7.0 POTENTIAL EFFECTS

One of the primary purposes of this project is to provide site-specific information for decisions on requests for non-competitive leases from other local, State, and Federal agencies. The information may be used to determine whether or not stipulations need to be applied to a lease. The information also may be incorporated into an Environmental Assessment (EA) or Environmental Impact Statement (EIS), if so required.

Environmental impact analyses of mining operations should be based on commodity-specific, technology-specific, and site-specific information, whenever possible (Hammer et al., 1993). First, the specific mineral of interest and the technological operations for a specific mining operation need to be defined because these two parameters determine the impact producing factors that need to be considered. Once the impact producing factors are known, this information can be translated into statements concerning the impacts that might occur to the full suite of potentially affected environmental resources that may need to be addressed, including geology, chemical and physical oceanography, air quality, biology, and socioeconomics. Then, decisions can be made regarding the type of mitigation necessary to determine the preferred alternative for a specific marine mining operation to acquire project approval.

This section focuses on providing information on potential impacts related to physical processes and biological considerations of sand mining for beach nourishment from four of the five sand resource areas offshore Alabama. Sand for beach replenishment is the commodity of interest. Two primary dredging technologies are available for offshore sand mining operations, depending on distance from source to project site, the quantity of sand being dredged, and the depth to which sand is extracted at a site (Herbich, 1992). They are: 1) cutterhead suction dredge, where excavated sand is transported through a direct pipeline to shore, and 2) hopper dredge, where sand is pumped to the hopper, transported close to the replenishment site, and pumped to the site through a pipeline from the hopper or from a temporary offshore disposal area close to the beach fill site. As a general rule, cutterhead suction dredging is most effective for projects where the sand resource is close to shore (within 8 km), the dredging volumes are large (>8 MCM), and the excavation depth is on the order of 2.5 to 4 m (Taylor, 1999). Hopper dredging becomes a more efficient procedure when the sand resource areas are greater than 8 km from shore, dredging volumes are relatively small (<2 MCY), and the excavation depth at the sand resource area is less than 2 m (Taylor, 1999). Ultimately, a combination of these factors will be evaluated by dredgers to determine the most cost effective method of sand extraction and beach replenishment for a given project. Availability of dredging equipment also may be a factor for determining the technique to be used; however, the number of cutterhead suction and hopper dredges in operation is about equal in the industry today (Taylor, 1999). As such, both technologies will be evaluated for potential biological effects.

7.1 POTENTIAL SAND BORROW SITES

Five potential sand resource areas were identified offshore Alabama in Federal waters by the Alabama Geological Survey and the U.S. Minerals Management Service, INTERMAR (Parker et al., 1993). Each site has specific geologic and geographic characteristics that make it more or less viable as a sand resource for specific segments of coast. Areas 1, 2, 3, and 4 contain borrow sites with the greatest potential for use in the future. Area 5 is unlikely to be used due to its location and geological composition relative to beach replenishment needs.

Areas 1, 2, and 3 are very similar geologically (medium-to-fine sand sheet deposit), whereas the identified borrow site in Area 4 has from zero to 30 cm of silt and clay overburden before encountering a medium-to-fine sand deposit. Currently, Areas 1, 2, and 3 (east of Mobile Bay) are thought to be of greatest interest to the State, due primarily to their proximity to beaches severely impacted by storms and hurricanes in 1998. Physical processes (waves and currents) and biological habitat illustrate minor variability offshore eastern Alabama. Although these three potential sand resource areas were designated in 1993 (Parker et al., 1997), it is possible that sand could be dredged from intervening areas because consistency of geologic deposits is widespread seaward of the eastern Alabama coast. Proximity to the beach replenishment site will be the significant factor for determining specific borrow area locations.

Area 4, west of the Mobile Bay entrance channel in an EPA-designated dredged material disposal area, has quite different physical characteristics (surface and subsurface sediment, and currents and flow from Mobile Bay) and biological communities than Areas 1, 2, and 3 (Hummell et al., 1996). Spatial and temporal variability in surface sediment characteristics reflect the influence of sediment and flow from Mobile Bay, as well as the impact of dredged material placement at or near the site (Douglas et al., 1995). Although the ecosystem dynamics at Area 4 appear significantly more variable than those offshore eastern Alabama, the sand resource identified by Parker et al. (1993, 1997) and Hummell et al. (1995, 1996) in this area could be a significant source of beach-quality sand for beaches along Dauphin Island.

The amount of dredging that occurs at any given site is a function of Federal, State, and local needs for beach replenishment. There is no way of predicting the exact sand quantities needed in the foreseeable future, so an upper value was estimated based on discussions with State personnel and the MMS, as well as the geological characteristics of specific resource targets. Preliminary analysis of short-term storm impacts at specific sites along eastern Alabama beaches indicates that about 750,000 m^3 of sand could be needed for beach replenishment after each event. Long-term shoreline change data sets suggest that a replenishment interval of about 10 years would be expected to maintain beaches. This does not consider the potential for multiple storm events impacting the coast over a short time interval, nor does it consider longer time intervals absent of destructive storm events. Instead, the estimate represents average change over decades that is a reasonable measure for coastal management applications.

Given the quantity of 750,000 m^3 of sand per beach replenishment event, the surface area covered for evaluating potential environmental impacts is a function of the average dredging depth. Two factors should be considered when establishing dredging practice and depth limits for proposed extraction scenarios. First, regional shelf sediment transport patterns should be evaluated to determine net transport directions and rates. It is more effective to dredge the leading edge of a migrating shoal, and infilling of dredged areas occurs more rapidly at these sites (Byrnes and Groat, 1991; Van Dolah et al., 1998). Second, shoal relief above the ambient shelf surface should be a determining factor controlling depth of dredging. Geologically, shoals form and migrate on top of the ambient shelf surface, indicating a link between fluid dynamics, sedimentology, and environmental evolution (Swift et al., 1976). As such, average shoal relief is a reasonable depth threshold for maintaining environmentally-consistent sand extraction procedures.

In Area 4, southwest of the Mobile Bay entrance channel, a relatively small, low-relief shoal was identified by the GSA as a potential borrow area (Hummell et al., 1996). Average sand thickness, as determined from core samples, for a 2.8 x 10^6 m^2 resource site in this area is 3 m (Figure 7-1), resulting in a potential sand volume of 8.4 MCM. Table 7-1 provides coordinate pairs defining the potential borrow site. Again, this volume of sand likely represents multiple beach replenishment events, meaning the cumulative impact of successive dredging events at the borrow site were estimated.

For Areas 1, 2, and 3, seaward of the eastern Alabama coast, maximum shoal relief is on the order of 4.5 m, and average shoal relief is about 3.0 m. Although specific beach replenishment practice is unknown for the Alabama coast, it is reasonable to expect multiple replenishment events over the next 50 years from the designated sand resource areas. As such, one shoal deposit was

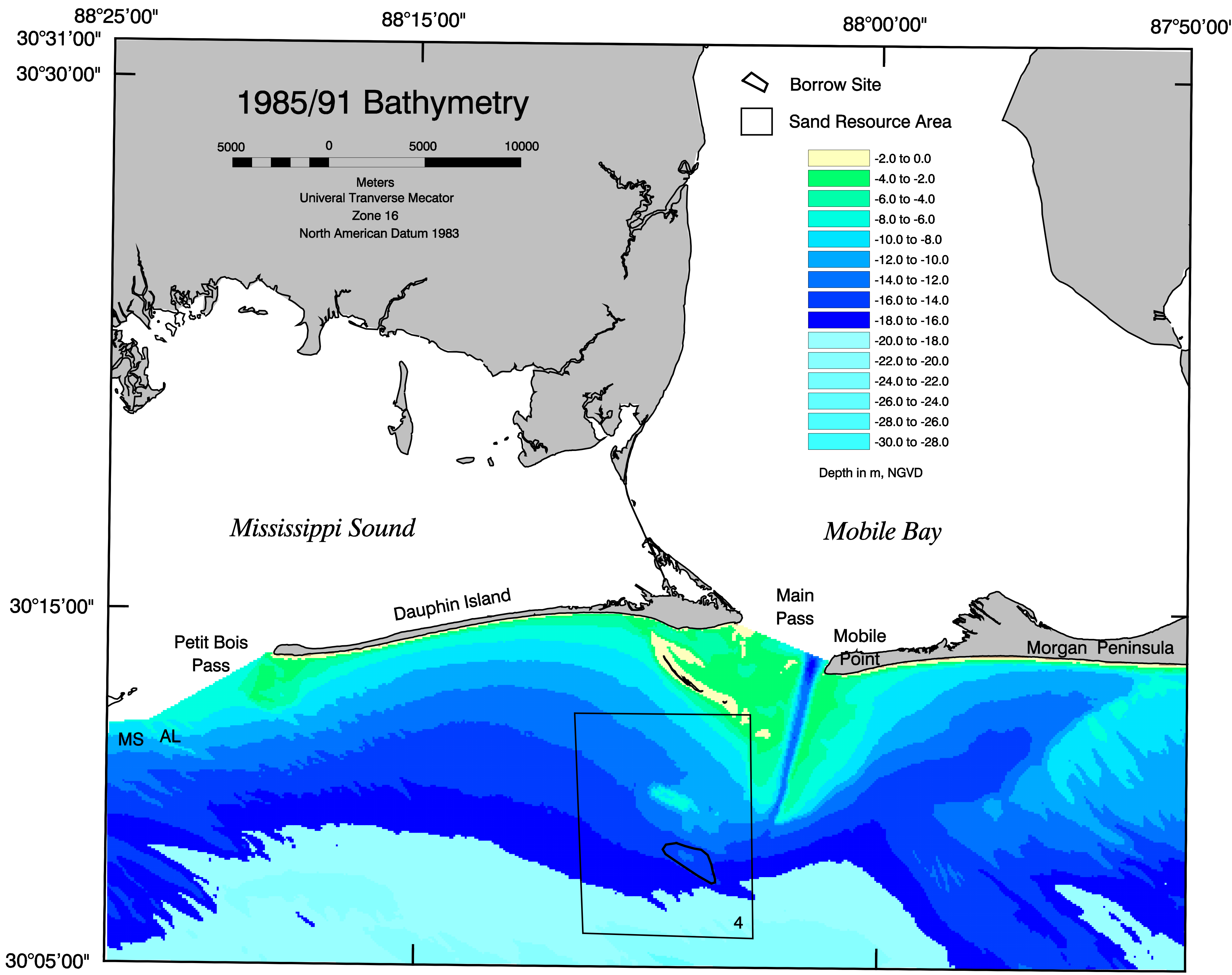

Figure 7-1. Location of potential borrow sites for Resource Area 4.

selected from Areas 1, 2, and 3 based on geological characteristics. A maximum excavation depth was determined for each specific site. In Area 1, a 1.94 x 10^6 m^2 borrow site was defined based on shoal morphology (Figure 7-2; see Table 7-1 for coordinate locations). Bathymetry data and geological samples (McBride and Byrnes, 1995) indicate a maximum excavation depth of 3.0 m, resulting in a 5.8 MCM extraction scenario. The same procedure was used for selecting borrow sites in Areas 2 and 3. The selected shoal borrow site in Area 2 encompassed 0.57 x 10^6 m^2 of seafloor to a depth of 3.0 m, resulting in 1.7 MCM of sand. Area 3 covers 1.19 x 10^6 m^2 of seafloor to a maximum excavation depth of 4.0 m. The resource site contains 4.7 MCM of sand. The sand volume at each of these borrow sites is greater than any single expected replenishment event, so all analyses were used to estimate potential cumulative effects of multiple extraction scenarios.

Table 7-1. UTM Coordinates defining borrow site polygons offshore Alabama.

UTM Coordinates (Zone 16, NAD83)	Borrow Site 1	Borrow Site 2	Borrow Site 3	Borrow Site 4
	433830.4, 3341520.5	426592.1, 3340396.3	412989.2, 3339789.3	393244.8, 3335024.1
	435593.5, 3341748.7	427163.0, 3340505.3	413053.5, 3339070.8	392701.1, 3334940.5
	436663.6, 3340943.7	427748.1, 3339248.1	414776.8, 3339000.6	392533.8, 3334689.4
	435291.6, 3340440.6	427621.6, 3339137.4	414724.2, 3339660.8	392680.2, 3334438.5
		426949.5, 3339872.8		393579.4, 3333832.0
				394374.1, 3333309.2
				395064.2, 3332911.9
				395252.4, 3332974.6
				395252.4, 3333141.9
				395210.6, 3333288.3
				395127.0, 3333602.0
				395064.2, 3333894.8
				394876.0, 3334396.8
				394541.4, 3334668.6
				394185.9, 3334731.4
				393704.9, 3334856.8

A primary question addressed by the modeling efforts relates to sediment transport and infilling estimates at potential borrow sites and the impact of dredging operations on these estimates. Combined wave-current interaction (waves mobilize the seabed and currents transport the sediment) at the borrow areas results in a net direction of transport into and out of potential sand resource sites. Historical sediment transport dynamics suggest that the net direction of sediment movement is from east to west at all potential sand resource sites, and the rate at which sand moves along the shelf is relatively slow. For a 65-yr period of record, very little net erosion or accretion was documented throughout the study area, except on the seafloor in Area 4, where net deposition occurred in response to natural outflow from Mobile Bay and dredged material disposal activities by the U.S. Army Corps of Engineers. Consequently, it is expected that the time required to refill borrow areas will be on the order of decades for Areas 1, 2, and 3 and years in Area 4 where net fine-grained sediment deposition is prevalent. Area 4 is a problem for multiple sand extraction because the material expected to fill the borrow area after excavation is silt and clay. As such, increasing overburden to the sand resource may result in abandoning the site for a more viable alternative.

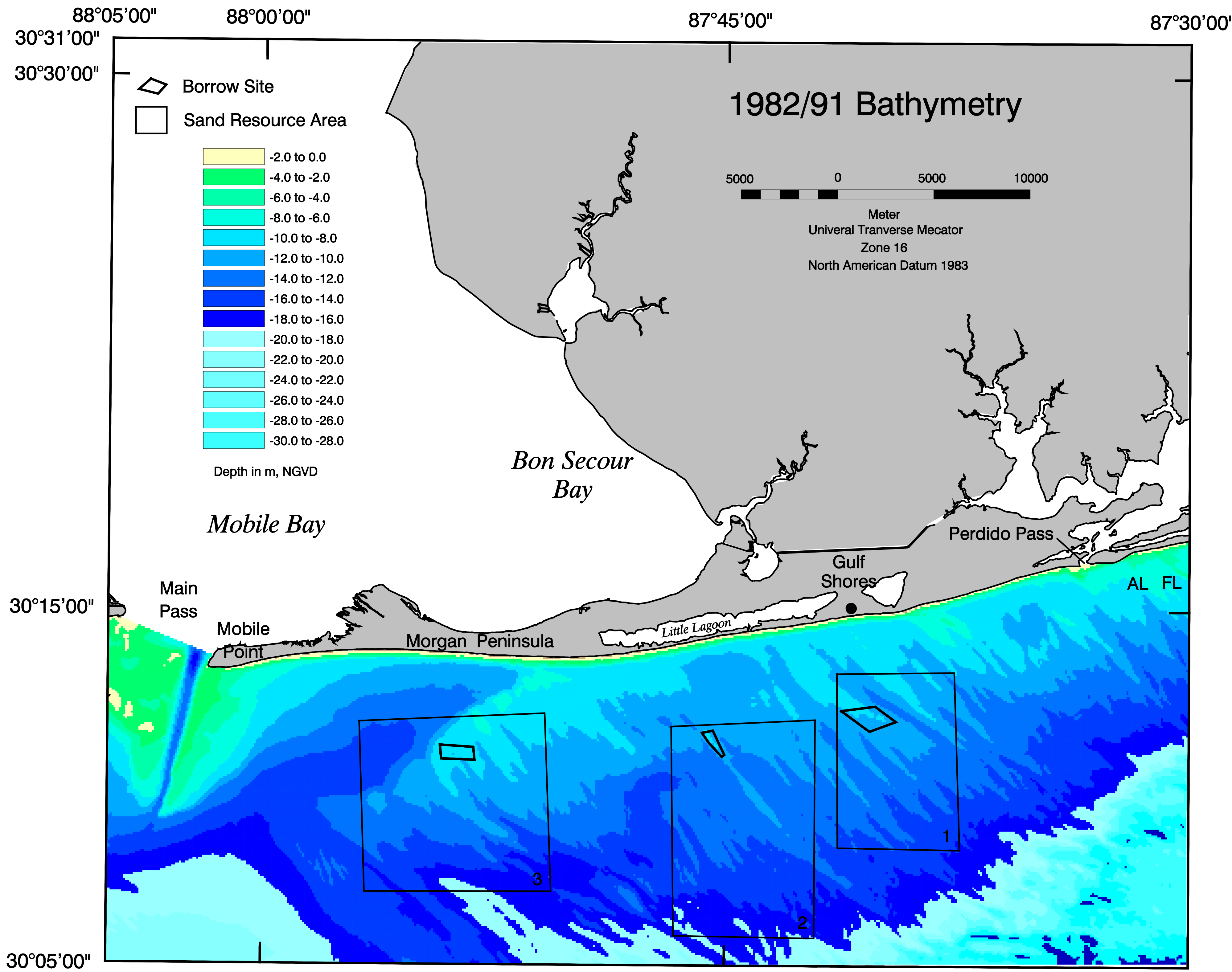

Figure 7-2. Location of potential borrow sites for Resource Areas 1, 2 and 3.

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7.2 WAVE TRANSFORMATION

Extraction of sediment from potential borrow sites may result in modifications to physical processes at local borrow sites and in the nearshore zone of Alabama. Wave modeling results indicate that minor changes will occur to wave fields under typical significant seasonal conditions and sand extraction scenarios representing multiple replenishment events. Changes in localized regions near borrow sites are apparent (maximum increases of 0.2 to 0.4 m in significant wave height; 12 to 24% of the initial wave height), but will not result in serious impact to the prevailing wave climate at the coast. Modifications to wave heights caused by extraction of sediment offshore Alabama decay as they approach the coastline. Under seasonal conditions, maximum changes in wave height dissipate significantly by the time the shoreline is encountered.

Under extreme conditions (i.e., the simulated 50-yr storm event), the same percentage change occurred to the wave field (12 to 24% of the initial wave height), although the magnitude of change increased (maximum increases of 1.0 to 2.0 m relative to initial waves). The 50-yr storm event and large sand extraction scenarios simulated in the present study represent a worst-case scenario (cumulative extraction impacts and storm waves). Although most events will not be as large as a 50-yr storm, during any storm event, dredged regions can be expected to have significant impact on the wave field in certain areas along the coastline. The magnitude of the impact will depend on the size and duration of the storm, the amount of material removed from the borrow site, and the time passed since dredging.

The most significant cumulative physical environmental impact appears to occur at the borrow site located within Sand Resource Area 2. Proximity of the borrow site to the coastline, orientation of the borrow site, and focusing of offshore wave energy seaward of the borrow site all contribute to the relative increase in wave height (0.4 m) at this location. A similar increase in wave energy is also evident near Sand Resource Area 3 due to the relatively large sand extraction depth (4 m).

Figures 7-3 and 7-4 show the present coastline configurations (thick line) versus differences in wave height, taken at approximately 100 m offshore, between pre- and post-dredging scenarios (thin line). These figures indicate approximate locations along the coastline where increases or decreases in wave height will occur due to potential sand extraction scenarios. Only small changes in wave height occur during typical significant seasonal conditions (<5 cm [<3% increase] for all of coastal Alabama), while storm results show a slightly larger modification to wave heights. A notable amount of wave energy decay is illustrated at transect locations, and because wave heights are taken at 100 m offshore, an additional reduction in the magnitude of change is expected as waves enter shallower water and decay.

7.3 CURRENTS AND CIRCULATION

Throughout the study area, currents were predominantly parallel to shelf depth contours and driven by wind stress. Winds were shown to produce an approximate five-fold increase in current speed, with order 10 cm/sec currents during mild wind conditions to order 50 cm/sec during strong wind conditions. Frictional effects on the continental shelf modified currents as well; currents were strongest in the surface layer and weaker along the bottom and nearshore boundary areas. Major bathymetric and shoreline features, for example, the ebb-tidal shoals encompassing Pelican Island and vicinity at the western margin of Main Pass, were shown to modify predominant flow directions, and provide turning points that signaled major shifts in large-scale circulation patterns. Less significant bathymetric features, such as the dredged material disposal mound located at Sand Resource Area 4 or shore-oblique shoals prevalent in Areas 1 and 2, were found to have little effect on large-scale circulation. No direct observations of currents were obtained near Sand Resource Area 3 immediately east of Mobile Bay.

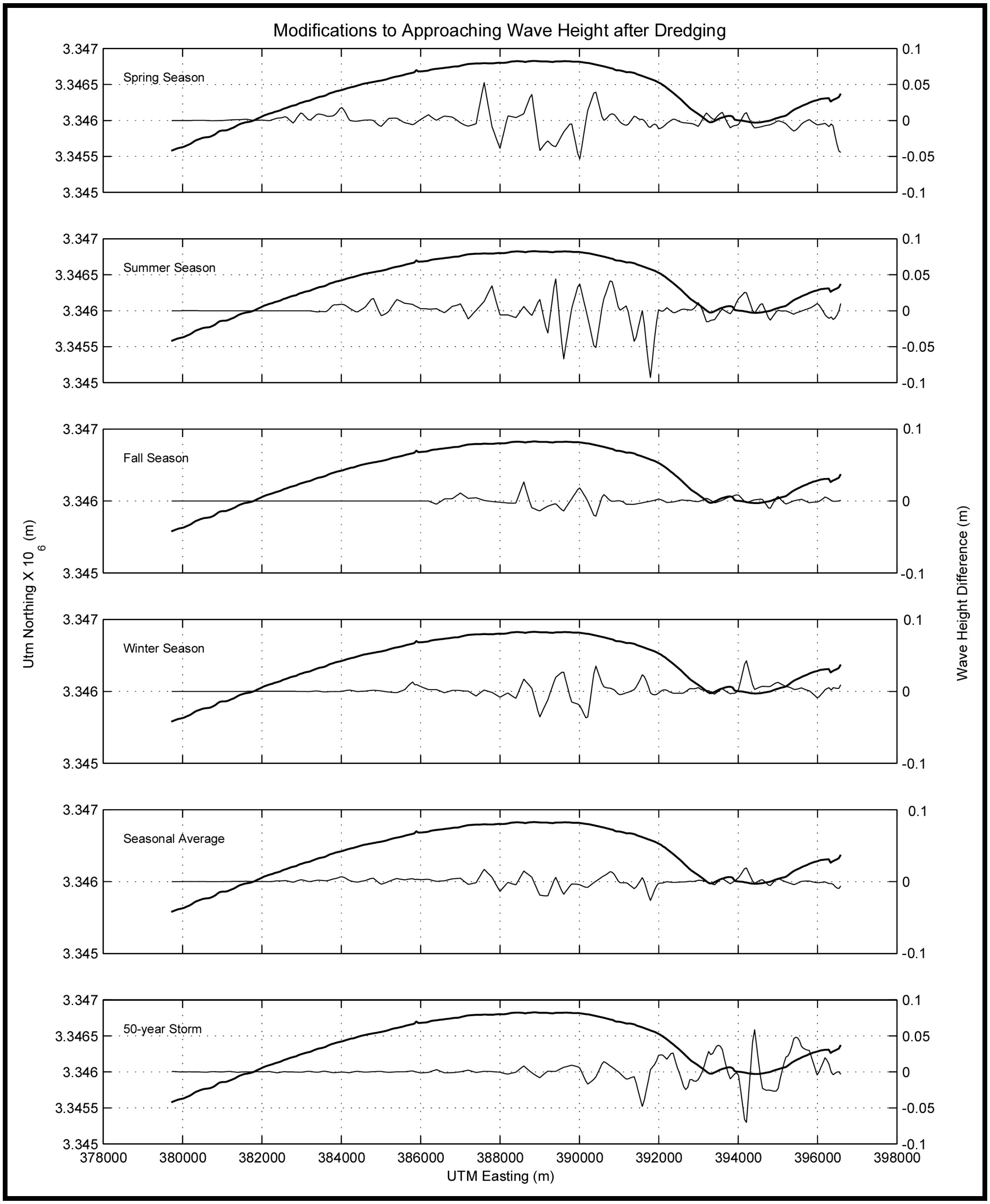

Figure 7-3. Present shoreline configuration (thick line) compared to differences in wave heights (thin line) caused by potential dredging scenarios offshore Dauphin Island. Wave heights (post-dredging minus pre-dredging) were taken from a baseline approximately 100 m seaward of the coastline.

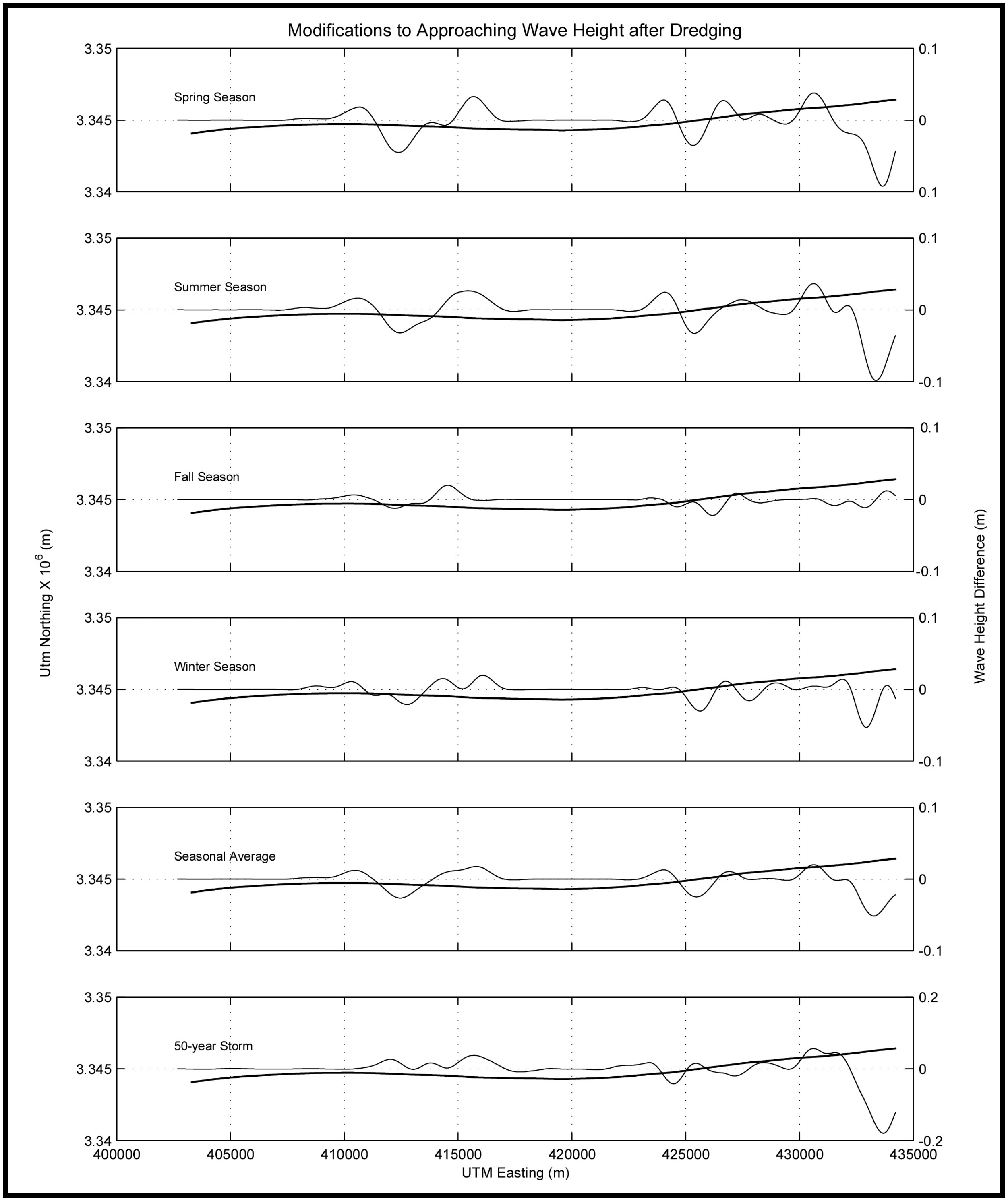

Figure 7-4. Present shoreline configuration (thick line) compared to differences in wave heights (thin line) caused by potential dredging scenarios offshore Morgan Peninsula. Wave heights (post-dredging minus pre-dredging) were taken from a baseline approximately 100 m seaward of the coastline.

While no large-scale predictive circulation models were developed to quantify effects of dredging in sand resource areas, the analysis of current patterns resulting from this study suggests proposed sand mining will have negligible impact on large-scale shelf circulation. The proposed sand mining locations are small relative to the entire shelf area, and it is anticipated that resulting dredging will not remove enough material to significantly alter major bathymetric features in the region. Therefore, the forces and/or geometric features that principally affect circulation patterns will remain relatively unchanged.

Currents within Sand Resource Area 4 were influenced primarily by Pelican Island, which produced a significant steering effect to divert flow along a general northwest/southeast axis, parallel to bathymetry contours. Mobile Outer Mound, with elevations approximately 2 to 6 m above average shelf elevation, also exists within this region. The ADCP field surveys showed highly localized bottom flow vectors influenced weakly by the presence of the dredged material mound, specifically with currents shown flowing around the feature. Adjacent flow vectors (of order 100's of meters removed from the mound) did not appear to be influenced by the mound, but they were directed along the depth contours, consistent with prevailing flow through the region. This suggests that small-scale bathymetric irregularities, such as a sand borrow site, while producing a localized effect on currents, will not impact prevailing or ambient flow characteristics. The proposed borrow site, approximately equal in area to the dredged material mound, is presumed to result in similar effects. Specifically, there is potential for localized impact on currents near the area but no effect on flow in adjacent areas.

For Areas 1 and 2, surface shape is rough with numerous ridges and troughs. Dredging is targeted to remove a portion of these shoal ridges. Circulation in the region did appear to be affected by bottom friction, but the influence was found to be manifest as weaker flow at the bottom and nearshore areas than at the surface. By removing a shoal ridge or a portion of a ridge, one may argue that there may be a resulting change to the bottom roughness, thus changing local current patterns. However, Areas 1 and 2 contain numerous ridges and troughs. Thus, it is unlikely the alteration of a single ridge would significantly impact bottom roughness. Also, these sand ridges migrate across the shelf surface (east to west), suggesting that any localized impacts due to dredging may be approximately equal to localized impacts due to natural transience of these sand ridges and shoals. As such, data suggest it is doubtful that removal or alteration of a small region of shoal ridges will have any measurable impact on regional current flow.

The sand borrow site in Sand Resource Area 3 is located on the seaward tip of a major sand shoal (Figure 7-2). While no analysis of flow was performed for Area 3, extrapolating our understanding of flow behavior from areas west and east suggests this large shoal may influence circulation. The shoal provides significant elevation and extent to modify alongshore flow, likely in terms of deceleration due to increased frictional effects and deflection of flow. The shape of the shoal suggests that westward-directed flow will be deflected slightly offshore, and that eastward flow may be slowed by friction as currents pass over the feature. Removing a small portion of the seaward tip of the shoal may reduce the steering effects of flow and possibly lessen frictional damping. Even so, the proposed borrow site represents a relatively small fraction of the shoal, hence effects on currents in Area 3 due to dredging will likely be negligible.

7.4 SEDIMENT TRANSPORT

Current measurements and analyses, and wave transformation modeling, provide baseline information on incident processes impacting coastal environments under existing conditions and with respect to proposed sand mining activities for beach replenishment. Ultimately, the most important data set for understanding physical processes impacts from offshore sand extraction is changes in sediment transport dynamics resulting from potential sand extraction scenarios relative to existing conditions.

Three independent sediment transport analyses were completed to evaluate physical environmental impacts due to sand mining. First, historical sediment transport trends were quantified to document regional, long-term sediment movement throughout the study area using historical bathymetry data sets. Erosion and accretion patterns were documented, and sediment transport rates in the littoral zone and at offshore borrow sites were evaluated to assess potential changes due to offshore sand dredging activities. Second, sediment transport patterns at proposed offshore borrow sites were evaluated using wave modeling results and current measurements. Post-dredging wave model results were integrated with regional current measurements to estimate sediment transport trends for predicting borrow site infilling rates. Third, nearshore currents and sediment transport were modeled using wave modeling output to document potential impacts to the longshore sand transport system (beach erosion and accretion). All three methods were compared for evaluating consistency of measurements relative to predictions, and potential physical environmental impacts were identified.

7.4.1 Historical Sediment Transport Patterns

Regional geomorphic changes between 1917/20 and 1982/91 were documented for assessing long-term, net coastal sediment transport dynamics. Although these data do not provide information on the potential impacts of sand dredging from proposed borrow sites, they do provide a means of calibrating predictive sediment transport models relative to infilling rates at borrow sites and longshore sand transport.

A comparison of erosion and deposition volumes at proposed borrow sites provided a method for quantifying net sediment transport rates (or borrow site infilling rates). For borrow sites in Sand Resource Areas 1, 2, and 3, net transport rates ranged from about 9,000 to 34,000 m^3/yr. This compared well with sediment transport predictions made near borrow sites using wave model output and currents measurements (13,000 to 100,000 m^3/yr). The net longshore sand transport rate for the Morgan Peninsula was determined by comparing zones of erosion and accretion in the littoral zone (seaward to 6-m depth contour [NGVD]) between Perdido Pass and Main Pass (Mobile Bay entrance) in a sediment budget formulation. The net transport rate for that portion of the study area was approximately 106,000 m^3/yr. Net transport rates determined via sediment transport modeling ranged from about 50,000 to 150,000 m^3/yr under seasonal conditions. These rates compare well and provide a measured level of confidence in wave and sediment transport modeling predictions relative to impacts associated with sand dredging from proposed borrow sites.

7.4.2 Sediment Transport Modeling at Potential Borrow Sites

In addition to predicted modifications to the wave field, potential sand mining at offshore borrow sites results in minor changes in sediment transport pathways in and around the dredged regions. The modifications to bathymetry caused by sand mining only influence local hydrodynamic and sediment transport processes in the offshore area. Although wave heights may change at the dredged borrow sites, areas adjacent to the sites do not experience dramatic changes in wave or sediment transport characteristics.

Initially, sediment transport at borrow sites will experience mild changes after sand dredging is complete. Given the water depths at the proposed borrow sites, it is expected that minimal impacts to waves and sediment transport will occur during infilling. Sediment that replaces the dredged material will fluctuate based on the location, time of dredging, and storm characteristics following dredging episodes. Borrow sites at Sand Resource Areas 1, 2, and 3 are expected to fill with the same material that was excavated (the entire shelf surface south of the Morgan Peninsula is at least 95% medium-to-fine sand). Sediment characteristics in this region are consistent, high-quality, and compatible with beach sand. The potential borrow site at Sand Resource Area 4, however, will likely be filled with fine sediment (i.e., fine sand to clay) exiting Mobile Bay by natural processes or human activities (maintenance channel dredging and disposal). Because the potential transport rate plus sediment flux from Mobile Bay is substantially greater than shelf transport rates alone, the borrow site in Sand Resource Area 4 will fill faster than other borrow sites, limiting the likelihood for multiple dredging events from the same area.

7.4.3 Nearshore Sediment Transport Trends

Development of the REF/DIF S wave model, the wave-induced current model, and the longshore sediment transport model provided a basis for comparing existing conditions with post-dredging coastal processes conditions. Dredging of major offshore borrow sites can have a significant effect on coastal erosion/accretion, since changes to the offshore bathymetry can focus wave energy by altering the nearshore wave characteristics. For example, waves encountering a hole created by dredging activities can be refracted toward the edges of the dredged area (refraction tends to bend waves parallel to shallower depth contours). Through this process, wave energy will be focused toward either side of a dredged area and a shadow zone of lower wave energy will be created directly landward of the borrow area.

For the coast of Alabama, the physical effects of dredging four different borrow sites were evaluated. Average annual sediment transport patterns for existing conditions, as well as post-dredging scenarios, were documented for the Morgan Peninsula and Dauphin Island sub-grids to determine whether dredging would cause a significant effect above normal conditions. In addition, sediment transport effects were evaluated for a 50-yr storm event. The physical environmental impacts of dredging in Sand Resource Areas 1, 2, and 3 are shown on Figure 7-5 for average annual conditions and on Figure 7-6 for a 50-yr storm event. The impacts of dredging in Resource Area 4 are shown on Figure 7-7 for average annual conditions and on Figure 7-8 for a 50-yr storm event.

7.4.3.1 Eastern Alabama Coast

Figure 7-5 illustrates that there is a defined, but somewhat minor impact, from dredging in Areas 1, 2, and 3. Due to the naturally higher transport rates at the eastern end of Morgan Peninsula, the magnitude of impacts associated with borrow sites at Resource Areas 1 and 2 appear to be higher than those associated with Resource Area 3. However, the net transport rate associated with pre-dredging conditions at Resource Area 3 is significantly lower than the rate associated with adjacent borrow sites. For all three borrow sites, the maximum variation in annual longshore sand transport rate is approximately 8 to 15% of the existing value. In general, the increase or decrease in longshore sediment transport rates associated with each potential borrow site amounts to approximately 3 to 8% of the net littoral drift, distributed over an approximate 10 km stretch of shoreline.

The predominant wave direction from the southeast shifts the wave-induced impacts of dredging towards the west. As described above, a shadow zone typically is created immediately shoreward of a borrow site, as wave energy is directed away from the shoreline immediately landward of the borrow site. Based on Figure 7-5, the shadow zone landward of Resource Area 3 is approximately 3 km to the west of the Easting coordinates for this area. This shadow zone is indicated by a significant reduction in west-directed wave energy. Due to the close proximity of Resource Areas 1 to 2, it is difficult to discern the individual impacts of each dredging scenario.

According to Figure 7-6, dredging in Resource Areas 1 and 2 will create a slight increase in west-directed transport during a storm. Again, the maximum impact of this dredging activity would be an approximate 8 to 15% increase in potential transport rates over a short stretch of shoreline. The average increase in west-directed transport would be 5 to 8%; however, a similar reduction in west-directed transport is associated with the shadow zone generated by the borrow site at Resource Area 1. Impacts associated with dredging at Resource Areas 2 and 3 are slightly lower than impacts associated with Area 1.

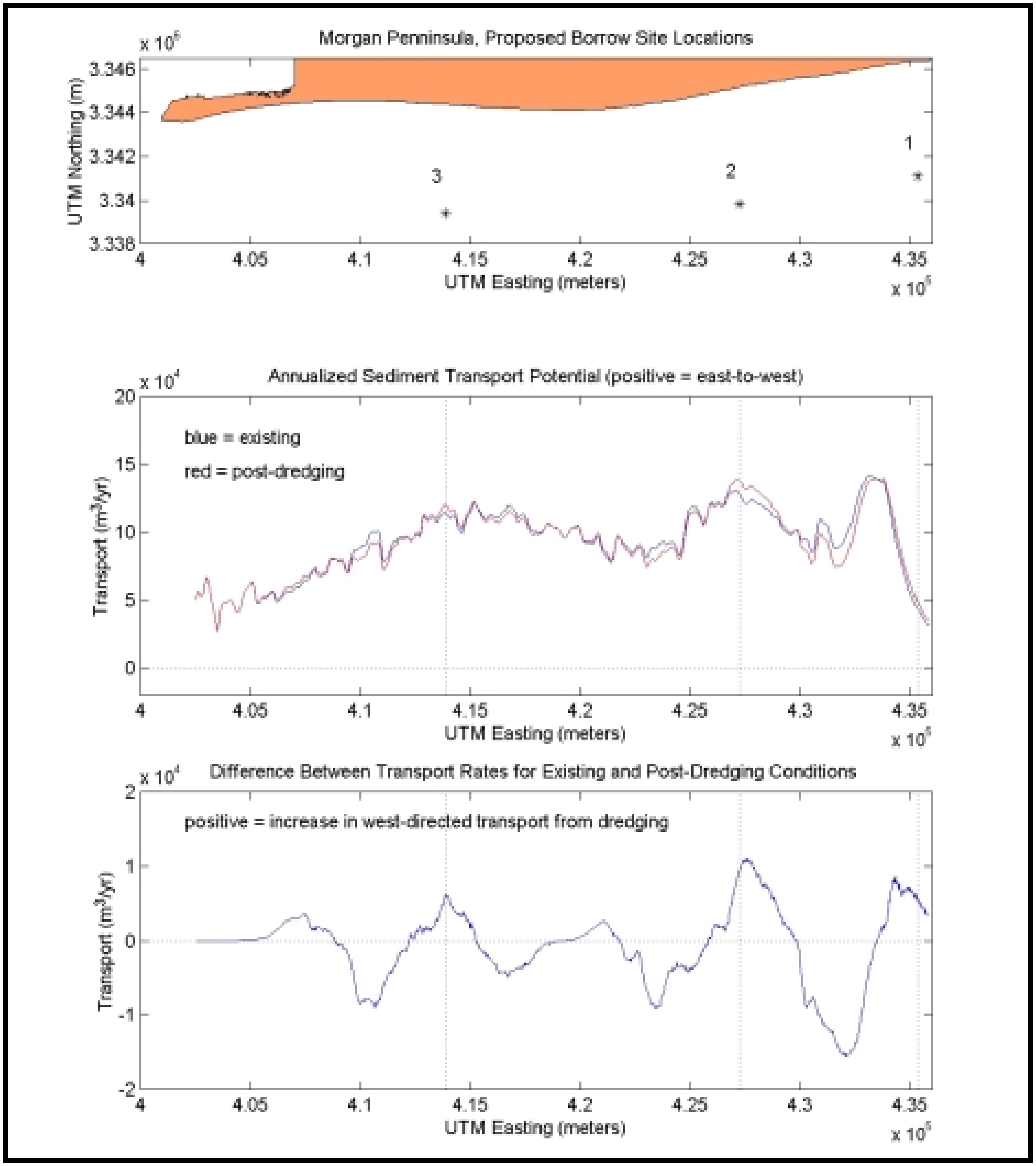

Figure 7-5. Difference in average annual transport rates associated with dredging sand resource sites along Morgan Peninsula.

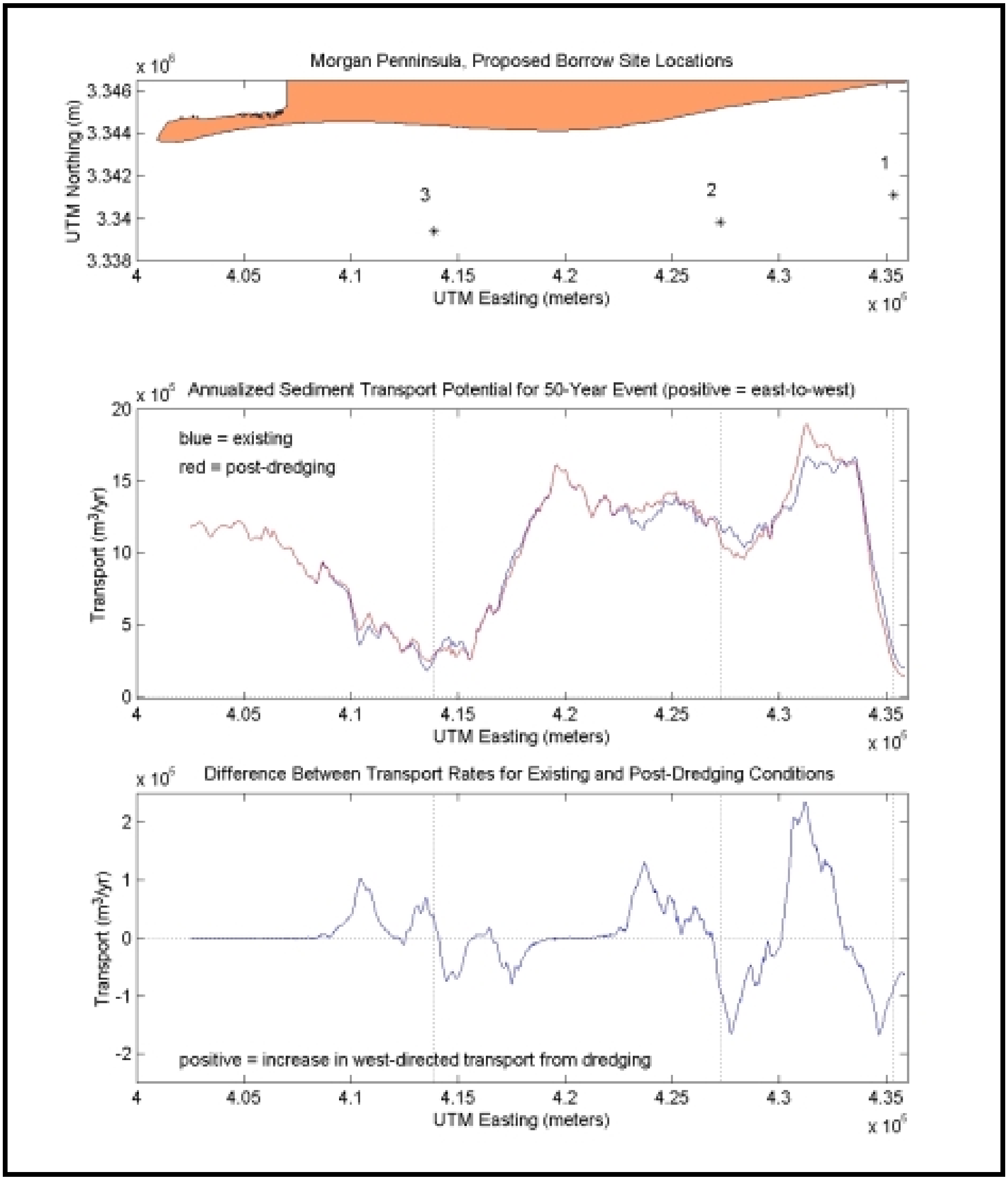

Figure 7-6. Difference in transport rates for 50-yr storm event associated with dredging sand resource sites along Morgan Peninsula.

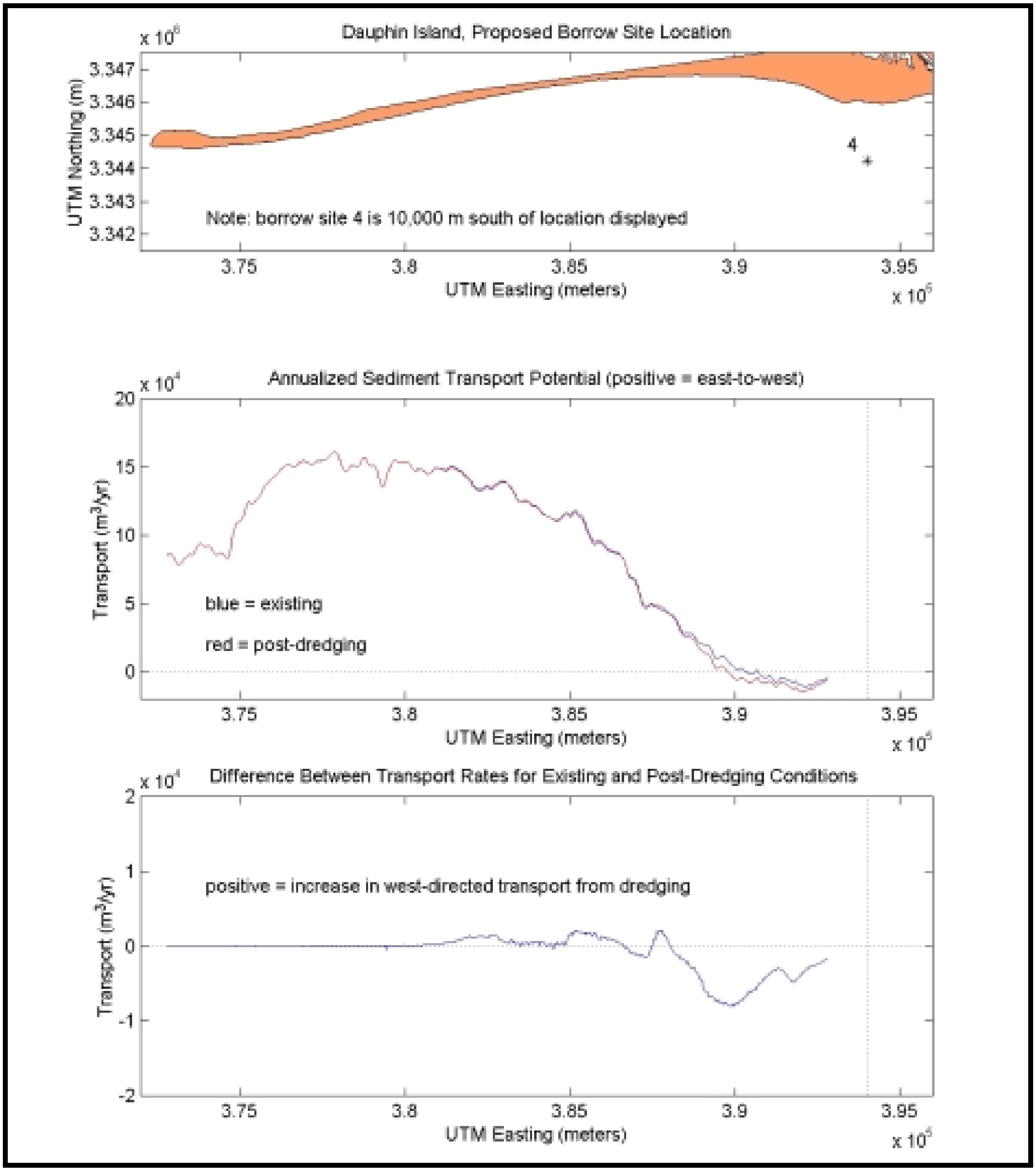

Figure 7-7. Difference in average annual transport rates associated with dredging sand resource area along Dauphin Island.

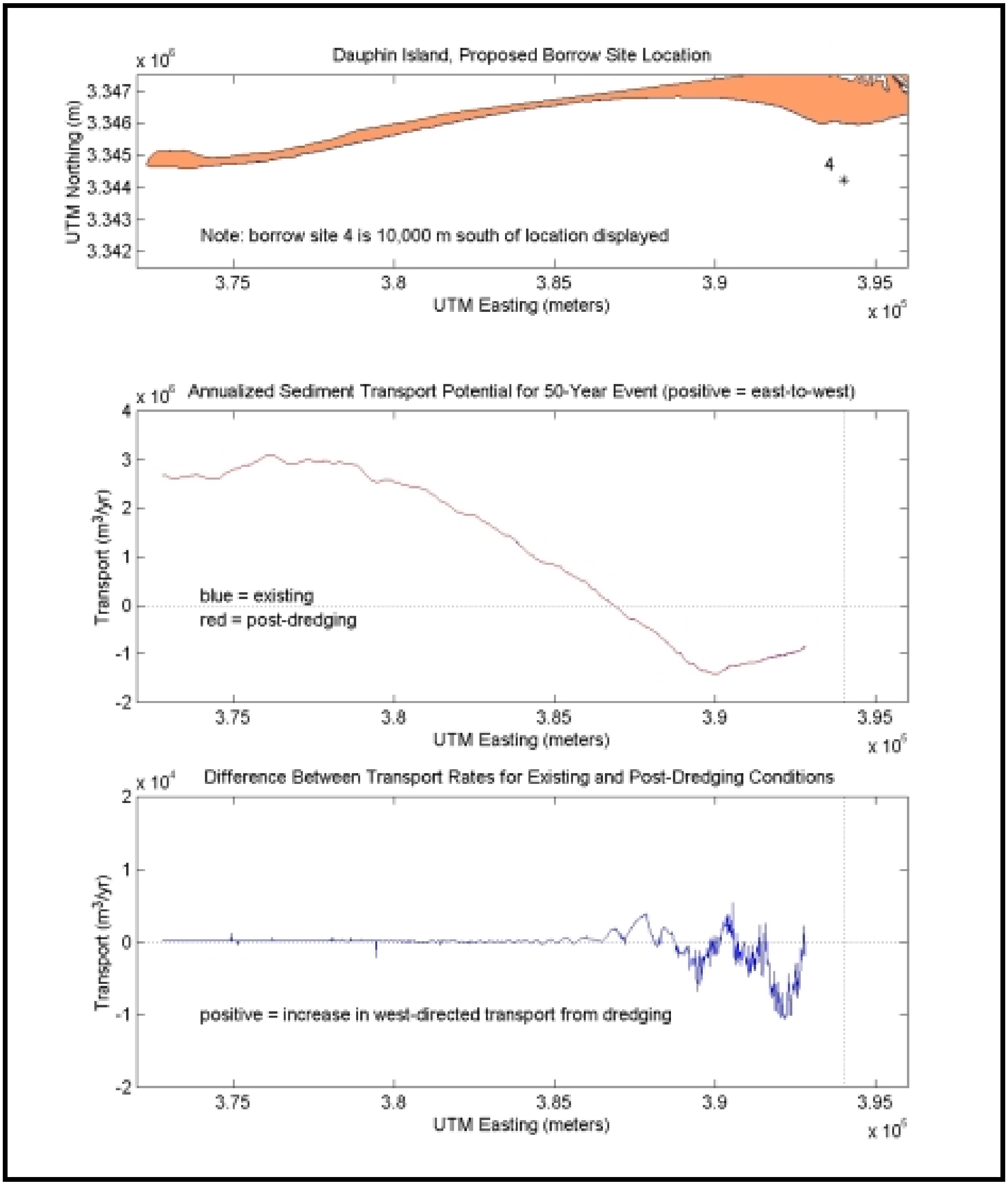

Figure 7-8. Difference in transport rates for 50-yr storm event associated with dredging sand resource area along Dauphin Island.

7.4.3.2 Western Alabama Coast

The potential impacts of dredging Resource Area 4 are insignificant in relation to Resource Areas 1 through 3. Average annual conditions illustrated in Figure 7-7 indicate a relatively high percentage change in transport rates along the eastern portion of Dauphin Island; however, the existing net littoral drift is almost non-existent at this location. The net effect of dredging the borrow site at Resource Area 4 would be to direct a greater percentage of sand transport to the east, with a maximum increase of approximately 8,000 m^3/yr. The limited influence of borrow site dredging is exemplified in the scenario for the 50-yr event, shown in Figure 7-8. The two lines showing existing conditions and the post-dredging scenario are nearly coincident. A slight increase (maximum of approximately 10,000 m^3/yr if this condition existed for an entire year) in east-directed transport is created as a result of dredging Area 4. As such, there is no significant impact to longshore transport rates on Dauphin Island as a result of potential sand mining activities in Resource Area 4.

7.4.3.3 Significance of Transport Trends

Quantitative evaluation of potential effects to nearshore sediment transport rates associated with dredging scenarios was performed using a statistical analysis of predicted rates for both annual average conditions (Table 7-2) and the 50-year event (Table 7-3). The region of influence for each borrow site was characterized using four calculated parameters, in addition to a visual comparison of existing and post-dredging sediment transport rates.

Table 7-2. Statistical parameters for annual average sediment transport conditions associated with Sand Resource Areas 1 through 4.

	Resource Area			
	1	2	3	4
Mean Transport (m^3/yr)	97,000	106,000	103,000	33,000
Absolute (Mean Difference in Transport (m^3/yr))	8,000	5,200	3,200	3,200
Standard Deviation (m^3/yr)	4,600	3,200	2,400	2,300
Percentage Difference	8.3	4.9	3.1	9.6

Table 7-3. Statistical parameters for 50-year event sediment transport conditions associated with Sand Resource Areas 1 through 4.

	Resource Area			
	1	2	3	4
Mean Transport (m^3/yr)	1,220,000	1,240,000	580,000	-620,000
Absolute (Mean Difference in Transport (m^3/yr))	102,000	69,000	33,000	2,200
Standard Deviation (m^3/yr)	60,000	51,000	27,000	2,400
Percentage Difference	8.3	5.6	5.8	0.3

For average annual conditions, mean longshore sand transport rates were approximately equal landward of borrow sites in Resource Areas 1, 2, and 3. Mean annual transport rates along the eastern portion of Dauphin Island (landward of Resource Area 4) were estimated to be approximately 35% of the rates associated with the Morgan Peninsula. The absolute value of the mean difference between existing and post-dredging conditions generally decreased from east-to-west, with a maximum difference of approximately 8,000 cubic meters per year (8.3%) along the shoreline stretch influenced by dredging in Resource Area 1. Because the net sediment transport rate predicted for the borrow site in Resource Area 4 was relatively low (approximately 33,000 cubic meters per year), the percentage difference between existing and post-dredging conditions was greatest for this site (9.6%). Results from analyses of the 50-year event indicated a similar trend, where the absolute value of the mean difference decreased from east-to-west. The maximum difference in transport rates was approximately 102,000 cubic meters per year at Resource Area 1. Due to wave breaking associated with Pelican Island and the shallow shoals seaward of the eastern end of Dauphin Island, the 50-year event created variations in transport similar in magnitude to those predicted for average annual conditions at Resource Area 4 (absolute value of the mean difference was 2,200 and 3,200 cubic meters per year for the 50-year event and average annual wave conditions, respectively).

Upon initial inspection, the differences between existing and post-dredging transport rates appear to be significant. To determine the relative significance of this difference, a simple analysis of uncertainties associated with nearshore sediment transport calculations was performed. An estimate of uncertainties was based on procedures described by Rosati and Kraus (1991). Although the sediment transport calculation technique used in this study was slightly different than the method employed by Rosati and Kraus (1991), both procedures were based on wave height and direction. Using conservative estimates for error associated with wave height and wave direction of 10%, sediment transport rates can be predicted to within ±35%. These errors can be attributed to the inherent uncertainties in the WIS data set (wave height and directional accuracy) used to develop offshore wave conditions. The ±35% value is significantly higher than the impacts associated with any of the borrow sites evaluated along the Alabama coast.

Analysis of uncertainties related to longshore sediment transport estimates indicates that variations in transport associated with potential dredging scenarios are an order of magnitude lower than the uncertainty associated with sediment transport calculations. Therefore, the potential effects of offshore sand mining seaward of the Alabama coast on longshore sand transport rates are insignificant for the scenarios tested in this study. Alternative scenarios are not expected to pose any greater effects unless the quantity of sand dredged from a site is substantially larger than potential dredged volumes selected for this study.

7.5 BENTHIC ENVIRONMENT

The purpose of this section is to address potential effects of offshore dredging activity on benthic organisms, including analyses of the potential rate and success of recolonization following cessation of dredging activities. This section is divided into three parts. The first two parts summarize information from the existing literature on effects and recolonization. The first part (Section 7.5.1) describes potential impacts to benthic organisms from the physical disturbance of dredging, which causes removal, suspension/dispersion, and deposition of sediments. The second part (Section 7.5.2) discusses the potential rate and success of recolonization. Finally, the third part (Section 7.5.3) provides predictions of impacts and recolonization relative to the five borrow sites off Alabama.

Ecological effects of marine mining and beach nourishment operations have been reviewed by numerous authors (Thompson, 1973; Naqvi and Pullen, 1982; Nelson, 1985; Cruickshank et al., 1987; Goldberg, 1989; Grober, 1992; Hammer et al., 1993; National Research Council, 1995). Effects vary from detrimental to beneficial, short- to long-term, and direct and indirect (National Research Council, 1995).

Most reviews on the effects of beach nourishment operations have focused on potential impacts at the beach. Comprehensive assessments of the effects on biological resources at open ocean sand borrow sites have been limited (National Research Council, 1995). Alterations to biological resources in offshore sand borrow areas are generally of longer duration, and the consequences of those changes have not been well-defined (National Research Council, 1995). The remainder of this section focuses on potential impacts of dredging operations at offshore borrow sites.

7.5.1 Effects of Offshore Dredging on Benthic Fauna

The primary impact producing factor relative to dredging offshore borrow areas is mechanical disturbance of the seabed. This physical disruption includes removal, suspension/dispersion, and deposition of dredged material. This section focuses on the potential biological effects of these physical processes on benthic fauna.

7.5.1.1 Sediment Removal

Physical removal of sediments from a borrow area removes benthic habitat along with infaunal and epifaunal organisms which are incapable of avoiding the dredge, resulting in drastic reductions in the number of individuals, number of species, and biomass. Extraction of habitat and biological resources may in turn disrupt the functioning of existing communities. Removal of benthic resources is of concern because they are important in the food web for commercially and recreationally important fishes and invertebrates, and contribute to the biodiversity of the pelagic environment through benthic-pelagic coupling mechanisms. These mechanisms include larval transport and diurnal migrations of organisms which may have substantial impact on food availability, feeding strategies, and behavioral patterns of other members of the assemblage (Hammer and Zimmerman, 1979; Hammer, 1981).

Removal of sand resources can expose underlying sediment and change the sediment structure and composition of a borrow area, consequently altering its suitability for burrowing, feeding, or larval settlement of some benthic organisms. Many studies show decreases in mean grain size, and in some cases, increases in silt and clay in borrow sites following dredging (National Research Council, 1995). Changes in sediment composition could potentially prevent recovery to an assemblage similar to that which occurred in the borrow area prior to dredging and could by implication affect the nature and abundance of food organisms for commercial and recreational fishery stocks (Coastline Surveys Limited, 1998; Newell et al., 1998). In some cases, dredging borrow areas may create new and different habitat from surrounding substrates which could result in increased habitat complexity and biodiversity of an area.

The influence of sediment composition on benthic community composition has been recognized since the pioneer studies of Peterson (1913), Thorson (1957), and Sanders (1958). However, more recent reviews suggest that precise relationships between benthic assemblages and specific sediment characteristics are poorly understood (Gray, 1974; Snelgrove and Butman, 1994; Newell et al., 1998). Sediment grain size, chemistry, and organic content may influence recolonization of benthic organisms (McNulty et al., 1962; Thorson, 1966; Snelgrove and Butman, 1994), although the effects of sediment composition on recolonization patterns of various species are not always significant (Zajac and Whitlatch, 1982). Because the complexity of soft-sediment communities may defy any simple paradigm relating to any single factor, Hall (1994) and Snelgrove and Butman (1994) proposed a shift in focus towards understanding relationships between organism distributions and the dynamic sedimentary and hydrodynamic environments. It is likely that the composition of benthic assemblages is controlled by a wide array of physical, chemical, and biological variables which interact in complex ways which are variable with time.

Removal of sediments from borrow areas can alter seabed topography, creating pits which may refill rapidly or cause detrimental impacts for extended periods of time. Borrow areas have been known to remain well-defined 8 years after dredging (Marsh and Turbeville, 1981; Turbeville and Marsh, 1982). Although nearly 12 years may be required for some offshore borrow sites to refill to pre-dredge profiles, intentionally locating borrow sites in highly depositional areas may dramatically reduce the time for refilling (Van Dolah et al., 1998). In general, shallow dredging over large areas causes less harm than small but deep pits, particularly pits opening into a different substrate surface (Thompson, 1973; Applied Biology, Inc., 1979). Deep pits also can hamper commercial trawling activities and harm level-bottom communities (Thompson, 1973). If borrow pits are deep, current velocity is reduced at the bottom, which can lead to deposition of fine particulate matter and in turn a biological assemblage much different in composition than the original. Deep holes may decrease dissolved oxygen to hypoxic or anoxic levels and increase hydrogen sulfide levels (Murawski, 1969; Saloman, 1974; National Research Council, 1995).

7.5.1.2 Sediment Suspension/Dispersion

Dredging causes suspension of sediments which increases turbidity over the bottom. This turbidity undergoes dispersion in a plume that drifts with the water currents. The extent of suspension/dispersion depends on sediment composition, sediment transport processes, the type of dredging equipment, techniques for operating the equipment, amount of dredging, thickness of the dredged layer, etc. Herbich and Brahme (1991) and Herbich (1992) reviewed sediment suspension caused by existing dredging equipment, and discussed potential technologies and techniques to reduce suspension and the associated environmental impacts. In general, cutterhead suction dredges produce less turbidity than hopper dredges.

A cutterhead suction dredge consists of a rotating cutterhead, positioned at the end of a ladder, that excavates the bottom sediment. The cutterhead is swung in a wide arc from side to side as the dredge is stepped forward on pivoting spuds, and the excavated material is picked up through a suction pipe and transferred by pipeline as a slurry (Hrabovsky, 1990; LaSalle et al., 1991). Sediment suspension is caused by the rotating action of the cutterhead and the swinging action of the ladder (Herbich, 1992). A properly operated cutterhead dredge can limit sediment suspension to the lower portion of the water column (Herbich and Brahme, 1991; Herbich, 1992). A well-designed cutterhead, selection of an appropriate cutterhead for a given sediment, the correct relationship between rotational speed of the cutterhead and the magnitude of hydraulic suction, and suitable swing rate of the cutterhead, along with hooded intakes, may reduce turbidity at the cutterhead, although these conditions are rarely achieved (Herbich, 1992). Measurements around properly operated cutterhead dredges show that elevated levels of suspended sediments can be confined to the immediate vicinity of the cutterhead and dissipate rapidly with little turbidity reaching surface waters (Herbich and Brahme, 1991; LaSalle et al., 1991; Herbich, 1992). Maximum suspended sediment concentrations typically occur within 3 m above the cutterhead and decline exponentially to the sea surface (LaSalle et al., 1991). Suspended sediment concentrations in near-bottom waters may be elevated up to several hundred meters laterally from the cutterhead location (LaSalle et al., 1991).

A hopper dredge consists of one, two, or more dragarms and attached dragheads mounted on a ship-type hull or barge with hoppers to hold the material dredged from the bottom (Herbich and Brahme, 1991). As the hopper dredge moves forward, sediment is hydraulically lifted through the dragarm and stored in hopper bins on the dredge (Taylor, 1990; LaSalle et al., 1991). Hopper dredging operations produce turbidity as the dragheads are pulled through bottom sediment. However, the main source of turbidity during hopper dredging operations is sediment release during hopper overflow (Herbich and Brahme, 1991; LaSalle et al., 1991; Herbich, 1992). A plume may occasionally be visible at distances of 1,200 m or more (LaSalle et al., 1991).

Much attention has been given to turbidity effects from dredging, although most reviews have concerned estuaries, embayments, and enclosed waters (e.g., Sherk and Cronin, 1970; Sherk, 1971; Sherk et al., 1975; Moore, 1977; Peddicord and McFarland, 1978; Stern and Stickle, 1978; Herbich and Brahme, 1991; LaSalle et al., 1991; Kerr, 1995). Turbidity effects should be less important in unprotected offshore areas for several reasons. Offshore sand tends to be coarser with less clay and silt than inshore areas. The open ocean environment also provides more dynamic physical oceanographic conditions which minimize settling effects. In addition, offshore organisms are adapted to sediment transport processes which create scouring, natural turbidity, and sedimentation effects under normal conditions. Impacts should be evaluated in light of average background conditions as well as occasional high level disturbances associated with storms, floods, hypoxia/anoxia, trawling, etc. (Herbich, 1992). Physical disturbance of the bottom and resulting biological impacts from dredging are similar to those of storms but at a much smaller spatial scale.

Turbidity interferes with the food gathering process of filter feeders and organisms that feed by sight by inundation with nonnutritive particles. Large quantities of bottom material placed in suspension decrease light penetration and change the proportion of wavelengths of light reaching the bottom, leading to decreases in photosynthetic activity. Suspension and dispersion of sediment may cause changes in sediment and water chemistry as nutrients and other substances are released from the substratum and dissolved during the dredging process. Coastline Surveys Limited (1998) proposed that for aggregate mining operations using hopper dredges, the far-field visible plume contains an organic admixture of fats, lipids, and carbohydrates from organisms entrained and fragmented during the dredging process and discharged with the overflow. Dredging may produce localized hypoxia or anoxia in the water column due to oxygen consumption of the suspended sediments (LaSalle et al., 1991). Suspension and dispersion processes also uncover and displace benthic organisms, temporarily providing extra food for bottom feeding species (Centre for Cold Ocean Resources Engineering, 1995).

7.5.1.3 Sediment Deposition

Suspended sediment settles and is deposited nearby or some distance from the dredge site. The extent of deposition and the boundaries of biological impact are dependent on the type and amount of suspended sediment and physical oceanographic characteristics of the area.

Dredging effects are not necessarily limited to the borrow area alone. The types of far-field impacts from suspension and deposition of sediment can be detrimental or beneficial. Deposition of sediment can suffocate and bury benthic fauna, although some organisms are able to migrate vertically to the new surface (Maurer et al., 1986). Johnson and Nelson (1985) found decreases in abundances and numbers of taxa at non-dredged stations, although these decreases were not as extreme as those observed in the borrow area. McCaully et al. (1977) as cited by Johnson and Nelson (1985) also observed that dredging effects can extend to other nearby areas, and noted decreases in abundance ranging from 34% to 70% at undredged stations within 100 m of a dredged area. Conversely, benthos may show an increase in biodiversity downstream from the dredge site (Centre for Cold Ocean Resources Engineering, 1995). In some areas, population density and species composition of benthic invertebrates increased rapidly outside dredging sites, with the level of enhancement decreasing with increasing distance from the dredged area up to a distance of 2 km (Stephenson et al., 1978; Jones and Candy, 1981; Poiner and Kennedy, 1984). The enhancement was ascribed to the release of organic nutrients from the dredge plume, a process known from other studies (Ingle, 1952; Biggs, 1968; Sherk, 1972; Oviatt et al., 1982; Coastline Surveys Limited, 1998; Newell et al., 1998). This suggestion was supported by records of nutrient releases from benthic areas during intermittent, wind-driven bottom resuspension events (Walker and O'Donnell, 1981), significant increases in nutrients in the water column from simulated storm events in the laboratory (Oviatt et al., 1982), and review of the literature indicating a major restructuring force in infaunal communities is the response of species to resources released from the sediments by periodic disturbance (Thistle, 1981). Fishing also may improve temporarily down current of the dredging area and continue for some months (Centre for Cold Ocean Resources Engineering, 1995).

7.5.2 Recolonization Rate and Success

7.5.2.1 Adaptations for Recolonization and Succession

In dynamic areas which undergo frequent perturbations, benthic invertebrates tend to be small bodied, short lived, and adapted for maximum rate of population increase with high fecundity, efficient dispersal mechanisms, dense settlement, and rapid growth rates (MacArthur, 1960; MacArthur and Wilson, 1967; Odum, 1969; Pianka, 1970; Grassle and Grassle, 1974). In contrast, organisms in stable areas tend to be relatively larger and longer lived with low fecundity, poor dispersal mechanisms, slow growth rates, and adaptations for non-reproductive processes such as competition and predator avoidance. Recolonization of a disturbed area often is initiated by organisms which have the adaptive characteristics for rapid invasion and colonization of habitats where space is available due to some natural or man-induced disturbance. These early colonizers frequently are replaced during the course of succession through competition by other organisms, unless the habitat is unstable or frequently perturbed.

Although the distinction between the adaptive strategies is somewhat arbitrary and is blurred in habitats which are subject to only mild disturbance, the lifestyle differences are fundamentally important because they help explain variations in succession and recolonization rate and success following disturbance (Coastline Surveys Limited, 1998; Newell et al., 1998). Knowledge of faunal component lifestyles allows some predictions of dredging impacts and subsequent recolonization and recovery of community composition (Coastline Surveys Limited, 1998; Newell et al., 1998).

7.5.2.2 Successional Stages

Successional theory states that organism-sediment interactions result in a predictable sequence of benthic invertebrates belonging to specific functional types following a major seafloor disturbance (Rhoads and Germano, 1982, 1986). Because functional types are the biological units of interest, the succession definition does not rely on the sequential appearance of particular species or genera (Rhoads and Boyer, 1982). This continuum of change in benthic communities has been divided arbitrarily into three stages (Rhoads et al., 1978; Rhoads and Boyer, 1982; Rhoads and Germano, 1982):

Stage I is the initial pioneering community of tiny, densely populated organisms which appears within days of a natural or anthropogenic disturbance. Stage I communities are composed of opportunistic species that have high tolerance for and can indicate disturbance by physical disruption, organic enrichment, and chemical contamination of sediments. The organisms have high rates of recruitment and ontogenetic growth. Stage I communities tend to physically bind sediments, making them less susceptible to resuspension and transport. For example, Stage I communities often include tube-dwelling polychaetes or oligochaetes that produce mucous to build their tubes which stabilizes the sediment surface. Stage I communities include suspension or surface deposit-feeding animals that feed at or near the sediment-water interface. The Stage I initial community may reach population densities of 10^4 to 10^6 individuals/m^2;

Stage II is the beginning of the transition to burrowing, head-down deposit feeders that rework the sediment deeper and deeper with time and mix oxygen from the overlying water into the sediment. Stage II animals may include tubiculous amphipods, polychaetes, and mollusks. These animals are larger and have very low population densities compared to Stage I animals; and

Stage III is the mature and stable community of deep-dwelling, head-down deposit feeders. In contrast to Stage I organisms, these animals rework the sediments to depths of 3 to 20 cm or more, loosening the sedimentary fabric and increasing the water content of the sediment. They also actively recycle nutrients because of the high exchange rate with the overlying water resulting from their burrowing and feeding activities. The presence of Stage III taxa can be a good indication that the sediment surrounding these organisms has not been severely disturbed recently, resulting in high benthic stability and health. Loss of Stage III species results in the loss of sediment stirring and aeration and may be followed by a build-up of organic matter (eutrophication) of the sediment. Because Stage III species tend to have relatively low rates of recruitment and ontogenetic growth, they may not reappear for several years once they are excluded from an area. These inferences are based on past work, primarily in temperate latitudes, showing that Stage III species are relatively intolerant to physical disturbance, organic enrichment, and chemical contamination of sediments. Population densities are low (10 to 10^2 individuals/m^2) compared to Stage I.

The general pattern of succession of benthic species in a marine sediment following cessation of dredging or other environmental disturbance begins with initial recolonization. Initial recolonization occurs relatively rapidly by small opportunistic species which reach peak population densities within months of a new habitat becoming available after catastrophic mortality of the previous assemblage. As the disturbed area is invaded by additional larger species, the population density of initial colonizers declines. This transitional period and assemblage with higher species diversity and a wide range of functional types may last for years, depending on numerous environmental factors. Provided environmental conditions remain stable, some members of the transitional assemblage are eliminated by competition, and the species assemblage forms a recovered community comprised of larger, long-lived, and slow growing species with complex biological interactions with one another.

7.5.2.3 Recolonization Rates

The rate of recolonization is dependent upon numerous physical and biological factors. Physical factors include the time of year, depth of the borrow area, water currents, sediment composition, bedload transport, temperature and salinity, natural energy levels in the area, frequency of disturbance, latitude, etc. Recovery times may be shorter in warmer waters at lower latitudes as compared to colder waters at higher latitudes (Coastline Surveys Limited, 1998; Newell et al., 1998).

Recolonization of borrow areas may occur by transport of larvae from neighboring populations by currents and subsequent growth to adults, immigration of motile species from adjacent areas, organisms contained in sediment slumping from the sides of pits, or return of undamaged organisms from the dredge plume. The rate of recolonization depends on the size of the pool of available colonists (Bonsdorff, 1983; Hall, 1994). Other biological factors such as competition and predation also determine the rate of recolonization and the composition of resulting benthic communities. Timing of dredging is important because many benthic species have distinct peak periods of reproduction and recruitment. Because larval recruitment and adult migration are the primary recolonization mechanisms, biological recovery from physical impacts generally should be most rapid if dredging is completed before seasonal increases in larval abundance and adult activity (Herbich, 1992). Recovery of a community disturbed after peak recruitment, therefore, will be slower than one disturbed prior to peak recruitment (LaSalle et al., 1991).

Benthic recolonization and succession have been reviewed to varying extents for a wide variety of habitats throughout the world (e.g., Thistle, 1981; Thayer, 1983; Hall, 1994; Coastline Surveys Limited, 1998; Newell et al., 1998). Recolonization is highly variable and ranges from within months (e.g., Saloman et al., 1982) to more than 12 years (e.g., Wright, 1977), depending on the habitat type and other physical and biological factors. Focusing on dredging, Coastline Surveys Limited (1998) and Newell et al. (1998) suggested that in general recovery times of 6 to 8 months are characteristic for many estuarine mud, 2 to 3 years for sand and gravel, and 5 to 10 years as the deposits become coarser.

The Centre for Cold Ocean Resources Engineering (1995) estimated times for recovery of a reasonable biodiversity (number of species and number of individuals) based on sediment type. In this study, recovery was defined as attaining a successional community of opportunistic species providing evidence of progression towards a community equivalent to that previously present or at non-impacted sites. Fine-grained sediments may need only 1 year before achieving a recovery level biodiversity, medium-grained deposits 1 to 3 years, and coarse-grained deposits 5 or more years. For a hypothetical borrow site dredging scenario off Ocean City, Maryland, the Centre for Cold Ocean Resources Engineering (1995) stated that virtually all benthic species would be lost, but there may be temporary improvement of fishing due to release of nutrients. Recolonization would start within weeks of closure and moderate biodiversity would occur within 1 year. The borrow area would be colonized initially by a very different species complex than originally present. An estimate of 2 to 3 years was given for the community to begin to show succession to pre-impact sand habitat species.

Studies of recolonization listed and discussed by Grober (1992) and the National Research Council (1995) indicate that recolonization of offshore borrow areas is highly variable. This variability is not surprising considering the differences between studies in geographic locations, oceanographic conditions, sampling methods and times, etc. Part of the problem in determining recolonization patterns is seasonal and year to year fluctuations in benthic community characteristics and composition. Without adequate seasonal and yearly data prior to dredging, it is difficult to determine whether differences in community characteristics and composition are due to temporal changes or dredging disturbance.

Results and conclusions from these offshore borrow area studies indicate that recolonization usually begins soon after dredging ends. Recolonization periods range in duration from a few months to several years. Although abundance and diversity of benthic fauna within the borrow sites often returned to levels comparable to pre-dredging or reference conditions within less than 1 year, several studies documented changes in benthic species composition that lasted much longer, particularly where sediment composition was altered (e.g., Johnson and Nelson, 1985; Bowen and Marsh, 1988; Van Dolah et al., 1992, 1993; Wilber and Stern, 1992).

Most recolonization studies of borrow areas concentrated on three main features of infaunal communities, namely the number of individuals (population density), number of species (diversity), and weight (biomass as an index of growth). Dredging is usually accompanied by an immediate and significant decrease in the number of individuals, species, and biomass of benthic infauna. Using biological community parameters (e.g., total taxa, total number of individuals, species diversity, evenness, richness, etc.), previous studies tend to indicate that recovery of borrow areas occurs in approximately 1 year after dredging. However, these parameters do not necessarily reflect the complex changes in community structure and composition which occur during the recovery process. Major changes in species assemblages and community composition usually occur shortly after dredging such that a different type of community exists. Although the number of individuals, species, and biomass of benthic infauna may approach pre-dredging levels within a relatively short time after dredging, recovery of community composition may take longer.

7.5.2.4 Recolonization Success and Recovery

Assessing impacts of dredging and recolonization and recovery of borrow areas is difficult because most biological communities are complex associations of species that often undergo major changes in population densities and community composition, even in areas which are far removed and unaffected by dredging and other disturbances. Recolonization success and recovery do not necessarily mean communities should be expected to return to the pre-dredged species composition. To gauge recovery, it is important to compare community composition of dredged areas with control areas during the same seasons because community composition changes with time.

When long-term alterations in sediment structure and composition occur as a result of dredging, long-term differences in the composition of benthic assemblages inhabiting those sites may occur as well. The recovery time of benthic assemblages after dredging can depend in large measure on the degree and duration of sediment alteration from sand borrowing (Van Dolah, 1996). Recolonization success and recovery also are controlled by compaction and stabilization processes involving complex interactions between particle size, water currents, waves, and biological activities of the benthos following sediment deposition (Oakwood Environmental Ltd., 1999). While the abundance and diversity of infaunal assemblages may recover relatively rapidly in dredged areas, it may take years to recover in terms of sediment and species composition.

One conclusion commonly held is that perturbations to infaunal communities in borrow areas are negligible because organisms recolonize rapidly (Wilber and Stern, 1992). This conclusion often is based on measures including densities, species diversity/evenness indices, relative distribution of classes or phyla, and species-level dendrograms. For example, many researchers have recognized that borrow and reference area infaunal communities can differ considerably at the species level, although these differences usually are considered insignificant because species diversity is high. According to Wilber and Stern (1992), reliance upon these studies may lead to a premature conclusion that impacts to borrow area infauna are minimal because these measures are relatively superficial and ambiguous characteristics of infaunal communities. Wilber and Stern (1992) re-examined infaunal data from four borrow area projects by grouping species into functional groups called ecological guilds based on similarities in feeding mode, locomotory ability, and sediment depth occurrence. Their analyses showed that infaunal communities in borrow and control areas can differ in several ways and that these differences can last several years. Polychaetes and amphipods that recolonize borrow areas are small-bodied and confine their movement and feeding to the surface sediment or the interface between the sediment and water column. In contrast, control areas have well-developed infaunal communities commonly consisting of large-bodied organisms that move and feed deep in the sediment (Wilber and Stern, 1992). They concluded that the infaunal communities recolonizing borrow areas may remain in an early successional stage for 2 to 3 years or longer as opposed to being completely recovered in shorter time frames.

The conclusions of Wilber and Stern (1992) coincide with the model of succession discussed previously. The model states pioneering or opportunistic species are the first to colonize an area after a physical disturbance to the bottom (e.g., dredging borrow areas). Pioneering species tend to share several ecological traits, including a tendency to confine activities to the sediment-water interface, possibly because subsurface conditions cannot support a significant number of organisms. The subsurface environment changes with time after the disturbance, possibly by actions of early colonizers, and becomes suitable for deposit feeders and mid-depth burrowers. The relative absence of deposit feeders and mid-depth burrowers is interpreted to mean an area is still in the state of recovery.

Although most of the literature on recolonization rate and success in borrow areas concerns infauna, some information exists for epifauna. The numbers of taxa and individuals collected by trawls in a borrow area off Duval County, Florida greatly exceeded the control area numbers 4 months after dredging and were generally higher 7 and 13 months after dredging (Applied Biology, Inc., 1979). There were no detectable differences between pre-dredging and post-dredging (8 and 16 months) epifaunal communities in a borrow area surveyed by otter trawl and video camera off Egmont Key, Florida (Blake et al., 1995).

7.5.3 Predictions Relative to the Borrow Sites

Based upon the commodity-specific, technology-specific, and site-specific information provided in Section 7.0, the following predictions can be made regarding the potential effects of offshore dredging on benthic organisms (Section 7.5.3.1) and the recolonization rate and success (Section 7.5.3.2) relative to the borrow sites off Alabama.

7.5.3.1 Potential Benthic Effects

Sediment Removal

The immediate impact of excavating upper sediments from the sand resource areas would be removal of portions of the benthic invertebrate populations that inhabit the seafloor. Lost individuals would be those with slow-moving or sessile lifestyles, primarily individuals of infaunal populations. Surveys within and adjacent to each of the five candidate borrow sites (see Section 6.0), as well as benthic investigations of nearby waters (see Section 2.3.1), reveal that the sand bottom benthic assemblages of inner shelf waters of the study area are comprised predominantly of invertebrates, including crustaceans, echinoderms, mollusks, and polychaetous annelids.

The expected loss of benthic fauna due to sediment excavation from the sand resource areas could be considered to represent a minimal impact to the ecosystem when evaluating the impact on a spatial scale. Impacts most likely would be short-term and localized. It should be noted that use of any of the sand resource areas does not entail complete excavation of those areas. For example, the potential high-end case of 750,000 m^3 of sand excavation would affect roughly 25 ha of seafloor, with an average excavation depth of 3 m. Specific locations within Areas 1 through 4 that are to be dredged will be selected based on particular sediment characteristics, leaving a significant extent of non-dredged areas surrounding and interspersed throughout the sand resource areas. These undisturbed "islands" would be a primary source of colonizing fauna for the excavated sites (Oliver et al., 1977; Van Dolah et al., 1984) and complement colonization of altered substrata via larval recruitment. The great densities and high fecundity of invertebrate populations, along with the relatively small area of impact proposed, likely would preclude significant long-term negative effects on benthic populations and assemblages.

Of the five sand resource areas offshore Alabama, Areas 1, 2, 3, and 4 have the greatest potential for use as borrow sites for beach replenishment projects. Areas 1, 2, and 3 are very similar with respect to sediment type, with all of these areas containing medium-to-fine sands. In contrast, some parts of Area 4 have up to 0.3 m of silt and clay overburden before encountering a medium-to-fine sand deposit. Infaunal assemblages that inhabit these areas are, at least partly, a reflection of these surficial geologic characteristics; Areas 1 to 3 support similar benthic assemblages, while Area 4 is characterized by assemblages that contain taxa adapted to living in finer sediments.

Correlation between sediment composition and the composition of infaunal assemblages has been demonstrated in numerous environmental surveys, including those of the sand resource areas. Invertebrate populations inhabiting marine soft bottoms offshore Alabama exhibit heterogeneous distributions that are largely the result of sedimentary regime and, to a lesser extent, water depth. Sediment removal could result in an alteration of the areal extent and relative distribution of assemblage types by altering the distribution of sediment types capable of supporting those assemblages.

It is possible that a change in the composition of surficial sediments within excavated areas could become a long-term result of dredging. Several factors could contribute to such an outcome, primarily the type of sediments exposed by dredging and the degree of deposition of fine sediments into dredged areas. These factors would depend primarily on the depth of excavation, which would be determined by the vertical extent of those sediments suitable for coastal nourishment projects, the volume of sand required, and the vertical relief of the sand shoal to be excavated.

Because the inner shelf ecosystem of the NEGOM exhibits some heterogeneity in sediment types and their associated assemblages, those transitional infaunal assemblages that would colonize dredged areas likely would be similar to some naturally occurring assemblages that inhabit nearby non-dredged areas. When viewed within a context of scale, the removal of sediments from portions of the inner continental shelf would, at most, minimally alter the existing spatial balance of habitat (sediment) types. Moreover, those habitats that have relatively high levels of finer sediments are not uninhabitable, or necessarily less desirable, when compared to sandier substrata. These habitat types merely differ in their level of suitability for certain types of infaunal taxa.

Motile populations, including non-migratory foragers, would be less stressed by sediment removal than infauna or sessile epifauna. Most adult epifaunal and demersal ichthyofaunal populations would have a low probability of being adversely impacted directly by dredging because of their mobility; however, adult entrainment is possible and some species release eggs on the bottom which would be vulnerable to sediment removal and deposition. Minimal impacts are expected, especially if dredging activity coincides with the seasonal absence of key epifaunal (e.g., brown shrimp) and demersal taxa. Slow-moving or sessile epifauna inhabiting the project area include echinoderm and cnidarian taxa. Local populations of these types of benthic organisms would most likely experience a reduction in density due to sediment removal. Highest numbers of motile epifaunal taxa are usually sampled from areas of relatively coarse-grained sand; however, these taxa generally are migratory and not endemic to the areas of proposed impact. Most demersal populations exhibit naturally dynamic distributions, as they move between areas within the Gulf of Mexico on a seasonal basis (Comiskey et al., 1985; Brooks and Giammona, 1991; Harper, 1991).

Impacts of sediment removal on epifaunal and demersal taxa would likely be indirect in nature, through habitat alteration. A reduction of infaunal biomass resulting from sediment removal could have an indirect effect upon the distribution of certain demersal ichthyofauna and other epibenthic predators by interrupting established energy pathways to the higher trophic levels represented by these foraging taxa. Reductions in densities of the preferred prey of bottom-feeding taxa could induce migration of foragers to unimpacted areas.

Darnell (1991) reported gut content analyses of demersal fishes sampled from Gulf shelf waters. In that study, large, motile prey items (shrimps, crabs, fishes, and cephalopods) made up 70% of the diet of demersal fishes. The preferred food of most demersal taxa apparently is the abundant motile epifauna (Rogers, 1977; Darnell, 1991), populations of which are not likely to be adversely impacted by mining of the sand resource areas due to their migration and general ability for flight response. A relatively small percentage of infaunal prey items that typically are consumed by these fishes would be rendered unavailable for consumption as a result of their removal along with surficial sediments. Benthic predators would simply select alternative areas in which to forage. Therefore, the loss of infaunal biomass due to sediment excavation is unlikely to adversely affect normal energy flow through Alabama inner shelf sand bottoms.

In addition to widely documented spatial variation, the location and extent of inner shelf-inhabiting infaunal and demersal populations varies seasonally in the study area. This seasonal variability should be considered when evaluating potential impacts due to sand removal. The timing of sand removal would seem to be less critical for minimizing the impact upon infauna than for other faunal categories of concern (e.g., key pelagic species), due to the great abundance and reproductive potential of these invertebrate populations. Surveys of the borrow sites, as well as previous studies (Barry A. Vittor & Associates, Inc., 1985; Harper, 1991), indicate that local benthic assemblages tend to maintain fairly consistent values of species diversity and richness year-round, whereas densities are lower during winter. Additionally, many numerically dominant infaunal taxa inhabiting the study area are known to exhibit year-round or late winter-early spring periods of recruitment. Because of these patterns of recruitment and lower winter densities, removal of sand between late fall and early spring would result in less stress on benthic populations.

Sediment Suspension/Dispersion

Whether cutterhead suction dredging or hopper dredging is ultimately utilized for sand mining activity, the amount of sediment resuspension that results from these excavation methods is not anticipated to be of a scale that would cause significant negative impacts to the benthic community. Impacts of dredging-induced elevations in turbidity would be short-term and localized. Motile taxa could avoid turbid areas. In general, benthic assemblages of the inner Alabama shelf are adapted to periodic resuspension of surficial sediments caused by tropical and extratropical (winter) storms. Along the nearshore area of Alabama, the winter season is characterized by frequent energetic storms and a well-mixed water column, while summer exhibits a reduction of storm-derived mixing and an increase in solar heating, resulting in water column stratification (Section 5.1.1.4; Kjerfve and Sneed, 1984). Removal of sediment during winter may therefore be advantageous in minimizing any adverse impacts upon benthos resulting from dredging-induced turbidity.

Sediment Deposition

Of the various faunal categories, infaunal and sessile epifaunal populations would be most negatively affected by significant deposition of sediments; however, this scenario is unlikely. The methods of sediment excavation that would be utilized will preclude all but a relatively minimal amount of sediment deposition. As a result, the suspension and transport of suspended sediments away from dredging sites should be minimal and, therefore, any subsequent deposition will be insignificant in degree. Areas 1, 2, and 3 are characterized by a lack of fine sediments. In the unlikely event that significant dredging-related excavation of fine-grained sediment does occur in these eastern sand resource areas, the deposited sediment should not persist on the seafloor. Area 4 does exhibit a higher percentage of fine sediments but, given the relatively small amounts of resuspended sediments anticipated to occur during dredging, the concentration will be substantially less than would be required to impact negatively on the infaunal community. Furthermore, the benthic community inhabiting Area 4 is probably adapted to periods of siltation as a result of outflow from Mobile Bay and nearby disposal of dredged material.

7.5.3.2 Potential Recolonization Rate and Success

The rate of post-dredging recovery of benthic assemblages within a sand resource area will depend primarily on the depth of sand excavation. While surface area of impact could be minimized by excavating a shoal to a greater depth, deep excavation likely would require a greater length of time for complete recovery of infaunal assemblages within the impacted area. Creation of a bathymetrically-abrupt pit has potential to inhibit water current flow through such a feature, resulting in a “dead zone” characterized by persistent hypoxia and deposition of fine particles. This situation would extend the duration of ecological impact beyond that which would occur with a more shallow cut over a much larger area. While the initial impact upon benthic assemblages would increase with increasing surface area of sand removal, the persistence of ecological impact that would occur with a relatively shallow excavation would be less than that of a deep pit. Paradoxically, the long-term impact of a maximum excavation of 3 m (Area 1) or 4 m (Area 3) would decrease with an increased area of sand removal because a more smoothly-graded, trough-like feature would allow greater bottom current flow than would an abrupt pit. The inner Alabama shelf sediment sheet does exhibit natural trough features within the sand resource areas.

The length of time required for reestablishment of pre-dredging infaunal assemblages depends in part on the length of time required for refilling of those areas. Sediment types exposed by dredging and deposited in excavated areas are additional considerations. The relatively shallow water benthic habitats of the Alabama inner shelf also are strongly influenced by factors such as Mobile Bay discharge (salinity and turbidity), currents and circulation, and storms (Barry A. Vittor & Associates, Inc., 1985). These same forces would tend to modify impacted areas in the direction of pre-dredging conditions. Movement of shelf sediment in offshore Alabama waters occurs primarily as a result of the high winds and waves that characterize intense storms, while transport of Alabama shelf sediment due to shelf currents appears to be minimal (Parker et al., 1997). Borrow area refilling probably will occur mainly by storm-induced sediment movement. Tropical and extra-tropical storms impact the offshore Alabama region more or less on an annual basis and these events would tend to refill seafloor depressions formed by dredging. Storm-induced sediment transport can be substantial at relatively shallow depths such as those in the region of the borrow areas. It is expected that the time required to refill borrow areas will be on the order of decades for Areas 1, 2, and 3 and years in Area 4 for the sand extraction scenarios evaluated in this study.

Assuming that the depth of sand excavation will not be so great as to substantially alter local hydrological characteristics, the removal of benthic organisms along with sediment would be followed quickly by initial recolonization of the dredged areas by opportunistic infaunal taxa. This scenario appears likely if the maximum depth of excavation at borrow sites ranges between 3 and 4 m, as is presently anticipated. Early-stage succession will begin within days of sand removal, through settlement of larval recruits, primarily annelids and bivalves. Initial larval recruitment will be dominated by the opportunistic taxa that were numerical dominants in the western sand resource areas during the biological surveys (e.g., *Magelona* sp. H*, Mediomastus* spp., and *Paraprionospio pinnata*). These species are well adapted to environmental stress and exploit suitable habitat (especially fine-grained sediments) when it becomes available. Later successional stages of benthic recolonization will be more gradual, involving taxa that generally are less opportunistic and longer lived. Immigration of motile crustaceans, annelids, and echinoderms into impacted areas also will begin soon after excavation.

Areas 1, 2, and 3 east of Mobile Bay exhibit limited sediment movement during historical time. The process of sediment refilling of excavated sites would be accomplished mainly by storm-induced transport and, to a lesser degree, normal shelf sediment transport processes. The rapidity of the refilling process will depend on the frequency and intensity of storms. However, the rate of refilling may not be a significant issue with respect to benthic recolonization in the eastern sand resource areas because the areas are fairly uniform with respect to biological habitat. Sediment consists of well-sorted sand and appear to be vertically uniform with respect to sedimentary regime. These areas are characterized by an absence of fine sediment. It may be predicted from this that recolonization of dredged areas offshore eastern Alabama likely will occur in a timely manner and without persistent inhabitation by transitional assemblages, not unlike the process which has been documented in comparable regional habitats (Saloman et al., 1982). Recolonization of surficial sediment by later successional stages likely will proceed even if dredged areas are not completely refilled. Furthermore, the horizontal uniformity of biological habitat across the eastern areas will ensure that a supply of non-transitional, motile taxa will be available for rapid migration into dredged areas. Infaunal assemblages that typically inhabit the eastern portion of the study area will most likely become reestablished within 2 years.

Area 4 infaunal assemblages can be expected to recover more quickly than those in the eastern areas. Because of the physical environmental characteristics of Area 4, especially outflow of fresh water and fine material (silts and organics) from Mobile Bay, existing assemblages are comprised of species that colonize perturbed habitats. The infaunal community in Area 4 is adapted to environmental instability and probably never fully reaches a stable Stage III community (Continental Shelf Associates, Inc. and Barry A. Vittor & Associates, Inc., 1989). As a result, many infaunal taxa that inhabit Area 4 are the transitional taxa that would colonize areas of sand removal. Infaunal assemblages that inhabit the western study areas would therefore become reestablished relatively rapidly, probably within 12 to 18 months.

7.6 PELAGIC ENVIRONMENT

This section discusses the potential effects of hydraulic (cutterhead and hopper) dredging on water column organisms at a borrow site, and seasonal windows that would reduce the effects to particular species or groups. Groups of organisms considered include zooplankton (including eggs and larvae of economically important fish and shellfish species), squids, pelagic fishes, sea turtles, and marine mammals.

7.6.1 Zooplankton

7.6.1.1 Entrainment

Zooplankters encountering the suction field of hydraulic dredges will be easily drawn into the system (i.e., entrained). Entrained zooplankters are assumed to die from abrasion and physical trauma (LaSalle et al., 1991; Reine and Clarke, 1998). The most detrimental consequence of zooplankton entrainment is the death of fish and invertebrate larvae which ultimately influences the age structure of adult populations.

The rate of zooplankton entrainment by hydraulic dredges depends upon local hydrographic patterns responsible for their transport and the spatial and temporal dynamics of local populations. Hydrographic patterns can be measured, whereas inherently variable zooplankton populations are more difficult to characterize (Sullivan and Hancock, 1977). Because of difficulties in measuring population parameters from field-collected data, direct estimates of zooplankton entrainment (and subsequent population effects) are not available in the dredging literature. An alternative to using field-collected data has been to develop numerical models that predict population effects given specific scenarios (discussed in LaSalle et al., 1991 and Reine and Clarke, 1998). Unfortunately, population effects estimated from models can differ greatly depending upon model assumptions (LaSalle et al., 1991; Reine and Clarke, 1998).

Entrainment rate also depends upon physical aspects of the dredging operation. Because the suction field of hydraulic dredges remains near the seafloor, species most susceptible to entrainment are those occurring in the lower portion of the water column. Taxa or life stages which spend part of their time associated with the benthic environment, such as demersal fish eggs or demersal zooplankton (Hammer, 1979), would be especially vulnerable. Unfortunately, no information exists on the abundance or composition of demersal zooplankton in the sand resource areas. Other zooplankters may occur in the lower water column under certain hydrographic or meteorological conditions (Rogers et al., 1993). Considering the high reproductive capacity of zooplankton along with the relatively small area of the dredge suction field and the volume of water entrained compared to the overall volume of surrounding waters, it is unlikely that entrainment would greatly affect zooplankton populations or assemblages in the Alabama sand resource areas.

7.6.1.2 Turbidity

Sediment suspended and dispersed by the action of a working dredge can affect zooplankters by 1) interfering with feeding activity; 2) direct mortality and toxicity; and 3) physiological impairment. Most crustacean zooplankters are filter feeders capable of filtering and processing particles between 3 and 10µ (Nival and Nival, 1976). Inorganic particles in this size range can easily foul the fine structures (setules) on feeding appendages of crustaceans such as copepods, and crab and shrimp larvae (Sullivan and Hancock, 1977). Laboratory studies have shown that mechanical disruption of feeding can affect growth and reproductive success (Kirk, 1992). Plankters feeding by ciliary action (e.g., echinoderm larvae) also would be susceptible to mechanical effects of suspended particles (Sullivan and Hancock, 1977).

Larval fishes are visual feeders that depend on adequate light levels for their foraging success (Blaxter, 1968). High turbidity reduces light levels in the water column which in turn shortens the reactive distance between a larval fish and its prey. Laboratory studies have demonstrated the negative influence of elevated turbidity on prey capture rates for larvae of herring, *Clupea harengus harengus* (Johnston and Wildish, 1982), striped bass, *Morone saxatilis* (Morgan et al., 1983; Breitburg, 1988), and dolphin, *Coryphaena hippurus* (Jokiel, 1989). In one laboratory study however, increased turbidity actually enhanced feeding abilities of larval herring (*Clupea harengus pallisi*) (Boehlert and Morgan, 1985). The authors suggested that suspended sediment may have provided better contrast against which small particles were viewed.

Direct mortality and toxicity caused by elevated turbidity varies with species and nature of the sediment and sediment-bound contaminants. Crustacean zooplankters will ingest suspended inorganic particles that may or may not contain contaminants. Contamination is expected to be low in all sand resource areas, although Area 4 may be influenced by Mobile Bay outflow and the dredged material disposal site to the northwest. A laboratory study showed that copepods ingesting high amounts of “red mud” grew slower than control groups feeding only on diatoms (Paffenhofer, 1972). This was attributed to the non-nutritive value of the red mud rather than to any associated toxic compounds. Sediment-bound toxic compounds introduced into the water column may be ingested by zooplankters. These substances can be detrimental to zooplankters. However, studies with copepods exposed to deep sea mine tailings containing trace metals showed minimal effects (Hirota, 1981; Hu, 1981).

High turbidity can cause physiological changes that can kill or retard developing eggs and larvae of fishes and invertebrates (Davis and Hidu, 1969; Rosenthal, 1971). High concentrations of suspended sediment can kill or deform fish eggs (Rosenthal, 1971). Laboratory studies investigating effects of elevated turbidity on eggs and larvae of bivalves show that slight increases in turbidity actually stimulated larval growth, whereas large increases in turbidity caused abnormalities (Loosanoff, 1962; Davis and Hidu, 1969). Hatching success of fish eggs exposed to high suspended concentrations varies, but most studies show minimal effects from acute exposures in the 50 to 500 mg/L range (Auld and Schubel, 1978; Morgan et al., 1983; Jokiel, 1989). In these same studies, artificially high suspended sediment concentrations (1,000 to 8,000 mg/L) were required to induce mortality.

As with entrainment, the effects of suspended sediments on zooplankters is primarily restricted to the lower portion of the water column for a cutterhead dredge because the turbidity plume remains near the cutterhead with little reaching surface waters (LaSalle et al., 1991). Suspended sediment plumes in near-bottom waters may extend for up to several hundred meters laterally from the cutterhead. In contrast, hopper barges may create turbid surface plumes due to overwash (LaSalle et al., 1991). With either dredge type, the turbidity plume is expected to cover a small portion of the water column relative to the surrounding waters. Due to the limited areal extent and transient nature of the sediment plume, it is unlikely that turbidity would greatly affect zooplankton populations or assemblages in the Alabama sand resource areas.

7.6.1.3 Project Scheduling

For open ocean environments, Sullivan and Hancock (1977) generalized that dredging effects on zooplankton would be minimal due to high spatial and temporal variability of the populations, whereas significant effects would be expected in enclosed waters with endemic populations. However, accurate prediction of the local effects of entrainment or dredge-produced turbidity on zooplankton populations of the sand resource areas requires adequate site-specific data. Zooplankton populations in general should not be subject to impacts from dredging, but available regional information (see Section 2.3.1) indicates that planktonic larvae, particularly those of shrimp and blue crab, occur in the project area during summer and fall months. Because adults of these species spawn offshore and larval forms make their way back to inshore nursery areas inside Mobile Bay, Area 4 could be construed as lying in a recruitment corridor. The other sand resource areas are not within such an important position relative to larval transport and therefore should not require any special project scheduling consideration.

When data are inadequate to accurately predict the magnitude of dredging effects, environmental windows have been required to provide a conservative approach and lessen potential effects on key species. However, LaSalle et al. (1991) and Reine et al. (1998) have stressed the need to base future environmental windows on sound evidence, and have argued against subjectively selected environmental windows. Environmental windows delay projects and greatly increase costs (Dickerson et al., 1998), and their use should not be driven by subjective or overly conservative approaches. If Area 4 is used as a sand source, an environmental window excluding summer and fall months could be considered to avoid dredging when shrimp and blue crab larvae are most prevalent, but only if additional data become available to determine the extent of impacts and justify the restriction. Progress toward understanding the real need for environmental windows can only be achieved by reducing the degree of uncertainty surrounding impacts and the means to avoid them (Dickerson et al., 1998).

7.6.2 Squids

7.6.2.1 Entrainment

No information exists regarding impacts of hydraulic dredging on squids. Nevertheless, squids could be entrained if they encountered the suction field of a hydraulic dredge. Some general aspects of squid behavior increase the chance of encountering the bottom-oriented dredge suction field. Adult squids are generally demersal by day and enter the water column at night to feed on zooplankton (Fischer, 1978). In addition, squids lay their eggs in large clusters on the seafloor (Vecchione, 1981). The early stages (prolarvae) of *Loligunculus brevis* may be susceptible as well.

7.6.2.2 Attraction

Because some squid species are attracted to lights at night (Fischer, 1978), it is likely that squids could be attracted to lights of a working dredge. This could draw them into the suction field and increase the chance of entrainment.

7.6.2.3 Project Scheduling

With no information on local squid populations available, reasonable predictions of demographic effects are difficult to make. As with the other pelagic organisms, dredging is unlikely to significantly impact squid populations in the vicinity of the sand resource areas. Quantitative data are lacking to support the use of an environmental window to protect squid resources.

7.6.3 Fishes

7.6.3.1 Entrainment

Entrainment of adult fishes by hydraulic dredging has been reported for several projects (Larson and Moehl, 1988; McGraw and Armstrong, 1988; Reine and Clarke, 1998). The most comprehensive study of fish entrainment took place in Grays Harbor, WA during a 10-yr period when 27 fish taxa were entrained (McGraw and Armstrong, 1988). Most entrained fishes were demersal species such as flatfishes, sand lance, and sculpin; however, three pelagic species (anchovy, herring, and smelt) were recorded. Entrainment rates for the pelagic species were very low, ranging from 1 to 18 fishes/1,000 cy (McGraw and Armstrong, 1988). Comparisons between relative numbers of entrained fishes with numbers captured by trawling showed that some pelagic species were avoiding the dredge. Another entrainment study conducted near the mouth of the Columbia River, WA reported 14 fish taxa entrained at an average rate of 0.008 to 0.341 fishes/cy (Larson and Moehl, 1988). Few of the coastal pelagic fishes occurring offshore of Alabama should become entrained because the dredge's suction field exists near the bottom and many pelagic species have sufficient mobility to avoid the suction field.

7.6.3.2 Attraction

Even though dredges are temporary structures, they can still attract roving pelagic species. Many pelagic fishes of the northern Gulf of Mexico are attracted to large objects or structures such as artificial reefs (Klima and Wickham, 1971) or oil and gas platforms (Stanley and Wilson, 1990). Bluefish, cobia, jacks, and king and Spanish mackerels that migrate through the area could be attracted to the dredge. This may temporarily disrupt a migratory pattern for some members of the stock, but it is unlikely that there would be an appreciable negative effect. There are already several artificial reefs and oil and gas structures in the area, so the presence of a dredge will not be novel.

7.6.3.3 Turbidity

Turbidity can cause feeding impairment, avoidance and attraction movements, and physiological changes in adult pelagic fishes. As discussed for larval fishes, pelagic species are primarily visual feeders and when turbidity reduces light penetration, the fishes reactive distance decreases (Vinyard and O' Brien, 1976). Light scattering caused by suspended sediment can also affect a visual predator's ability to perceive and capture prey (Benfield and Minello, 1996).

Some species will actively avoid or be attracted to turbid water. Experiments with pelagic kawakawa (*Euthynnus affinis*) and yellowfin tuna (*Thunnus albacares*) demonstrated that these species would actively avoid experimental turbidity clouds, but would also swim directly through them during some trials (Barry, 1978). Turbidity plumes emanating from coastal rivers may retard or affect movements of some pelagic species.

Gill cavities can be clogged by suspended sediment preventing normal respiration and mechanically affecting food gathering in planktivorous species (Bruton, 1985). High suspended sediment levels generated by storms have contributed to the death of nearshore and offshore fishes by clogging gill cavities and eroding gill lamellae (Robins, 1957).

The limited spatial and temporal extents of turbidity plumes from either cutterhead or hopper dredges are expected to be limited. Therefore, there should be no significant impact on adult pelagic fishes.

7.6.3.4 Project Scheduling

Hydraulic dredging should not present a significant problem for pelagic fishes offshore Alabama. If an environmental window is sought to protect pelagic fishes from dredging impacts, the spring to fall period would encompass the peak seasons for the economically important species. Temporal scheduling as means to avoid impacts is practical if the organism in question is highly concentrated in waters of the area during some specific time period. Quantitative data are lacking to support the use of an environmental window to lessen effects on pelagic fishes.

7.6.3.5 Essential Fish Habitat

The Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. § 1801-1882) established regional Fishery Management Councils and mandated that Fishery Management Plans (FMPs) be developed to responsibly manage exploited fish and invertebrate species in Federal waters of the United States. When Congress reauthorized this act in 1996 as the Sustainable Fisheries Act, several reforms and changes were made. One change was to charge the NMFS with designating and conserving Essential Fish Habitat (EFH) for species managed under existing FMPs. This was intended to minimize, to the extent practicable, any adverse effects on habitat caused by fishing or non-fishing activities, and to identify other actions to encourage the conservation and enhancement of such habitat.

EFH is defined as “those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity”[16 U.S.C. § 1801(10)]. The EFH interim final rule summarizing EFH regulations (62 FR 66531-66559) outlines additional interpretation of the EFH definition. Waters, as defined previously, include "aquatic areas and their associated physical, chemical, and biological properties that are used by fish, and may include aquatic areas historically used by fish where appropriate." Substrate includes “sediment, hard bottom, structures underlying the waters, and associated biological communities.” Necessary is defined as "the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem." “Fish” includes "finfish, mollusks, crustaceans, and all other forms of marine animal and plant life other than marine mammals and birds," whereas "spawning, breeding, feeding or growth to maturity" cover the complete life cycle of those species of interest.

The Gulf of Mexico Fishery Management Council (GMFMC) has produced several FMPs including those for coastal migratory pelagic fishes, coral and coral reefs, red drum, reef fishes, shrimp, spiny lobster, and stone crab. To ammend these FMPs with respect to EFH of managed species, the GMFMC prepared a generic document that identified and described EFH for 26 species (Gulf of Mexico Fishery Management Council, 1998). This document presented maps depicting EFH for all life stages of the 26 species. Mapped EFH for several of these species (and life stages) overlapped the five sand resource areas offshore Alabama. EFH characteristics for these overlapping species are presented in Table 7-4. Of the species listed, several are hard bottom associates (i.e., gag, scamp, greater amberjack, red snapper, and lane snapper). Hard bottom habitats or inhabitants were not covered in Section 2.0 of this report because no known hard bottom occurs in the immediate vicinity of the sand resource areas.

Table 7-4. Invertebrate and fish species managed by the Gulf of Mexico Fishery Management Council for which Essential Fish Habitat has been identified in the vicinity of the five sand resource areas offshore Alabama (adapted from Gulf of Mexico Fishery Management Council, 1998).

Species (Phylogenetic Order)	Life Stage (Seasonal Occurrence); Reproductive Activity; Habitat Affinity
Invertebrates	
Brown shrimp (*Penaeus aztecus*)	Adults (year-round); spawning year-round in water depth >14 m; soft bottom
Pink shrimp (*Penaeus duorarum*)	Adults (year-round); soft bottom
White shrimp (*Penaeus setiferus*)	Adults (year-round), spawning from March to October; soft bottom
Stone crab (*Menippe mercineria*)	Adults (year-round); soft bottom
Fishes	
Gag (*Mycteroperca microlepis*)	Adults (year-round);hard bottom
Scamp (*Mycteroperca phenax*)	Adults (year-round);hard bottom
Cobia (*Rachycentron canadum*)	Adults (summer); water column
Red drum (*Sciaenops ocellatus*)	Adults (year-round); spawning in fall and winter; soft bottom
Greater amberjack (*Seriola dumerili*)	Adults (year-round); hard bottom
Red snapper (*Lutjanus campechanus*)	Juveniles (year-round);soft bottom
Lane snapper (*Lutjanus synagris*)	Adults (year-round); hard bottom
King mackerel (*Scomberomorus cavalla*)	Adults (year-round); pelagic
Spanish mackerel (*Scomberomorus maculatus*)	Adults (year-round); pelagic

The area encompassed by the five sand resource areas is very small relative to the mapped EFH characteristics. For this reason, the effect of dredging on EFH for the managed species is expected to be minimal.

7.6.4 Sea Turtles

7.6.4.1 Physical Injury

The main potential effect of dredging on sea turtles is physical injury or death caused by the suction and/or cutting action of the dredge head. Numerous sea turtle injuries and mortalities have been documented during dredging projects, particularly along Florida's east coast (Studt, 1987; Dickerson et al., 1992; Slay, 1995). Impacts typically can be minimized by some combination of project scheduling and equipment selection, accompanied if necessary by turtle removal and/or monitoring.

Although any of the five sea turtle species may be present in the project area, loggerhead, green, and Kemp's Ridley turtles are considered to be most at risk from dredging activities because of their life cycle and behavioral patterns (Dickerson et al., 1992). Loggerheads are expected to be the most abundant of these three turtles in the project area. Hawksbill turtles are usually associated with coral reef environments and are the least abundant sea turtle in the northern Gulf. Leatherbacks are predominantly found in deep waters over the continental slope (see Section 2.3.2.4).

Physical impact can occur when a turtle resting on (or buried in) the seafloor is contacted by the dredge head. Two types of dredges may be used on the proposed project (see Section 7.0). Cutterhead suction dredges are considered unlikely to kill or injure turtles, perhaps because the cutterhead encounters a smaller area of seafloor per unit time, allowing more opportunity for turtles to escape (Palermo, 1990). Hopper dredges are believed to pose the greatest risk to sea turtles (Dickerson, 1990; NMFS, 1997). There has been considerable research into designing modified hopper dredges with turtle deflectors that reduce the likelihood of entraining sea turtles (Studt, 1987; Berry, 1990; Dickerson et al., 1992; U.S. Army Corps of Engineers, 1999). If a hopper dredge is used on this project, its design is likely to be a significant consideration in minimizing potential impacts to sea turtles.

7.6.4.2 Turbidity and Anoxia

Sea turtles in and near the project area may encounter turbid water during dredging. For those turtles known to forage visually (e.g., leatherbacks feeding on jellyfishes), this turbidity could temporarily interfere with feeding. However, due to the limited areal extent and transient occurrence of the sediment plume (see Section 7.5.1.2), turbidity is considered unlikely to significantly affect turtle behavior or survival.

In addition to turbidity, dredging may produce localized anoxia in the water column due to oxygen consumption of the suspended sediments (LaSalle et al., 1991). In general, oxygen levels in the plume and near-bottom waters may approach zero, but levels in adjacent waters outside the plume are at or near normal. Due to the limited extent and transient occurrence of anoxia, no significant effects on turtles are expected.

7.6.4.3 Noise

Dredging is one of many human activities in the marine environment that produce underwater noise. This noise is unlikely to significantly affect sea turtles because of their limited hearing ability (Ridgway et al., 1969; Lenhardt, 1994). These animals do not rely upon sound to any significant degree for communication or food location. Studies in the northern Gulf of Mexico have shown some evidence for positive association of sea turtles with petroleum platforms (Rosman et al., 1987; Lohoefener et al., 1990) despite the industrial noise associated with these sites.

7.6.4.4 Project Scheduling

Project scheduling is one way to avoid or minimize turtle impacts during dredging (Studt, 1987; Arnold, 1992). There are currently no turtle-related seasonal restrictions on dredging in the Alabama/Florida Panhandle area (R. Nyc, 1999, personal communication, U.S. Army Corps of Engineers, South Atlantic Region). However, dredging for beach restoration obviously would not occur during the loggerhead nesting season because nesting beaches cannot be disturbed during this time.

Loggerheads are expected to be the most abundant turtle in the project area, and there is a significant nesting subpopulation of loggerhead turtles along the Florida Panhandle, with some loggerhead nesting on Alabama beaches (see Section 2.3.2.4). Increased loggerhead densities may be expected during the nesting season, which in the Panhandle region extends from 1 May through 30 November (Minerals Management Service, 1997). A schedule that avoids the loggerhead nesting season also would avoid potential impacts to occasional nesting green and leatherback turtles.

Although green turtles also may nest on Alabama beaches (Alabama Game and Fish Division, 1997), the Minerals Management Service (1997) indicates that the green turtle nesting in the northern Gulf is “isolated and infrequent” during the season lasting from 1 May through 31 October. Leatherbacks occasionally nest on Florida Panhandle beaches from 1 May through 30 September (Minerals Management Service, 1997) but are not listed as nesting in Alabama by the Alabama Game and Fish Division (1997). Hawksbill and Kemp’s Ridley turtles do not nest anywhere near the project area.

Winter seasonal restrictions have been necessary in some channel dredging projects along Florida’s east coast due to turtles aggregating in bottom sediments (Studt, 1987). From December or January (depending on water temperature) through April, large numbers of loggerhead turtles rest along the bottom in the Canaveral Harbor entrance channel (Carr et al., 1981). These aggregations were a surprising discovery, and little is known of this behavior in other areas (Lutz, 1990). In the northern Gulf, Lohoefener et al. (1990) reported seeing loggerheads with mud trails on their carapaces, suggesting that they had been partially buried during cold spells. However, loggerheads also may move into deeper water during winter (Lohoefener et al., 1990). Similarly, Richardson (1990) reported that turtles do not brumate in the St. Mary’s entrance channel (Georgia) during winter, but instead migrate south to warmer waters (e.g., the Canaveral area).

It is not known whether sea turtles are likely to be brumating in bottom sediments of the project area during winter. Consequently, there is insufficient information to determine whether seasonal restrictions on dredging during winter months would be appropriate. However, this is mainly an issue during channel dredging because narrow channels tend to concentrate turtles moving between estuaries and the open ocean. So far, it has not been an issue for dredging offshore borrow areas (E. Hawk, 1999, personal communication, NMFS Southeastern Regional Office).

7.6.5 Marine Mammals

7.6.5.1 Physical Injury

Unlike sea turtles, marine mammals are unlikely to be physically injured during dredging because (1) they generally do not rest on the bottom and (2) they can easily avoid contact with the dredge. The two marine mammals most likely to be found in and near the project area are the Atlantic spotted dolphin and the bottlenose dolphin (Davis and Fargion, 1996; Davis et al., 1998; see

Section 2.3.2.5). Both are fast, agile swimmers and are presumed capable of avoiding direct physical injury by either a cutterhead suction dredge or hopper dredge. Dolphins also may avoid the immediate vicinity of the project due to the associated noise and turbidity.

7.6.5.2 Turbidity

Marine mammals in and near the project area may encounter turbid water during dredging. This turbidity could temporarily interfere with feeding or other activities, but the animals could easily swim to avoid turbid areas. Due to the limited areal extent and transient occurrence of the sediment plume (see Section 7.5.1.2), turbidity is considered unlikely to significantly affect marine mammal behavior or survival.

7.6.5.3 Noise

Underwater noise from dredging activities could have minor impacts on marine mammals. Noise can cause marine mammals to temporarily avoid certain areas (Gales, 1982; Richardson et al., 1995). However, sound levels from dredging activities are likely to dissipate to the tolerance of most cetaceans within a few tens of meters from the source. Hearing loss or other auditory discomfort or damage is not likely to result to marine mammals from normal noise produced during dredging operations because the pressure variations produced from most sounds are far less than those which marine mammals must tolerate during dives (Gales, 1982). Furthermore, dolphins could easily move away from noise that would cause them discomfort, danger, or harm, or interfere with normal behaviors. Observations of marine mammals in the vicinity of active platforms (a common source of underwater noise in the northern Gulf of Mexico) suggest that routine operations have little effect on normal behavior (Gales, 1982; Malme et al., 1983).

7.6.5.4 Project Scheduling

As discussed in Section 2.3.2.5, the two marine mammals most likely to be found in and near the project area are the Atlantic spotted dolphin and the bottlenose dolphin (Davis and Fargion, 1996; Davis et al., 1998). Neither exhibits strong seasonality of occurrence.

Atlantic spotted dolphins can be expected to occur near the project area during all seasons. It has been hypothesized that they are more common during spring, but data supporting this hypothesis are limited (see Section 2.3.2.5). Bottlenose dolphins were sighted on the continental shelf off Mobile Bay during all seasons during GulfCet II aerial and shipboard surveys (Mullin and Hoggard, 1998). For either species, there is no strong seasonal pattern in abundance that would provide an appropriate basis for seasonal restrictions on the project. In addition, the likelihood of significant impact is low even if these animals are present.

7.7 POTENTIAL CUMULATIVE EFFECTS

Cumulative physical environmental impacts from multiple sand extraction scenarios at one or all sand borrow sites within the study area were evaluated to assess long-term effects at potential borrow sites and along the coastline. Results presented above for wave and sediment transport processes reflect the impact of large extraction scenarios that are expected to be within the cumulative sand resource needs of the State for the next 50 years. Therefore, the cumulative impacts of sand mining offshore Alabama on wave propagation and sediment transport processes are expected to be negligible under the conditions imposed. Unless substantially larger borrow sites and extraction volumes are selected for sand mining, no significant impacts to normal and storm physical processes are expected.

Cumulative impacts resulting from multiple sand mining operations within a sand resource area are a concern when evaluating potential long-term effects on benthic and pelagic assemblages. Given that the expected beach replenishment interval is on the order of a decade, and that the expected recovery time of the affected benthic community after sand removal is anticipated to be much less than that – certainly within 5 years – the potential for significant cumulative benthic impacts is remote. No cumulative impacts to the pelagic environment, including zooplankton, squids, fishes, sea turtles, and marine mammals, are expected from multiple sand mining operations within a sand resource area.