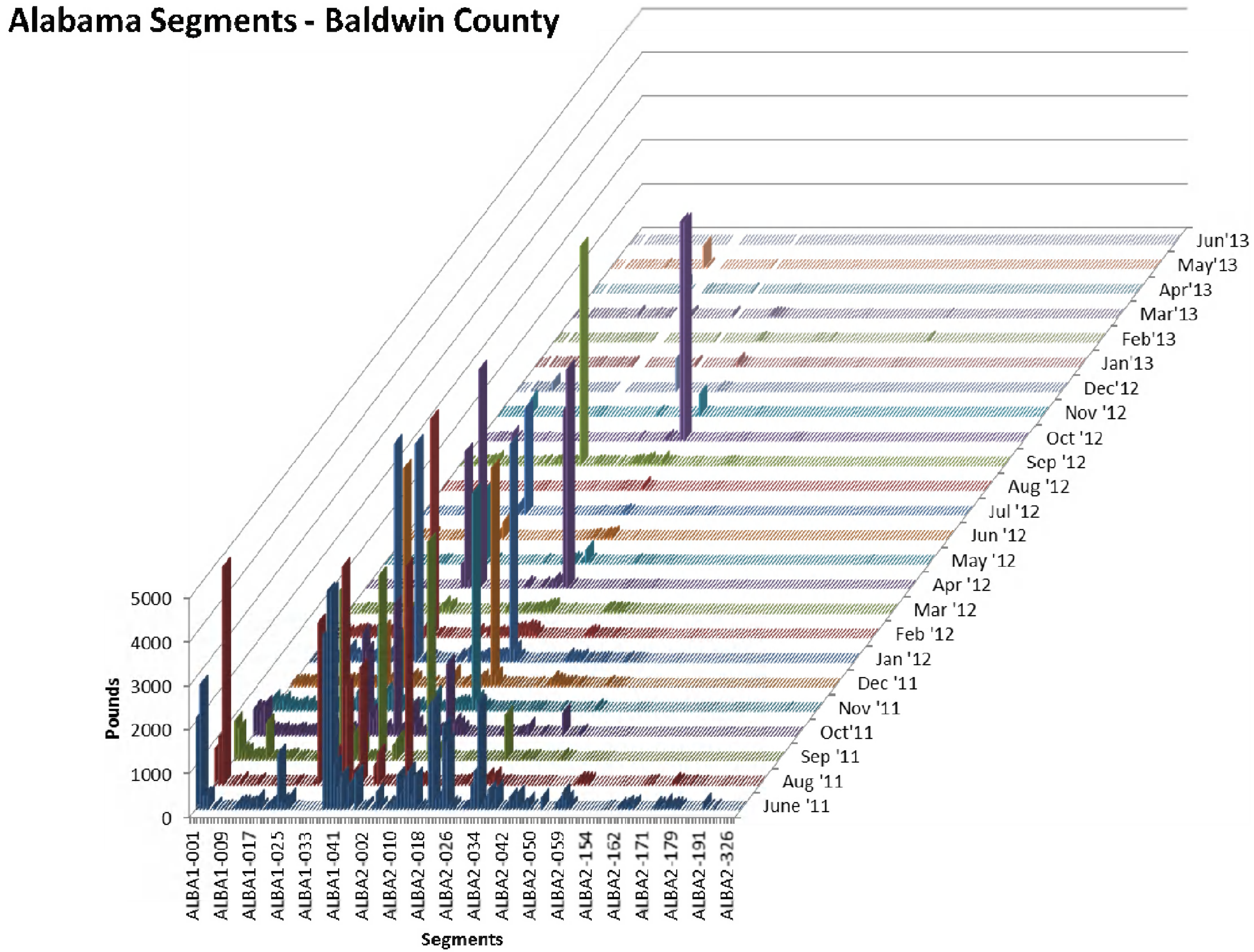

Figure 21. Pounds of oiled waste removed from sand beaches in Baldwin County, AL Jun 2011-Jun 2013. Note scale.

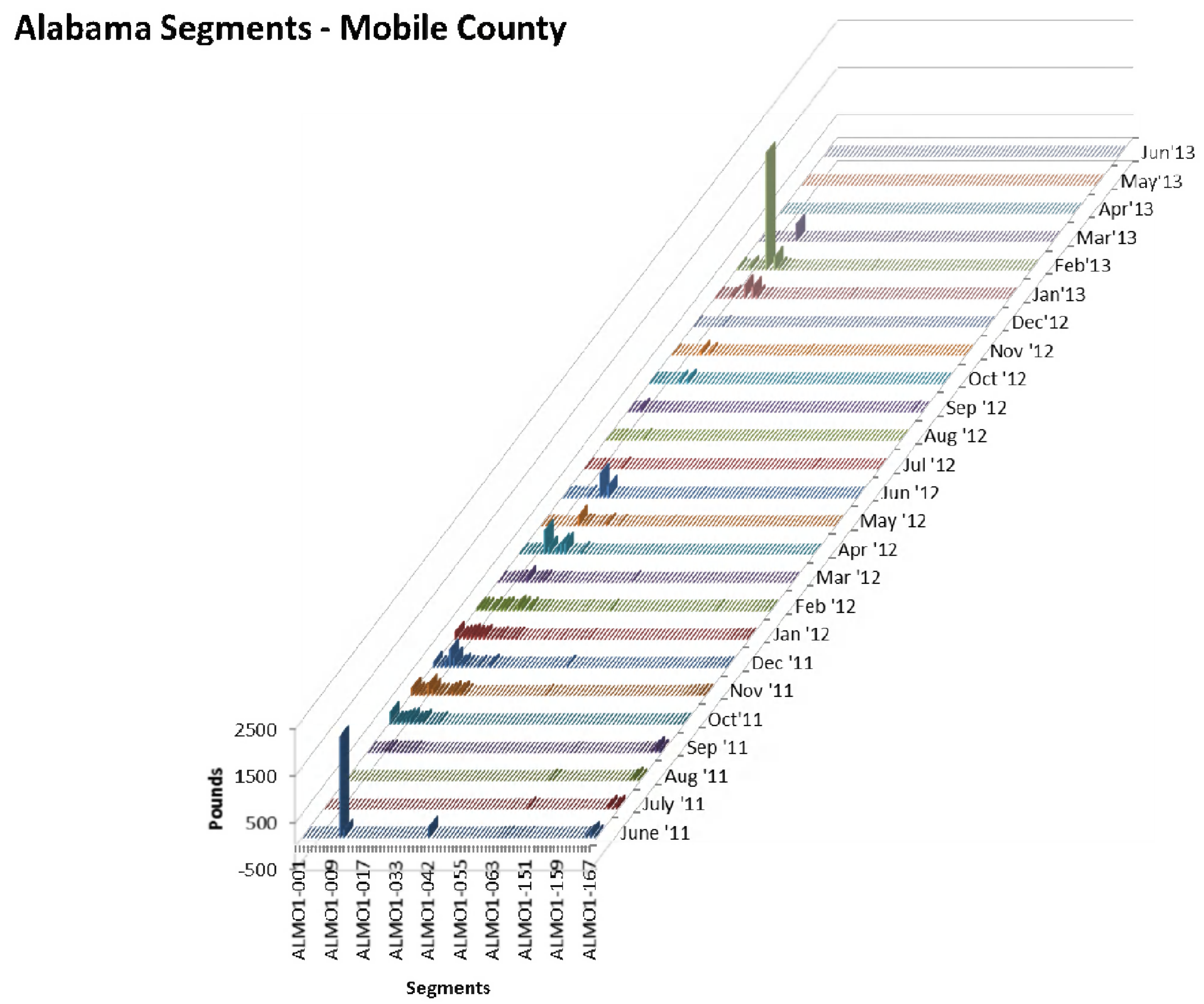

Figure 22. Pounds of oiled waste removed from sand beaches in Mobile County, AL Jun 2011-Jun 2013. Note scale.

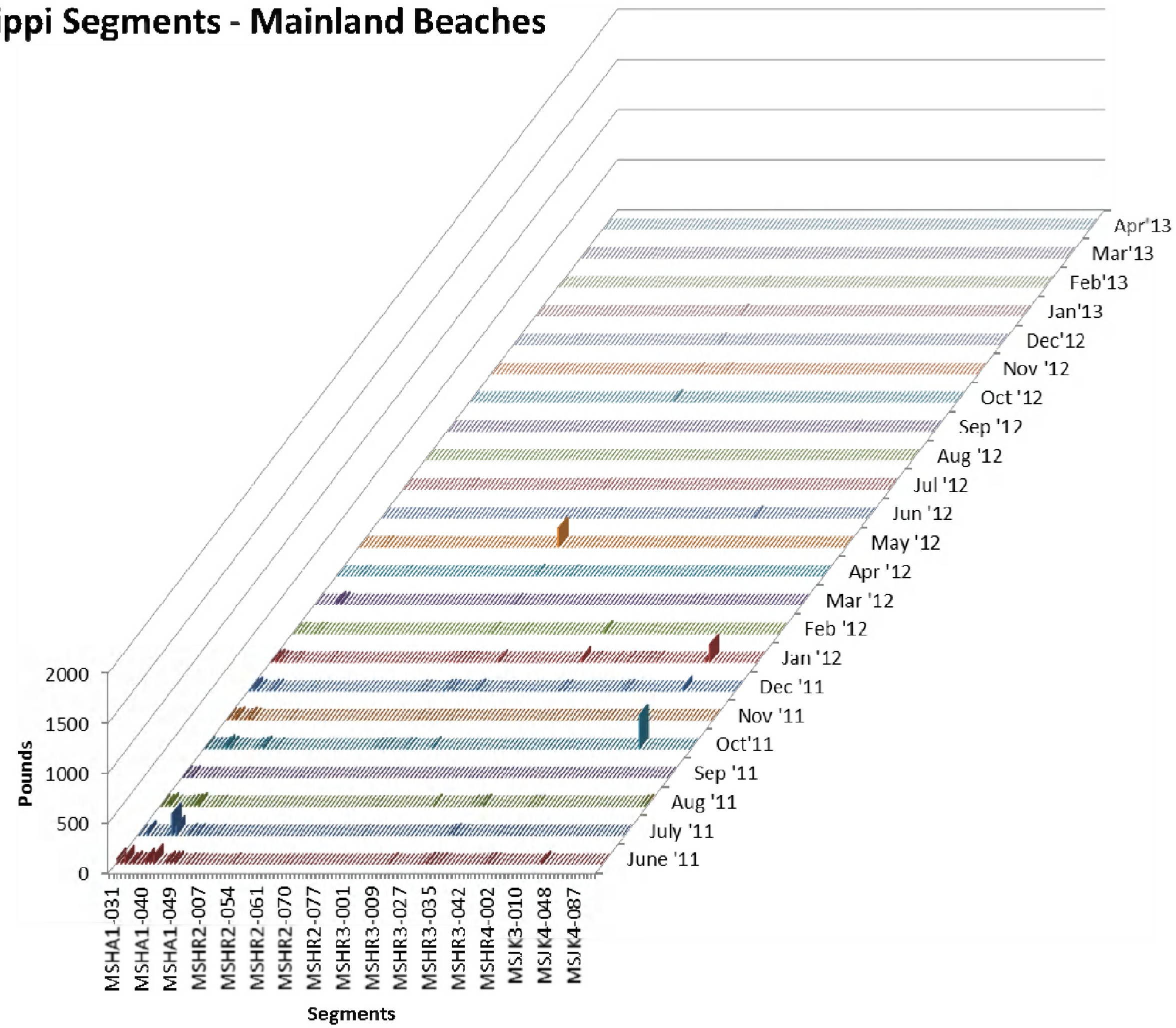

Figure 23. Pounds of oiled waste removed from sand beaches on the Mississippi mainland Jun 2011-Apr 2013. **Note scale.**

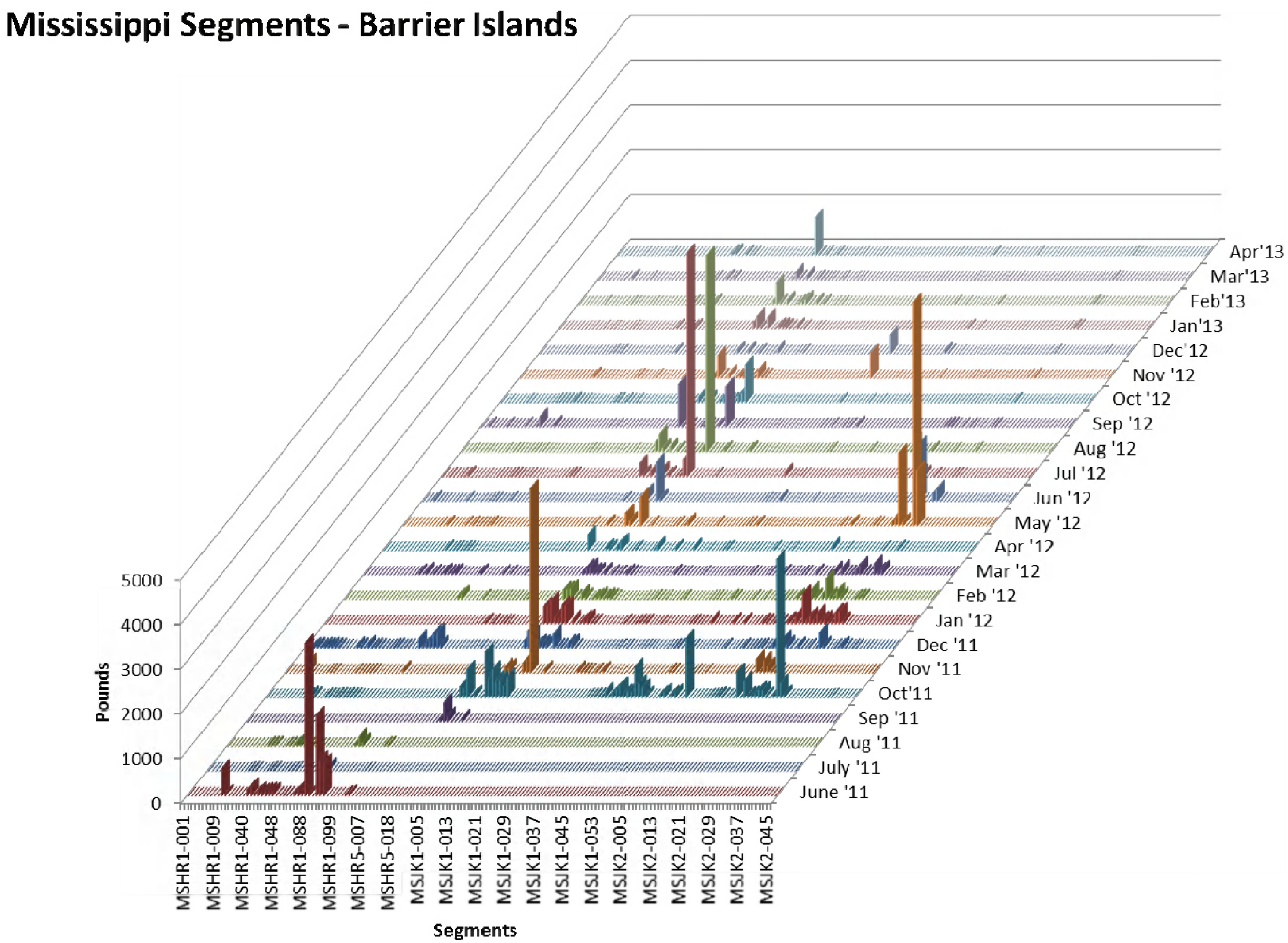

Figure 24. Pounds of oiled waste removed from sand beaches on the Mississippi barrier islands Jun 2011-Apr 2013. **Note scale.**

Final

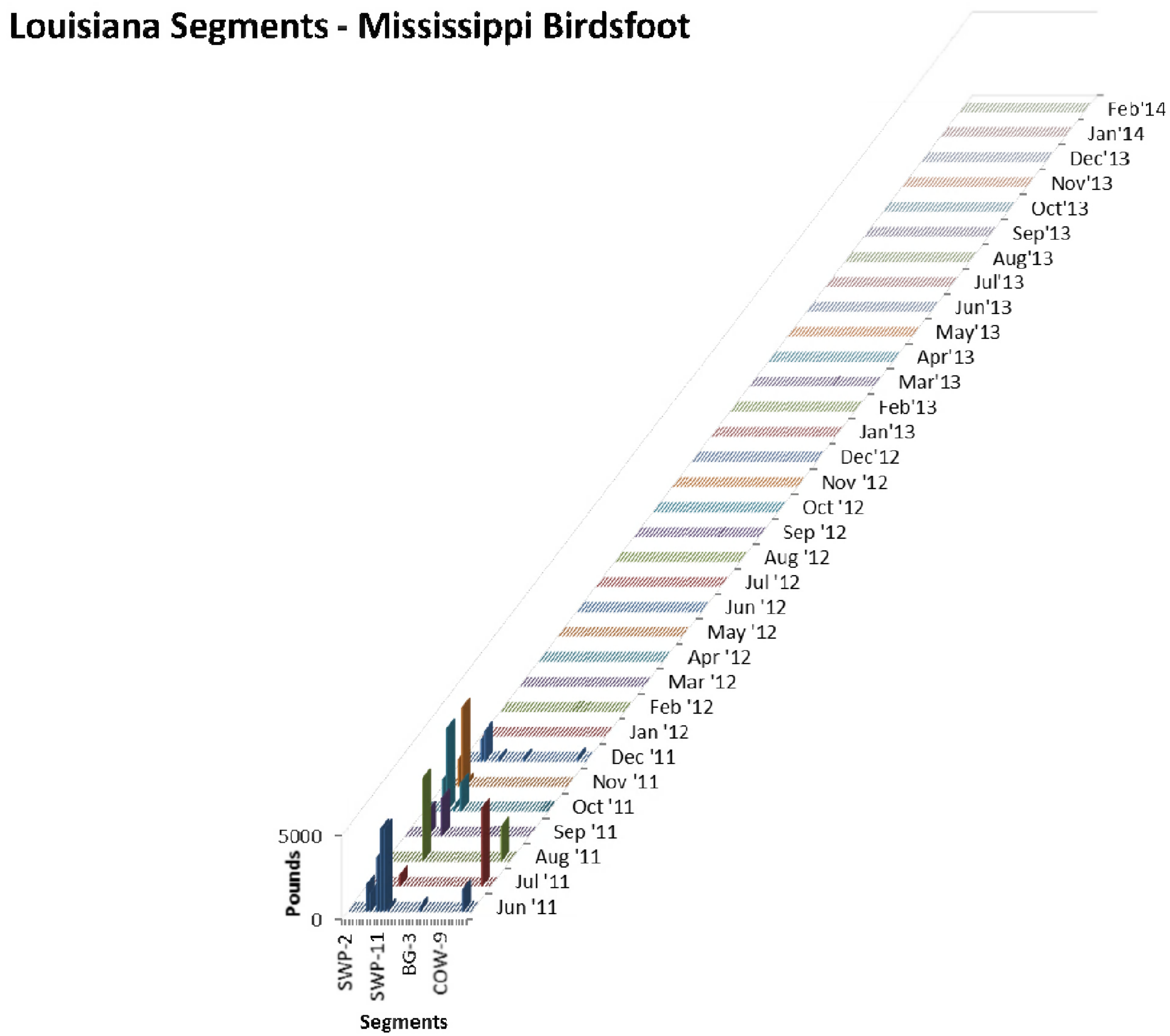

Figure 25. Pounds of oiled waste removed from sand beaches on the Mississippi birdsfoot, LA Jun 2011-Feb 2014. **Note scale.**

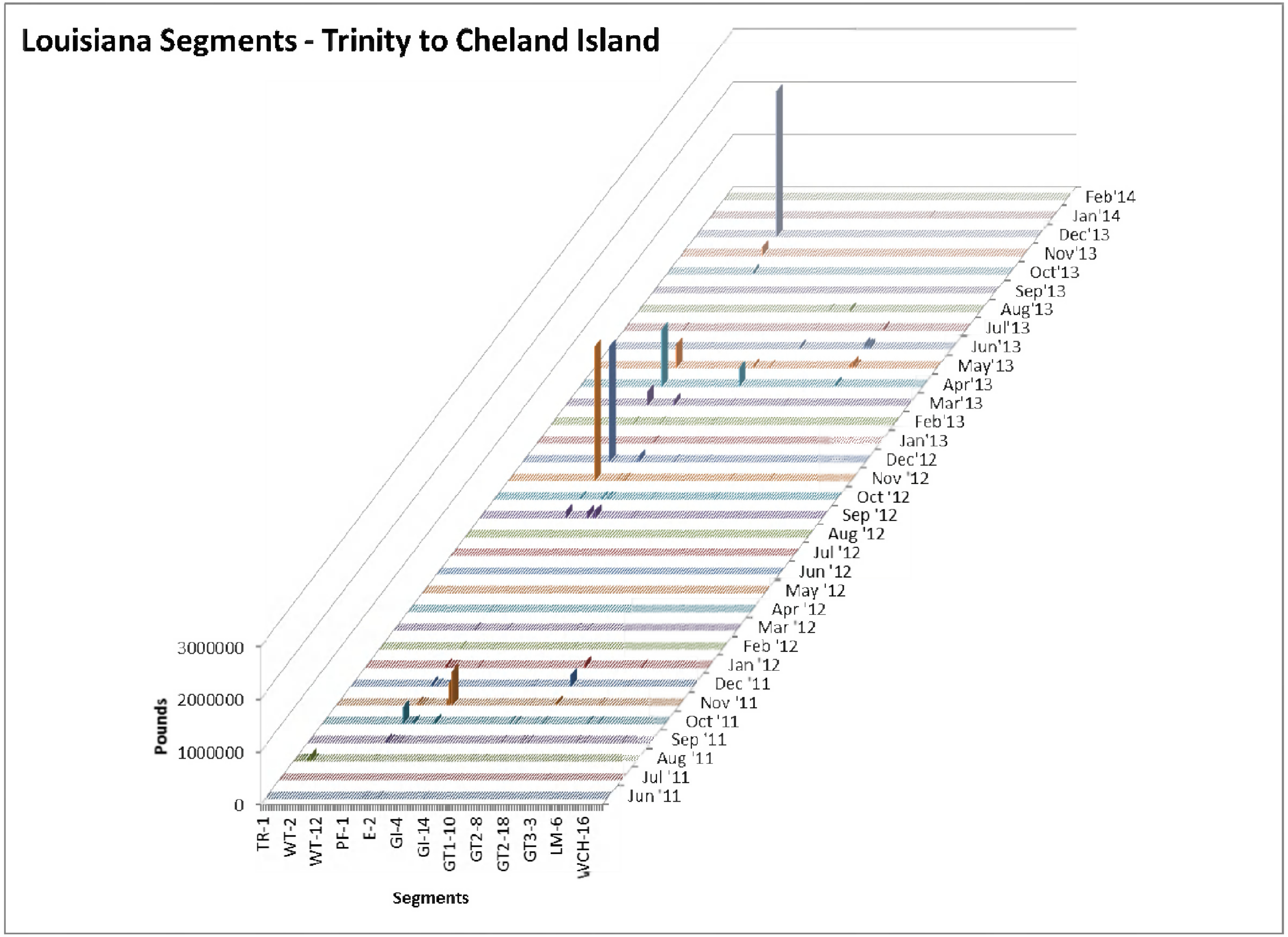

Figure 26. Pounds of oiled waste removed from sand beaches from Trinity Island to Chaland/Bay La Mer, LA Jun 2011-Feb 2014. **Note dramatic change in scale.**

4.6 Shoreline Protection Types of Response Injury

As part of the response to the *Deepwater Horizon* oil spill, physical barriers and berms were constructed to prevent the transport of oil through topographically low areas on into highly sensitive back-barrier environments. These physical barriers and berms had varying levels of success. For sand beach habitats, the barriers and berms were constructed primarily in Louisiana and Alabama. Table 6 summarizes the locations, types, lengths, and duration of these barriers and berms. Where the lengths were not provided in existing documents, the lengths were digitized along the shoreline using the latitudes and longitudes provided in permits or other sources.

Figure 27 shows examples of several of these structures in Louisiana. Figure 28 shows the areas on the bay side of Dauphin Island where sand was excavated to build sand berms on both the north and south sides of the island. After Hurricane Isaac, some of these excavated areas were opened to the Mississippi Sound, with the potential for significant erosion during north winds in winter.

The topographically low areas that were blocked by these structures are important pathways for animals to transit between terrestrial and marine environments. Their blockage would have affected movement between habitats, access to food and water, and nesting sites.

Installation of these features required the construction of access points, transport of heavy equipment to the site, extensive equipment operations at the site during installation, vehicular traffic for inspection and maintenance, and repeated access and equipment operational impacts during removal. Figure 29 shows the intensive supratidal habitat disturbances associated with removal of the Hesco baskets. Information will need to be compiled on the types of impacts associated with the placement or removal of these barriers.

Figure 27. Examples of physical barriers placed on sand beaches in Louisiana. Top left: Closing a breach on Fourchon Beach, 18 May 2010. Top right: Tiger Boom on Grand Isle, 4 June 2010. Bottom row: Hesco baskets on Fourchon Beach in May 2010. Photos courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

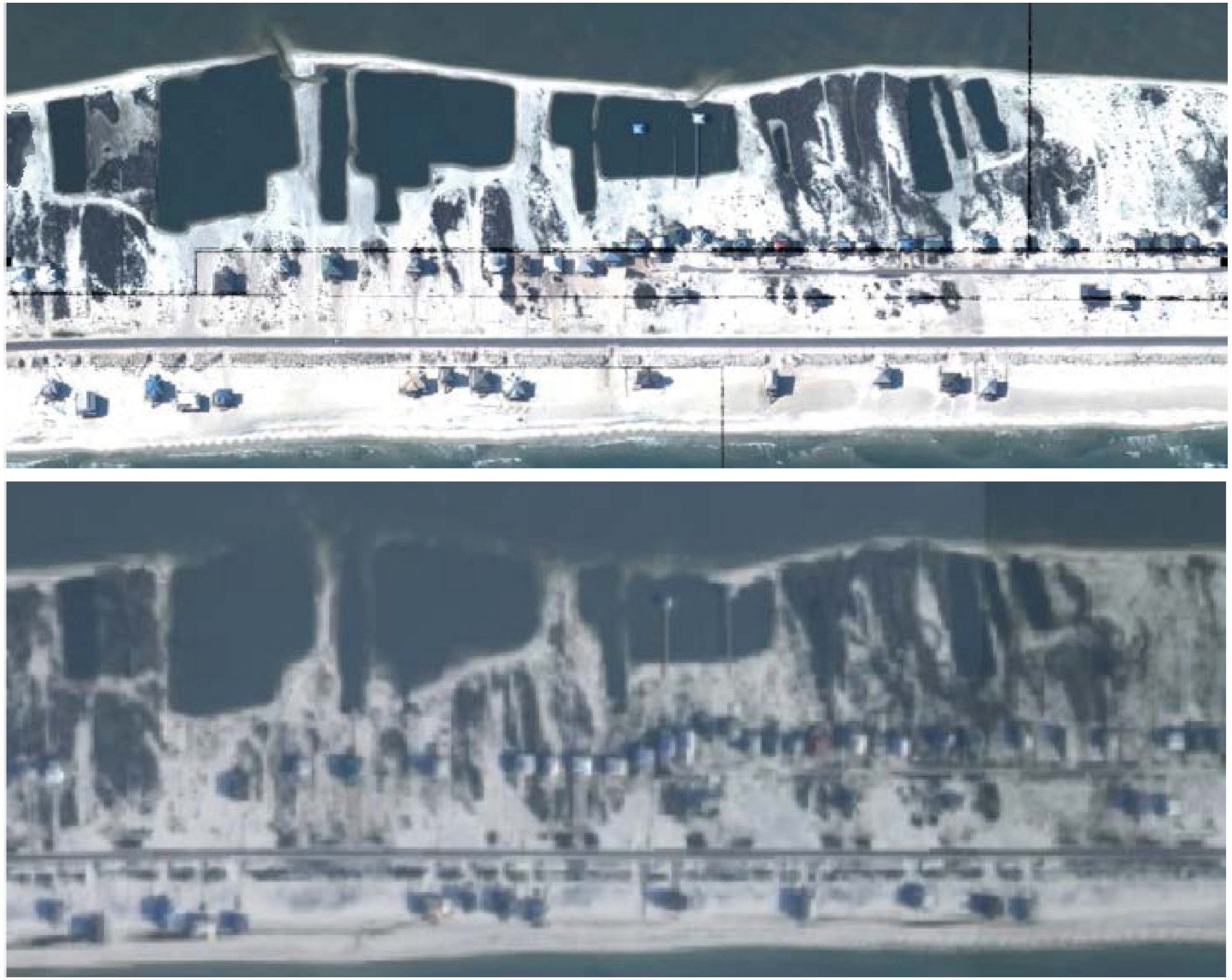

Figure 28. Areas on Dauphin Island that were excavated for construction of sand berms. Top = 1/14/2012 Google Earth Image; Bottom = September 2012 Post-Hurricane Isaac imagery.

Figure 29. Top Row: Removal of Hesco baskets on Fourchon Beach in fall of 2012. Bottom Row: Before (left) and after (right) removal. Map courtesy DWH SCAT program provided by Unified Command and RPI, uncredited.

Table 6. Known physical barriers, sand berms, breach closures, and borrow sites on sand beach habitats as part of the response to the DWH oil spill.

Location	Type	Length (Ft)	Duration in Place
Louisiana			
Cameron Parish: 7 segments	Hesco baskets	Total = 43,500	Installed June 2010, removed January 2011; 7 mo
Trinity Island	Sand bags, 25 sheets of plywood	125	Installed July 2010, removed Dec 2011; 17 mo
Timbalier Island	Sheet piling	243	Installed July 2010, removed Dec 2011; 17 mo
Fourchon Beach: 29°6'16"N/90°10'45.90" W to 29°7'46.80"N/ 90°8'55.5"W	Hesco baskets	16,290	Installed July 2010, removed February 2011; 7 mo
Fourchon Beach 5 sites	Breach closures: riprap, sand bags, sand, geotextiles, sheet piling	2,500	Installed May 2010, Removed Nov-Dec 2012; ~29 mo
Southwest Pass South Island: 28.966607, 89.365392 to 28.948688, 89.386279 North Island: 29.972522, 89.364683 to 29.003451, 89.333979	Tiger Dam boom	South Island = 9,800 North Island = 15,000	Installed mid-May 2010, still present 22 Sept 2010: at least 5 mo
Alabama			
Dauphin Island, Mississippi Sound shoreline: 88.202, 30.251 to 88.146, 30.254	Hesco baskets, with associated erosion and undercutting visible on late 2010 photos	18,520	Installed early May 2010, removed September 2010
Dauphin Island, Bienville Blvd: 30.248, 88.191 to 30.252, 88.147	Sand berm on Gulf side of Bienville Blvd, with gaps across roads and driveways, final height 3-4 m	14,240 long, 16-25 ft base width	Installed 4 May 2010, vegetated and remains as of April 2012
Dauphin Island, Gulf-front: 30.248, 88.191 to 30.247, 88.128	Sand berm, 2-3 m high	20,410 16-25 ft base width	Installed 19 May 2010, reduced by wave action in winter 2010/2011; ~ 7 mo
Little Lagoon	Sand dike north of the bridge, constructed with sand from adjacent shoreline	~6,000 yd^3	Installed June 2010, breached in August 2010
Orange Beach	Sand berm dune repair A90	1,015 30 ft base width	Installed June 2010, left in place, vegetated
Gulf Shores	Area A – 850 linear ft, 55-ft base width for dune breach Area B – 315 linear ft, 40-ft base width; 1,120 linear ft of dune escarpment repairs Area C – 1,100 linear ft, 55-ft base width for dune breach Area D – 2,275 linear feet, 55-ft base width for dune breach		Installed June 2010, left in place, vegetated

5.0 SAND AND BEACH INJURY ASSESSMENT

5.1 Sand Beach Communities

This section of the report focuses on estimating the injury and subsequent recovery of macroinvertebrate faunal communities that play pivotal roles in determining the quality and quantity of many beach ecosystem services.

The macrofauna that occur in beaches affect nutrient cycling rates and largely determine carbon (C) transfer to upper trophic levels. Sufficient general information about the behaviors and population characteristics of these species is available to provide reasonable estimates of the effects of oiling and response activities to the degradation and recovery of these ecosystem components, when combined with the limited amount of site-specific data. Remarkably, almost all studies on beach fauna conducted in the GOM have been conducted in regions outside of the coastal areas that were documented as oiled as a result of the DWH oil spill. A limited number of relevant studies have occurred either on the Texas coast (Hooper, 1981; Kindinger, 1981) or in the central-western portion of Florida, near Tampa Bay (Cobb and Arnold, 2008; Irlandi and Arnold, 2008). These locations represent the western and eastern ends of a recognized biotic province, the northern GOM warm-temperate region (Yanez-Arancibia and Day, 2004). A few studies have been conducted on beaches in the western Florida panhandle (Rakocinski et al., 1991; 1998a,b) that provide some information on spatial and seasonal densities of beach fauna, but the spatial and temporal resolutions of these studies are very coarse and consequently provide limited information for constructing life-history patterns. Consequently, reasonable extraction of temporal and spatial patterns for the macrofauna from these studies is warranted.

The structure and nature of the habitat, fauna, and services offered by the supratidal and intertidal differ sufficiently that separating the beach into two functional components is warranted. Figure 30 shows a schematic of these tidal zones and representative sand beach macroinvertebrates associated with each zone.

The supratidal, or back beach, is the portion of the beach where wrack accumulates because this elevated portion of the beach is infrequently inundated by tides and wave run-up. The wrack, which generally consists of *Sargassum*, *Spartina* stems, and subtidal vascular grasses in the GOM, supports a community of invertebrates consisting of terrestrial, semi-terrestrial, and marine species. The terrestrial species (air-breathing species where the majority of their life-cycle occurs in terrestrial or freshwater habitats) include insects (springtails, flies, beetles, and ants) and chelicerates (spiders and mites). The semi-terrestrial species (air-breathing through moistened gills but dependent on saline waters for part of their life cycle) include several species of talitrid amphipods and ghost crabs. The marine species (water-breathing through gills and dependent on saline waters for all of their life cycle) include haustorid amphipods and some polychaetes. These organisms shred the wrack while feeding and are, themselves, often consumed by shorebirds, passerines, and mammals. The shredding of the wrack produces fine particulate organic matter that subsequently is degraded by bacteria, releasing the nutrients bound within. The predation of this community directs C transfer into terrestrial food webs primarily. Ghost crabs do not depend directly on wrack. They are omnivores capable of feeding on marine and terrestrial plants and animals as well as carrion. Because of the relatively large size of ghost crabs, only a limited number of consumers predate them (e.g., raccoons, coyotes, gulls).

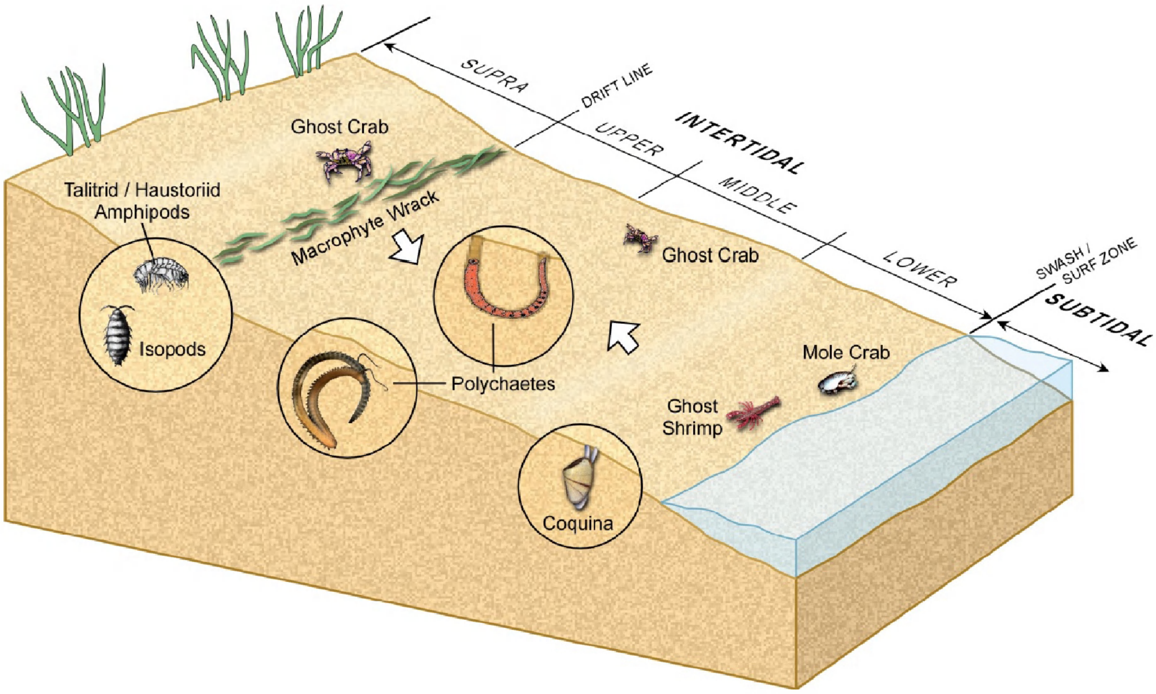

Figure 30. Distribution of representative sand beach invertebrates within the intertidal zone. The three zones of the intertidal zone grade into each other and are not necessarily rigid in their extent. The fauna typical of the middle intertidal zone is a combination of those found on the upper and lower intertidal zones (represented by arrows).

Wrack-associated organisms may comprise up to 40% of the intertidal species and represent an important prey source for higher trophic levels (Dugan et al., 2003). Dugan et al. (2000) found that species richness and abundance of selected taxa were positively correlated with macrophyte wrack cover. Dugan et al. (2003) recorded a mean abundance of 85 to 17,230 individuals/m for wrack-associated species in southern California. The density and species richness of Coleoptera (staphylinids, histeriids, and carabids) were greatest on beaches with high wrack input (5-11 species) and significantly reduced on beaches where wrack had been removed (0-2 species) (Dugan et al., 2003). This study also found that macrofauna associated with wrack only comprised <0.01-9% of the total macrofaunal biomass (ranging from 660 to >21,000 grams/meter [g/m]) on sand beaches. The mean biomass of wrack-associated macrofauna was low, ranging from 1 to 390 g/m.

Talitrid amphipods, ghost crabs, Haustoriid amphipods, and isopods are common organisms found in wrack (Nelson, 1993; Rothschild, 2004). Non-aquatic wrack species typically include wrack flies (Order Diptera), rove beetles (staphylinids; Order Coleoptera), and springtails (Order Collembola) (McLachlan and Brown, 2006). These species feed on decaying wrack as well as use the material for shelter.

Engelhard and Withers (1997) found that amphipods (Talitridae and Haustoriidae) comprised the majority of the wrack-associated macrofauna collected, representing 78.9% of the wrack community. The talitrid amphipod, *Orchestia grillus*, one of the most commonly found beach-endemics, is a detritivor that decomposes *Sargassum* and a primary contributor to biomass (Williams et al., 2008). This species peaks on Texas sand beaches from June through August and, along with insects, were the dominant grazers among the stranded wrack (Engelhard and Withers, 1997). Engelhard and Withers reported relative abundances of 1.7% and densities ranging from 0-600 individuals/m^2. The biomass values reported for *O. grillus* in this area ranged from 0-0.4 g/m^2. In southern California talitrid amphipods (*Megalorchestia* spp.) were the most abundant invertebrate in the wrack with a mean abundance ranging from 85 to 10,200 individuals/m and a biomass ranging from 1-378 g/m (Dugan et al., 2003).

Ocypode quadrata (ghost crab) is another supratidal zone invertebrate that burrows during the day and is surface-active mainly at night. This species is active from March through December and dormant during the winter months (Britton and Morton, 1989). Juveniles have shallow burrows (<0.5 m) and are typically found closer to the swash zone; adult ghost crabs are found from the swash zone landward toward the backshore with most burrows located above the drift line. The adult ghost crab burrows are typically deeper than juvenile burrows in order to have sufficient water supply. The burrows serve as protection from predators, harsh weather conditions, and provide a habitat for reproduction (Lucrezi and Schlacher, 2010). *O. quadrata* plays a key energetic role as the apex invertebrate predator and a major food source for higher trophic levels (e.g., birds). They are also prolific bioturbators (Schlacher, 2011) and one of the indicator species (i.e., species presence is indicative of the health of the ecosystem) listed for beach habitat in Florida's Comprehensive Wildlife Conservation Strategy (Irlandi and Arnold, 2008). Shelton and Robertson (1981) reported biomass values of 7 mg/m^2 and densities of 0.08 individuals/m^2 for *O. quadrata* on an exposed sand beach in Texas. Hobbs et al. (2008) recorded 0.02-0.13 individuals/m^2 on a North Carolina sand beach.

Insects collected within the wrack were from the orders Coleoptera, Collembola, Hemiptera (nymphs) and Diptera (larvae), and represented 12.4% of the wrack macrofauna (Engelhard and Withers, 1997). The rove beetle (Order Coleoptera) was the most common insect collected representing 62.7% of the wrack insects. Diptera typically colonize stranded wrack first, followed by beetles and other insects, and then amphipods. Engelhard and Withers (1997) reported peak densities for insects in mid-June and August along the Texas shoreline. The southern California wrack study reported density values for beetles (primarily Staphylind, *Bledius fenyesi*) from 51 to 5,160 individuals/m (Dugan et al., 2003). Juno et al. (2005) documented Diptera densities of 4.9 individual/m^2 from sand beaches in Spain. Filho et al. (2009) recorded total insect densities of 50-100 individuals/m^2 during the dry and wet season, respectively, in Brazil.

The intertidal beach community differs from the supratidal community in species composition, nutritional foundation, and fate of trophic transfer. The standing biomass in the intertidal greatly exceeds that which occurs in the supratidal zone. In the northern GOM, the intertidal benthic community consists entirely of marine species and is dominated by coquinas, mole crabs, polychaetes, and haustorid amphipods. The majority of these species are suspension feeders relying on beach or surf diatoms as their primary source of nutrition. Several shorebirds feed on these invertebrates, but almost no passerines do. Fish, especially juveniles of several species, predate on these invertebrates when the beach is inundated. Consequently, trophic transfer of C and nutrients from this part of the beach goes into both terrestrial and marine food webs.

Donax (the coquina clam) is a dominant genus on sandy beaches worldwide. This invertebrate is a major food source for birds (e.g., plovers, sanderlings), fish (e.g., drum), and crabs (Rothschild, 2004). They inhabit beaches with medium to strong water currents. This bivalve is both subtidal and intertidal, moving up and down on the intertidal zone with the tides (McLachlan and Brown, 2006). Their movements across the beach face are cued by the vibrations of the waves on the shoreline (Rothschild, 2004). Keller and Pomory (2008) observed an increase in *Donax* on the Florida Panhandle in the summer months. Shelton and Robertson (1981) found *Donax* to be most abundant on Texas sand beaches in spring and summer in the low to middle intertidal zone with a subtidal movement during the winter. Recruitment of young occurred mainly in May and October (Rothschild, 2004). The density of this species is quite variable within and among studies, recording 10,000 and 22-6,542 individuals/m^2 in Texas (Getter et al., 1981; Thebeau et al., 1981, respectively), 264-334 individuals/m^2 in North Carolina (Peterson et al., 2000), and 72-13,114 individuals/m^2 in Florida (Mikkelson, 1981 cited in Irlandi and Arnold, 2008). Shelton and Robertson (1981) observed high densities of *Donax* spp. on exposed sand beaches in Texas, with 233 individuals/m^2 on a mainland beach and 871 individuals/m^2 on a barrier island beach. *D. variabilis* was one of the most common and dominant species in the swash zone of selected beaches on the Gulf Islands National Seashore, where their densities ranged from 8 to 1,272/m^2 (Rakocinski et al., 1995). On some exposed beaches, this species tends to be one of the dominant species of the swash zone particularly during summer and fall (Rakocinski et al., 1998a).

Emerita (the mole crab) is an extremely mobile and patchy animal typically found on moderately exposed surf-swept sand beaches (Diaz, 1980; McLachlan and Brown, 2006). Like *Donax*, it migrates up and down with the tides, and feeds via suspension feeding through the filtering of water with their antennae. *Emerita* are most abundant on exposed sand beaches between spring and fall in the Florida Panhandle and Mississippi/Alabama barrier islands (Rakocinski et al., 1998a). On selected beaches of the Gulf Islands National Seashore, the density of *E. talpoida* ranged from 8 to 6,608/m^2 (Rakocinski et al., 1995). In the GOM, eggs are produced in the spring and females carry these eggs during the summer months (Rothschild, 2004; Britton and Morton, 1989). A Florida study in the GOM found that *Emerita* larvae may be released in early summer and fall with recruitment of individuals also occurring at this time (Irlandi and Arnold, 2008). Peterson et al. (2000) found densities from 137-159 individuals/m^2 in North Carolina. *Donax* and *Emerita* are both considered indicator species for beach habitat in Florida's Comprehensive Wildlife Conservation Strategy (Irlandi and Arnold, 2008). Although their temporal variability has not been fully documented in beaches of the GOM, an earlier study on a beach in North Carolina found large changes in their abundance, spanning several orders of magnitude, over a 15-month period and particularly between April and November (Leber, 1982). *Emerita* and *Donax* appear to be important trophic links between planktonic and detrital energy sources and important beach predators such as portunid and ocypodid crabs, and shorebirds (Leber, 1982).

Another group of common beach residents, polychaetes, are tube-dwelling or burrowing worms that suspension and deposit feed on detritus and organic material at the sediment surface (Engelhard and Withers, 1997). Most polychaetes are not deep burrowers as they require aerobic conditions; they are typically found in the upper layers of sediment. A common polychaete of the middle to lower tidal zone, *Scolelepis squamata*, is a fairly inactive species with low mobility. The absence of swimming activity makes this species particularly vulnerable to disturbance or contamination (Junoy et al., 2005). *S. squamata* has a peak in density in the summer (July) on Texas beaches (Engelhard and Withers, 1997) and in winter and spring on Mississippi beaches and the west coast beaches of Florida (Rakocinski et al., 1998a; Irlandi and Arnold, 2008, respectively). Thebeau et al. (1981) recorded densities of *S. squamata* between 22 and 1,658 individuals/m^2 along Texas beaches, and Rakocinski et al. (1995) reported densities from 8 to 3,536/m^2 on beaches of the Gulf Islands National Seashore. Shelton and Robertson (1981) saw much lower values during their study in Texas with densities ranging from 307 (barrier island) to 579 individuals/m^2 (mainland beach). This study also recorded biomass values of 0.33 (barrier island) and 0.45 g/m (mainland beach). Filho et al. (2009) recorded 350 individuals/m^2 of *S. squamata* on a Brazilian sand beach. *Dispio uncinata* is another beach polychaete most commonly found on protected beaches (Rakocinski et al., 1998a) at densities from 8 to 160/m^2 (Rakocinski et al., 1995).

Separating the beach into supratidal and intertidal portions also is necessitated given how beach treatment response activities were parsed between the two portions of the beach. The vast amount of mechanical beach cleanup activities occurred in the supratidal, with the notable exceptions of where intertidal and subtidal oil mats were removed. The pattern of recovery of supratidal populations will differ between the different tidal zones based on this condition alone.

5.2 Factors Influencing Rates of Recovery of Sand Beach Communities after Disturbance

Persistent strong forces generated by winds, waves, and currents on the beach induce frequent passive dispersal and active movement by both supratidal and intertidal species (McLachlan and Brown, 2006). In consequence, many studies examining the effects of disturbances to beach communities (e.g., dredge disposal, physical disruption by vehicular or pedestrian traffic, space-limited oil spills) find that beach faunal species recover to pre-disturbance abundances over relatively short time frames. However, accumulation of dispersing individuals in a previously disturbed location does not represent recovery of ecosystem services within the broader area. The absence of the emigrating individuals from the location from which they originated means that ecosystem services in the original location become lessened. The only net gain for ecosystem services to disturbed beach ecosystem arises from reproduction providing new individuals that survive and grow, thereby actually replacing those killed by the disturbance. Consequently, estimating actual recovery of oiled beaches services dependent on benthic invertebrates requires understanding the reproductive capabilities of the constituent species.

5.2.1 Reproduction of Beach Invertebrates

Two aspects of reproduction are relevant to considering the effects of oil spills and response activities to remove the oil on the indigenous beach species: the mode of reproduction and the occurrence of any seasonality in reproductive effort.

Invertebrate species occurring in the beach exhibit one of two different life-history modes (McLachlan and Brown, 2006; Figure 31). For the majority of species, the earlier life-history stages occur in a habitat or location distant from where the juveniles and adults occur.

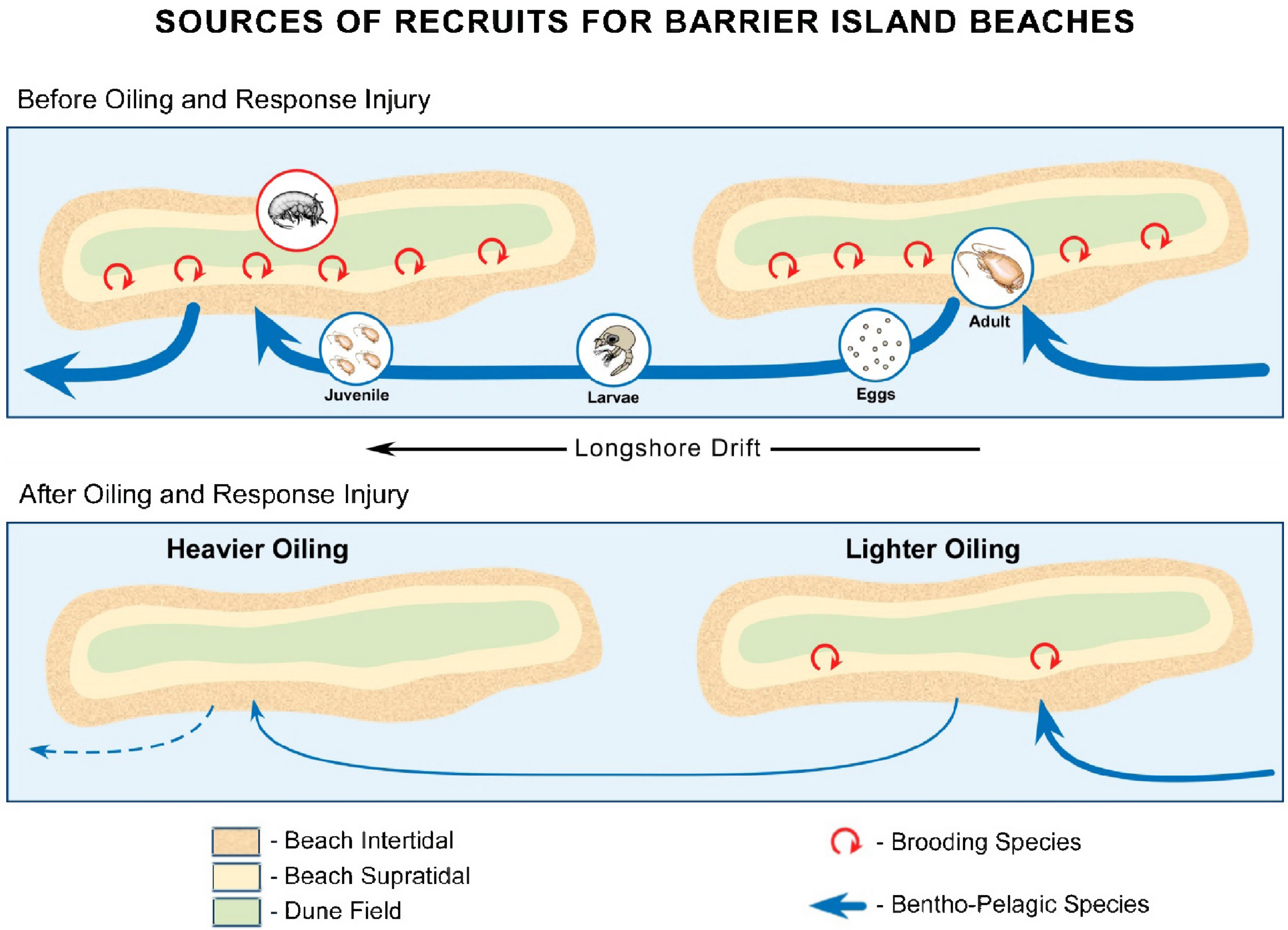

Figure 31. Schemmatic of the different life history modes of recruitment of of the bentho-pelatic species of the intertidal zone community and the brooding species that dominant the supratidal zone community.

For the marine species, this is known as the bentho-pelagic life cycle. Mature adults, living in the sediments, release fertilized eggs or larvae into the water column. The larvae drift passively for an interval of days to weeks, rarely months, while they develop. When they reach the last stage of larval development and if they have drifted to appropriate habitat, they metamorphose into juveniles. Similarly, many terrestrial species associated with wrack pass their earliest life-history stages in a location separate from the beach (although some diptera species use the wrack as their larval habitat). Usually dispersal does not occur in the nursery habitat. The second dominant life history mode occurs in the amphipods that exist in both the supratidal and intertidal zones. They are brooders. Females retain fertilized eggs on their body and, with all larval development occurring within the egg, release juveniles directly into the same location where the adults reside.

The consequences of these different life-history patterns on recovery of the respective species populations are substantial. Bentho-pelagic females produce thousands of larvae in each spawning event, and the larvae are widely dispersed, rarely back to the same location as their parents. This means that these species cannot exploit site-specific conditions if they are favorable, and the fate of the larvae (good or bad) differs from the adults. Dispersion to new habitats occurs during the larval phase. The terrestrial species likewise separate habitats for the adults and larvae, but the adults are the dispersive part of the life cycle. Brooders, which produce only a few (10's of individuals, at the most) young in each reproductive event, can exploit local conditions if they are favorable to the species. However, if local conditions deteriorate, they do so for both the parents and their progeny. Dispersion of brooders, which is limited in distance compared to planktonic larvae, occurs in the juvenile or adult stages and generally involves a small subset of the resident population.

For both life-history patterns, reproductive effort is constrained generally to discrete times of the year. The metabolic costs of reproduction are so high that it must follow intervals when the adults feed sufficiently well to support the metabolic costs of reproduction. For *Emerita*, on both the eastern U.S. and GOM coasts, reproduction occurs largely in a discrete two-month event in mid-summer as determined by counting the number of gravid females in the population or by back calculating from when juveniles recruit to the beach (Figure 32; Irlandi and Arnold, 2008). *Donax* show a more complex pattern. In the GOM, reproduction has been recorded as occurring in two, two-month long pulses, one in the spring and a smaller one in fall, with a very low level of persistent reproduction year round (Figure 31; Rothschild, 2004; Irlandi and Arnold, 2008). The third dominant species in the intertidal beach, *Scolelepis*, reproduces in a single pulse starting in the mid to late spring, but the pulse can extend over half year (Figure 32; Cobb and Arnold, 2008; Irlandi and Arnold, 2008). Less information is available on the timing of reproduction for the amphipod brooders in the beach, but what is available indicates that it occurs most often in late spring through early autumn (Croker, 1967). What is common to all of these species, regardless of reproductive mode and species-specific differences, is that late spring and early summer represent the interval when the annually dominant proportion of reproduction / recruitment occurs.

All three of these dominant intertidal species are functionally annual species. Although there is some evidence that a proportion of adults could live more than one year, all individuals that survive to reproduce do so for the first time in less than 12 months and only a small proportion of

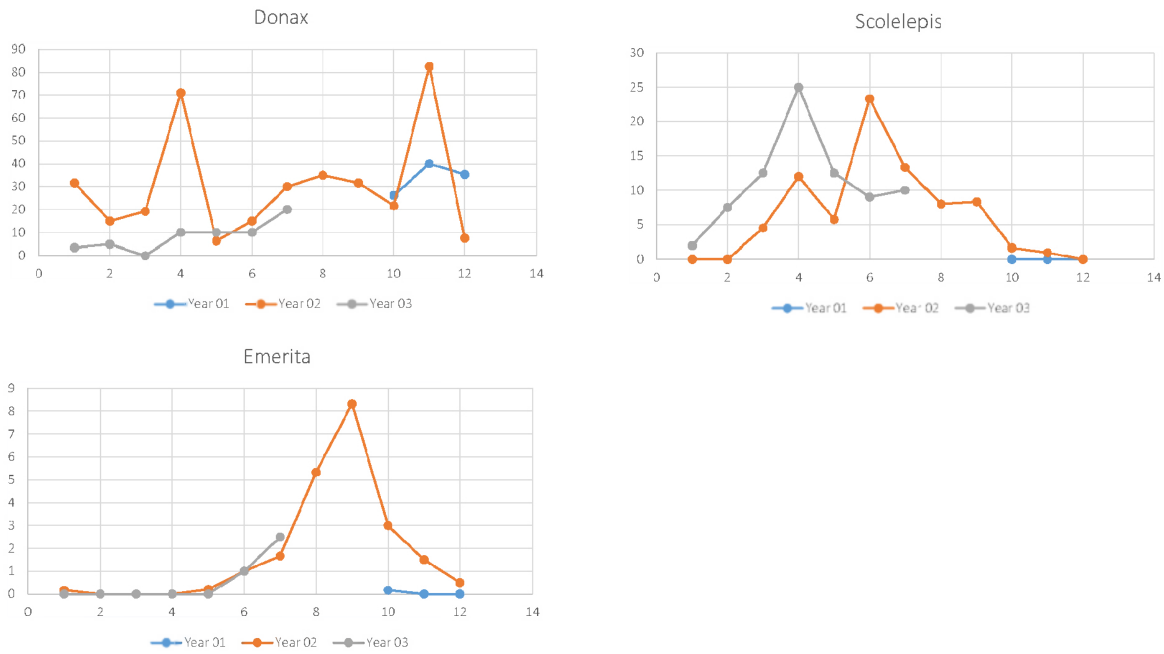

Figure 32. Monthly mean abundances (per unit volume) of the dominant intertidal benthos at exposed beaches in the Tampa Bay region (data from Irlandi and Arnold, 2008). The study began in October of 2005 (Year 1), continued through 2006 (Year 2), and ended in July of 2007 (Year 3).

the spawning population, if any, reproduce in a second year (Wilson, 1999). The population may have a mix of individuals at different stages of reproductive condition, allowing some reproduction throughout the year in GOM beaches (Cobb et al., 2008). Loss of an entire reproductive cohort before they have spawned would lead to substantial subsequent recruitment failure. Less catastrophic levels of mortality could also lead to recruitment failure because of sublethal effects leading to abortion of gamete development, production of non-viable gametes, reduced numbers of juveniles that would have grown into the mature phase during the spawning interval, and an Allee effect where the density of reproducing individuals is so low that mates fail to find each other, or gametes released into the water are diluted to concentrations too low to lead to substantial fertilization.

Based on the studies referenced above, in 2010 the beaches along the northern GOM coast were oiled during the interval of annually high reproduction and recruitment for the populations comprising the beach intertidal communities. As a consequence, any mortality induced by the oiling had a compounded effect. It induced individual mortality, removed or diminished the young of the year cohort, and removed or diminished the capacity of the surviving population to replenish itself by reproduction. Given the spatial scale of the oiling, this means that repopulation of many beaches would be dramatically reduced in the year following oiling and that reservoirs of spawning adults, at varying distances from impacted beaches, would have to serve as the source of new individuals for one or more years.

5.2.2 Connectedness of (Source and Sink) Populations

The loss of reproductive capacity for populations in both the supratidal and intertidal beach populations requires examination of the spatial matrix of impacted and unimpacted populations. For species with bentho-pelagic life histories, recognition that an understanding of meta-population characteristics (the collection of spatially constrained breeding populations and the pathways by which they exchange larvae) is important for predicting local population sustainability (Page et al., 2008). Local populations of bentho-pelagic species are rarely self-sustaining. The larvae from one population drift to other locations before entering the benthos in sites distant from that of their parents. Distances among suitable habitats, prevailing or episodic hydrodynamic conditions, the abundances of food for or predators of larvae all affect how, when, and in what numbers the larvae are dispersed and contribute to annual variability in population recruitment in any given location. Loss of any of the local populations in this interconnected matrix of populations can lead to complex changes in recruitment cycles in multiple locations, including those not directly affected by depression of reproduction as a result of oil exposure and response-related disturbances. Populations separated by greater distances are less connected (fewer larvae are exchanged with or received from the distant population). Populations “upcurrent” due to prevailing current or wind directions serve as sources for “downcurrent” populations. Estimating recovery for impacted beach populations, regardless of the cause of the impact, will depend upon estimating degrees of connectedness.

The spatial matrix among beaches is an even more important consideration for populations of brooding amphipod species that inhabit both tidal regions of the beach. Normally, brooding populations are self-sustaining with the progeny living in the same location as their parents. Without a dispersing larval phase and only limited adult dispersal capability (they do not swim well nor do they fly), loss of reproductive capability means no recruitment to the population is possible until the uncommon, episodic event of a juvenile or adult emigrates from an unimpacted location. In the aftermath of the oiling and response-related disturbances of the northern GOM, there are potential sources of emigrating amphipods. If sound-side beaches are present and they were not oiled or oiled only lightly, talitrid amphipods can move directly across the island from the sound-side wrack to the Gulf side supratidal wrack. In addition, many of the haustorid species that occur in the intertidal extend their ranges into sound-side beaches as well, but these individuals must move through the water to gain access to the Gulf side. If sound-side beaches are not connected to the Gulf or were heavily oiled, then the only source of haustorid amphipod migrants will be distant unoiled beaches.

Nearshore current patterns are complex along the northern margin of the GOM. Several studies suggest that net transport is westerly from peninsular Florida to the Mississippi delta (Stone and Stapor, 1996; Georgiou et al., 2005). However, the few studies that have examined nearshore flow patterns in greater detail with smaller spatial and temporal resolution indicate more complex patterns (Cipriani and Stone, 2001). Dzwonkowski et al. (2011) demonstrate that flow emanating from Mobile Bay induces hydrographic variability on the Alabama shelf. In a subsequent study where they used oil from the DWH as a tracer to reveal current patterns across the Alabama shelf, they documented complex flows, in both easterly and westerly directions, depending on the directions of wind stress and local variations in bathymetry. Sedimentological studies uncovering patterns of sediment transport likewise find complex patterns congruent to the hydrology patterns. Byrnes et al. (2013) found that tidal currents in the passes between all of the barrier islands fronting Mississippi Sound are strong enough to disrupt weak, alongshore currents. They and Morang et al. (2012) found that onshore-offshore transport of sediments frequently exceed longshore transport of sediments, creating a series of sediment circulation cells centered on each of the barrier islands fronting Mississippi Sound. Even less information is available on nearshore currents associated with the Mississippi delta, but hydrological studies indicated that outflow from the passes of the delta strongly influence water movement and quality as well (Dzwondowski et al., 2011). In a study following larval drift of red snapper larvae along the northern GOM, Johnson et al. (2009) found seasonal patterns in prevailing current directions (westward in May, September, and October while June, July, and August were weakly eastward and offshore). They also found that the Mississippi delta, DeSoto Canyon, and Apalachicola peninsula were major impediments to flow. The sum of these studies suggest that, although net longshore drift, and potentially transport of beach benthos larvae, may generally be east to west, hydrodynamic conditions exist that would disperse and dilute larval concentrations and, by transient changes in flow direction, decrease linear transport efficiency. In addition, due to the relatively large amounts of flow exiting the major rivers of the Mississippi delta as revealed by sediment transport (Morang et al., 2012; Byrnes et al., 2013), many of the embayments around the delta may have little communication with neighboring coastal areas.

5.2.3 Condition/Disturbance of the Habitat

Both the supratidal and intertidal beach habitats are viewed as environmentally controlled and harsh to the organisms inhabiting the beach. This perspective may explain why diverse and patently abundant biological populations do not occur on beaches, but it fails to characterize the beach properly for those species that are adapted to the prevailing beach environmental conditions. Populations of these species do not act as though they are in a harsh habitat (McLachlan and Brown, 2006). Alterations of the beach habit induced by human activities cannot be viewed automatically as trivial to the dynamic, environmentally induced conditions because the beach organisms are not adapted to anthropogenic changes in: 1) sediment composition; 2) exposure to desiccation by excavation; and 3) compressive forces from heavy equipment or repeated tramping. Oil-removal operations impart many of these changes to the beach and could decrease the survival of resident and recruiting individuals, thereby delaying the ability of the beach ecosystem to recover or even reverse recovery that had been in progress since oil stopped stranding onshore.

For the supratidal beach community, the presence of wrack is an essential prerequisite to the development of the wrack community and the provision of organic material subsidizing beach recycling of nutrients. If no wrack is present on the beach, no wrack community can develop, even if reproductively capable adults of wrack species are present. Individuals of wrack-dependent species have some capability of awaiting wrack arrival and can utilize alternative sources of nutrition such as phytoplankton and terrestrial flora (Bessa et al., 2014). Wrack also provides habitat for the wrack species as well as nutrition, reducing exposure of the organisms to high temperatures and arid wind (Dugan et al., 2003). Consequently, the absence of wrack substantially reduces the abundances of wrack-related species and, because the decomposition of wrack is the beginning of the provision of nutrients via remineralization of wrack material by beach microbes, eliminates a beach ecosystem service. The composition of wrack can differ regionally and within a region temporally. In the northern GOM, wrack consists generally of stranded *Sargassum*, *Spartina* stems, or subtidal grasses, with the latter dominating for beaches in proximity to extensive subtidal seagrass beds (e.g., Morrow et al., 2011). The presence of *Sargassum* on beaches relies on the development and extent of the offshore *Sargassum* population and on meteorological conditions sufficient to transport portions of that offshore population onshore. *Sargassum* presence as wrack is somewhat predictable (see below). The presence of grasses as a major component of wrack also depends to some extent on the viability and condition of local populations, but removal of grass blades and their transport to beaches is frequently accomplished by storm events, making prediction of when and how much grass wrack is present more challenging.

Few studies are available on species associated with stranded wrack in the GOM. The literature that is available comes from studies conducted in Texas on Padre Island National Seashore and Galveston Island. To broaden the knowledge of wrack and wrack-associated species, studies conducted in California were also included in this effort. Wrack has been studied in more detail on the sand beaches of California and even though the environment is quite different, some of those measurements are included here for comparison. In Bejarano et al. (2011), Table 5-2 lists the life history data available for the dominant wrack-associated beach macrofauna of the northern GOM; Table 5-3 provides available community metrics for these species.

Stranded wrack is generally deposited on Texas beaches between May and August (Engelhard and Withers, 1997; Williams et al., 2008). The most common species of wrack found along the Texas coast is the brown algae, *Sargassum natans*; however, *S. fruitans* and driftwood are also found in stranded wrack material (Engelhard and Withers, 1997). Masses of intertwined *Sargassum* mats may span over 100 m in length on the upper beach in Texas (Williams et al., 2008). A study conducted on Padre Island, Texas recorded that wrack biomass ranged from 0 to 650 g/m^2 (Engelhard and Withers, 1997). In this location, wrack was deposited in May and June and then decreased after the end of June. The Galveston Island study found biomass values ranging from 241 g to 1,387 g/0.5 m^2 (dry weight) (Williams et al., 2008).

To determine patterns of wrack accumulation on beaches affected by the DWH oil spill, we examined photographs taken during SCAT surveys from two locations, Trinity Island and Fourchon Beach. SCAT segments at these two locations were visited numerous times from 2010-2013, and multiple photographs of the beach were taken on each visit. We randomly selected photographs from each visit and examined each one for visual evidence of wrack accumulation in the supratidal zone. The dominant floral component of the wrack was identified (*Sargassum* vs. marsh grasses) and the abundance of the wrack was categorized into one of the following:

- <u>None</u> - no visible wrack, or only a few isolated clumps less than ~1 m2 in area;
- <u>Light</u> - numerous clumps scattered near the high water mark but with patches of sand still separating them;
- <u>Moderate</u> - a mostly continuous band of wrack that is <1 m wide, with scattered clumps at other locations in the back beach; and
- <u>Heavy</u> - an all but continuous band of wrack, >>1 m wide, covering much of the back beach.

The two locations examined produced very different results. Trinity Island wrack was composed primarily of *Sargassum* throughout the three-year interval for which photographs were available. *Sargassum* presence showed high synchrony along the island and was most abundant in mid spring (Figure 33). At Fourchon Beach, wrack consisted primarily of *Spartina* stems (*Sargassum* constituted generally 5-10% or less of the apparent composition), showed high alongshore variability, and almost no seasonal pattern (a slight increase in abundance occurred in late winter –early spring; Figure 33). The seasonal appearance of *Sargassum* on Trinity Island corresponds to the growth and transport of offshore *Sargassum*, which begins on the west side of the GOM in March and moves easterly as the season progresses into spring (Gower and King, 2011). The annual cycle of offshore *Sargassum* growth and transport suggests that the appearance of *Sargassum* as wrack should begin on westward beaches in the spring and occur on more eastward beaches later in the year. Wrack dominated by marsh grasses most likely occurs after the growth of new *Spartina* vegetation in the spring, when the previous years' stems slough and currents transport them out inlets and into coastal waters.

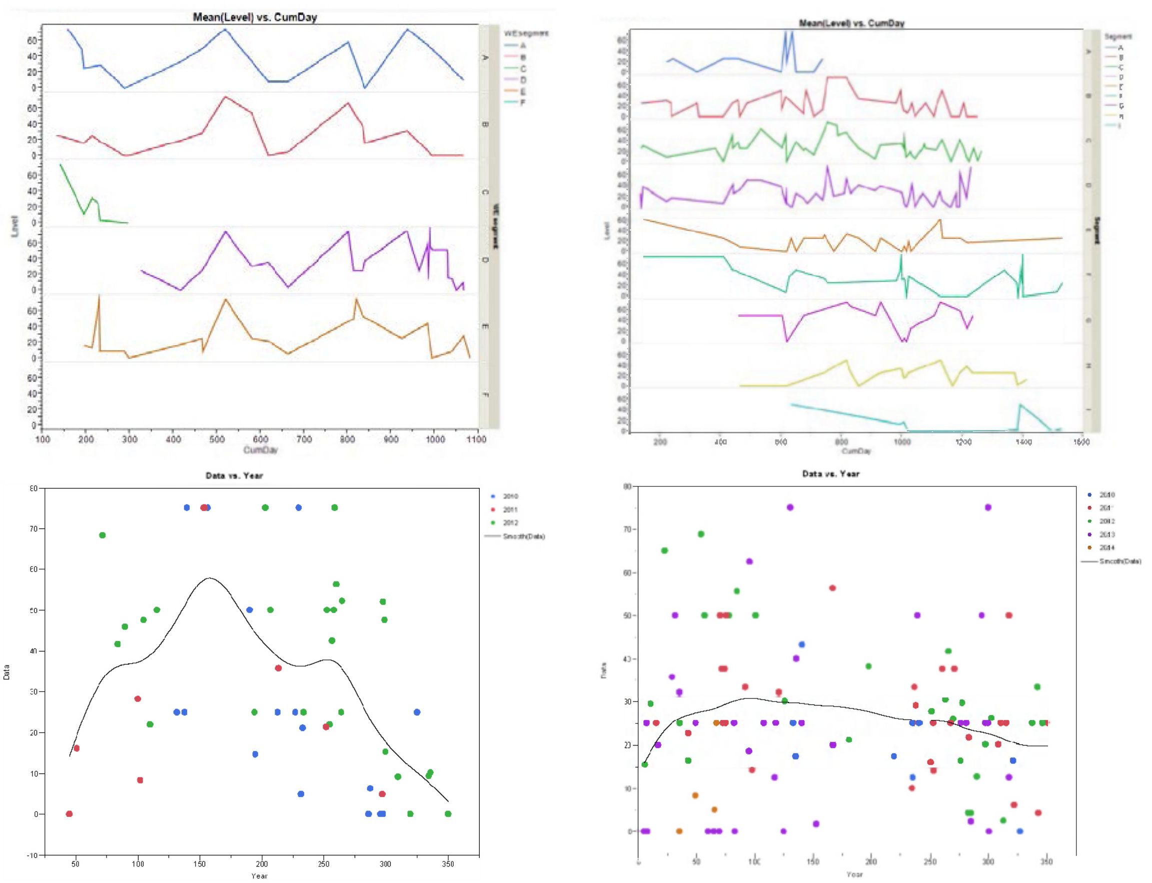

Figure 33. Relative abundance and seasonal patterns of wrack accumulation in the supratidal of Trinity Island (two panels on the left) and Fourchon Beach (two panels on the right). The upper panels show relative abundance within each SCAT segment of each island from 2010 – 2013. The lower two panels show the observed relative abundance (dots) and, to aid visualization, a smoothed (cubic spline, lambda = 0.05) seasonal pattern (line) distributed across the day of the year.

5.3 Sand Beach Community Impacts and Recovery Rates following Oil Exposure

5.3.1 Oil Spill Literature Review

Data from previous oil spills show a greater than one year recovery time of the invertebrate community on sand beaches, though recoveries have ranged between 0.5 to 5 years (Table 6-2 in Bejarano et al. 2011; Wormald, 1976; Giere, 1979; Boucher, 1980; Raffin et al., 1981; Bodin, 1988; Ansari and Ingole, 2002; Barth, 2002; and others). Six months after the 1975 Florida Keys oil spill, Chan (1976) did not observe oily debris, and the macrofauna abundance was similar to that of an unoiled beach. Moore et al. (1997) also found no evidences of major impacts on the meiofauna community nine months after the *Sea Empress* oil spill, and only in the most severely impacted areas recovery of burrowing invertebrate populations required at least two full years (Moore, 2006). Amphipod densities and population levels of two long-lived species (spiny cockle and heart urchin) were still low two and ten years, respectively after the spill (Moore, 2006). In contrast, a longer recovery was documented by Blaylock and Houghton (1989), who noted that three years after the *Arco Anchorage* spill the infaunal assemblage and residual oil concentrations on sand beaches were similar to pre-spill conditions.

Perhaps one of the longest sand beach recoveries was required following the Gulf War oil spills. Barth (2002) found that high-energy sand beaches completely recovered after five years, while low energy beaches (20% of the total impacted sand beaches) were almost completely recovered ten years after the spill. Data from experimental studies also provide valuable information on the response and recovery of invertebrates to oil exposures. The benthic fauna in sediments oiled with Forties oil (Schratzberger et al., 2003) showed shifts in dominance patterns, reduced nematode species, and absence of rare species eleven weeks post treatment; however, the structure of the nematode assemblage resembled that of unoiled sediments 45 weeks post treatment. In a similar study, 15 months after sands were oiled with Prudhoe Bay crude, the fauna abundance was 48-75% of the non-treated sands, and the invertebrate community was largely dominated, in number of species and abundance, by polychaetes (Vanderhorst et al., 1980). Full community recovery in oil-treated sands was estimated at 31 months post treatment.

Based on the body of literature available, it is clear that the recovery of the intertidal community after an oil spill is not only dependent on the persistence of the oil and on beach dynamics and characteristics (shoreline type, degree of exposure, beach geomorphology), but also reliant on the invertebrate community assemblage and species-specific characteristics (their sensitivity to residual toxic compounds and fouling from oil in the sediment, recruitment pattern of the affected species, and their life history traits). Buried oil on sand beaches and the intertidal zone can persist from years to decades (Long et al., 1987; Barth, 2002; Jones et al., 2008b; Short et al., 2007), particularly in the absence of cleanup activities, or in the absence of strong physical forces of natural attenuation (e.g., tidal flushing, wave action, erosion/deposition cycles). Not surprisingly, exposed high-energy sand beaches recover faster from an oil spill than low-energy sand beaches (Bodin, 1988; Barth, 2002; Michel et al., 2008). The recovery times reported here are generally in agreement with those from an earlier report (AURIS, 1995). For tropical beaches, that report documented recovery times between five months and two years for treated beaches, and from four months to five years for untreated beaches. For boreal and temperate beaches, the same report documented biological effects between one and six years, with no biological recoveries for seven years.

Several different recovery curves must be developed to reflect spatially explicit differences in: (1) resident biological assemblages (supratidal versus intertidal); (2) life-history characteristics of the dominant species; (3) intensity and frequency of oiling, (4) the extent and nature of response actions; and (5) the connectedness of different beaches to sources of recruits. The resulting curves reflect impacts to the invertebrate communities below steady-state levels of service provision. Ecosystem services, and the biological populations producing those services, vary naturally among years and among seasons within each year. Our estimates of the expected percentage increases in services provided by the sand beach invertebrate communities are with respect to the level of services that would be provided but for the spill and response actions. In addition, beaches that frequently experience persistent and intense human activities (high-use amenity beaches) provide typically lower absolute levels of ecosystem services because human activities depress invertebrate abundances and disturb the habitat, particularly where beach grooming removes wrack and disturbs the upper level of sand (Llewellyn and Shackley, 1996; Dugan et al., 2003; Dugan and Hubbard, 2010).

5.3.2 Intertidal Invertebrate Community Impacts from DWH Oil Spill

With few exceptions, the structure and function of the intertidal macrofaunal assemblage are dominated by bentho-pelagic, suspension-feeding species. Although, full recovery of the intertidal beach will not occur until the haustorid amphipod populations recover, these brooding species represent a lesser fraction of the intertidal community, and much of the recovery of ecosystem function in the intertidal can be expect to arise from the bentho-pelagic species. Limited intensive beach cleaning activities were directed at the intertidal regions of the beaches, and most that did occur were discrete from the oiling events. The effects of this activity will be considered for specific beach segments where intertidal response activities occurred.

Heavier Oiling Impact

Given the absence of any pre- and post-spill sampling in the intertidal on the beaches with moderate to heavy oiling by the DWH spill, we estimate the average survival of invertebrates on these beaches by extracting information from studies conducted elsewhere, especially two that share some similar characteristics to the DWH spill. The Ixtoc I spill occurred on beaches with similar fauna, with a similar type of oil (heavily weathered crude oil that had been transported long distances before stranding onshore), and with comparable ranges of site-specific oiling intensity (Kindinger, 1981; Tunnell et al., 1982). They report a wide range of survival of infauna from before and after the spill across the thirteen beaches they sampled. At seven of the thirteen beaches they sampled, intertidal infauna ranged from 85-97% lower after the spill. Three beaches showed no to modest increases in abundance (0-19%). The remaining beaches decreased in intertidal infaunal abundance (21-74%). Relating their results, with respect to oiling intensity or response injury effects, is challenging because: 1) the number of replicate samples taken from every beach fell short of the number needed to adequately represent the in-situ populations and to have sufficient statistical power detect changes in infaunal abundances; 2) beaches that received lighter amounts of oil received intense response activities but sampling of the beaches occurred after both events had occurred preventing separation of oil and response injury in those locations; and 3) all of the beaches were affected by tropical storm conditions in the interval between the prespill and post-spill sampling and the effects of these storm conditions on dispersing oil and transporting infauna are unclear.

We also examined the studies documenting the consequences of the T/V *Prestige* oil spill on the Galician coast of Spain, (de la Huz et al., 2005; Junoy et al., 2005). The wreck of this tanker offshore released heavy oil that reached beaches over 300 km of coastline (de la Huz et al., 2005). No pre-spill samples from immediately before the event were gathered, but many of the oiled beaches had been sampled for invertebrate abundances in prior years. Post-spill sampling on the eighteen beaches sampled occurred after oiling and cleanup responses had ended, preventing separation of oiling and response injury effects. For both the supratidal and intertidal portions of the beaches they observed decreases in species richness and abundances. In one beach, oligochaetes appeared to exploit the change in community structure and increased in abundance (e.g., oligochates in the supratidal). Decreases in infauna in the intertidal zones were more consistent among beaches and of greater magnitude than observed for supratidal zones. In heavily oiled beaches, one of the most abundant species before the spill, *Scolelepis squamata*, literally disappeared in samples after the spill. The percentage decreases in abundances for the more abundant (pre-spill) species ranged from 60-85% across all beaches. The only abundant species prior to the spill that increased in abundance was the amphipod *Pontocrates arenarius*, which doubled across many beaches (this species does not occur in the GOM).

The spatial extent, the amounts of oil, the frequency of oiling, and the interval over which oiling occurred were greater during the DWH spill than either the Ixtoc I or *Prestige* spills, and all of other studies of oil-affected beaches (see synthesis in Bejarano et al., 2011). We argue that the greater magnitude of oiling occurring during the DWH spill would produce, on average, downward changes in population sizes and ecosystem services from those observed in the other studies. We estimate that the heavier oiled intertidal beaches in the northern GOM would only retain 5% of ecosystem services after oiling.

Several factors unique to the DWH spill, including 1) the extensive spatial scale of affected beaches, 2) the contiguity of oiled beaches over these long distances, 3) the long time interval over which beaches continued to receive oil, and 4) the interaction of affected beaches in Louisiana with riverine discharge from the Mississippi delta, limit the utility of estimating the rates and timing of recovery for benthic populations and associated ecosystem services of a heavier oiled intertidal beaches from the literature. Recovery of infauna on any beach depends on the location of the beach relative to sources of larvae or emigrating adults in addition to seasonal patterns of reproduction. The first factor, sources of recruits, will rely on prevailing hydrodynamic patterns. Based on the general review of coastal current patterns above, beaches from western Florida to the Chandeleur Islands, Pass a Loutre to the Southwest Pass, and the Southwest Pass west to Isles Dernieres should have distinct recovery trajectories.

From western Florida to the Chandeleur Islands, the prevailing westerly currents would serve as a conduit for larvae from beaches where breeding populations escaped heavy oiling. Most beaches east of Pensacola Beach, the eastern half of Dauphin Island, and West Ship Island were not heavily oiled and would serve as important sources of recruits to beaches west of them that were heavily oiled. The level of recruitment on a heavily oiled beach would be a function of the distance to the nearest lightly or unoiled beach and the sizes of the breeding populations in the lightly impacted beaches. We have no quantitative data for the latter and must use the areal extent of lightly impacted beaches as a surrogate for spawning potential (more area = larger populations = larger pool of larvae produced). Based on these considerations sand beaches are divided into four recovery categories based primarily on expected larval supply (Table 7).

Table 7. Expected annual recovery of intertidal communities for heavier-oiled beaches based on the population dynamics of the benthic fauna and the spatial relationships among beaches producing recruits. The 2010 post-oiling communities were at 5% of pre-spill abundances. These general recovery patterns do not consider beach-specific injuries associated with response activities, which are addressed by a separate analysis.

Beaches	Condition	Year 1 (May 2011)	Year 2 (May 2012)	Year 3 (May 2013)	Year 4 (May 2014)
(1) Santa Rosa west to Gulf shores (2) Western half of Dauphin Island	Relatively close proximity (<50 km) to beaches with large source populations	Some larvae arrive (**13% community recovery**)	Substantial numbers of larvae arrive and survive at levels above annual rate (**44% community recovery**)	Substantial numbers of larvae arrive and survive at levels at annual rate (**32% community recovery**)	**Full recovery**
(1) Bon Secour to Fort Morgan (2) Petit Bois to Cat Island	Far distances (>50 km) to large source populations or only small source populations nearby	Modest numbers of larvae arrive and survive (**10% community recovery**)	Modest numbers of larvae arrive and survive at levels above annual rate (**24% community recovery**)	Substantial numbers of larvae arrive and survive at levels at annual rate (**39% community recovery**)	**Full recovery**
Chandeleur Islands	Small, local source populations, very distant from large source populations	Limited numbers of larvae arrive and survive (**7% community recovery**)	Improved, but low recruitment due to low population densities of adults locally (**15% community recovery**)	Increased recruitment due to growing local populations of beach macrofauna (**27% community recovery**)	Modest numbers of larvae arrive and survive at levels above annual rate (**38% community recovery**) **Full recovery by June 2014**
(1) Islands located between SE and SW Passes (2) Islands west of SW Pass to Isle Dernieres	These beaches are isolated from large source populations and would rely on very small, local spawning populations	Very few larvae arrive although survival is high (**4% community recovery**)	Limited numbers of larvae arrive and survive (**12% community recovery**)	Improved, but low recruitment due to low population densities of adults locally (**21% community recovery**)	Modest numbers of larvae arrive and survive at levels above annual rate (**27% community recovery**) **Full recovery by May 2015**

Lighter Oiling Impacts

The direct negative effects of oil on individual organisms on lighter-oiled beaches are the same as those occurring on heavier-oiled beaches. However, less of the beach area is covered by oil and fewer individual organisms encounter oil. After the *Prestige* spill, beaches that were lightly oiled demonstrated smaller percentage decreases in faunal abundances (30-50%) and fewer reductions in species richness (de la Huz et al., 2005; Junoy et al., 2005). Conservatively, we estimate that lighter-oiled intertidal beaches in the northern GOM would retain 60% of the pre-spill biotic community on average after oiling.

The estimated recovery curves for these beaches would still rely on expected larval supply. Lighter-oiled beaches "downcurrent" or surrounded by beaches that received little or no oil would receive relatively high numbers of recruits. Lighter-oiled beaches, or lighter-oiled segments of beaches, with primarily heavier-oiled beaches "upcurrent" will receive very little recruitment even though substantial numbers of reproducing adults may survive on the lighter-oiled beach. Larvae spawned from small, isolated beaches will be dispersed in nearshore currents, generally downcurrent away from the parent population. In addition, because the majority of resident benthos have a lifespan of ~1 year, these isolated lighter-oiled locations will see a decrease in their resident adult populations that survived oiling without sufficient larval supply to replace senescing individuals. Because of this linear, landscape effect, recovery of resident populations and the associated ecosystem services in the years following 2010 will mimic those of neighboring heavier-oiled beaches (Table 8).

Table 8. Expected annual recovery of intertidal communities for lighter-oiled beaches based on the population dynamics of the benthic fauna and the spatial relationships of beaches producing recruits. The 2010 post-oiling communities were at 60% of pre-spill abundances. These recovery patterns do not consider beach-specific injuries associated with response activities.

Beaches	Condition	Year 1 (May 2011)	Year 2 (May 2012)	Year 3 (May 2013)
St. George Island west to Santa Rosa Island	These beaches are in immediate proximity to extensive, source populations for recruits.	Substantial numbers of larvae arrive. Recruit survival is at average year levels. **(20% community recovery)**	**Full recovery** of services occurs.	
All islands and sections of islands west of Ft. Morgan to Cat Island	Site-specific spawning is high but recruitment is low due to an inability to retain larvae locally	Modest numbers of larvae arrive and survive, but many resident adults die **(15% community recovery)**	**Full recovery** of services occurs.	
Chandeleur Islands	Site-specific spawning is high but recruitment is low due to an inability to retain larvae locally	Limited numbers of larvae arrive and survive but resident adults die **(10% community recovery)**	Improved, but low recruitment due to low population densities of adults locally **(20% community recovery)**	**Full recovery** of services occurs.
(1) Islands located between SE and SW Passes (2) Islands west of SW Pass to Isle Dernieres	Site-specific spawning is high but recruitment is low due to an inability to retain larvae locally	Very few larvae arrive although survival of recruits is high, but not of 1-year olds **(10% community recovery)**	Limited numbers of larvae arrive and survive **(15% community recovery)**	**Full recovery** of services occurs by summer

5.3.3 Supratidal Beach Community Impacts from the DWH Oil Spill

Several conditions separate supratidal beach recovery estimates from those for intertidal beach recovery. First, because wrack and detritus are essential substrates for the majority of species and individuals occurring in the supratidal zone, the temporal provision and persistence of wrack must be estimated. Second, although brooding species occur in the intertidal, several brooding amphipod species represent the majority of marine individuals occurring in wrack assemblages, and the provision of juveniles and adults (as opposed to larvae) by emigration will play a greater role here in recovery of services than in the intertidal zone (where the majority of benthos are bentho-pelagic). Third, because the semi-terrestrial, wrack amphipod species do not swim well or are not carried far by currents (Wildish, 2012; Fanini and Lowry, 2014), storms and transport of previously beached wrack are likely to be essential agents in redistributing reproductively capable talitrid adults to locations defaunated by oiling and response actions. Fourth, terrestrial arthropod populations (but not the services they provide in the supratidal zone) were likely to be less affected by oiling and response actions because of the ability of the adults to fly or migrate on land to alternative habitats to exploit when beach wrack was oiled or removed. The high vagility of these species also suggests that they would discover and use wrack washed onto a beach fairly rapidly. Consequently, their presence in the supratidal zone most likely closely mirrors that of the wrack. Fifth, ghost crabs, the faunal component of the supratidal zone that is independent of the wrack, have a bentho-pelagic life cycle. They, like the insects, would suffer less from oiling and response actions than other marine beach fauna because of their ability to move inland and to sound-side beaches.

Heavier-oiled Supratidal Zone Impacts

Hooper (1981) reports a complete loss of talitrid amphipods from beaches affected by the Ixtoc I spill, indicating how sensitive this group is to oiling. In addition, in the first couple months of oil removal activities, literally all wrack was bagged and removed from the beach, whether individual patches of wrack were oiled or not. This activity began while beaches were still receiving oil or shortly after oiling ended. Consequently, this response injury cannot be separated from the oiling injury. Ghost crabs that were not killed by oiling would have moved away from the supratidal as a response to the absence of prey (both wrack and intertidal) on oiled beaches and to the actions of cleanup teams walking and driving vehicles on the beach, to which ghost crabs are very sensitive (Steiner and Leatherman, 1981; Barros, 2001; Lucrezi et al., 2009). We estimate that heavier oiled intertidal beaches in the northern GOM would retain 0% of the community in the aftermath of oiling and subsequent intense response actions, which often were conducted years after the oil stopped coming ashore.

Recovery of the majority of the community in the supratidal zone would be determined by the arrival and persistence of wrack. Exploitation of the wrack would be rapid by terrestrial arthropods. The ability of amphipods to use the wrack would depend on either across-island migration, from the sound side if they survived there, or between-island migration, which would be dependent on transport of wrack from beaches where the amphipods survived. Once present, the amphipods would be able to exploit available wrack habitat relatively quickly. Complete recovery would occur only after the frequency and type of human activity in the supratidal zone reverted to pre-spill conditions (i.e., no oil removal activities of any level). Generally, substantial gains in supratidal ecosystem services would be realized each year (Table 9). Unfortunately, in many cases oil removal activities after the winter of 2010/11 most frequently occurred in the supratidal zone. Because the type and intensity of these activities varied greatly from location to location, we present site-specific, expected recovery curves below.

Table 9. Estimated recovery of supratidal communities, by the anniversary date of the spill (May of each year), based on whether the beaches were originally heavier- or lighter-oiled, based on a synthesis of the literature. These general recovery patterns do not consider beach-specific response injuries associated with activities subsequent to 1 October 2010.

Beaches	Condition	Year 1 (May 2011)	Year 2 (May 2012)	Year 3 (May 2013)	Year 4 (May 2014)
Heavier-oiled Post-spill services until October 1, 2010 = 0%	Migration or mortality of supratidal invertebrates, combined with aggressive removal of wrack	Wrack accumulates. Rapid colonization of the wrack by terrestrial arthropods. **(25% community recovery)**	Wrack accumulates. Rapid colonization of the wrack by terrestrial arthropods and a limited number of marine amphipods. **(35% community recovery)**	Wrack accumulates. Rapid exploitation of the wrack by terrestrial arthropods and marine amphipods (**Full recovery.**	
Lighter-oiled Initial post-spill services in 2010 = 80%	Limited migration and mortality of supratidal invertebrates. Persistence of some wrack throughout.	Wrack accumulates. Rapid exploitation of the wrack by terrestrial arthropods and marine amphipods (**Full recovery.**			

Lighter-oiled Supratidal Zone Impacts

The same hydrodynamic forces that transport, accumulate, and abandon drifting wrack onto a beach do the same to oil. Consequently, even on lighter-oiled beaches much of the oil occurring in the supratidal zone will co-occur with the wrack. But, as long as patches of unoiled wrack remain, the highly mobile arthropod fauna would have been able to move from oiled patches to oil-free patches of beach and wrack. In addition, oil removal activities on many lighter-oiled beaches were less aggressive with regard to removal of all wrack material. We expect that, on average, 80% of individuals in the community survived on lighter-oiled beaches after the initial injury. Full recovery of ecosystem services in these locations would be much faster than on heavier-oiled beaches because reproductively capable adults of the talitrids would be present locally and would not have to emigrate from distant locations (Table 9).

5.3.4 Rationale Underlying Estimation of Faunal Community Losses Associated with Sand Beach Response Injury Categories.

Response Activity Impacts from the Literature

Intertidal communities on sand beaches are frequently thought as rather tolerant to disturbances because they are well adapted to the unstable and dynamic nature of the beach environment. However, these fauna can be impacted through cleanup operations by crushing, changing habitat suitability (substrate compaction or softening), disrupting reproduction and recruitment patterns, altering or removing food supplies, or remobilizing oil residues (Chan, 1976; Blaylock and Houghton, 1989; De La Huz et al., 2005; Michel et al., 2008; Borzone and Rosa, 2009). The combined effects of oiling and cleanup activities have shown to alter the composition of talitrid amphipods (Borzone and Rosa, 2009), reduce species richness and eliminate entire species (De La Huz et al., 2005), and cause near complete mortality of the infaunal community (Blaylock and Houghton, 1989).

Sediment Removal and Placement

Cleanup operations, involving translocation of large volumes of sand, can be equated with beach nourishment projects, as in the latter sand is mechanically moved and redistributed on the beach surface, resulting in sizable changes in the sand beach ecosystem (beach profile, morphology, substrate compaction), as well as in temporary changes to the beach inhabitants (flora and fauna). Studies have documented changes to the intertidal community resulting from beach nourishment projects and related activities. Some of these studies found that: 1) slow recovery of an intertidal clam (Donax) population was noted after a nourishment project that replaced the original substrate with sediment containing high levels of shell fragments (Peterson et al., 2000); 2) macrobenthos exhibited slow recoveries after a nourishment project that increased concentration of fine sediments (Rakocinski et al., 1996); 3) changes in grain size and slope from disposal of mine tailing were correlated with decreased species richness and macrobenthic abundance, and this activity was attributed to the disappearance of the local Donax species (McLachlan, 1996); 4) nourishment projects that coincide with the recruitment period of indicator species can have large impacts on invertebrate populations (Cobb and Arnold, 2008); and 5) beach nourishment can lead to low species diversity, richness, and equitability compared to pre-nourishment levels (Reilly and Bellis, 1983). Major disruptions of the sand beach surface can have significant impacts at the population (demography and dynamics), community (species richness), and ecosystem (functional processes, nutrient flux, trophic dynamics) levels (Defeo et al., 2009). Furthermore, the reduction in the abundance and biomass of dominant species has been linked to disturbances in the foraging behavior of shorebirds and to reduced habitat productivity (see Defeo et al., 2009 and references therein; Peterson et al., 2006). However, others (Nelson and Collins, 1987) have also reported no measurable effects of nourishment projects on indicator species.

Beach nourishment can cause immediate ecological damage to the resident sand beach invertebrate community including complete mortality of resident intertidal biota. Bilodeau and Bourgeois (2004) evaluated the impacts of beach nourishment projects on the conspicuous ghost shrimp, *Callichirus islagrande*, at two barrier islands of the Isles Dernieres chain of Louisiana (East and Trinity Islands). Two and a half years post-restoration, these restored beaches did not have the large densities of ghost shrimp seen at reference sites within the chain of islands, which had generally well-established populations. Only a few juveniles and one ovigerous female were found, indicating that the population did not show any signs of recolonization or recruitment. The lack of recolonization was attributed to changes in the sediment composition. Sand beach restoration projects on the eastern Atlantic have also shown impacts on dominant members of the intertidal community (Peterson et al., 2000; Lindquist and Manning, 2001; Peterson et al., 2006). Lindquist and Manning (2001) evaluated the impacts of beach nourishment and mechanical redistribution of beach sand (bulldozing) on dominant intertidal macroinvertebrates, and found significant declines in the abundance of ghost crabs (*Ocypode quadrata*) 6 to 8 months post-bulldozing. Possible explanations for this decline included the substantial changes in the sand composition, which likely impeded the formation of stable burrow structures; and/or the timing of the bulldozing (mid-November to March), which may have caused direct mortality through burying as these activities coincided with the season when crabs are permanently below ground. Bulldozing also reduced the abundance of mole crabs (*Emerita talpoida*), though these changes were not statistically significant from controls. Other species (i.e., coquina clams Donax variabilis, spionid polychaete *Scolelepis squamata*, and amphipod *Amphiporeia virginiana*) appeared to have escaped the impacts of bulldozing as their abundances resembled those of control beaches.

In contrast, Peterson et al. (2000) found that both beach nourishment and bulldozing had quantifiable effects on intertidal species 5 to 10 weeks post treatment compared to control beaches. Nourishment reduced the density of two dominant species, mole crab and bivalve mollusks (Donax spp.) by 99% and 86%, respectively, possibly by altering the composition of the substrate, whereas bulldozing reduced the abundance of mole crabs and ghost crabs active burrows by 37% and 65%, respectively, probably by changing the beach morphology enough to reduce the habitat suitability for intertidal macroinvertebrates. Peterson et al. (2006) also attributed large mass mortality of benthic macroinfauna to beach filling (nourishment). Over several months post-treatment, Donax spp. and amphipods had much higher abundances (85% and 89%, respectively), and ghost crab burrow density across the flat beach were up to twice as high on undisturbed control beaches; in contrast, ghost crab summertime recruitment appeared to have been inhibited on filled beaches. Evidence of the effect of sand disturbance on invertebrates has also been documented in other parts of the world. In Australia, a beach nourishment caused the elimination of the amphipod, *Exoediceros fossor*, with some signs of recovery seen nine weeks later (Jones et al., 2008a). In South Africa, a single excavation event removed sand to a depth of 0.3 m causing temporary changes in the abundance of macrofauna; this community required 7-16 days to recover following a single disturbance event (Schoeman et al., 2000). Beach nourishment projects or major sand beach cleanup operations that cause compaction of the substrate can be particularly problematic to the invertebrate community. Compaction increases the bulk density of the substrate, and reduces the interstitial space thereby reducing the capillarity, water retention, permeability and the exchange of gases and nutrients within the substrate matrix (USACE, 1989; Defeo et al., 2009). Compaction also increases the penetration resistance obstructing the construction of burrows, which can impact burrowing behavior and reduce the abundance of burrowing fauna (Lindquist and Manning, 2001). The overall impacts of compaction can be translated into reduced substrate productivity and microhabitat suitability (Lindquist and Manning, 2001).

Beach Grooming and Wrack Removal

The large majority of documented effects on invertebrates come from periodical grooming of wrack from amenity beaches (Dugan et al., 2000; Gheskiere et al., 2005; Weslawski et al., 2000a; Weslawski et al., 2000b), while only a few are from activities associated with oil cleanup (Chan, 1976; Blaylock and Houghton, 1989; De La Huz et al., 2005; Michel et al., 2008; Borzone and Rosa, 2009). Defeo et al. (2009) indicated that, in general, macrobenthic populations and communities respond negatively to increased human activity levels. Beach grooming activities that remove wrack have significant effects on the community structure (depressed species richness, abundance, and biomass) of wrack-associated fauna, causing significant ecological consequences, including the substantial reduction of prey for higher trophic levels (Dugan et al., 2000; Dugan et al., 2003; Defeo et al., 2009) and, depending on the spatial scale of grooming (<1 to 100 km), the effects could be noticeable at scales ranging from weeks to years (Defeo et al., 2009). For example, temporal mechanical raking (0-3 cm penetration) for wrack removal on the upper intertidal zone at Padre Island National Seashore lowered the mean density and biomass of all macrofauna within three days post-raking, and the density and biomass of the amphipod *Orchestia grillus* and polychaetes up to 10 days post-raking, compared to unraked areas (Engelhard and Withers, 1997).

Studies in Europe (Weslawski et al., 2000a; Weslawski et al., 2000b; Malm et al., 2004; Gheskiere et al., 2005; Gheskiere et al., 2006) have also reported the biological and ecological impacts of beach cleaning. At two tourist beaches, removal of wrack with mechanical beach cleaners reduced the percent total organic matter in the upper beach zone and caused high community stress (i.e., lowered invertebrate diversities, the number of distinctive taxa and genetic diversity, caused replacement of species with higher number of opportunist species), compared to non-tourist beaches (Gheskiere et al., 2005). In a related study, the top 5 cm of sand surface was removed with mechanical beach cleaners (Gheskiere et al., 2006). This short-lived disturbance caused significant changes in the total abundance and community structure immediately after cleaning by reducing the abundance of dominant nematode species (*Theristus otoplanobius*, *Trissonchulus benepapilosus*, *Chromadorina germanica*) and harpacticoid copepods, which recovered completely following two tide cycles. In Sweden, beach cleaning caused significant changes in the organic content of sediments (Malm et al., 2004). Cleaned beaches had a much lower level of organic carbon than un-cleaned beaches, and the most intensively cleaned beaches had lower total benthic biomass. However, biodiversity and community structure were not significantly different between cleaned and un-cleaned beaches.

Weslawski et al. (2000a; b) have extensively documented the effects of beach cleaning in Poland. They suggested that trampling and mechanical cleaning may have contributed to the disappearance of air-breathing amphipods or sandhoppers from the most frequently visited beaches (Weslawski et al., 2000a; Weslawski et al., 2000b and citations therein). Furthermore, wrack removal from the upper layer of sand and sand sifting through a 5-mm sieve effectively removes important food sources for key species, which are linked to disappearance of macrofauna and the decline of their predators (Weslawski et al., 2000b and citations therein). They also indicated foot traffic (3,000 steps/m2 day) caused sufficient beach fragmentation, and mixed debris with sediment down to l0-30 cm.

Off-Road Vehicle Traffic

Off-road traffic on sand beaches (i.e., four-wheelers and small vehicles) is an activity that has been studied relatively extensively and that is somewhat comparable to cleanup activities. Recent studies (Schlacher et al., 2008a,b; Schlacher and Thompson, 2008) indicated that the effects of anthropogenic disturbance on local invertebrate assemblages vary greatly depending on their spatial and seasonal occurrence and abundance, and on their specific life histories. Schlacher et al. (2007) found that ghost crabs are frequently crushed by off road traffic if their burrows are relatively shallow (5 cm), and that this species is particularly vulnerable because of its soft exoskeleton. Not surprisingly, ghost crab mortality declined exponentially with burrow depth. Schlacher et al. (2007) also found that ghost crab densities were higher in areas subjected to low to moderate traffic, while individuals were smaller in heavily impacted areas, suggesting alterations of the population structure. Beaches with heavy off road traffic also had lower abundance, species richness, and diversity of intertidal macrobenthos, and strong changes in the community structure were driven by the low abundances of the cirolanid isopod *Pseudolana concinna* (Schlacher et al., 2008a). Direct crushing appeared to be the main cause of community changes.

Lucrezi and Schlacher (2010) also reported that sand beaches impacted by traffic were slightly hotter and had lower moisture content than beaches closed to traffic, and that on vehicle-impacted beaches not only were ghost crabs smaller, but also constructed much deeper and longer burrows possibly to avoid desiccation. Another study (Kluft and Ginsberg, 2009) demonstrated that vehicle traffic can degrade the quality of beach wrack by crushing, scattering or burying, impacting the survival of invertebrates that depend on this habitat for food and shelter. For example, open-beach species (i.e., the beach hopper *Talorchestia longicornis* and the wolf spider *Arctosa littoralis*) were more susceptible to disturbance than wrack inhabitants (enchytraeid oligochaetes and tethinid flies *Tethina parvula*). The former were likely crushed in their shallow burrows during daylight traffic, while the latter (interstitial detritivores) may have benefited from the increased moisture and mechanical breakdown of the wrack by vehicle traffic. Gastropod species, on the other hand, appeared to be most resistant than soft-bodied invertebrates (mysid and isopod) to vehicle traffic (van der Merwe and van der Merwe, 1991). Aside from direct crushing, heavy traffic decreases invertebrate abundance by reducing food availability (including wrack), increasing species displacement, disrupting the intertidal habitat and the physical properties of the sand substrate, and increasing invertebrate exposure to predators from the continuous maintenance of burrows (Schlacher et al., 2007; Kluft and Ginsberg, 2009). Many of these factors in turn can influence recruitment.

From literature, it is clear that species susceptibility to off road traffic, as well as beach cleaning and grooming, is largely dependent on body size, species fragility (soft vs. hard bodies), turnover rates, and burrowing behavior (deep vs. shallow). Generally, large-scale operations would be more detrimental to species that: 1) brood their young; 2) have a soft exoskeleton; 3) have larger sizes and lower turnover rates; 4) build shallow burrows; 5) have seasonal reproductive cycles that coincide with cleaning activities; 6) occur at high densities in soft, non-compacted sand; and 6) are more closely associated with the substrate, and therefore are more strongly impacted by changes in the structure of the sand matrix (compaction) (van der Merwe and van der Merwe, 1991; Schlacher et al., 2007; Jones et al., 2008a; Schlacher et al., 2008a,b).

Foot traffic

Persistent human trampling on beaches also results in reduced faunal abundances. Noriega et al. (2012) showed consistent 10-fold decreases in ghost crab abundances between visited and unvisited beaches (actual densities changed inversely with intensity and frequency of human activity. Moffett et al. (1996) demonstrate experimentally that barefoot human traffic reduced the survival of softer-bodied crustacea and juvenile bivalves in the lower intertidal. Compared to other disturbances to the beach that result in faunal losses, foot traffic appears moderate in its effects (McLachlan and Brown, 2006), but consistent but small losses in faunal abundances are reliably seen.

All sand beach response operations inescapably injured resident sand beach biota. The extent to which the faunal communities were reduced in each instance depended on the type, intensity, frequency, and extent (both spatial and temporal) of the response. The specific, component activities in each sand beach response producing injury include foot traffic, vehicular traffic, sediment disruption at the surface and at depth, and physical removal of wrack from the habitat. The proportion of these components within a given sand beach response varies depending on the type of response (Table 10).

We derive specific estimates for the loss of ecosystem services associated with each sand beach response by considering: 1) the levels of intensity of the component activities (Table 10); 2) where the activity occurred on the beach; and 3) whether the activity occurred coincident with oiling of the beach (May 2010 through September 2010).

RI = 1: Intermittent manual treatment. This response was applied mostly within the supratidal portion of the beach, and its impact would have been limited to that area. Although the number of individuals in a team could be high and teams may have had vehicular support, the frequency of team visits within a month reduces the sum of negative effects produced by the team's trampling and vehicle use. The primary activity of these teams was removing tar balls and oiled wrack from the beach. During the interval when oil was coming ashore, the teams were aggressive in removing all wrack, whether it was visibly oiled or not. The virtually complete removal of wrack would have also removed many wrack fauna and the essential habitat for them to utilize subsequent to the team visit. Because this activity was coincident with oiling during the summer of 2010 we cannot separate oiling and response injury effects. Consequently, during this time we assign a 100% loss of the faunal community in the backbeach arising from the combined effects of oiling and intensive wrack removal.

When oil ceased washing ashore, starting in late summer, it is assumed, and was subsequently observed, that these teams also altered their practice of removing all wrack and only removed portions that were visibly oiled. Under these conditions loss of the faunal community would result from just the removal of the oiled wrack and the trampling and vehicle traffic of the team. We assign a 1% loss of the faunal community to this level of response. This loss is assigned only to non-amenity beaches. The scale of effects from the manual treatment operation would have been insubstantial compared to daily trampling, physical disturbance, and wrack disruption/removal by recreational and grooming activities on amenity beaches. No detectable loss due to intermittent manual treatment would be expected on an amenity beach.

Table 10. General intensity categories for component activities associated with each sand beach response. These categories reflect the magnitude of a given activity within a segment within a month interval based on direct observations by SCAT teams or reports of the activities.

Response Injury (RI) Category	Foot Traffic	Vehicular Traffic	Sediment Disruption / Excavation	Wrack Removal	Spatial Extent of Activity within Segment
RI = 1: Intermittant Manual Treatment	Very Low to Low	None to low depending on whether any or how many vehicles were present.	None to Low	Prior to 1 October 2010 - High After 1 October 2010 - Low	Entire
RI = 1: Augering	Low to Moderate	High due to use of the tracked auger	Very High in augered pits	Low. Incidental physical disruption only.	Limited. The area excavated comprised only 1% of the backbeach area.
RI = 1: SOMs removal	Moderate	High due to use of tracked vehicles and towed equipment.	High	None to Very Low	Limited. Activity was concentrated in the intertidal adjacent to the subtidal location of the SOM
RI = 2: Intensive Manual Treatment	Moderate	None to low depending on whether any and how many vehicles were present.	None to Low	Prior to 1 October 2010 - High After 1 October 2010 - Low	Entire.
RI = 3: Beach Grooming / Tilling / Very Intensive Manual	Moderate	High	High	High due to direct removal and physical disruption	Entire.
RI = 4: Excavation	Moderate	High	High	High	Extensive.
RI = 5: Intensive Mechanical Treatment; Staging areas; Dredging	Moderate	High	High	High	Extensive.

RI = 1: Augering. This response was applied mostly within the supratidal portion of the beach. The mechanical auger generally removed sediment to depth of 1.2 m in a 0.3 m wide bore hole. These bore holes were augured in a grid pattern with 10 m intervals. The direct physical disruption of the beach by augering consequently represents ~1% of the area. Physical trauma and subsequent burial or exposure of the infauna would lead to almost 100% mortality to organisms in the sediments removed by the augur. In addition, some mortality would be expected from foot and vehicle traffic during operations. Combining these considerations, we assign a 2% loss of the faunal community per segment per month.

RI = 1: SOMs removal. This response was staged in the intertidal portion of the beach. Although some collateral foot and vehicular traffic may have occurred in the supratidal, the impact of this activity was mostly constrained to the intertidal. In those portions where the mechanical equipment were operating, the mortality of organisms would have been extensive or absolute due to the repeated movement of heavy vehicles over the area. However, the spatial extent of the activity was limited within the segment to the area adjacent to the SOM. We have no evidence that intertidal organisms away from the target area would have been negatively affected except during transit to that area. We assign, for the segment, a loss of 5% the faunal community during each month this response was applied.

RI = 2: Intensive manual treatment. This response was applied mostly in the supratidal portion of the beach and was very similar to intermittent manual treatment in the nature and type of activities. The major difference between these two categories is that the intensive manual treatment occurred much more frequently than the intermittent treatment. The greater frequency of all activities associated with this treatment would impose marginally higher mortalities than expected during the intermittent treatments. Consequently, we assign a 100% loss during the interval when oil was coming ashore and wrack removal was complete and a 2% loss of the faunal community during times subsequent to oil washing ashore. As with intermittent manual treatment, and for the same reasons, this community loss is applied only to non-amenity beaches.

RI = 3: Beach Grooming /Tilling /Very Intensive Manual Treatment. These responses were applied primarily in the supratidal portion of the beach although some of the intensive manual treatment occurred in the intertidal portion. All of these practices involved substantial disruption, removal, and subsequent replacement of sediments. Organisms burrowing in the sediments would have been displaced, damaged by physical trauma, exposed to dessication, and potentially reburied beneath excessive amounts of sediment: all of which would induce mortality. The amount of foot and vehicle traffic was high during these operations. Although these responses did not target beach wrack they would have removed and disrupted any beach wrack present very thoroughly. We assign 100% loss of the faunal community in the beach segment for the month in which any of these responses were applied in both supratidal and intertidal zones.

RI = 4: Excavation. This response was applied mostly in the supratidal portion of the beach although some occurred in the intertidal portion. Similar to the conditions produced by RI = 3, excavation operations removed sediment using mechanical devices. The removed sediment was then sifted, guaranteeing that any organisms would be removed and killed. These operations also had high amounts of collateral foot and vehicle traffic and would have disrupted some wrack while in transit to targeted areas of the beach. We assign 100% loss of the faunal community in the beach segment for the month in which any of these responses were applied in both supratidal and intertidal zones.

RI = 5: Intensive Mechanical Treatment/Staging Areas/Dredging. This response was applied in the supratidal portion of the beach although some occurred in the intertidal portion. The scale of disruption of the beach associated with this response exceeded those of all of the other responses.

Mechanical means were used to excavate sediments over large areas to substantial depths (>12 inches). Only adult ghost crabs burrowed in the beach would have escaped displacement. Even so, several studies indicate that factors that disrupt sediments over ghost crab burrows subsequently result in either immigration of surviving or mortality. These operations also maintained staging areas where disruption of the habitat by trampling and vehicles would have been intense. We assign 100% loss of the faunal community in the beach segment for the month in which any of these responses were applied in both supratidal and intertidal zones.

Barriers

At some locations physical barriers were erected to stem transport of oil through inlets into lagoons behind the barrier islands (see section 4 for a review of these structures). Most of these structures were not erected on beaches. However, access to the construction locations did generally involve transporting equipment and crews over beaches. Consequently, we would expect losses to the beach faunal communities, especially in the supratidal during construction and removal resulting from foot and vehicular traffic (Table 11).

Table 11. Estimated loss of faunal beach communities associated with construction and placement of known physical barriers, sand berms, and breach closures on sand beach habitats as part of the response to the DWH oil spill.

Location	Type	Loss during placement	Loss while in place*	Loss during removal
Louisiana				
Cameron Parish	Hesco baskets	**50% loss**	**20% loss**	**50% loss**
Trinity Island	Sand bags, 25 sheets of plywood	**50% loss**	**20% loss**	**50% loss**
Timbalier Island	Sheet piling	**50% loss**	**10% loss**	**50% loss**
Fourchon Beach	Hesco baskets	**50% loss**	**20% loss**	**50% loss**
Fourchon Beach	Breach closures, using riprap, sand bags, sand, geotextiles	**20% loss**	**0% loss**	**20% loss**
Southwest Pass	Tiger Dam boom	**5% loss**	**20% loss**	**5% loss**
Alabama				
Dauphin Island, Mississippi Sound	Hesco baskets, with associated erosion and undercutting visible on late 2010 photos	**100% loss**	**50% loss**	**50% loss**
Dauphin Island, Gulf	Sand berm on Gulf side of Bienville Blvd, gaps across roads/driveways, height 3-4 m	**0% loss**	**0% loss**	**0% loss** – left in place
Dauphin Island, Gulf	Sand berm, 2-3 m high	**50% loss**	**10% loss**	**0% loss** – did not persist
Orange Beach	Sand berm dune repair A90	**50% loss**	**0% loss**	**0% loss** – left in place
Gulf Shores	Dune breach closures; dune repairs	**50% loss**	**0% loss**	**0% loss** – left in place

Our estimate of losses due to the presence of the barriers follows from one of the few studies that examined the effects of these structures on beaches. Bessa et al. (2013) documented a 67% decrease in the most abundant talitrid, without increases in any other wrack fauna, on beaches with sandbags and geotubes. In the majority of cases the barriers were landward of the backbeach. They would not have had as large effect as that documented in this study. But even barriers that are landward of the beach can have some effect. Barros (2001) found an almost 9-fold decrease in ghost crab abundances on urban (wall-fronted) beaches than non-urban, sloped beaches (the former also had higher human activity levels). Lucrezi et al. (2009) found a 50% decrease in ghost crabs between a beach with a back wall and one without. Based on these studies, it is probable that the disruption of cross-island movement by fauna, sediment, and detritus imposed by any barrier would produce faunal losses. We assign a much higher loss of faunal community to the sand berm erected on the sound side of Dauphin Island because these structures largely covered much of the supratidal and abutted the high water mark.

6.0 SUMMARY OF SAND B EACH IMPACTS

Injury to sand beaches resulted from both oil exposure and the disturbances associated with response actions. Figure 34 shows the approach to the sand beach exposure and injury assessment, for impacts resulting from both oiling and response activities during the Deepwater Horizon spill. Steps 1 and 2 are described in detail in the previous section of this report. Based on the data collected from the response the lengths and areas of oiling by state lands and federal (Department of the Interior (DOI) and Department of Defense [DOD]) lands as well as the oiling degree were summaries for the affected Gulf beaches (Tables 12 and 13). The degree of oiling (heavier and lighter) are presented in Figure 35 which shows a plot of the total miles by state and federal lands oiled, and Figures 36 and 37 show the miles and acres of oiling by heavier and lighter categories. Of the 600 miles (12.662 acres) of sand beach habitat that was oiled, 236 miles (5781 acres) were assigned to the heavier oiling category 364 miles (6881 acres) were assigned to the lighter oiling category.

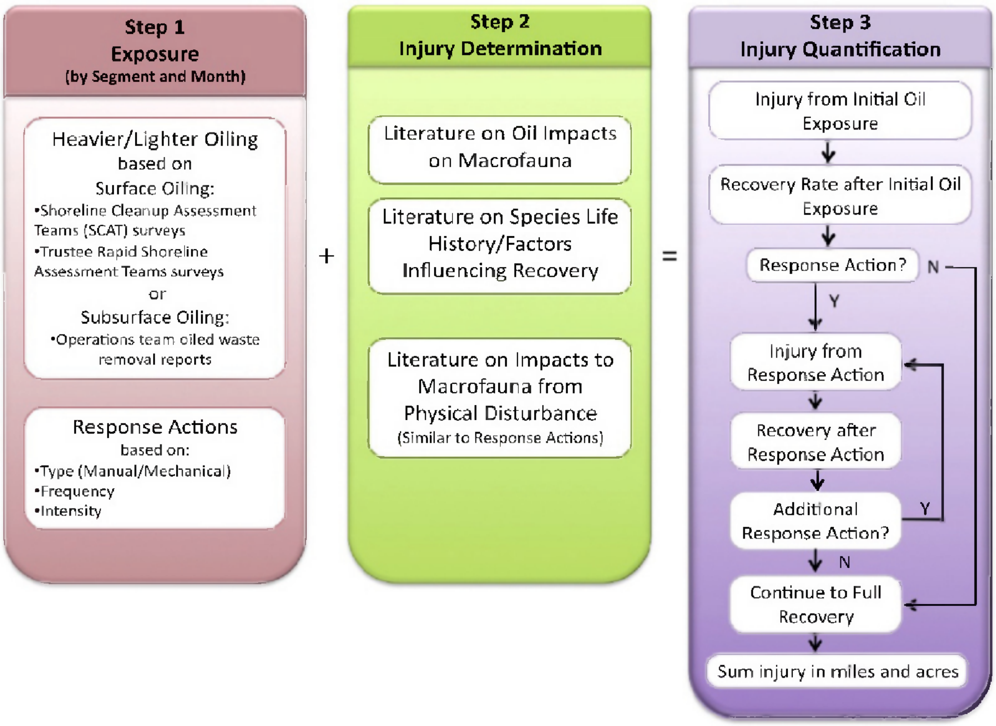

Figure 34. Flow chart of the approach to the sand beach exposure and injury assessment.

As discussed in section 5, based on a review of the literature, the impacts of oiling reduced the beach fauna of the intertidal zone by at least 95% on heavier oiled beaches and by approximately 20% on the lighter oiled beaches. In the supratidal zone, the impacts of oiling could not be separated from the response-related injury because of the extensive removal of the wrack, which is an essential component of the supratidal habitat. Therefore, on heavier oiled beaches, the oil exposure and subsequent wrack removal resulted in 100% reductions in the supratidal zone faunal communities for the heavier oiled beaches and at least a 40% reduction for the lighter oiled beaches.

Table 12. Detailed miles and acres of oiling by oiling category, by state lands and DOI and DOD lands, by state (acres are based on length and the measured width of the beach, as described in Appendix A). Sums may not total due to rounding.

Miles Oiled	Texas		Louisiana		Mississippi		Alabama		Florida		TOTAL MILES	
	Heavier	**Lighter**	**Heavier**	**Lighter**	**Heavier**	**Lighter**	**Heavier**	**Lighter**	**Heavier**	**Lighter**	**Heavier**	**Lighter**
State	0	27	109	46	8	55	36	36	3	93	156	258
DOI	0	8	10	17	27	31	8	4	33	38	78	98
DOD	0	0	0	0	0	0	0	0	1	8	1	8
TOTAL	0	35	119	63	36	86	44	41	38	139	236	364

Acres Oiled	Texas		Louisiana		Mississippi		Alabama		Florida		TOTAL ACRES	
	Heavier	**Lighter**	**Heavier**	**Lighter**	**Heavier**	**Lighter**	**Heavier**	**Lighter**	**Heavier**	**Lighter**	**Heavier**	**Lighter**
State	0	842	2618	750	128	979	869	430	68	1752	3683	4754
DOI	0	197	241	391	761	589	219	25	874	836	2095	2039
DOD	0	0.0	0	0	0	0	0	0	3	88	3	88
TOTAL	0	1039	2859	1142	889	1569	1088	455	944	2677	5781	6881

Table 13. Length and area of oiling by state lands and DOI and DOD lands, by state. Top table is in miles and acres. Bottom table is in kilometers (km) and hectares (ha).

	Texas		Louisiana		Mississippi		Alabama		Florida		Totals	
	Miles	Acres	Miles	Acres	Miles	Acres	Miles	Acres	Miles	Acres	Miles	Acres
State Lands	27	842	156	3368	64	1124	72	1299	96	1820	415	8437
DOI	8	197	27	632	57	1334	12	244	71	1710	176	4134
DOD	0	0	0	0	0	0	0	0	9	91	9	91
Total	35	1039	182	4001	121	2458	84	1543	176	3621	600	12662

	Texas		Louisiana		Mississippi		Alabama		Florida		Totals	
	km	ha	km	ha	km	ha	km	ha	km	ha	km	ha
State	43	341	250	1363	102	448	116	526	155	737	667	3414
DOI	13	80	43	256	93	546	20	99	114	692	283	1673
DOD	0	0	0	0	0	0	0	0	15	37	15	37
Total	57	421	293	1619	195	995	136	624	284	1465	965	5124

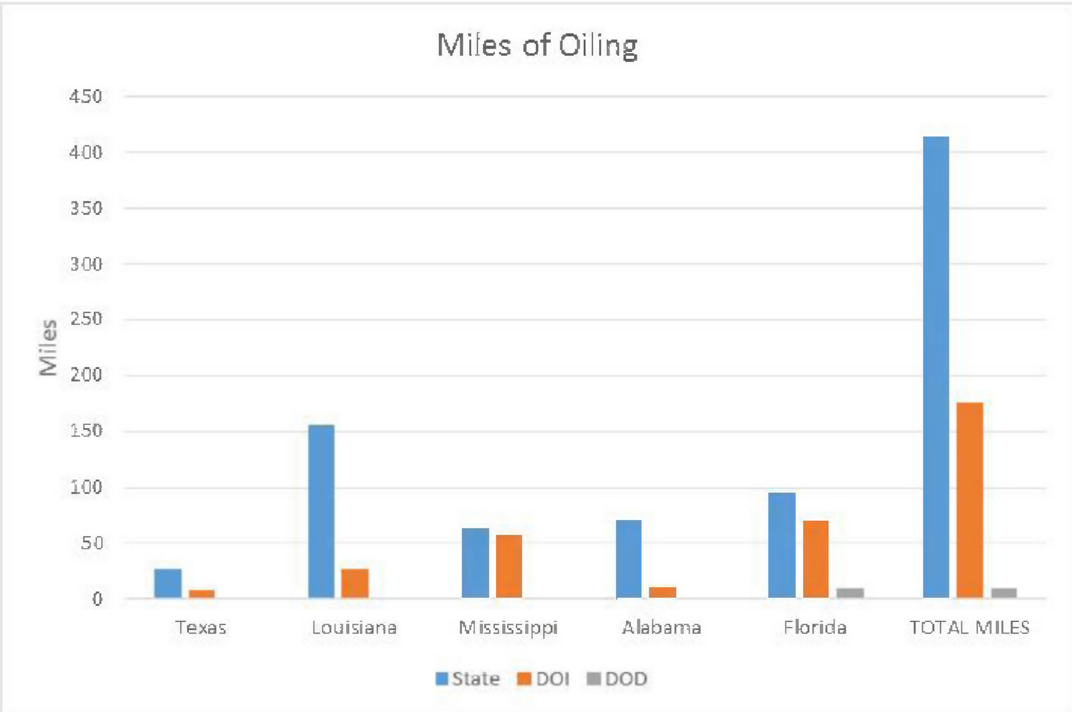

Figure 35. Total miles of shoreline oiling in each state and federal lands (DOI/DOD).

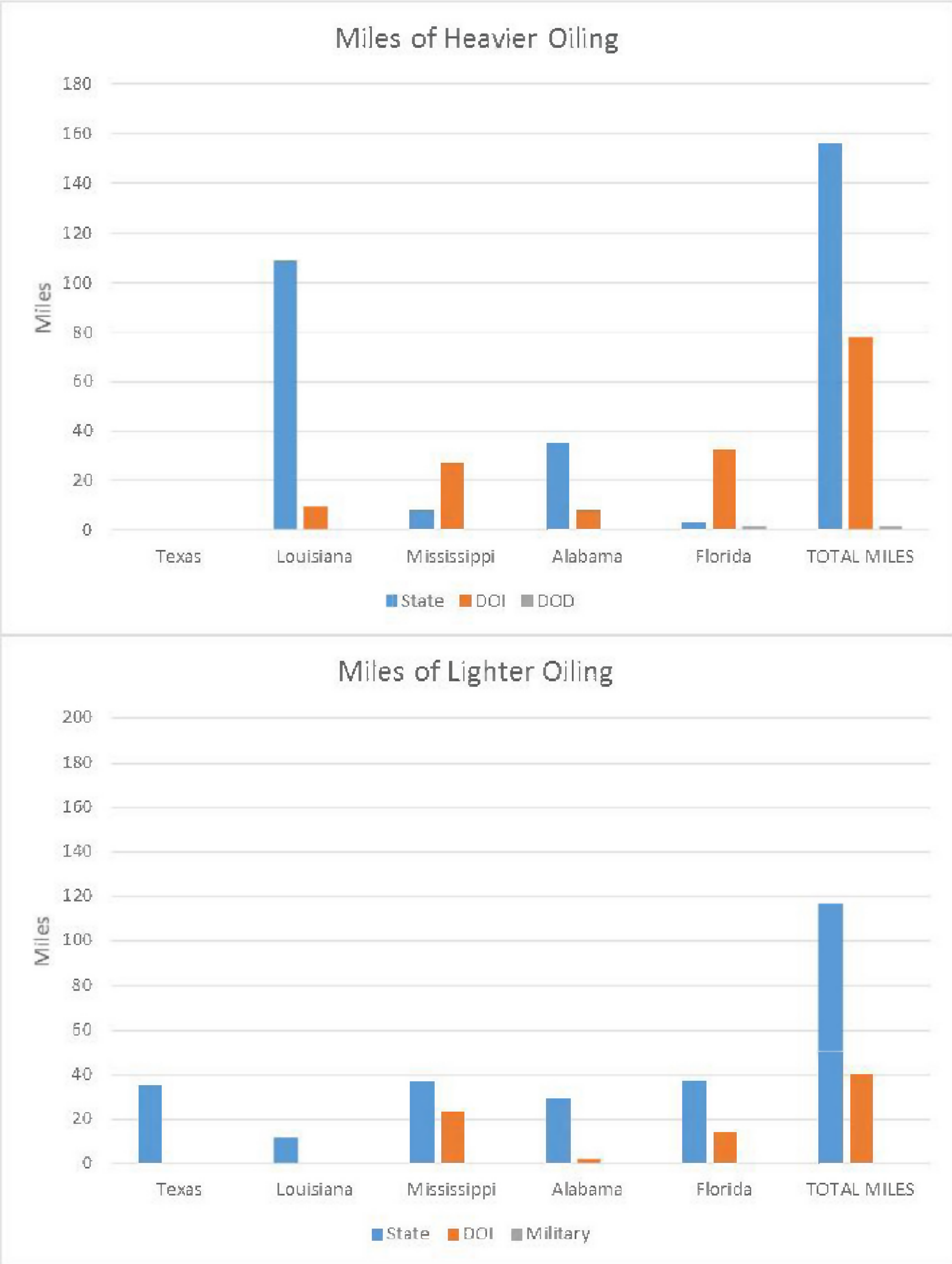

Figure 36. Plots of the miles of heavier and lighter oiling by state and DOI/DOD lands.

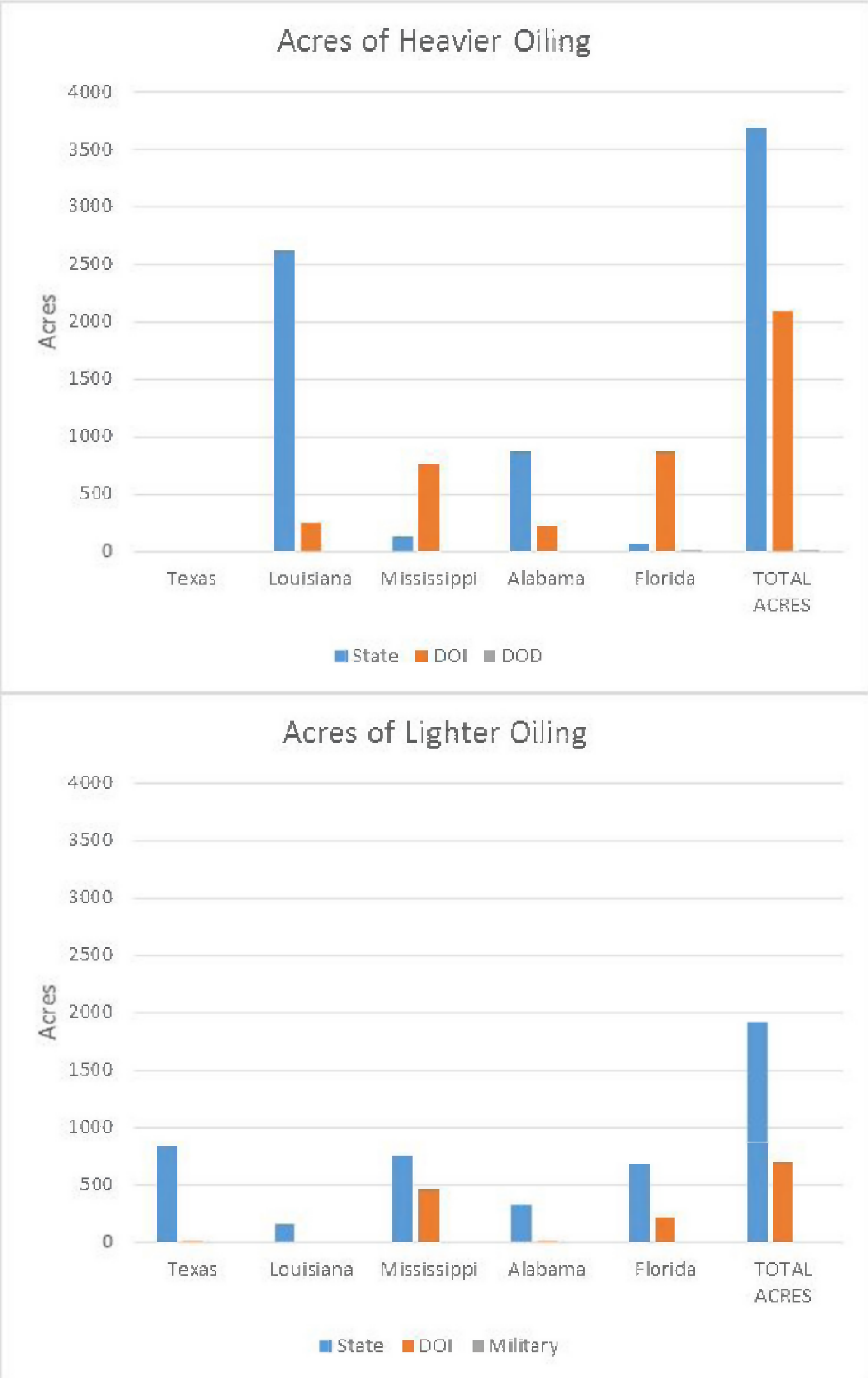

Figure 37. Plots of the acres of heavier and lighter oiling by state and DOI/DOD lands.

We evaluated recovery rates in section 5.3 of this report and based on those findings determined that recovery from the oiling alone would have been extended beyond the rates cited in the literature for previous spills because: 1) the oil initially stranded on sand beaches over three months rather than as a single event; 2) oil stranded onshore during the periods of peak recruitment, which would affect the next year's population as well as those present at the time of oiling; 3) the geographic extent of the oil, over 600 contiguous miles of beach habitat, greatly reduced the sources of potential recruits, particularly for those species who brood their young, but also for those with a pelago-benthic life history where upcurrent beaches were heavily oiled. Four different recovery patterns were developed, depending on the degree of initial oiling and the geographic location of the sand beach habitat, focused on the rate of recruitment from upcurrent beaches and the return of wrack. If there had been no additional injury during the response, we have estimated that recovery would have taken up to 5 years from the oiling alone on the heavier oiled beaches.

As the beach started to recover from the oil exposures, the extensive response activities delayed the recovery, depending on the intensity of the response activity.

Response injury scores were assigned to each of the beach response segments using the methodology described in section 5.3. Tables 14 and 15 show the miles and acres of sand beach that were assigned a Response Injury category (the maximum RI assigned per segment) in total and by RI category. Figures 37 and 38 show the data from Tables 14 and 15 as histogram plots. Based on literature studies of similar types of disturbances, a percent reduction in sand beach faunal communities was assigned to each segment for the five response injury categories. A similar analysis was conducted for segments for barriers placed to protect sensitive areas. Whenever a response activity was conducted in a month, the percent reduction for that category of response was applied to that segment for that month. The beach would have begun to recover at the assigned recovery pattern for the intertidal communities (Table 7 for heavier oiled beaches and Table 8 for lighter oiled beaches) or at the rate described in Table 9 for supratidal communities. This process is shown as Step 3 in Figure 34. This process continued until the last time a response activity was conducted; then the segment would recover at the assigned rate until full recovery was estimated to occur.

Table 14. Summary of miles and acres of shoreline that were assigned a Response Injury category, including unoiled segments where barriers were placed, by state lands and Department of the Interior (DOI) and Department of Defense lands, by state, and totals in miles and acres. Sums may not total due to rounding.

	Louisiana		Mississippi		Alabama		Florida		Totals	
	Miles	**Acres**	**Miles**	**Acres**	**Miles**	**Acres**	**Miles**	**Acres**	**Miles**	**Acres**
State Lands	129	2635	46	863	70	1275	41	1884	286	6657
DOI	12	363	57	1338	10	235	65	4144	144	6080
DOD	0	0	0	0	0	0	5	47	5	47
Total	**141**	**2998**	**103**	**2201**	**81**	**1510**	**112**	**6074**	**436**	**12784**

Table 15. Detailed miles and acres of response injury (RI) by RI category, by state land and federal lands (DOI, DOD). No DOD lands with sand beach were impacted outside Florida. Sums may not total due to rounding.

	Louisiana		**Mississippi**		**Alabama**		**Florida**		**Total Miles**	**Total Acres**
State Land	Miles	Acres	Miles	Acres	Miles	Acres	Miles	Acres	Miles	Acres
RI 1	38	498	0	0	0	0	0	0	38	498
RI 2	37	623	27	437	42	550	35	1580	141	3190
RI 3	16	423	19	427	11	248	3	137	48	1235
RI 4	10	306	0	0	14	394	3	166	27	867
RI 5	20	596	0	0	0	0	0	0	20	596
Barriers	8	189	-	-	4	83	-	-	11	272
TOTAL	**129**	**2635**	**46**	**863**	**70**	**1275**	**41**	**1884**	**286**	**6657**
DOI Land										
RI 1	12	363	0	0	0	0	0	0	12	363
RI 2	0	0	42	744	6	93	34	2035	81	2872
RI 3	0	0	15	593	4	120	22	1648	41	2361
RI 4	0	0	0	0	1	22	9	461	1	484
RI 5	0	0	0	0	0	0	0	0	0	0
TOTAL	**12**	**363**	**57**	**1338**	**10**	**235**	**65**	**4144**	**144**	**6080**
DOD										
RI 1	-	-	-	-	-	-	0	0	0	0
RI 2	-	-	-	-	-	-	5	47	5	47
RI 3	-	-	-	-	-	-	0	0	0	0
RI 4	-	-	-	-	-	-	0	0	0	0
RI 5	-	-	-	-	-	-	0	0	0	0
TOTAL	**-**	**-**	**-**	**-**	**-**	**-**	**5**	**47**	**5**	**47**

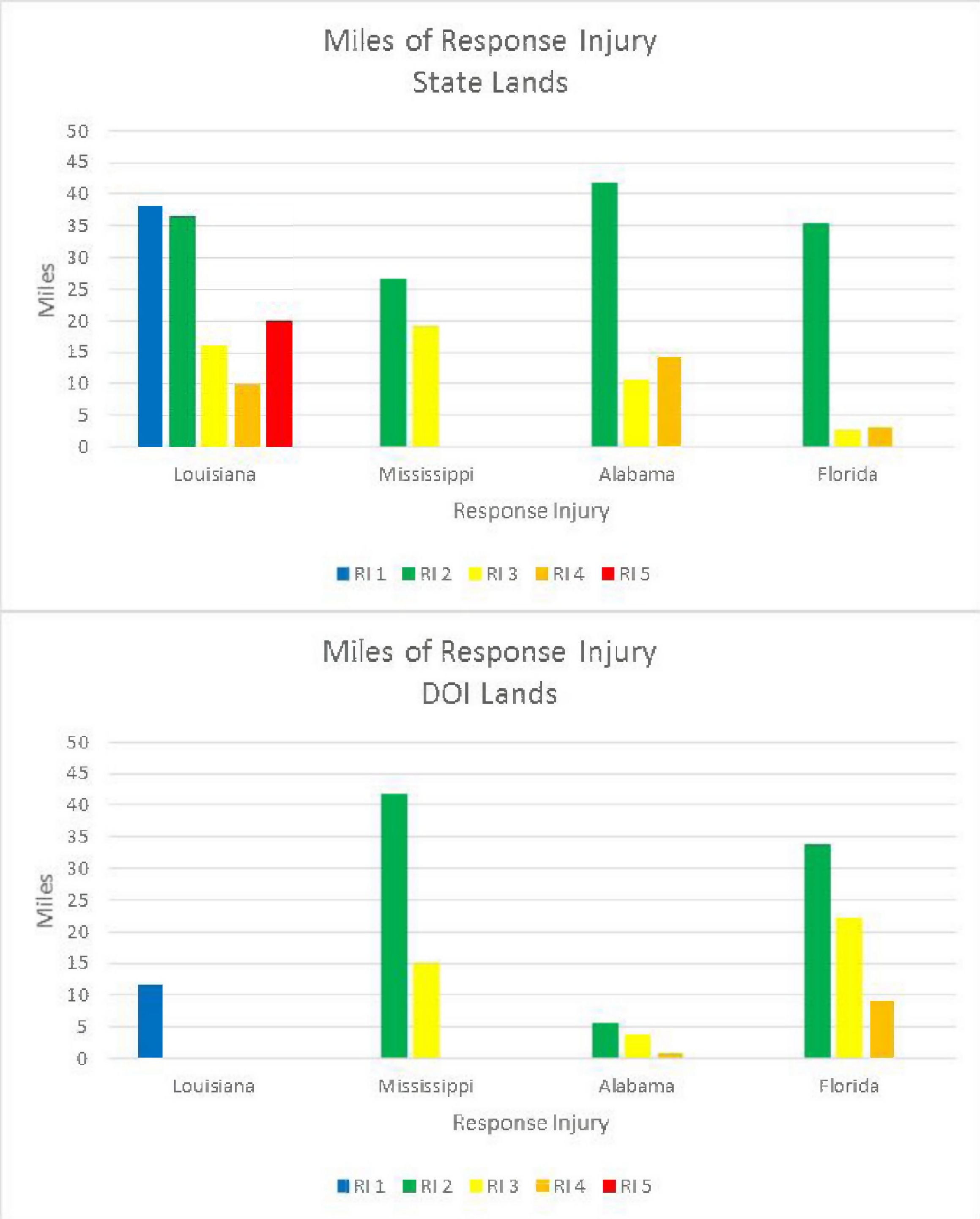

Figure 38. Plots of the miles of Response Injury by category and by state and DOI/DOD lands.

Figure 39. Plots of the acres of Response Injury by category and by state and DOI lands.

Our approach relied heavily on the literature for individual types of disturbances to sand beach communities; for example, recovery of intertidal community abundance and species composition from a single oil spill stranding, studies of vehicle traffic on damage to ghost crab burrows on a single beach, and beach grooming on wrack communities in limited areas. The literature studies were analogues to the types of response and corresponding injury that would have been expected for the types of oil removal activities conducted across the Gulf. However, the *Deepwater Horizon* oil spill was unprecedented in terms of the areal extent and duration of both oil exposure and response activities. These disturbances to over 600 contiguous miles of beach shoreline in the northern GOM likely far exceed the damages documented in individual studies of small areas over short time periods. As noted previously, recovery times would have been extended by 1 to 4 years from the individual studies. In all recovery would not be anticipated to have occurred until 2017. Clearly, based on the findings of this and other studies the *Deepwater Horizon* oil spill and subsequent response actions resulted in significant loss in ecosystem function of sand beach habitats in the northern GOM and that substantive restoration activities will be required to compensate for the loss.

7.0 REFERENCES CITED

Ansari, Z. and B. Ingole (2002). Effect of an oil spill from M/V Sea Transporter on intertidal meiofauna at Goa, India. *Marine Pollution Bulletin* 44(5):396-402.

Anders, F.J. and S.P. Leatherman (1987). Effects of off-road vehicles on coastal foredunes at Fire Island, New York, USA. *Environmental Management* 11 (1):4552.

AURIS (1995). *Scoping evaluation of the biological recovery of Mangroves, Coral Reefs, Seagrasses and Sedimentary Shores*, A report by AURIS Environmental, Aberdeen. 148.

Barros, F. (2001). Ghost crabs as a tool for rapid assessment of human impacts on exposed sandy beaches. *Biological Conservation* 97:399-404.

Barth, H. J. (2002). The 1991 Gulf War Oil Spill: Its Ecological effects and recovery rates of intertidal ecosystems at the Saudi Arabian Gulf Coast - Results of a 10-Year Monitoring Period. University of Regensburg, Regensburg, Germany, pp. 270.

Bessa, F., A. Baeta and J.C. Marques (2014). Niche segregation amongst sympatric species at exposed sandy shores with contrasting wrack availabilities illustrated by stable isotopic analysis. *Ecological Indicators* 36:694-702.

Bilodeau, A.L. and R.P. Bourgeois (2004). Impact of beach restoration on the deep-burrowing ghost shrimp, *Callichirus islagrande*. *Journal of Coastal Research* 20(3):931-936.

Bird, B.L., L.C. Branch and D.L. Miller (2004). Effects of coastal lighting on foraging behavior of beach mice. *Conservation Biology* 18(5):1435-1439.

Blaylock, W. and J. Houghton (1989). Infaunal recovery at Ediz Hook following the *Arco Anchorage* oil spill. 1989 Oil Spill Conference (Prevention, Behavior, Control, Cleanup), San Antonio, TX.

Bodin, P. (1988). Results of ecological monitoring of three beaches polluted by the *Amoco Cadiz* oil spill: development of meiofauna from 1978 to 1984. *Marine Ecology Progress Series* 42(2):105-123.

Borzone, C. and L. Rosa (2009). Impact of oil spill and posterior clean-up activities on wrack-living talitrid amphipods on estuarine beaches. *Brazilian Journal of Oceanography* 57:315-323.

Boucher, G. (1980). Impact of *Amoco Cadiz* oil spill on intertidal and sublittoral meiofauna. *Marine Pollution Bulletin* 11(4):95-101.

Britton, J.C. and B. Morton (1989). Shore Ecology of the Gulf of Mexico. University of Texas Press, Austin, TX, 387 pp.

Byrnes, M.R., J. D. Rosati, S.F. Griffee and J.L. Berlinghoff (2013). Historical sediment transport pathways and quantities for determining an operational sediment budget: Mississippi Sound barrier islands. *Journal of Coastal Research* 63(SI):166-183.

Chan, E. (1976). Oil Pollution and Tropical Littoral Communities: Biological Effects of the 1975 Florida Keys Oil Spill, University of Miami, Rosenstiel School of Marine and Atmospheric Science, pp. 539-542.

Cipriani, L. E. and G. W. Stone (2001). Net longshore sediment transport and textural changes in beach sediments along the southwest Alabama and Mississippi barrier islands, U.S.A. *Journal of Coastal Research* 17:443-458.

Coastal Planning & Engineering (2013). Project Completion Report: West Belle Pass Barrier Headland Restoration Project. Available at: http://lacoast.gov/reports/project/5015680~1.pdf

Cobb, J. C. and B. Arnold (2008). Assessment of Nourishment Impacts to Beach Habitat Indicator Species in Pinellas County, Florida October 2005 - July 2007. Final Report to the Florida Fish and Wildlife Conservation Commission. St. Petersburg, Florida. 78 pp.

Croker, R. A. (1967). Niche diversity in five sympatric species of intertidal amphipods (Crustacea: Haustoriidae). *Ecological Monographs* 37(3):173-200.

Defeo, O., A. McLachlan, D. Schoeman, T. Schlacher, J. Dugan, A. Jones, M. Lastra and F. Scapini (2009). Threats to sandy beach ecosystems: A review. *Estuarine, Coastal and Shelf Science* 81(1):1-12.

De La Huz, R., M. Lastra, J. Junoy, C. Castellanos and J. Vieitez (2005). Biological impacts of oil pollution and cleaning in the intertidal zone of exposed sandy beaches: Preliminary study of the *Prestige* oil spill. *Estuarine, Coastal and Shelf Science* 65(1-2):19-29.

Diaz, H. (1980). The mole crab *Emerita talpoida* (Say): a case of changing life history pattern. *Ecological Monographs* 50(4):437-456.

Dingler, J.R., S.A. Hsu and T.E. Reiss (1992). Theoretical and measured aeolian sand transport on a barrier island, Louisiana, USA. *Sedimentology* 39:1031-1043.

Drake, K.A., J.E. Thompson, K.L. Drake and C. Zonick (2001). Movements, habitat use and survival of wintering Piping Plovers. *Condor* 103:259-267.

Dow, W., K. Eckert, M. Palmer and P. Kramer (2007). An Atlas of Sea Turtle Nesting Habitat for the Wider Caribbean Region. The Wider Caribbean Sea Turtle Conservation Network and The Nature Conservancy. WIDECAST Technical Report No. 6. 267 pp, plus electronic appendices.

Dugan, J.E., D.M. Hubbard, D.L. Martin, J.M. Engle, D.M. Richards, G.E. Davis, K.D. Lafferty and R.F. Ambrose (2000). Macrofauna communities of exposed sandy beaches on the Southern California Mainland and Channel Islands, 99-0038:339-344.

Dugan, J.E., D.M. Hubbard, M.D. McCrary and M.O. Pierson (2003). The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of Southern California. *Estuarine, Coastal and Shelf Science* 58:25-40.

Dugan, J.E., O. Defeo, E. Jaramillo, A.R. Jones, M. Lastra, R. Nel, C.H. Peterson, F. Scapini, T. Schlacher, and D.S. Schoeman (2010). Give beach ecosystems their day in the sun. *Science* 329:1146.

Engel, A.S. and A.A. Gupta (2014). Regime shift in sandy microbial communities following *Deepwater Horizon* Oil spill remediation efforts. *PLoS ONE* 9(7):e102934. doi:10.1371/journal.pone.0102934

Engelhard, T. and K. Withers (1997). Biological Effects of Mechanical Beach Raking in the Upper Intertidal Zone on Padre Island National Seashore, Texas, Padre Island National Seashore, National Park Service, Department of the Interior, Resource Management Division, Corpus Christi, TX. 50 pp.

Fanini L. and J. Lowry (2014). Coastal talitrids and connectivity between beaches: a behavioral test. *Journal of Experimental Marine Biology and Ecology* 457:120-127.

Filho, J. S. R., M. F. Almeida, and D. E. Aviz (2009). Spatial and temporal changes in the benthic fauna of a macrotidal Amazon sandy beach, Ajuruteua, Brazil. *Journal of Coastal Research* 56:1796-1780.

FitzGerald, D. and S. Jepson (2010). Surf-Washing Plan for Grand Isle. Report submitted to the *Deepwater Horizon* Unified Command.

Georgiou, I. Y., D. M. Fitzgerald, and G. W. Stone (2005). The impact of physical processes along the Louisiana coast. *Journal of Coastal Research,* Special Issue No. 44: 72-89.

Getter, C.D., G. I. Scott, and L.C. Thebeau (1981). Biological Studies, pp. 119-174. In: C.H. Hooper (Editor). The *Ixtoc I* Oil Spill. U.S. Department of Commerce, NOAA Office of Marine Pollution Assessment. (Publication number 577-846-1982). U.S. Government Printing Office. 202 pp.

Gheskiere, T., V. Magda, P. Greet and D. Steven (2006). Are strandline meiofaunal assemblages affected by a once-only mechanical beach cleaning? Experimental findings. *Marine Environmental Research* 61(3):245-264.

Gheskiere, T., M. Vincx, J.M. Weslawski, F. Scapini and S. Degraer (2005). Meiofauna as descriptor of tourism-induced changes at sandy beaches. *Marine Environmental Research* 60(2):245-265.

Giere, O. (1979). The Impact of oil pollution on intertidal meiofauna: field studies after the La Coruna-Spill, May 1976. *Cahiers de Biologie Marine.*

Gower, J.F.R. and S.A. King (2011). Distribution of floating *Sargassum* in the Gulf of Mexico and the Atlantic Ocean mapped using MERIS. *International Journal of Remote Sensing* 32(7):1917-1929.

Hobbs, III, C.H., C. B. Landry, and J. E. Perry, III. (2008). Assessing Anthropogenic and natural impacts on ghost crabs (*Ocypode quadrata*) at Cape Hatteras National Seashore, North Carolina. *Journal of Coastal Research* 24(6):1450-1458.

Hooper, C. (1981). The Ixtoc I Oil Spill: The Federal Scientific Response, US Dept. of Commerce, National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment.

Irlandi, E. and B. Arnold (2008). Assessment of Nourishment Impacts to Beach Habitat Indicator Species. Final Report to the Florida Fish and Wildlife Conservation Commission. Grant Agreement No. 05042. St. Petersburg, Florida. 39 pp.

Johnson, C.M. and G.A. Baldassarre (1988). Aspects of wintering ecology of piping plovers in coastal Alabama. *Wilson Bull.* 100:214-233.

Johnson, D.R., H.M. Perry, J. Lyczkowski-Shultz and D. Hanisko (2009). Red snapper larval transport in the northern Gulf of Mexico. *Transactions of the American Fisheries Society* 138:458-470.

Jones, A., A. Murray, T. Lasiak and R. Marsh (2008a). The effects of beach nourishment on the sandy-beach amphipod *Exoediceros fossor*: impact and recovery in Botany Bay. New South Wales, Australia. *Marine Ecology* 29:28-36.

Jones, D., M. Hayes, F. Krupp, G. Sabatini, I. Watt and L. Weishar (2008b). The Impact of the Gulf War (1990-91) Oil Release Upon the Intertidal Gulf Coast Line of Saudi Arabia and Subsequent Recovery. Protecting the Gulf's Marine Ecosystems from Pollution, pp. 237-254.

Junoy, J., C. Castellanos, J. Viéitez, M. De La Huz and M. Lastra (2005). The macroinfauna of the Galician sandy beaches (NW Spain) affected by the *Prestige* oil-spill. *Marine Pollution Bulletin* 50(5):526-536.

Keller, W. J. and C. M. Pomory (2008). Effects of porous mesh groynes on macroinvertebrates of a sandy beach, Santa Rosa Island, Florida, U.S.A. *Gulf of Mexico Science* 1:36-45.

Kindinger, M. E. (1981). Impacts of the *Ixtoc I* Oil Spill on the Community Structure of the Intertidal and Subtidal Infauna Along South Texas Beaches. Corpus Christi, Texas, Corpus Christi State University. 91 pp.

Kluft, J.M. and H.S. Ginsberg (2009). The Effect of Off-Road Vehicles on Barrier Beach Invertebrates at Cape Cod and Fire Island National Seashores. Technical Report NPS/NER/NRTR-2009/138. National Park Service. Boston, MA.

Leatherman, S.P. and P.J. Godfrey (1979). The Impact of Off-Road Vehicles on Coastal Ecosystems in Cape Cod National Seashore: An Overview. University of Massachusetts/National Parks Service Cooperative Research Unit Report No. 34. 34 p

Leber, K. M. (1982). Seasonality of macroinvertebrates on a temperate, high wave energy sandy beach. *Bulletin of Marine Science* 32(1):86-98.

Lindquist, N. and L. Manning (2001). Impacts of Beach Nourishment and Beach Scraping on Critical Habitat and Productivity of Surf Fishes. Final Report to the NC Fisheries Resource Grant Program, Morehead City. 107 pp.

Long, B., J. Vandermeulen and T. Ahern (1987). The evolution of stranded oil within sandy beaches. Oil Spill Conference, American Petroleum Institute, Washington, DC: 519-524.

Lucrezi, S., T.A. Schlacher and S. Walker (2009a). Monitoring human impacts on sandy shore ecosystems: a test of ghost crabs (*Ocypode* spp.) as biological indicators on an urban beach. *Environmental Monitoring and Assessment* 152:413-424.

Lucrezi, S., T.A. Schlacher and W. Robinson (2009b). Human disturbance as a cause of bias in ecological indicators for sandy beaches: Experimental evidence for the effects of human trampling on ghost crabs (*Ocypode* spp.). *Ecological Indicators* 9:913-921.

Lucrezi, S. and T.A. Schlacher (2010). Impacts of off-road vehicles (ORVs) on burrow architecture of ghost crabs (Genus Ocypode) on sandy beaches. *Environmental Management* 45(6):1352-1362.

Malm, T., S. Råberg, S. Fell and P. Carlsson (2004). Effects of beach cast cleaning on beach quality, microbial food web, and littoral macrofaunal biodiversity. *Estuarine, Coastal and Shelf Science* 60(2):339-347.

Manning, L.M., C.H. Peterson, and S. Fegley (2013). Degradation of surf-fish foraging habitat driven by persistent sedimentological modifications caused by beach nourishment. *Bulletin of Marine Science* 89(1):83-106.

Manning, L.M., C.H. Peterson, and M.J. Bishop (2014). Dominant macrobenthic populations experience sustained impacts from annual disposal of fine sediments on sandy beaches. *Marine Ecology Progress Series* 508:1-15.

Morang, A., J.P. Waters and S.M. Khalil (2012). Gulf of Mexico regional sediment budget. *Journal of Coastal Research* 60(SI):1-29.

Maslo, B., S.N. Handel and T. Pover (2011). Restoring beaches for Atlantic coast piping plovers (*Charadrius melodus*): A Classification and regression tree analysis of nest-site selection. *Restoration Ecology* 19:194-203.

McLachlan, A. (1996). Physical factors in benthic ecology: effects of changing sand particle size on beach fauna. *Marine Ecology Progress Series* 131:205-217.

McLachlan, A. and A. C. Brown (2006). The Ecology of Sandy Shores, 2nd edition. Academic Press, Elsevier, Burlington, MA. 373 pp.

Michel, J., E.H. Owens, S. Zengel, A. Graham, Z. Nixon, T. Allard, W. Holton, P.D. Reimer, A. Lamarche, M. White, N. Rutherford, C. Childs, G. Mauseth, G. Challenger and E. Taylor (2013). Extent and degree of shoreline oiling: Deepwater Horizon oil spill, Gulf of Mexico, USA. PLoS ONE 8(6):e65087.

Michel, J., H. Dunagan, J. Turek, D. Janik, V. Varela, G. Harmon and M. Markarian (2008). Bouchard B-120 Oil Spill Shoreline Injury Assessment: Injury Quantification, Buzzards Bay, Massachusetts and Rhode Island. Shoreline Assessment Team. 195 pp.

Moffett, M.D., A. McLachlan, P.E.D. Winter and A.M.C. Ruyck (1998). Impact of trampling on sany macrofauna. *Journal of Coastal* 4:87-90.

Moore, C., D. Harries and F. Ware (1997). The Impact of the *Sea Empress* Oil Spill on Sandy Shore Meiofauna of South West Wales. CCW Sea Empress Report No. 230:79.

Moore, J. (2006). State of the Marine Environment in Sw Wales, 10 Years after the *Sea Empress* Oil Spill. A Report to the Countryside Council for Wales from Coastal Assessment, Liaison and Monitoring. CCW Marine Monitoring Reports. Cosheston, Pembrokeshire 21:30.

Morrow, K., Bell, S. S., and Tewfik, A. (2014). Variation in ghost crab trophic links on sandy beaches. *Mar. Ecol. Prog. Ser.* 502, 197-206.

Nelson, W.G. (1993). Beach restoration in the Southeastern US: environmental effects and biological monitoring. *Ocean and Coastal Management* 19:157-182.

Nelson, W.G. and G.W. Collins (1987). Effects of Beach Renourishment on the Benthic Macrofauna and the Fishes of the Nearshore Zone at Sebastian Inlet State Recreation Area. Melbourne, FL, Florida Institute of Technology. Report No. 87-14:180.

Nelson, D.A. (1987). Effect of the use of tilling to soften nourished beach sand consistency for nesting sea turtles. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, MP-87. 18 pp.

Nelson, D.A. and D.D. Dickerson (1988). Response of Nesting Sea Turtles to Tilling of Compacted Beaches, Jupiter Island, Florida. Unpubl. report. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS. 26 pp.

Niedoroda, A.W. (1979). The Geomorphologic Effects of Off-Road Vehicles on Coastal Ecosystems of Cape Cod, Massachusetts. University of Massachusetts/National Park Service Cooperative Research Unit Report No. 17.

Nixon, Z., S. Zengel and J. Michel (2015). Shoreline oiling from the *Deepwater Horizon* oil spill. Prepared for National Oceanic and Atmospheric Administration.

Nolan, J.P. (2015). FOSC memo 16451: FOSC Update on *Deepwater Horizon* Response. Federal Onscene Coordinator, Gulf Coast Incident Management Team, U.S. Coast Guard, New Orleans, LA. 4 pp.

Page, H.M., C.S. Culver, J.E. Dugan,and B. Mardian (2008). Oceanographic gradients and patterns in invertebrate assemblages on offshore oil platforms. *ICES Journal of Marine Science* 65:851-861.

Peterson, C., D. Hickerson and G. Johnson (2000). Short-term consequences of nourishment and bulldozing on the dominant large invertebrates of a sandy beach. *Journal of Coastal Research* 16(2):368-378.

Peterson, C.H., M.J. Bishop, G.A. Johnson, L.M. D'Anna and L.M. Manning (2006). Exploiting beach filling as an unaffordable experiment: Benthic intertidal impacts propagating upwards to shorebirds. *Journal of Experimental Marine Biology and Ecology* 338(2):205-221.

Peterson, C.H., M.J. Bishop, L.M. D'Anna, and G.A. Johnson (2014). Multi-year persistence of beach habitat degradation from nourishment using coarse shelly sediments. *Science of the Total Environment* 487:481-492.

Raffin, J., J. C. Godineau, J. Ribier, R. Platel, H. Francillon, F. Meunier and G. Benest (1981). Evolution on three years of a few sites of Brittany after the Amoco Cadiz oil spill. *Cahiers de Biologie Marine* 22(3):323-348.

Rakocinski, C. F., R. W. Heard, T. Simons, and D. Gledhill (1991). Macroinvertebrate Associations from the beaches of selected barrier islands in the northern Gulf of Mexico: important environmental relationships. *Bulletin of Marine Science* 48(3):689-701.

Rakocinski, C. F., S. E. LeCroy, J. A. McLelland and R. W. Heard (1995). Macrobenthic inventory of the aquatic shoreline habitats within the Gulf Islands National Seashore. Final Report to the U.S. Dept. of the Interior. Ocean Springs, MS. 248 pp.

Rakocinski, C., R. Heard, S. LeCroy, J. McLelland and T. Simons (1996). Responses by macrobenthic assemblages to extensive beach restoration at Perdido Key, Florida, USA. *Journal of Coastal Research* 12(1):326-353.

Rakocinski, C. F., S. E. LeCroy, J.A. McLelland, and R.W. Heard (1998a). Nested Spatiotemporal scales of variation in sandy-shore macrobenthic community structure. *Bulletin of Marine Science* 63(2):343-362.

Rakocinski, C. F., S. E. LeCroy, J. A. McLelland and R. W. Heard (1998b). Macrobenthic effects of hurricanes Opal and Erin within the Gulf Islands National Seashore. Final Report to the U.S. Dept. of the Interior. Ocean Springs, MS. 67 pp.

Reilly, J. F. and V. Bellis (1983). The Ecological Impact of Beach Nourishment with Dredged Materials on the Intertidal Zone at Bogue Banks, North Carolina. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Miscellaneous Report. 83 pp.

Rothschild, S. (2004). Beachcomber's Guide to Gulf Coast Marine Life: Texas, Louisiana, Mississippi, Alabama, and Florida. Lanham, MD: Taylor Trade Publishing. 179 pp.

Schlacher, T.A. and L. Thompson (2012). Beach recreation impacts benthic invertebrates on ocean-exposed sandy shores. *Biological Conservation* 147:123-132.

Schlacher, T. A., R. de Jager and T. Nielsen (2011). Vegetation and ghost crabs in coastal dunes as indicators of putative stressors from tourism. *Ecological Indicators* 11(2):284-294.

Schlacher, T. A., A. Holzheimer, T. Stevens and D. Rissik (2010). Impacts of the *Pacific Adventurer* oil spill on the macrobenthos of subtropical sandy beaches. *Estuaries and Coasts*:1-13.

Schlacher, T. A. and L. M. C. Thompson (2008). Physical impacts caused by off-road vehicles to sandy beaches: Spatial quantification of car tracks on an Australian barrier island. *Journal of Coastal Research* 2:234-242.

Schlacher, T. A., D. Richardson and I. McLean (2008a). Impacts of off-road vehicles (ORVs) on macrobenthic assemblages on sandy beaches. *Environmental Management* 41(6):878-892.

Schlacher, T. A., D. S. Schoeman, J. Dugan, M. Lastra, A. Jones, F. Scapini and A. McLachlan (2008b). Sandy beach ecosystems: key features, sampling issues, management challenges and climate change impacts. *Marine Ecology* 29:70-90.

Schlacher, T.A., L. Thompson and S. Price (2007). Vehicles versus conservation of invertebrates on sandy beaches: Mortalities inflicted by off-road vehicles on ghost crabs. *Marine Ecology* 28(3):354-367.

Schoeman, D., A. McLachlan and J. Dugan (2000). Lessons from a disturbance experiment in the intertidal zone of an exposed sandy beach. *Estuarine, Coastal and Shelf Science* 50(6):869-884.

Schratzberger, M., F. Daniel, C. Wall, R. Kilbride, S. Macnaughton, S. Boyd, H. Rees, K. Lee and R. Swannell (2003). Response of estuarine meio-and macrofauna to in situ bioremediation of oil-contaminated sediment. *Marine Pollution Bulletin* 46(4):430-443.

Shelton, C. R. and P. B. Robertson (1981). Community structure of intertidal macrofauna of two surf-exposed texas sandy beaches. *Bulletin of Marine Science* 31(4):833-842.

Short, J., G. Irvine, D. Mann, J. Maselko, J. Pella, M. Lindeberg, J. Payne, W. Driskell and S. Rice (2007). Slightly weathered Exxon Valdez oil persists in Gulf of alaska beach sediments after 16 years. *Environmental Science and Technology* 41(4):1245-1250.

Steiner, A.J. and S.P. Leatherman (1981). Recreational impacts on the distribution of ghost crabs *Ocypode quadrata* Fab. *Biological Conservation* 20:111-122.

Thebeau, L., J. Tunnell, Q. Dokken and M. Kindinger (1981). Effects of the *Ixtoc I* oil spill on the intertidal and subtidal infaunal populations along lower Texas coast barrier island beaches. Oil Spill Conference. American Petroleum Institute, Washington, DC.

Tunnell, J., Dokken, Q., Kindinger, M., and Thebeau, L. (1982). Environmental impact of IXTOC I oil spill on south Texas sandy beaches: Infauna and shorebirds (pp. 25). Corpus Christi, TX: Corpus Christi State University.

Ugolini, A., G. Ungherese, S. Somigli, G. Galanti, D. Baroni, F. Borghini, N. Cipriani, M. Nebbiai, M. Passaponti and S. Focardi (2008). The amphipod *Talitrus saltator* as a bioindicator of human trampling on sandy beaches, *Marine Environmental Research* 65(4):349-357.

Vanderhorst, J., J. Blaylock, P. Wilkinson, M. Wilkinson and G. Fellingham (1980). Recovery of Strait of Juan De Fuca Intertidal Habitat Following Experimental Contamination with Oil: Second Annual Report, Fall 1979-Winter 1980. EPA-600/7-80-140 US Environmental Protection Agency. Washington, DC. 89 pp.

van der Merwe, D. and D. van der Merwe (1991). Effects of off-road vehicles on the macrofauna of a sandy beach. *South African Journal of Science* 87(5):210-213.

Viera, J.V., C.A. Borzone, L. Lorenzi and F. Grecco de Carvalho (2012). Human impact on the benthic macrofauna of two beach environments with different morphodynamic characteristics in Southern Brazil. *Brazilian Journal of Oceanography* 60(2):135-148.

USACE (1989). Environmental Engineering for Coastal Protection. U.S. Army Corps of Engineers, Washington, DC, Engineer Manual 1110-2-1204:1110-1112.

USFWS (2013). Rufa Red Knot Ecology and Abundance. Supplement to Endangered and Threatened Wildlife and Plants; Proposed Threatened Status for the Rufa Red Knot (*Calidris canutus rufa*) [Docket No. FWS–R5–ES–2013–0097; RIN 1018–AY17].

Weslawski, J., A. Stanek, A. Siewert and N. Beer (2000a). The sandhopper (*Talitrus saltator*, Montagu 1808) on the Polish Baltic Coast. Is it a victim of increased tourism? *Oceanological Studies* 29(1):77-87.

Weslawski, J., B. Urban-Malinga, L. Kotwicki, K. Opalinski, M. Szymelfenig and M. Dutkowski (2000b). Sandy coastlines-are there conflicts between recreation and natural values? *Oceanological Studies* 29(2):5-18.

Wetland Sciences, Inc. 2014. Assessment of Gulf Coast Beach Mouse Habitat Impacts Associated with Oil Spill Clean Up Efforts Necessitated by the Deepwater Horizon Oil Spill. Prepared for the U.S. Fish and Wildlife Service. 232 pp.

Wildish, D. J. (2012). Long distance dispersal and evolution of talitrids (Crustacea: Amphipoda: Talitridae) in the northeast Atlantic islands. *Journal of Natural History* 46(37-38):2329-2348.

Williams, A., R. Feagin and A.W. Stafford (2008). Environmental Impacts of beach raking of *Sargassum* spp. on Galveston Island, TX. *Shore and Beach* 76:63-69.

Wilson, J. G. (1999). Population dynamics and energy budget for a population of *Donax variabilis* (Say) on an exposed South Carolina beach. *Journal of Experimental Marine Biology and Ecology* 239:61-83.

Witherington, B.E. 1992. Behavioral responses of nesting sea turtles to artificial lighting. *Herpetologica* 48:31-39.

Wolcott, T.G. and D.L. Wolcott (1984). Impact of off-road vehicles on macroinvertebrates of a mid-Atlantic beach. *Biological Conservation* 29:217-240.

Wolfe, J.L. and C.T. Summerlin (1989). The influence of lunar light on nocturnal activity of the old-field mouse. *Animal Behavior* 37:410-414.

Wormald, A. P. (1976). Effects of a spill of marine diesel oil on the meiofauna of a sandy beach at Picnic Bay, Hong Kong. *Environmental Pollution* 11(2):117-130.

Yáñez-Arancibia, A. and J.W. Day (2004). Environmental sub-regions in the Gulf of Mexico coastal zone: the ecosystem approach as an integrated management tool. *Ocean and Coastal Management* 47:727-757.

Appendix A:

Sand Beach Width Determination Methods

MC252 NRDA Beach Width Determination

Introduction
We computed the across-shore widths of the entire beach at regularly placed transects along shorelines representing surveyed and oiled beach habitats by digitizing features from aerial imagery. We also computed the across-shore width of the intertidal portion of some of these transects in Florida and Alabama using digital elevation models derived from aerial laser-derived topographic-bathymetric survey data (lidar) where suitable data existed. The across-shore extent of beach shoreline is defined here as the distance between the seaward extent of the foreshore (including the intertidal beach-face and berm if present), and the landward extent of back-beach (BB), which is generally not regular inundated by tides or wave swash and run-up. The across-shore extent of the intertidal portion of the beach is defined here as the distance between the seaward mean low-low water tidal elevation contour (MLLW) and the landward mean high-high water (MHHW) tidal elevation contour. Three transects were generated for each oiled beach segment or operational zone at equidistant spacing. We then computed summary statistics for all total beach widths and intertidal widths, and average total beach widths by shoreline segment or operational zone.

Methods
Shore-normal transects of a fixed length were automatically generated along shorelines representing oiled beach operational zones and segments extracted from the shoreline oiling database (Nixon et al., In prep). SCAT segments and operational zones both describe portions of the shoreline of fixed extent (~ 500 m) used to track operational activities and are used to summarize sand beach oiling. In Florida, Mississippi, and Alabama, SCAT segments were of relatively standardized length and are used directly. In Louisiana, SCAT segments were of variable length and so were subdivided by the response into operational zones of roughly similar length (~500 m). These two terms thus describe comparable shoreline units, both spatially and administratively, and are hereafter referred to as "segment". Three transects were generated along the sand beach component of every segment. Transects were spaced regularly along the length of that beach portion of segment, such that one transect was located in the center of each third of the length of the sand beach component of each segment. In some cases, not all of a given segment was sand beach habitat, in which case only the sand beach component of a given segment was used to generate transects. The sand beach component of segments range in length from 10 m to over 2.5 km, with 90% of the beach component of segments between 150 and 1200 meters in length. In Texas, no segments were established, so transects were evenly spaced along all impacted shorelines at 1 km alongshore spacing.

Where the digital shoreline did not reflect current position of the shoreline visible in imagery, transects were moved or scaled. For example, some transects fell just beyond the beach in the ocean, some did not cross the entire width of the beach, and some were not perpendicular to the beach. Transects that were properly placed but where no beach was visible in imagery, such as a transect that crossed a marsh with no sand beach, were noted and excluded from further analysis.

For all transects, we digitized the points representing the landward boundary features of the back-beach (BB) and the instantaneous water line (IWL) at a scale of 1:2,500 from fall 2010

BP/Quantum Spatial Digital Orthophoto Quarter Quarter Quadrangle (DOQQQ) imagery (AeroMetric, 2010). The BB and IWL were digitized for all 4,330 transects where a beach was visible in the imagery. The width of the total beach was estimated by calculating the distance between the BB and IWL points along each transect (Figure A-1). This imagery represents the best synoptic data set suitable for extracting beach widths that is contemporaneous with shoreline oiling. We selected the instantaneous water line (IWL) as the best feature to represent the seaward extent of the intertidal portion of the beach that is visible in imagery (Boak and Turner, 2005). Because this imagery was not acquired with tidal control and the precise date, time and water level at each location in this imagery is not known, the IWL is likely landward of the actual MLLW. In some areas, the beach was bounded on the seaward side by a man-made feature such as a rip-rap seawall or fringed by marsh. These transects were noted and their beach widths were included in the calculations.

Figure A-1. An example of back-beach (BB) and instantaneous water line (IWL) points digitized from fall 2010 DOQQQs.

The landward boundary of the back-beach (BB) was defined as the most seaward position along each transect of one of the following features:

1.) The toe of the first linear dune;
2.) The seaward extent of a man-made structure or;
3.) The seaward extent of persistent vegetation.

If the transect was positioned on a wash-over or other feature such that the back-beach terminated at the waterline of an enclosed water body not represented by the digital shoreline, then the waterline of this waterbody was used as the landward boundary of the BB. If the transect was positioned such along a spit or narrow barrier island with no discernable back-beach, such that it crossed the digital shoreline multiple times, then the landward boundary of the BB was defined as a point equidistant from the both waterlines along that transect. These transects were split into two different portions, and the width of the beach along each portion of that transect was considered to the distance between the IWL and BB.

To determine the width of only the intertidal portion of beaches, the MLLW and MHHW were estimated using USACE (JALBTCX) spring 2010 topographic-bathymetric (topo-bathy) lidar data that were obtained for FL and AL (USACE JALBTCX, 2012). This lidar data has poor coverage areas of turbid water areas or breaking surf, so MLLW and MHHW contours were not able to be extracted for some transects. Lidar suitable for reliable extraction of the position of the MLLW contour was not available for TX, LA, and MS, so intertidal widths were not estimated for any transects in those states. The lidar topo-bathy data consist of digital elevation model (DEM) with orthometric heights in feet referenced to the North American Vertical Datum of 1988 (NAVD88). NOAA's VDatum software (NOAA, 2012) was used to adjust these heights to MLLW and MHHW. The location of the MLLW and MHHW contours was digitized along each transect. The widths of the intertidal zone were estimated by calculating the distance between the MLLW and MHHW points on each transect (Figure A-2). The lidar data and the aerial imagery were acquired at different periods of time and beaches may have eroded, accreted, or undergone morphological change in the interval between data acquisition. As such, the specific location of MHHW and MLLW along each transect is not necessarily related to the locations of the IWL.

Figure A-2. An example of MHHW and MLLW points estimated from spring 2010 lidar.

Finally, we computed summary statistics for both total and lidar-derived intertidal beach widths for the entire population of transects, for all transects by state, and for transects within each segment. Note that individual segment-wise width values are used in all areal calculations of beach injury.

Results
A total of 4,766 width calculations were made using the IWL and back-beach points digitized from the DOQQQs. Widths ranged from 0.5 m to 424.8 m, with a median width of 45.8 m and an average width is 51.5 m. Table A-1 summarizes the width statistics by state. Box plots of the distribution of all widths (Figure A-3) show a distribution skewed to the right.

Table A-1. Total beach width (BB to IWL) summary statistics by state in meters. Note that summary statistics are presented for all transects in a given state, but that segment-wise mean widths are used for all areal calculations.

State	Transects	Min.	Max	Mean	Median	St. Dev.
AL	715	1.7	242.1	49.5	50.2	33.4
FL	1531	2.0	235.5	52.3	48.4	27.8
LA	1558	0.5	315.8	52.1	41.2	39.9
MS	917	2.7	245.2	50.2	39.6	41.8
TX	45	13.4	424.8	68.0	59.8	62.5

Figure A-3. Box plot of beach widths (BB to IWL) derived from fall 2010 imagery analysis. The average width for all 4,766 transects is 51.5 m. The minimum and maximum widths are, respectively, 0.5 m and 424.8 m. Note that summary statistics are presented for all transects, but that segment-wise mean widths are used for all areal calculations.

While the distribution of all widths is strongly skewed, reflecting the influence of a few large width values, the average difference between mean and median widths for transects within the same segment (generally 3 per segment) is about centered about zero and generally unbiased (Figure A-4). Because segment-specific beach widths are used to compute injury, we conclude that mean transect length per segment is a reasonable estimate of overall beach with within that segment.

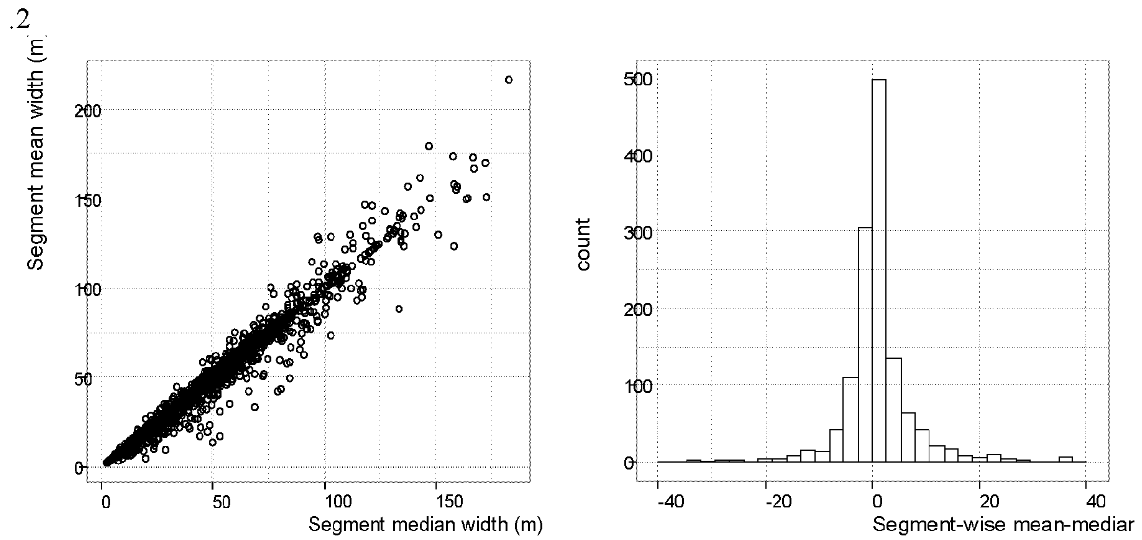

Figure A-3. Scatterplot of (A), and histogram of differences (B) between, segment-wise mean and median beach widths (BB to IWL) derived from fall 2010 imagery analysis. Three transects were measured per segment in most cases.

We also computed intertidal widths for a total of 1,392 transects using the lidar-based MHHW-MLLW distance. Of these 1,392 intertidal widths, 1,261 were less than the BB-IWL width. Seasonal differences between time of lidar data collection and time of imagery acquisition likely accounts for the remaining 131 transects that had estimated intertidal widths greater than the estimated beach width (BB-IWL). Supratidal widths were calculated for those 1,261 transects by subtracting the intertidal width from the total beach width (BB-IWL). The mean intertidal width was 17 m and the mean supratidal width is 55.8 m. Table A-2 and Figure A-5 summarize the tidal zone width statistics. Figure A-6 depicts all transects symbolized by both total (BB to IWL) and intertidal (MHHW-MLLW) with in meters. Note that intertidal widths are not explicitly used in areal analyses of beach injury, and are presented here for potential future use. As such, the fact that intertidal widths are computed for only a subset of segments in Florida and Alabama is of limited impact.

Table A-2. Intertidal and supratidal beach width summary statistics in meters.

	Min.	Max.	Mean	Median	St. Dev.
Intertidal	0.3	76.3	14.8	8.6	13.7
Supratidal	2.1	242.1	57.8	54.9	28.7

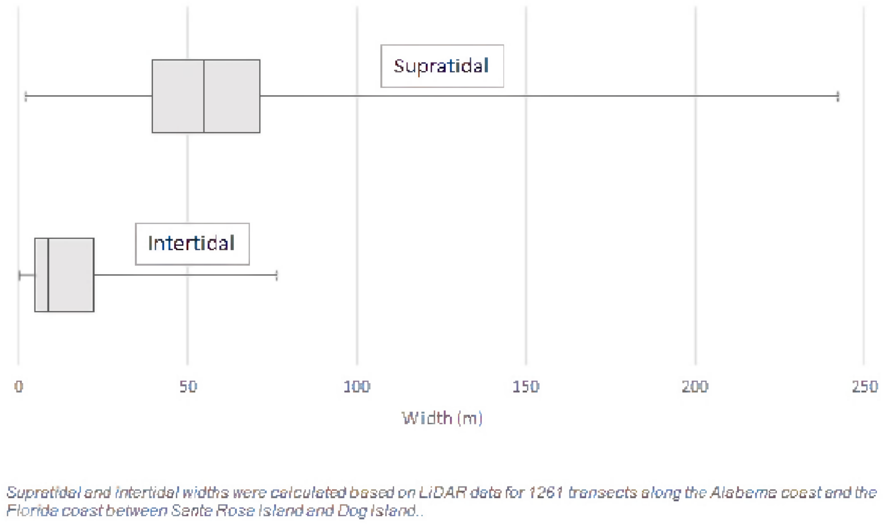

Figure A-5. Box plots of intertidal and supratidal beach widths. Intertidal widths were calculated by measuring the distance between MHHW and MLLW as estimated from lidar datasets. Supratidal widths were calculated by subtracting the intertidal widths from the imagery-based BB-IWL.

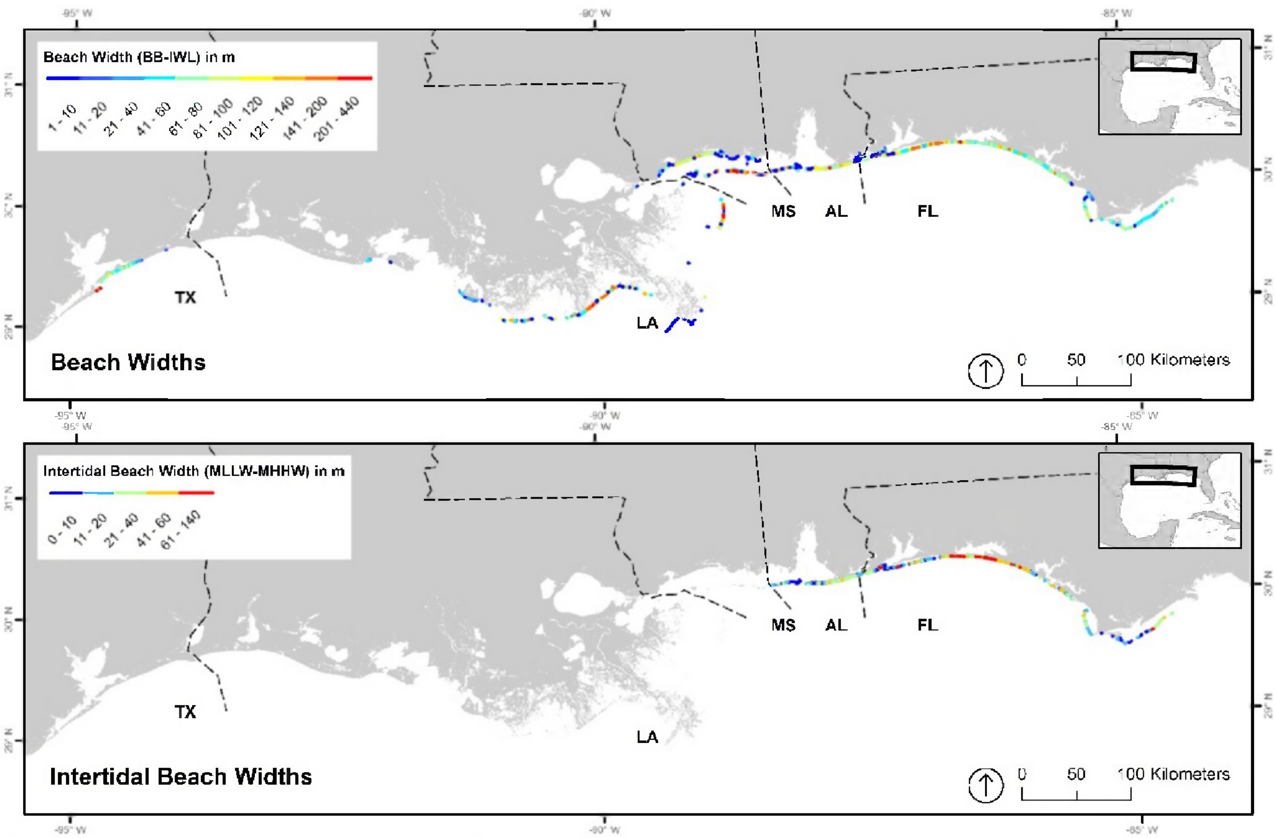

Figure A-6. All transects symbolized by both total width (BB to IWL) in meters (top) and intertidal width in meters (MHHW-MLLW) in AL and FL (bottom).

References

AeroMetric (2010). Fall 2010 AeroMetric Digital Orthophoto Quarter-Quarter Quads for BP MC252 Incident.

Boak, E. and I. Turner (2005). Shoreline definition and detection: A review. *Journal of Coastal Research* 21(4):688-703

U.S. Army Corps of Engineers (USACE) Joint Airborne Lidar Bathymetry Technical Center of eXpertise (JALBTCX) (2012). Florida and Alabama 2010 Lidar Coverage, USACE National Coastal Mapping Program.

Nixon, Z., Zengel, S., and J. Michel (In prep). Shoreline oiling from the Deepwater Horizon Oil Spill.

NOAA (2012). VDatum Manual for Development and Support of NOAA's Vertical Datum Transformation Tool, VDatum. Version 1. 1 June 2012.